Replacing the RAAF F/A-18 Hornet Fighter

Strategic, Operational and Technical Issues

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"qui desiderat pacem, praeparet bellum"

De Re Militari,

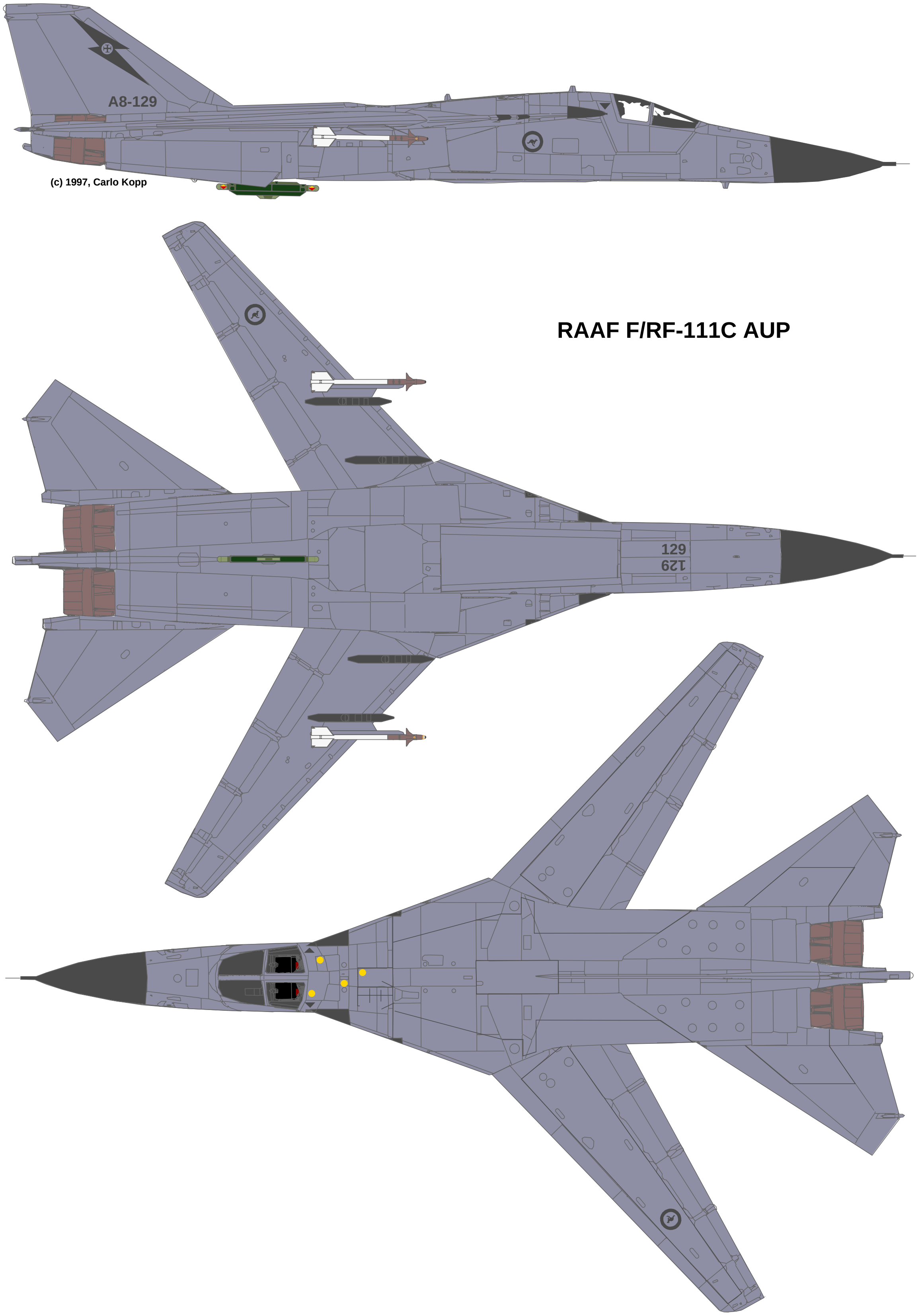
Flavius Vegetius Renatus,
Fourth Century A.D.

Drawing 1. Sukhoi Su-30MK/MKI Tactical Fighter

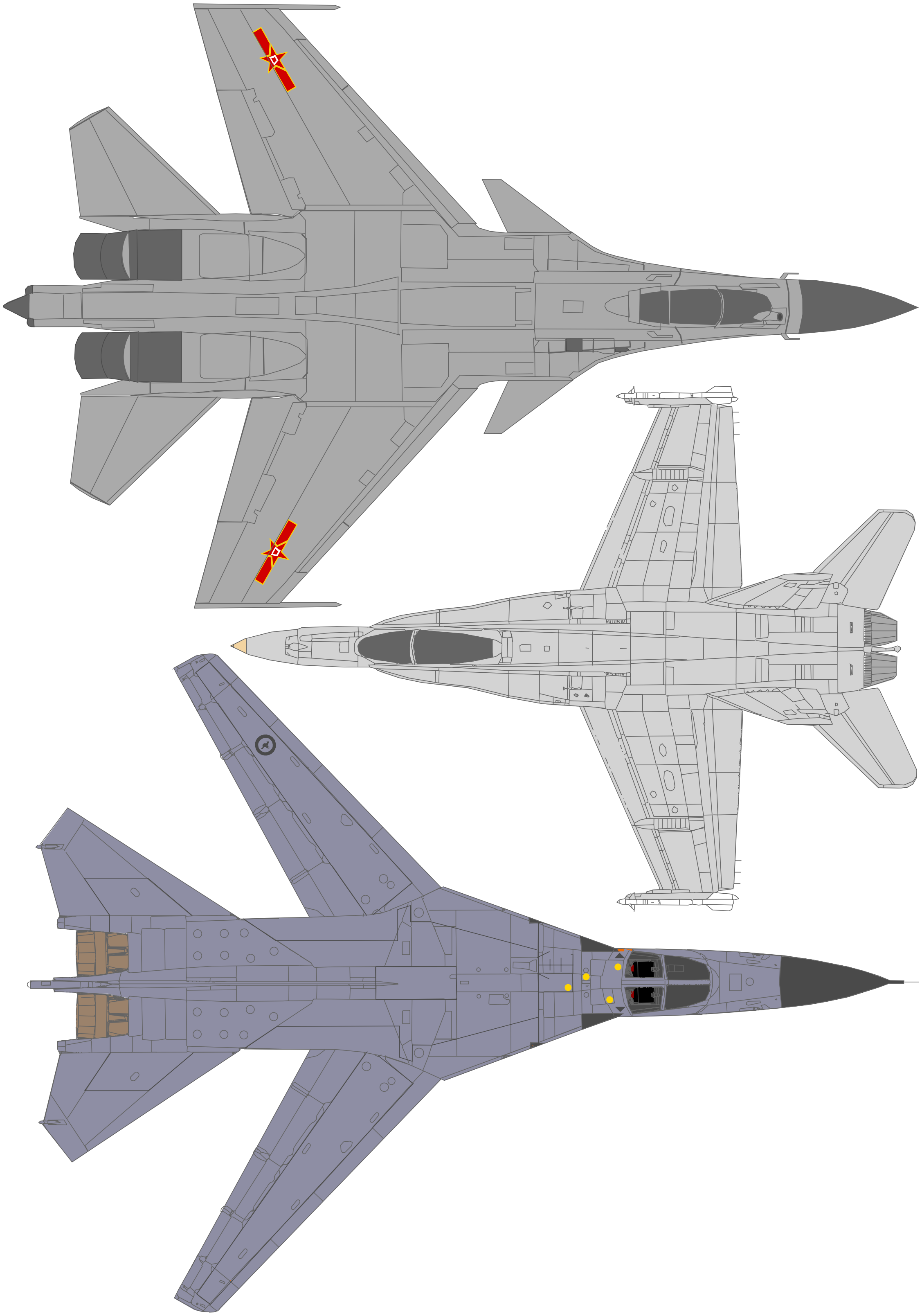
The Sukhoi Su-27P/S, Su-30M/MK/MKI, and Su-35/37 family of fighters represent the Soviet/Russian capability response to the US developed F-15A/C and F-15E Eagle fighters. Employing vortex lift techniques, these aircraft are unsurpassed in sustained and instantaneous close in manoeuvre capability, while offering 1000 NMI class unrefuelled combat radius and a respectable Beyond Visual Range radar and missile capability. The PLA-AF intend to deploy in excess of 350 such aircraft, and the IAF may deploy as many as 200 aircraft in time. The type is also operated by Vietnam and was ordered by Indonesia prior to its economic collapse. Depicted is an aircraft in Indonesian TNI-AU colours.

Drawing 2. RAAF/Boeing F/A-18A+ Hornet Tactical Fighter

Deployed during the eighties, the Boeing (MDC) F/A-18A+ Hornet is the ADF’s principal air superiority asset, which also has a respectable maritime and theatre strike capability. A capable and flexible second tier multirole fighter, the Hornet has now become marginally competitive with the large scale deployment of first tier Russian Sukhoi Su-27 and Su-30 fighters in the broader region. The RAAF’s 72 F/A-18A aircraft are to be equipped with the Matra-BAe AIM-132 ASRAAM and the Raytheon/Hughes AIM-120B air-to-air missiles under AIR 5400.



Drawing 3. RAAF/GD F-111C Strike Aircraft



Drawing 4. Relative Size Comparison - Su-30MK, F/A-18A, F-111C

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Executive Summary

The last decade has seen a significant increase in the number of modern combat aircraft acquired in the nearer and broader region. The most important acquisitions have been variants of the capable Russian built Sukhoi Flanker aircraft. Current projections, based upon existing orders, indicate that in excess of four hundred such aircraft are likely to be fielded by the PRC and India, by 2015. This growth in combat aircraft capability has been paralleled by the deployment of highly capable Surface-to-Air missiles, such as the SA-10 and SA-15. It is highly probable that the more capable SA-12 will also be deployed within the next decade.

Because the Flanker has a combat radius of a similar magnitude to the F-111 and the F-15E, it renders ineffective much of the modernisation carried out by South East Asian nations over the last decade. The impending acquisition of AEW&C and air-to-air refuelling tanker capabilities by the PRC and India will further enhance this capability.

The RAAF's F/A-18A is aerodynamically uncompetitive against all variants of the Sukhoi Flanker. Upgrades to its weapons and sensors, and operational tanker and AEW&C support, will extend its tactical usefulness, but not cannot remedy its inherent design limitations. The F-111 will cease to be competitive, without fighter escort, after 2010, as broader regional capabilities and numbers strengthen.

The Sukhoi Flanker is being further developed, and has sufficient growth potential in the existing airframe to accommodate significant improvements in agility, weapons, sensors and air-to-ground capability. Of particular importance is the expected emergence in the next half decade of Flankers equipped with Low Probability of Intercept radar technology, radar signature reduction measures, and advances in cockpit and mission avionics made possible by easier access to Western computer technology. Of major concern is the likely proliferation of long range "AWACS Killer" missiles to regional users of the Flanker.

There is a very high risk of early technological obsolescence, and a certainty of ongoing frequent expenditure on upgrades, should the RAAF choose to replace the F/A-18A with a current technology, non-stealthy, production combat aircraft. These risks are not significantly changed by the adoption of combat aircraft with reduced radar signatures, as compared to genuine stealth aircraft. An important consequence of this is that during the coming decade, when the US begins the large scale manufacturing of genuinely stealthy fighters, the commercial prospects for current technology, non-stealthy, production combat aircraft will drop sharply. Therefore we can expect to see a major marketing effort by manufacturers of non-stealthy combat aircraft to make sales before this occurs.

The adoption of stealthy combat aircraft to replace the F/A-18A and F-111 will confer important economies in numbers of aircraft required to maintain a given level of capability, while providing unprecedented force survivability, and will also confer important economies in the use of cheap and lethal guided bombs, rather than expensive stand-off weapons.

Two stealthy combat types will enter production over the coming decade. These are the USAF's F-22A Raptor, which is a long range multirole fighter, employing revolutionary stealth, sensor fusion and sustained supersonic cruise technology, and the developing Joint Strike Fighter, a shorter ranging bomber devised to supplement the F-22A.

Given the genuine risks associated with acquiring existing production aircraft, the best long term investment in the replacement of the F/A-18A, and later the F-111, is the F-22, supplemented by the Joint Strike Fighter. The F-22 would replace the F/A-18A in the counter-air role, and the F-111 in the long range strike role. The Joint Strike Fighter would supplement the F-22 in the shorter ranging strike role, and the defensive counter-air role.

This submission details and substantiates the reasoning behind these conclusions, a provides a substantial amount of supporting background information.

A package of specific recommendations is included, for the process of replacement of the F/A-18 and later F-111, and the effective utilisation of these assets in the latter period of their operational life cycle.

Notes

This paper was compiled wholly from public domain sources of information, including the author's previously published work.

Sections 1 through 2.1.7 are intended to provide the reader with a familiarity in the general issues, and technological developments in air warfare in recent years.

Sections 2.1.8 through 5 deal with issues of specific relevance to the subject of the F/A-18 replacement.

Author Background

Born in Perth, Western Australia, Carlo Kopp has been researching military aviation, air warfare strategy and the applications of missile technology since 1980. His work has been published by the *RAAF Air Power Studies Centre*, the *USAF Center for Air Doctrine Research and Education*, the US *Journal of Electronic Defence*, *Australian Aviation* and most recently, *Air Power International* and *Jane's Rockets and Missiles*.

Carlo graduated with first class honours in Electrical Engineering in 1984, from UWA, has since completed a research Masters in Computer Science, and is currently working on his PhD at Monash University in Melbourne. He has extensive industry experience, and has consulted to DSTO. Until 1994 he flew competition aerobatics, and was a formation flypast display lead pilot between 1993 and 1994. Due to postgraduate study commitments he is currently inactive. He is a member of the IEEE, AOC and a registered professional engineer.

Section 1 The Strategic Context

1.1 Historical Perspective on Existing RAAF Force Structure

The existing RAAF tactical jet force structure, comprising the 72 F/A-18A Hornets of 81 WG and the 35 F/RF-111C/G of 82 WG, is the product of an evolutionary process which commenced during nineteen forties. As such, it reflects successive changes in doctrine, strategic circumstances and technology.

Given the benign threat environment which Australia faced through most of this period, the established force structure model has mostly been adequate to any potential demands which it could have been expected to satisfy during this period.

The central paradigm which was espoused through most of this period by the RAAF is that of employing a long range bomber type, capable of unescorted attack on strategic and maritime targets, and a multirole tactical fighter of modest performance and range, capable of achieving air superiority against expected regional air capabilities, and of providing a theatre strike capability against land and sea targets.

The bomber element was initially equipped with the Consolidated B-24J Liberator, 287 of which were acquired, and later replaced by the mostly Australian built Avro/GAF Lincoln Mk.30/31, 73 of which were acquired. With the arrival of the jet age, the Lincolns were replaced by 55 examples of the English Electric / GAF Canberra Mk.20/21. The Canberra remained in front line service until the 24 US built General Dynamics F-111C entered service during the mid seventies. During the early nineties, an additional 15 F-111G aircraft were acquired to supplement the existing fleet. The F/RF-111C is currently undergoing an avionic refit with a digital nav-attack system, and current intentions are to upgrade the F-111G with similar systems, to carry the aircraft through to a planned retirement around 2020[1].

The fighter element of the RAAF experienced significantly more evolutionary change, especially during the fifties when technological pressures led to the rapid obsolescence of late piston and early jet types.

At the end of the Second World War the RAAF's primary fighter was the Curtiss P-40E/M/N, a rugged fighter bomber of modest performance, supplemented by the Supermarine Spitfire Mk.V and Mk.VIII, the latter a high performance fighter bomber with limited range performance. A total of 848 P-40 aircraft were acquired, the type acquitted itself well in combat despite its performance limitations in comparison with Japanese fighters of the period. The Spitfire, optimised for air superiority in the European Theatre, was less successful than the P-40, the RAAF acquiring a total of 656 aircraft[2].

The performance limitations of the P-40 and the range limitations of the Spitfire were impediments to the RAAF's capability to effectively project air power at strategic ranges, a key issue in the defence of the Australian continent and the projection of power by forward deployed forces.

In April 1945 the RAAF took delivery of the first of 298 US built North American P-51D/K Mustangs, with deliveries of 200 Australian built CAC Mustang Mk.20/21/22/23 aircraft commencing in June, 1945, and ending in August, 1951[3]. The Mustang provided highly competitive air superiority performance and the range to escort the RAAF's B-24 bombers. The aircraft performed well in the ground attack role and was used extensively in Korea.

The arrival of the jet age saw the operational deployment by the RAAF of the De Havilland Vampire F.30, FB.31 and T.33, 110 of the total of 195 examples being built in Australia. In addition, 104 Gloster Meteor F.8 fighters were acquired for use in Korea, deploying in 1951. The Vampire served in the fighter role until 1960, while the T.33

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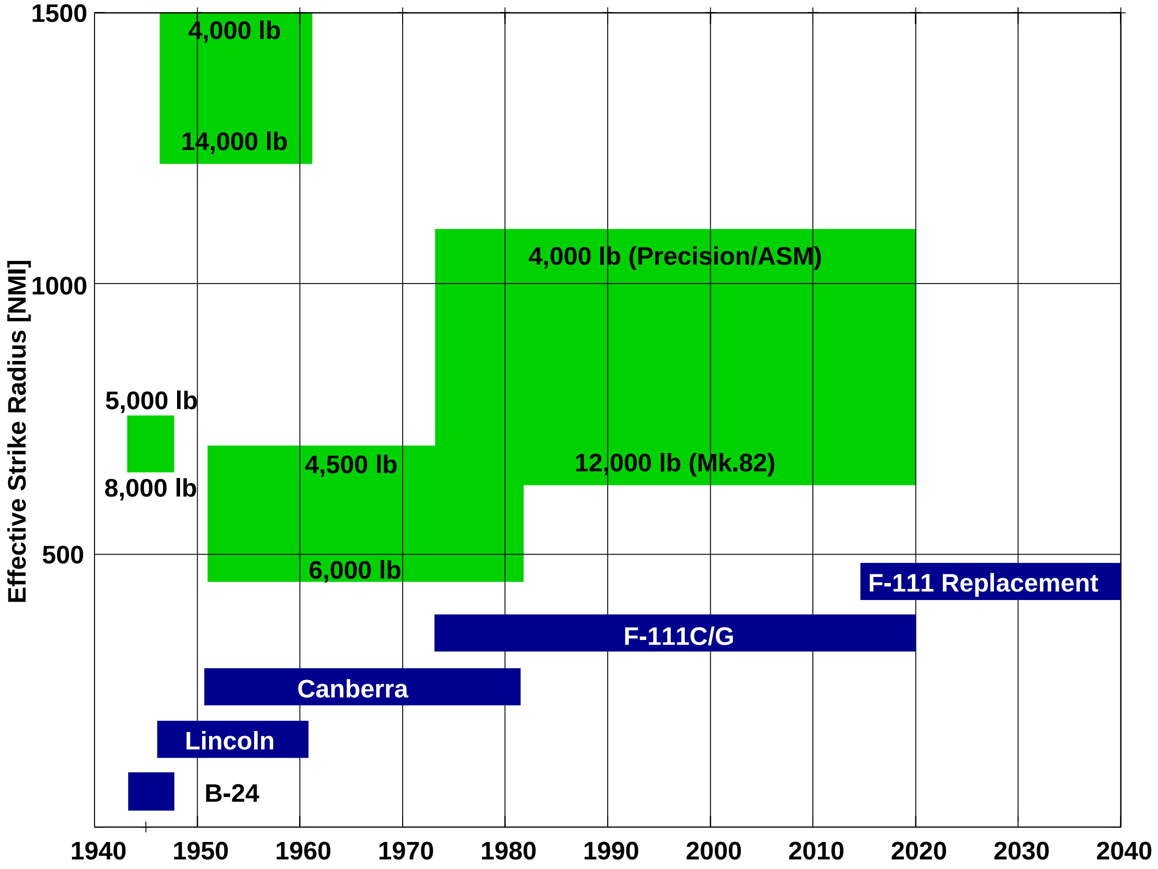
[1] Wilson, S., *Military Aircraft of Australia*, Aerospace Publications, 1994.

[2] Wilson, S., *Military Aircraft of Australia*, Aerospace Publications, 1994. See also Wilson, S., *Spitfire, Mustang and Kittyhawk in Australian Service*, Aerospace Publications, 1988.

[3] ibid.

trainer served until 1970. The Meteor was phased out in 1963, but was no longer competitive after the deployment of the MiG-15 during the Korean War.



Evolution of RAAF Bomber Capability (1945 - 2020)

Chart 1.

The most important subsonic jet fighter to be used by the RAAF was the CAC Avon Sabre Mk.30/31/32, 112 of this substantially redesigned variant were built in Australia. The aircraft deployed in 1954 and was retired in 1971[4].

The deployment of the MiG-21F Fishbed by Indonesia's TNI-AU during the Konfrontasi period rendered the Sabre uncompetitive. It was replaced in front line units by the Australian built Dassault Mirage IIIO from 1964. The Mirage was the RAAF's first supersonic fighter, but in operational service was found to possess marginally useful combat radius. It served until 1988, as a fighter-bomber and interceptor[5].

The McDonnell-Douglas F/A-18A Hornet was selected over the General Dynamics F-16A Falcon in 1981, and entered operational service with the RAAF in 1985. A total of 75 aircraft were acquired, most of which were assembled in Australia. The Hornet was the RAAF's first fighter to possess a genuine Beyond Visual Range (BVR) Air Air Missile (AAM) capability, and a genuine all weather capability in counter-

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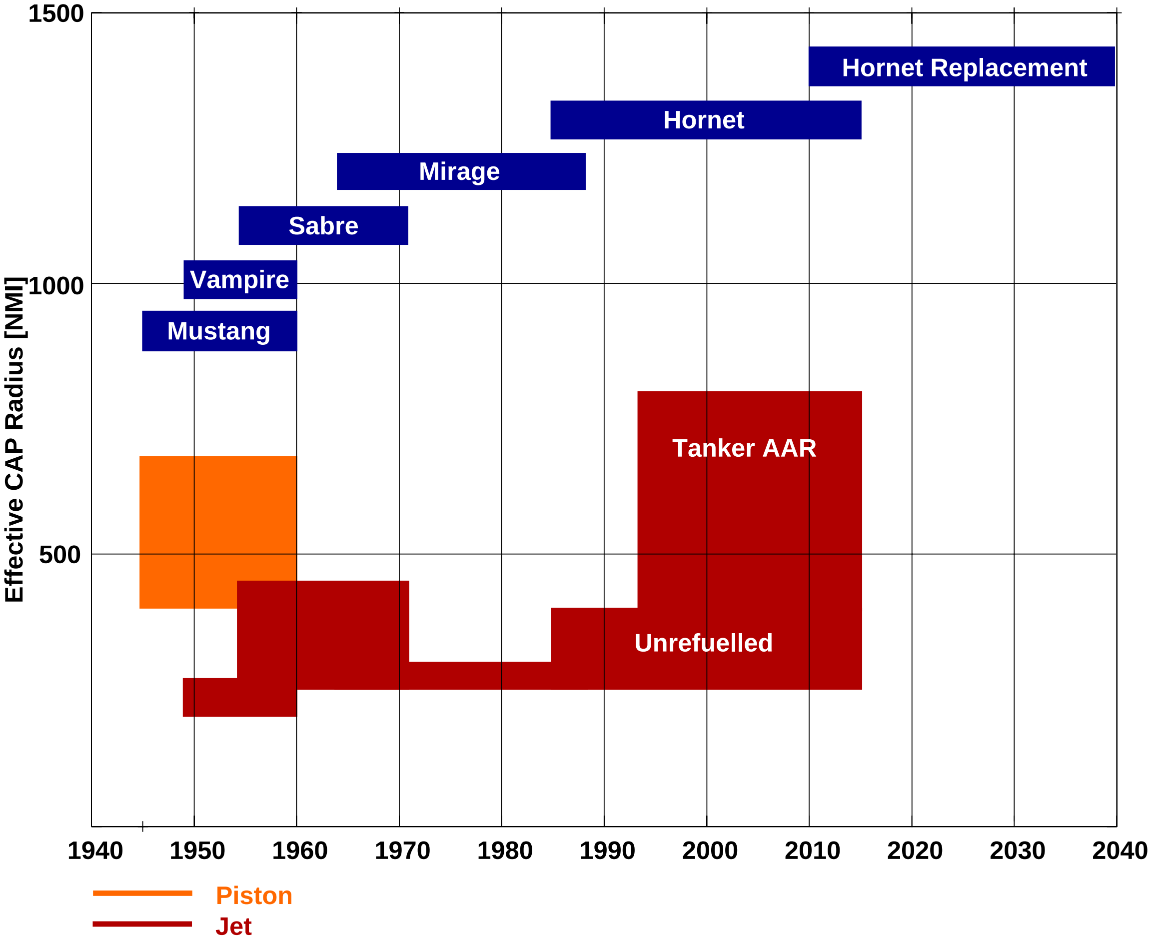
Wilson, S., *Military Aircraft of Australia*, Aerospace Publications, 1994. See also Wilson, S., *Vampire, Macchi and Iroquois in Australian Service*, Aerospace Publications, 1994, and Wilson, S., *Meteor, Sabre and Mirage in Australian Service*, Aerospace Publications, 1989.

[4] ibid.

[5] ibid.

air and strike roles.



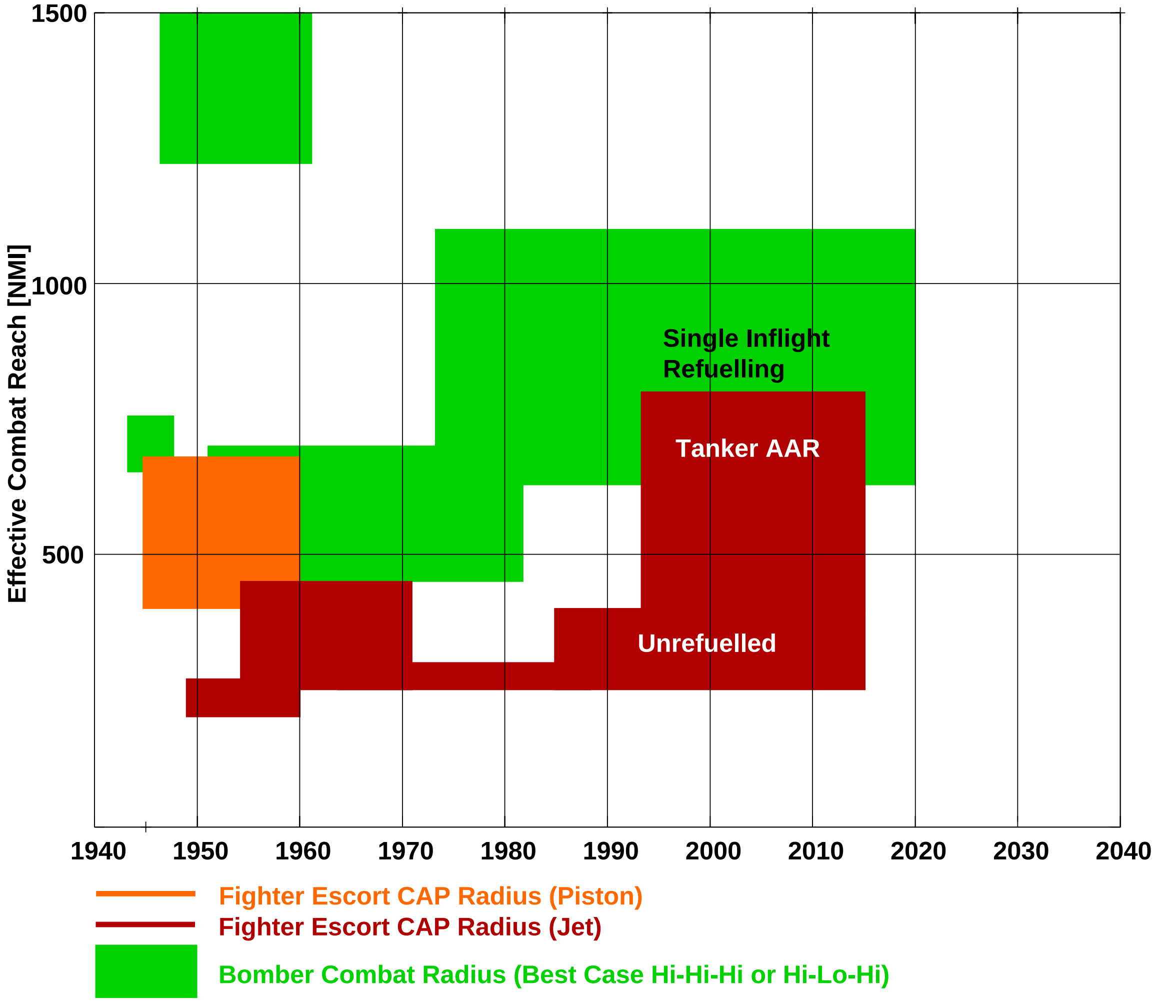
Evolution of RAAF Fighter Capability (1945 - 2015)

Chart 2.

From a strategic perspective, the combat capability and deterrent value of an air force is a function of its ability to project combat power at a given radius. This radius, termed Effective Combat Reach (ECR), is determined by the aerodynamic performance of the aircraft, defined by payload radius, and survivability for bombers and Combat Air Patrol (CAP) radius and lethality for fighters. In situations where bomber survivability is compromised by hostile fighter defences, the limit is determined by the CAP radius of fighters tasked with bomber escort missions.

Charts 1 through 3 depict, respectively, the historical evolution of RAAF Bomber Capability, Fighter Capability and Combat Reach from 1945 until 2015, assuming existing timescales for the replacement of current types are adhered to.

With the exception of the four engined piston Lincoln, the RAAF was mostly constrained to an unescorted strike radius slightly in excess of 1000 NMI, since the introduction of the F-111C, and below 1000 NMI should substantial payloads be carried[6]. Such a radius, operating from bases on the Australian continent, would be adequate to cover airbases situated in Eastern Java and Timor, the nearest points from which a credible strike against the Australian mainland could be mounted. It is also adequate for anti-shipping strikes against fleets approaching the continent or threatening Australian ports and associated SLOCs.



Evolution of RAAF Combat Reach (1945 - 2020)

Chart 3.

The importance of having the capability to strike at an opponent's airbases from outside an opponent's strike radius cannot be understated. The destruction of an opponent's air capabilities, particularly on the ground, is a vital component of the battle for air superiority. The RAAF's continued emphasis on this important capability demonstrates clear and focussed strategic and doctrinal thinking[7].

The RAAF's capability to provide fighter escort to useful radii has been modest, compared to the effective reach of its bombers. Given the absence of effective air defences and air defence fighter capability in the broader region through most of this period, excluding Vietnam which acquired a comprehensive Warpac IADS, the RAAF's

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[6] Wilson, S., *Military Aircraft of Australia*, Aerospace Publications, 1994. See also Wilson, S., *Boston, Mitchell and Liberator in Australian Service*, Aerospace Publications, 1992, Wilson, S., *Lincoln, Canberra and F-111 in Australian Service*, Aerospace Publications, 1989, and Taylor M.J.H, *Jane's American Fighting Aircraft of the 20th Century*, Mallard, 1991

[7] *AAP 1000, The Air Power Manual*, First, Second and Third Editions, RAAF Air Power Studies Centre, Canberra.

bombers would under most circumstances be capable of penetrating with low or modest loss rates in the event of a shooting war. Under these circumstances, fighter combat radius limitations are mostly an impediment to offensive and defensive counter-air operations, since bomber escort missions are not a critical requirement for sustained operations.

The combat radius of the RAAF's fighters has thus not been the foremost priority in the selection of new types, over the last five decades. While a significantly better combat radius was sought for the Mirage replacement, the F/A-18A Hornet did not provide a dramatic improvement, and thus four B-707 transports were equipped as Air Air Refuelling (AAR) tankers during the early nineties to provide additional reach for the Hornets where required. The four tankers provide a training and limited operational AAR capability. In a genuine operational contingency, the small number of tankers in RAAF service would severely restrict the availability of AAR for offensive and defensive operations[8].

This is therefore the historical context in which we can view the RAAF's current force structure, and the context in which an F/A-18A Hornet replacement will be considered.

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[8] For a discussion of combat radius issues in this context see Kopp C., *RAAF B-707 Tanker Program* , Australian Aviation, May, 1990. Also Spangenberg G.A., *Naval Aviation Planning - A Retrospective View*, pp286, in The Gold Book of Naval Aviation, 1985, The Association of Naval Aviation, Virginia. Spangenberg, an aeronautical engineer and former project manager for the F-8U-3 Crusader variant, discusses the definition of the F/A-18 by the USN and OSD through the VFAX program. The radius limits inherent in the design are related to force structure and capability needs. There was considerable opposition to the short ranged F/A-18 by a number of planners, who preferred an aircraft in radius class of the F-14 and F-15. The concerns of these planners were borne out upon the deployment of the aircraft, and the more recent F/A-18E/F, built to a US Navy requirement without outside direction on capabilities, is very close to the early F-15C in weight and achievable combat radius.

1.2 Historical Perspective on Regional Capabilities

The end of the Cold War and the collapse of the Soviet Union has produced fundamental and wide ranging changes to the world's strategic environment. Importantly, this outcome has unburdened the West of a significant part of its post Second World War defence commitments. By the same token, this very same outcome has created a situation where the latest and best equipment designed in the latter phase of the Cold War has become widely available at very competitive pricing. The aggregate reduction in Western defence budgets has created a highly competitive international arms market, in which almost any Western or former SovBloc capability can be acquired at the right price. While major Western powers still apply constraints to which equipment may be supplied to whom, many smaller nations, together with post Soviet Russia, will supply any weapon to any client.

This situation has produced an unprecedented and rapid increase in air and missile capabilities deployed in the Asia-Pacific, which until very recently has enjoyed booming economic performance and thus surplus funds with which to acquire modern equipment.

The scale of this change is best understood by exploring the historical evolution of broader regional air capabilities since the Second World War.

1.2.1 Fighter, Strike and Multirole Capabilities

Prior to the Korean War, what air forces existed in Asia mostly comprised a ramshackle collection of Second World War piston engined fighters. The Korean War saw the first major use of air power by a non-Western nation, when the PLA-AF (People's Liberation Army - Air Force) deployed the Russian built MiG-15 Fagot fighter in significant numbers, flown by Chinese, North Korean and Warsaw Pact pilots. The MiG-15 was more than a match for the RAAF's Meteor F.8, which was relegated with the Mustang to ground attack duties. Until the early sixties, the MiG-15 was the capability benchmark to be matched in Asia. The RAAF's CAC Avon Sabre, equipped with Sidewinder missiles, had a credible capability margin over the MiG-15, and the GAF Canberras were easily capable of evading the daylight / visual MiG-15 if well flown[9].

In the immediate post Second World War period Australia was unchallenged in the nearer and broader region, in terms of capability and initially also numbers. The first significant challenge to the RAAF's undisputed dominance in South East Asia was the initial build up of Indonesia's TNI-AU (Tentara Nasional Indonesia - Angkatan Udara), during the late fifties and early sixties, under the Sukarno regime.

Indonesia acquired from the Soviet Union approximately 25 Tupolev Tu-16 Badger A strategic bombers, 10 Ilyushin Il-28 Beagle tactical bombers, around 40 subsonic MiG-15/17 fighters, and importantly, 35 or more supersonic MiG-21F Fishbed C supersonic air superiority fighters. This was an important change in the regional balance of power. The MiG-21 Fishbed outperformed the Sabre by a significant margin, and the Badger outranged[10] the Canberra almost by a factor of two, with a respectable bomb load. The Beagle provided similar range and performance to the Canberra, with about half of the Canberra's bombload[11].

While the MiG-21F suffered from extremely short combat radius, typically between 150 and 250 NMI[12], it was an agile and manoeuvrable interceptor and later accounted for many US aircraft lost over North Vietnam[13]. The Tu-16 Badger was a fast turbojet powered swept wing bomber, equipped with defensive gun turrets and optical

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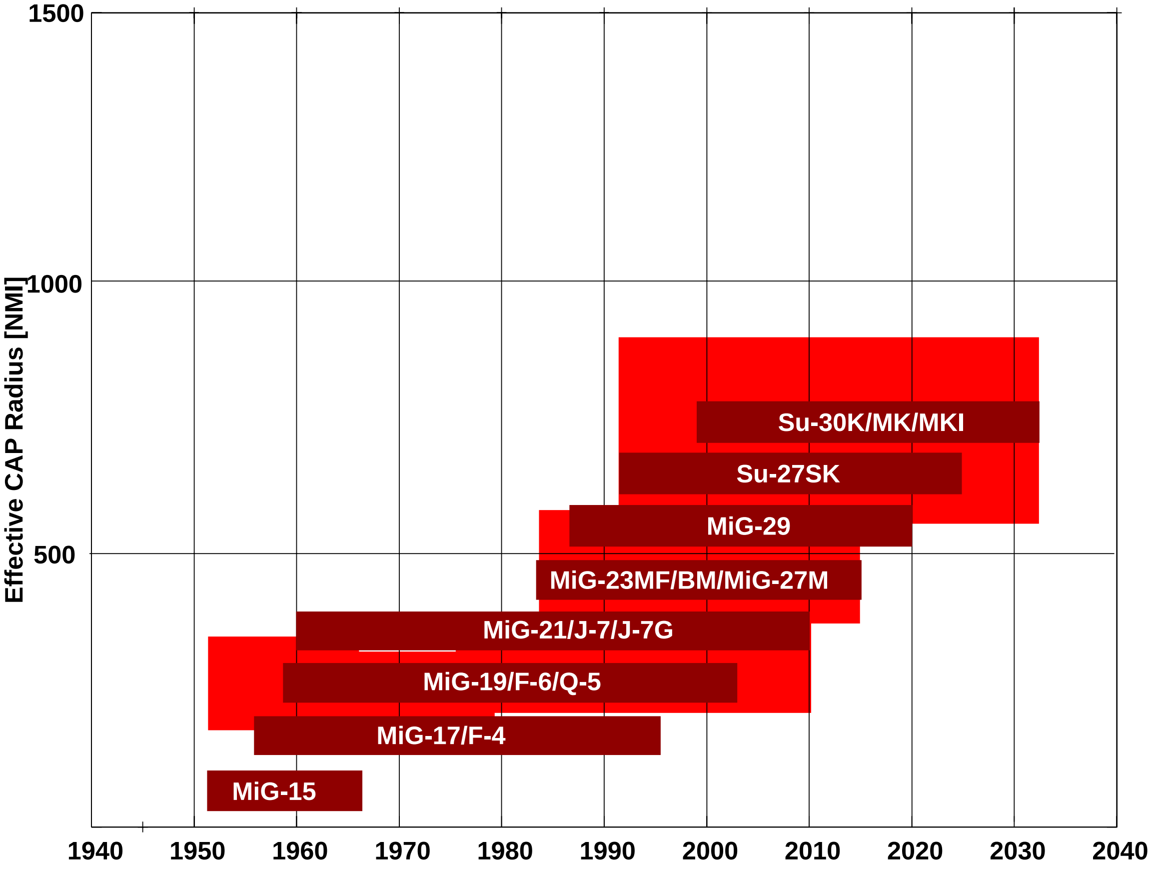
[9] Wilson, S., *Sabre, MiG-15 and Hunter,* Aerospace Publications, 1995.

[10] *Jane's All the World's Aircraft, 1991-92, Lambert M. Ed, pp 45, and Bock R., Tu-16 Badger, Squadron/Signal, 1990.*

[11] Wilson, ibid, and also Kopp C., *Indonesia's Air Capability*, Australian Aviation, 1992 for a more detailed summary of Indonesian air assets during this period.

bomb aiming equipment derived from the Tu-4 Bull, in turn a copy of the US B-29 bomber. A well flown Badger would be difficult target for the subsonic Sabre.

The overthrow of the Sukarno regime in Indonesia led to a change in political posture, and the rapid unserviceability of the TNI-AU's fleet of Soviet types.



Evolution of Regional Fighter Capability (1945 - 2015)

Chart 4.

Importantly, during this period the PRC commenced the large scale licence manufacture of the supersonic MiG-19 Farmer, designated the Shenyang F-6 (J-6). Several thousand F-6 aircraft were built, and the type has been widely exported. The PRC's domestic manufacturing effort commenced in earnest in 1957-58, with the manufacture of the MiG-17 Fresco, designated the F-4, an improved derivative of the MiG-15.

The Tu-16 Badger was also supplied to the PRC during this period, following the political break with the Soviet Union the PRC commenced the unlicensed manufacture of a reverse engineered variant of the Tu-16 Badger, the Xian H-6 (B-6). The first Chinese built examples were delivered in 1968. The PRC during this period also reverse engineered the Il-28 Beagle and the MiG-21F Fishbed, designated the H-5 (B-5) and F-7 (J-7) respectively. In 1970, the PLA-AF began to deploy the NAMC Q-5, an indigenously

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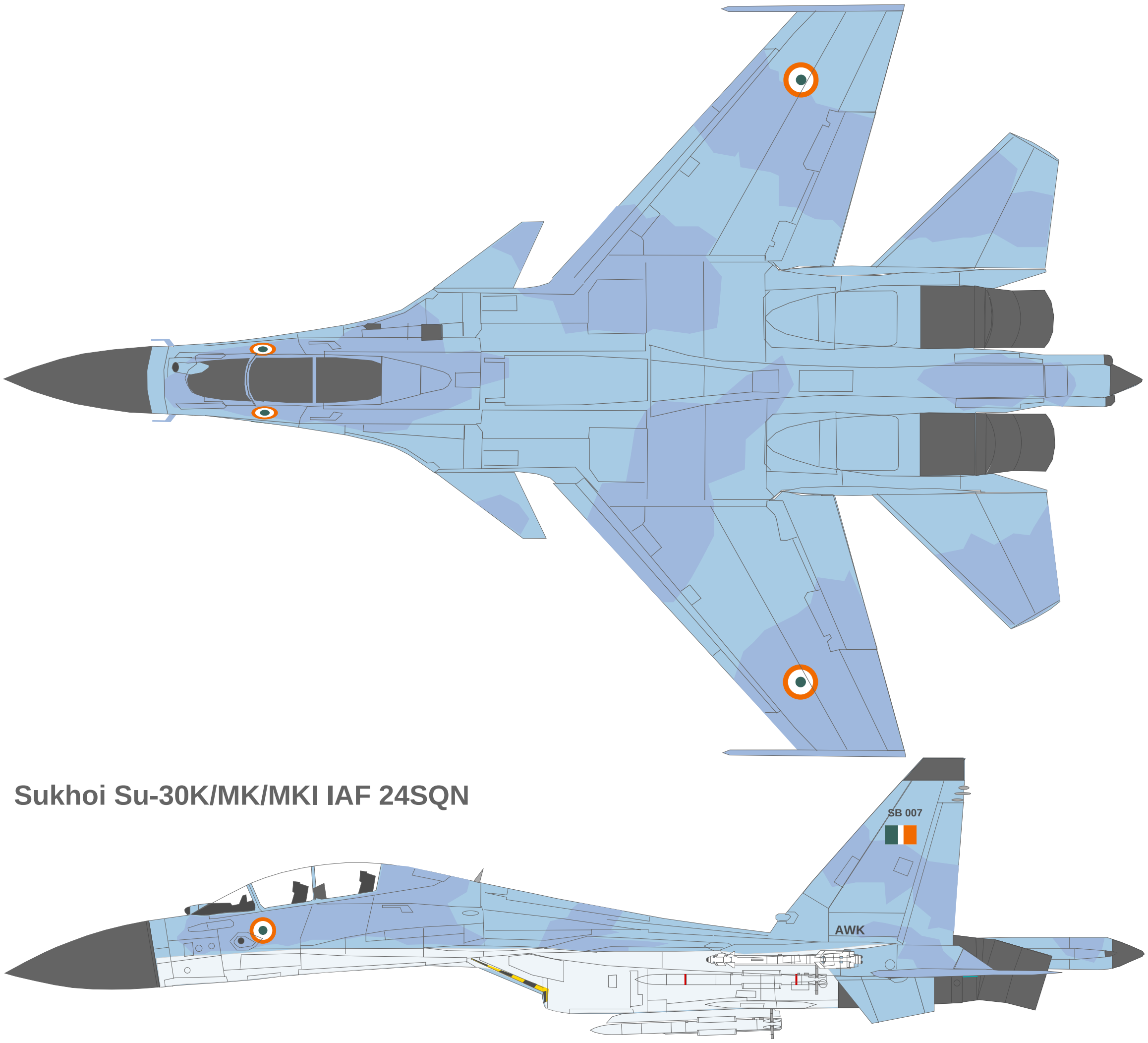
[12] *Jane's All the World's Aircraft*, 1991-92, Lambert M. Ed, pp 255.

