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Promise and Reality: Beyond Visual Range (BVR) Air-To-Air Combat

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Introduction

The promise of beyond visual range (BVR) air-to-air combat makes sense: kill the enemy at long range—before he can harm you. Developed throughout the Cold War, BVR capabilities fit the US force structure framework which favored quality over quantity. This framework envisioned a highly-trained force (US or US client) equipped with advanced weapons defeating a numerically superior enemy (USSR or Soviet client). Unfortunately, the pursuit of costly BVR capabilities during the Cold War was not justified by actual BVR performance.

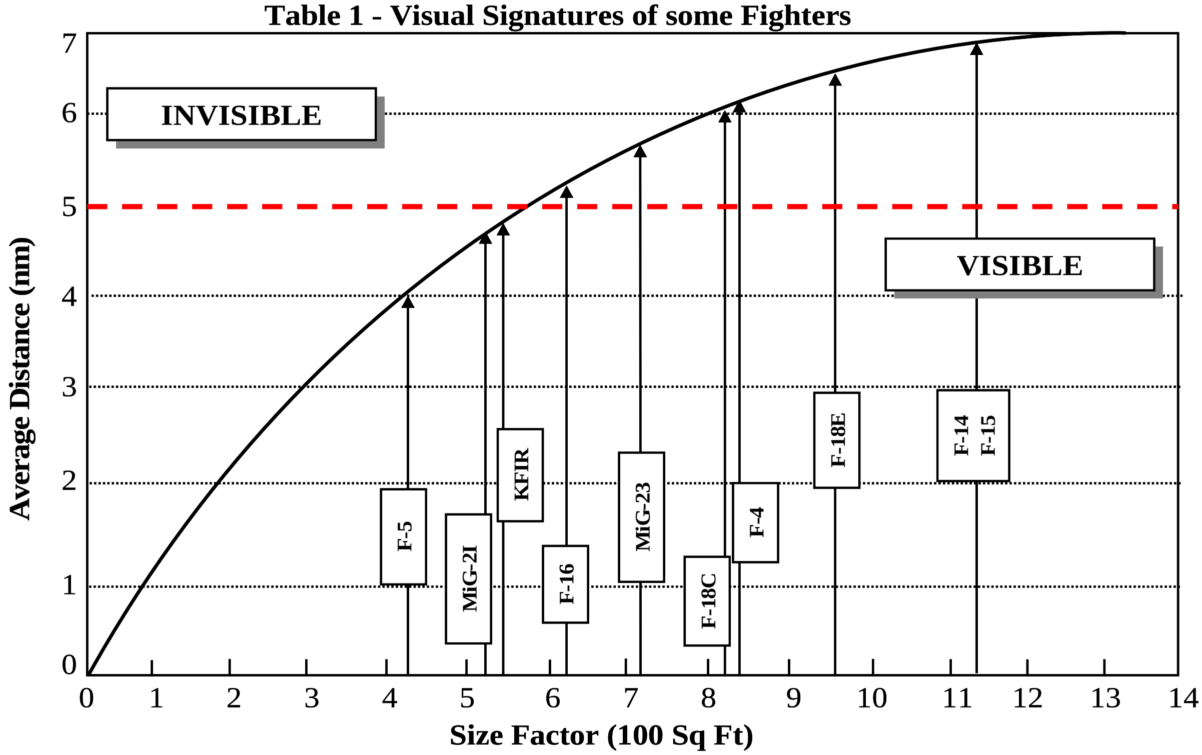
To prove this thesis, this paper will first review BVR theory and BVR implementation. This is followed by a detailed analysis of BVR in practice—actual combat results from the only four Cold War era conflicts involving any documented BVR air-to-air combat. The Desert Storm section shows BVR performance improved relative to the Cold War era, although not for the original reasons purported by BVR pundits. The limited post-Desert Storm BVR data is reviewed in the Post-Desert Storm section. Prior to offering conclusions and recommendations, the paper will also present relevant counterarguments.

BVR Theory

BVR theory has its genesis at the close of World War II, a conflict witnessing operational use of radars, guided missiles, and jets. For example, the primary US BVR missile throughout the Cold War was the radar-guided AIM-7 Sparrow, which was developed by the US Navy starting in 1946.[i] Although World War II also witnessed some degree of radar-directed BVR air-to-air night combat, the story of night fighters is beyond the scope of this paper, which focuses on radar-guided missile platforms vice radar-guided gun platforms used at very close ranges.

