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The Sixth-Generation Quandary

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Panel 12. Considerations for Focusing Development and Controlling Growth in MDAPs

Thursday, May 5, 2016	
9:30 a.m. – 11:00 a.m.	**Chair: Nancy Spruill,** Director, Acquisition Resources & Analysis, Office of the Under Secretary of Defense for Acquisition, Technology, & Logistics ***Blockmodeling and the Estimation of Evolutionary Architectural Growth in Major Defense Acquisition Programs*** LTC Matthew Dabkowski, U.S. Army, University of Arizona Ricardo Valerdi, Associate Professor, University of Arizona ***An Assessment of Early Competitive Prototyping for Major Defense Acquisition Programs*** William Fast, COL, U.S. Army (Ret.), Senior Lecturer, NPS ***The Sixth-Generation Quandary*** Raymond Franck, Professor Emeritus, U.S. Air Force Bernard Udis, Professor Emeritus, University of Colorado at Boulder

The Sixth-Generation Quandary

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Abstract

During the Cold War and its aftermath, technical superiority was a core competency of the U.S. military, which relied on platforms that were high-performance, multi-role, expensive, and with long development times. This approach generally worked because adversaries couldn't easily counter those capabilities. However, the "unipolar moment" featuring the U.S. as the sole superpower may well be ending, and a number of capable rivals have emerged.

In this changed world, a well-considered, timely response is therefore strongly indicated. But U.S. acquisition programs are taking ever longer to field combat capability. At the same time, adversaries are becoming more sophisticated and agile.

Accordingly our paper addresses the following questions concerning 6th-gen air combat. First, what are the lessons learned from 5th-generation fighter programs, especially the F-35? Second, how many new 6th-generation fighter aircraft should the U.S. develop and field? Two, one, or none? Third, what are the likely building blocks of the kinetic component of the next generation of air combat forces? Fourth, what might all this mean for acquisition professionals?

Introduction

Based on open sources, a 6th-Generation Fighter(s) with an Initial Operational Capability (IOC) of 2030 is taken as a commitment, if not a requirement. However, Figure 2 strongly suggests that this is not an attainable goal within the current state of the art for defense acquisition management. Moreover, our adversaries (real and potential) are becoming increasingly sophisticated, agile, and capable. And the combination of those developments is central to the 6th-gen quandary.

Accordingly our paper addresses the following questions.

First, what are the lessons learned from 5th-generation fighter programs, especially the F-35?

Second, how many new 6th-generation fighter aircraft should the U.S. develop and field? Two, one, or none? We do not intend to offer a definite answer, but these alternatives should be (a) described and (b) provided with a rationale. We think doing this will be a useful addition to the ongoing discussion of 6th-gen air combat capabilities.

Third, what are the likely building blocks of the kinetic component of the next generation of air combat forces? The kinetic component is, of course, not the entire force, but we regard this as a prudent limitation for this paper.[1]

Fourth, what might all this mean for acquisition professionals? It's natural to expect that with changes in military affairs, there would also be changes in defense acquisition. In fact, there is good reason to believe that "we can't keep doing things the way we did before," as one authority on military aviation put it.[2] It also indicates that the operating environment for defense acquisition ("small A") is increasingly shaped by the imperatives of network-centric warfare, and the requirements process ("big A"), as depicted in Figure 1. And as we'll discuss below, there's good reason to believe that acquisition of systems will be supplanted by acquisition of systems of systems—at least to some extent.

During the Cold War and its aftermath, the United States could rely on technical superiority as a core competency, relying on "highly capable, multi-function platforms," which were expensive and had long development times. However, their "sophisticated military technology" could not be quickly or easily countered (Shaw, 2016). However, the "unipolar moment" featuring the United States as the sole superpower may well be ending.

Within this context, a number of the threats to U.S. air superiority are in place or developing, as part of access-denial military complexes, to include long-range, stealthy tactical fighters; ballistic and cruise-missile weapons capable of targeting U.S. air bases (land and sea). In particular, modern integrated air defenses pose a particularly acute threat to U.S. air superiority and therefore to global precision strike warfare. Threat systems include advanced surface-to-air missile (SAM) systems, highly networked command and control, improved ground and airborne radar systems and advanced airborne interceptors—all enabled by modern information technology.