[13] Gurney G., Col. USAF, *VietNam - The War in the Air*, Sidgewick & Jackson, 1985, also Francillon R.J., *Tonkin Gulf Yacht Club*, Conway, 1988 and Nordeen L., *Air Warfare in the Missile Age*, Arms & Armour Press or Smithsonian, 1985.

evolved strike variant of the F-6, later exported with the F-6 to Pakistan[14].

The Fishbed, Beagle and the Badger set the capability benchmark for the Asia-Pacific region until the arrival of more advanced types during the seventies and eighties. This period also saw the large scale deployment of the V-75 Dvina (SA-2 Guideline) Surface Air Missile (SAM) in Asia, both in Vietnam and the PRC.



Regional capabilities at this level were not competitive with the RAAF’s Mirage IIIO, Canberra, and later F-111C aircraft. The F-111C in particular had the capability to evade both fighters and SAMs, and was until recently unchallenged in the broader region.

India during the sixties shifted from the UK as primary aircraft supplier, to the Soviet Union. This association continues to this day, with Russia remaining the primary supplier of combat aircraft to the IAF.

Hindustan Aeronautics Limited licence built variants of the MiG-21 Fishbed until 1986, and commenced the manufacture of the variable geometry MiG-23/27/27M Flogger in 1984. The Flogger is regarded to be similar in performance to the US F-4 Phantom, which was the primary US fighter during the sixties and late seventies.

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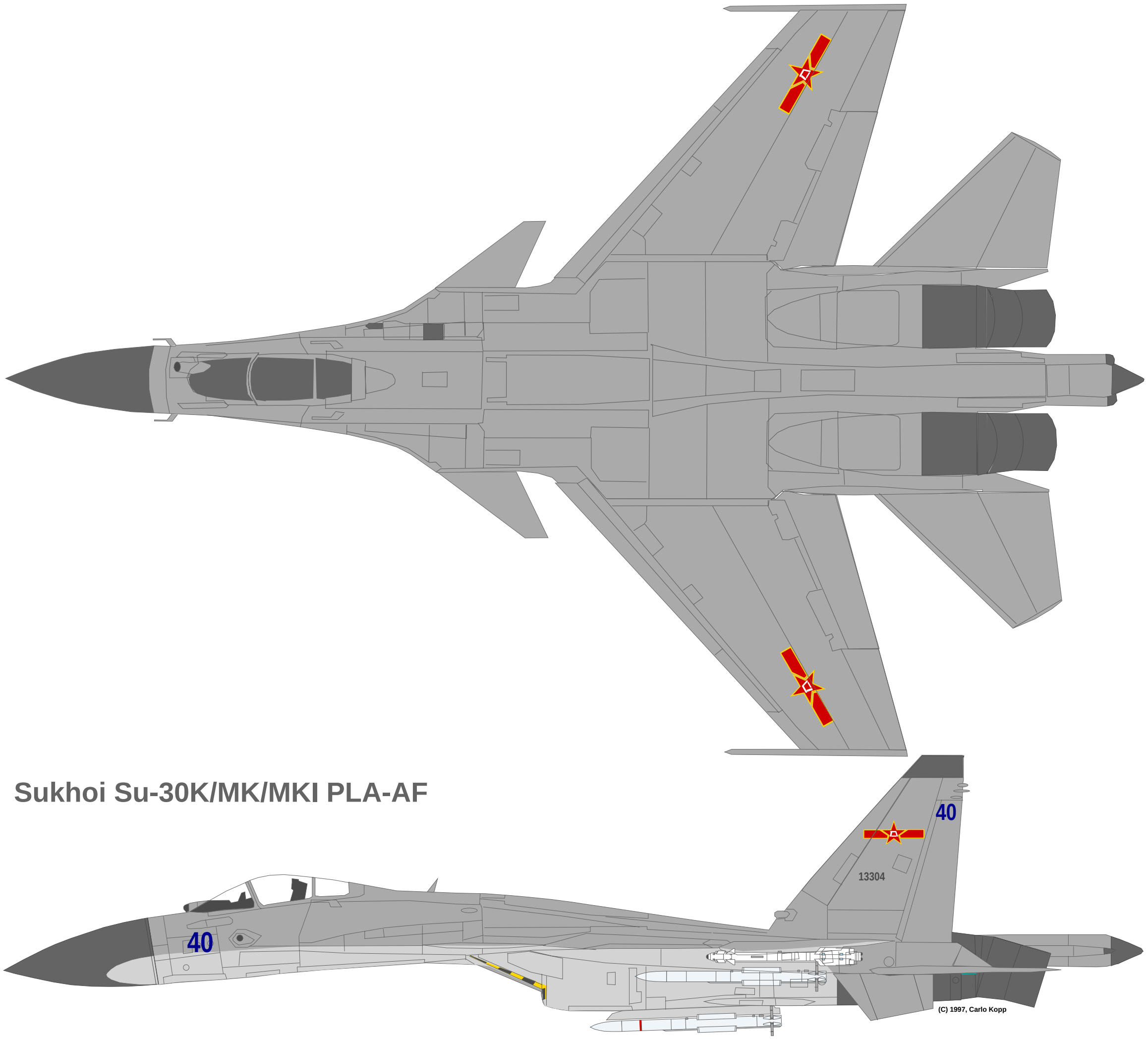
[14] Dornan Dr J.E., de Lee N., Editors, *The Chinese War Machine*, Salamander, 1979, discusses the early development of military jet production in the PRC. Also *The Dragon Stirs*, Air Forces Monthly, July, 1997 contains an interview with PLA-AF Deputy Chief of Staff, Training, and a summary of PLA-AF force development history.

The eighties were a period of important capability growth throughout the Asian continent, and in South East Asia. Pakistan ordered the GD F-16A block 15 in 1981, in response to incursions by Soviet MiGs based in Afghanistan[15]. The first of 40 aircraft was delivered in October, 1982. India responded quickly, and ordered 45 MiG-29 Fulcrum A fighters in 1985, with subsequent deliveries bringing the current total to 53 fighters and 4 dual seat trainers. These aircraft were supplemented by 46 Dassault Mirage 2000 multi-role fighters.



Sukhoi Su-30K/MK/MKI PLA-AF

Both the F-16 and the MiG-29 are modern agile fighters, with look-down shoot-down capable pulse Doppler radars[16]. Both types were front line second tier multirole fighters deployed at that time by NATO and Warsaw Pact air forces.

In January, 1985, Singapore ordered 8 F-16/79 fighters, later changing the order to the more capable F-16A/B Block 150 OCU, and achieving Initial Operational Capability (IOC) in 1990. These aircraft were later supplemented by 18 F-16C/D aircraft, and four refurbished KC-135R tankers are being acquired from USAF stocks. Indonesia's TNI-AU ordered the F-16A/B in 1985, with 12 F-16A/B Block 150 OCU examples

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[15] *Jane's All the World's Aircraft, 1991-92*, Lambert M. Ed, pp 401, and World Air Power Journal, Volume 5, Spring, 1991, pp 50 detail the Asian sales of F-16A aircraft.

[16] ibid.

delivered by 1990[17]. Thailand acquired the F-16A/B Block 150 OCU during this period, and deployed a total of 36 aircraft. It appears that a Thai order for 8 F/A-18C/D aircraft will not proceed due to economic difficulties.

The eighties thus represent the second phase of major regional capability growth, which was balanced by the RAAF's deployment of the F/A-18A and the Pave Tack and Harpoon upgrade to the F-111C.

The most recent phase of broader regional capability growth began after the fall of the Soviet Union, when the PLA-AF ordered its first batch of Sukhoi Su-27SK/UBK Flankers, a Soviet equivalent to the US F-15A. The first 26 aircraft were delivered in 1993, later followed by an additional 22 aircraft, for a total of 36 single seat and 14 dual seat aircraft[18].

In November, 1996, Taiwan responded by ordering 60 Dassault Mirage 2000-5 multirole fighters, delivered from May, 1996. In February, 1996, Taiwan responded to further Su-27 deployments by ordering 120 F-16A Block 20 and 30 F-16B Block 20 aircraft[19].

The PLA-AF responded in turn, and ordered an additional 55 Su-27SK/UBK aircraft[20], and negotiated the licence manufacture of 200 Su-27SK aircraft[21] within the PRC. Unconfirmed reports suggest that the PRC was also negotiating for the purchase of former Soviet Il-78 Midas AAR tankers, or baseline Il-76 transports for conversion to tankers.

India, evidently alarmed by the massive build up of the PLA-AF's capability, negotiated in 1996 the purchase of 40 advanced dual seat Sukhoi Su-30MKI strike variants of the Flanker. Initial aircraft delivered to India are in the Su-30K and MK configurations, with final deliveries and refitting of all aircraft to Su-30MKI configuration planned for the year 2000. The Su-30MKI has thrust vectoring nozzles, canards and an aft facing fire control radar[22]. It is regarded to be a Russian equivalent to the US F-15E Strike Eagle.

Recent reports suggest that India is now negotiating for the domestic manufacture of up to 200 Su-30MKI aircraft. Current reports also indicate that the PRC is negotiating with Sukhoi for the delivery of 55 single seat Su-30MK variant aircraft, slightly less capable multirole variants of the subtype supplied to India.

During this period South East Asia further modernised. The RMAF acquired 20 late model MiG-29 Fulcrums and 8 night attack F/A-18D Hornets. Reports indicated that the RMAF was to acquire a further 18 Fulcrums, but recent economic events indicate that this is unlikely to occur. Vietnam acquired 12 Su-27SK aircraft in 1995[23].

Indonesia during this period sought a portion of the 28 F-16C/D aircraft originally built for Pakistan and currently in storage in the US. Following a widely reported dispute with the US over East Timor, Indonesia cancelled this order and negotiated a barter with Russia for the supply of 12 Su-30MK Flankers and other military equipment. With the recent economic events in Indonesia, this order has been either cancelled or deferred, and is not expected to proceed.

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[17] ibid.

[18] Anselmo J.C., *China's Military Seeks Great Leap Forward*, Aviation Week & Space Technology, May 12, 1997, also *The Dragon Stirs*, Air Forces Monthly, July, 1997, and *National Security of the Asian Pacific Region Countries and Export of Russian Arms*, Russia's Aerospace News, 1997, Vol.2, #1, ITAR-TASS.

[19] Allport D., *Taiwan Update*, Air International, February, 1998, *Jane's All the World's Aircraft, 1991-92*, Lambert M. Ed, pp 401, and *World Air Power Journal*, Volume 5, Spring, 1991, pp 50 detail the Asian sales of F-16A aircraft.

[20] *National Security of the Asian Pacific Region Countries and Export of Russian Arms*, Russia's Aerospace News, 1997, Vol.2, #1, ITAR-TASS.

[21] ibid. The original terms of the contract were that the PRC would manufacture 200 airframes, within a five year period and without a licence to export. Subsequent reports suggest that the re-export restriction make have been lifted, and timescales amended.

[22] ibid.

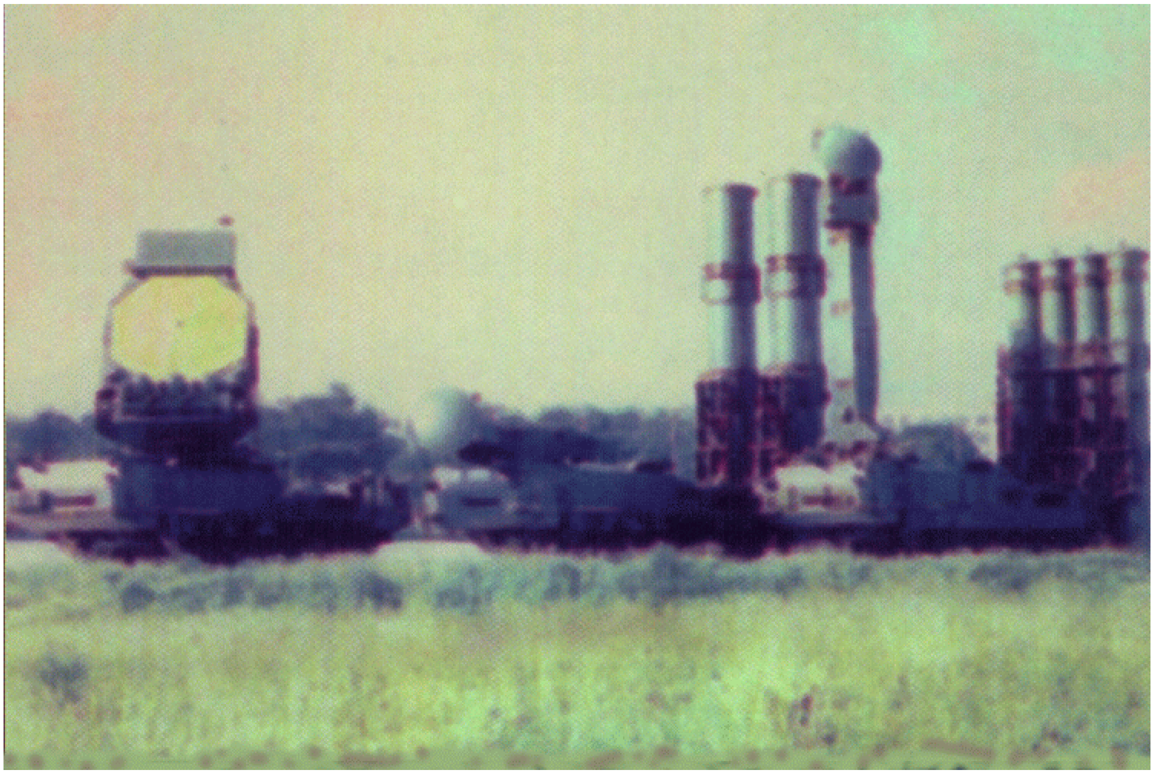
[23] ibid.

At this time deployed numbers of the Su-27/30 and firm orders amount to a total of about 350 aircraft across the broader region, with the acquisition of a further 55 aircraft very likely and the manufacture of another 200 or more possible. This means that between the PRC and India, and smaller players, the total number of Su-27/30 aircraft will amount to a number between 400 and 600 aircraft.

The semi-mobile S-300PMU-1/48N6D (SA-10D Grumble) is the most capable SAM system deployed in the broader region. Depicted are the system components. Upper left: The 48N6 being launched from its tubular container on the 5P85 Transporter/Erector/Launcher (TEL). Upper right: The S-300PMU Flap Lid engagement radar. Lower left: The Tombstone 3D surveillance and acquisition radar. Lower right: The 76N6 Clam Shell low level acquisition radar (photos US DoD, Rosvooruzhenye, LEMZ).

Because the Su-27/30 has an effective combat radius approaching 1000 NMI, similar to the F-111C/G and F-15E, and all variants are strike capable to various degrees, this represents an unprecedented growth in power projection capability across the broader region.

Prior to the deployment of the Flanker in Asia, the most capable strike fighters were limited in combat radius to about 500 NMI, with useful payloads. The Flanker, which is highly competitive as an air superiority fighter, has doubled the effective reach of those air forces which have deployed it, both for strike and counter-air missions.



The fully mobile S-300V/9M82/9M83 (SA-12A/B Gladiator/Giant) is the most capable SAM system currently on offer to the broader region, with India considered the most likely first user[24]. Depicted is a standard battery, to the left is the 9S19M High Screen engagement radar, to the right the elevated tubular launchers for the 9M82 Giant, and 9M83 Gladiator SAMs (US DoD).

1.2.2 Surface Based Air Defence Capabilities

Surface-Air Missile capability in the broader region has shown some growth in the last decade. Until the late nineteen eighties, the most widely deployed weapon in the region was the wholly obsolete Soviet command link guided V-75 Dvina (SA-2 Guideline), which is reported to still be in manufacture in the PRC as the HQ-2J, using a PRC variant of the Fan Song radar, the Gin Sling[25]. The SA-2 system is deployed also by India, since 1962, and by Vietnam and North Korea. The more capable but equally obsolete S-125 Neva (SA-3 Goa) was deployed by India, Vietnam, and North Korea. Only India regionally deployed the mobile ZRK Kub/9M9 (SA-6 Gainful), after 1976, and deployed 185 fire units (TEL). One report suggests that the PRC has manufactured replacement rounds for export clients, based on documentation supplied by Egypt.

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[24] *National Security of the Asian Pacific Region Countries and Export of Russian Arms,* Russia's Aerospace News, 1997, Vol.2, #1, ITAR-TASS.

[25] *Jane's Radar and Electronic Warfare Systems, 1993-94,* 1993. Zaloga S.J., *Soviet Air Defence Missiles,* Janes, 1989.

The first of the later generation of Soviet SAM systems to be deployed in the broader region was the Buk M1/9K37 (SA-11 Gadfly), India is reported to have acquired a number of fire units to replace or supplement their existing SA-6 assets. The 9K37M1 Buk M-1 is a mobile battlefield area defence SAM, a missile very similar in configuration to the RIM-66 Standard. A true mobile system, linked by radio datalinks, the SA-11 carries four rounds on its TELAR, and the Fire Dome engagement radar on the 9A310M1 TELAR. Each battery has a 9S18M1 Tube Arm acquisition radar, and has a separate 9S470M1 command post vehicle, all based on the same tracked AFV chassis. The Russians claim the 4 TELAR battery can be ready to engage within five minutes of arriving on site.

The most capable of the current generation of Soviet/Russian equipment to deploy in the region is the DSC S-300P/48N6 (SA-10 Grumble), at least four batteries purchased by the PLA[26]. The S-300PMU-1/SA-10D Grumble area defence SAM, is optimised for killing cruise missiles, bombers at all altitudes, and has a respectable Anti Tactical Ballistic Missile (ATBM) capability. Often described as a "Patriot-ski", the S-300PMU-1/SA-10 uses the 30N6E1 Flap Lid phased array fire control radar, truck or mast mounted, and is supported by the truck or mast mounted 76N6 Clam Shell FMCW low level early warning radar and the Big Bird or Tin Shield early warning radar. Whilst earlier variants used semi-active homing, the latest S-300PMU-1/PMU-2 and 48N6D/E missiles use Patriot style Track-Via-Missile (TVM) guidance. A typical battery has 8 to 12 5P58/MAZ-7910 8x8 TELs, each with four rounds.

The more capable fully mobile Antey S-300V/9M82/9M83 (SA-12 Gladiator/Giant) SAM/ATBM has been offered to India but as yet there are no reports of a commitment[27]. The S-300V/SA-12 was designed to provide long range area defences for Army level forces in the field, against aircraft, cruise missiles and TBM/IRBMs such as the Lance and Pershing. A fully mobile system, the S-300V uses the 9S15MV Bill Board 3D surveillance radar and the 9S19M2 High Screen engagement radar, both large phased arrays mounted on turntables on tracked vehicles. Each TELAR carries the 9S32-1 guidance radar, and either two SA-12B/9M82 Giant ABMs or four SA-12A/9M83 Gladiator SAMs. The Gladiator has a quoted range of up to 40 NMI with an altitude capability of between 75 to 80,000 ft. A typical battery has a mix of TELARs, with 2-4 ABM rounds and 8-16 SAM rounds. The S-300PMU and S-300V are regarded to be Soviet equivalents to the US Patriot SAM/ATBM PAC-2 and PAC-3 variants.

The most capable point defence SAM system deployed to date is the Tor M1 (SA-15 Gauntlet) mobile battlefield system. The PLA is reported to be taking delivery of 15 fire units[28].

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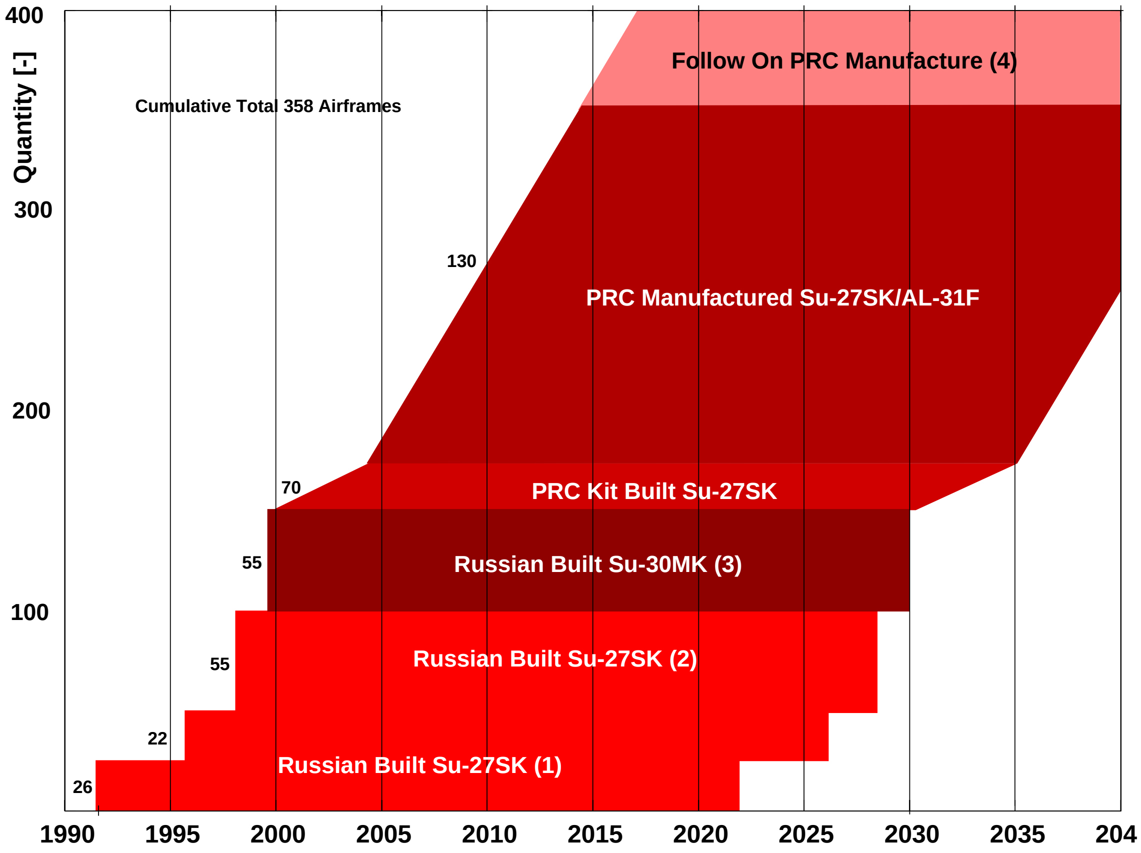
[26] Kopp C., *Benchmarking the Wider Regional Threat*, Australian Aviation, December 1997, also Anselmo J.C., *China's Military Seeks Great Leap Forward*, Aviation Week & Space Technology, May 12, 1997, and Zaloga S.J., *Future trends in Air Defence Missiles*, Journal of Electronic Defence, October 1997, and *National Security of the Asian Pacific Region Countries and Export of Russian Arms*, Russia's Aerospace News, 1997, Vol.2, #1, ITAR-TASS.

[27] ibid.

[28] Novichkov N., *Russian Arms Technology Pouring Into China*, AW&ST, May 12, 1997. For details see *Jane's Radar and Electronic Warfare Systems, 1993-94*, 1993.

1.3 Projected Regional Flanker Deployments

An accurate estimate at this time of the rate at which numbers of Flanker aircraft will build up in the region is difficult, since many variables interact which can both compress and stretch timescales. However, the rate at which the capability builds up is of critical importance, since it will determine the point at which existing capabilities in South East Asia are rendered ineffective. It also imposes constraints on how long the RAAF can retain the F/A-18A and still maintain a credible deterrent posture in the broader region.



(1) 48 aircraft currently in service comprising mix of Su-27SK and Su-27UBK (ITAR-TASS)
(2) Reported follow on order of 55 Su-27SK and Su-27UBK (ITAR-TASS 1997)
(3) Currently under negotiation, reported to be 55 examples of single seat Su-30MK variant
(4) Speculative

Projected PLA-AF Flanker Variant Deployments

Chart 5.

The PRC deployed its initial 26 Su-27SK/UBK aircraft in 1993, and at this time has at least 48 in operational service. The follow-on order for 55 Su-27SK/UBK was placed in late 1996 and therefore we can expect, given past experience with Sukhoi, that all of these aircraft will be delivered by the turn of the century.

The purchase of 55 single seat Su-30MK strike fighters is currently being negotiated and reports suggest that it was intended to be finalised in June this year, which suggests deliveries over the following 2-3 years. Current estimates[29] suggest that the PRC will start the delivery of aircraft assembled from Russian component kits around the turn of the century, and will start delivering wholly Chinese manufactured aircraft from about

2004 onward.

Given these constraints, we can expect to see the total deployed by the PLA-AF to be around 100 aircraft by the turn of the century, with cumulative totals ramping up to 200 by about 2005-2008, 300 by about 2012 and production run completion in 2014. There is some speculation in the trade press that further airframes may be built, but since the decision point for that is almost a decade away, it may or may not transpire.

Because the Su-27/30 uses titanium structure generously, it will not be a trivial airframe to manufacture and good quality control will be required. As a result, there may be some lag in deliveries to the PLA-AF. This will be evident from delivery schedules post 2000.

In the longer term the picture is unclear at this time. The Russians have stated their intention to supply "more than 500 of the latest fighter aircraft to China[30]". It is currently expected that the Su-32FN strike aircraft, regarded to be a genuine F-111 equivalent, will be soon released for export. There have been some reports that the PLA-AF was interested in this aircraft.

The first Russian built batch of Su-30K aircraft was supplied to the IAF ahead of schedule. The breakdown of the original contract for IAF aircraft was such:

- first batch of 8 aircraft in standard Su-30K configuration

- second batch of 8 aircraft in standard Su-30K configuration, with additional aft fire control radar, to be delivered in 1998.

- third batch of 12 aircraft in Su-30MK configuration, with aft fire control radar, improved avionics and canard foreplanes, to be delivered in 1999.

- final batch of 12 aircraft in Su-30MKI configuration, including the AL-37FU Thrust Vector Control engines.

Subsequent to the delivery of the final batch, the first 28 aircraft were to be upgraded to the final Su-30MKI configuration[31].

Recent reports indicate that the second batch of aircraft may be delayed by twelve months, since the IAF has yet to finalise its choice of glass cockpit. This may result in a rearrangement of deliveries, with the remaining portion of the build delivered as fully configured Su-30MKIs[32].

The economic problems in South East Asia are likely to prevent further deliveries of Russian aircraft in the nearer future. However, reports suggest that the Russians are still trying to revive the sale of 12 Su-30MK to Indonesia, and are continuing negotiations with Vietnam for a follow on order of 24 Su-27SK aircraft[33].

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[29] Anselmo J.C., *China's Military Seeks Great Leap Forward*, Aviation Week & Space Technology, May 12, 1997.

[30] Novichkov N., Morocco J.D., "Russia Alters Arms Export Strategy for Southeast Asia", AW&ST, February 23, 1998.

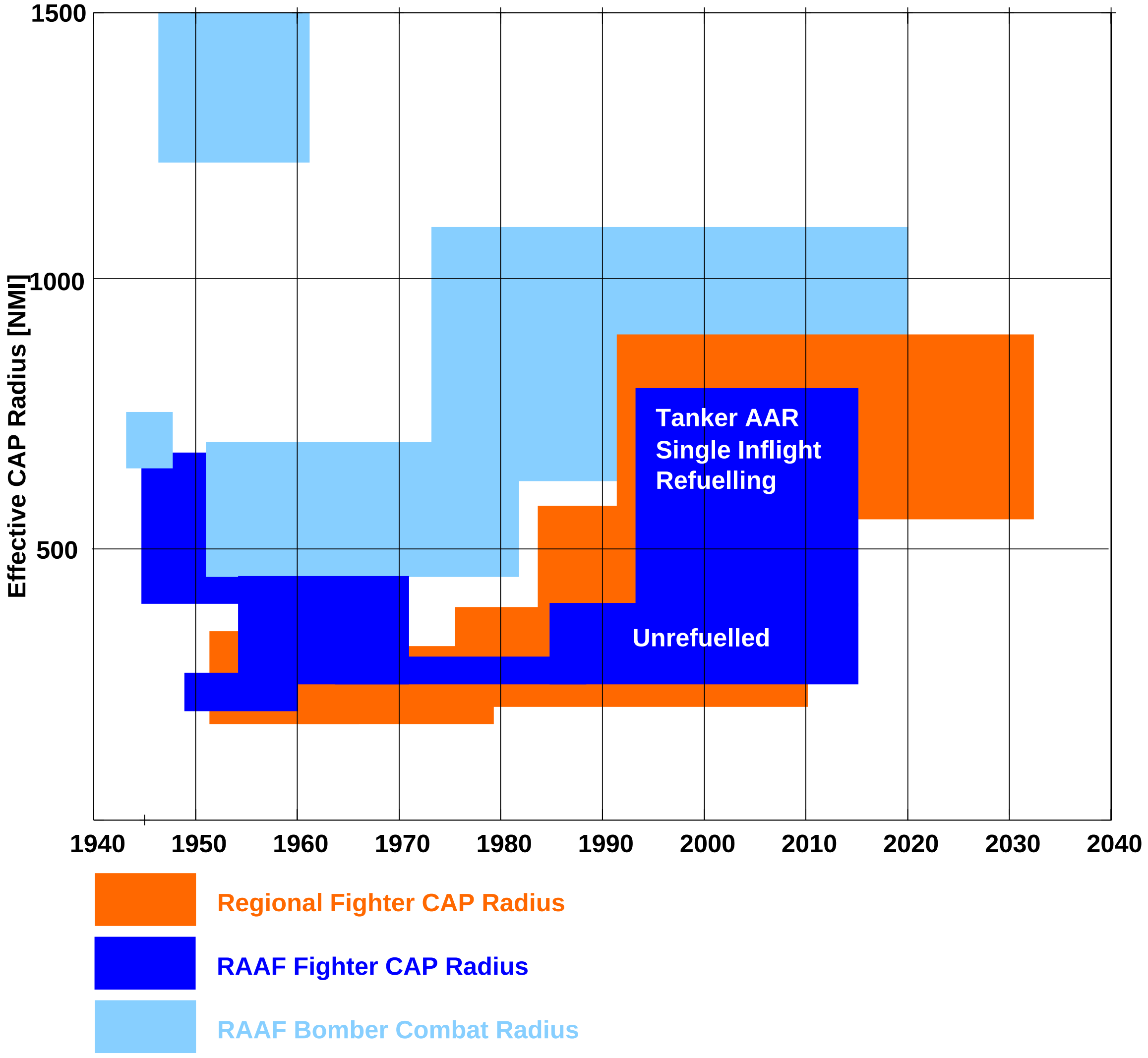
[31] *National Security of the Asian Pacific Region Countries and Export of Russian Arms*, Russia's Aerospace News, 1997, Vol.2, #1, ITAR-TASS. Also Chopra, V., *Extravagant & Unnecessary ?*, Air Forces Monthly, September, 1997.

[32] Velikovich A., Barrie D., *India's avionics indecision holds back second batch of Su-30s*, pp 16, Flight International, 29 April, 1998.

[33] Novichkov N., Morocco J.D., "Russia Alters Arms Export Strategy for Southeast Asia", AW&ST, February 23, 1998.

1.4 The Projected Strategic Context

There is no recent historical precedent for the scale and speed with which the deployment of the Flanker in Asia has altered the broader regional strategic balance. Because the Flanker aerodynamically outperforms all other types in the Asia-Pacific, and has a highly capable radar/missile package, it can effectively challenge any regional air force equipped with modern US, European and lesser Russian/Soviet types in a direct counter-air confrontation.



Evolution of Comparative Regional Air Capability (1945 - 2030)

Chart 6.

The Flanker has a combat radius two to three times greater than any other air superiority type deployed in the region, with the exception of the US F-14 and F-15C/E, and Japan's F-15CJ[34]. Therefore the Flanker can be based well outside the combat radius of most types in the region, and at the radius limit of the F-111C/G and F-15E. This has two important implications.

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[34] *Jane's All the World's Aircraft*, 1991-92, Lambert M. Ed , 1991.

The first is that an air force deploying the Flanker can use escorted strike packages to attack the air bases of its opponents, from outside the range at which credible counter-strikes can be launched. This is an important advantage, since the effort required to defend the bases from which the Flanker operates can be reduced significantly.

The second reason is that the Flanker, if used to defend its airbases, has the combat persistence and radar/missile capability to do so both effectively and efficiently, notwithstanding limitations to capabilities in earlier variants. The Flanker, if well flown and supported by proper AEW&C[35] or decent surface based radar coverage, can seriously threaten both the F-15E and the F-111C/G. Unless both types are well supported by AAR tankers, they will be at a significant disadvantage in fuel state. Tankers will require escorts, since they will be within the reach of the Flanker, and the refuelling package will need to be held at a greater range from the target than has been common operational practice to date.

Because the Flanker is being deployed in large numbers, comparable to the USAF's total deployments of the F-15C and F-15E, the broader region is acquiring an aggregate conventional power projection capability of a similar magnitude. With at least 350 aircraft planned for deployment by the PLA-AF, the capability so acquired would be roughly equivalent to 60% of the USAF's combined F-15C and F-15E deployments.

Some broader regional factors, which are likely to influence the long term strategic situation, are worth noting:

- increased strategic rivalry between India and the PRC[36].

- the ongoing territorial disputes between India and the PRC.

- the ongoing disputes between the PRC and RoC/Taiwan.

- strong growth in industrial manufacturing capability, particularly in the PRC

- increasing demand for energy resources to support industrial economies, in particular in the PRC and India[37].

- ongoing disputes between the PRC and South East Asian nations over the Paracel and Spratley islands, and oil/gas drilling access in the South China Sea.

- an economic loss of momentum in Japan and South Korea, and a defacto financial collapse in South East Asia

- a military build up by the PRC in Tibet and East Turkmenistan, possible basing of PLA-N assets in Myanmar, and an broad modernisation of the PLA.

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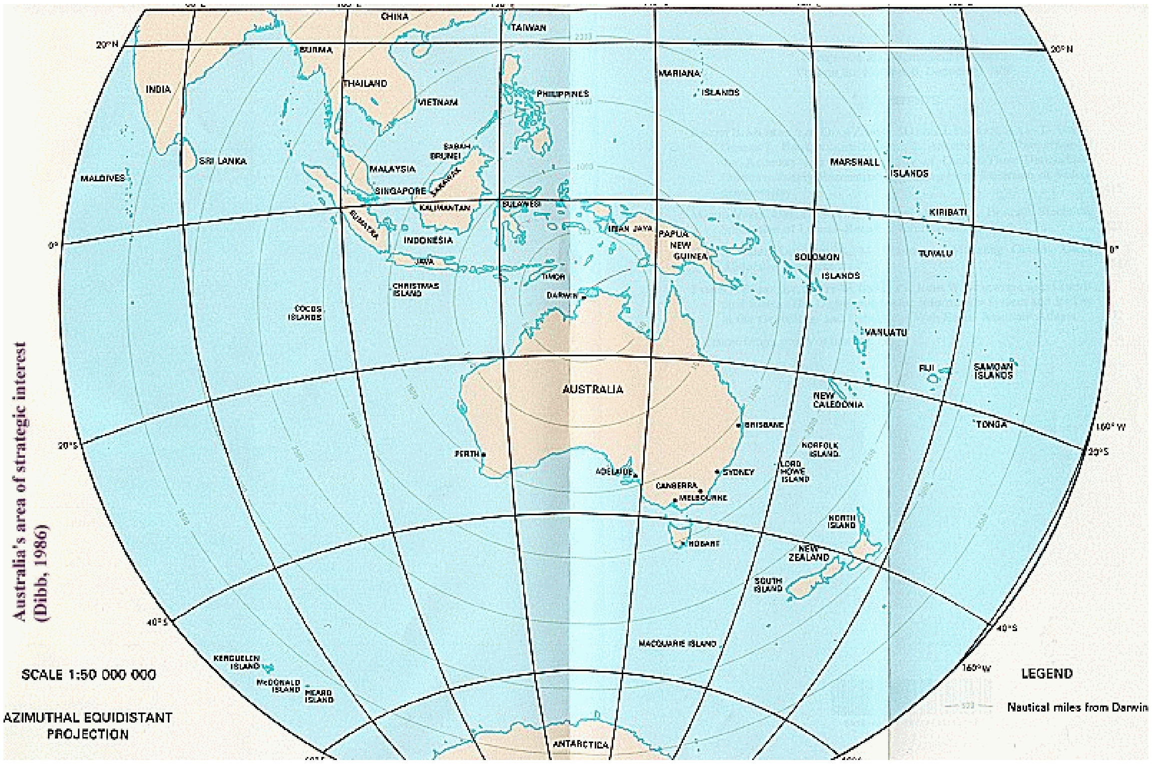
[35] Both the PRC and IAF are now actively seeking AEW&C and tanker capability. See Novichkov N., Taverna M.A., *Russia, Israel plan A-50;...*, AW&ST, June 23, 1997, *Beijing to Acquire AEW Capability*, JDW, June 4, 1997, the intent is to supply the PLA-AF with a Mainstay AEW&C fitted with an IAI/Elta Phalcon radar. *IAF Requires Tankers to Fulfill Su-30's Potential*, JDW, June 11, 1997.

[36] Recent public statements by India's Defence Minister in relation the lengthening of eleven PLA-AF runways in Tibet, ostensibly to allow the Flanker to operate from these, indicate that the Flanker may already have perturbed the political equilibrium. *India sees China as Threat*, HeadsUp Newsletter, Issue 48, pp 4. Certainly India's overt nuclear sabre rattling in recent weeks suggests strategic rivalry between these two great Asian nations is unlikely to abate in the foreseeable future.

[37] CIA Director R. James Woolsey in Anselmo J.C., *China's Military Seeks Great Leap Forward*, Aviation Week & Space Technology, May 12, 1997. The CIA estimates that once India and China reach the per capita energy consumption of South Korea, their combined demand for energy will reach 120 million barrels of oil per day. To place this in perspective, current aggregate world consumption is at 60-70 million barrels per day, with the expectation that readily accessible reserves will begin to decline post 2000, triggering gradual upward creep in energy costs.

It is clearly evident that we are entering a period of increased strategic uncertainty on the Asian continent, and a period which may not see the relative political stability of recent decades persisting.

The large scale deployment of the Flanker in the broader region has important implications for the nearer region.


Australia's area of strategic interest (Dibb, 1986)

The first and most important is that it wholly offsets any capability gains over the last decade, in South East Asia. The deployment of modest numbers of teen series fighters, and Russian fighters, by ASEAN nations does not represent a serious capability in the face of multiple regiments of Su-27SK and SU-30MK aircraft.

The second is that with even modest air to air refuelling, or the provision of drop tanks, Flankers can hold at risk substantial portions of South East Asian airspace. While there are as yet no firm reports of a genuine air-to-air refuelling tanker capability either in India or the PRC, there have been persistent reports of the PRC and India seeking to acquire such, concurrently with reports of an interest in acquiring AEW&C aircraft[38].

In practical terms this means that the level of regional defence self reliance which Australia has encouraged in South East Asia has become mostly irrelevant. Should a contingency arise where ASEAN nations are challenged either by India or China, possibly as a result of a dispute between the two, then South East Asia will have a very limited capability to fend for itself, more so following the recent economic collapse.

The implications for the ADF are that this is the emergence of a strategic context in which both India and China will develop within the next two decades a credible capability to project air power into Australia's traditional geographical area of immediate

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[38] This key battle management asset is on the PLA-AF's shopping list for the next decade, and will most likely be the IAI/Ilyushin A-50 Mainstay using the Israeli Phalcon radar. Abundant reports exist of the PRC intending to retrofit inflight refuelling equipment to the H-6 Badger and the Il-76, or purchase Il-78 tankers from Ilyushin, although there is no firm evidence that this has been done as yet. Inflight refuelling probes are an off-the-shelf item for the Flanker, if specified, and may be retrofitted.

interest.

It would therefore be prudent for the ADF to maintain a sufficient level of capability to credibly challenge any such incursions. At a minimum, this would provide a deterrent to the major regional powers, to discourage them from seeking to use South East Asia for political or geostrategic leverage against one another.

Section 2 Technical and Operational Issues

2.1 Recent Technological Trends in Fighter Development[39]

The central issue for any discussion of a Hornet replacement must be the roles which the aircraft is to perform, because optimisations of airframes, propulsion and sensor packages for one type of mission can strongly influence an aircraft's suitability for another. As noted earlier, any RAAF replacement fighter must have the ability to successfully defeat an numerically superior opponent flying the Su-27 Flanker, or evolved derivatives thereof. If this aircraft is to provide in the nearer term escort for the F-111, and in the longer term also replace the F-111, it must be able to at least match the F-111's 1000 NMI class combat radius with a robust payload of weapons. Both of these factors indicate that range will be a vital issue, as vital as air combat performance and strike capability.

A modern combat aircraft is essentially a high performance sensor and weapons platform, and to gauge the measure of this importance, it is worth noting that 40-60% of the cost of a modern fighter is in its onboard avionic package, and embedded software. A good indicator of this trend is that Boeing are building the F/A-18E for about the same cost that they are building the latest F-15E derivatives, despite these being a larger and better performing airframe. The cost of the radar, InfraRed Search & Track (IRS&T), ESM/RWR (radar homing/warning receivers), ECM (jammers), Missile Approach Warning System (MAWS), thermal imaging targeting system(s) (FLIR/Laser), IFF/communications, mission computers and stores management computers, databussing, cockpit displays, Helmet Mounted Display and software required to integrate such systems, together rivals the cost of the basic airframe, powerplant(s), fuel, electrical and other systems. So much so that an incremental increase in airframe size does not have the effect on aircraft price which it may have had two decades ago. The increasing level of miniaturisation and declining cost of high performance embedded computers have translated into vasty more intelligent and thus more capable missiles, which in turn require vastly more capable offensive systems to exploit them, and defensive systems to defeat them.