BVR theory entails a technologically sophisticated fighter, equipped with a powerful radar and fire control system, launching accurate radar-guided missiles at distant enemy aircraft.[ii] In the Cold War context, these enemy aircraft might be Soviet bombers attacking the US homeland or droves of Soviet fighters seeking to establish air supremacy over Western Europe. In either case, the intended targets are well out of sight—beyond visual range. Visual range depends on various factors: visual acuity, visual enhancements (e.g. binoculars or long-range imaging devices), visual inhibitors (e.g. clouds or dirt on the canopy), light conditions, target aspect, and target size. Colonel James Burton selected five nautical miles—in daylight—as his BVR limit for evaluating air-to-air missiles.[iii] Alternatively, the Gulf War Air Power Survey (GWAPS) BVR criteria depended upon whether the target was visually identified.[iv] Table 1 is adapted from Stevenson[v] and shows the average distance (in nautical miles) at which different aircraft are visible during daytime, based on airframe size. Factors such as engine smoke for the F-4 are not included. The dotted line shows Burton's five nautical mile criteria.

Table 1 - Visual Signatures of some Fighters



The powerful radar called for by BVR theory extends the range at which a pilot might detect enemy aircraft—thereby justifying the increased size and range at which one's own aircraft is visually detectable. Unfortunately, history demonstrates that the trade-off made to pursue this aspect of BVR theory is also unwarranted, especially in the age of radar detectors.

BVR Implementation

During 1950s, the USAF procured the "century series" fighters (F-100, 101, 102, 104, 105, 106), which already exhibited many of the characteristics called for by BVR theory. With some exceptions, they were significantly larger, more complex, faster (when clean), and more expensive than their predecessors. The Navy, exploring two views of BVR combat, pursued the F6D Missileer, which was a very complex but slow-cruising missile platform designed to defeat airborne threats at ranges of 100 miles with enormous Eagle missiles.[vi] But during this time, the Navy also procured the most prolific BVR fighter: the F4H-1 Phantom II. First flying in 1958, this was the first fighter designed to carry the radar-guided Sparrow missile,[vii] although some of the century series were modified for that purpose. Ultimately, the USAF adopted the Navy Phantom as the F-110A Spectre, the nomenclature of which later changed to F-4C Phantom II. Other BVR fighters followed: the joint Navy-USAF "TFX" which became the F-111, the F-14, and the F-15. Not to be outdone, the Soviets procured large/complex BVR fighters during the 1960s and 1970s as well: Yak-28, Tu-28, and of course the MiG-25.

Built around large and complex radar and avionics systems, these fighters required two powerful engines to overcome not only their excessive weight, but also the drag associated with the large radar dish mounted in the nose. Their costs—in terms of both procurement and sustainment—were staggering. As shown in Table 2, for example, the operations and maintenance (O&M) costs of operating a BVR-capable F-4 or F-15 was significantly higher than their non-BVR F-5 or F-16 counterparts.[viii] Although the unit cost for an F-15 was more than double an F-4, the F-15 was promised to have much lower O&M costs. In 1999 dollars, the F-15C was costing $8000 per flight hour (direct O&M) versus $5000 for an F-4E. A similar promise is now being made for the next-generation BVR fighter, the F-22,[ix] vis-à-vis the F-15.[x]

Table 2: O&M Costs per Flight Hour of Selected Fighters (1980 data)

	F-5E	F-16A	F-4E	F-15A
Direct O&M cost/flight hr (1980 $)	$940	$1734	$2733	$3305

The most overlooked aspect of BVR implementation, however, was the persistent technological shortfall in identifying an enemy at long ranges. Identification Friend or Foe (IFF) technology is still not considered reliable today,[xi] as evidenced by the requirement for identification by other systems, such as the Airborne Warning and Control System (AWACS).

Not surprisingly, the IFF shortfall created a concern about fratricide, leading to extreme constraints on the employment of BVR capabilities. Nevertheless, the US continued to pay a significant premium to procure and operate BVR-capable systems, although the capability was generally not useable in practice.