Given these circumstances, a well-considered, timely response (offset strategy) is strongly indicated. However, U.S. acquisition programs are taking ever longer to field combat capability. The situation for tactical fighters is discussed below.

With the change in military affairs will likely come a change in acquisition needs and acquisition management practices, discussed below.

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[1] Based on space constraints, limitations on our areas of expertise, and (most important) on our current levels of clearance.

[2] An opinion offered not for attribution in May 2015.

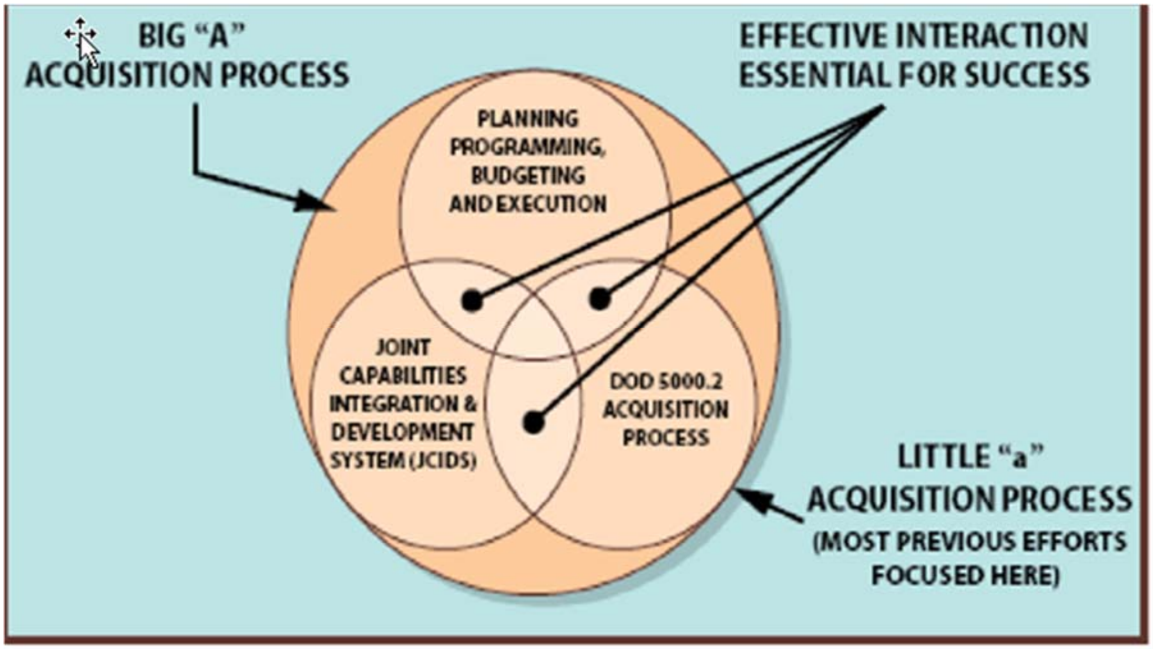

Figure 1. Depiction of the Defense Acquisition System
(Schwartz, 2014)

Air Dominance and Related Initiatives

One aspect of the U.S. response to the new international environment is a multi-faceted effort to study air combat needs for 2030 and beyond. A new start on next-generation air combat capabilities is underway with modest resource levels (e.g., LaGrone, 2015; DoD, 2014). It is, we think appropriately, a wide-ranging, and decentralized effort.

The multiple initiatives include the following:

- DARPA's air dominance initiative is charged to study means "for maintaining air dominance beyond the next decade" (Under Secretary of Defense for Acquisition, Technology & Logistics (USD[AT&L]), 2014). Its tasks include "exploring systems-of-systems concepts in which networks … interact to succeed in a contested battlespace" (Senate Appropriations Committee, Defense Subcommittee [SAC-D]), 2014, p. 4);
- An Air Force study of air dominance in 2030 and beyond, which was expected to issue a report in March this year (Tirpak, 2015);
- Navy initiatives which study replacements for the F-18 Super Hornet, to include new technologies and a joint analysis of alternatives, working with the Air Force (LaGrone, 2015);
- The Air Force Capability Collaboration Team, charged with identifying relevant technologies, drafting a course of action (road map) to field them. The team is expected to issue a final report in 2018 (Mehta, 2015).

1. Lessons From the F-35 Program

The F-35 experience has produced a number of lessons for future acquisition efforts. And there have been serious efforts to understand that experience and glean those lessons (some of which are cited in this section).