One of the side effects of this revolution in weapons and sensors is stealth, which evolved as a specific response to increasing missile and radar capability. Stealth impacts airframe design through shaping and materials, and sensor design through the need to minimise electromagnetic emissions in all bands, leading to Low Probability of Intercept (LPI) techniques in active sensors, and higher sensitivity in passive sensors. Experience in the US suggests that a stealthy airframe has a flyaway cost about 25-35% greater than an equivalent conventional airframe[40], indeed the inflated cost figures we see in the media reflect more than anything US accounting practices which lump basic R&D and manufacturing/support expenditure into the type specific program cost.

We are seeing a strong shift in air superiority toward Beyond Visual Range (BVR) combat, which demands highly capable and comprehensive sensor suites, fusion of data from multiple sensors, and the ability to evade or defeat the opponent's sensors.

This is the context in which a modern fighter must be assessed. How well does the sensor package fit the role, how well does the airframe fit the role, how well is the package blended together, how well can the airframe and sensor package support the weapons carried.

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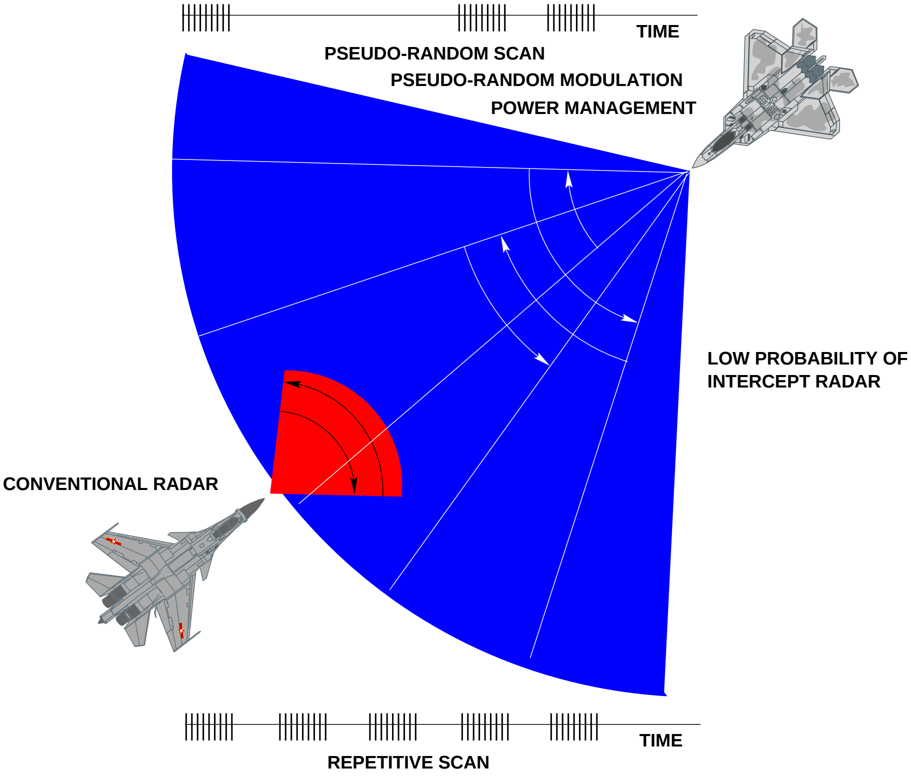
[39] Section 2.1 is an amended version of a multi-part series currently being published by the author in Australian Aviation under the title of *Measures of Fighter Capability*.

[40] This estimate is based upon comparisons of the flyaway cost of the F-117A compared the F-15C, the B-2A compared to a new build B-1C, and the 1996 flyaway cost of the F-22 compared to the F-15E/I/S. For more detail see Kopp C., *NORTHROP B-2A - The 70 Billion Dollar Bomber ?*, Australian Aviation, March, 1990, and Warwick G., *The F-22 Story*, Flight International, Supplement, 1997.



CONVENTIONAL RADAR VS LPI RADAR

2.1.1 Radar Issues

A modern fighter radar built to support air superiority roles must have dogfighting modes to engage close targets at high relative angular rates, as well as providing high detection range performance against small targets at long ranges, looking down into clutter, and having the ability to track, identify (Non-Cooperative Target Recognition or NCTR) and target multiple threats. The recent availability of stealth treatments for existing aircraft, as seen with the USN F/A-18C/E/F or Russian absorbent coating work applied to the Flanker[41], indicates that detection range performance will be an important issue in coming decades, since reduced RCS (Radar Cross Section - a measure of radar signature) fighters may have signatures a factor of ten or more below existing in service aircraft. This in turn roughly halves the detection range of such aircraft in comparison with non-treated airframes.

While InfraRed sensors such as IRS&T/FLIR/Laser may provide good capability at WVR ranges, and under suitable weather conditions, even at BVR ranges, they cannot compare with the true all weather capability of radar at any range. Therefore defeating radar provides and will continue to provide a significant tactical payoff.

All other things being equal, the easiest way to increase radar detection range performance is to employ a larger antenna, which not only improves range, but also angular resolution at a distance, vital for BVR combat. This is a strong argument for aircraft with wide forward fuselages, which usually leads to a larger airframe. An example here would be Hughes APG-70 series of fighter radars, which share a very high degree of

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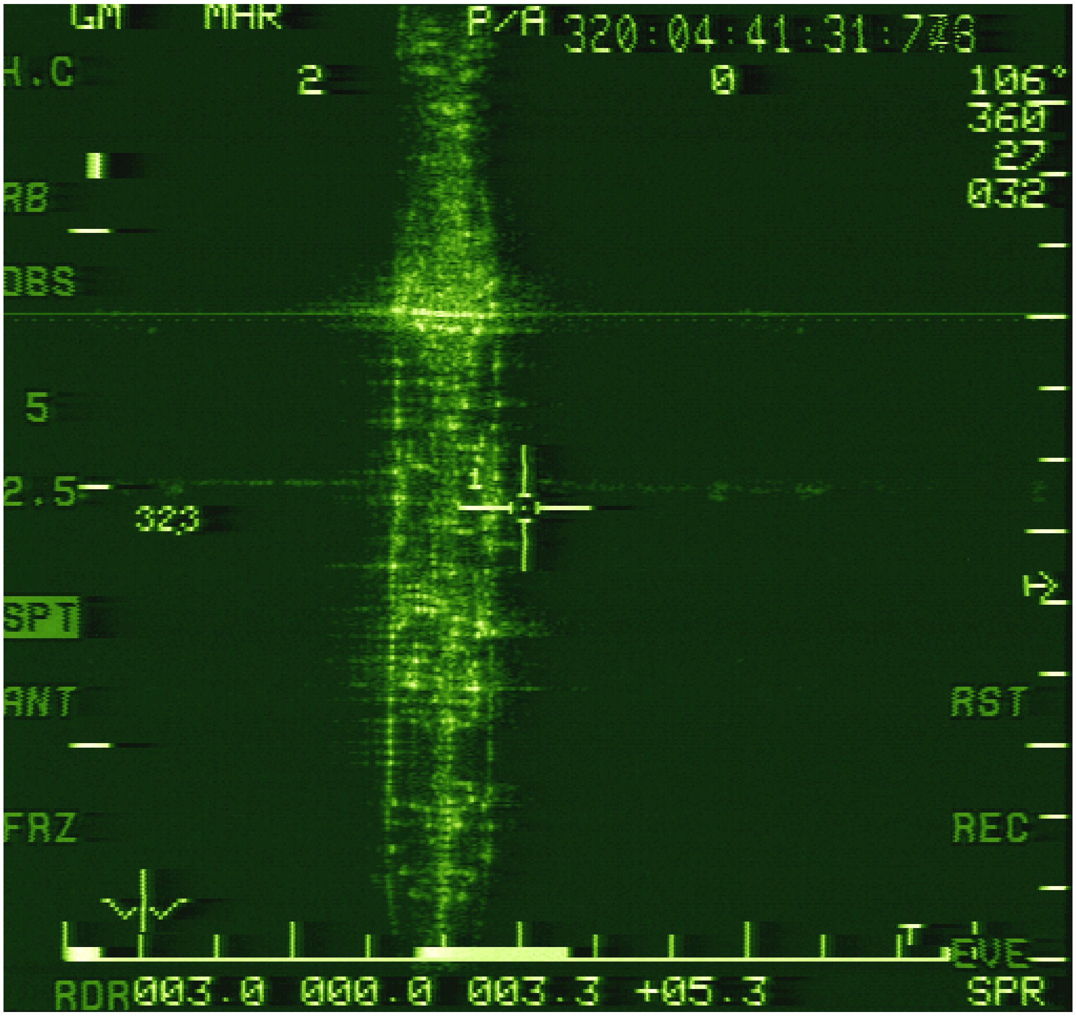
[41] Numerous media reports indicate that the Russians have sold large amounts of a radar absorbent coating to India, and offered the same material to Indonesia. While no details have been published on its composition, or its performance, this is a clear indication of the fact that R&D effort is being expended in the area and materials being produced in respectable volumes.

commonality between types at a module level. The "larger" radars in this family have larger antennas and more powerful transmitters.

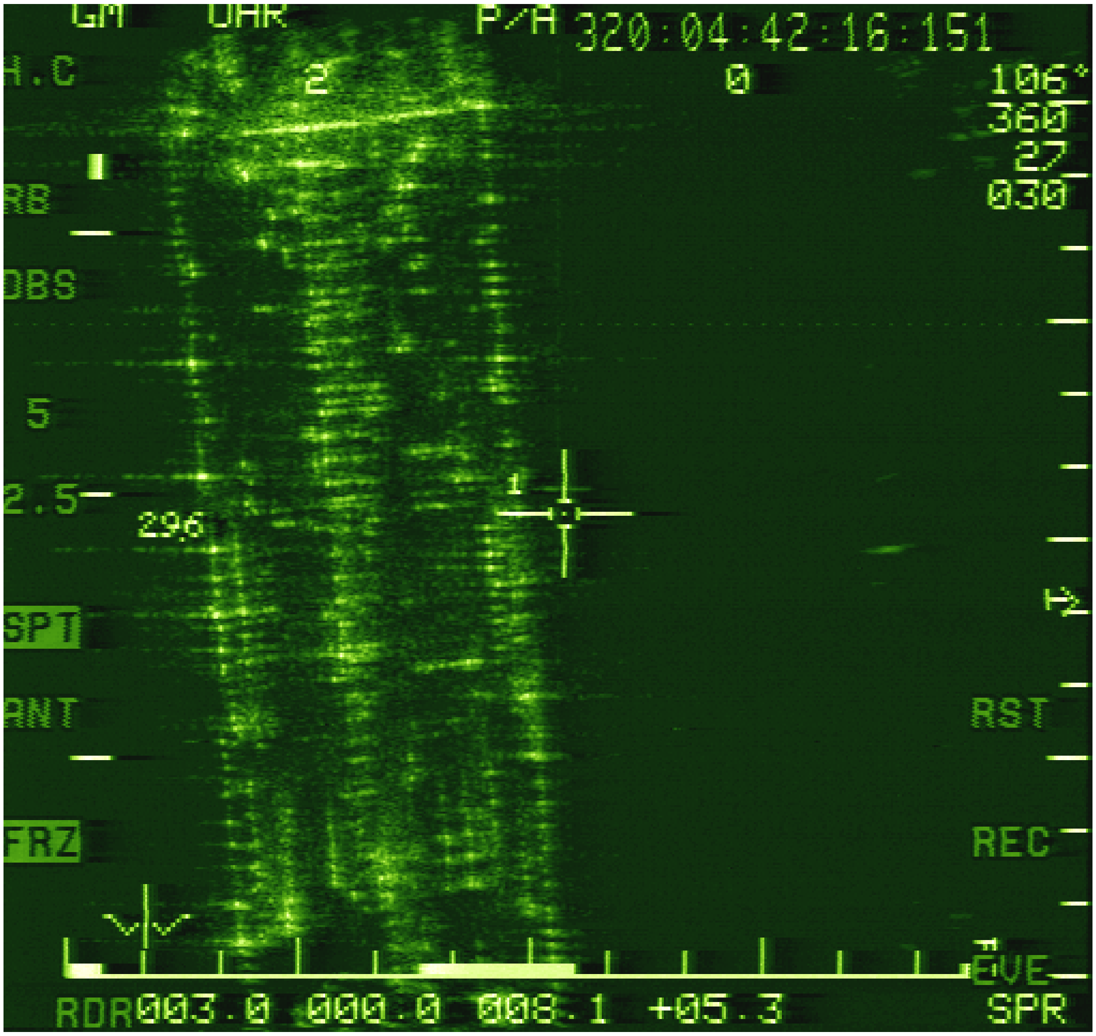


Imagery of a tanker vessel in Delaware Bay, produced by a Northrop-Grumman APG-76 SAR/GMTI attack radar from 32.3 NMI, resolution is 1 metre. This radar is carried by upgraded Israeli F-4 aircraft, and is representative of the current state of the art in the technology (Northrop-Grumman).

Another technology which is beginning to emerge in fighter radars is the electronically steered phased array, and in particular the active array. A conventional fixed slotted array antenna, or a passive phase shifter based phased array, as used in the B-1B’s APQ-164, the B-2A’s APQ-181, the Flanker’s NIIP N-011M/Phazotron Zhuk Ph, or the Thomson RBE both use a conventional Travelling Wave Tube (TWT) transmitter feeding into the antenna.

Active arrays however are quite different, with each element (slot) in the antenna having its own electronically controlled transistor or MMIC (Monolithic Microwave Integrated Circuit) receiver/transmitter/phase-shifter module. An active array can achieve potentially better receiver sensitivity by placing the first receiver stage right behind the antenna slot, as well as vastly improving reliability since the loss of any module in several hundred costs a fraction of a percent of performance.

The less obvious advantage of the active array (or phased array) antenna is its potential for stealthiness (LPI). Whereas a mechanically steered antenna exhibits repetitive scan behaviour, easily identified by a hostile radar warning receiver, a phased array can be suitably programmed to perform a pseudo-random scan pattern, which means that pulse trains are no longer detected periodically by an opponent. If pseudo-random scanning is combined with spread spectrum modulation techniques on individual radar pulses (ie direct spreading and frequency hopping), a significant reduction in detected power per bandwidth can be achieved. Most established radar warning receivers and ESM systems will be totally deaf to such radars[42].



Further imagery of a tanker vessel in Delaware Bay, produced by a Northrop-Grumman APG-76 SAR/GMTI attack radar. Range is 29.6 NMI, resolution is 0.3 metre (Northrop-Grumman).

The recent advent of anti-radiation variants of established radar guided BVR AAMs suggests that those who choose to fly with a conventional non-LPI radar will be exposed to yet another form of BVR AAM attack.

For strike roles, the current generation of radars provide focussed Synthetic Aperture Radar (SAR) and Ground Moving Target Indicator (GMTI) modes, which provide very high resolution groundmapping and the ability to detect, identify and track

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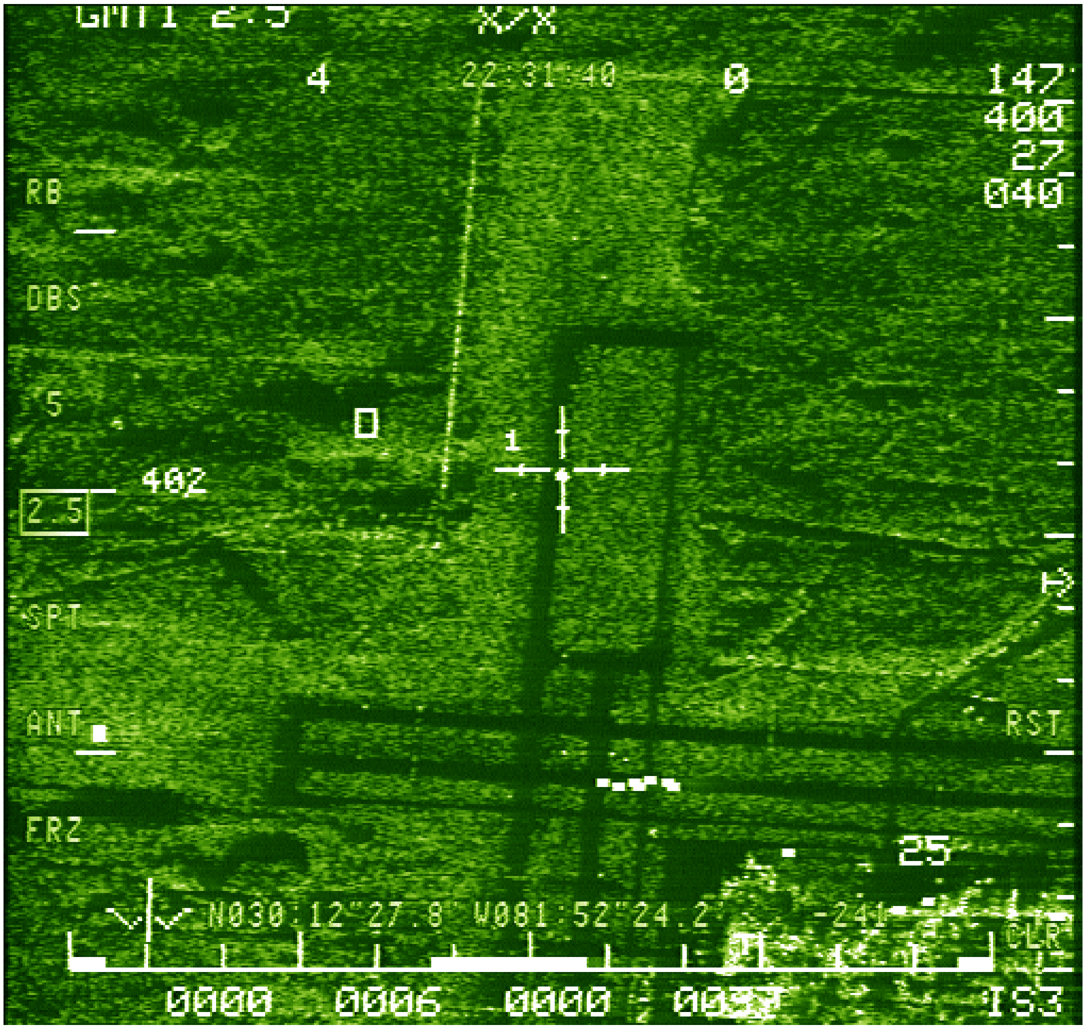
[42] Current active array development programs are the Westinghouse APG-77 SSPA (Solid State Phased Array) for the F-22A, the Hughes APG-73 RUG (Radar Upgrade Program) Phase III for the F/A-18C/E, and the European AMSAR / E-Scan projects for ECR-90.

vehicles on the ground. The state of the art in this technology is an ability to map with 3-1 ft resolution from tens of NMIs, while concurrently operating a GMTI mode and overlaying the two images in real time (Lockheed/Norden APG-76). This technology also has an inherent ability to identify target types, and differentiate between wheeled vehicles, tracked vehicles, rotating radar antennas and hovering helicopters, if enough computing power is available. Since it is radar, cloudbase and humidity are no longer an issue in precision bombing, should (cheap) GPS guided bombs and glide weapons be used[43].



Overlayed realtime SAR and GMTI imagery of taxiing aircraft at an airfield, produced by a Northrop-Grumman APG-76 SAR/GMTI attack radar at a distance of 40.2 NMI (Northrop-Grumman).

2.1.2 Electronic Warfare Systems

Traditionally the Electronic Warfare (EW) suite on a fighter comprised a radar warning receiver (RWR) of some type and a package of defensive jammers, complemented by a chaff and flare dispenser. This was generally adequate for dealing with older generation SAMs, AAMs and AAA. Only aircraft specialised for the SEAD (Suppression of Enemy

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[43] For an overview of this technology see Kopp C., *SAR/GMTI Radars - A Revolution in Bombing Technology*, Australian Aviation, March, 1998.

Air Defences) role, such as the F-4G Weasel and Tornado ECR carried more sophisticated precision homing and rangefinding Electronic Support Measures (ESM) equipment used to hunt down hostile radar emitters.

The growing sophistication of the air-to-air and surface-air threat, typified by highly jam resistant AAM and SAM seekers, has brought about major changes in this area[44].

The trend today is to use a true ESM receiver on a fighter, rather than the established and relatively simple Crystal Video Receiver (CVR) or scanning superhet (SSH) based Radar Warning Receiver[45]. The ESM typically employs a channelised receiver design, which is significantly more sensitive than older CVR, and has higher probability of signal intercept compared to the SSH, and thus if designed properly can not only detect threats at much greater ranges, but also has the potential to detect low peak power emissions from stealthy LPI radars. Moreover, we are seeing the use of interferometric techniques for the precision angular measurement of threat position, and passive rangefinding techniques to provide accurate surface emitter location. This means that the modern ESM fitted to a fighter is as much a defensive aid, as an offensive targeting tool to support BVR AAM launches, and attacks on surface based radar systems.

While the adoption of a stealth airframe defeats most missile threats at long ranges, at very close ranges (ie well inside visual range), a stealth aircraft is almost as vulnerable as a conventional aircraft, particularly to optically guided missiles, and thus defensive electronic countermeasures (DECM) and expendables will continue to be used, on both stealthy and conventional airframes. A package for a stealth aircraft can however be simpler, since it need only deal with terminal threats such as missile seekers.

A contemporary DECM suite is substantially more complex than its predecessor of one or two decades ago. While the basic model of a set-on receiver and jammer is retained, the jamming techniques generators are vastly more sophisticated. Moreover, we are seeing a trend toward the use of highly integrated defensive suites, where a central controller box is used to coordinate jamming with the release of expendables, to achieve maximum effect[46].

Expendable decoys have evolved considerably in recent years. Radar threats have evolved to the point where the dropping of chaff is seldom effective, and this has led to the development of the expendable repeater decoy, which dangles on a parachute and rebroadcasts the impinging radar emissions from a threat, to seduce the missile away. More recently, electronic counter-countermeasures (ECCM) features have evolved to defeat such decoys by discriminating by velocity. The response to this ECCM has been the adoption of the towed decoy, which follows the aircraft at the end of a long cable. Simpler towed decoys contain a ram air driven repeater package, smarter decoys have an optical fibre embedded in the cable and provide for much more sophisticated seduction and general jamming techniques, using a jamming techniques generator carried on the aircraft itself.

Other than towed decoys, we are also seeing lightweight gliding and powered decoys (eg Northrop-Grumman MALDS), which can by carried in large numbers and emulate the radar signatures, emissions, and flight profile of a full sized fighter or bomber. A strike package can therefore launch multiple MALDS and use these to seduce hostile air defences.

We are also seeing a trend to fit conventional aircraft with Missile Approach Warning Systems (MAWS), either aft or fore and aft. MAWS are either radar or optical devices. Radar based MAWS provide angle/range/velocity information and optical

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[44] Kopp C., *Fourth Generation AAMs & Rafael's Python 4*, Australian Aviation, April, 1997, *Fourth Generation WVR AAMs - Matra-BAe AIM-132 ASRAAM*, Australian Aviation, November, 1997, and *Fourth Generation AAMs - Understanding the Threat*, Air Force Today, May, 1997.

[45] Adamy D., *Search Strategies Using Wideband Receivers*, Journal of Electronic Defense, April, 1998.

[46] The RAAF's Echidna suite planned for the F-111 and other types is an example of such a design strategy. While there is some penalty in complexity, integrated suites are significantly more effective at defeating more capable threats.

MAWS (infrared/ultraviolet) typically provide only angle and coarse range information, on an inbound threat. A MAWS is typically integrated with the rest of the defensive suite, to enable the best possible application of jamming and expendables to defeat the missile seeker.

Another increasingly common defensive aid is the Laser Warning Receiver (LWR), designed to detect the rangefinding component of the Flanker/Fulcrum IRS&T/Laser fire control package. It is most often integrated as an adjunct to the RWR/ESM package[47].

Flares continue to be used for the seduction of heatseeking missiles. Almost a decade ago the Soviets deployed the first "blackbody matched" flares, which emulate the thermal radiation characteristics of an aircraft exhaust, thus defeating most heatseeking missiles then in service. This technology has since proliferated.

IR jammers designed to defeat heatseeking missiles do not appear to be common for fighter applications, although they have seen wide deployment on "slow movers" like helos and transports.

It is evident that the contemporary EW suite on a state of the art fighter is vastly more capable than established technology, both as a defensive aid and an offensive package. The stealth centred trend in modern air warfare, where any signals emitted can and will be used by an opponent, suggests that we will see a growing focus on long range passive detection of threats for defensive and offensive purposes.

2.1.3 Optical Sensors

Traditionally, airborne optical sensors were split between specialised thermal imagers, usually equipped with laser rangefinders, for strike roles, and specialised stabilised TV telescopes for target identification, and IRS&T for passive target acquisition. The division was clear cut, and the equipment design focussed on a single role.

Examples of the air-to-ground optimised thermal imagers abound, either as embedded systems (F-117A IRADS, A-6 TRAM) or self contained pods (Pave Tack, Lantirn, TIALD, Litening). TV telescopes were used widely on the USAF F-4 and USN F-14 as BVR visual identification sensors, while the IRS&T has seen a major revival with the Russians fitting an IRS&T/laser rangefinder as standard equipment on the MiG-29 and Su-27 series.

We are now seeing a trend toward merging the functions of the TV telescope, IRS&T and forward looking navigation thermal imager into a single device. The technological development behind this is the Indium Antimonide (InSb) single chip 4-5 μm band Focal Plane Array imager[48], similar in design to the single chip CCD cameras which are so commonly used now. Such a device can be operated as a passive IRS&T to search for airborne targets over a wide field of view, or to zoom in on a specific target for BVR visual identification and missile targeting. In the air-to-ground scenario, such a device can provide the pilot with HUD or steered helmet visor projected thermal imagery (Eurofighter, F-16 CAS demonstrator) of the terrain he is penetrating, and surface targets he is to attack.

Another important development in this area is the "long-wave" IRS&T/FLIR, which employs HgCdTe thermal imaging techniques in the 8-12 μm band. The first such operationally deployed system is the AAS-42, on the USN F-14D fighter. In comparison with 4-5 μm band "mid-wave" IRS&T equipment, long-wave equipment is more sensitive and offers greater detection ranges, especially against non-afterburning targets[49].

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[47] A comprehensive review of current EW trends by Phillip J. Klass may be found in the October 27, 1997, issue of AW&ST. This covers the material in considerably more detail.

[48] *PIRATE Technical Overview*, Pilkington Thorn Optronics, technical brochure.

[49] Schoeppner J.P., *Silent Stalker*, Air Force Today, Vol.2, No.2, 1997. It is worth noting that the more difficult background environment for long-wave IRS&Ts requires considerably more signal processing power, and better decluttering algorithms, in comparison with 4-5 μm band equipment.

Where a conventional radar is carried for the air superiority role, there is a considerable tactical advantage in silently hunting for targets with an IRS&T, and in any BVR scenario the ability to visually identify the target before shooting is a important advantage, especially where restrictive Rules of Engagement apply. There is still some debate about the utility of the IRS&T should a fighter be equipped with a NCTR capable LPI radar, but certainly with less capable radars it is a very useful tool.

The thermal imager/designator pod has a future as long as Laser Guided Bombs continue to be used. The current trend is for all weather capable GPS guided bombs to be used against fixed targets, relegating the LGB to the role of a niche Battlefield Air Interdiction/Close Air Support (BAI/CAS) weapon for use against moving targets. This may or may not persist with the evolution of SAR/GMTI and Millimetric Wave Imaging (MMWI) seekers for GPS guided bombs and glide weapons. Until the latter mature, the LGB will continue to be used.

An issue with GPS guided bombs will be Rules of Engagement mandating strict visual identification of targets prior to attack. Given the CNN factor, and the Law Of Armed Conflict (LOAC), considerable pressure will exist in many circumstances to visually ID targets. Whether this significantly prolongs the life of the laser and television guided bombs remains to be seen.

2.1.4 Cockpits and Computers

The cockpit is another area which has seen significant evolution in recent years. From the "steam gauge" analogue cockpits of the sixties, with a scope for radar and FLIR, we have seen the increasing proliferation of "glass" cockpits with multiple displays. In recent years the thermionic Cathode Ray Tube (CRT) has been supplanted by the flat panel Active Matrix Liquid Crystal Display (AM-LCD)[50], which eats much less power and volume, and provides a more stable picture with better image registration.

A late teen series fighter, or current Russian fighter, will have three or more glass colour displays, providing the pilot with separate screens for radar, navigation, FLIR, systems and weapons status and EW activity. The drawback of this arrangement is that the pilot is presented with a deluge of information, which he/she must integrate in his/her head, not an easy task by any means in the heat of battle.

This in turn has resulted in a trend toward performing the integration in software, and presenting the pilot with a combined display. An example would be a colour terrain map with the location of the target, planned ingress and egress routes, surface based defences circled by detection and engagement radii, airborne threats and associated wedge shaped radar and missile detection and engagement envelopes, and the position and status of friendly aircraft. The air to air equivalent would be "decluttered" by removing the surface map.

This technology significantly reduces workload and speeds up pilot response times, since the task of sorting threats and targets and developing the "big" tactical picture is performed by software. The pilot can concentrate on flying the aircraft, making tactical decisions and attacking his targets. In the first-shot-is-the-killing-shot game, response time is everything from a pilot's perspective, and taking the load off the pilot will make an important difference.

The weapon system is in modern aircraft mostly controlled by switches on the throttle and stick (the Eurofighter includes voice input for everything but weapon launch[51]), which means that a pilot can operate his weapon system heads up at any time in air-to-air combat, and much of the time in air-to-ground combat.

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[50] For a detailed discussion of this technology see Kopp C., *The Liquid State of Displays*, Systems, March, 1998. The most recent development in flat panel displays is the Light Emitting Polymer (LEP), developed by the UK based Cambridge Display Technology. The LEP provides an emissive rather than transmissive display, and offers considerable weight and volume savings over the AM-LCD.

[51] Briefing by BAeA to author, in late 1997.

The Helmet Mounted Display (HMD) has now become an essential item for air superiority fighters, with the advent of fourth generation WVR AAMs. This technology evolved from simple mechanical "ring and bead" sights, through simple optical reticles, to sophisticated visor projection schemes which present the pilot with optically collimated missile boresight reticles, threat status data and aircraft and weapon system mode indicators. Top tier HMDs include the ability to display FLIR/IRS&T imagery (Eurofighter) and may include integrated stereoscopic image intensifiers (Eurofighter), or FPA thermal imagers embedded in the helmet. Head position sensing is typically optical in Russian designs such as the ZSh-7 sight, or electromagnetic in Western designs such as the Elbit DASH III[52]. A key issue in HMD equipped helmets will continue to be weight, since in air-to-air close in combat every extra gram of helmet mass translates into neck strain for its wearer. At 9 G a 2 kg helmet weighs effectively 18 kg.

It is not an overstatement to observe that the HMD will supplant the pilot's Head Up Display (HUD) as the primary display and weapons cueing device within the next decade[53].

Automation in the offensive and defensive systems is paralleled by increasing automation in flight management functions, and the now common ability to insert a cartridge into a socket when the pilot climbs into the aircraft, to completely preprogram the mission flight plan and prebriefed threat environment into the aircraft.

Software controlled stores management using "smart" Mil-Std-1760 digital weapon stations is now a defacto standard for any state of the art fighter. Whether we look at current build older airframes, like the F-15I/S, or newer airframes, like the F/A-18E or Eurofighter, smart digital weapon stations are the standard and provide unparalleled flexibility in integrating new weapon types, since all that is needed is the addition of more software, and appropriate clearance testing.

The baseline for onboard computers has also moved up significantly. Whereas eighties generation aircraft were hamstrung by a US DoD directive to use the Mil-Std-1750A 16-bit (defacto PDP-11) architecture, the latest generation of aircraft commonly exploits the militarised variants of the latest commercial processor chips. The Rafale for instance uses a SPARC architecture RISC processor. We can expect to see this trend broaden, with militarised variants of the MIPS R-series, DEC Alpha and Intel i960 and Pentium series chips proliferating further.

The future clearly lies with highly integrated cockpit/HMD environments and weapon systems, for very good reasons, and that what we see today in the F/A-18E/F, Eurofighter and F-22A will be the benchmark for 21st century fighters and bombers.

2.1.5 Propulsion

The afterburning low bypass ratio turbofan is now the standard powerplant for a modern fighter, providing typically dry Specific Fuel Consumption of the order of 0.7-0.8 lb/lb/hr, and full afterburning SFC of the order of 2 lb/lb/hr. The hot end failures, frequent compressor stalls and durability problems of first and second generation afterburning fans are now much less common problems. Current engines in this class are highly durable, typically employ a "smart" digital engine controller and allow the pilot generally carefree engine handling in most or all regimes of flight. Typically, extra performance can be extracted at some expense in Mean Time Between Overhaul (MTBO), or vice versa.

Contemporary conventional low bypass ratio fans fall squarely into two categories, the "small" category, typified by the evolved 22,000 lb (A/B) class GE F404 used by the Hornet family, and the new 20,000+ (A/B) class EJ200 to be used in the

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[52] An important recent technology development in this area is the inertial head tracking system, invented by MIT researchers. This scheme employs a miniature inertial package embedded in the helmet, providing substantially faster, cleaner and jitter free tracking, with some weight saving. See *InterSense IS-300 Precision Motion Tracker*, Technical Brochure, 1998. Recent advances in eye tracking may also proliferate into HMDs over the next decade, thus removing important limitations of existing technology.

[53] Kopp C., *Helmet Mounted Sights and Displays*, Air Power International, as yet unpublished draft.

Eurofighter. The "large" engine category is dominated by 30,000 lb (A/B) class variants of the P&W F100 and GE F110, and the Lyulka AL-37F and 41 series. It is expected that growth variants of these engines will deliver 35,000 lb (A/B) in post 2000 airframes.

There is a clear and established trend for growth variants of engine types to be fitted to airframes in service, or late build variants of established airframes. In this sense assessing the performance of any established airframe type must be done in the context of what is the likely powerplant it is to use in the post 2005 timeframe. An F-15, F-16 or Flanker variant built in 2005 is likely to use a 35,000 lb class engine, as compared to the 25,000 lb and 29,000 lb engines used in currently fielded airframes.

Conventional exhaust nozzles for the larger engines have seen development in two separate directions. One is typified by recent US testing of a reduced RCS nozzle, employing absorbent materials and flat petals with a serrated trailing edge to break up the characteristic all aspect RCS of circular tailpipe edge. The other direction in engine nozzle development is 2 Dimensional (2D, up or down) and 3 Dimensional (3D) Thrust Vector Control(TVC), intended to improve aircraft turning performance, especially in regimes where aerodynamic controls begin to lose effectiveness. The Russians are clearly leading here[54], with 2D TVC nozzles to be fitted to the Indian Su-30MKI, and a 3D nozzle providing pitch/yaw control under development.

Whilst there is still some debate under way as to the merits of high sustained turn rate performance in the age of fourth generation 50G+ WVR missiles and HMD, it is clearly one way of giving a very large fighter turn rate performance competitive with much smaller and lighter airframes. In the very long term, 3D thrust vectoring offers the potential for smaller tail surfaces, or none at all, the latter removing the RCS penalty of tail surfaces altogether. In an environment where stealth dominates, 3D TVC technology will be a useful addition to a designer’s toolset.

The most radical propulsion development in recent years has been the P&W F119 supercruising turbofan for the F-22[55]. Conventional fighter turbofans do not cope well with sustained dry supercruise, since the higher inlet temperatures in turn raise the whole temperature profile across the engine, with unhealthy consequences for the turbine stages. Should a conventional fan be run for more than several minutes or tens of minutes in this regime, it will suffer damage to turbine blades possibly leading to a hot end failure. The F-22 required sustained supercruise as part of its basic role and thus needed a quantum leap in engine capability. The F119 won the flyoff in 1990/91 against GE’s F120. Critical design features are increased cooling of both counter-rotating turbine stages, and the use of titanium in the six stage compressor. The combustors are convection and film cooled. The result of this effort is a powerplant delivering twice the dry supersonic thrust of the F-15’s F100-PW-200, and 1.5 times the afterburning thrust, with the same engine durability, all in a similar form factor to the established F100/F110.

2.1.6 Airframes

Unlike avionic systems, which have seen at least two generations of evolution since the RAAF selected the Hornet, airframes have evolved at a more sedate pace. We have seen much wider use of composite materials for structural components, especially load bearing skins, and more common use of exotic materials such as titanium and lithium aluminium alloys. All have improved structural stiffness and strength with a cost penalty, since all of these materials are more expensive to produce and much more difficult to fabricate than

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[54] Novichkov N., *Sukhoi Set to Exploit Thrust Vector Control*, AW&ST, August 26, 1996, Butowski P., *Russian thrust vectoring fighter programmes*, Air International, October, 1996. The AL-37FU was tested on the Su-37 prototype and is now being incorporated in the IAF Su-30MKI variant. Other efforts are also progressing, with the Eurofighter team developing a TVC nozzle for the EJ200. Of note is work done by the Israeli Institute of Technology, Technion, on nozzles for the F-16 and F-15, see Proctor P., *Israelis Test Thrust Vectoring*, AW&ST, May 11, 1998. The Israeli effort is exploring the potential for reducing the size of, or removing altogether, the vertical tail surfaces.

[55] Warwick G., *The F-22 Story*, Flight International, Supplement, 1997.

the traditional Aluminium alloys. An important plus is that the fatigue behaviour, especially of composites, is superior to that of Aluminium thus providing better airframe durability. Another useful attribute of composites is their potential to be laminated with radar absorbent materials, thus contributing to stealthiness. At a system level, the use of lighter and stronger materials translates into less weight in structures for a given volume and thus more space for fuel and systems.

In terms of air superiority fighter airframe configuration, two forms are dominant at this time. The first is the twin tail straked arrangement, typified by the Flanker, the F-15, the F/A-18E and the F-22A. The second is the combined delta-canard, typified by the Eurofighter, the Rafale, the stillborn Israeli Lavi, the Gripen and some cited proposals for the MiG I.42. In both instances the airframe is designed to provide the best possible high Angle of Attack (AoA) turning performance and controllability.

A major issue in fighter airframes has always been the "large fighter vs small fighter" argument, and it is clear that this will also be a core issue in the RAAF's selection of a Hornet, and later F-111 replacement. The other major issue in fighter airframe design is that of what is it primary airframe optimisation.

Fighter airframes are usually exceptionally well suited to one task, reasonably good at a range of other tasks, and marginal for some tasks. In the days of single purpose highly specialised airframes, this was never an issue, since a designer built an aircraft for a particular role and that was all it ever performed. Advances in avionics and shrinking budgets spawned the idea of the genuine multirole fighter, which by virtue of incorporating or externally adding additional avionic equipment could perform a wide range of tasks, and as argued by proponents of the model, equally well. Certainly there are good economic and strategic/doctrinal arguments for multirole fighters, all deriving from the idea that a commander should never have idle assets. The alternate side of this argument is the overcommitment of assets in combat. Anecdotally, a commander who thought he saved money by buying half the equivalent number of multirole assets, suddenly finds he does not have enough airframes to fly counter-air and strike at the same time.

In practice, the multirole model has met with varying degrees of success over the last two decades. An example of a failure would be the MiG-23 Flogger, which never had the air superiority performance to hold its ground, just like the stillborn naval F-111B. More successful were the F-16 and F/A-18, both born as lightweight transonic dogfighters. Their limitation as bombers lay primarily in limited payload radius performance, low level ride quality for deep penetration, and initially with the F-16, limited tools for precision weapon delivery and defence penetration. The most successful example is without doubt the F-15E/I/S which has proven to be almost as good a bomber as the F-111, and improves upon the superb counter-air lethality of the F-15C.

Much of the very high cost of modern fighters is a direct result of fitting them with expensive avionic systems to provide a multirole capability, and the often small purchase price differentials between large and small fighters today are a direct result of this effect. Indeed the most significant cost difference between large and small fighters today is the extra cost of maintaining a larger, twin engined airframe and the associated fuel, hydraulic, bleed air and other accessory systems.

The now classical air superiority aerodynamic performance model is based on the idea of superior energy manoeuvrability, a concept created by the USAF's John Boyd[56]. In this model, a fighter gains a manoeuvre advantage to fire its weapons by outclimbing, outaccelerating, outturning and outlasting its opponent in a manoeuvring engagement. With the shift to BVR combat and high off-boresight fourth generation WVR AAMs supported by HMD, optimising an airframe today for the close in high AoA subsonic/transonic engagement will not yield the return it may have in the days of the AIM-7F Sparrow and AIM-9H/J Sidewinder[57].

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[56] Shaw, R.L., *Fighter Combat - Tactic and Maneuvering*, Naval Institute Press, 1985.

[57] Since modern WVR missiles can achieve load factors well in excess of 50G and seeker tracking rates over 100° per second, with off boresight angles in excess of 90°, the ability to pull a sustained 9G may not be useful

The contemporary approach is to stay out of WVR AAM engagement envelopes if possible, and instead of manoeuvring tightly at subsonic/transonic speeds around an opponent at close quarters, the trend is to fly supersonic and pick off the opponent with BVR AAMs. Unless the fighter has good sustained supersonic manoeuvre ability and persistence the pilot does not have the option of disengaging, as he will be shot in the back with a BVR AAM. Without good supersonic performance the pilot will be committed to fight it out at close quarters unless he can kill the opponent with a pre-merge BVR missile shot. An airframe built for this style of air combat must have the ability to fly high G supersonic manoeuvres with minimal energy bleed, high installed dry thrust for supersonic persistence, and a large load of fuel to maintain the tempo of the engagement. Compared with transonic teen series fighters, the need for high thrust/weight ratio and low wing loading is much greater as these are critical performance parameters for such high energy manoeuvres.

Low RCS and infrared signature can be a great advantage in this style of air combat, since it can dramatically shrink an opponent's BVR engagement envelopment, while the best possible radar, IRS&T and ESM detection and tracking performance are clear assets in this model.

Clearly flying high energy supersonic manoeuvres will require both wing design optimisation for minimal energy bleed, and a large internal fuel capacity. If the supersonic drag characteristics of the wing are not well matched to this model, more thrust will be required in turn limiting persistence, especially if reheat is required to sustain such manoeuvres. Large fighters like the F-15, the evolved Su-27 and the F-22A (and the stillborn and smaller F-16E/XL) have a major advantage in this style of air combat, since the visual detection range argument for small airframes becomes irrelevant. The anecdotal statement of this new reality is that *Speed is life, and gas is speed*.

In this context the ability of the powerplant to sustain supersonic dry cruise for extended periods of time is critical, for two important reasons. The first is because SFC in dry operation is substantially lower than in afterburner, and thus the aircraft can maintain a high sustained speed for much longer, for a given fuel load. The second reason is that afterburner operation increases the aircraft's heat signature many fold, and thus makes it susceptible to long range passive detection by IRS&T and missile attack without prior warning.

The pure air defence role is today firmly shifting away from the ground based standby intercept role[58], to the forward Combat Air Patrol role, supported by an AEW&C platform. In the Australian context, the latter aspect of the role is by far the more important, given our geography. In this model, persistence with a substantial load of BVR AAMs, and radar/IRS&T/ESM performance are decisive measures of success. So yet again, fuel load is a decisive parameter for success. If the threat aircraft are defenceless bombers then the demand for supersonic manoeuvre performance is lesser than for air superiority sorties, but if they are late model Flankers capable of BVR engagement, then the requirements of this air superiority model apply yet again. Given the shift toward multirole fighters over the last decades, most engagements will be against aircraft which can shoot back. The pure air defence fighter (Tornado ADV, Foxhound, F-106) is now a historical artifact.