BVR in Practice

During the Cold War, there were eight conflicts in which operational air-to-air missiles were used, accounting for 407 known missile kills (radar-guided missiles plus heat-seeking missiles): Formosa Straits (1958), Vietnam/Rolling Thunder (1965-1968), Vietnam/Linebacker (1971-1973), Six Day War (1967), India-Pakistan (1971), Yom Kippur War (1973), Falklands (1982), and Bekáa Valley (1982).[xii] No reliable data is available for the Iran-Iraq War (1980-1988, formerly called the Gulf War). As stated in the introduction, only four of these conflicts saw any use of radar-guided missiles designed to achieve BVR kills: Vietnam/Rolling Thunder (1965-1968), Vietnam/Linebacker (1971-1973), Yom Kippur War (1973), and Bekáa Valley (1982). Table 3 shows the total air-to-air kills documented for the US or US client (i.e. Israel) in each of these conflicts. Reliable data on aerial victories for the opposition—North Vietnamese or Arab air forces—is not available, but likely consisted exclusively of guns and heat-seeking missiles. For example, during the Bekáa Valley War, the Syrians claimed to have intercepted the second wave of the initial Israeli air attack, downing 19 Israeli jets, while losing 16 of their own.[xiii] Israel claims 22 Syrian jets downed, with zero losses of their own. The USAF analysis conducted by Burton falls on the side of the Israeli claims, albeit shorting them a few aerial victories.

Table 3: Air-to-Air Kills in Cold War Era Conflicts Involving Radar Missiles[xiv]

	Total Air-Air Kills	Guns	Heat-seeking Missiles[a]	Radar Missiles[b]	Other
US: 65-68/Vietnam	**117**	**40 (34%)**	**51 (44%)**	**26 (22%)**	**0**
US: 71-73/Vietnam	**73**	**11 (15%)**	**32 (44%)**	**30 (41%)**	**0**
Israel: 73/Yom Kippur	**261**	**85 (33%)**	**171 (66%)**	**5 (2%)**	**0**
Israel: 82/Bekáa Valley	**77**[c]	**8 (10%)**	**54 (70%)**	**12 (16%)**	**3**[d]
TOTAL	**528**	**144 (27%)**	**308 (58%)**	**73 (14%)**	**3 (1%)**

Notes:
a. AIM-9B thru AIM-9M Sidewinder.
b. Primarily AIM-7D thru AIM-7M Sparrow, but also some AIM-4D Falcons in Vietnam.
c. Israel claims 85 (with 0 losses).
d. No data found.

Despite the significant investment in BVR capability throughout the Cold War, Table 3 shows that radar-guided missiles only accounted for 14% of the total kills. Twice as many kills (27%) were made by guns and over four times as many (58%) were made by heat-seeking missiles. It is interesting to ponder the potential of a lightweight/agile fighter equipped with a gun and Sidewinders in the hands of pilots skilled enough to successfully dogfight F-4s and F-105s against MiG-21s. Such a lightweight fighter corresponds to a 1960/1970 equivalent of what the P-51 was in World War II, as compared to a costlier, heavier P-38 or P-47.

What is more disturbing about radar-guided missile performance is that the vast majority of kills (69 of 73, or 95%) were initiated and scored within visual range, as shown in Table 4. The acquisition process delivered weapons systems such as the F-4 and AIM-7 missile that were intended to kill the enemy with accurate BVR missile shots. Unfortunately, doctrine and actual employment practice did not match (even in Israel) due to the aforementioned IFF constraints. Yet, even when the IFF shortfalls were overcome and BVR shots were taken, only four of 61 were successful. This translates to a "probability of kill" or P_K of only 6.6%!