Cost Growth Was a Result of Acquisition Strategy

The F-35 emerged from Milestone B with a highly optimistic, success-oriented acquisition strategy: The "Milestone B program schedule, driven by the need to develop an affordable aircraft to replace aging combat aircraft, was aggressive and highly concurrent" (Blickstein et al., 2011, p. 37). Moreover, F-35 design requirements posed difficult design choices (Blickstein et al., 2011, p. 49, Table 4.6). Notably, an independent DoD cost estimate in 2001 rated the F-35 as high risk for both technical and schedule reasons (Blickstein et al., 2011, p. 37). Nonetheless, this fragile plan was adopted and pursued.

When unexpected difficulties (or problems that were assumed away) emerged during the SDD process, there were cost and schedule difficulties directly related to that problem. There were also "spillover" problems because of effects on other parts of the design. The result was a significant increase in cost and also significant delays (Arnold et al., 2010, esp. pp. 6–9; Blickstein et al., 2011, esp. pp. 39–41, 55).

Cost Growth Events Also Had Schedule Effects

F-35 experience suggests that platform density has also been a cost driver for aircraft. RAND's Root Cause Analysis of F-35 cost overruns contains some interesting observations. Requirements for stealth, supersonic flight (all models), STOVL[3] capability (B), and carrier landings (C) (Blickstein et al., 2011, p. 49, esp. Table 4.6). These requirements were frequently conflicting (Blickstein et al., p. 36); that is, the F-35 entered development with its engineering "trade space" considerably truncated. This design problem caused the cascading design issues that arose from a more powerful engine[4] (F-135 vice F-119): "the increase in thrust also lead to an increase in the engine size by a reported 1.5 inches in diameter. This small change in the engine generated a need to redesign the airframe, which in turn changed everything from aerodynamics to stealth signature, all of which needed to be re-baselined" (Blickstein et al., 2011, p. 53). While RAND's RCA focused on cost implications, there were schedule effects as well. These schedule slippages were reported (as of 2009) in Table 4.3 of Blickstein et al. (2011, p. 43)

Requirements Growth Was a Key Factor in Cost Growth

> *"Sometimes stakeholders despite their best intentions can derail your program."* —Maj Gen Christopher Bodgan, 2012

The Joint Strike Fighter began with timeliness and affordability as key program considerations. This was in its CALF (Common Affordable Lightweight Fighter) and JAST (Joint Attack Strike Technology) incarnations (Aboulafia, 2015, p. 8; Arnold et al., 2010, p. 2; Blickstein et al., 2011, p. 35). The design strategy then evolved to making the new fighter something described as a revolution in air combat (e.g., Laird et al., 2015). The acquisition strategy might then be described as devolving to the acquisition of that aircraft no matter how long it took or how much it cost.

Schedule Delays Had Wide-Reaching Effects

The IOC in the F-35 was scheduled for an IOC (Initial Operational Capability) in June 2011, 117 months after contract award (Blickstein et al., 2011, esp. p. 48). The F-35B

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[3] Short takeoff, vertical landing

[4] That, in turn, arose from actual weight exceeding planned weight.

(Marine Corps) was declared operational in July 2015 (166 months), with software limitations to operational capability. F-35A IOC is expected in late 2016 (~179 months; DOT&E, 2015). F-35C IOC is expected in late 2018 (~202 months; DoD, 2013).

The effects of F-35 delays were not limited to the JSF program itself. Delays meant deferred production, which, in turn led to shortages in fighter aircraft. Addressing these shortages, entailed keeping "legacy" fighters in service longer than planned, with associated O&S expenditures. It also meant new programs, and associated expenses to extend airframe life, and upgrades to lessen degree of obsolescence against improving threat (Tirpak, 2011). As one observer put it, "the failure of … fifth-generation fighters … to arrive on time and on cost is having cascading effects throughout U.S. and allied fighter forces" (Sweetman, 2012).