In the surface and maritime strike roles, the decisive measure of performance, sensor capability being equal, is payload/radius performance. The more stores can be carried further, the better. A typical land strike sortie for a conventional fighter or bomber would involve an efficient cruise climb to the boundary of the opponent's IADS, upon which the penetrating aircraft would descend to low level, and using either automatic

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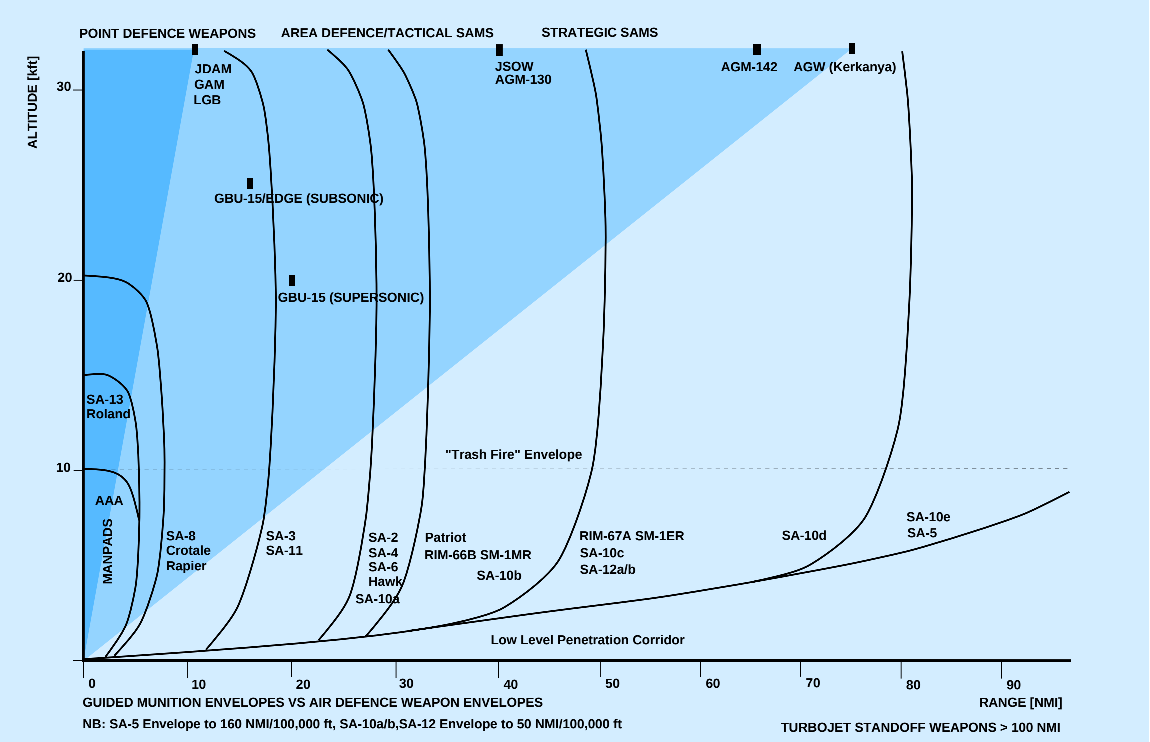
defensively, while HMD sighting is argued to diminish the need for rapid nose pointing for missile shots. See Kopp C., *Fourth Generation AAMs & Rafael's Python 4*, Australian Aviation, April, 1997, *Fourth Generation WVR AAMs - Matra-BAe AIM-132 ASRAAM*, Australian Aviation, November, 1997, and *Fourth Generation AAMs - Understanding the Threat*, Air Force Today, May, 1997.

[58] In this paradigm, interceptors waiting on the ground for incoming aircraft are scrambled when the incoming raid is detected and then fly a high performance afterburning intercept to engage.

terrain following radar or visual terrain following, hug the ground to avoid area defence SAMs and hide from fighters in low level clutter. A laser guided bomb is then tossed at the target and the aircraft then does its best to quietly egress in the same manner it ingressed. This is the now classical Hi-Lo-Lo-Hi mission profile.



GUIDED MUNITION ENVELOPES VS AIR DEFENCE WEAPON ENVELOPES

NB: SA-5 Envelope to 160 NMI/100,000 ft, SA-10a/b,SA-12 Envelope to 50 NMI/100,000 ft

AIR DEFENCE WEAPON ENVELOPES VS WEAPON DELIVERY ENVELOPES

Flying such sorties at transonic or supersonic speed below 1000 ft AGL demands a high wing loading on deep penetration sorties, to reduce crew fatigue, and improve the stability of the airframe as a bombing platform. At low level the aircraft is exposed to point defence SAMs, AAA and with the deployment of the pulse Doppler radar equipped Fulcrum, Flanker and teen series fighters, BVR AAM attack.

With the advent of GPS guided glide munitions, and powered standoff munitions, in many instances the need for low level penetration will decline, more so if fighter escorts are available to keep the opponent's interceptors at bay. However, it is clear that the single unescorted penetration role is today the exclusive domain of the stealth aircraft. The sanctuary of low altitude is largely gone with universal availability of pulse Doppler capable fighter radars, AEW&C radars, SAM engagement radars and SAM/AAM seekers. The only instance where low level penetration still offers a useful advantage is where a pure SAM/AAA surface threat exists, and terrain allows a masked approach until weapon release. While much of the Asia-Pacific today still fits this model, the ongoing proliferation of the SA-10, AEW&C and the Flanker suggest that its days are clearly numbered.

The US approach to this environment has been to adapt the F-22A, originally defined for an air superiority role alone, during its development phase to drop internally carried GPS guided bombs on a Hi(subsonic)-Hi(supercruise)-Hi(subsonic) mission profile exploiting its stealth, supercruise and ESM to bypass hostile defences and attack its targets under all weather conditions, using its APG-77 radar to precisely map the aimpoint programmed into the nav-attack system. This is a direct application of the

F-117A/B-2A penetration model, and is planned for the JSF should it go into production. It is envisaged that stealthy strike will be used to break the opponent's air defence system, upon which the reduced threat will allow the carriage of additional external weapons.

In the absence of stealth, and the presence of a modern fighter and SAM threat, the only manner in which targets can be attacked with low loss rates is either by strike packaging, using SEAD aircraft to take down the SAM/AAA threat and fighter escorts to keep fighters away, or by shooting $0.5-1.5 million cruise missiles from outside hostile defences. Both are much more expensive than flying in individual penetrators dropping $20,000 GPS guided bombs, especially in a sustained air war scenario. The longer the war lasts, the cheaper the stealth model becomes, both in terms of airframe losses and munitions expended[59].

Even a basic analysis of air-to-air and air-to-ground roles unambiguously demonstrates that range/persistence is of critical importance, more so given the developing style of BVR air-to-air combat.

At this point it is worth making some comparisons between small and large fighters, to emphasise some important points.

The first area to explore is that of achievable combat radius. Typical modern turbofans exhibit a slight improvement in SFC with altitude, but do experience a loss in dry thrust with altitude, so much so that at cruise altitudes the achievable dry thrust is about 35-45% of that at sea level. The typical cruise regime for jets is a constant Mach number cruise climb, at altitudes between 20,000 and 40,000 ft subject to the type[60].

The classical Breguet equation tends to lose some accuracy when jet range performance is considered, primarily since some of the basic assumptions do not hold very well for low aspect ratio wings and a drag environment where parasitic drag dominates over lift induced drag. The critical factors for range in fast jets are the fuel fraction (a measure of fuel capacity against weight) and the aircraft's drag. A typical rule of thumb for jets is that 75% of the total drag is parasitic drag and only about 25% is lift induced drag. It follows therefore that a range advantage is held by the aircraft which has the higher fuel fraction and lower parasitic drag, factors such as SFC and cruise Mach number being constant[61].

As an instance we shall consider a generic small fighter, and a generic large fighter, each with weight, fuel loads, and installed thrust produced by averaging the values across each class[62]. The large fighter has an empty weight of 32,600 lb, an internal fuel load of 23,500 lb, 40,000 lb of total dry SL thrust and 62,000 lb of reheated SL thrust, with a wing area of 706 ft^2 and fuel fraction of about 42%. The small fighter, this yields an empty weight of 22,700 lb, an internal fuel load of 10,600 lb, 24,120 lb of total dry SL thrust and 36,700 lb of reheated SL thrust, with a wing area of 416 ft^2 and a fuel fraction of about 32%. It should be noted that the variance on these parameters is not very large.

Assuming that the aircraft have a very similar lift to drag ratio and cruise at the same Mach number and the same SFC, then the ratio of relative range performance is given by the ratio of the natural logarithms of the ratios of total weight to empty weight, excluding stores. Inserting these numbers yields a result which indicates that the large fighter will have about 40% better range. In practice the unrefuelled clean range advantage of a larger fighter varies between 10% and 50%, and should be roughly halved for combat radius, allowing for additional fuel consumed in combat.

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[59] This can be proven with even trivial operational analysis and will discussed in more detail later in this document.

[60] *The Jet Engine*, Rolls-Royce, Fourth Edition, 1986, Treager I.E., *Aircraft Gas Turbine Engine Technology*, Second Edition, McGraw Hill, 1979, *Aerodynamics for Naval Aviators*, NAVWEPS 00-80T-80, also *Performance Data*, McDonnell-Douglas A-4E/F, NAVAIR 01-40AVC-1, Section XI.

[61] Stinton D., *The Anatomy of the Aeroplane*, BSP Professional Books, 1985. This engineering text covers range issues in fighter design in considerable detail.

[62] To preclude vendor bias here, three current large fighters (F-22, F-15, Flanker) and four current small fighters (Eurofighter, F-16C, F-18C and MiG-29) were used.

The drag term in the denominator of the range equation is critical when assessing the relative range/radius performance of fast jets, particularly due to the dominance of parasitic drag sources. While the fuel fraction of both small and large fighters can be significantly improved with external tanks, more so with the smaller fighter, the penalty to be paid is additional parasitic drag, which offsets to some degree the improvement in fuel fraction. Drag also increases with externally carried weapons. In practice therefore care must be exercised since idiosyncrasies of particular designs may introduce significant drag at cruise speeds and thus impair combat radius performance[63].

Clearly the superlative range of the Flanker is a direct consequence of its blended airframe geometry and large fuel fraction, which means that it need not carry draggy external tanks. Whatever parasitic drag it suffers through stores alone is very modest, more so since the largest of these are mostly carried semi-conformally. While the USAF have not released combat radius and range numbers for the F-22A, with its large internal fuel fraction and drag free internally carried weapons it can be expected to outperform both the F-15E and Flanker for combat radius[64].

Conformal fuel tanks (CFT) have become a very popular measure to improve the fuel fraction of a fighter without much of the drag penalties of external drop tanks, indeed a well designed CFT can contribute to area ruling and actually reduce the transonic and supersonic wave drag. CFTs are available for the F-15C/D, permanently fitted to the F-15E/I/S and under development for the F-16C Block 60 and Eurofighter.

The other basic aerodynamic parameter of interest is agility, basic measures of which are the combat thrust to weight ratio, and combat wing loading, both defined for an aircraft weight with a given stores load and 50% of internal fuel. Higher thrust to weight ratio translates into better climb rates, acceleration and given similar wing design, sustained turn rates. Wing loading directly affects climb rate and turning performance.

Calculating the combat thrust/weight ratios, dry and reheated, and wing loadings for the generic large and small fighter aircraft, assuming 50% total internal fuel load and 2,000 lb of weapons, ie 4x BVR and 4x WVR AAMs yields for the large fighter, thrust/weight ratios of 0.86 and 1.33 dry and reheated respectively, with a wing loading of 65.5 lb/ft^2. For the small fighter this yields slightly worse numbers of 0.8 dry, 1.22 reheated and 72.2 lb/ft^2, about 10% below and above, respectively, the large fighter, but hardly decisively inferior. Values at sea level are used here, but since the thrust loss factor with altitude will be similar for both types, the performance ratio between the types at altitude will not vary significantly from sea level.

Now this calculation assumes that both fighters are operating at their respective radius limits on internal fuel, in a clean air superiority configuration. The small fighter will under such conditions achieve typically about 70-85% of the combat radius of the large fighter.

Now let us assume that the small fighter is flown out to a combat radius equivalent to that of the large fighter. It is therefore loaded with external drop tanks, possibly also scab on conformal tanks (F-16, Eurofighter), accepting a substantial drag penalty, and it is carrying a total fuel load at takeoff identical to the internal fuel load of the large fighter (ie better fuel fraction for the smaller fighter). This is arguably a little optimistic, but still reasonable.

Recalculating the combat weight yields a revised thrust weight ratio of 0.7 dry, 1.06 in reheat, and a wing loading of 82.3 lb/ft^2. These numbers are interesting, if compared to the performance figures for the large fighter at this radius. The small fighter has 20% lower dry and reheated thrust weight ratios, and a 26% higher wing loading. Whatever performance gain may be found in giving the small fighter a lesser weapon load and

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[63] A useful example and one which is most relevant in the context of this paper is the F/A-18A/C. Development F/A-18s with a better fuel fraction did indeed outrange the early F-16, but production aircraft with a much draggier pylon design due to a higher stores cant angle fell short by a significant margin.

[64] USAF statements indicate that it has roughly twice the subsonic and supersonic combat radius of the F-15C on internal fuel, which is consistent with the evident drag and fuel fraction ratios of these types.

higher performance engines, is lost on the additional fuel load. The small fighter is well behind the large fighter in agility, since the ratio of remaining internal fuel weight to total weight is much higher. A small fighter with superior agility at 50% internal fuel, compared to a larger fighter, will almost certainly fall behind the large fighter in such a scenario.

An inevitable consequence of the physics of flight is that long range aerial combat demands larger airframes, all other parameters being equal.

Inflight refuelling is clearly a necessity for small fighters, but this can complicate operational deployment and mission tactics since a tanker is a high value asset (HVA) and will in many situations require its own fighter escorts if it is to refuel small fighters with minimal external fuel load, since the last refuelling must be done much closer to contested airspace. This is particularly true of situations where the Flanker is the opposing aircraft.

In summary, all other capabilities being equal, a small fighter can contest a large fighter successfully only at shorter unrefuelled ranges, and the initiative will thus be in the hands of the user of the large fighter.

2.1.7 Air to Air Weapons[65]

The all weather radar guided Beyond Visual Range (BVR) missile is now a mainstay of both air defence and air superiority combat operations. Ongoing development over the last three decades has seen BVR missiles split into large heavyweight weapons, typified by the AIM-54 Phoenix and AA-9 Amos, with F-pole/A-pole[66] ranges in excess of 60 NMI, and smaller and more agile general purpose "medium range" weapons such as the AIM-120 AMRAAM, the Matra MICA and the R-77 Adder. The latter are in the 350 lb weight class, 50 NM range class, and are sufficiently agile to be used as both air superiority and air defence weapons, and sufficiently light to be carried by smaller fighters.

The clear sky heatseeking Within Visual Range (WVR) missile[67] has always been primarily an air superiority weapon, used by fighters to kill opposing fighters. It has driven fighter development toward ever increasing agility, to provide the earliest opportunity to shoot the opposing aircraft, over an increasingly wide performance envelope.

Until a few years ago, WVR missiles were very effective, but could be defeated by aggressive manoeuvre if not launched under optimal conditions. They could also be successfully decoyed or jammed, and required excellent aircraft instantaneous manoeuvre performance to get an early firing opportunity. With the deployment of fourth generation missiles such as the Archer, Python 4, AIM-132 ASRAAM and AIM-9X, this is no longer true. All of these missiles can be cued using Helmet Mounted Sights or Displays, all have very large "no escape" zones by virtue of the ability to pull in excess of 50G, indeed some can engage a target pursuing the launch aircraft, all are difficult to jam or decoy, and all have significantly greater range than earlier WVR weapons, in some instances challenging the performance of older radar guided BVR missiles[68].

Medium range radar guided BVR missiles have also evolved dramatically in recent years, and now are becoming extremely difficult to defeat by manoeuvre or jamming. Moreover we are beginning to see the first air-to-air anti-radiation seekers, which will home on an opposing fighter’s air intercept radar, and we are also seeing air breathing BVR weapon proposals. An air breathing BVR missile will have double or triple the range of a pure rocket missile of similar size, as it need not carry the oxidising agent in its

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[65] Modified from material to be published in Air Power International journal, by the author.

[66] The F-pole range is defined as the range at which a semi-active homing missile is launched in a closing engagement. The A-pole range is defined as the range at which an active homing missile is launched in a closing engagement, under datalink or illuminator midcourse guidance.

[67] WVR missiles employ one or another form of optical guidance, typically infra-red. Older technology used rotating reticle seekers, but newer designs employ scanning or staring multi-element arrays.

[68] The AIM-132 ASRAAM, long burn heatseeking variants of the Vympel R-27 (AA-10 Alamo), and Matra MICA, all have range performance competitive with medium range radar guided BVR missiles.

propellant, it collects it in as it flies. An example in this class is the proposed FMRAAM, derived from the AMRAAM, or the Vympel R-77M variant of the AA-12 Adder.

What we can expect to see in the coming two decades is the deployment of WVR missiles with further improved speed, agility, range, jammer and flare resistant seekers and supporting sensors such as radar homing receivers, infra-red search and track (IRS&T) equipment, and Helmet Mounted Displays which may include helmet mounted thermal imagers. Such missiles will be extremely lethal and virtually impossible to defeat, unless you engage them with a high power laser or microwave beam. The BVR missile of the next two decades will also be faster, much longer ranging, more autonomous, and much more difficult to jam or outmanoeuvre.

We can also expect to see the first generation of hybrid seekers, combining anti-radiation and or radar homing with heatseeking guidance, indeed such a scheme was used in a little known RIM-7 Sea Sparrow variant, which employed a hybrid device combining an AIM-9M IR seeker and RIM-7M semi-active radar seeker. Such missile seekers are virtually impossible to jam effectively as they will continuously compare the quality of sensor outputs, and select that which is providing the best quality signal. If one is jammed, it switches to the other, and vice-versa, frustrating virtually any conventional jamming strategy.

With high speed, low smoke motors, low frontal radar signatures, and passive or low-probability of intercept seeker techniques, an inbound missile will be hard to detect with sensors or visually, and the victim aircraft will have little if any warning of impending impact.

It is fair to say that we live in the decade during which the air-to-air missile has finally matured, and is close to reaching its full potential as an air superiority weapon. It is by no means the end of the evolutionary process in air to air weapons. The USAF New World Vistas technology survey published last year indicates that another weapon is reaching the level of development where it can move to deployment in the next two decades. This weapon is the high power laser cannon, capable of burning a hole through an aircraft's skin at several miles of range, under visual clear sky conditions.

Whilst the first operational laser weapon to deploy (cca 2005) will be the USAF's YAL-1A[69] anti-ballistic missile weapon, mounted in a nose turret in a dedicated B-747 airframe, a large weapon with perhaps 300 km or greater range, it is the forerunner of a whole new family of air combat weapons. It is only a matter of time before the technology is well understood, compacted in size, and made robust enough for wider deployment. Laser beams travel at the speed of light, and cannot be evaded. Whilst some opportunities will exist to jam the laser's tracking systems, high energy lasers (HEL) will become yet another serious threat to modern aircraft.

In the face of a mature missile threat, and the possibility of early directed energy weapons cca 2025, conventional air superiority models begin to break down. Once the opponent has acquired the target, he can shoot it and most likely, kill it. Exchange rates then become a function either of superior sensors and missiles, used at standoff ranges, introducing difficulties with Rules of Engagement, or other measures must be sought to improve survivability. Clearly throwing expensive fighter assets into a Somme style attrition warfare meat grinder is not the optimal strategy for winning an air war, unless a player has twice as many expendable aeroplanes and pilots as his opponent has. With the slow production rates typical of modern high technology weapons and expensive and time consuming training of scarce aircrew , this is without any doubt a losers' strategy.

This is a strong argument for stealth and will be further addressed.

2.1.8 Air to Ground Weapons

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[69] Forden G.E., *The AIRBORNE LASER*, IEEE Spectrum, September, 1997, provides the best open sources analysis of this important program. A recent report, Proctor P., *Airborne Laser Passes Key Technical Hurdle*, AW&ST, May 4, 1998, indicates this project is maturing and likely at this stage to meet projected timelines.

One of the most important lessons from the 1991 Desert Storm campaign was that precision guided bombs were significantly more effective than dumb bombs, even should the latter be delivered by aircraft with highly accurate nav-attack systems. There did exist a previous expectation, from the Cold War period, that air superiority would take long to establish and thus that bombing sorties would be predominantly flown at low altitudes. Dumb bombs delivered from low altitudes by a highly accurate nav-attack system can be effective for many target sets. Laser guided bombs could be delivered under most weather conditions quite effectively from low level, as the delivering aircraft would be flying under the weather.

The Desert Storm campaign saw air superiority established early in the course of events, with the Coalition quickly gaining control of medium to high altitudes, by virtue of the rapid destruction of the Iraqi IADS. However, to the very end of the Desert Storm campaign, the threat from manually aimed AAA, small arms and shoulder launched SAMs (MANPADS) , i.e. "trash fire", persisted, indeed the majority of Coalition losses during the campaign were due to attacks by these weapons. In an attempt to reduce losses the USAF and RAF rapidly shifted operations to medium and high altitudes and immediately encountered difficulties.

The dispersion errors experienced by unguided bombs dropped from medium altitudes significantly reduced bombing effectiveness. There was a serious shortage of laser designator equipped aircraft available to deliver laser guided bombs, moreover weather conditions led to a significant abort rate for laser guided bomb delivery. A cloudbase below the delivery aircraft’s altitude could obscure the target and thereby prevent the weapons from guiding. The scale of this problem can best be appreciated by examining the Baghdad bombing statistics for the USAF 37th TFW (F-117A), which used only the GBU-27 laser guided bomb and thermal imaging for target acquisition (therefore there can be little ambiguity in these results). Of a total of 301 sorties flown, 96 resulted in "no drops" [70].

The weather limitations of the widely deployed laser guided bomb and the high cost of laser designator pods clearly indicated that new technology would be required to provide most aircraft with a precision or near precision capability. Indeed this was the primary operational impetus which led the US to develop the current generation of GPS guided bombs and dispensers.

During the eighties the US conducted a series of trials under the Inertially Aided Munition (IAM) program, using a modified Paveway III bomb kit. The purpose of the IAM program was to prove the concept of using a inertially guided bomb kit to allow an aircraft to toss a bomb at a target from low level, minimising exposure to point defence weapons yet still achieving acceptable accuracy. The Ring Laser Gyro (RLG) had yet to become cost competitive, and the Fibre Optical Gyro (FOG) was still a developmental item. The IAM program did not lead to a deployable weapon since it was found that the cost of inertial packages with the required accuracy was too great for a low cost bomb kit.

After the Gulf War, the USAF re-evaluated the IAM program and decided that the combination of a low cost inertial package and a high performance GPS receiver would be cost competitive, and provide acceptable accuracy under most conditions. This would provide a new category of guided bombs which would not suffer the weather limitations of optically guided bombs, but still provide good lethality per unit cost.

The first GPS/Inertial guided bomb was the Northrop GBU-36/GAM84 (previously GAM, GPS Aided Munition), designed under a USAF contract to Northrop’s ATD as a near precision 900 kg munition for the B-2A stealth bomber, which at that time was under the threat of cancellation in the post Cold War USAF drawdown. Using the Mk.84 warhead, the GAM84 would allow a B-2 to engage multiple aimpoints on a single pass, thus transforming a nuclear weapon system into an highly accurate conventional strike platform, with the lethality of a respectable strike package of fighters and a combat radius

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[70] Arkin W.M., *Baghdad, The Urban Sanctuary in Desert Storm ?*, USAF Air Power Journal, Spring 1997, pp 7.

similar to that of the B-52. A GAM84 equipped B-2 could hold at risk an arbitrary target set deep within defended airspace. According to publicly disclosed material, only 128 GAM84s were built, pending early deployment of the JDAM. The GAM tailkit has since also been adapted to the 2,100 kg BLU-113 warhead, previously used in the GBU-28, as the GBU-37.

While development proceeded on the GAM84, the USAF initiated the Joint Direct Attack Munition (JDAM) program, competing designs from Martin-Marietta (GBU-29/30) and McDonnell-Douglas (GBU-31/32). The MDC GBU-31/32 kit won this competition, and will provide the USAF, USN and USMC with tailkits and strakes for the 900 kg Mk.84 and BLU-109/B warheads, and the 450 kg Mk.83 and BLU-110/B warheads. It appears that a 250 kg JDAM variant may also be built. Current plans call for 80,000 or more JDAM rounds to be built, in effect displacing the laser guided Paveway II/III as the principal US guided bomb. The Hammerhead and Orca programs will see Millimetric Wave Imaging (MMWI) and Synthetic Aperture Radar (SAR) terminal seekers developed for the JDAM, to increase accuracy and improve resilience to jamming.

While the GPS guided bomb was in development, GPS became the preferred method of midcourse guidance for tactical cruise missiles.

The Northrop AGM-137A TSSAM[71] was to be a tri-service stealthy cruise missile, using a high performance digital nuller equipped anti-jam GPS receiver, the AGR, designed by Magnavox. The TSSAM was to have used an autonomous thermal imaging terminal seeker in the USAF variant, and a Walleye datalink in the USN variant, to provide precision terminal guidance. Difficulties with the autonomous seeker, and high unit costs, led to the termination of the TSSAM during the early nineties.

Since the TSSAM requirement persisted, the JASSM, another joint program, was initiated to replace the TSSAM and is was competed between Boeing and Lockheed-Martin, with selection for FSD recently awarded to Lockheed-Martin.

Concurrently, we are seeing a new generation of cruise missiles evolve in Europe, with the Matra-BAe Apache and Storm Shadow, and the DASA KEPD-350 weapons all utilising GPS to supplement the inertial and terrain profiling guidance package. These weapons can be supplied with a broad range of warloads, including various types of submunitions and bunker busting warheads.

Another area which has rapidly evolved and essentially represents a new class of weapon is the low cost standoff glidebomb and gliding dispenser. Prior to the advent of GPS, such weapons could not be built competitively due to the high cost of the inertial package required to provide suitable accuracy. The US AGM-154 Joint StandOff Weapon (JSOW) and the European AFDS both provide up to tens of kilometres of range and sufficient accuracy with GPS alone to deliver their payloads of submunitions. It also now appears that the DSTO developed Kerkanya glidebomb may see eventual production, using GPS/inertial guidance.

The high volume production of the US JDAM and JSOW has also produced a follow-on trend of fitting the low cost GEM-III (Rockwell) and RIM-III (Texas Instruments) receivers as supplementary navigational data sources to existing weapons. Both the TI Paveway III laser guided bomb and the HARM anti-radiation missile are soon to acquire a GPS receiver to improve midcourse flight profiles, as well as provide some measure of accuracy should the guidance signal be lost. The Block II Harpoon is to acquire an additional land attack role, and a loiter capability, with the fitting of the JDAM GPS receiver.

Clearly the trend at this time is to fit GPS as a supplementary source of position and velocity data to most established classes of weapons, be they bombs or missiles. Concurrently there is an increasing number of weapons being designed and deployed which rely completely upon GPS/inertial guidance.

The rapid progress being made with Wide Area Differential GPS (WADGPS),

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[71] Tri Service Standoff Attack Munition, intended for use on USAF bombers and fighters, USN/USMC fighter-bombers and US Army mobile launchers.

as evidenced by the USAF EDGE and WAGE trials[72], indicates that significant gains in the accuracy of all classes of GPS guided weapons can be expected in the next decade or so. Whether WADGPS is implemented via dedicated datalink channels, or later embedded in GPS navigation messages, it will provide such accuracy that most conventional guidance schemes will not be able to compete in cost.

The conclusion at this time is that GPS and WADGPS supplemented inertial guidance will become the dominant form of all weather guidance for accurate and precision weapons over the next decade. GPS and WADGPS guided weapons may employ additional terminal seekers. The primary means of targeting such weapons will the the high resolution Synthetic Aperture Radar. The Laser Guided Bomb and Television/Thermal Imaging guided bombs and weapons will become specialised tools for situations where their limitations and higher cost will not penalise capability.

The cost differential between guided bombs and standoff missiles will continue to be high, although the latter have become somewhat cheaper in recent years. The existing economic relationships between the use of stealthy aircraft to deliver very cheap munitions, and conventional aircraft to deliver expensive standoff munitions, will persist for the forseeable future.

2.1.9 Stealth Issues

Low Observables (LO) or Stealth is the most important paradigm shift in air warfare since the invention of the jet engine. Stealth technology aims to reduce the radar signature and infrared signature of an aircraft to the point, where detection ranges by hostile sensors and weapons are so small, as to render them tactically ineffective.

The increasing capabilities of guided missiles and airborne radar during the late sixties and early seventies reached the level where the established methods of defence penetration, based upon a combination of manoeuvre and jamming, became increasingly less effective. The wide proliferation of pulse Doppler radar and IRS&T equipment, and improvements in missile performance and seeker technology, produced a situation manoeuvre and low altitude flight could not prevent engagements from being initiated, especially against bombers.

The increasing sophistication of radar and seeker technology caused significant and growing costs in electronic countermeasure (ECM or jammer) equipment, and the increasing tempo of warfare meant that time would not be available to adapt existing in service ECM equipment to hitherto unknown threat systems, before unacceptable combat losses were incurred.

Both manoeuvre and jamming are techniques which defeat specific weaknesses of an opponent’s sensors and weapons. Without knowledge of these weaknesses, apriori, gained for instance through human intelligence operations, signals and electronic intelligence, or capture of an opponent’s equipment, it is extremely difficult and often impossible to develop particularly effective countermeasures.

The central philosophy behind Stealth is to defeat the basic physics underlying the opponent’s sensors and weapons. By reducing the signatures of an aircraft down to an extremely low level, an opponent’s sensor and weapons technology is denied any information about the aircraft. Very faint and fluctuating signatures will be extremely difficult to detect until the aircraft is very close to the threat system, and will also be extremely difficult to track successfully.

A typical missile engagement requires that the aircraft be detected, tracked, its flightpath predicted, and missiles launched and guided to impact for the engagement to be successful. Should any of these phases of the engagement be disrupted or defeated successfully, the engagement will not be successful.

Extremely short detection ranges produce the further advantage of compressing the time available for the opponent and his automated equipment to react, thereby

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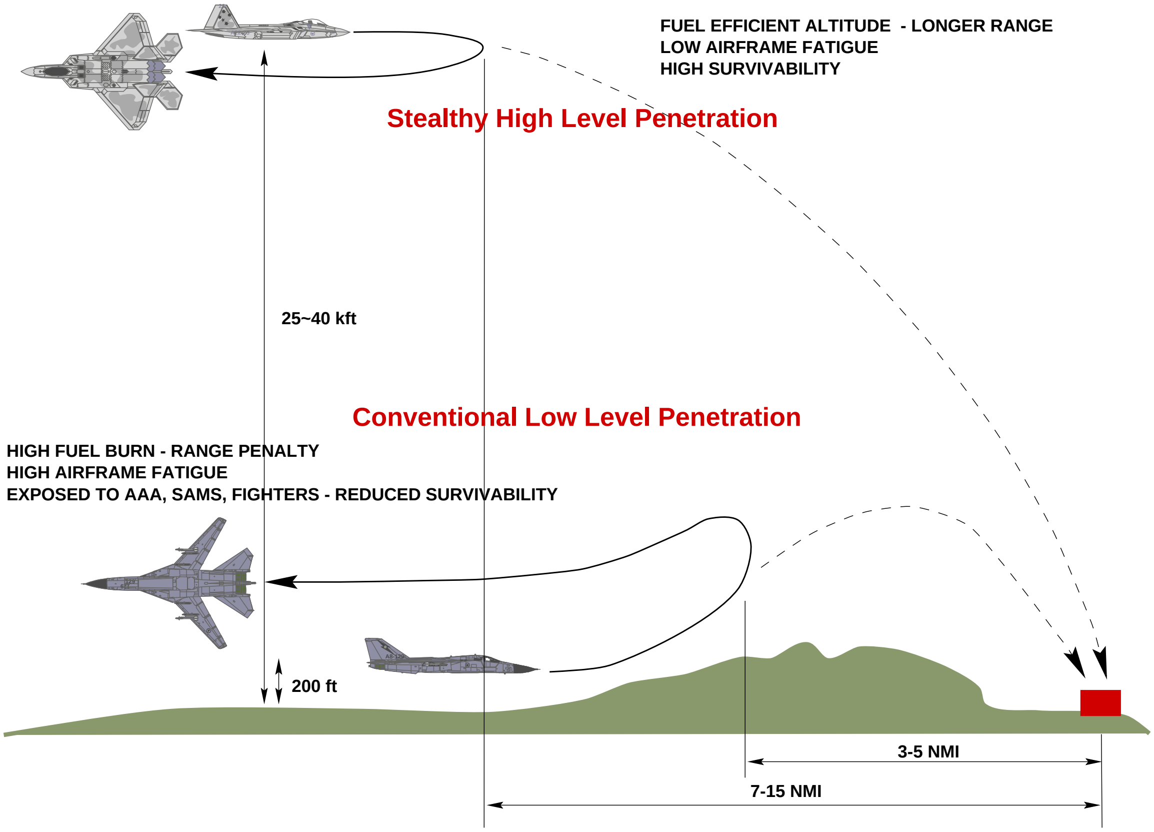
[72] Kopp C., *The USAF EDGE High Gear Program*, Australian Aviation, May, 1998.

increasing the chances of the equipment not performing, or the operators making mistakes.

Stealth restores the element of surprise at a tactical, operational and strategic level, and will place an opponent in a situation not unlike that which predated the invention of radar.



DELIVERY PROFILES FOR GUIDED BOMBS

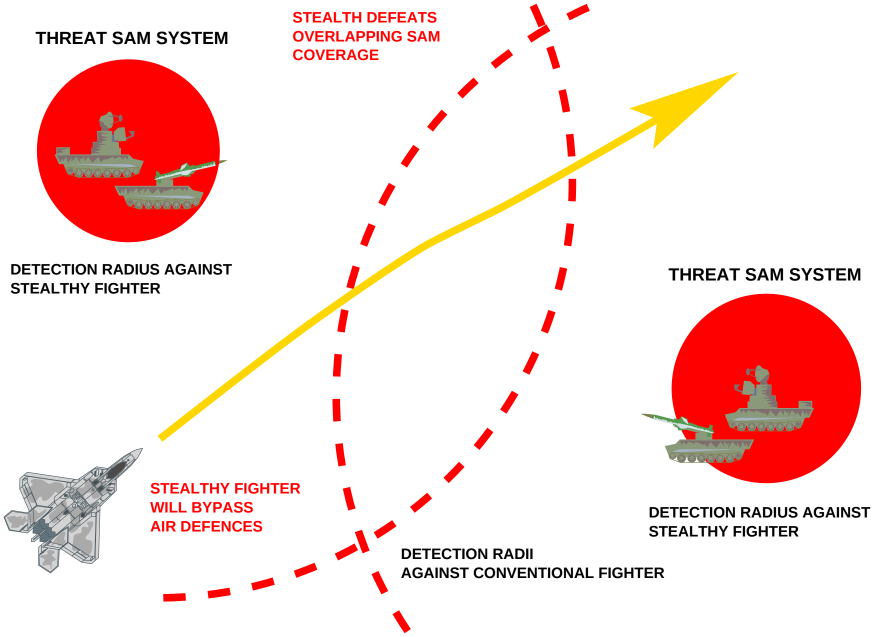
Stealth techniques are technologically demanding, since they require that designers address the necessary constraints inherent in signature reduction first and foremost, requiring significantly more complex tradeoffs in other areas of a design.

At this time only two operational types, the F-117A and B-2A, employ genuine stealth technology. The USAF's F-22A Raptor will be the next production aircraft to employ genuine stealth technology, which is also to be incorporated into the planned Joint Strike Fighter.

2.1.9.1 Stealth In Strike Warfare

The established penetration technique for strike aircraft, pioneered by the F-111 design, involves flying into defended airspace at very low altitudes and high speeds, and defeating hostile radar and weapon guidance by using jammers. For this purpose, conventional strike aircraft are equipped with Terrain Following or Avoidance Radars (TFR or TAR), thermal imagers, and typically comprehensive packages of radar warning and jamming equipment. In a situation where the opponent lacks pulse Doppler technology capable of detecting low flying targets, and uses relatively simple and unsophisticated radar and missile guidance equipment, low level defence penetration can be very effective. Until recent times this has been true of the broader region, and thus the RAAF's F/RF-111C/G has been an effective penetrator.

Low level penetration, while tactically effective in relatively benign threat environments, has some important limitations. The first is that it incurs a significant penalty in combat radius, since turbojet and turbofan Specific Fuel Consumption is poor at low altitudes, and the higher air density requires higher thrusts be employed to achieve tactically useful airspeeds. Moreover, continuous manoeuvres to clear terrain impose a significant fatigue load on the airframe, and the aircrew, thus limiting airframe life and aircrew endurance in combat. Often much effort is required in mission planning to select the lowest risk ingress and egress routes, and in some instances supporting aircraft armed with anti-radiation missiles may be required, as well as fighter escorts[73].



STEALTHY STRIKE FIGHTER VS SAM SYSTEMS

At low and very low levels, aircraft will be exposed to fire from a wide range of weapons, including small arms, AAA, short range point defence SAMs, and Man Portable SAMs (MANPADS), collectively termed "trash fire". While not particularly effective on a per-firing basis, large numbers of firings will often yield a statistically significant outcome and aircraft will be lost, as happened with RAF Tornadoes during the early phase of the 1991 air war. In more recent times, the proliferation of pulse Doppler technology in air defence radars, medium and long range area defence SAM seekers, fighter radars and AAM seekers has significantly reduced the survivability of aircraft using low level penetration techniques.

The strategy recently adopted by users of conventional low level penetration aircraft to defeat such defences has been the adoption of standoff missiles and glide weapons, which may be launched from outside the effective range of the target’s defences. This technique can often be highly effective, but incurs a major cost penalty since standoff weapons are typically 10 to 50 times more expensive than guided bombs. Moreover, fighter aircraft can often engage bombers at ranges of hundreds of miles from the intended target. Defeating fighters requires standoff weapons such as medium and

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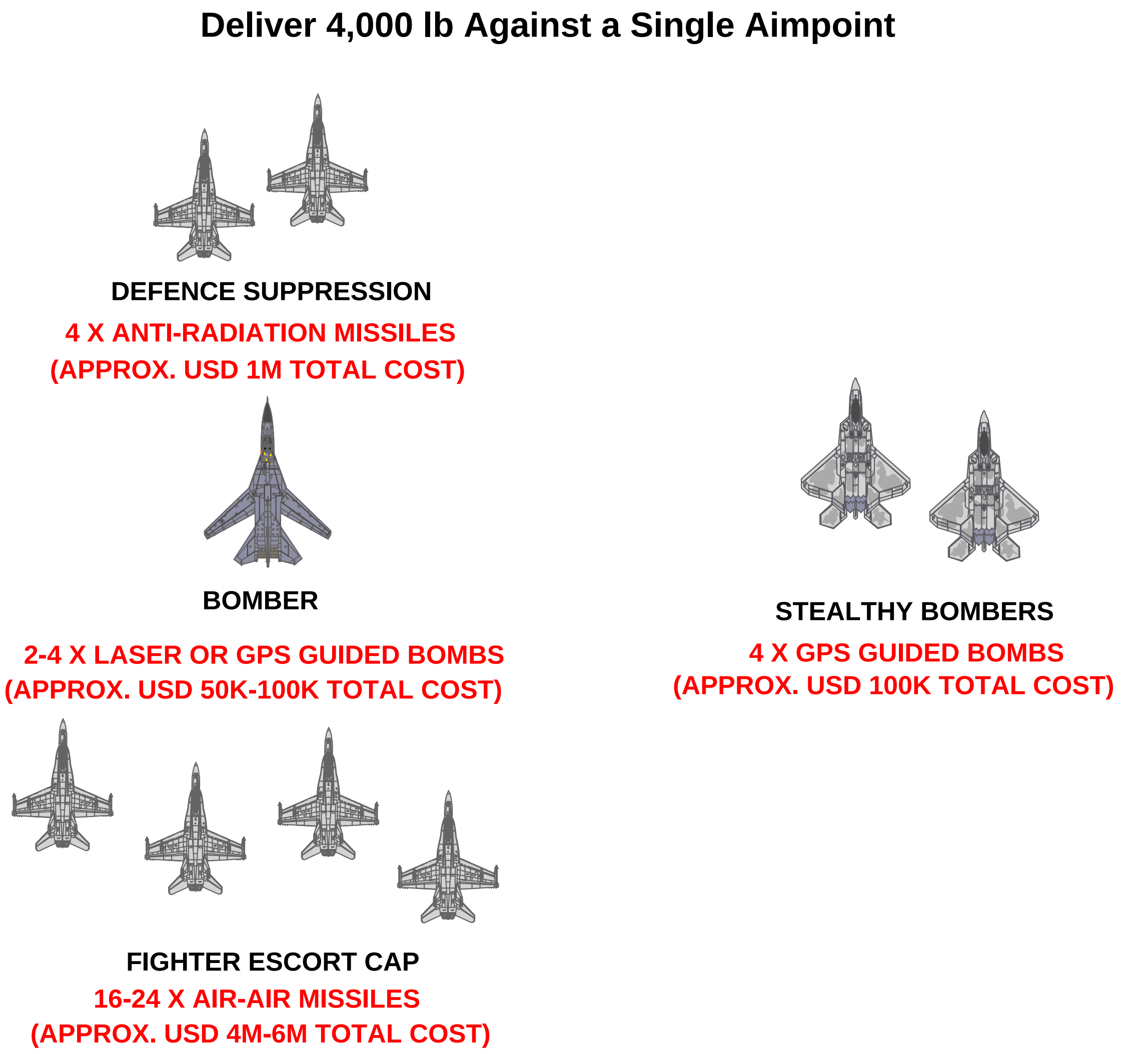
[73] This technique is termed "Strike Packaging", and was pioneered during the Vietnam War. Its primary drawback is the costs incurred per damage inflicted, since the supporting assets typically outnumber the bombers.

long range cruise missiles, which can be launched from safe distances. Such weapons are mostly very expensive, with costs in excess of a million dollars per round, and carry relatively small warheads[74]. Unless the conflict is very short, stocks of weapons may be expended before the desired military effect is achieved.



STRIKE PACKAGING VS STEALTHY PENETRATION

The use of Stealth techniques avoids most of these difficulties. A stealth aircraft may penetrate at a high subsonic or low supersonic speed at medium or high altitudes, thus achieving the best possible fuel efficiency and combat radius for the airframe, while incurring minimal airframe and aircrew fatigue. Mission planning is much simplified, since terrain is no longer a factor.