Table 4: Radar Missile Combat Data

	Total Shots	Total Kills	P_K	BVR Shots	BVR Kills	BVR P_K	Overall BVR Success[c]
US: 65-68/Vietnam	**321**	**26**	**8.1%**	**33**	**0**	**0.0%**	**0.0%**
US: 71-73/Vietnam	**276**	**30**	**10.9%**	**28**	**2**[a]	**7.1%**	**0.7%**
Israel: 73/Yom Kippur	**12**	**5**	**41.7%**	**4**	**1**[b]	**25.0%**	**8.3%**
Israel: 82/Bekáa Valley	**23**	**12**	**52.2%**	**5**	**1**	**20.0%**	**4.3%**
TOTAL	**632**	**73**	**11.6%**	**61**	**4**	**6.6%**	**0.6%**

Notes:
a. According to Jeff Ethell's interviews with Steve Ritchie, there is a slight possibility one of these two BVR kills may be fratricide against a Korat-based F-4E.
b. Israel does not claim this as a BVR kill, but it was made in excess of 5 nm.
c. Since radar-guided missile systems were procured to score BVR kills, the overall success is the percentage of BVR kills based on total radar missile firings.

As shown in Table 4, there were only four documented BVR air-to-air kills in the entire history of aerial warfare up until Operation Desert Storm. This revelation is astonishing because throughout the Cold War era, radar-guided missile platforms were touted as a transformation that would fundamentally change aerial warfare.[xv] Air combat would consist of missile platforms (complex, heavy, expensive fighters), armed with radar-guided missiles, destroying the enemy BVR. There was no need for agility, only to get to the missile launch location rapidly. As designed, the F-102, F-106, and F-4 serve as examples of this concept. Based on lessons learned in Vietnam, later versions of the F-106 and F-4 were finally equipped with an internal gun, and the F-4 was given wing slats for better maneuverability in dogfights. Another century series fighter, the F-105, was equipped with a gun (after much debate and despite conventional wisdom) and, although designed as a tactical nuclear delivery platform, actually scored numerous aerial victories during Vietnam with its gun.

There are three major shortfalls associated with using the AIM-7 Sparrow missile that led to the disappointing results in the hands of experienced operators: 1) the missile often failed to operate properly;[xvi] 2) the shooter had to keep his aircraft's nose pointed at the target throughout the engagement (to keep the target illuminated); and 3) the element of surprise was lost. Once illuminated by the targeting radar required to guide the missile, the intended victim is prompted by a radar warning receiver and begins evasive maneuvering to cause the missile or the shooting aircraft's radar to lose lock. When the incoming missile is visually spotted, evasive maneuvering may also cause a miss by exceeding the maneuvering capability of the missile.

Desert Storm – A BVR Turning Point?

With as many as 16 possible BVR victories,[xvii] one can view Operation Desert Storm as a turning point for aerial BVR combat. GWAPS annotates 24 of 41[xviii] total kills as being visually identified, plus one non-identified target crashing into the ground (later identified as a Mirage F-1). This leaves 16 kills that were not visually identified, meeting the GWAPS criteria of a BVR kill. Unfortunately, the actual GWAPS verbiage is vague concerning BVR victories. GWAPS Volume 2, page 113 says "sixteen *involved* missiles that *'were fired'* BVR" (inner quotation marks used in GWAPS) and "more than 40% of engagements resulting in kills *involved* BVR shots." The first quotation could mean all sixteen BVR shots missed. The second quotation could mean 16 of the 41 aerial victories achieved in Desert Storm were prefaced with BVR shots that missed and that the kill was made with subsequent missile shots fired within visual range. However, there are five BVR victories for sure: one at 16 nm (and at night), one at 8.5 nm (night) and three at 13 nm. This alone more than doubles the number of BVR kills in the entire history of aerial combat.

For comparison, Tables 5 and 6 add the Desert Storm kills to the tables shown previously. Table 5 shows that proportionally, more radar-guided missiles were used in Desert Storm than in previous conflicts. Simultaneously, gun kills were significantly lower—the only two gun kills credited in Desert Storm were A-10s using their 30-mm GAU-8 anti-armor cannon to destroy two helicopters, a Bo-105 and a Mi-8. Historically, however, most kills were still

Table 5: Air-to-Air Kills in Selected Cold War Conflicts and Desert Storm

	Total Air-Air Kills	Guns	Heat-seeking Missiles[a]	Radar Missiles[b]	Other
US: 65-68/Vietnam	**117**	**40 (34%)**	**51 (44%)**	**26 (22%)**	**0**
US: 71-73/Vietnam	**73**	**11 (15%)**	**32 (44%)**	**30 (41%)**	**0**
Israel: 73/Yom Kippur	**261**	**85 (33%)**	**171 (66%)**	**5 (2%)**	**0**
Israel: 82/Bekáa Valley	**77[c]**	**8 (10%)**	**54 (70%)**	**12 (16%)**	**3[d]**
US: 91/Desert Storm	**41[e]**	**2 (5%)**	**10 (24%)**	**24 (59%)**	**5[f]**