Joint Programs Don't Save Money

We believe a definitive answer to the joint-program cost question comes from a recent RAND report (Lorell et al., 2013). Its basic conclusion is that the practical disadvantages of joint programs outweigh their theoretical advantages. The putative advantages for joint systems programs are

1. Lower total R&D costs for one joint system vs. multiple single-service systems
2. One production line offers economies of scale and greater learning curve effects
3. Lower O&S costs for highly common models vs. total O&S for multiple types (Lorell et al., 2013, esp. pp. 12–14)

One practical disadvantage of joint systems is that there is inevitably a compromise between individual service needs and preserving design commonality, which practically guarantees lower system performance and less commonality than originally planned (Lorell et al., 2013, p. 20). And instead of cost savings, the RAND research identified "a joint cost growth premium" (pp. 10–11).

The result has been cost increases from joint programs, relative to single-service programs. The R&D cost savings have been more than offset by relative cost increases later in the life cycle. (This finding is summarized particularly well by Figure 3.2 [p. 27] and Figure 3.4 [p. 29] in Lorell, 2013).

The bottom line seems plain. Joint programs deliver less performance at higher cost. And this conclusion appears to have been taken as a lesson learned throughout the DoD (e.g., Seligman & Swarts, 2016).

How Many New Fighters?

A significant part of the ongoing discussion concerns manned fighters. It seems there's an emerging consensus for two fighters. However, that approach, while sensible, should not be chosen without full consideration of alternatives that appear discredited, or have been neglected.

Two New Fighters?

The case for two fighters appears to be highly credible with the two services most affected: the Navy and the Air Force. It draws much support from two sources. First is the F-35 experience, analyzed in a RAND study (Lorell et al. 2013) whose results are discussed above.

Second is the common-sense (and empirically-supported) view that Navy- and Air Force–designed operational roles (and design requirements) are sufficiently different that pursuing a common airframe is probably not indicated (e.g., Lt Gen James Holmes, quoted in Seligman and Swarts, 2016). These conclusions were strongly stated in a 2014 RAND research brief: "Unless the participating services have identical, stable requirements, DoD should avoid future joint fighter and other complex joint aircraft programs" (RAND, 2014).

A variant of this alternative is two aircraft with some common subsystems—engines and software being most commonly mentioned. The principal author of the 2013 RAND study, Mark Lorell, noted, "Initial analysis suggests jointly developed engines, avionics, and subsystems can lead to significant savings, even if these common elements are installed in completely different airframes optimized for different service requirement" (Lorell, 2015). And indeed, the two services are planning to collaborate on studies of new aircraft designs (LaGrone, 2015).

Based on publicly available sources, two aircraft with significant commonality is the most widely accepted view of the best approach to a 6th-generation fighter. The case for two aircraft summarized above for two aircraft (as opposed to one) makes persuasive points and appears to be what will emerge if nothing changes the current discussion.

One New Fighter: Apparently Discredited

However, it's possible to make a case that inadvisability of a multi-service program is based on a lesson overlearned. There are historical cases of one fighter aircraft being successfully developed for multiple users with different needs—both domestic and international. These include the F/A-18 (discussed below), in which one aircraft was adapted to multiple customers' needs and situations. Our take is that the F/A-18's success in service with multiple air services was due to good management, a user community governance structure, and transfer of technology sufficient to adapt the aircraft to customer-specific needs.

Among other things, having a clearly defined lead customer (U.S. Navy) provided a clear demarcation of responsibility that was not present in the JSF program. The Air Force's C-17 program was similarly successful (Franck et al., 2012, esp. pp. 20–21). Perhaps an even better example is the F-4 Phantom II, which was used by all three U.S. services (Navy, Air Force, Marines), plus a number of allied nations.

We consider the F/A-18 case in more detail below.

The RAND conclusions notwithstanding (Lorell et al., 2013), it might be premature to dismiss a joint program. But in any case, it would appear to be wise and emulate the F/A-18 and C-17 (Franck et al., 2012a, esp. pp. 20–31) approaches, rather than the F-111 and F-35. In short, joint-use systems can be successful if they do not start as jointly-managed acquisitions.

No New Fighters: Largely Neglected

Although advocating 6th-generation air combat as a system-of-systems problem (e.g., Prabhakar, 2015, p. 4), there has been no strong advocacy for no new fighters, with the possible exception of Admiral Mullen (quoted in McQuain, 2009). Until recently, that is. Rob Weiss, head of Lockheed-Martin's Skunk Works, recently stated that fielding a 6th-gen fighter should wait until 2045 (Tirpak, 2016).