The target may be attacked with relatively cheap guided bombs, which provide very high lethality even against hardened targets. This will translate into a lesser number

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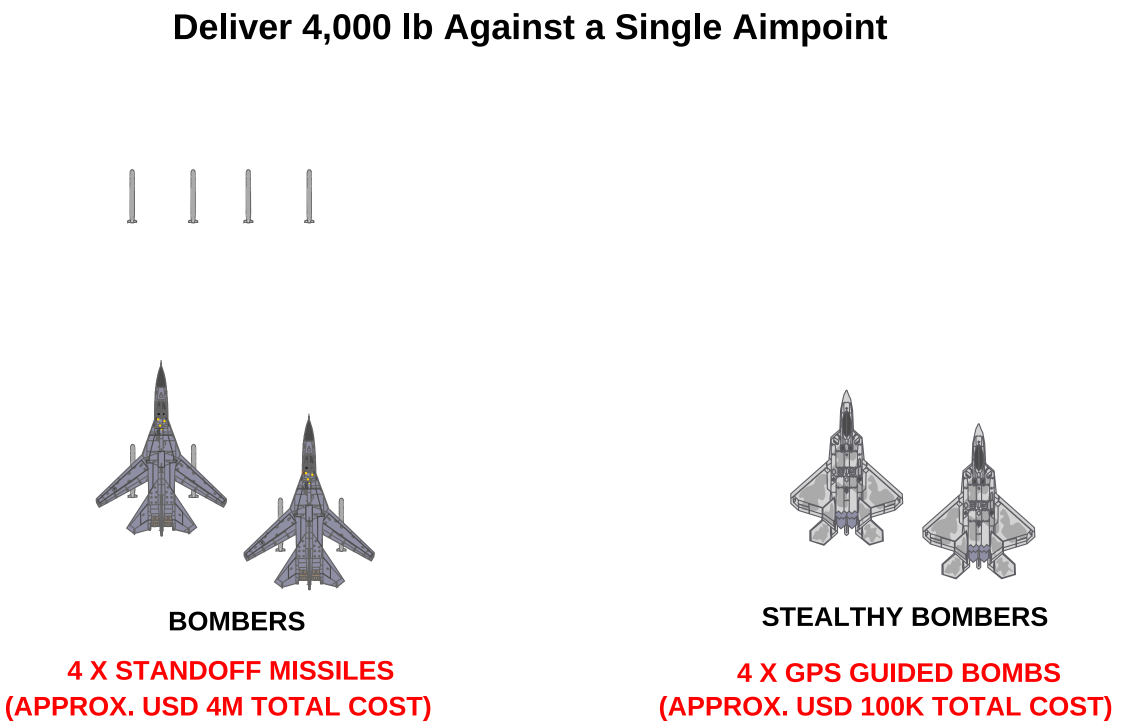
[74] Cruise missiles and standoff missiles most often carry warheads of weights between 500 lb and 1000 lb. With the exception of the UK's Royal Ordnance BROACH warhead, most such munitions have a limited ability to defeat thick reinforced concrete structures such as bunkers and Hardened Aircraft Shelters. It is worth noting the large numbers of Tomahawk cruise missiles typically expended by the US in strikes against Iraq or more recently, in Bosnia. It is often necessary to target 4-8 rounds to achieve the same damage effects as produced by a pair of cheap guided bombs.

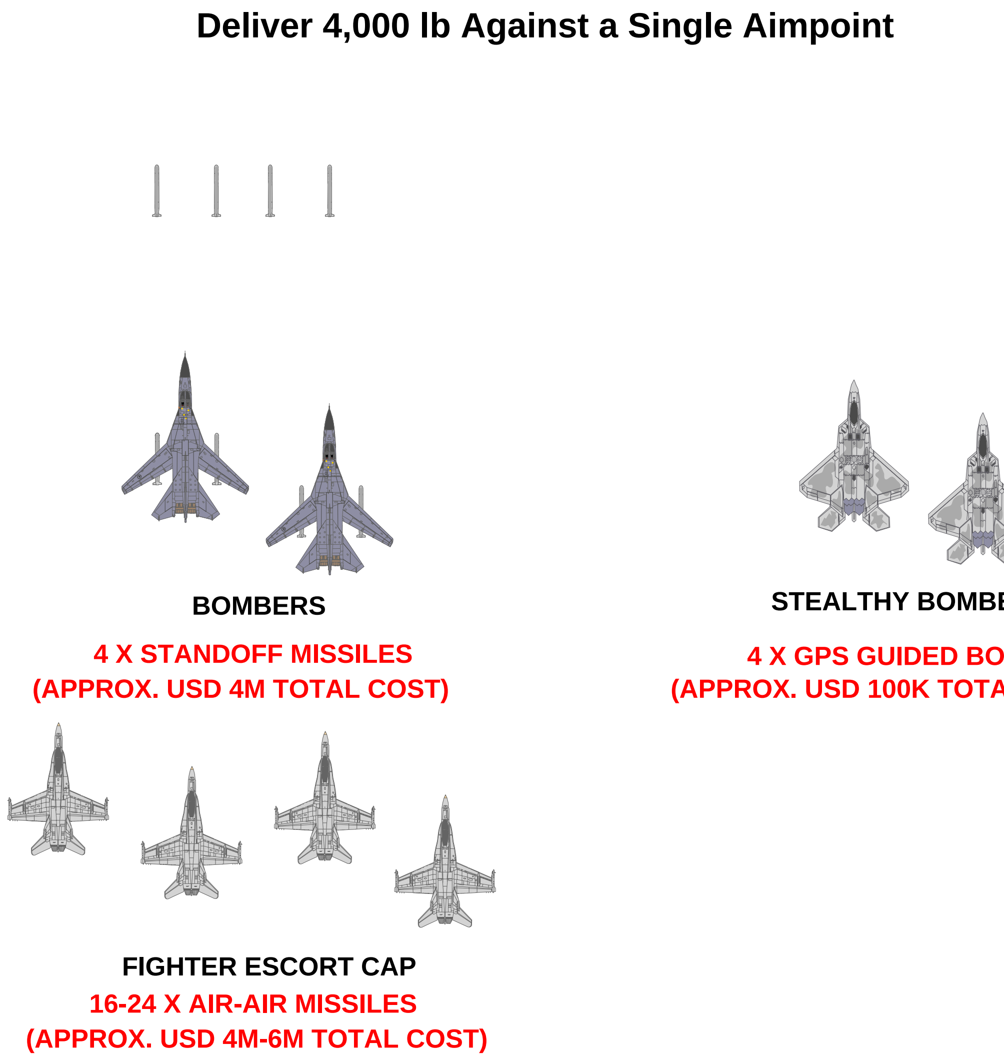
of sorties required to achieve the desired military effect, since the lethality per sortie is much increased. In terms of "bang per buck", Stealthy penetration is significantly cheaper than either strike packaging or using standoff weapons.



STANDOFF MISSILES VS STEALTHY PENETRATION

This is most apparent in a sustained combat situation. If we make the arguably optimistic assumption that adequate standoff missile stocks are available for the duration of the conflict, we find that the USD 70-100M cost of a stealthy strike aircraft is equal to the cost of the standoff missiles expended after a mere 35-50 strike sorties flown against defended airspace. If we assume a turnaround time of 2 hours per sortie, and a sortie duration of 4 hours, i.e. 4 sorties per day, then the cost of the stealthy strike aircraft is amortised in 9-12.5 days of sustained combat operations. For higher sortie rates at shorter ranges, this amortization rate is even higher. The case is even stronger should we consider using strike packaging rather than standoff weapons.

The issue of war stocks of expensive standoff weapons, and the replenishment rate of these by production is problematic. Since production rates for such munitions are modest, due to their complexity, in a conflict what stocks are available will more than likely have to last the duration of the conflict. Once stocks are expended operations must fall back on strike packaging, further increasing costs. Where a fighter threat exists, we must also budget the costs of the AAMs expended and the costs of mounting fighter sorties to defend the standoff missile shooters. If we are operating beyond the CAP radius of the fighter, then the cost of tanker sorties must be included. Therefore, shooting standoff missiles may not confer a significant cost advantage unless the duration of the conflict can be guaranteed to be shorter than about one week. Recent historical experience suggests that conflict durations are typically of several weeks, therefore the argument for the use of either strike packaging or standoff missiles is not sustainable, unless the opponent’s air defence capabilities can be defeated very quickly.



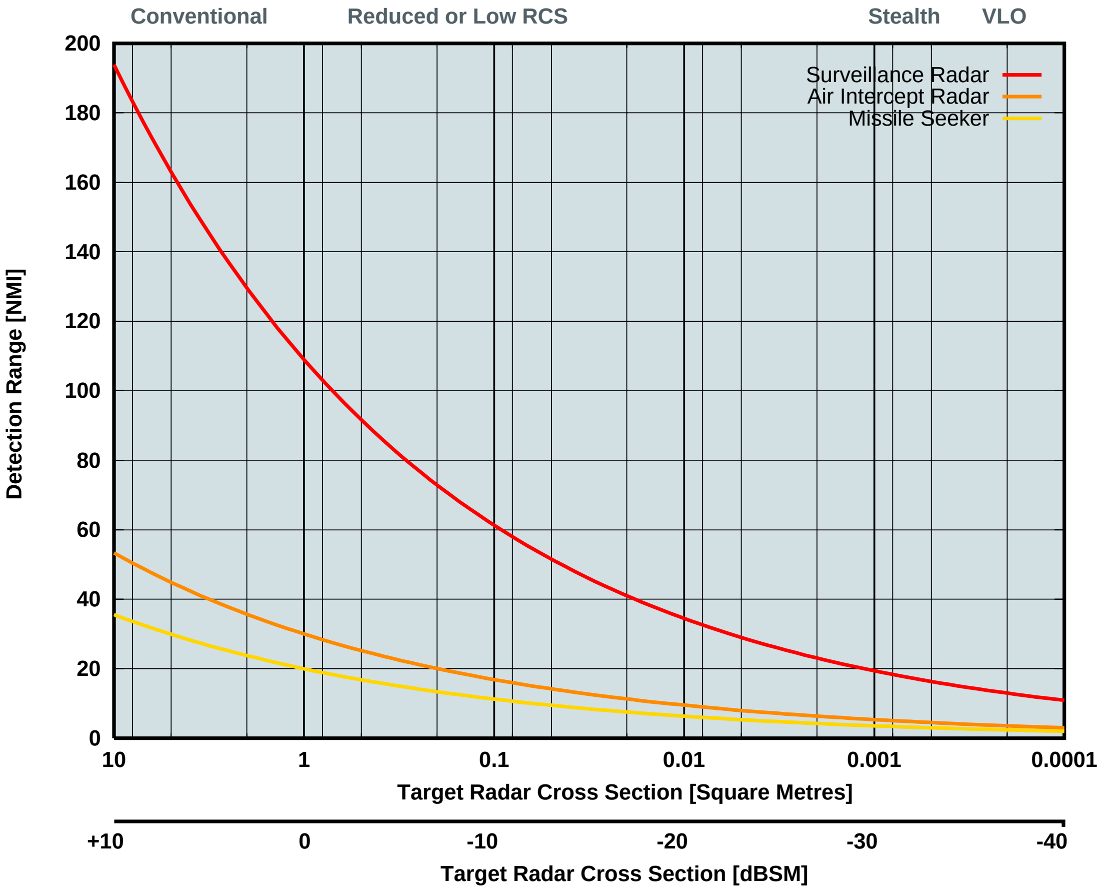
STANDOFF MISSILES VS STEALTHY PENETRATION (LONG RANGE FIGHTER THREAT)

A scenario of regional relevance would be such, where the RAAF is attempting to shut down several airfields, defended by fighters and SAMs. Given that an airfield basing one or two squadrons of aircraft will have a dozen or more critical aimpoints, and will most likely need to be reattacked to keep runways and taxiways closed, it is unlikely that the RAAF, or any air force of similar modest size, will be able to sortie enough aircraft to achieve a knock-out blow in the first few days. Therefore the opponent’s air capability will have to be reduced by repeated strikes over a one or two week period until rendered operationally ineffective.

As a result, the expectation that air superiority can be achieved quickly and decisively is somewhat optimistic. Under such conditions, the cost advantages of stealthy strike over strike packaging or escorted standoff missile attacks are truly compelling.

2.1.9.2 Stealth In Air Combat

The emergence of stealth technology in air superiority fighters fundamentally changes the established tactical and operational paradigm.



Detection Range for Surveillance, Air Intercept and Missile Seeker Radars vs Target RCS

The conventional model of air combat has traditionally been based upon the idea of using advantages in fighter manoeuvre, climb and acceleration performance to get a positional advantage in order to fire a missile, or at close quarters a gun, to destroy the opposing aircraft. With first and second generation heat-seeking and beyond visual range (BVR) radar guided missiles, which had poor kinematic performance and turn rates, a fighter needed to typically manoeuvre for several minutes to position itself for the killing shot. Whilst early radar guided missiles could be used in head on engagements, their performance against turning targets was poor. Early heatseekers had to be shot up the opponent’s tailpipe to lock on to the engine exhaust. Therefore fighters would have to engage in often complex manoeuvres, until the opponent was positioned for a shot.

The deployment of all-aspect heatseekers, typically third generation weapons[75], as well as more capable radar guided missiles, expanded the engagement envelope significantly. Whoever got their nose on the opponent first could get the first shot off and if not win, certainly force the opponent into a defensive manoeuvre costing position and energy, and therefore set the opposing fighter up for another shot, most likely a lethal one.

With the latest fourth generation heatseekers, such as the Archer, Python 4, ASRAAM or AIM-9X, Helmet Mounted Sights and Displays allow early shots even from geometries which would be impossible to exploit with older weapons. Moreover, modern active radar homing BVR missiles have a fire and forget capability, once guided by

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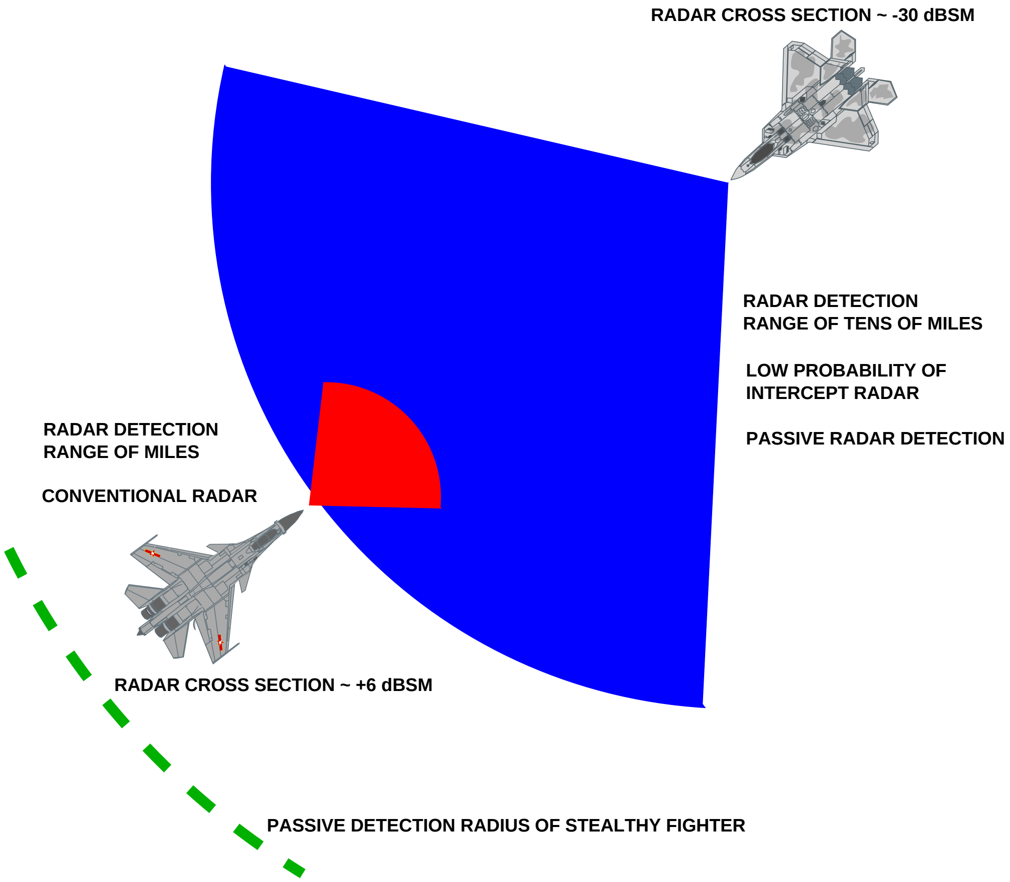
[75] Examples would be the AIM-9L and AIM-9M Sidewinder, and the Rafael Python 3 WVR AAMs.

datalink into their acquisition box and actively homing, they can be left to complete the engagement. With such weapons firing the first shot can be decisive. This forces pilots to shoot as early as possible, cutting time for target identification. Missile speed, target identification capability and pilot response times become important determinants of success in this game.



CONVENTIONAL AIR SUPERIORITY FIGHTER VS STEALTHY AIR SUPERIORITY FIGHTER

Stealth changes the tactical environment in fundamental ways. The first result of stealth is that the opponent cannot see the stealthy fighter on radar, or detect its radar on a warning receiver. Therefore, the stealthy fighter can locate, identify and stalk its opponent without being detected. A stealthy fighter can therefore exploit von Richtoven’s fundamental axiom, approach its victim undetected and shoot from the most advantageous geometry before the opposing fighter even knows it is there.

To fully exploit its technological advantage, the stealthy fighter will therefore need to adopt hit-and-run ambush tactics and avoid being drawn into a "turn-and-burn" close quarters engagement. At ranges inside several miles, a stealthy fighter loses its basic advantage of undetectability, as it may be tracked visually, and an opposing fighter’s radar and missiles may be able detect it and track it.

Therefore a stealthy fighter will maximise its survivability and lethality by staying outside its opponent’s visual engagement envelope, positioning itself for a shot and then shooting a fire-and-forget missile.

Because the conventional fighter will not know where the stealthy fighter is, it will not have the option of choosing an advantageous opening geometry in an engagement. It may detect the stealthy fighter using radar or IRS&T at ranges similar to visual detection range. A stealthy fighter can therefore choose the opening geometry to its advantage, for instance by approaching from the aft quarter.

In basic defensive counter-air scenarios, where a fighter CAP is being vectored to engage known inbound hostiles in a BVR head-to-head closing geometry engagement, the stealthy fighter can shoot multiple rounds at multiple targets well before it is detected by the targets. This significantly improves lethality since the targeted aircraft cannot initiate defensive manoeuvres or employ countermeasures until the missiles are actively homing at close range.

In offensive fighter sweeps into hostile airspace, the stealthy fighter can ambush defending CAPs or GCI controlled interceptors in whatever engagement geometry is most favourable. Where Rules of Engagement mandate visual identification of a target before firing, stealth still provides an advantage as the stealthy fighter can approach from an aft quarter low position undetected. Because tail warning radars and aft facing fire control radars, such as those on advanced Flanker variants, have much inferior detection range performance to forward facing fire control radars, the stealthy fighter will in most situations not be detected until it is too late for the victim aircraft to respond.

A conventional air superiority fighter with equal or better aerodynamic performance compared to a stealthy fighter is unlikely to get an opportunity to exploit that performance to its advantage. Performance can only be made use of where the opponent is seen and can therefore be manoeuvred against. An opponent unseen cannot be engaged.

Statistics from previous air wars suggest that most aircraft lost in combat did not see the SAM or fighter that attacked them. Caught by surprise, the pilot either did not or could not react appropriately and was in turn hit. The recent statistics from Desert Storm bear out this observation, interestingly many Iraqi pilots were reported to be flying with their warning receivers off and thus did not know they were under attack until they were hit. This is an interesting parallel to the situation where a stealthy fighter's LPI radar cannot be detected, and the victim is deaf to the inbound attacker.

With a stealthy air superiority fighter, an opponent faces this fundamental problem in every engagement. He is disadvantaged in reaction time in every situation, and if the pilot of the stealthy fighter exploits his advantage systematically, the conventional fighter will lose almost every time.

There is no historical parallel for this. *Therefore, the established doctrine for air combat tactics is largely obsoleted, regardless of its relevance in the past.* Only should the pilot of the stealthy fighter choose to be drawn into a close quarters visual engagement, or do so by poor choice of engagement geometry, does the conventional fighter have a chance of success in the engagement.

Therefore, trivial comparisons of manoeuvre performance between conventional and stealthy air superiority fighters are quite meaningless. Capability can only be measured in the context of a suitable air combat doctrine for the stealthy fighter. Should this doctrine be designed to exploit stealth to its fullest, then the conventional fighter will suffer overwhelming losses in almost any scenario.

The argument for stealth in air superiority aircraft is no less compelling than the argument for stealth in strike aircraft.

2.1.9.3 Technical Issues in Stealth

As noted earlier, stealth provides a decisive advantage in a BVR oriented air combat environment, as well as allowing for unescorted deep penetration into well defended airspace for strike missions. The question however will arise as to much much stealth is really required for a given level of threat[76]. Much has been published about the reduced RCS of more recent conventional fighters. This needs to be more carefully explored, since stealth is new and excluding the few initiated, most observers will have little intuitive insight into the basic issues.

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[76] Arguably this will arise as a major debating issue during the Hornet replacement bidding, asserted by vendors of aircraft lacking genuine stealth capability.

An important distinction must be made here between "true" stealth aircraft with an all aspect RCS below -30 dBSM[77] (0.001 m^2) and reduced RCS aircraft, with typically head on RCS values between 0 and -10 dBSM (1 - 0.1 m^2). The former can be detected by large early warning radars and SAM acquisition radars inside 20 NMI or less, by large fighter AI radars at about 10 NMI, and locked on by missile seekers at 2-3 NMI. This contrasts starkly with the detection range performance against reduced RCS conventional aircraft, which can be detected by large early warning radars and SAM acquisition radars at 60 - 100 NMI, large fighter AI radars at 40-70 NMI, and locked on by missile seekers at 5 - 8 NMI.

Therefore, a reduced RCS fighter may be competitive against a fighter/AAM threat, or short range point defence SAM system. It will not be particularly competitive against a modern area defence SAM system like the SA-10 or SA-12, designed to engage cruise missiles and standoff missiles like the SRAM, which have RCS values of about -10 dBSM (0.1 m^2). This is more so the case since reduced RCS fighters usually retain very large beam and tail aspect RCS, which means that their ability to fly the air-to-ground penetration mission differs only marginally from conventional fighters.

One important issue to stress in this context is that there is no necessary relationship between aircraft size and RCS, ie a large fighter which is suitably shaped even without specific RCS reduction measures may have a much lower RCS than a significantly smaller aircraft which is less suitably shaped. The assertion that airframe size differences in fighters amount to significant RCS differences is simply not true[78].

The popular media assertion that "stealth is in the paint and washes off in the rain" is plainly absurd, and its popularity indicates how little stealth is understood outside the radar and stealth community[79].

If we look at the major RCS contributors to any airframe, viewed head on, we will find a major RCS contribution from the aircraft’s basic shape, and what are termed "flare spot" contributions from smaller design features on the airframe. The total RCS is the sum of the shaped related RCS and the flare spot RCS values. Looking at the basic shape of the aircraft, from a head on perspective the biggest RCS contributors will be the leading edges of the wings, tailplane or canards, vertical tail(s), the inlets and the nose radar bay and cockpit. Of particular interest will be any airframe features which form acute angles or dihedral or trihedral corners, since these form excellent broadband wide angle radar reflectors, producing an equivalent RCS far greater than their geometrical size for the upper microwave bands of interest (SAM/AAM guidance bands)[80].

With an established airframe, there is little that can be done to reduce the RCS contribution of the leading edges, other than apply a radar absorbing coating which can help reduce but not eliminate the signature. If the option of a systematic RCS reduction redesign such as that applied to the F/A-18E/F is available, then leading and trailing edges, and panel boundaries can be aligned to scatter energy away to the sides. Straight edges and panel boundaries, angled away from the normal, and if possible grouped in parallel, are highly desirable here.

The nose radar bay can be fitted with broadband absorber material behind the antenna, and if a phased array is used, it can be tilted up slightly to bounce the return upward. A "tuned" or bandpass radome, transmissive in the AI radar’s band alone, can

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[77] dBSM is a standard measure used in the RCS engineering community, i.e. deciBels referenced to a Square Metre. It is a logarithmic measure, where 10 dB denotes a factor of ten change in magnitude, 20 dB a factor of 100, etc.

[78] This may seem counterintuitive, but reflects the physics of radar scattering, which are dominated by shaping. A good reference is Knott E.F., Schaeffer J.F. & Tuley M.T., *Radar Cross Section*, 1st and 2nd Editions, Artech House, 1986 and 1993.

[79] Fulghum D.A., *B-2’s Durability Faces Foreign Test*, AW&ST September 22, 1997, discusses the widely reported RCS problems in the B-2, which are the result of water ingress into seals between some panels, and did not result in an operationally relevant loss of RCS performance.

[80] For a more detailed discussion see Knott E.F., Schaeffer J.F. & Tuley M.T., *Radar Cross Section*, 1st and 2nd Editions, Artech House, 1986 and 1993.

significantly reduce nose area RCS to out of band threats like early warning radars, AEW&C and SAM guidance radars.

Cockpit canopies and windshields can be laminated or coated with conductive materials to make them radar opaque and hide the highly reflective cockpit interior.

Inlets are a major problem area, since the inlet entry edges are significant reflectors and the inlet tunnels behave as blanked off waveguides, which guide impinging radiation to the fan face(s), where it is modulated with an engine signature, and then guide it back out through the inlet to be reradiated out again, over a wide angular range. Inlet treatments are quite difficult, since absorbent linings must be used in the inlet tunnel, and inlet edges must be treated with absorbent materials, and also possibly geometrically realigned to scatter away from the boresight. A major issue is Foreign Object Damage (FOD) to powerplants should absorbent material delaminate or separate. A clear indicator of poor inlet RCS performance are rectangular inlet leading edges which are aligned normally to the aircraft’s boresight.

The other major issue with reduced RCS and conventional aircraft is the area of external stores. If the aircraft has an RCS of -10 dBSM (0.1 m^2), but is carrying a package of drop tanks and weapons with an RCS of 3 dBSM (2 m^2), then the stores will clearly compromise the aircraft. While conformal or semiconformal carriage are helpful, there is no substitute for internally carried stores. This is all the more important for the strike role, since the aircraft must contend with large high performance early warning and SAM radars, painting the aircraft from any azimuth.

Having addressed major RCS contributors, it is necessary to deal with the smaller flare spot contributors. These can have RCS values up to 0.5 m^2, particularly if they resonate at a particular wavelength. Good examples of flare spots are the various small air scoops which are typical on many an airframe, RWR/ESM and navigation/communications antennas, semi-conformal weapon stations, poorly aligned panels, air vent grilles, gaps between control surfaces and the airframe, and optical sensor domes such as MAWS, FLIR and IRS&T. Should the aim be significant stealth performance, then it is necessary to eliminate rivet heads, drain holes and gaps between panels.

While flare spots have much lower unit signatures than major airframe components, there are usually a great many of them and their effects are additive. Moreover, they often produce their RCS over a wide angular range, and thus will provide a stable rather than scintillating radar return. Therefore any airframe RCS reduction effort, if serious, will almost certainly need to deal with the most troublesome minor flare spots on the airframe.

The wide range of values associated with reduced RCS aircraft reflects essentially the amount of effort expended on RCS reduction. A comprehensive redesign like that performed on the F/A-18E/F will yield a much lower RCS than a minimal effort to make the canopy opaque, fit absorber around the radar antenna, and put absorber in key areas around the inlet. In any event it is worth stressing here that a reduced RCS aircraft still has a 100 times or greater RCS than a true stealth aircraft, even if it is 10-100 times smaller than that of an untreated conventional aircraft.

At best, a reduced RCS fighter when clean and carrying semiconformal AAMs, will have increased survivability against a fighter/AAM threat or short range point defence SAM threat[81].

Infrared signature is another aspect of aircraft observables which requires scrutiny, since the Flanker and Fulcrum both carry respectable IRS&T sets, and by 2020 this can be expected to be a standard fit on most fighters. Such equipment can typically detect a fighter tailpipe on dry thrust at altitude, from tens of miles away, and a large afterburning exhaust plume signature out to distances of 100 NMI or more. As a result,

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[81] Any assertions by manufacturers that reduced RCS aircraft provide a significant improvement in survivability against an area defence SAM threat are a simply not true, a marketing tactic aimed at those lacking basic literacy in stealth issues. Because area defence SAMs employ large antennas, they have much better detection range performance, both for seekers and engagement radars.

this places a large premium on dry engine thrust performance, since a fighter which requires generous use of afterburning thrust to maintain speed and agility will beacon its position and likely intent from afar. Again, this reinforces the argument for large fighters vs small fighters, if fighting at the limits of combat radius.

Thus the argument of "how much stealth is really necessary" is a sensitive one, since even small perturbations in threat capability, like the acquisition of fighter IRS&T and modern area defence SAMs can render any minimal incremental stealthing measures quite impotent[82]. Since the Flanker and SA-10 are now deployed in the broader region, and the SA-12 may deploy soon, a reduced RCS fighter offers only a marginal survivability advantage over a conventional fighter when dealing with this level of capability.

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[82] The extent on the radar detection range curve within which conventional and reduced RCS fighters lie, has a steep slope. As a result of this, even a modest improvement in radar performance translates into into a tactically useful gain in engagement ranges. This is not true of genuine stealth aircraft, since incremental improvements in radar detection performance produce little useful improvement in engagement range. This is an instance where the public unavailability of classified RCS performance figures is exploited for marketing purposes.

Section 3 Capability Issues

By 2015 variants of the Flanker will be the numerically most important modern type of fighter deployed in the broader region, by a substantial margin. For this reason alone this family of aircraft must be considered the baseline capability benchmark for the selection of the Hornet replacement.

While factors such as strategic, operational and tactical doctrine, availability of tankers, airborne early warning and control, communications, electronic combat support, logistical support, and aircrew training and ability are all important determinants of the outcome of an air campaign, the basic equation of numbers / aircraft and weapons capability in a 1 vs 1 or 2 vs 2 engagement has historically been of critical importance[83].

The Sukhoi Flanker family of fighters is therefore well worth careful examination, to determine the capabilities of established variants, and future growth variants. Because the basic design retains considerable growth potential, this paper will outline the most likely areas of capability growth over the next one to two decades.

3.1 The Sukhoi Su-27/30/35/37 Flanker Family of Fighters[84]

The deployment of the F-14 and F-15 by the US in the early seventies provided the West with an important capability advantage over the deployed Soviet designs of that period. In response, the Soviets commenced work on a new generation of fighters during the early seventies, drawing heavily on the concepts adopted by the Americans in the teen series fighters. Clearly the new aircraft had to provide a worthwhile performance margin against the US aircraft as they would be at least half a decade later in deployment. Also they had to be manufactured within an industrial base much less sophisticated than that of the Western world, while also retaining the simplicity and ruggedness which the Soviet military uncompromisingly demanded.

There is still contention at this time concerning the origin of the basic aerodynamic configuration which the Soviets adopted for both the MiG-29 Fulcrum and Su-27/30 Flanker, its nearest equivalent in the West was one of Grumman's early F-14 proposals[85] with a fixed rather than variable geometry wing. This configuration was adopted with the addition of ogival forebody strakes and wing/fuselage blending, a technique first used in the West on the YF-16 LWF demonstrator. We now know that the commonality in layout between both Soviet fighters, is due to research effort by TsAGI (Central Aero-Fluid-dynamics Institute), who are known to have wind tunnel tested a Sukhoi design of the given configuration extensively during the early seventies.

The twin engine twin tail blended fuselage/strake hybrid planform configuration common to both designs is optimised for sustained high subsonic manoeuvring. Excellent high Angle of Attack (AoA) lifting performance is achieved by a combination of body lift generated by the large fuselage carapace, and enhanced wing lift resulting from the formation of vortices by the large forebody strakes. In this fashion the configuration exploits attributes of both the F-14 family and the F-17/18 family.

The usage of large strakes well forward substantially affects the lift distribution by shifting the centre of pressure forward and thus reducing the static stability margin, particularly with increasing AoA. This, used with a stability augmentation system, improves instantaneous pitch rates while reducing the necessary tailplane download required to maintain high AoA. The twin vertical tails of both the MiG-29 and Su-27 are large and very widely spaced to avoid interference with the forebody vortices at high

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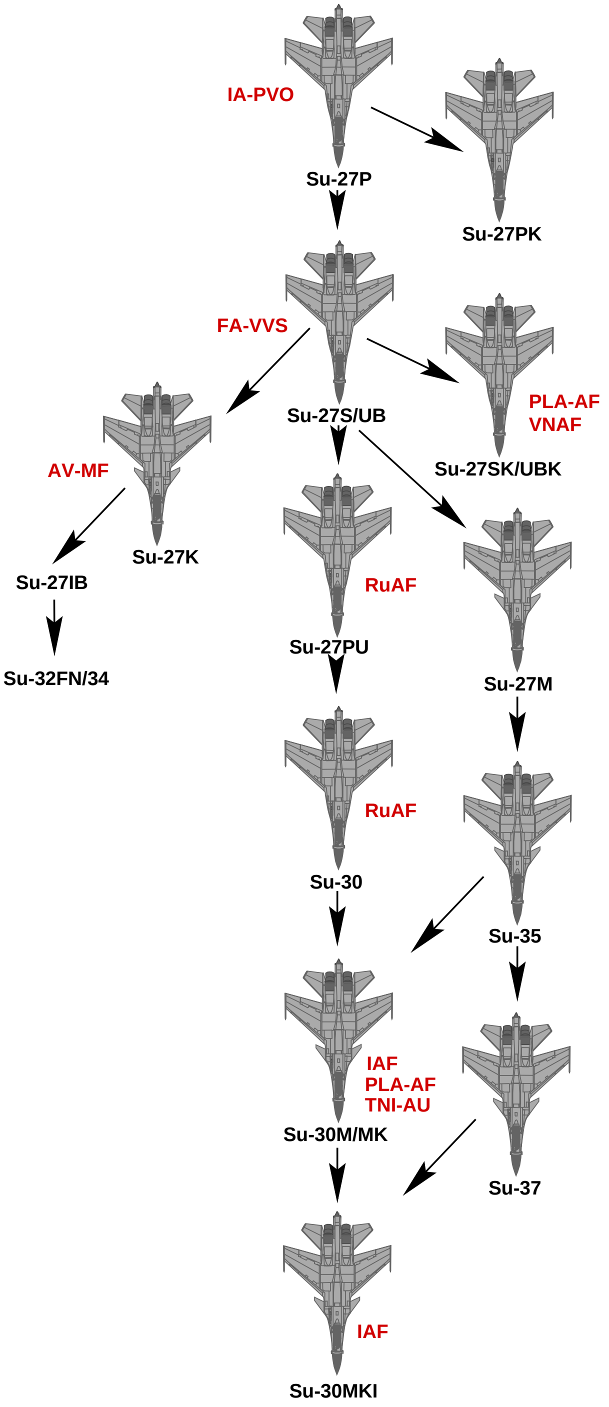
[83] Lanchester's equations of attrition warfare provide a good insight into this relationship, and one with much historical statistical background to substantiate it.

[84] Derived from Kopp C., *The Su-27 Flanker*, Australian Aviation, May, 1990, with updates based upon Easy T., *Su-37 Superb Sukhoi*, Air Force Today, Vol.1, #3 and Vol.1, #4, 1997. The author's original 1990 analysis of the strategic implications of the regional deployment of the Flanker has unfortunately appeared to have been fulfilled.

[85] VFX-404, later dropped in favour of the variable geometry configuration seen in production aircraft.

angle of attack. As a result, the aircraft exhibits superb low speed manoeuvre performance, evident from many an airshow display.



Evolution of the Flanker

The powerplant installation in long nacelles, with inlets well below the forward fuselage, is designed for minimum interference with external flow and best possible pressure recovery at high AoA. While this arrangement has some penalties insofar as vulnerability to Foreign Object Damage (FOD), weapon carriage and undercarriage stowage go, these were sacrifices made quite readily in the quest for good engine performance at high AoA. Both the Fulcrum and Flanker have relatively narrow fuselage tunnels in comparison with the F-14, which limits the usefulness of the fuselage for semiconformal weapon or fuel tank carriage, again this penalty was accepted to ensure the desired relative geometry between the inlets and forebody/nose of the aircraft. The upper lip of the variable geometry inlets is clearly offset to ensure removal of the ventral forebody boundary layer.

Supersonic dash performance for the air defence role was a lesser priority but reflects in the use of variable inlet geometry and the pronounced area ruling of the fuselage, resulting in the substantial forward hump. The resulting airframe configuration thus offers excellent sustained and instantaneous turn performance at high subsonic and transonic speeds, adequate supersonic dash performance and a substantial internal volume for fuel. It is penalised by limited fuselage area available for stores carriage, particularly in the MiG design, and poor fuselage and inlet clearance in landing configuration. Clearly air combat manoeuvring performance was the highest priority in the minds of the designers and little was compromised in the pursuit of this objective.

The common configuration of the Fulcrum and Flanker cleverly blends aerodynamic features used in several earlier Western designs with the result of superb subsonic manoeuvring performance, without the benefit of sophisticated flight control software[86]. The agility displayed by both types at various events over the last several years provides practical evidence of that what can be inferred from the geometry of the aircraft. The detail areas in which the two aircraft differ in turn reflect the specific roles of the aircraft.

The development of the Flanker was a protracted affair. It appears that conceptual work on the design began as far back as 1969, in response to the emerging US F-14 and F-15. In any event, the design effort progressed slowly as the first prototype of the T-10-1 Flanker A first flew on the 20th May, 1977, soon receiving the provisional US intelligence designation of Ram-K. The A model was largely a technology demonstrator for aerodynamic, propulsion and structural design purposes. It differed from later airframes in many respects, with vertical tails above the engine nacelles, beavertail afterbody, different wing planform with fences and a lanky rearward retracting forward undercarriage assembly. While this aircraft had many of the sought aerodynamic characteristics, its undercarriage and inlet arrangement were unsuitable for field deployment, its strakes did not perform to expectations and its vertical tails would have suffered similar problems to those of the F-17/18 family ie vortex interference. No less than six development aircraft were built, but endemic problems by 1977 forced a major four year redesign effort to produce a viable design, in the T-10S prototype.

The prototype for the production standard Su-27P Flanker B first flew in 1981 but again experienced numerous delays to deployment reportedly due to difficulties with the radar and avionic equipment. Su-27P IOC was achieved in 1985/1986, when the first aircraft were delivered to Voyska-PVO[87] regiments. About 200 aircraft were supplied to the PVO.

3.1.1 Airframe and Propulsion

The airframe of the Flanker is far more aerodynamically refined than that of the smaller Fulcrum. Like the Fulcrum, the general layout dictates much of the structural configuration of the aircraft, with correspondingly similar placement of functional blocks. The structure of the Flanker employs generous amounts of titanium.

The fuselage/carapace of the Flanker employs wing body blending most apparent aft of the strakes, this provides considerable internal volume for fuel, usually quoted at between 19,000 and 22,000 lb, subject to variant. Further fuel is housed in the pronounced hump which also structurally supports an F-15 style dorsal speedbrake. This

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[86] The Flanker variants in production employ analogue fly-by-wire controls, technologically of the same generation as the F-16A system.

[87] Voyska Protivo-Vozdushnoy Oborony Strany, former Soviet Air Defence Forces.

arrangement cleverly exploits area ruling for low wave supersonic drag while maximising fuel volume, fuel is held in urethane foam cells.

The inlets of the Flanker are typical of a multiple oblique shock ramp inlet , as used on the F-14. The result is an inlet with very good performance at high supersonic speeds. Like the Fulcrum, protection against FOD is used, with an internal grill deployed at low speed which diverts ingested solids out through a bank of ventral louvres.

The aft fuselage uses a tailboom arrangement for structural support of the vertical tails and stabilators, with additional ventral strakes fitted to enhance directional stability and high AoA. The fuselage centrebody ends in a distinctive tail bullet, housing additional fuel cells, and a braking parachute in early models.

The undercarriage is conventional with nosewheel and mainwheels retracting forward, the nosewheel has a mud guard fitted.

The large size of the Flanker allows a reasonably wide fuselage tunnel which is much like the F-14 used for stores carriage. The aircraft has two tandem tunnel stations and two nacelle stations, typically used for BVR missile carriage.

The wing is moderately swept and fitted with full span leading edge manoeuvre flaps and part span inboard flaperons for roll control, all tied into the fly-by-wire system. Two pylons are fitted in earlier models and the wingtip carries a fixed launch rail, which can be used to mount an ECM pod.

The fly-by-wire control system was a first in a Soviet tactical aircraft, it is a triple redundant analogue system comparable to that in the F-16A. An AoA limiter[88] load factor, roll, yaw and pitch rate limiters are built in, some of these may be disengaged by the pilot.

The baseline aircraft is fitted with a pair of Lyulka AL-31F twin spool turbofans with a 0.6:1 bypass ratio, delivering up to 16,755 lb of dry thrust at a respectable SFC of 0.67 lb/lb/hr, and up to 27,560 lb of reheated thrust at an SFC of 1.92 lb/lb/hr. The engine uses a hydromechanical control system, which is coupled to the fly-by-wire flight controls. The Mean Time Between Overhauls (MTBO) is typically quoted between 700 to 1,000 hr, with an engine life of 3,000 hr.

A number of growth versions of the powerplant exist and are used on later variants. The AL-31FM for the Su-35 demonstrator is rated at 29,320 lb, while the much newer AL-37F and TVC AL-37FU deliver 30,866 lb, with a slightly lower nominal dry SFC of 0.070 lb/lb/hr. The lifetime of the TVC nozzle is quoted at 500 to 1,000 hrs[89]. A follow on engine, the AL-41F, is rated at 40,466 lb reheated, it is however unclear whether this engine will be adapted to the Flanker.

3.1.2 Cockpit

The cockpit of the baseline Flanker B/C is much like that of the baseline Fulcrum, both in usage of conventional instruments and in layout. Unlike the Fulcrum, the Flanker has a large bubble canopy with sills well below pilot shoulder height, and much larger consoles on either side. The instrument panel has a similar layout, but is less crowded with most of the switches shifted to the side consoles. The left hand console mounts the twin throttles, while the right hand consoles are occupied with three sets of keypads, one of which is associated with the flight control computer.

The HUD is similar to that of the Fulcrum, but uses slightly different controls and does not appear to have the lensing and cable associated with the gun camera. Below the HUD is the optical head positioning tracking system associated with the Helmet Mounted Sight. The standard sight is used with the Zsh-7 Helmet, which employs a clip-on reticle with a projected cursor.

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[88] Fulghum D.A., *Military Aircraft Pilot Reports AW&ST,* McGraw Hill, 1996. Typical operational limit is 26°, although the FBW limit is cited closer to 35 °.

[89] Easy T., ibid, Novichkov N., *Sukhoi Set to Exploit Thrust Vector Control*, AW&ST, August 26, 1996, also Butowski P., ibid.

The upper right corner of the cockpit mounts the rectangular display shared by the aircraft's radar and IRS&T.

The Flanker cockpit offers excellent visibility in all directions, much like Western fighters and is spacious enough to be comfortable on long range missions. As such it was major departure from traditional Soviet design practice which suggests a more serious view of this matter.

Growth variants of the aircraft employ glass cockpits, either of Russian or Western origin.

3.1.3 Radar and IRS&T

The baseline radar used on the Su-27P/S is a variant of the Phazotron (formerly OKB-339) Zhuk-27 Slot Back[90]. This type has been offered on late model MiG-29 aircraft, and has also been exported to the PRC for use on the J-8 series.

The Zhuk-27 is an I/J band, pulse Doppler radar, comparable in technology to seventies US APG-60 series radars. It delivers a peak power of 5 kW, and average power of 1 kW, weighs between 551 to 573 lb, depending on variant, and is credited with an MTBF of 120 hr. A conventional mechanically steered slotted planar array of about 4 ft diameter is employed. Angular coverage is up to 90° off-boresight.

For BVR combat the radar provides Range-While-Search (RWS), look-up and look-down, and Track-While-Scan (TWS) modes, and can support the Alamo and Adder BVR AAMs. The manufacturer states a detection range of 54 NMI[91] for closing targets, and 27 NMI for receding targets. The radar can track up to ten targets and engage 2 to 4 targets simultaneously. For WVR combat the radar provides a Vertical Scan Mode, a HUD Search Mode, a Wide Angle Mode and a Boresight Mode, essentially similar to Western types. It provides cueing for the Archer WVR missile.