TOTAL	**569**	**146 (26%)**	**318 (56%)**	**97 (17%)**	**8 (1%)**

Notes:
a. AIM-9B thru AIM-9M Sidewinder.
b. Primarily AIM-7D thru AIM-7M Sparrow, but also some AIM-4D Falcons in Vietnam.
c. Israel claims 85 (with 0 losses).
d. No data found.
e. US only; 2 additional coalition kills were made with AIM-9s from RSAF F-15C.
f. 4 crashed, 1 spontaneously ejected.

achieved with heat-seeking missiles (56%) and guns (26%) even when the Desert Storm numbers are added to the four Cold-War conflicts are evaluated previously.

Looking at Table 6 (which adds Desert Storm results to the previous radar missile table), it is unknown how many of the 88 AIM-7 shots were made BVR. At most it was 59, since USN and USMC fighters launched 21 (14 and seven, respectively) which resulted in one non-BVR kill, while another eight non-BVR kills were made by USAF F-15s using AIM-7s.[xix] One BVR kill listed in GWAPS required five AIM-7s shots (P_K=20%) to down a MiG-23.[xx] As shown in the table, this result is on par with the Israeli BVR experience with F-15As and AIM-7s over the Bekáa Valley.

Table 6: Radar Missile Combat Data including Desert Storm

	Total Shots	**Total Kills**	**P_K**	**BVR Shots**	**BVR Kills**	**BVR P_K**	**Overall BVR Success[c]**
US: 65-68/Vietnam	**321**	**26**	**8.1%**	**33**	**0**	**0.0%**	**0.0%**
US: 71-73/Vietnam	**276**	**30**	**10.9%**	**28**	**2[a]**	**7.1%**	**0.7%**
Israel: 73/Yom Kippur	**12**	**5**	**41.7%**	**4**	**1[b]**	**25.0%**	**8.3%**
Israel: 82/Bekáa Valley	**23**	**12**	**52.2%**	**5**	**1**	**20.0%**	**4.3%**
US: 91/Desert Storm	**88**	**24**	**27.3%**	**?[d]**	**16**	**?**	**18%**
TOTAL	**720**	**97**	**13.5%**	**n/a**	**20**	**n/a**	**2.8%**

Notes:
a. According to Jeff Ethell's interviews with Steve Ritchie, there is a slight possibility one of these two BVR kills may be fratricide against a Korat-based F-4E.
b. Israel does not claim this as a BVR kill, but it was made in excess of 5 nm.

c. Since radar-guided missile systems were procured to score BVR kills, the overall success is the percentage of BVR kills based on total radar missile firings.
d. It is unknown how many of the 88 AIM-7 shots were made BVR.

USAF F-15Cs also fired 12 AIM-9 Sidewinders during Desert Storm, resulting in eight kills: a P_K of 67%. For the same USAF F-15Cs, the P_K for AIM-7 Sparrows was only 34% (67 shots and 23 kills)—making the AIM-7 half as effective as the AIM-9. Each Desert Storm AIM-7M Sparrow cost $225,700 compared to only $70,600 for the AIM-9M Sidewinder.[xxi] Not including the indirect costs of the AIM-7—larger, costlier launch platform, which uses more gas and needs more maintenance—this translates to each AIM-7 kill costing 620% more than each AIM-9 kill. Nevertheless, scoring between five and 16 BVR kills is still drastically above the historical average for BVR aerial combat.