It's easy to interpret this statement cynically; in effect, Weiss said that the Lockheed-Martin monopoly on new fighters should stay in place for at least another quarter century. One could also note that his first suggested priority is to complete acquisition of all the planned F-35s (and maybe more). His second priority is to "accelerate modernization of the F-22 and F-35" (Tirpak, 2016). Also, Weiss recommends minimized expenditures on 4th-gen fighters (Drew, 2016). This can translate readily to spending lots of money with Lockheed-Martin and minimizing how much goes to Boeing.

Nonetheless, there is a coherent case for delaying new fighters for a very long time. We'll try to summarize that case in this section. However, a variation of this alternative could include selections from the following list:

- a weapons truck (F-15SE variant perhaps),
- new models of the F-35 (perhaps optimized for air combat [Majumdar, 2014]),
- a variant of the B-21 as a long-range, multi-role aircraft,
- arsenal platforms (like B-52s [Harper, 2015a]), and
- UAV mother ships (like C-130s [Atherton, 2014]).

We'll essay a summary of that case in this section. It rests on the improbability of a 6th-generation fighter by 2030, or even 2035. It's also founded on a strategy emphasizing opportunities that are arguably more promising.

<u>The Time Curve Argues Against Timely Fielding of a New Aircraft</u>

First is the Time Curve. The time it takes to get new weapons system in service continues to grow, as shown in Figure 2. Lacking a serious bending of the "time curve" below, we can expect a new fighter no sooner than the late 2030s, even with a forced march from here to Milestone B.

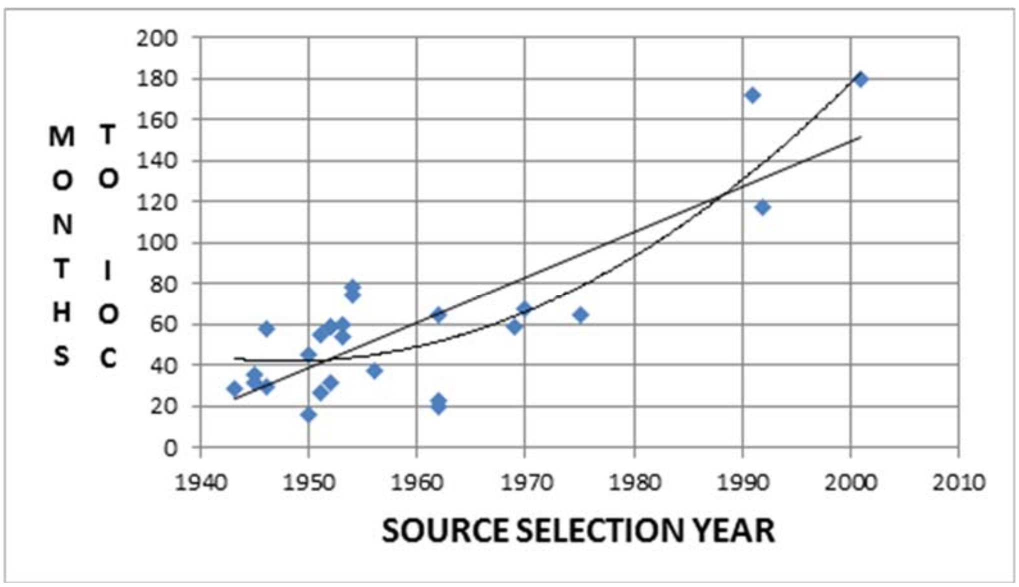

Figure 2. The Time Curve
(adapted from Blickstein, 2011, p. 48, Table 4.5)

Extrapolating from this curve gets us an IOC in the late 2030s, assuming a source selection and start of SSD in the early 2020s (which seems optimistic). This raises two critical questions for those advocating new airframes. First, how important is a 2030 IOC? Much public discussion of U.S. air combat capabilities (e.g., DSB, 2013) uses 2030 as a reference point. At one point, the commander of the Air Force Air Combat Command held the 2030 IOC to be a "requirement" (General Hostage, quoted in Mehta, 2012). Similarly, RADM Manazir (Navy Director of Air Warfare) has noted a need for a replacement for the Super Hornet fleet starting in 2030 (LaGrone, 2015).

Second, if an IOC sooner rather than later is preferred, how will we bend the Time Curve downward? The F-35 program set out to do just that (e.g., Blickstein et al., 2011, p. 43) but has turned out to be (at best) just an extension of the overall trend.