The radar provides a range of air-to-ground modes, comparable to the early APG-63/65. Modes include Real Beam Groundmapping, Doppler Beam Sharpening, Ground Moving Target Indicator, GMTI Track While Scan on up to 4 surface targets, Air to Surface Ranging and Velocity Update for the INS. A Synthetic Aperture mode with map freeze is claimed for later models of the radar.

In overall capability, the Zhuk-27 compares most closely to an early APG-63 or 65, but is volumetrically larger and slightly heavier, and employs a larger antenna. Its limitations lie primarily in the data processing and pulse Doppler look down signal processing[92], areas critically dependent upon the availability of high performance digital microprocessor technology.

Later Flankers carry the more capable NIIP N-011, which is credited with similar range performance to the Zhuk, but capable of tracking 15 and engaging up to 4-6 targets. Details of the Flanker's IRS&T/Laser package have not been disclosed. The IRS&T is most likely a multi-element scanning InSb design, and is boresighted with a laser rangefinder to allow "radar silent" attacks with AAMs or the gun. The fire control system is integrated and has the capability to automatically switch between radar and IRS&T should either sensor lose signal quality, for instance the radar through jamming, or IRS&T through cloud.

3.1.4 Electronic Warfare

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[90] Other sources have credited this radar with between 70 to 130 NMI detection range. Target RCS is stated to be 3 m^2, in Rosvoorouzhenie literature.

[91] Butowski P., *Russian radar fights to sharpen image*, JDW, 18 December, 1996. Also *Zhuk Airborne Radar*, Phazotron marketing brochure, 1995. Also discussions by the author with Phazotron engineering staff at the 1995 Avalon airshow.

[92] The author was advised in informal discussions with IDF aircrew familiar with the Flanker, that the Zhuk does not perform well in lookdown modes and experiences frequent false alarms and track loss, not unlike the early APG-63 on the F-15A.

Few details have been publicly disclosed on the defensive aids packages fitted to the Flanker. Early aircraft were fitted with the Sirena III warning receiver, and the aircraft is claimed to have a defensive jamming package, in addition to a flare dispenser. Some aircraft have been photographed with wingtip jammer pods, displacing the wingtip Archer rounds.

Later aircraft are reported to carry the SPO-15 warning receiver, common to the Su-24 Fencer, and an MAK optical warning sensor.

3.1.5 Weapons

The Flanker is equipped with a single internal GSh-30 30 mm gun carrying 149 rounds of ammunition, which given its rate of fire is a reasonable figure if Soviet statements concerning the accuracy of the infrared/laser fire control are correct.

The baseline aircraft can carry up to ten air-to-air missiles which would be mixed for the mission to be flown. Operational aircraft have been photographed with loads of six BVR R-27 (AA-10 Alamo) missiles, two rounds on tandem tunnel stations, two on nacelle stations and two on inboard wing stations. Typically the wing station rounds are the heatseeking variants and the fuselage rounds the semiactive radar variants. Outboard wing and wingtip stations are then available for the R-73 (AA-11 Archer) heatseeking dogfight missile.

The Vympel R-27 Alamo is at this time the most widely used BVR missile on the Flanker, and is available in a wide range of variants[93]. The design is modular, and a short and long burn motor (denoted by E designation) is available, with an F-pole range cited by the manufacturer to be 43 NMI and 70 NMI respectively, or about 10% less for the heatseeking variants. The cited minimum launch range is about 500 yards. Vympel claim the missile can defeat targets manoeuvring up to 8 G. The blast fragmentation warhead weighs 86 lb, with long burn variants weighing in at about 770 lb, and short burn variants 550 lb.

The semi-active radar seeker equipped R-27ER1 and R-27R1 variants employ inertial midcourse guidance with a radio command link for midcourse updates prior to seeker homing. No details have been disclosed on the all-aspect R-27ET1 and R-27T1 heatseeking variants, although they can be expected to employ similar technology to the early R-73, and provide a capability to engage targets outside the range envelope of the R-73. An anti-radiation variant capable of attack on radiating fighter air intercept radars exists, and it is likely that the AGAT 9B-1103 and 9B-1348 active seekers may be adapted as well.

A more recent development is the Vympel R-77 RVV-AE, dubbed the "Amraamski" by Western observers[94]. The Vympel R-77 (AA-12 Adder) is an active radar guided BVR AAM and is designed to engage 12 G targets. It employs fuselage strakes for enhanced body lift at an AoA in excess of 40°, and unique electrically actuated "grid" control surfaces to achieve additional control force at high AoA. This is claimed to provide a 150°/sec turn rate. The R-77 weighs in at 386 lb and Vympel quote an A-pole range at altitude of up to 54 NMI, with a minimum range of about 1000 ft. A 48.5 lb continuous rod warhead is initiated by a laser proximity fuse.

This missile, like the US AIM-120, uses digital datalink/inertial midcourse guidance and active terminal homing, supports an LOBL off-the-rail active launch mode and is claimed to have a Home-On-Jam (HOJ) capability. Carried by the Flanker and Fulcrum, the missile requires the APU-170 pylon adaptor, and a late model AI radar such as the Phazotron Zhuk or N-011.

The AGAT 9B-1103 and 9B-1348 active radar seekers for the R-77 employ a dual plane monopulse antenna, for inherent resistance to amplitude based jamming techniques, and pulse Doppler signal processing which the manufacturer claims allow snap down attacks on targets as low as 60 ft AGL. The Adder was to be supplied to Malaysia

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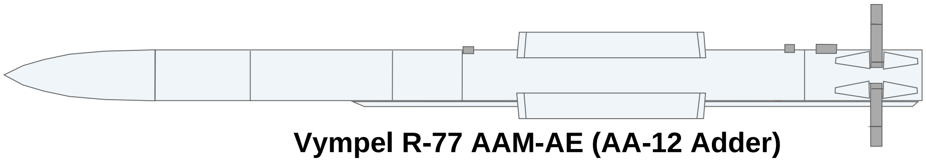
[93] Vympel marketing literature.

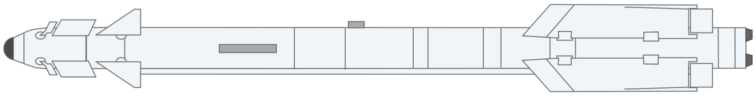
and India.

The latest variant of the Adder is the R-77M RVV-AE-PD, which employs a new airframe with a KRLD-TT variable thrust air breathing rocket ramjet, claimed to have a 7:1 cruise thrust adjustment range. Its A-pole range is estimated at 86 NMI. The airframe employs a combined quadruple inlet/strake design.

Some reports also exist of an anti-radiation variant of the Adder. Given the known existence of anti-radiation variants of the Alamo, integration of such a seeker on the Adder airframe would be primarily an issue of packaging.



Vympel R-77 AAM-AE (AA-12 Adder)



Vympel R-73 (AA-11 Archer)

(c) 1997, Carlo Kopp

For WVR combat the Flanker can carry the older R-60 Aphid, and the capable Vympel R-73E (AA-11 Archer). The Vympel R-73 is a true fourth generation WVR AAM with exhaust paddle thrust vectoring and a significant off-boresight acquisition capability using the helmet mounted sight, Vympel claiming target acquisition to ±45°, and tracking to ±75°. This 232 lb AAM carries a 16 lb continuous rod warhead[95], and has a useful envelope between 1000 ft and 16.2 NM, with a claimed capability against 12 G manoeuvring targets. The seeker is an all aspect multi-element scanning design. A number of variants exist. The R-73M has improved range to 20 NMI and off-boresight capability well in excess of 60°. R-73EL employs a laser proximity fuse rather than the standard radio proximity fuse. The follow on R-74 series (K-74 in development) employs a digital signal processor and laser proximity fuse, with a claimed 30% increase in acquisition range[96]. In addition, an aft firing variant of the basic R-73 has been tested, with an additional rocket booster pack.

For air-to-ground roles, the basic Su-27S/SK can carry Russian standard 500 kg dumb bombs, KGMU-2 cluster bombs, and S-8, S-13 and S-25 unguided rockets.

3.1.6 Performance

The Flanker is an air superiority fighter with aerodynamic performance in the class of the F-15 and F-14D, with good manoeuvring ability, acceleration and excellent combat radius. Rated at 9G maximum load factor and using a fly-by-wire control system and relaxed static stability, the Flanker offers excellent sustained and instantaneous turning performance which are essential for successful gun and all aspect missile engagements.

The aircraft's controllability at extreme AoA, demonstrated at many air shows, suggests few restrictions upon manoeuvring during dogfights. The roll rate is claimed to well exceed 270°/sec. Compared to the US F-15, the Flanker is a much better performer in a low speed turning engagement. The combat thrust/weight ratio of 1.25 at 30% fuel load implies excellent acceleration and climb performance thus providing the Flanker with a major energy advantage against most opponents. Given the combination of turning ability and persistence, and good BVR capability, the aircraft will provide an opponent

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[94] ibid, also Cook N., *Russian Missiles Hot Up Western Market*, JDW, 6 November, 1996, and Fricker J., *Vympel to Export Upgraded Missiles*, AW&ST, September 1, 1997.

[95] ibid.

[96] ibid, *Vympel reveals previously classified air-to-air missiles*, Flight International, 27 August, 1997.

with few opportunities to disengage in a post merge situation.

As an interceptor, the 20,000 lb of internal fuel, and superb climb performance provide the combination of excellent persistence and short dash time to station or engagement. The combat radius will depend upon variant, profile and payload, generally the Su-27 is regarded to be a 1,000 NMI combat radius class aircraft. Later model aircraft have retractable AAR probes.

3.2.1 The Sukhoi Su-27P/PU/PK/UB Flanker

The Su-27P was the basic PVO air defence fighter, and the first variant to be deployed operationally. The Su-27PU is a fully combat capable dual seat model, which is often employed as a command aircraft of a multiple aircraft defensive CAP, and is an upgraded Su-27UB dual trainer.

3.2.2 The Sukhoi Su-27S/SK and Su-27K/Su-33 Flanker

The Su-27S was the initial Frontal Aviation tactical fighter variant, broadly comparable in role to the early USAF TAC F-15A. It is capable of delivering unguided bombs, rockets and cluster munitions, in addition to its suite of AAMs. The Su-27SK is the export variant.

The Su-27K/Su-33 is the AV-MF navalised variant, with folding wings, tailhook and other design changes required for carrier operations. The Russian carriers employ ski jumps rather than catapults for aircraft launches. This variant was the first to employ canards.

3.2.3 The Sukhoi Su-30/30K, Su-30M/MK and Su-30MKI Flanker

The Su-30 evolved from the Su-27PU airframe, and incorporated the canards from the Su-27K. The initial Su-30 was developed as a more capable Command & Control (C2) aircraft for extended range air defence missions, with additional air-to-air capabilities in the N-011 radar. The Su-30M incorporated much of the technology developed for the Su-35 multirole fighter, to provide in effect a Russian equivalent to the F-15E. The Su-30MK is the export variant of the Su-30MK, while the Su-30MKI is the variant specific to the IAF, with thrust vectoring and a glass cockpit.

3.2.4 The Sukhoi Su-27M and Su-35 Flanker

The Su-27M was a late eighties genuine multirole variant of the Su-27S airframe, incorporating canards, a digital flight control system, a glass cockpit with four displays, a 30° inclined ejection seat, an additional pair of outboard pylons and a retractable refuelling probe.

The Su-35 was the first model to carry the NIIP N-011M radar, which employs a passive phase shifter technology electronically steered phased array, first tested in 1992/93. This antenna technology allows the radar to timeshare multiple modes, and track targets for engagement while maintaining Track While Scan coverage. The N-011M is capable of mechanically steering the array, as the B-1B does, to search an azimuth of 270°, or to maintain track in an A-pole escape manoeuvre. The Su-35 was the first variant to carry the NIIP N-012 tail warning radar, credited with the ability to cue the R-73 and the R-77 AAMs.

3.2.5 The Sukhoi Su-37 Flanker

The Su-37 is a progressive development of the Su-35, a single seat multirole fighter with thrust vectoring and a French SAGEM HUD and Ring Laser Gyro based inertial digital

Nav-Attack package. The glass cockpit uses four displays, with failover redundancy. The aircraft also has a range of other important improvements over the Su-35.

The first is the use of the Phazotron Zhuk-Ph phased array radar, which is an improved baseline Zhuk with the NIIP phased array. The Zhuk-Ph formed the technology testbed for the RP-35 and Sokol phased array radars. It has a detection range of in excess of 76 - 86 NMI (3 m^2), can track 24 targets, and engage 6 to 8 targets with missile shots. It provides the capability to timeshare multiple air-to-air and air-to-ground modes. It is supplemented by the Phazotron N-104 tail warning radar.

The digital flight controls are linked to the thrust vectoring nozzles, and operate at this stage in pitch only, although roll and yaw control, the latter linked to the pedals, is under discussion. The cockpit employs a force sensitive side-stick controller, much like the F-16 and F-22, and force sensitive throttles.

The Su-37 has been used as a testbed for new technology, some of which is now appearing in the Indian Su-30MKI.

For air-to-ground sorties, the Su-37 can carry laser guided bombs, ASMs and the capable supersonic ramjet Kh-31 missile, either in its anti-shipping or anti-radiation variants.

3.2.6 The Sukhoi Su-27IB and Su-32FN, Su-34

The Su-27IB was the canard equipped side-by-side dual trainer variant for naval CTOL operations, characterised by a unique chined nose geometry. Dubbed the "Duck Bill", this aircraft soon evolved into a dedicated design, optimised as an F-111 class deep strike fighter with additional air-to-air capability[97]. The first variant of the Su-7IB was the Su-34, which flew in 1993. It evolved into the Su-32FN, which is optimised for the maritime strike environment. These aircraft both employ a spacious cockpit, accessed by a ventral ladder rather than raised canopies, with the whole crew area protected by a tub of titanium armour. The aircraft has a substantially increased internal fuel capacity over the tandem seat variants, by virtue of the much greater internal volume provided by the wider fuselage and hump behind the cockpit. The fuel capacity has not been disclosed. The aircraft has a tandem wheel main undercarriage, built for substantially higher gross weights than the basic tandem seat variants.

The Su-34/32FN both retain the twelve weapon stations standard to late model Flankers, and the internal gun and air air missile capabilities. The stinger mounted N-012 or N-104 aft facing fire control radar is employed in conjunction with the aft firing Archer variant.

The avionic package on offer by Sukhoi for the Su-32FN is optimised for a littoral maritime strike role. Designated the Sea Snake, this Nav-Attack system is built around a pair of digital mission computers and a multimode coherent pulse Doppler radar, and includes integrated support for GLONASS and GPS satellite navigation. The avionic package was to support a wide range of air ground munitions, including a little curiously, also ASW munitions and sonobuoys.

The Su-34//32FN is potentially the most important strike capable Flanker variant, by virtue of its considerable combat radius potential and internal volume for mission avionics. Production for the RuAF was planned, to replace the Su-24 Fencer after the turn of the century.

3.2.7 Advanced Munitions for the Flanker

A number of highly capable munitions[98] have been proposed by the Russians for use on the Flanker family of aircraft.

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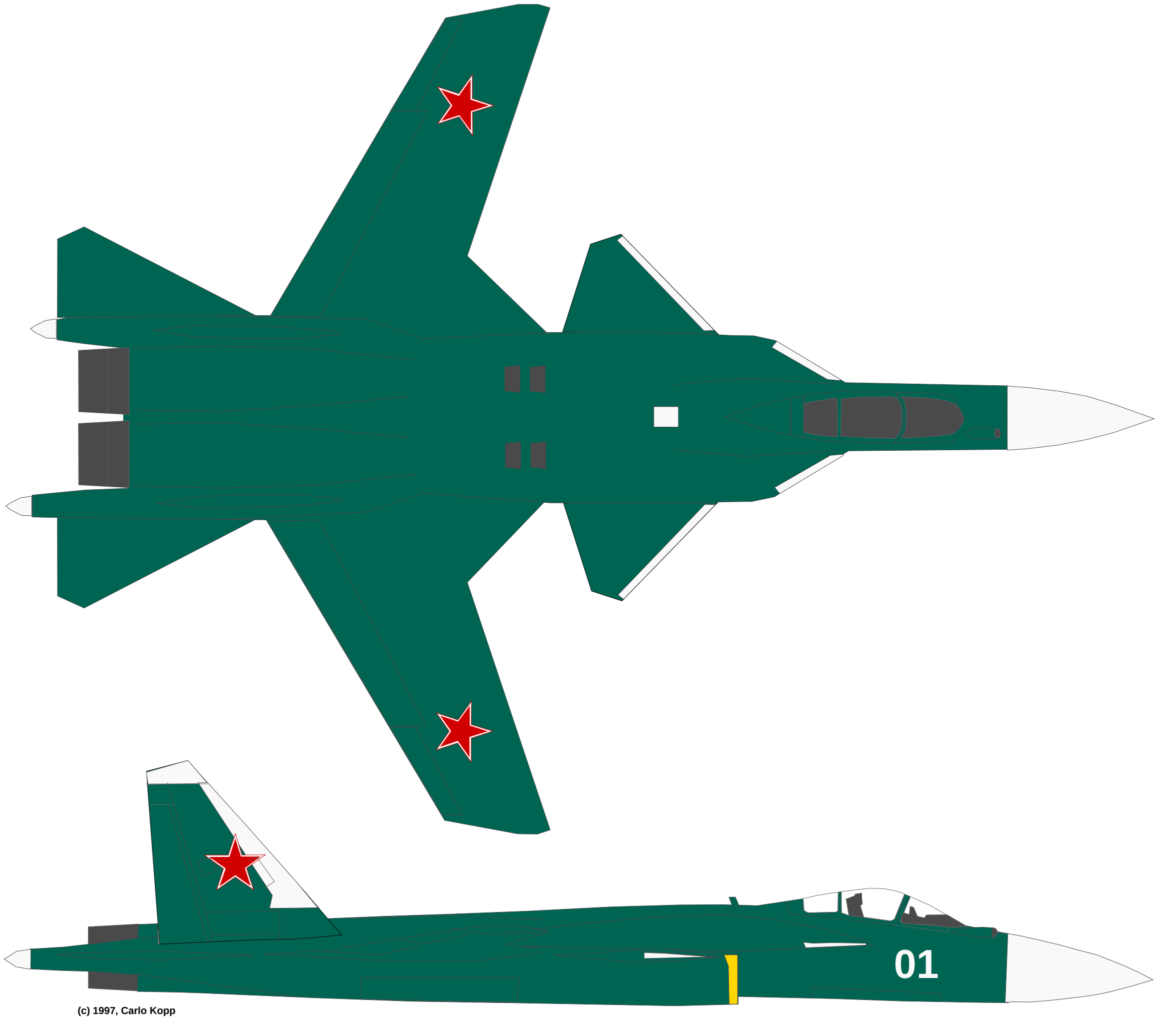
[97] Easy T., *Sukhoi Su-30/32FN* , Air Power International, Vol.2, #3 . This is the most comprehensive description of the type published to date.

[98] Barrie D., *In From The Cold*, Flight International, 21 April, 1993, and Fricker J., *Battle of the Missiles*,

The most capable new AAM in this category is the 1,650 lb launch weight Novator KS-172 AAM-L, a 215 NM range class AAM, with datalink/inertial midcourse and active terminal homing. The missile is claimed to have a snap up capability to 98,000 ft and a snap down capability to 10 ft, against low RCS targets. The status of this program is unclear at this time, but mockups have been photographed with the Su-27/30 at airshow displays.



Sukhoi S-32 (Provisional)

Less capable, but technologically mature, is the long range Vympel R-33 (AA-9 Amos) carried since 1982 by the MiG-31 Foxhound and regarded to be an equivalent to the US Navy AIM-54 Phoenix. The follow-on to the R-33, the new Vympel R-37 (AA-X-13), was designed for the enhanced MiG-31M Foxhound. With the production of the MiG-31M now unlikely, the R-37 is now being proposed for use on the Su-27M/Su-35 Flanker. The R-37 is a large 1,000 lb class missile, which employs an AGAT designed dual mode semiactive and active homing seeker, with a seeker active mode acquisition range quoted to be "well in excess of 13.5 NMI". In firing trials, an R-37 development round successfully intercepted a target at an A-pole range in excess of 162 NMI[99]. The exceptional range performance of the R-37 would make it a viable candidate for the "AWACS Killer" role.

Air International, February 1997.

[99] *AGAT unveils dual-mode seeker for AA-X-13 AAM*, Flight International, 25 September, 1996, pp 17.

Another munition carried by some Flanker variants is the Raduga Kh-41 Moskit derived from the presently deployed surface launched 3M80 (SS-N-22 Sunburn) antishipping SSM family. This large missile is credited with a high supersonic cruise speed and a range of about 100 NMI, and may employ a directional warhead, evolved from technology used on the Kh-22M (AS-4 Kitchen) and KSR-5 (AS-6 Kingfish) ASMs.

The Zvezda Kh-31R (AS-17 Krypton) is another important missile. It employs an NPO Soyuz/Turayevo TKMB ramjet propulsion package which provides a Mach 4+ cruise speed and a range of about 60 NMI, the Krypton is available in air-to-surface and air-to-air antiradiation variants. The air-to-air variant of the Krypton family of missiles is claimed to have been specifically built as an "AWACS Killer" antiradiation weapon, with a seeker optimised to home on the emissions of the E-3 AWACS APY-1 and 2 radars. The missile has been on offer to export clients but there have been no official disclosures of sales to date[100].

Strike variants of the Flanker are claimed to capable of launching the AS-16 Alfa ASM, the AS-17 Krypton, TV and anti-radiation variants of the AS-12, TV and laser semi-active homing variants of the AS-14, and the AS-15 cruise missile. In addition, Russian laser guided bombs may be carried, although to date the aircraft has not been photographed with a laser designation pod of any type.

The large S-32/37 demonstrator is the latest Sukhoi to fly. The aircraft is clearly optimised for air combat, with an internal weapons bay reported and RCS reductions incorporated in the design. The forward swept wing configuration is intended to provide improved close in manoeuvre performance over the established Flanker (photo Flight International).

3.3 Advanced Russian Fighter Projects

The principal impediment to rapid progress in new Russian airframe designs is funding. As a result, the most activity has been seen by the Sukhoi enterprises, which have had a steady revenue stream from the sale of Flankers to the PRC and India. This has allowed further incremental development of the Flanker family of aircraft, which is the favoured type by the RuAF at this time and accounts for the few domestic production orders seen to date.

The MiG/MAPO enterprise has been less successful, with the only recent sale of any importance being the Malaysian MiG-29 Fulcrum batch, although they have been

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[100] A report by the Taiwanese *World Journal* earlier this year claimed that the PLA-AF has recently acquired this missile from ByeloRussia, although there has been no confirmation of this to date from official sources in the PRC or Russia. Also Barrie D., *Cultural Revolution*, Flight International, October 8, 1997.

active in the area of upgrades.

Sukhoi proposed the S-55 lightweight fighter, which employs a similar layout to the Flanker, but is a much smaller single engine design. Phazotron developed the Sokol phased array for this aircraft, with substantially better performance than the Zhuk-Ph.

At the time of compilation the only new type to have flown was the Sukhoi S-32/37 demonstrator. This large aircraft, similar in size to the Flanker, is reported to be powered either by a pair of AL-41F or D-30F 30,000 lb powerplants, and employs forward swept wings, internal weapons carriage, canards and pronounced strakes. The aircraft has clearly been optimised for air combat in the BVR and WVR regimes, and will provide substantially better manoeuvre capability at high Angles of Attack.

The aircraft is claimed to have a much lower RCS than the established Flanker, although the large semicircular inlet design and general airframe layout indicate that this aircraft will at best be competitive with current Western reduced RCS fighters, such as the F/A-18E/F, the Rafale and the Eurofighter. It does however indicate a clear trend by Russian designers to focus on both BVR and WVR combat performance.

At this stage it is unclear whether the aircraft will be further developed, or become a technology testbed, as appears to have been the case with the Su-37 to date.

Numerous speculative reports abound of other Russian advanced technology types in development, some incorporating important stealth features such as planform alignment, edge alignment, and tail surface canting (MiG I.42/MFI). Because of Russian security restrictions, little certain is known in the public domain about progress with these projects. However, it is clear that the Russians intend to incorporate whatever low observables technology they have, based upon various public statements made to date. While this is unlikely to be competitive against the mature technology base applied to the F-22A, it is likely to be highly competitive against variants of existing Western fighters, such as the F/A-18E/F, the Rafale and the Eurofighter.

3.4 Capability Issues in the Hornet Replacement[101]

In selecting a Hornet replacement, the chosen aircraft's capability margin over types deployed in the region, and likely to be deployed during the life of the new aircraft, will be of much important since it determines the quantity of aircraft the RAAF will need to deploy to achieve a given capability margin for the total fighter force.

The Flanker variants deploying in the region comprise both first and second generation variants, and do not embody the latest avionics packages available for the aircraft. There is considerable growth potential remaining in the Flanker, and a number of new capabilities will therefore become available for retrofit in coming years. The PLA-AF's earliest aircraft will be due for a midlife refit around 2005-2010, which is likely to the time datum for the initial introduction of growth capabilities in deployed aircraft.

In terms of airframe performance growth, higher thrust powerplants are available at this time in the AL-35F and the AL-37FU, pushing the thrust past 30,000 lb per engine. While the AL-41F is claimed to provide 35,000 lb of reheated thrust, it is not clear at this time that this engine will be used. However, we can expect that by 2005 a 35,000 lb class engine will be available, given current trends.

Lyulka are also now offering a "package of measures developed to reduce powerplant infrared signature under dry thrust", details of which are yet to be revealed. How effective this is cannot be judged in the absence of hard data. It is however a trend indicator, that observables are now high on the priority list for technology development[102].

Thrust Vector Control is another area of capability growth which is yet to be fully exploited. The basic 2D TVC nozzle package tested on the AL-37FU will be made available for the earlier AL-31F, this nozzle design provides only up/down control over ±15°. Current development effort is aimed at providing also differential nozzle control to

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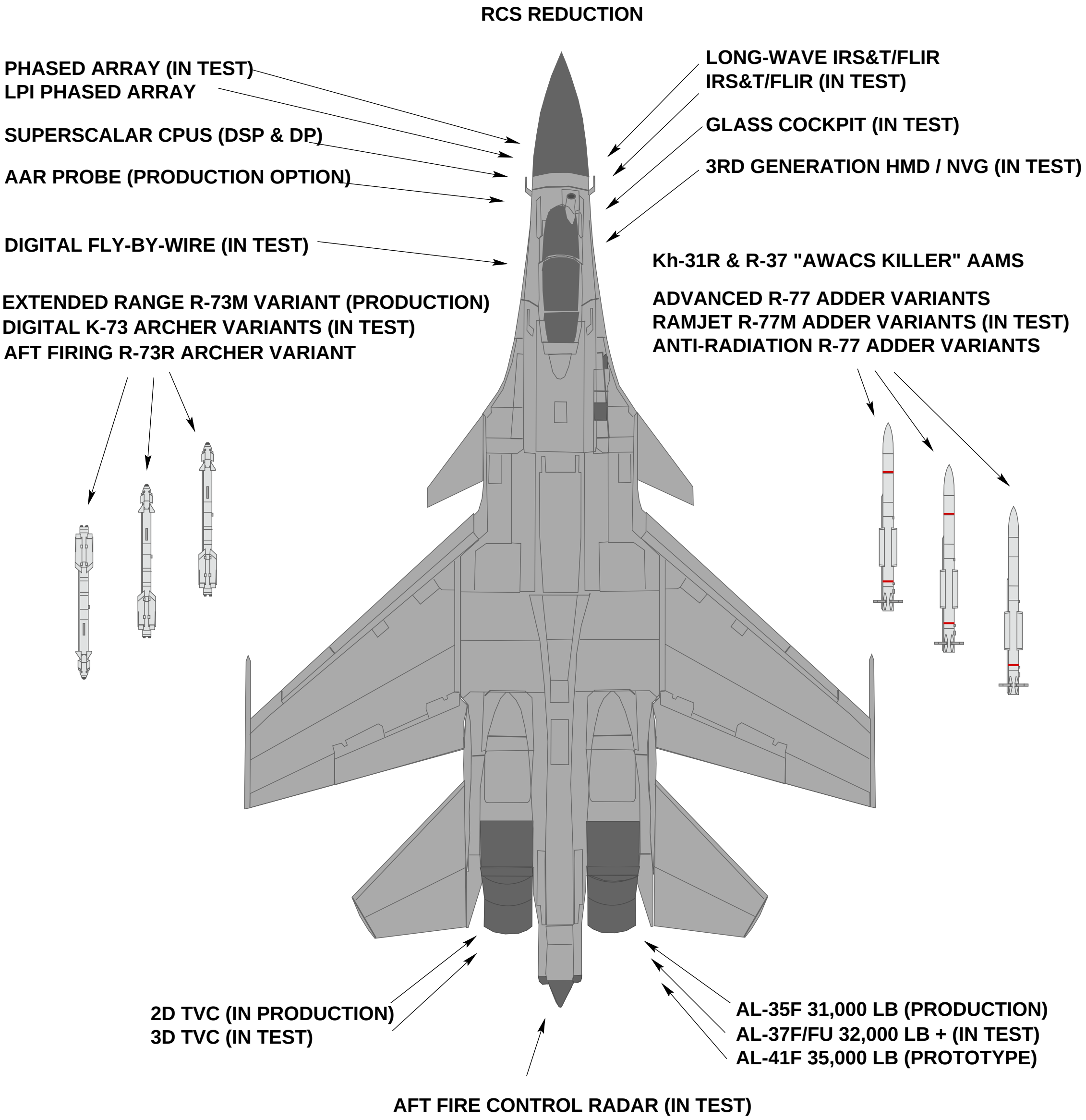
[101] Based on as yet unpublished trade journal articles for Air Power International.

[102] ITAR-TASS, ibid.

enhance aircraft roll rate, and eventually also yaw control to provide additional control authority at high AoA.

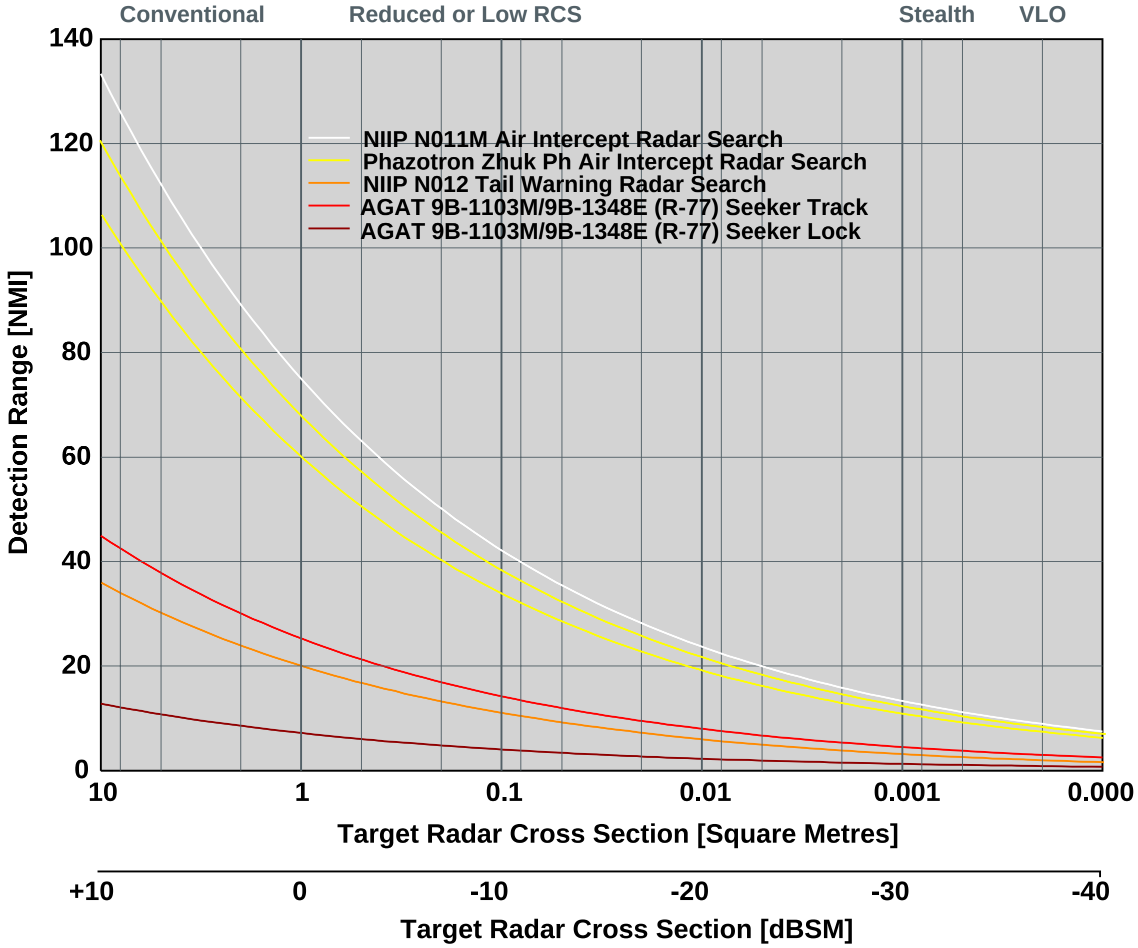


FLANKER CAPABILITY GROWTH

A digital Fly By Wire control system has been tested on the Su-35 and Su-37, and will be mature enough for deployment in production aircraft in the post 2000 period. This will provide for more refined handling at the boundaries of the envelope, and allow integration of more sophisticated thrust vectoring modes.

In terms of close combat manoeuvre performance the Flanker will remain competitive for the forseeable future.

A retractable inflight refuelling probe, similar in style to that on the F-14 and F/A-18, is now available as a production option, and may also be offered for future upgrades. Range performance is unlikely to improve dramatically over existing variants, since higher weights will reflect in higher thrust settings required, thus offsetting any marginal improvements in internal fuel capacity. However, modifying the fuel system to accommodate external drop tanks is not a difficult engineering task.



RCS figures for fighters are very approximate for I/J bands
Detection range performance for N011, N012, 9B-1103, 9B-1348 based on Russian data

Detection/Engagement Ranges for Flanker/Adder Weapon System vs Target RCS

The avionic package is an area where there is also much growth potential yet to be fully exploited. Given the greater availability of Western equipment in the post Cold War period, we are likely to see increasing amounts of such used to enhance the capability of the Flanker. The use of a French RLG/nav-attack package on the Su-37 indicates the likely trend to incorporate items of Western avionic equipment where domestic Russian capability is lagging.

The Russians have made much progress in radar technology in recent years, and with the early production of the Su-35 for the RuAF will be the first to deploy an electronically steered phased array on a modern fighter[103]. The Phazotron Zhuk Ph and

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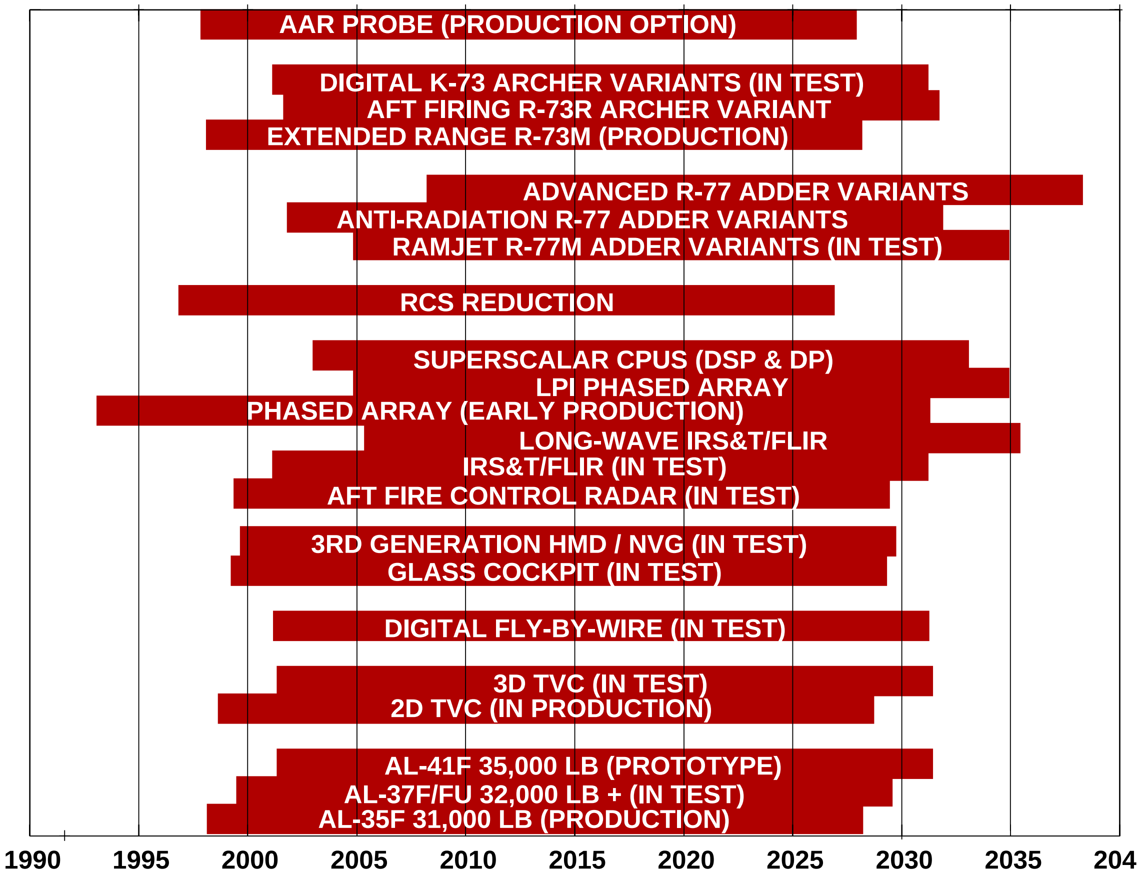
[103] The Zaslon (Flash Dance) radar on the MiG-31 Foxhound uses a passive shifter technology phased array and has been in service since the early eighties, therefore the Russians have had the opportunity to amass operational experience with this technology, which is as yet lacking in the West. It is worth noting that the PVO deployed no less than 425 MiG-31 aircraft, and have also used passive shifter based phased arrays in the S-300P Flap Lid, of which several hundred were deployed. Given numerous early deployments of the Army PVO S-300V, which employs two large phased arrays, it is quite clear that the former USSR was the world's leading

NIIP N-011M both employ this technology, and can be expected to exploit the timesharing capability to provide concurrent Track While Scan with Single Target Track engagement modes for BVR combat. This is important because existing mechanically scanned antennas can have difficulty in BVR combat with maintaining a target track for missile midcourse updates while also maintaining TWS coverage of other targets in the forward sector, especially in situations where multiple concurrent engagements are being attempted.



Projected Flanker Capability Growth

What is however much more important is that NIIP and Phazotron now have one of the most important building blocks for a Low Probability of Intercept mode in the radar. The remaining capabilities needed, which is the design of hardware for the modulator and receiver, to provide spread spectrum direct spreading and frequency hopping modulation of the carrier, is not that difficult to do. Western radars have employed biphase coding, typically with Barker codes, for at least a decade, and the technology is well described in the unclassified literature[104]. Adapting this technology for use with long code sequences, to provide LPI spread spectrum operation, is thus relatively simple to do. Frequency

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user of the phased array in airborne fighter and missile guidance applications. This means that Russian designers will have a solid grasp of the theoretical and practical system design issues with airborne phased arrays for fighters, learned from almost two decades of engineering design and operational experience. The principal impediment to radar capability then lies primarily in the component technology, where the West leads, but is still experiencing serious cost problems. The Russians have accepted the weight penalties of older passive shifter technology, since the large Sukhoi airframe is not critically penalised, and thus have a mature and cost competitive component level technology base to work with.

hopping has been widely used since the sixties in Western and Russian equipment, and thus is also not an issue technologically.

The operational deployment of an LPI variant of the NIIP and Phazotron radars will in effect obsolete a large proportion of the Radar Warning Receivers currently in Western service, which are designed to detect narrowband pulse trains characteristic of conventional radars[105]. As a result, it will be necessary to replace a large proportion of such equipment, or perform major upgrades involving essentially redesign of the equipment.

Given that the engineering effort to get a design to a production standard will be at least five years, this suggests that 2005 is the datum point in time at which we can expect an IOC for an LPI capable radar on the Flanker. No less importantly, existing Flankers with phased arrays may be upgraded with what may be only a board level upgrade to various modules in the radar, and a software update.

An important weakness in existing radars such as the Zhuk and N-011 is limited lookdown performance and track capability, resulting primarily from inadequate computing performance in the signal processor and the data processor. The massive growth in the performance of cheap commodity consumer microprocessors suggests that this weakness in Russian radars will be overcome very soon. Recent radars such as the Zhuk-Ph and Sokol[106] offer competitive performance with Western radars, in terms of track count and modes, suggesting that this is already occurring. The incorporation of Non Cooperative Target Recognition modes is likely soon, if it has not occurred to date.

The IRS&T/laser package on the Flanker also has further growth potential. At least one report suggests that the Su-37 IRS&T is a combined thermal imager/search & track package, similar in concept to the mid-wave (4-5 μm) PIRATE on the Eurofighter. Whether the Su-37 already has this capability or not, it is certainly an area where we can expect to see growth in the next decade. The Russians have built 8-12 μm band thermal imagers in the past, and therefore we can expect to see a long-wave IRS&T/FLIR deployed on the aircraft by 2005-2010. We can anticipate that they will experience similar problems to those seen by Western manufacturers, who built such equipment in the early nineties. The computing performance for the required video signal processor will be easily within the reach of commercial microprocessors by that time.

It is therefore reasonable for us to expect to see early deployment of Flanker variants or upgrades with an LPI capable radar and long-wave thermal imaging IRS&T in the 2005-2010 period. This would provide a respectable capability to support the R-77 Adder missile, which is regarded to be highly competitive with the AIM-120A and AIM-120B AMRAAM variants, and provide a significant advantage in BVR combat over current Western fighters using existing pulse Doppler radars, and radar warning equipment.

There is further growth potential in the R-77 Adder family of missiles. The rocket-ramjet R-77M is in advanced development, and has stimulated the European

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[104] Skolnik, M.E., *Radar Handbook, Second Edition*, McGraw Hill, 1990, Section 10.6

[105] The problem is systemic, in the sense that receivers using Crystal Video Receiver techniques cannot readily detect spread spectrum signals, by design. Receivers based on Scanning Super Heterodyne technology may have the sensitivity to detect the signals, but will suffer difficulty with the probability of intercept against a signal which appears at irregular intervals.

[106] Phazotron marketing brochures. The Sokol employs the NIIP phased array antenna, and achieves a 100 NMI detection range on closing targets, and a 43 NMI range on receding targets. The design employs a software programmable digital signal processor, and a data processor programmed in a high level language, rather than assembly code. The Sokol employs a multichannel receiver, claimed to have state of the art noise figure performance, a software controlled exciter is employed, and a liquid cooled TWT transmitter. This radar provides low, high and medium PRFs. For air to air operation, it offers RWS, VS, TWS on 24 targets with engagement on 6, STT, Raid Resolution, and four ACM modes. For air-to-ground roles, it provides real beam mapping, Doppler Beam sharpening, Synthetic Aperture Mapping with frame freeze and zoom, beacon tracking, GMTI with tracking, providing TWS on four targets, velocity update and rangefinding. Datalink and command link support is provided for the the Adder and Alamo, respectively. In terms of nominal capability, this radar is highly competitive with early nineties Western designs.