There are several reasons for the increase in radar missile and BVR success in Desert Storm. Primarily, there was persistent AWACS availability, which provided a better air picture than was previously available. Though not perfect, AWACS offered unprecedented situational awareness for Coalition pilots as well as air campaign commanders and aircraft controllers. In addition to AWACS, US F-15Cs were equipped with a Non-Cooperative Target Recognition (NCTR) system. Despite the shortfalls of the existing IFF system, the combination of AWACS and NCTR gave commanders sufficient confidence to permit BVR shots for US F-15Cs. Nevertheless, a positive determination was still required to ensure the target was hostile and there were no friendlies in the area.[xxii] An additional factor improving the performance of radar-guided missiles was that Iraqi pilots did not take any evasive action once radar lock occurred. This indicates a training failure, an equipment failure (of the radar warning receiver), or a combination of both. All of these factors (AWACS, NCTR, and Iraqi pilot/equipment failures) served to improve BVR performance, but none were envisioned as part of the original BVR theory, which put the burden of performance on the missile, aircraft radar, and fire control system.

Post-Desert Storm

Although aerial victory data is available for selected post-Desert Storm conflicts such as Operation Deny Flight, Operation Allied Force, and Operation Southern Watch, this data does not include the number of shots taken or the engagement range. During Operation Deny Flight, for example, there were four aerial victories scored by two USAF F-16Cs on February 28th, 1994: three kills were with AIM-9s and one kill with an AIM-120 AMRAAM (a much improved replacement for the AIM-7).[xxiii] It is unlikely the AMRAAM shot was BVR, since the four enemy aircraft were simultaneously attacked with visual-range Sidewinders. Additionally, F-16Cs are not equipped with NCTR to augment the legacy IFF system, making BVR approval from AWACS very unlikely. There were also two kills as part of Operation Southern Watch in 1992 and 1993 by F-16s using AMRAAMs. Again, what is not given is the number of shots taken or the range.

A more recent Operation Southern Watch engagement occurred on January 5th, 1999 when two Iraqi MiG-25s violating the southern "no-fly" zone illuminated two F-15Cs with their BVR radar.[xxiv] The F-15s responded by firing three AIM-7 Sparrows and one AIM-120 AMRAAM. All missiles missed. Subsequently, two Navy F-14s fired two AIM-54 Phoenix missiles at the two MiG-25s. Despite the Phoenix being the most expensive—and supposedly most capable—air-to-air radar-guided missile ever made, both missed. The violating MiG-25s escaped to fight another day. Thus it would appear radar-guided missiles are continuing on their dismal track record established during the Vietnam War, especially for BVR situations.

Counterarguments

Counterargument: large fighters were developed to go fast, not to accommodate large/heavy radar assemblies to support radar-guided missile warfare. **Response:** although the maximum "clean" speed of large fighters such as the F-4 and F-15 is higher than their smaller, non-BVR counterparts (F-5 and F-16), once put into a combat configuration, the speed difference is negligible, especially at lower altitudes[xxv]. Furthermore, "Mach-2.5" F-15s spend a fraction of time flying supersonic, even when clean, due to the immense engine and airframe wear.[xxvi]

Counterargument: another reason Desert Storm radar-guided missile results were better than in previous conflicts was due to the much-improved "Mth" generation AIM-7 Sparrow and second generation F-15C. **Response:** granted, but these levels of technological achievement were promised throughout the development of the Sparrow missile. Some of those BVR promises were finally delivered on in Desert Storm—25 years late. As stated previously, BVR success required the assistance of AWACS, NCTR, and an incompetent enemy.

Counterargument: BVR shots are beneficial even if they miss because they cause the enemy to react, surrender the initiative, or do something stupid, resulting in an easy follow-on shot. **Response:** granted. But due to unreliable IFF, the opportunities for BVR shots remain limited. Additionally, with anti-radiation missile technology (which has a range-squared advantage over radar-guided missiles) someone will eventually field inexpensive air-to-air (or surface-to-air) anti-radiation missiles, perhaps calling one the

AIM-122 Sidearm-B. It therefore appears unwise to rely on an air superiority scheme that requires friendly fighters to emit any signals.

Possible counterargument: the purported "lightweight" fighter (e.g. F-16) plus Sidewinder combination performed much worse in Desert Storm than the F-15 plus Sparrow combination. F-16s fired 36 Sidewinders in Desert Storm and scored zero kills.