Exploit the Weapons Revolution

There have also been serious efforts to upgrade existing weapons and develop new-technology munitions. These include the following:

- Upgrade initiatives for older weapons, such as improved seekers (Tomkins, 2016) and warheads (Defense Industry Daily Staff, 2016) for Tomahawk cruise missiles; and new seekers for bombs (Tucker, 2016).
- New-technology developments such as directed energy (Wilson, 2015) and hypersonic missiles (Seligman, 2016);
- Unmanned, expendable UAVs (Tucker, 2016), including swarms.

These are in various stages of development, but all have attracted both interest, with the Secretary of Defense's stated willingness to fund their acquisition by cutting back on other programs (Harper, 2016a). In short, there's a case for emphasizing weapons now and letting the 6th-generation manned aircraft wait for a good while, perhaps until 2045. There's also a good case for upgrades of existing aircraft being a better exploitation of the weapons revolution than developing a new fighter aircraft.

Finish the Nail Soup

An old folktale is about starting with a nail in boiling water, and adding various ingredients to make an excellent meal.[5] The nail soup analogy applies here. An operational F-35 fleet, taken alone, looks a lot like that nail in boiling water; it's merely a start.

The F-35 has only four weapons stations in stealthy configuration. To contribute significantly to the fight, it needs to collect sensor data, fuse data, and bring other weapons to bear. One British commentator put it this way:

> If seamless interoperability is reached, the F-35 will allow … legacy assets to operate against targets and in areas which otherwise would be too heavily defended—either by providing targeting data in real time for stand-off munitions or by suppressing key defensive nodes to provide a window for the main force. (Bronk, 2016)

The same observation applies to the U.S. force. In addition, U.S. planners want the F-35 to direct stand-off strikes from non-stealthy platforms: "In practice, the arsenal plane will function as a very large airborne magazine, networked to 5th-generation aircraft that act as forward sensor and targeting nodes—essentially combining different systems already in our inventory to create wholly new capabilities" (Secretary Carter, quoted in Harper, 2016a).

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[5] One version of the story is available at http://wayback.archive.org/web/20020316195723/http://hem.fyristorg.com/kulturkemi/net/soup.htm.

That implies seamless interoperability and excellent networking, with a decentralized command and control focus. Or as ACC commander Gen Hawk Carlisle put it, “The centralized hub-and-spoke architecture becomes a decentralized many-to-many network” (Laird et al., 2015).

However,” networked operations” is much easier to say than to do. Just a year ago, for example, the Air Force reported difficulties in sharing operational awareness even within F-35 formations (Butler & Norris, 2015). Likewise reported was an unsatisfactory degree of connectivity between F-22s and F-35s, and other Air Force assets. Networking with other services was even worse: “USAF can’t buy a solution unless it’s compatible with an inter-service interoperability standard … and there may not be one, yet” (Tirpak, 2015). More recent reports likewise don’t indicate a quick or easy solution. According to RADM Mike Manzir, director of Navy air warfare,

> I would *hope* … that when that aircraft in the mid ’20s comes off the flight deck doing an ISR and tanking role, we can connect it through a waveform *still to be determined* to an F-35 or an E-2 or a Super Hornet and be able to give that aircraft commands. (emphasis added; Harper, 2016b)

In short, without networked operations, the F-35 doesn’t add all that much; and, judging from the open literature, we aren’t even close to achieving the networking that can “deliver the operational situational awareness critical to joint forces” (Wynne, 2012). Those problems are undoubtedly solvable, but doing that will take time, effort and resources. And reasonable people could decide that this capability is more important that what’s offered by a new fighter platform.

By the way, we do not take any position on the “how many fighters” question. We do, however, believe that all three approaches presented here have serious rationales. Our emphasis on “no fighters” reflects our perception that this alternative has received much less attention than is warranted.

Two Useful Questions

We close this part of the discussion posing two useful questions. There appears to be a consensus that stealth is a necessary condition for air operations in contemporary high-threat environments. This gets to our first question: is stealth sufficient? Second, is the F-35 platform sufficiently “persistent” to stay effective over a long operational life against improving threats?