FMRAAM requirement for the Eurofighter. We can expect incremental improvements in the AGAT active seekers, and probably the incorporation of spread spectrum operation once this is developed in the fighter radar. The latter would significantly complicate endgame defensive countermeasures for Western aircraft. An anti-radiation seeker will also be deployed, since it is an option for the R-27 Alamo.

The close-in R-73 Archer has further growth potential. A digital variant is about to deploy and be exported, in the R/K-74E/ME. This indicates that the Russians have closed the gap with the Rafael Python, in processing technology for scanned seekers. It will improve clutter rejection and provide better IRCCM. Since the seeker will also be available for retrofits, this means that existing stocks of the analogue Archer models may be improved. While this will not close the technology gap with the AIM-9X and AIM-132 ASRAAM, it will further widen the gap against older Western missiles such as the AIM-9M, rendering them of little value tactically.

An improved third generation Helmet Mounted Display is in test and will be integrated with a thermal imager and the IRS&T. The current optically scanned head tracking design is reported to perform very well.

Most of these capability improvements to the Flanker are in advanced development, pre-production test or early production at this time. This indicates that they will be established production items by 2005-2010, and likely also retrofit options for existing in service aircraft, many of which will be due for mid-life updates by then due to the support level obsolescence of their existing equipment, and older engines.

From a practical perspective, this raises some very serious questions about the value for money in the RAAF acquiring a conventional or reduced RCS current fighter design, such as the F/A-18E/F, the Rafale or the Eurofighter. While all of these types have a capability margin in most, many or some critical areas, against the baseline Su-27SK and the Su-35, this will be seriously eroded if not removed with the introduction of capabilities such as an LPI phased array, LPI missile seekers and advanced IRS&T.

This would suggest that the F/A-18E/F and the Eurofighter would require a radar upgrade to an LPI variant of the APG-73 RUG Phase III or AMSAR, respectively, as early as 2010, to remain genuinely competitive in BVR combat. This would be about 5 years after a 2005 IOC for these aircraft. Moreover, the development of initial sensor fusion technology by the Russians is likely by 2005-2010, since the computing power will be available in the commercial marketplace.

Clearly there is a genuine risk of early technological obsolescence in the adoption of any non-stealthy fighter type as a Hornet replacement. Because these aircraft gain their capability margin by superior missile and sensor performance, their capability margin is inherently sensitive to incremental improvements in capability by an opposing aircraft. This indicates that the adoption of any of these types as a Hornet replacement would have to be considered in the context of a continual and ongoing incremental capability upgrade program to maintain competitiveness with the Flanker. Once the expected stealthy follow-on to the Flanker is deployed, in the 2010-2025 timescale, then these types will become wholly obsolescent since their signature performance will be inadequate.

The argument may be raised that the Russian economy is not up to the task of funding the required development effort. This is however a questionable argument, in the sense that the Russians managed to develop and deploy their thrust vectoring capability, helmet mounted sights, fourth generation missiles, advanced flares and fighter phased array radars well before the West has. Since the Russian development effort is now mostly funded from export revenues, the only impediment to their development effort is the availability of export clients with the cash to support the effort. This has not proven to be an obstacle to date, especially for incremental upgrade efforts.

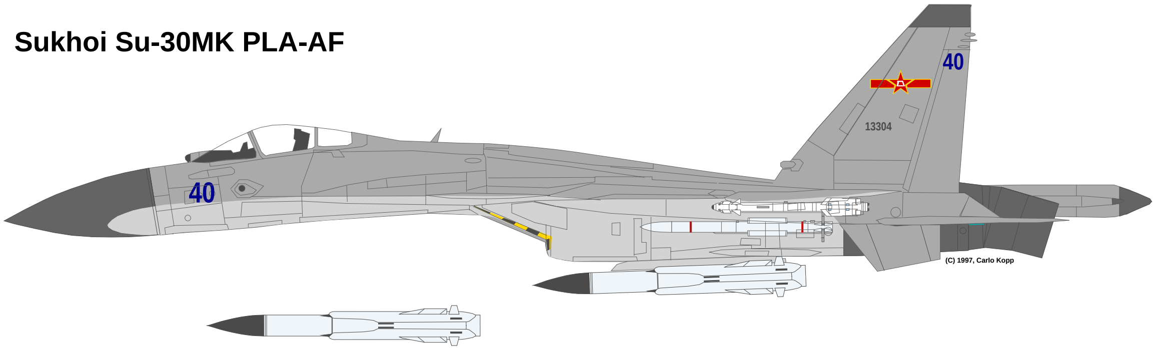
The other argument which might be raised is that a superior battle management capability will be decisive, and offset any capability margin existing in favour of the Flanker. This is only true to a degree, since a sufficiently big capability margin in fighters, radars and missiles will offset any advantages in battle management technology. An uncompetitive fighter cannot be applied offensively. Moreover, strong reliance upon battle management assets such as AEW&C increases their value as targets and invites the use of specialised weapons to defeat them[107]. The centralised battle management asset becomes a single point of failure for the whole capability package, and should it be destroyed by a concentrated attack, then the battle is essentially lost.

Clearly the RAAF's Wedgetail program is essential, and should proceed as planned. However, the operational model for its use, and the fighter acquired to replace the Hornet, should be such as to guarantee that the Wedgetail will be survivable in a genuine wartime situation.

The essential conclusion is that the RAAF has little choice long term, than to acquire a Hornet replacement with a genuine stealth capability, to preclude both early technological obsolescence, and to allow it to operate survivably at the boundaries of effective AEW&C coverage, and guarantee AEW&C platform survivability. This narrows the RAAF's choices down to the Lockheed-Martin/Boeing F-22A or a Hi-Lo mix of the Lockheed-Martin/Boeing F-22A and the Joint Strike Fighter[108].

Cost considerations suggest that a fighter force comprising only the F-22, however desirable, will be difficult to fund. Therefore the only practical consideration is the latter, a Hi-Lo mix.

Sukhoi Su-30MK PLA-AF



Counter AWACS/AEW&C Role (2 x Kh-31R)

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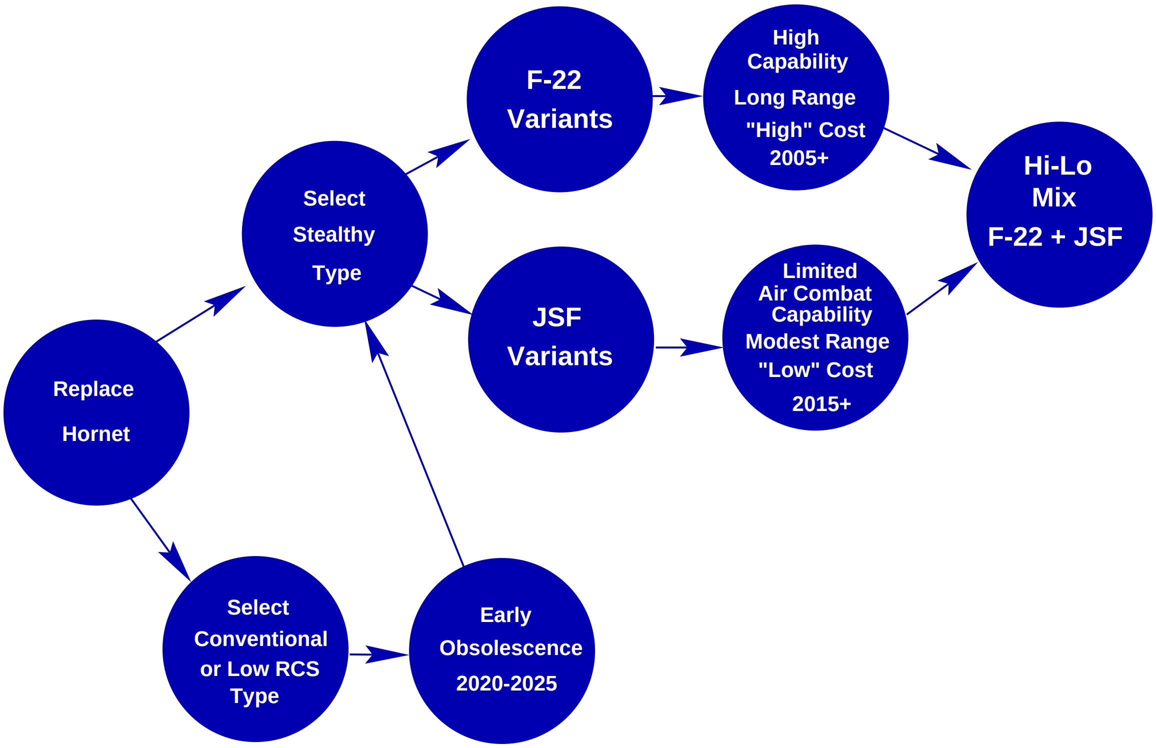
[107] The deployment of existing "AWACS Killer" missiles such as the Kh-31R, with 60-100 NMI class engagement range, or newer missiles like the R-37, with 150+ NMI class engagement range, would require that the AEW&C aircraft be held back to such a distance, to allow defensive Combat Air Patrols to destroy an attacking fighter before it reaches launch range. Existing reports suggest the PLA-AF will acquire the Kh-31R.

[108] This is because the Joint Strike Fighter is primarily a **bomber**, rather than an air-to-air **fighter**, in terms of classical nomenclature. Its design optimisation is best compared to that of the F-105 Thunderchief or F-111, an aircraft designed to drop bombs, with a secondary capability to shoot down other aircraft.

Section 4 Replacement Strategy

4.1 Rationale

It is clearly evident that the adoption of a stealthy replacement for the Hornet will provide a much more robust long term outcome for the RAAF, since incremental improvements in regional capabilities will be much less important to the aircraft's combat effectiveness and survivability. Moreover, the adoption of a stealthy replacement confers other important advantages at a tactical, operational, and strategic level.



Decision Rationale - F/A-18 and F-111 Replacement

At a tactical and operational level it provides the advantage of surprise, either in counter air or strike operations, which can greatly offset any numerical disadvantage suffered by the RAAF. Since survivability is enhanced, there is a much lesser reliance upon direct support by battle management assets such as the Wedgetail and JORN, which provides greater freedom in deployment and more operational flexibility in usage.

Should the aircraft have to be used in genuine combat, rather than merely perform a deterrent role, its ability to attack using cheaper and more lethal munitions, penetrating singly or in small numbers, will provide very important economies compared to the use of standoff weapons from conventional aircraft. This is an important force multiplication effect, and also a major source of economy in the holding of weapons war stocks, since guided bombs are cheaper to procure and stockpile, than standoff weapons.

Since stealth capability defeats battle management assets such as AEW&C, it in effect defeats any broader regional capability growth in this area, which at this time is the principal operational limitation of broader regional air forces. This would further enhance the robustness of the RAAF's future capability base.

At a strategic level, the possession of a stealthy fighter force is a major deterrent capability, since it can effectively balance a much larger force of conventional fighter aircraft. Moreover, the "mystique" associated with stealth in the perception of lay observers will contribute strongly to the credibility of the deterrent[109].

The critical issue will be that of costs to be borne in the timescales involved, and the longer term issue of replacing the F-111, and its deep strike and long range maritime strike capabilities. To best understand this issue, it is necessary to explore the range of role requirements which aircraft replacing the F/A-18 and F-111 will have to meet.

4.1.1 Role Spectrum

The role spectrum to be covered by the RAAF's fighter and bomber assets is well described in existing doctrinal literature, and ADF strategic policy documents[110].

The primary role[111] of the RAAF is to provide control of the air, termed the Counter Air Role. This comprises Offensive Counter Air (OCA) and Defensive Counter Air (DCA).

Offensive Counter Air requires the capability to attack and destroy an opponent's air defence infrastructure and air assets, by air strikes and offensive fighter sweeps. The key capabilities required for OCA are competitive aerodynamic performance in fighters, range and endurance, information superiority, surprise, and effective weapons. The capabilities for OCA at this time are provided by the F/A-18A with B-707 tanker support, and the F-111C/G, and it is intended that the Wedgetail provide information superiority when it becomes operational.

Defensive Counter Air requires the capability to defeat air attacks against forward deployed ADF assets and Australian territorial airspace, by intercepting and destroying hostile air assets. The key capabilities required for DCA are range and endurance in fighters, information superiority and Command Control Communications, and effective weapons. The capabilities for DCA are provided at this time by the F/A-18A with B-707 tanker support, and it is intended that the Wedgetail and JORN provide information superiority when they become operational. The RAN's Destroyers and Frigates provide a supplementary surface based radar and SAM capability, together with Army low level SAMs.

DCA is inherently reactive and thus essentially yields the initiative at every level to the opponent. Therefore, in the balance, OCA and DCA operations are complementary, and the OCA requirements must dominate capabilities.

Suppression of Enemy Air Defences (SEAD) and the associated battle for electromagnetic superiority, are implicitly tied to the control of the air. Information superiority requires control of the air, since airborne sensor platforms and surface based sensors cannot operate effectively if subjected to air attack. The prosecution of OCA operations will require supporting SEAD operations.

The ability to perform other roles, such as Maritime and Land Strike, or Combat Support for Army and Navy, critically depends upon the ability to achieve and

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[109] Harvey J.P., *Conventional Deterrence and National Security*, RAAF APSC, 1997. Harvey makes the very apt observation that the Australian public has little confidence in the ADF's capacity to deter or defeat regional aggression. Such perceptions may be shared more widely through the region, especially given the growing numerical imbalance in modern equipment, between the RAAF and nations in the nearer and broader region.

[110] *RAAF Air Power Manual, AAP 1000*, Second and Third Editions, RAAF APSC, and *Australia's Strategic Policy*, Department of Defence, 1997. The latter document specifies the priorities in the ADF's capabilities to be, in the following order, information superiority, defeating air and naval threats in Australia's maritime approaches, strike against an adversary's territory, and the defeat of land force incursions into Australian territory.

[111] The role and capability model in this paper merges fundamental aspects of the RAAF's established doctrine, and the 1997 White Paper, to produce a simpler and more general model for defining priorities in capability.

maintain control of the air within the area of interest. Without control of the air, loss rates incurred on strike and support sorties would quickly render the RAAF ineffective.

Therefore maintaining control of the air is a vital prerequisite for all other RAAF roles.

The secondary mission of the RAAF is to provide a strike capability, comprising Maritime Strike and Land Strike.

Maritime Strike requires the capability to destroy an opponent's maritime surface and subsurface assets. The key capabilities required for Maritime Strike are payload radius performance in strike aircraft, survivability, information superiority, and effective air-to-surface and air-to-subsurface weapons. The capabilities for Maritime Strike are provided at this time by the F-111C/G, the P-3C and the F/A-18A with B-707 tanker support. The primary weapons are the Harpoon and air delivered mines, with torpedoes used for subsurface strike by the P-3C.

Land Strike requires the capability to destroy an opponent's land force and critical military and infrastructure assets. The key capabilities required for Land Strike are payload radius performance in strike aircraft, survivability, information superiority, and effective air-to-surface weapons. The capabilities for Land Strike are provided at this time by the F-111C/G, and the F/A-18A with B-707 tanker support. The primary weapons are guided and unguided bombs, and standoff missiles.

Land Strike may be strategic, or tactical. Strategic strike is aimed at infrastructure and logistical support, whereas tactical strike, comprising Battlefield Air Interdiction and Close Air Support, is aimed at hostile forces deployed in the field.

The central tenet in capability requirements is that of being able to maintain control of the air, information and surface environments[112]*. Achievement of information superiority and control of the surface environment require that control of the air be achieved and maintained. Therefore, at a most fundamental level, the RAAF must have the capability to achieve control of the air. This implicitly requires the ability to perform Offensive Counter Air better than an opponent can.*

In terms of defined capability requirements, we may reach the following conclusions:

OCA - best possible aerodynamic performance, combat radius, sensor capability, survivability and air-to-air and precision air-to-ground weapons for fighter sweep and OCA strike operations, respectively. The ability to flexibly deploy a modest number of aircraft to prosecute individual targets of high value.

DCA - best possible aerodynamic performance, endurance on station, sensor capability, survivability and air-to-air weapons for defensive air patrols and intercepts. The ability to flexibly deploy a large number of aircraft to prosecute individual targets of high to modest value.

Maritime Strike - modest aerodynamic performance, best possible combat radius, sensor capability, good survivability and weapons for anti-shipping strikes. The ability to flexibly deploy a large number of aircraft to prosecute individual targets of high to modest value.

Strategic Land Strike - best possible combat radius, sensor capability, survivability and precision and dumb weapons for destroying strategic assets in defended airspace. The

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[112] A more detailed and refined definition of these issues has been produced by Dr Alan Stephens in the Theatre Control Model.

ability to flexibly deploy a modest number of aircraft to prosecute individual targets of high to modest value.

Tactical Land Strike - modest combat radius, sensor capability, good survivability and precision and dumb weapons for destroying fielded land forces. The ability to flexibly deploy a large number of aircraft to prosecute individual targets of modest to low value.

This yields the following priorities for capabilities:

- best possible aerodynamic performance, combat radius, sensor capability and survivability (OCA, DCA, Maritime Strike, Strategic Land Strike).

- modest aerodynamic performance, good combat radius, sensor capability and survivability (DCA, Maritime Strike, Tactical Land Strike).

Clearly the only roles where modest aerodynamic and combat radius performance are acceptable are Tactical Land Strike and Maritime Strike under some conditions, and reactive DCA where there is no threat of long range missile attack on AEW&C aircraft. All other roles have a critical requirement for aerodynamic performance, sensor capability and combat radius to defeat opposing fighter aircraft.

Survivability against air and surface threats is significantly enhanced by the adoption of stealthy aircraft. Once stealthy types are selected, the primary issues then become the aerodynamic, sensor and weapons capabilities, and combat radius.

The use of tankers can alleviate limitations in combat radius performance, but requires a significant investment into tanker assets, and the further operational effort in allocating DCA assets to protect tankers. Therefore, biasing numbers toward shorter ranging aircraft will require a compensating increase in the numbers of tankers, and fighter aircraft, to rebalance the capability.

In terms of defining a force structure to replace the F/A-18A and later the F-111, it is therefore necessary to balance the numbers between highly capable long range aircraft, modestly capable shorter ranging aircraft, supporting assets such as tankers and AEW&C, manpower and training costs, and the acquisition and support costs of all assets.

In the context of Australia's developing strategic situation, the bias would lean toward a force of highly capable but expensive long range assets. In the context of a limited defence budget, problematic balance of payments, an electorate mostly indifferent to defence issues, the bias would favour a force of low cost assets, with modest capability and combat radius.

It would appear therefore that the only practical choice is a two tier Hi-Lo mix of assets, with a modest number of highly capable long range aircraft, complemented by a number of low cost aircraft of modest capability and combat radius, with enough tanker support to remain useful in the critical maritime and DCA roles.

4.1.2 Type Capabilities and Availability

The only two stealthy aircraft types which will be available[113] in the timescale required to replace the F/A-18 and the F-111 are the F-22 and the JSF. These aircraft are to provide the US services with the Hi-Lo mix of capabilities and cost to fulfill the whole role spectrum required of the traditional tactical fighter.

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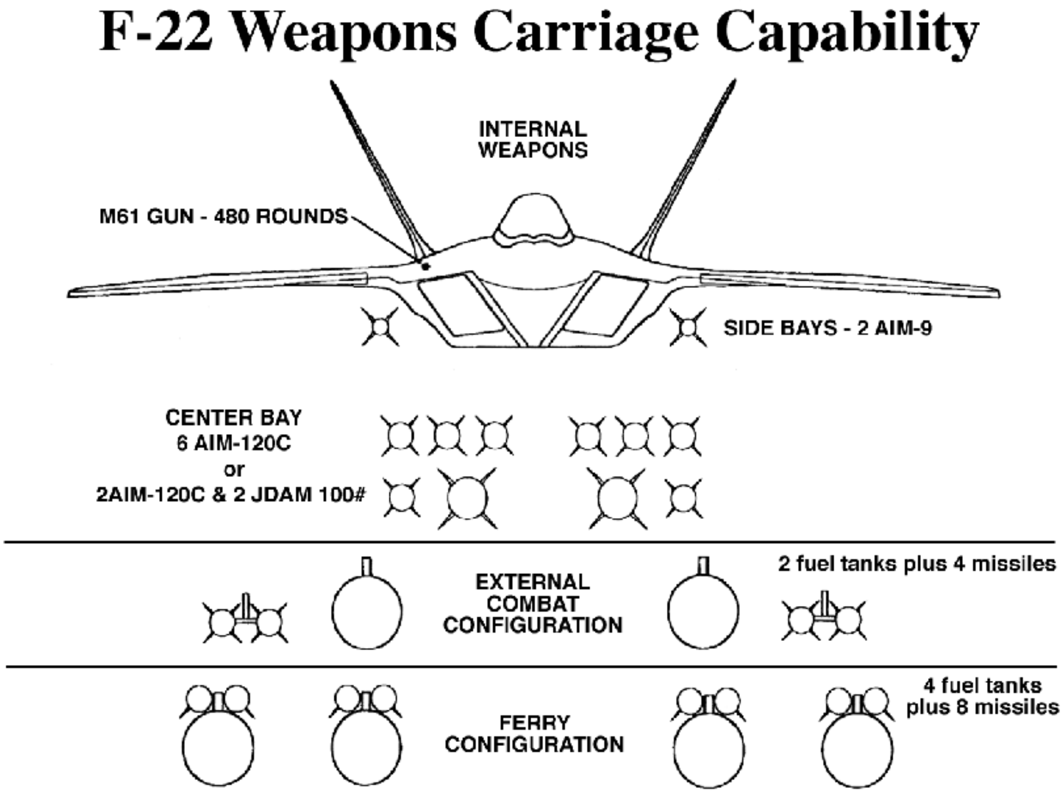
[113] As yet the F-22 has not been cleared for export. However, this was also true of the F-15, yet to date F-15 export sales have exceeded those of the F/A-18 by at least 25%. The budgetary pressures of funding new fighter purchases will inevitably force the US to export the F-22, initially to trusted allies. The aircraft had previously been proposed to the UK. Export aircraft may have some reductions in capability, such as less capable sensor fusion software and less effective radar absorbent materials. Such capability limitations could be later remedied through in service upgrades, once the technology is released for export.

The USAF’s F-22A Raptor fighter is intended to replace the F-15C, the F-117A, and some of the role performed by the F-4G Wild Weasel and HARM capable F-16C subtypes. The Raptor incorporates genuine stealth capability, sustained supersonic cruise, sensor fusion, active phased array radar technology, and a passive detection package more capable than that in the retired F-4G. It has more than twice the combat radius of the baseline F-15C, and carries AIM-120 missiles and JDAM guided bombs internally (Lockheed-Martin).

The **F-22 Raptor** is designed to provide air superiority against a numerically superior opponent, operating aircraft with capabilities beyond that of the Flanker, while also providing the capability to precisely strike deep into defended airspace, without escort. The aircraft evolved from the initial Advanced Tactical Fighter requirement, aimed at replacing the F-15C as a high performance air superiority fighter, capable of engaging and defeating an opponent deep inside hostile or contested airspace. The requirement evolved through the eighties, to incorporate several fundamental advances in technology, including stealth, supersonic cruise, active phased array technology and sensor fusion[114]. Initial US force structure planning was based on the model of replacing the F-15, and possibly the F-14, with the F-22, and replacing the F-111, F-15E and A-6 with the stealthy A-12 Avenger II, in the deep strike role[115]. The cancellation of the A-12 in 1991 led to fundamental changes in the ATF requirement, since it was evident that a role specific replacement for the A-12 was unlikely to be funded, yet the requirement for a deep strike capability persisted. Therefore, the ATF was to be adapted to fulfill both the air superiority and deep strike roles.

In 1991 the Lockheed/Boeing/GD YF-22 was selected over the Northrop/MDC YF-23 as the preferred airframe proposal, and the P&W YF119 engine was selected over the GE YF120, as the preferred powerplant proposal. Full scale development program contracts were awarded and the aircraft is about to enter initial production of development airframes. The planned USAF Initial Operational Capability is in 2005.



The basic weapons capability of the baseline F-22A is designed to fit the OCA, DCA and stealthy strike roles. For OCA and DCA, the aircraft carries two internal WVR missiles, and either four internal AIM-120A/B BVR missiles, or six internal short span AIM-120C BVR missiles. For DCA sorties, the aircraft can carry an additional four external AIM-120 BVR missiles, and a pair of 600 USG drop tanks to further enhance endurance on station. For strike sorties, a pair of internal 1,000 lb GBU-32 JDAMs are carried, in addition to a pair of AIM-120C BVR missiles. The pylons and external stores may be jettisoned to regain performance and stealth. Current USAF planning envisages the internal carriage of six or more MMTD derivative "small bombs", and the weapon bay may be further enlarged in the baseline F-22A. It is expected that the Strike Raptor will have an enlarged weapon bay, and provisions for external bomb carriage when stealth is no longer required (Lockheed-Martin).

The initial production F-22A[116] variant is intended to replace the F-15C and F-15E in all air superiority roles, and has the capability to defeat superior numbers of evolved Flanker

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[114] Kopp C., *Advanced Tactical Fighter*, Australian Aviation, April and May, 1991, reviews the history and technology base used for the F-22.

[115] Kopp C., *US Naval Tactical Aviation, Pt.II*, Australian Aviation, August, 1990, reviews the A-12 ATA.

variants and projected stealthy follow on aircraft. Compared to the F-15C, it has more than twice the subsonic and supersonic combat radius, more than twice the acceleration performance, double the achievable sortie rate, one third the turnaround time and support manpower requirements, and half the maintenance manhours per flying hour. The F-22 is described as having the combat effectiveness of 9-15 F-15 aircraft.

The F-22A will initially supplement the F-117A stealth fighter in the unescorted stealthy deep strike and SEAD roles, carrying internally a pair of 1,000 lb GPS guided JDAM bombs, WCMD accurate cluster bombs, or HARM Block 7 and with planned advances in guided munitions, replace the F-117 upon its retirement. A stealth treated laser designator has been proposed as an optional chin installation, as part of the IRS&T/FLIR package.

Current USAF thinking is to produce a growth variant of the F-22A with enhanced strike capability, beyond that in the basic F-22A, to replace the F-15E and the F-111E/F/G[117]. This aircraft may be a dual seat variant, and would employ a sensor package with further enhanced air-to-ground modes for strike operations, and support a much wider range of munition types. It is very likely that the "Strike Raptor" will incorporate some technology developed for the JSF program, to reduce development costs. Another growth variant proposed is the "Electronic Combat Raptor", intended to replace the capability lost with the retirement of the F-4G Wild Weasel. This proposed two seat derivative would have an enhanced sensor package and dedicated back-seat Electronic Combat Officer, to autonomously attack surface based air defences and C3 facilities.

Given the similarity between the planned strike optimised variant and the proposed electronic combat variant of the F-22, and the highly capable baseline passive radar homing and warning package on the F-22A, we can reasonably expect to see both requirements collapsed into the single F-22 Strike Raptor variant.

Most recent data suggests a unit flyaway cost of between USD 72M and 90M, which compares favourably with the flyaway unit cost for current build F-15s, at about USD 53M. Production is planned to run until at least 2015.

The **Joint Strike Fighter** is a multi-service program aimed at the technology demonstration of a low cost, high volume, strike optimised single seat fighter[118], capable of replacing the USAF's F-16C and A-10, the USN's F/A-18C, the USMC's F/A-18C and the Royal Navy's Sea Harrier[119].

The basic concept of the JSF is to produce a modular design, sharing major airframe, propulsion and avionic components between land based, conventional carrier based and STOVL land/carrier based variants of the aircraft. The aircraft's primary role is strike against land and maritime targets, but it is to retain sufficient aerodynamic performance to be competitive against types such as the baseline Su-30, in order to defend itself. The JSF is by design not intended to be an air superiority fighter, a popular misconception[120]. It has an air-to-air capability primarily to defend itself, and supplement the USAF's F-22 where required.

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[116] Lockheed-Martin and Boeing web sites and background literature, also *F-22 Raptor ... The Keystone of Air Dominance for the 21st Century*, published by the Deputy Chief of Staff, Air and Space, HQ USAF, and *F-22 Raptor*, pp S1, AW&ST September 15, 1997.

[117] Fulghum D.A., *Expanding Roles May Shield F-22, Weapons Mix Broadens F-22*, AW&ST, January 6, 1997. The USAF F-111 was not replaced, and its numbers only partially made up by shorter ranging F-15E deployments, resulting in a shortfall in USAF medium to deep strike capability. This has resulted in repeated calls for either a new aircraft, further B-2 production, and more recently, the B-X proposal for a cheaper an less capable supplement to the B-2, see Fulghum D.A., *B-X, Joint STARS Acquisition Proposed*, AW&ST, December 8, 1997.

[118] The nomenclature of the JSF is problematic. In terms of capability, were it a program under USN/USMC lead it would be designated under the Attack (A-) category, i.e. XA/YA-32/XA/YA-35. As the program lead service is the USAF, it has been designated under the Fighter (F-) category.

[119] Joint Strike Fighter program office web site, JAST program avionic system definition specifications, and Lockheed-Martin and Boeing web sites.

[120] This has presumably arisen as a result of historical circumstance: the F-16 (YF-16) and F/A-18 (then YF-17) were developed initially as low cost pure air superiority fighters, under the Light Weight Fighter pro-

The multi-service Joint Strike Fighter is a multirole, strike optimised, stealth aircraft. It is being designed to replace the USAF F-16C and A-10, the USN F/A-18C in its strike role, and the USMC and RN AV-8B and Sea Harrier STOVL light fighters. Low cost is to be achieved by reducing the aircraft's capability to autonomously locate targets, instead it will employ off-board targeting resources via a datalink. Air-air performance will be competitive with current multirole fighters. Depicted to the left is the Lockheed-Martin X-35 proposal, to the right the Boeing X-32 proposal.

The JSF is to fulfill the following role requirements:

- USAF JSF - multirole fighter to replace the F-16C and the A-10A, carrying a 1,000 lb class internal bomb payload. The target unit cost is USD 28M.

- USN JSF - survivable "first day of the war" stealthy strike aircraft, intended to replace the F/A-18C and A-6E in high threat environments, where the F/A-18E is not survivable. The aircraft is to carry a pair of 2,000 lb internal bombs, and JSOW glide dispensers. The target unit cost is USD 31-38M.

- USMC/RN JSF - STOVL multirole fighter for deployment from small carriers and

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gram, both types later developing a significant strike capability. As a result, there seems to be an expectation in many quarters that a low cost fighter must by definition be an excellent air superiority type. Given that a successful air superiority fighter today must be aerodynamically competitive with a super-manoeuvrable growth variant of the Flanker, possess a competitive BVR sensor package, and be genuinely stealthy, this expectation is wholly false. Progress in BVR sensor and weapons technology has rendered the lightweight air superiority fighter paradigm mostly obsolete.

forward land bases, intended to replace the AV-8B and Sea Harrier, carrying a 1,000 lb class internal bomb payload. Target cost is USD 30-35M.

All JSF variants will have the capability to carry a wide range of air-to-ground weapons on four external pylons, as well as the AIM-120 missile. The USAF variant has an additional internal gun.

The concept of operations is for the aircraft to operate with internal stores only, to be stealthy, during the opening phase of a conflict. Once the opposing fighter and SAM threat has been defeated, then the aircraft will fly with a full load of external stores.

Combat radius was not deemed to be a high priority for the JSF, in comparison withe the larger F-22. The methodology used for defining the JSF range requirement was to define the target set remaining after strikes by strategic (i.e. B-2) and deep strike (F-22, F-117A) assets. This resulted in a requirement for the USAF variant of striking 400 NMI deep into hostile airspace, paralleled by a USN requirement of least 600 NMI, and a USMC requirement of 450-550 NMI. The manufacturers claim their variants achieve about twice the combat radius of the F-16 and the F/A-18C, for typical strike warloads.

Stealth performance though reduced radar, infrared and electromagnetic signatures was deemed a high priority due to its effect upon survivability.

Speed and manoeuvrability performance are a design variable which is intended to be traded down to maintain a low unit cost[121]. The avionic architecture to be used for the JSF is a fundamental departure from established technology, and is intended to use COTS (i.e. commercial) software, microprocessor and bus technology. The JSF will carry a small multimode LPI phased array radar, with air-to-air and SAR/GMTI air-to-ground modes. At this stage research is focussing on incorporating 3D (i.e multichannel) SAR techniques in conjunction with seeker equipped JDAM variants to provide a precision all weather strike capability, and the internal thermal imager/laser designator may be dispensed with, should 3D SAR prove to be adequate in the timescale for deployment.

An important aspect of cost control in the JSF program is the exploitation of off-board sensor resources, such as AEW&C/AWACS, E-8 JSTARS, RC-135 Rivet Joint and satellite reconnaissance to allow for a much simplified onboard sensor package.

The low cost of the JSF is to be the direct result of limiting the aircraft's capability to perform autonomously, by reducing the capability of its radar and other sensors, and limiting its air combat capability[122].

From a capability and force structure perspective it is evident that the capabilities of the F-22A Raptor and evolved strike Raptor replace the OCA and DCA capabilities provided by the RAAF F/A-18A, and the OCA Strike and Land Strike capabilities provided by the RAAF F-111. Adaptation of Raptor to long range maritime strike would require only the integration, and external carriage of suitable anti-shipping missiles and air delivered mines.

The JSF on the other hand, will provide shorter range land strike and maritime strike capabilities, and a limited OCA strike and DCA capability, all capabilities provided

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[121] *JSF Requirements Definition*, Section 5, 5.3.6, cited: "JSF should retain capabilities comparable to current multirole aircraft. This level of performance is required to successfully engage, counter and survive both air-to-air and surface-to-air threats." This is another aspect of where the JSF falls short as a candidate for an OCA fighter. A successful OCA fighter must have a clear aerodynamic performance margin over its opposition, as well as a capable BVR sensor and weapons package.

[122] Recent reports form the US suggest that the USN component of the JSF team progressively increased the capability of their sensor package, to increase the aircraft's autonomous engagement capability. This tempted the other service teams to increase their specified capabilities, compromising the cost of the aircraft. The result was a somewhat acrimonious public debate on the subject, and the reduction of the capability package to fit within cost parameters. Historically, divergence in fundamental requirements was the cause of collapse in the TFX program to develop the F-111 as a dual service aircraft.

by the RAAF's F/A-18A. Given the small airframe size, modest air superiority performance and thus limited growth potential, the aircraft will never be capable of performing the OCA fighter sweep role in the face of serious opposition[123].

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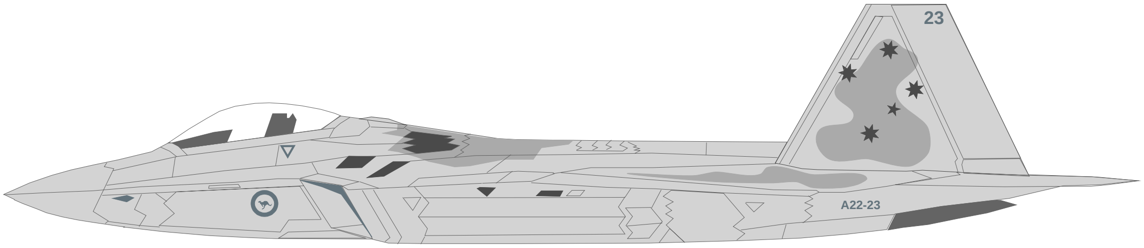
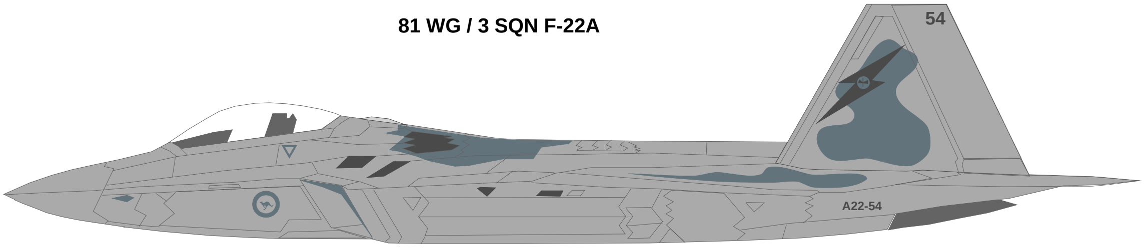
[123] In particular, the fuselage size will preclude the installation of a large antenna and radar installation which is a necessary requirement for effective BVR capability. The danger lies in the possibility of the aircraft's radar range falling well below the detection range provided by a capable IRS&T on an opposing aircraft, thus exposing the aircraft to attack by an opponent who is still outside of the JSF's engagement envelope. Internal volume limitations will also restrict the capability of passive ESM equipment which can be fitted, a critical requirement for both BVR air combat and SEAD operations.

4.2 Strategy

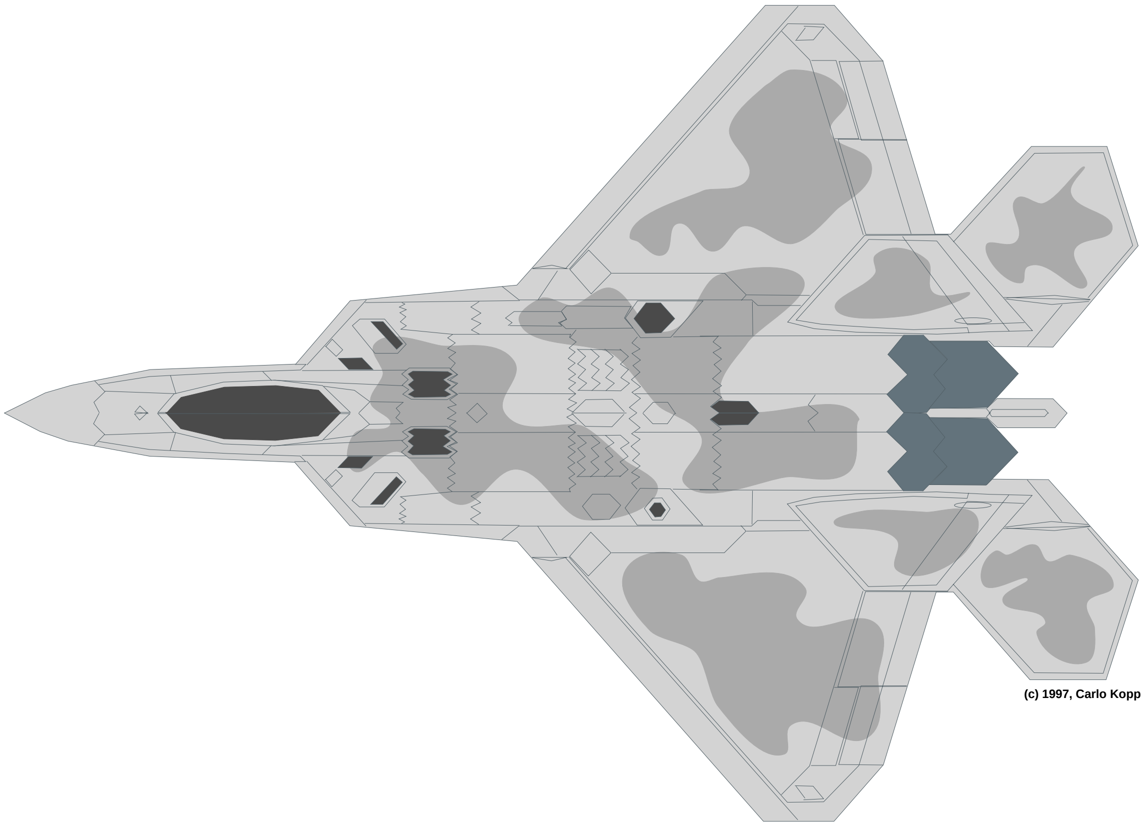
Should we assume that the RAAF is to acquire a mix of the F-22 and the JSF, initially to replace the F/A-18 in OCA and DCA roles, and later the F-111C/G, several important issues arise.



81 WG / 3 SQN F-22A



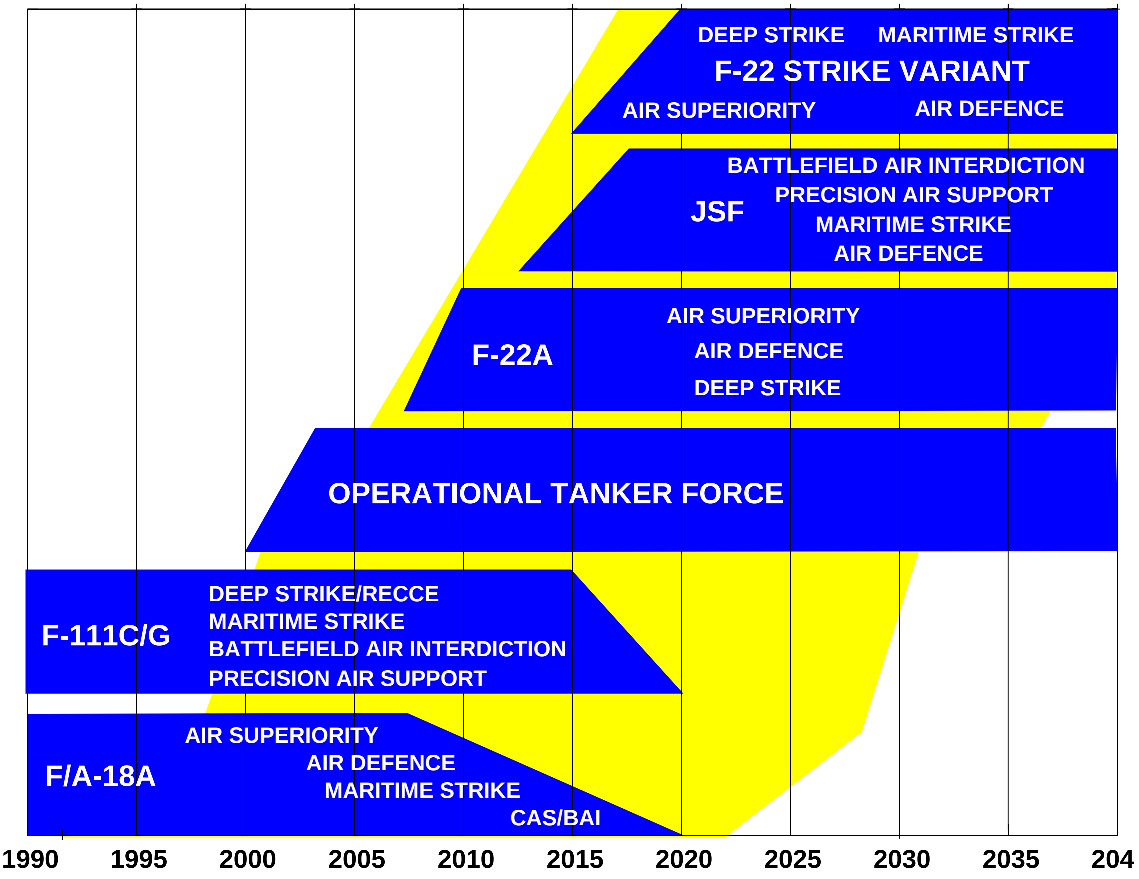
82 WG / 1 SQN F-22 Strike Raptor



(c) 1997, Carlo Kopp

Lockheed Martin / Boeing F-22 Raptor

The first is that of the intended mix ratio between the two types. How many F-22As will be required, how many JSFs will be required, and how many F-22 Strike Raptors will ultimately be needed ?