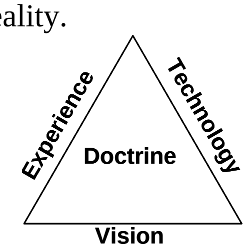
Response: granted. Based on the data, the F-15C was the best tool available for skilled pilots to achieve air superiority in Desert Storm, whether with AIM-7 Sparrows or AIM-9 Sidewinders. According to GWAPS, at least 20 of the 36 Sidewinder launches from F-16s were accidental. This was due to poor ergonomics on the joystick which was quickly modified. Additionally, the F-16s which fought in Desert Storm are a far cry from the "lightweight" fighter originally envisioned by the lightweight fighter mafia. The other "lightweight" fighter program grew into the porky Navy/Marine F-18, which also performed poorly in air-to-air situations in Desert Storm. Combined, the Navy/Marines fired 21 Sparrows and 38 Sidewinders from F-18s and F-14s scoring one kill with a Sparrow (P_K = 4.8%) and two with Sidewinders (P_K = 5.3%). Perhaps a better testimony for the lightweight fighter plus Sidewinder combination are the British Harriers in the 1982 Falklands War: 27 AIM-9s were fired for 24 hits and 19 kills (P_K = 70.4%).

Conclusions & Recommendations

This paper has shown that the pursuit of costly BVR capabilities during the Cold War was not justified by actual BVR performance. Air-to-air combat has not transformed into a long-range slugfest of technology wherein radar-guided missiles score near-guaranteed kills. Human factors, such as pilot skill—or the opponent's ineptness—still trump technology. Furthermore, BVR appears to work best in situations it is needed least. In Desert Storm—unlike Vietnam, Yom Kippur, and Bekáa Valley—the enemy had no chance of establishing localized or temporary air superiority. This allowed a persistent AWACS presence—coupled with overwhelming numbers of Coalition aircraft—permitting up to 16 BVR kills in the least stressing BVR scenario.

According to AWC Professor Ted Kluz, doctrine entails a Trinitarian balance between vision, technology, and experience.[xxvii] Although BVR theory became the driving vision in procuring US fighter aircraft throughout the Cold War, the vision was not balanced against technological potential and actual combat experience. The result was a mismatch between the

acquisition process, doctrine, and reality.



The vigor with which BVR capabilities were pursued throughout the Cold War is puzzling considering there were only four BVR victories during the entire period. Following Vietnam, the USAF and Navy were perhaps concerned that the number of fighter wings—and fighters—would dwindle, thereby incentivizing procurement of what was deemed as more capable (read BVR) fighters vice larger numbers of less capable fighters. In this regard the services were much like the yuppie driving a high-end four-wheel drive Sport Utility Vehicle (i.e. Porsche Cayenne Turbo). Despite their touted off-road capability, most SUVs remain on pavement for their entire life cycle. The difference between SUVs and BVR, of course, is that the SUVs can actually function off-road when needed. Unfortunately, both approaches are costlier than the mission-matched alternative in terms of both acquisition and sustainment costs.

Cautions and recommendations for the future include the following:

1) Human factors trump technology. Training should garner a larger portion of the "transformation" budget. Transforming people is more important than transforming systems.
2) Technology is frequently overpromised and looks better in theory than in practice. A degree of wariness is needed when confronted by promises of lower maintenance costs or flawless performance of the next gadget/platform.
3) If technology, vision, and experience are not balanced as part of an overarching doctrine, the acquisition process will continue wasting resources on superfluous capabilities. Despite the improvements of the AIM-120 AMRAAM relative to the AIM-7, current IFF technology is still insufficient to warrant full-fledged BVR aerial combat.
4) US air supremacy faces asymmetric challenges in the future—anti-radiation missiles, counter-network operations, directed energy, electromagnetic pulse weapons, or geopolitical legal constraints. Incrementally improved BVR capability (i.e. F-22 and AMRAAM) does not help counter any of these challenges.
5) Weight is the most important factor in determining the total cost of ownership of fighter aircraft. Higher cost means more complexity, but not necessarily more capability (except on paper).
6) Visual-range kills result in better battle-damage assessment than BVR kills (Serbian MiG-29, Operation Allied Force, 1999, circulated via email).

[i] Stevenson, James P., *The Pentagon Paradox*, Naval Institute Press, 1993, page 54.

[ii] These characteristics of a "quality" fighter are adapted from Walter Kross who, like John Warden, comes down on the "high" side of the "high-low mix" debate (15 Feb 05 statements at AWC elective seminar).
Kross, Walter, Military *Reform: The High-Tech Debate in Tactical Air Forces*, National Defense University Press, 1985.