<u>Is stealth sufficient for successful operations in high-threat environments?</u>

While the United States has emphasized stealthy designs, all concerned parties (including the United States) have been developing countermeasures to the stealth threat. The list includes the following:

- Advanced lower-frequency radars, which can cause a resonant return from a stealthy airframe (McGarry, 2014). New developments include phased-array radars operating in the VHF frequency band (Sweetman, 2015b);
- New-generation, higher-frequency, airborne radars such as SAAB’s ErieEye, which provide improved detection of lower-RCS targets and better tracking through improved interpretation algorithms (Sweetman, 2016);
- Bistatic (and multi-static) radar networks featuring passive receivers and rapid analysis of sensor information (Westra, 2009);
- Detection and tracking using non-radar emissions, such as heat (Sweetman, 2015a) and sound (Smith, n.d.);

- Far-forward airborne interceptors, such as the J-20, which could cause major problems for, *inter alia,* U.S. refueling orbits for stealth aircraft, particularly if China can improve its engines relative to those that are currently planned (Erickson & Collins, 2012).

Many of these programs are still in development, and it's safe to say not all will succeed. Nonetheless, these stealth countermeasures constitute a rich and promising menu. As time goes on, we can expect at least some of them to be operational and effective. While there are certainly counter-countermeasures possible, it may be difficult to keep pace (Sternstein, 2015). Or as an Air Force flag officer put it: "Emerging threats' timelines are decreasing. (Our) acquisition times are increasing."[6]

Second, is the F-35 platform sufficiently persistent to stay ahead of the threat environment over its very long operational life?

"Persistent platform" means a system that is sufficiently adaptable (with respect to both technical upgrades and new tactics) to remain effective despite changes in operational environment and mission. Lewis (2015) operationalized this idea in the context of the DDG-51 destroyer class, "(which) features the expandability (growth margin) and open systems characteristic that continues in ... service for a greater period of time than … originally ... contemplated." Franck et al. (2012, pp. 101–106) similarly narrates the persistent-platform aspect of the B-52's service.

While the F-35s may indeed age as well as DDG-51s and B-52s, and fit into Weiss' program of accelerated modernization (Tirpak, 2016), that's not self-evident. The set of requirements for the aircraft (supersonic flight, vertical landing, carrier operations, stealth) did much to reduce trade space (Blickstein, et al., p. 36, Table 4.1), and perhaps limit the expandability so important to platform persistence. (The "flying blivet"[7] epithet for the F-35 is unnecessarily pejorative, but not unfounded.)

The F/A-18 Case

This section is intended to amplify the rationale for one new fighter. While F-35 experience has rightly cast some doubt on the advisability of one fighter aircraft for many customers, the F/A-18 is a successful example of such a program. It has had multiple users, not only across services but across nations. This might have seemed unlikely since the F/A-18 was designed, to operate from catapult-launch carriers, most of which are in the U.S. Navy. Aircraft flying such missions require special features such as very strong airframes and undercarriages as well as hook mechanisms to facilitate carrier landings. Somewhat longer wings are also necessary to permit slower approach speeds.

Export Sales of the F/A-18

Deliveries of F/A-18 aircraft between 1980 and 2000 totaled 1,480, with over 400 exported (Powell & Renko, 2010). These countries purchased an already existing aircraft currently in use by the U.S. Navy, unlike the F-35 acquisition strategy. Hence, while some production modifications were possible, their role essentially is that of customer rather than a partner.

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[6] Observation offered at a 2015 symposium, not for attribution.
[7] A "blivet" is basically a large amount of stuff put into a small sack.

Many issues were resolved between the customer and the principal contractors. These include location of the assembly facilities and the identity of the organization performing that function, as well as subsequent maintenance and modification. This takes the U.S. government outside of the loop dealing with industrial participation in the buyer country.

Throughout the entire post–World War II period, countries buying foreign military aircraft and other advanced technology products have attempted to acquire the underlying technologies in order to lessen their dependence on foreign sources. Frequently, this goal also reflected a belief that advanced technologies were the key to modern economic growth and a higher standard of living. These demands for industrial participation often were a major factor in selecting the winner of contract competitions (Udis, 2009).

With the exception of Kuwait and Malaysia, all of the export buyers participated in the assembly of their aircraft, and in mid-life upgrades. Without exception, those nations claimed significant industrial benefits and technological advances from their experiences with the aircraft.[8] This was matched with a high level of satisfaction with the performance of their aircraft and their working relationship with U.S. Navy and industry personnel (Powell & Renko, 2010).