Proposed F/A-18 and F-111 Replacement Strategy

The second issue is that of scheduling the introduction of these new types into service in such a manner so at to minimise short term outlays, and maximise the utilisation of the F/A-18 and F-111 in the latter years of their operational life. Because of the limited duration of planned production runs, compared to established types, there may be little scope for selecting timing.

Production of the F-22 is intended to run, in volume, from 2002 to about 2015. Production of the JSF is intended to start after 2005, with an IOC of 2009, assuming no slippages occur.

The following strategy is therefore proposed:

- maintain the F/A-18A in service as a frontline OCA asset until 2007-2008, with a suitable package of upgrades to airframes which have the best fatigue life. The upgrade package is detailed below.

- accelerate the deployment of an operational tanker force to extend the useful operational combat radius and endurance of the F/A-18A, and to provide the F-111 with additional survivability at extended combat radii.

- apply a package of survivability upgrades to the F-111, to extend its tactically useful life. These would include RCS reduction measures, a defensive package capable of handling LPI threats, and internally carried GPS guided bombs and glidebombs.

- acquire a "silver bullet" squadron of F-22A aircraft commencing 2007-2008, to provide the OCA capability, and to provide deep strike capability in situations where the F-111 is no longer survivable.

- as the F-22A is deployed, progressively retire the F/A-18A aircraft with the least airframe fatigue life, using these as appropriate to provide spare components.

- deploy the JSF, starting from about 2012, to make up the shortfall in numbers resulting from the drawdown of the F/A-18A.

- commencing 2015, commence the deployment of a second F-22 squadron, comprising the Strike Raptor growth variant. This variant would require integration of a suitable anti-shipping missile.

- progressively phase out the F-111 as the Strike Raptor is deployed.

This replacement strategy is designed to maintain the existing OCA capability of the RAAF, as the established types are replaced, so that at no time is there a gap in capability. The final outcome is a force structure with two squadrons of F-22 variants, and a supplementary force of JSF variants to perform strike roles to shorter radii, and provide a supplementary DCA capability.

The final outcome of this replacement strategy is that the RAAF retains its basic capability package, in a broader regional environment where the baseline capabilities have grown substantially.

4.3 Specific Recommendations

A number of specific recommendations are proposed to implement this replacement strategy, while maintaining a credible level of capability. These involve a rigourous analysis of requirements, to determine the optimal balance between the F-22 and JSF, and a package of specific measures applied to existing aircraft, to retain their competitiveness until the new types can be introduced.

4.3.1 Balancing The Hi-Lo Mix and Stretching Existing Assets

The significant cost of replacing the F/A-18A and later the F-111C/G justifies the conduct of a rigourous and comprehensive operational analysis of capability requirements[124]. The purpose of such an analysis will be to determine what capability upgrades should be conducted in the interim, on what scale, and what numbers of the F-22 and JSF should be acquired to produce the required outcome in terms of total capability once the F/A-18A and F-111 have been retired.

Failure to perform a rigourous, and ongoing study, over the next five to ten years is guaranteed to produce a suboptimal outcome. This is because we are in a period of an important paradigm shift in military aircraft technology, therefore "off-the-cuff" estimates based on past experience cannot be a reliable basis for force structuring and acquisition decisions. The issue exceeds in scope the importance of the classical "risk reduction" justification for operational analysis.

As experience with the Wedgetail program has shown, there are considerable benefits to adopting such a strategy[125]. The starting point for such an analysis is to develop a package of scenarios for the broader and nearer region, based upon existing and planned deployments of capabilities. This would be the "Orange Force" model, which would need to be periodically revised with capabilities as deployed, and projected.

The Orange Force model should be based upon aircraft capabilities, sensor capabilities, weapons capabilities, supporting asset capabilities, such as tankers and AEW&C, training standards and known broader and nearer doctrine.

Scenarios should cover a spectrum of contingencies, ranging from full scale war down to minor engagements and political posturing. It would be prudent to structure this model, such that nations in the nearer region are modelled either as Blue Force or Orange Force players, to guard against any possible future political realignments in the ASEAN block.

The Blue Force model, accounting for aircraft capabilities, sensor capabilities, weapons capabilities, supporting asset capabilities, such as tankers and AEW&C, training standards and doctrine, can then be incrementally adjusted for various levels of RAAF capability. It is proposed that the model explore outcomes for a force comprised wholly of the F-22, and force structures employing various "mix ratios" between the F-22 and JSF.

The modelling effort should be repeated annually, to determine the impact of growth in Orange Force capabilities, so that the government has an objective picture of likely outcomes in the near term and the longer term, and so that a clear picture exists of what the aimpoint for future RAAF capabilities should be.

A rigourous analysis should provide answers to the following questions:

- How many F-22s and how soon ?

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[124] DSTO AMRL have the capability to perform such an analysis. Their simulation capability meets a very high standard.

[125] Importantly, the government can make an objective decision which produces the best possible outcome for the taxpayer, rather than expend taxpayer’s resources to satisfy the expectations of portions of the defence industry, or vocal lobby groups. Because the government’s decision is based upon a rigourous analysis, it is much less exposed to possible political criticism.

- What are implications of acquiring reduced capability "export" F-22s ?

- How many JSFs and how soon ?

- How long can the RAAF stretch the F/A-18, fatigue life permitting, and the F-111 ?

- What level of interim upgrades to the F/A-18 and F-111 is justified ?

Examples of measures which could be taken to stretch existing assets are described. Whether these provide a genuine payoff can only be determined by a rigourous analysis, as described above.

4.3.2 F/A-18A Hornet

The baseline F/A-18A is uncompetitive against current and growth variants of the Flanker in the specific areas of aerodynamic performance, combat radius, BVR sensor and weapons capability, and WVR weapons capability. The introduction of the AIM-132 ASRAAM and AIM-120B AMRAAM under AIR 5400 will provide the F/A-18A with a competitive missile package for BVR and WVR combat. However, an improvement in BVR sensor capability would be desirable to exploit the BVR potential of the AIM-120 and the AIM-132 to best advantage.

Given the expectation that some proportion of the F/A-18 fleet will be retired from 2008 onward, and some retained possibly until 2020, it would make some sense to consider the full HUG radar and EW upgrade package only for those airframes which are intended to remain in service past 2010-2012. However, cheaper means of enhancing the remaining aircraft would be desirable.

Possible measures are detailed as follows:

- apply the full HUG radar and EW upgrade only to those aircraft which have the airframe life to last until full replacement can occur. The EW upgrade must include the capability to deal with first generation LPI threats.

- explore measures to provide a full BVR capability for aircraft without new radars.

- deploy an operational tanker force in sufficient numbers to offset the combat radius and endurance limitations of the F/A-18A.

- explore either the leasing of several Su-27SK aircraft for dissimilar air combat training, or the feasibility of all RAAF Fighter Combat Instructors being provided with conversion training to the SU-27SK by an agreeable user of the aircraft[126].

- explore the feasibility of RCS reduction to the F/A-18A, specifically in the areas of inlet, radar bay and cockpit. Should this prove feasible, apply such measures.

In BVR combat the principal weakness of the F/A-18A is sustained supersonic speed and endurance, and the sensor package. The deployment of operational tankers can alleviate the former, while the improvement of the sensor package would improve the latter. However, the latter constitutes a large investment across the whole fleet, which would be unlikely to be amortised in the shorter term. An "add-on" package which could be moved

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[126] The Ukraine based International Fighter Pilot's Academy (IFPA) provides contract conversion training and advanced air combat training on the Su-27SK, including live missile firings. See Berger H., *Top Gun for Everyone*, Air Forces Monthly, January, 1996. Curiously, Lt.Col Tom Orsos, commander/manager of the IFPA, in an Australian national.

across airframes would therefore be of some interest, since a modest number of sets could be acquired, and assigned to aircraft tasked with DCA and OCA. As the F/A-18 force is contracted in size, these sets would be concentrated in the remaining aircraft.

In terms of providing an ESM package for this purpose, it is worth noting that the USN is currently testing the Lockheed Martin Aeronutronics (formerly Loral) Target Acquisition System (TAS), which is a precision direction finding receiver package embedded in the inboard wing pylons of an F/A-18, and intended to provide the aircraft with a precision range known targeting sensor for the HARM, and a standoff passive targeting capability for BVR combat[127].

Provision of an IRS&T package is also feasible. The USN's AAS-42 long-wave IRS&T, deployed since the early nineties on the F-14D, is now available podded for the F-16 and the F/A-18. It is claimed to provide a passive detection range under some conditions superior to that provided by the F-16C's APG-68 radar[128].

4.3.3 F-111

Since the F-111 can be expected to remain in service until 2020, to provide the critical long range maritime strike capability, there is possibly considerable merit in making the necessary investments into improving its long term survivability. Current programs such as the Echidna upgrade to the EW package should be be pursued vigourously, as should the weapons capability upgrade under AIR 5398.

Given the likely appearance of a basic LPI capability in radars deployed across the broader region in the 2005-2010 timescale, improved in SAMs and fighter radar lookdown capability, and BVR missiles with an effective snap-down capability against low flying targets, the following measures are proposed:

- provide the operational tanker force with booms to refuel the F-111s. This will provide the fuel reserves to allow the aircraft to ingress and egress defended airspace at supersonic speed, making interception by fighters much more difficult.

- upgrade the Echidna ALR-2002 requirement to include the capability to detect an LPI threat radar[129].

- implement RCS reduction measures to the airframe, concentrating on the forward and aft sectors[130].

- explore the feasibility of modifying the APQ-171 Terrain Following Radar to employ spread spectrum modulation techniques in order to defeat radar warning receivers and ESM equipment. The existing frequency hopping design produces a distinct emission which can be used to track the aircraft, and provide raid warning.

- integrate the AIM-132 ASRAAM and a Helmet Mounted Display. Explore the feasibility of using the upgraded Echidna for passive targeting of the ASRAAM.

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[127] Kopp C., *Rangefinding Targeting Receivers*, Australian Aviation, July, 1997. Other alternatives would be to use ESM hardware from the Eurofighter or F-16C HARM Targeting System, and repackage it into a pylon. North D.M., *US Military Weighs Future of SEAD*, AW&ST, June 16, 1997, pp 153, describes the detection of an F-14 radar at 200 NMI using the podded F-16C HTS.

[128] See Schoeppner J.P., *Silent Stalker*, Air Force Today, Vol.2, No.2, 1997. Other alternatives would be to repackage the Eurofighter's PIRATE FLIR/IRS&T into a pylon.

[129] This will most likely require a channelised high band receiver to provide the required sensitivity, suitable signal processing to detect LPI waveforms, and suitable data processing upgrades to accommodate pseudo-random scanning.

[130] At a minimum, this will require the addition of absorbent materials to the radar bay, inlet area, inlet tunnels, and exhaust nozzle area. The canopies will require a conductive coating, and a revised, serrated, exhaust nozzle shroud should be considered. Other, more extensive measures, are possible.

• reactivate the internal weapon bay[131] for the purpose of carrying a pair of internal GBU-31 or GBU-32 GPS guided bombs, and glide variants thereof[132]. This will improve survivability since the aircraft can penetrate faster due to the drag reduction, minimise its exposure during the weapon delivery toss manoeuvre, and gain some range improvement. Importantly this reduces aircraft RCS by removing external stores carriage. The principal cost will be in weapons clearance testing.

• fit the F-111, or proportion of the fleet, with a SAR/GMTI capable attack radar[133], with the capability to target standoff weapons accurately for safe distances.

A rigourous analysis of the impact of such a combination of upgrades to the F-111 will indicate to what degree they provide useful improvements to its survivability against shorter range SAM systems, and useful improvements in survivability against types such as the SU-27SK, and improved variants.

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[131] Weapon bay reactivation is a low cost proposition, since the task requires the fitting of a pair of MAU-12 ejectors to existing hardpoints, the addition of a pair of station decoders, relocating the existing decoders in the weapon bay, software modifications, and the addition of a short cable harness to couple into the existing AUP wiring loom entry into the weapon bay. The author, in concert with Boeing engineering staff, verified this at Amberley in late December last year.

[132] During 1997 the author proposed to Boeing and British Aerospace Australia, AeroSystems Division, the use of the GBU-31 JDAM tailkit and the DSTO Kerkanya glide wing package to provide a low cost GPS guided glide munition. The feasibility of this was explored, and found to be technically viable. The primary cost consideration is clearance testing for the F-111. This "winged JDAM" is a cheap means of providing a 30 NMI plus standoff range for many target sets.

[133] The most viable candidates would appear to be a repackaged Norden APG-76 or the Israeli Elta attack radar, of similar capability, being currently fitted to Turkish F-4 fighters.

Section 5 Summary

The last decade has seen a significant increase in the number of modern combat aircraft acquired in the nearer and broader region. The most important acquisitions have been variants of the capable Russian built Sukhoi Flanker aircraft. Current projections, based upon existing orders, indicate that in excess of four hundred such aircraft are likely to be fielded by the PRC and India, by 2015. This growth in combat aircraft capability has been paralleled by the deployment of highly capable Surface-to-Air missiles, such as the SA-10 and SA-15. It is highly probable that the more capable SA-12 will also be deployed within the next decade.

Because the Flanker has a combat radius of a similar magnitude to the F-111 and the F-15E, it renders ineffective much of the modernisation carried out by South East Asian nations over the last decade. The impending acquisition of AEW&C and air-to-air refuelling tanker capabilities by the PRC and India will further enhance this capability.

The RAAF's F/A-18A is aerodynamically uncompetitive against all variants of the Sukhoi Flanker. Upgrades to its weapons and sensors, and operational tanker and AEW&C support, will extend its tactical usefulness, but not cannot remedy its inherent design limitations. The F-111 will cease to be competitive, without fighter escort, after 2010, as broader regional capabilities and numbers consolidate.

The Sukhoi Flanker is being further developed, and has sufficient growth potential in the existing airframe to accommodate significant improvements in agility, weapons, sensors and air-to-ground capability. Of particular importance is the expected emergence in the next half decade of Flankers equipped with Low Probability of Intercept radar technology, radar signature reduction measures, and advances in cockpit and mission avionics made possible by easier access to Western computer technology. Of major concern is the likely proliferation of long range "AWACS Killer" missiles to users of the Flanker.

There is a very high risk of early technological obsolescence, and a certainty of ongoing frequent expenditure on upgrades, should the RAAF choose to replace the F/A-18A with a current technology, non-stealthy, production combat aircraft. These risks are not significantly changed by the adoption of combat aircraft with reduced radar signatures, as compared to genuine stealth aircraft. An important consequence of this is that during the coming decade, when the US begins the large scale manufacturing of genuinely stealthy fighters, the commercial prospects for current technology, non-stealthy, production combat aircraft will drop sharply. Therefore we can expect to see a major marketing effort by manufacturers of non-stealthy combat aircraft to make sales before this occurs.

The adoption of stealthy combat aircraft to replace the F/A-18A and F-111 will confer important economies in numbers of aircraft required to maintain a given level of capability, while providing unprecedented force survivability, and will also confer important economies in the use of cheap and lethal guided bombs, rather than expensive standoff weapons.

Two stealthy combat types will enter production over the coming decade. These are the USAF's F-22A Raptor, which is a long range multirole fighter, employing revolutionary stealth, sensor fusion and sustained supersonic cruise technology, and the developing Joint Strike Fighter, a shorter ranging bomber devised to supplement the F-22A.

Given the genuine risks associated with acquiring existing production aircraft, the best long term investment in the replacement of the F/A-18A, and later the F-111, is the F-22, supplemented by the Joint Strike Fighter. The F-22 would replace the F/A-18A in the counter-air role, and the F-111 in the long range strike role. The Joint Strike Fighter would supplement the F-22 in the shorter ranging strike role, and the defensive counter-air role.

This submission details and substantiates the reasoning behind these conclusions, a provides a substantial amount of supporting background information.

A package of specific recommendations is included, for the process of replacement of the F/A-18 and later F-111, and the effective utilisation of these assets in the latter period of their operational life cycle.

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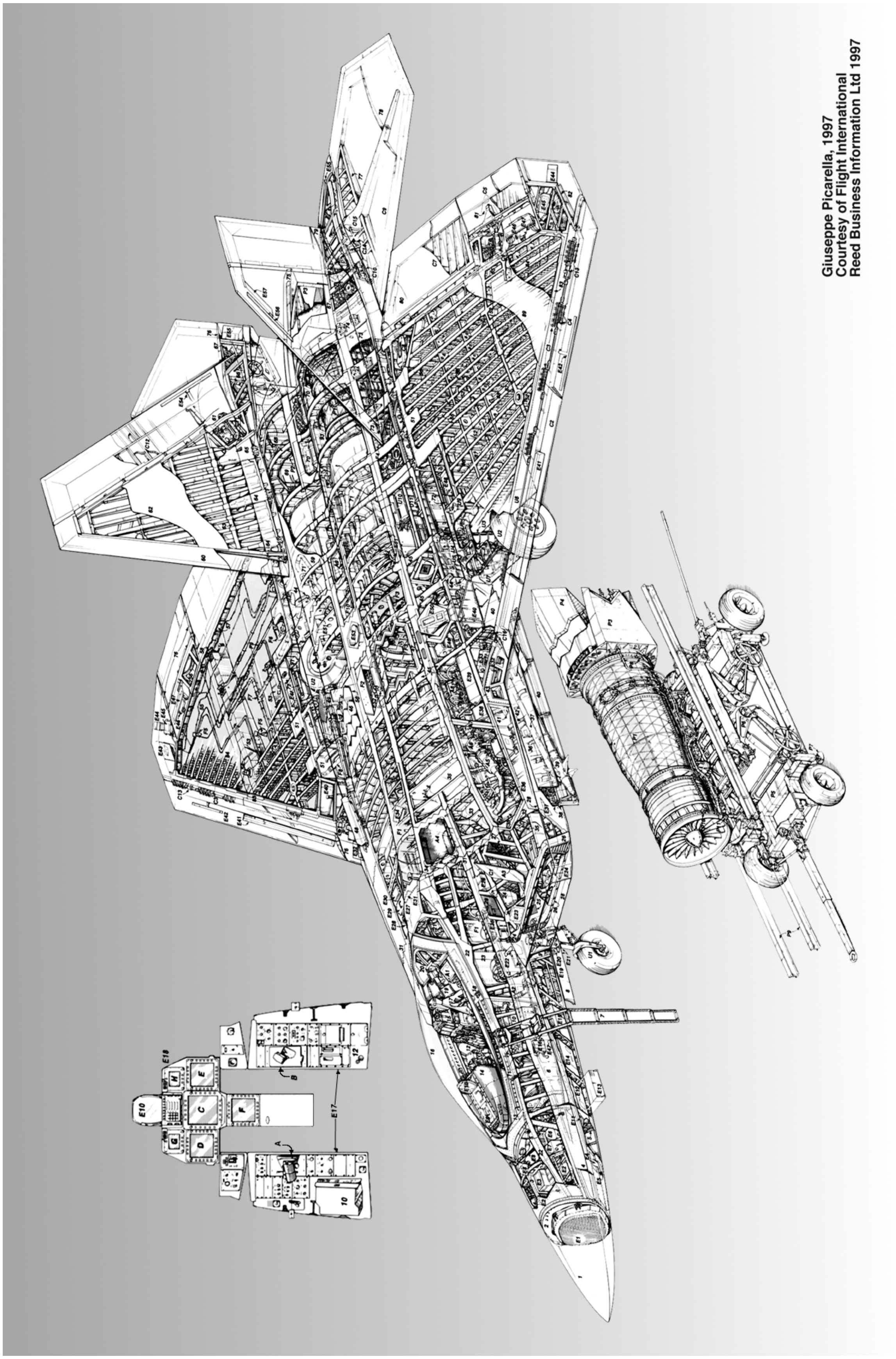
Section 6 F-22 Technical Data



Giuseppe Picarella, 1997
Courtesy of Flight International
Reed Business Information Ltd 1997

THE F-22 RAPTOR AIR DOMINANCE FIGHTER

KEY TO CUTAWAY

STRUCTURE AND GENERAL

1. Integrated forebody (radome)-composite (LMSW)

2. Forward-canted bulkhead-machined aluminum alloy (radar mounted on forward face)

3. Forward-fuselage keel frame-machined aluminum alloy

4. Forward-fuselage chine-composite

5. Forward pressure bulkhead-machined aluminum alloy

6. Single-piece chine beam closeout-machined aluminum alloy

7. Pilot deployable ladder, intended for emergency and off-field use only-aluminum alloy

8. Nose landing gear door-thermoplastic composite

9. Boundary-layer diverter

10. Boarding ladder stowage container

11. Forward fuselage frame-machined aluminum alloy

12. Pilot’s umbilical connection panel

13. Canopy sill seal

14. Instrument panel glare shield

15. Modified ACES II zero-zero ejection seat, with fast-acting drogue and arm restraints (McDonnell Douglas)

16. Single-piece canopy, tinted monolithic poly-carbonate transparency (Sierracin) with aluminum/titanium frame incorporating eight latching points

17. Ejection-seat mounting frame and guide rails, mounted directly on to canted bulkhead

18. Sill-mounted canopy latch fitting

19. Canopy electro-mechanical lifting actuator

20. Actuator support and closeout structure

21. Canopy hinges (2)

22. Single-piece cockpit sill-forged and machined titanium

23. Forward fuel tank sidewall-composite

24. Inlet to forward-fuselage attachment points

25. Inlet bleed plate to remove intake boundary-layer air

26. Inlet C-channel single-piece frame-hot isostatic pressed (HIP) cast titanium (Howmet)

27. Fixed bleed air exhaust

28. Inlet lip and side-of-body chine-resin transfer molded (RTM) composite (Dow-UT)

29. Diverter air-vent

30. Forward fuel-tank internal structure-RTM composite (Dow-UT)

31. Forward fuselage to mid fuselage body mate joint

32. Mid fuselage single-piece bulkhead-machined aluminum alloy

33. Avionics bay-both sides

34. Air cooled fuel cooler (ACFC) exhaust panel

35. Inlet duct-epoxy composite

36. Side weapons bay, also provides stowage for fins removed from external-mounted missiles while in ferry configuration

37. Missile launch rail incorporating plume deflector

38. Side weapons-bay door actuator-hydraulically operated driveshaft mechanism (Curtiss Wright)

39. AIM-9M Sidewinder infra-red guided air-to-air missile (also compatible with AIM-9X)

40. Side weapons-bay doors-thermoplastic composite

41. Trapeze launcher actuator-hydraulic

42. LAU-141/A trapeze launcher (LMTAS)

43. Wing stub antenna fairing-composite

44. Fuselage to wing attachment lugs

45. Single-piece carry-through main-frames-forged titanium (Wyman-Gordon)

46. Bleed-air doors-aluminum

47. Bleed-air door housing-aluminum

48. Gun port and hydraulically actuated door-titanium

49. M61A2 20-mm rotary cannon (General Dynamics), with linear linkless ammunition

handling system (LMTAS)

50. Feed track from lateral ammunition bay-480 rounds

51. Wing side of body fitting-HIP cast titanium (Howmet)

52. Weapons/drop tank pylon uplock casting-HIP cast titanium (Howmet)

53. Jettisonable external stores pylon with BRU-47A rack (EDO) for carriage of fuel tank

54. Pylon forward uplock fitting

55. Electrical and hydraulic routing

56. Aileron strongback casting

57. Single piece trailing-edge spar-machined titanium

58. Pylon aft pivot casting outboard pivot integral to spar

59. Fuselage skin panel

60. Fin leading edge-composite

61. Rudder servo-actuator fairing

62. Multi-spar fin-RTM composite spars (Dow-UT)

63. Machined titanium rib to increase fin ballistic tolerance

64. Fin attachment frames-machined titanium

65. Rudder servo-actuator housing-HIP cast titanium (Howmet)

66. Horizontal stabilizer pivot-shaft housing

67. Aft fuselage boom-HIP cast titanium "isogrid" plates electron-beam welded to form box structure (Aerojet)

68. Engine bay frames (lower sections of frame 5 and 6 drop out for engine fitting)-machined titanium

69. Engine bay

70. Stored energy system (SES) bottles-engine out restart

71. Dry-bay fuel transfer lines

72. Dry-bay fire extinguishers

73. Fin to fuselage fairing-composite

74. Rear fuselage to fin attachment fittings

75. Emergency arresting gear fairing

76. Control-surface interface "cats eye"

77. Horizontal stabilizer inboard "closeout" rib-RTM composite (Dow-UT)

78. Horizontal stabilizer structure

79. Rudder lower fairing-composite

80. Flaperon servo-actuator fairing

81. Aileron servo-actuator fairing

82. Wing tip structure-machined titanium

83. Leading-edge spar- machined titanium

84. Sine-wave intermediate spar-RTM composite (Dow-UT)

85. Aileron servo-actuator housing-HIP cast titanium (Howmet)

86. Intermediate rib, for ballistic tolerance-machined titanium

87. Pylon segmented ribs-mixed HIP cast and machined titanium construction

88. Fuel anti-slosh wing rib- mixed construction

89. Wing skin panel-composite

90. Mid fuselage to aft fuselage mate joint

91. Main-gear door hinge

92. Auxiliary power unit (APU) exhaust

93. Engine-bay keel/firewall-mixed construction titanium

Environmental Control System/Thermal Management System (ECS/TMS)(AlliedSignal)

Open-loop air-cycle system cools flight-critical avionics and supplied life-support system. Closed-loop vapor-cycle systems provides liquid cooling (polyalphaolephin coolant-PAO) for mission-critical avionics. Uses fuel as heat sink. Thermal-management system cools fuel. Fire protection provided using infra-red and ultra-violet sensors and halon extinguishers.

A1. Cockpit ventilation/canopy de-fog

A2. ECS ducting

A3. ACFC ram-air intake (in boundary layer diverter), injectors suck air into ram ducts when aircraft is on the ground

A4. ACFC exhaust outlet

A5. Low pressure water separator

A6. Load heat exchanger

A7. Air cycle machine

A8. Vapor cycle system

A9. Primary heat-exchanger, cools engine/APU bleed air for supply to air-cycle refrigeration pack

FLIGHT CONTROLS

Vehicle management system (Lear Astronics) includes triple-redundant flight-control computers, with no backup. There are three independent sources of electrical power, two 276 bar hydraulic systems, and one actuator (Parker Bertea) for each control surface. Flight and propulsion control is integrated; Thrust-vectoring operation is transparent to the pilot.

C1. Hydraulically actuated inlet bleed-air door, also acts as a secondary control surface (45° up deflection)-HIP cast titanium (Howmet)

C2. Leading-edge flap (35° down deflection)-composite

C3. Leading-edge flap rotary actuator (Curtiss Wright)

C4. Leading-edge flap spar-carbon fiber

C5. Aileron (25° up, 25° down deflection)-mixed construction co-cured composite multi-rib box assembly

C6. Aileron servo actuator (Parker Bertea)

C7. Flaperon (35° down, 20° up deflection)-mixed construction co-cured composite-multi-rib box assembly

C8. Flaperon servo actuator (Parker Bertea)

C9. Horizontal stabilizer (30° down, 25° up deflection)

C10. Horizontal control surface servo actuator (Parker Bertea)

C11. Rudder servo actuator (Parker)

C12. Rudder (30° left, 30° right deflection), rudders are deflected outwards simultaneously to act as speedbrake, composite multi-rib box assembly with HIP cast titanium actuator support housing (Howmet)

C13. Leading-edge flap asymmetry brake

C14. Pivot shaft servo-actuator attachment fitting

C15. Horizontal stabilizer pivot shaft-fiber-placed composite (Alliant Techsystems)

C16. Leading-edge flap power-drive unit (PDU) (Curtiss Wright)

AVIONICS AND ELECTRICAL

Highly integrated digital avionics built around common integrated processors (Hughes) that perform signal and data processing for the radar, communication/ navigation/identification (TRW) and electronic warfare (Lockheed Martin Sanders) systems, and fuse data from sensors for display to the pilot. All apertures are conformal for low observability. Electrical system(Sundstrand) is 270V DC, with 65kW generators on each engine, a 27kW generator on the auxiliary power unit and a battery.

E1. Active electronically scanned array for AN/APG-77 multimode radar (Northrop Grumman/Texas Instruments)-growth provisions for side arrays (2)

E2. Air data sensor system (ADSS) (Rosemount)-upper Beta (sideslip) plate

E3. Radar RF receiver

E4. ADSS Alpha (angle-of-attack) probe

E5. ADSS lower Beta unit

E6. Flight control system converter regulator

E7. LN-100G laser-gyro inertial-reference/global-positioning system (Litton)

E8. Missile launch detector 1 (MLD) and window (Lockheed Martin Sanders)

E9. Head up display (HUD) video camera

E10. Wide-angle head-up display (HUD), collapses if canopy hits HUD after a birdstrike to avoid shattering transparency (GEC Marconi)

E11. MLD 3 and window

E12. Two-tier liquid-cooled integrated avionics racks (IAR)-machined aluminum, common integrated processor (CIP) (Hughes)

E13. Avionics rack in lowered/maintenance position

E14. Three-tier IAR

E15. Avionics growth rack (3rd CIP)

E16. Emergency escape system sequencer

E17. Cockpit side consoles, throttle on left, sidestick on right (Lear Astronics)-hands on throttle and stick control

E18. Instrument panel, six active-matrix liquid-crystal color multi-function displays (Lockheed Martin Sanders/Kaiser/OIS)

E19. Battery compartment-28V

E20. Glideslope antenna, mounted inside nosegear door

E21. Landing/taxi lights

E22. Power distribution center (PDC)

E23. Communication/navigation/identification (CNI) system (TRW) -inter/intraflight datalink (IFDL) support antenna

E24. Microwave landing system (MLS) antenna-growth provisions

E25. Onboard oxygen generating -system (OBOGS)

E26. 28V DC converter

E27. CNI IFDL upper steerable, narrow-beam antenna

E28. Integrated vehicle subsystem control (IVSC) (Lear Astronics)-controls aircraft subsystems via data bus, including electrical, hydraulics, fuel, APU, ECS, landing gear and brakes, diagnostics and structural-integrity monitoring

E29. Generator distribution center

E30. 28V DC converter

E31. MLD 2 and window

E32. Electronic-warfare (EW) system (Lockheed Martin Sanders)-Band 3 and 4 forward-azimuth array and Band 4 elevation array

E33. CNI Band 3 and 4 electronics

E34. Upper L-band antenna

E35. Environmental control system (ECS) (PAO) pump controller

E36. Auxiliary generator control unit

E37. External canopy jettison point

E38. IVSC

E39. Band 2 electronics

E40. CNI UHF antenna

E41. CNI Band 2 forward antenna

E42. Instrument landing system (ILS) localizer antenna

E43. Navigation light

E44. CNI Band 3 and 4 EW aft array

E45. Band 3 and 4 aft electronics

E46. Band 3 and 4 power supply

E47. Formation lighting strip

E48. Power inverter

E49. AlliedSignal Aerospace G250 auxiliary power-unit (APU) for engine start and emergency power 335kW, drives 27kW electrical generator, 102 liters/min hydraulic pump

E50. APU intake

E51. Fuel/ECS PAO heat exchanger and fuel/oil heat-exchanger

E52. In-flight refueling receptacle location light

E53. CNI global-positioning system (GPS) antenna

E54. CNI Aft VHF antenna

E55. CNI Band 2 aft antenna

E56. CNI Rear VHF antenna

E57. Fin formation lighting strip

FUEL SYSTEM

F1. Forward-fuel tanks F1 and 2

F2. In-flight refueling receptacle-inner guides protect composite external doors from probe damage

F3. Mid-fuselage fuel tanks A3 left and right

F4. Side of body fuel tanks A1 left and right

F5. Wing fuel-quantity gauge probes

F6. Fuel transfer pipe

F7. Pylon fuel connection lines

F8. Fuel breather pipe

F9. Pylon air line

F10. Onboard inert gas generation system (OBIGGS)

POWERPLANT AND TRAILER

P1. Pratt & Whitney F119-PW-100 turbofan engine (rated at 155.6 kN) with afterburning

P2. Engine thrust mounting

P3. Two dimensional convergent-divergent thrust-vectoring nozzles (20° up and down deflection)-Pratt & Whitney

P4. Thrust-vectoring nozzles shown in maintenance configuration

P5. Ground-handling trailer/lift incorporating vertical, lateral, pitch, roll and yaw controls, for engine alignment and fit-(Boeing)

P6. Mechanically actuated scissors lift assembly

P7. Leveling/support jacks

P8. Engine thrust-mounting

P9. Extension rails (locate on engine-bay frames 4, 5 and 6)

P10. Engine upper forward mount

P11. Engine front side-load mount

UNDERCARRIAGE AND HYDRAULICS

U1. Nose gear (Menasco)-forward retracting, hydraulically actuated, electrically controlled, steer-by-wire: wheel (AlliedSignal), tire 23.5 x 7.5 R10 Michelin)

U2. Main gear (Menasco)-outboard-retracting, hydraulically actuated, electrically controlled, brake by wire: wheel (AlliedSignal), Carbonex 4000 carbon brakes (AlliedSignal), tire 37 x 11.5 R18 (Michelin)

U3. Main landing gear dual-piston shock strut assembly-Aermet 100 steel

U4. Side-brace beam

U5. Retract actuator

U6. Unlock actuator

U7. Inboard main landing-gear doors

U8. Outboard main landing-gear doors

U9. Outboard door retract actuator

U10. Hydraulic reservoir

U11. Hydraulic accumulator

INSTRUMENT PANEL AND SIDE CONSOLES LAYOUT

A. Throttle

B. Sidestick control

C. Situation display

D. Defense display

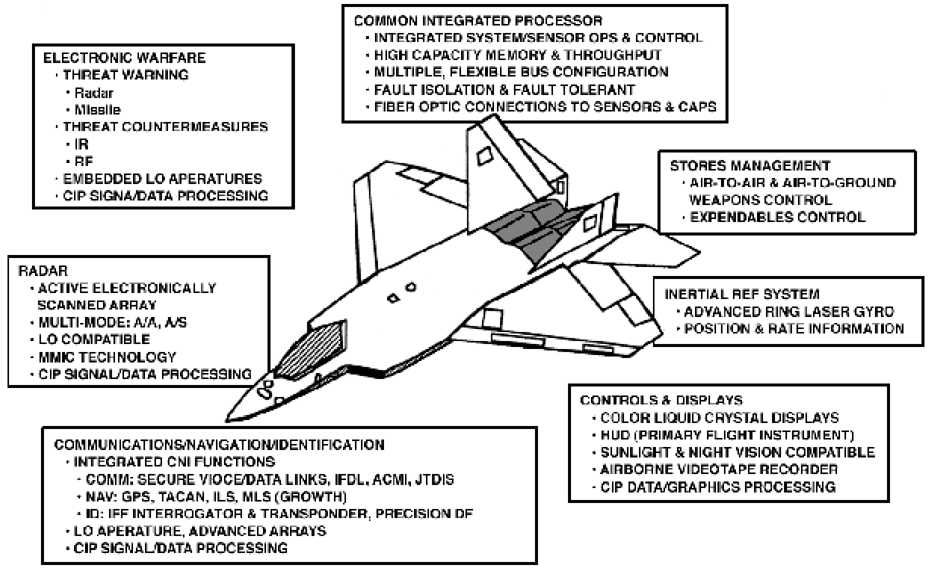
E. Attack display

F. Stores management display

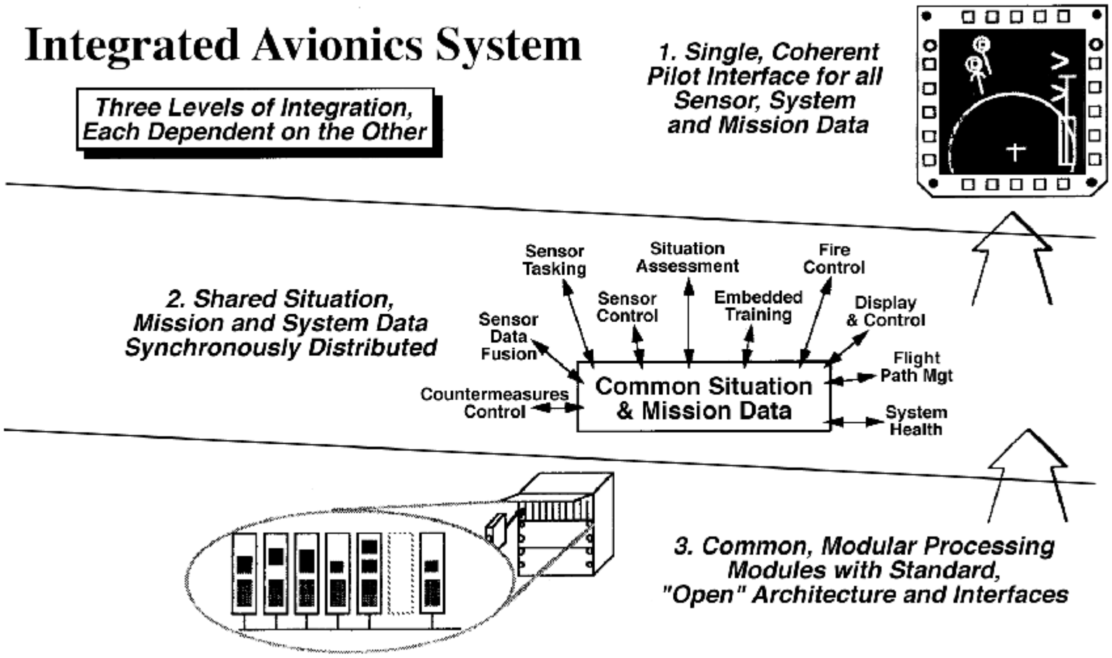
G. Communications/navigation/identification display

H. Standby flight group

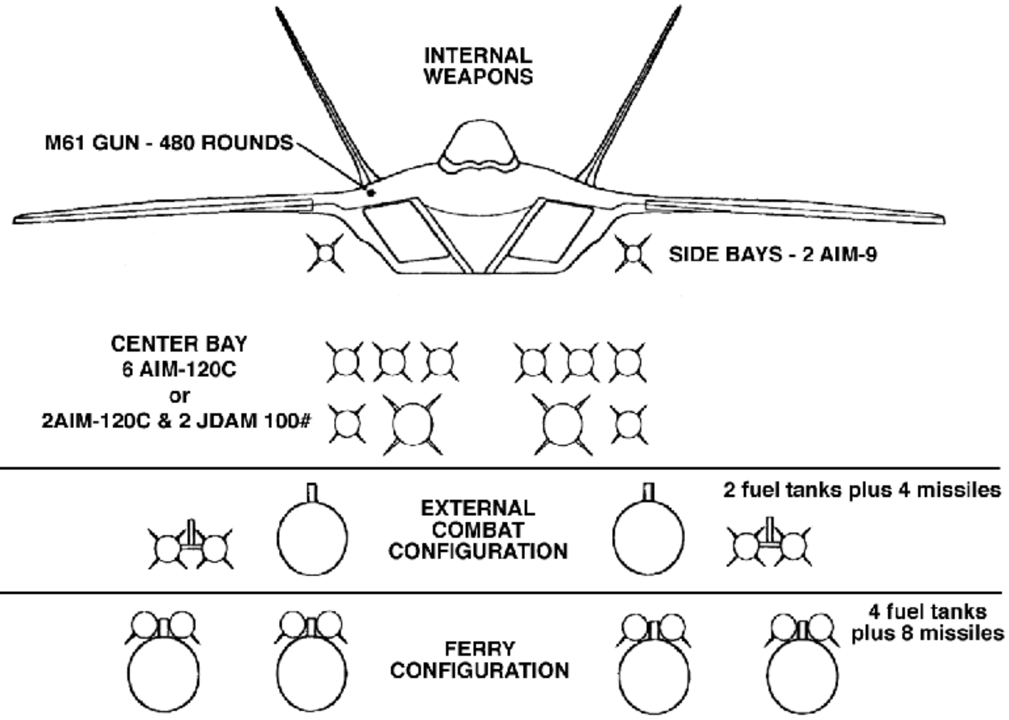
F-22 Integrated Avionics Systems



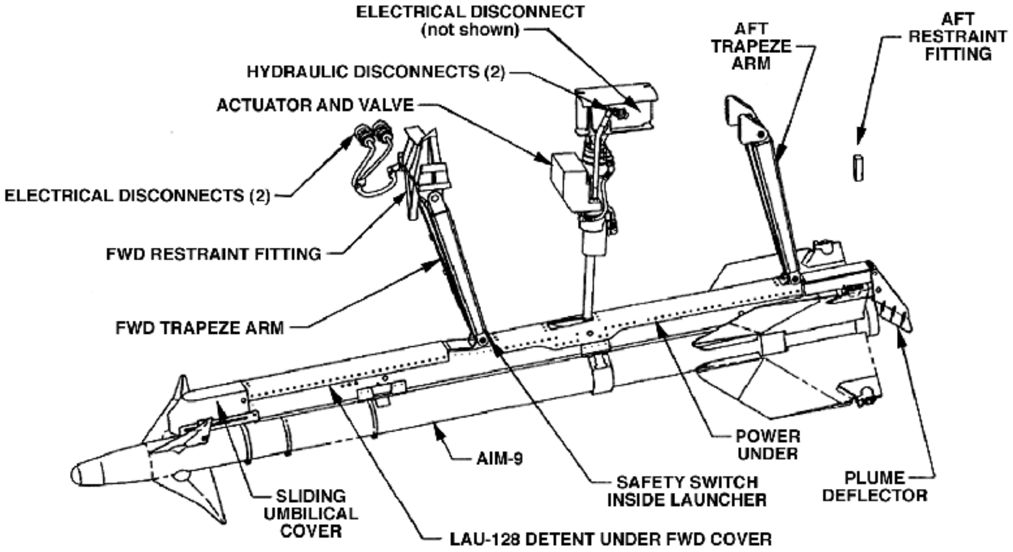
Integrated Avionics System



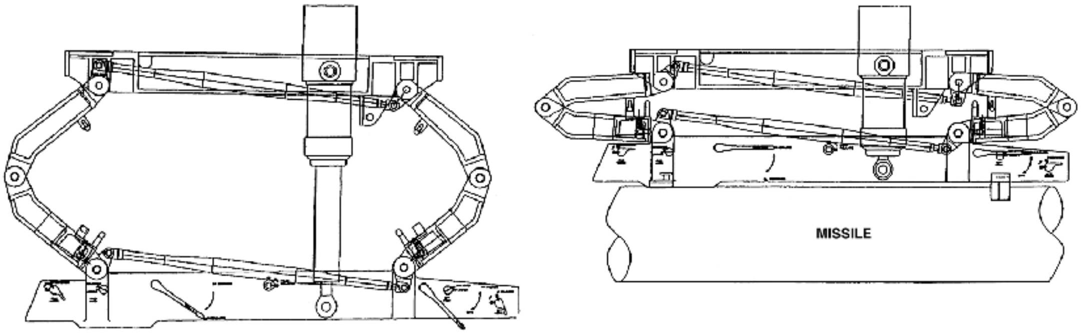
F-22 Weapons Carriage Capability



LAU-141/A Trapeze Launcher with Missile



LAU-142/A AMRAAM Vertical Eject Launcher


Extended for Ground Operations Such as Missile Loading or Servicing

Retracted with Missile Attached