[iii] Burton, James G., "Letting Combat Results Shape the Next Air-to-Air Missile," USAF Slide Presentation, 1985.

[iv] Cohen, Eliot A., et al, *Gulf War Air Power Survey (GWAPS)*, US Government Printing Office, 1993 (unclassified version, Volumes 2 and 5).

[v] Stevenson, page 34.

[vi] Gunston, Bill, et al, *The Encyclopedia of Modern Warplanes*, Aerospace Publishing Limited, 1995, page 6.

[vii] Stevenson, page 54.

[viii] Stevenson, page 242.

[ix] Though contrary to current AF political correctness, the use of "F-22" rather than "F/A-22" is intentional, since the historic definition of "fighter" includes multipurpose aircraft also designed for attacking ground targets. AFDD 2-1 (page 9) acknowledges a fighters carry a "standard air-to-ground weapons load."

[x] Spinney, Franklin "Chuck," data base of various slide presentations and individual charts,
http://www.d-n-i.net/fcs/defense_death_spiral/dds_images/slide37.gif.

[xi] Stevenson, page 9. Historic IFF shortfalls are further discussed in Armitage and Mason, *Air Power in the Nuclear Age*, University of Illinois Press, 1985, page 267.

[xii] Burton, slide 2. Subsequent charts regarding these four conflicts are also adapted from the data collected by Burton.

[xiii] Flintham, Victor, *Air Wars and Aircraft*, Facts on File, Inc, 1990, page 70.

[xiv] Adapted from Burton's presentation, which used percentages and co-mingled missile type with aspect angle. Data for US victories was cross-referenced against information on the web site "Aerial Victory Credits" provided by Air University at http://www.maxwell.af.mil/au/afhra/wwwroot/aerial_victory_credits/avc_index.html.

[xv] Chant, Christopher, et al, The Encyclopedia of Air Warfare, Spring Books, 1975, pages 194 and 249.

[xvi] An allegation confirmed by Lt Col "Nigel" Doneski, during a discussion about this topic in AWC Seminar 7 on 29 Mar 05. Nigel is an F-15 pilot, frequent AIM-7 shooter, and credited with an aerial victory during Desert Storm…happily, with an AIM-9 Sidewinder.

[xvii] GWAPS and ACSC/DED, *Gulf War Toolbook*, ACSC Distance Learning, Multimedia Edition Ver 2.1, Maxwell AFB, 1998.

[xviii] GWAPS credits **41**. "Aerial Victory Credits" site cited in note 14 credits **40** (includes 2 kills with GBU-10 from F-15E and 2 kills with AIM-120 AMRAAMs from F-16Cs in 1992 and 1993, but does not credit any USN kills). ACSC *Gulf War Toolbook* cited in note 16 credits **43** (the same 41 from GWAPS plus one for F-15E/GBU-10 and one for EF-111A which allegedly caused an Iraqi F-1 to crash while in pursuit).

[xix] Per the Rules of Engagement, only USAF F-15Cs were cleared for taking BVR shots due to their Non-Cooperative Target Recognition (NCTR) system.

[xx] F-15C, call-sign CITGO 27, 26 Jan 91. The MiG-23 was in a flight with at least two others, who were engaged by CITGO 25 and 26. GWAPS is likely in error on the firing of five AIM-7s by CITGO 27, since F-15s only carried four, plus four AIM-9s. In contrast, today's F-15s can carry six AMRAAMs (the AIM-7 replacement) plus two AIM-9s.

[xxi] GWAPS

[xxii] GWAPS.

[xxiii] AU "Aerial Victory Credits" (cited in note 14).

[xxiv] Wolfe, Frank, and Muradian, Vago, "DoD Not Investigating Why US Missiles Failed to Down Iraqi MiGs," Defense Daily, Volume 201, Issue 2, Potomac MD, 6 Jan 1999.

[xxv] Stevenson, page 21, based on USAF Test Reports.

[xxvi] Stevenson, page 21, based on Pratt & Whitney engine data recorders.

[xxvii] Kluz, Ted, from a seminar lecture on 23 Sep 04 given as part of the Air War College "Technology and the History of Warfare" elective.