Worth noting is that carrier-specific design features (strengthened undercarriage and tail hook) did prove useful for some customers. For example, the Finnish and Swiss Air Forces operating concepts included launching and recovering their F/A-18s from selective sections of their highway systems (Embassy of Finland, personal communication, December 16, 2009; Embassy of Switzerland, personal communication, November 15, 2011), which greatly benefited from those features.

F/A-18 International Governance

Most disputes dealt with rather mundane issues like transfer of spare parts, and test and repair capabilities between countries that had already been certified as members of the F-18 user community. However, the F/A-18 international community had a governance structure that worked well in resolving many of these problems.

A very active user community discussed common problems with U.S. Navy and Boeing representatives. One important example deals with efforts by the Navy to have the State Department standardize and clarify the application of U.S. export control regulations to the activities of the F/A-18 Community (Powell & Renko, 2010). The work of the Community has been divided into several interest groups as follows:

- HISC: Hornet International Steering Committee;
- HIRG: Hornet International Requirements Group, now called CCC;
- THRILL: Logistics;
- AV TCM: Logistics and Engineering;
- LPIT: Logistics Process Improvement Team;
- FISIF: F/A-18 International Structural Integrity Forum;

[8] This and related information were obtained in a series of confidential interviews held with representatives of these five countries in June 2010 and February 2011

- CREDP: F/A-18: Composite Repair Engineering Development Program; and
- NDTWG: Nondestructive Testing Working Group (Embassy of Finland, personal communications, February 8 and 22, 2016).

Very close relations are maintained between members of the User Community and representatives of the U.S. Navy and Boeing (F/A-18 Users Group Meeting discussions, 2010).

Export Control and Technology Transfer Issues

Occasionally, there were conflicts with the United States over a need to protect technologies deemed crucial to national security, against an interest in making the most of a national (albeit imported) military asset. In the F/A-18 case, these conflicting goals were resolved in the context of U.S. export control and technology transfer regulations. However, relations were not trouble-free, particularly with respect to the application of U.S. export control and technology transfer regulations. Over time it became clear that authority was also necessary to allow users to coordinate joint development efforts. Finally, a memorandum of understanding was obtained in 2005 to address this issue. It allowed multinational exchange of information and initiation, conduct and management of cooperative efforts [and also permitted] cooperation in acquisition arrangements and research, development, testing, evaluation, and production (including follow-on support) efforts (Powell & Renko, 2010).

Despite such efforts at clarification and simplification, minor problems seemed to appear without limit, requiring creative attention. According to ITAR regulations, the export of components and spare parts required separate approval, even when they are to be used in support of previously approved and exported end products. The U.S. Navy played an important role in resolving such issues (Powell & Renko, 2010). Of particular significance was its role in dealing with customer concerns about the continued access to U.S. supplied parts and other essential components for foreign inventories as the Navy moved to retire its use of the F/A-18, series A-D. NAVAIR's International Programs group conducted a major effort to alleviate that potential problem through careful advanced planning (Powell, 2010).

Lessons Learned From the F/A-18 Experience

In multinational weapon systems projects, somewhat different results have emerged regarding the problem of dealing with administrative disputes, especially the U.S. export control and technology transfer regimen. There are several factors that may explain such different experiences.

- In the case of the F/A-18, there was one clear lead service, which had undisputed responsibility for program success. This was not a joint acquisition program.
- The nature of the purchase agreement may influence access to information. Foreign Military Sales (FMS) arrangements are more likely to be associated with liberal information sharing than direct commercial sales since the military service whose weapon system is involved in the transaction serves as something of an intermediary between the buyer and the U.S. government.
- An active interest community with a defined governance structure and robust communications channels can do much to resolve issue among the participating natures.

- Having a lead service willing to act as a champion for the other participating services is potentially useful in dealing with issues related to export control and technology transfer.

The F/A-18 community was generally successful in solving problems while satisfying the needs of the participating services. By way of contrast, we note the following statement from the Right Honourable James Arbuthnot, Chair of the UK House of Parliament Defence Committee concerning the F-35 experience: “In all candour, I would encourage UK industry to design around the ITAR and produce ITAR-free items” (Moore et al., 2011, p. 86).

A Notional Force for 2035 Air Combat

Starting with a concept of operations, we offer some thoughts on a future air combat force structure, with emphasis on the “kinetic” component. Based on open discussions of the topic, we think it’s reasonable to suppose the following constitutes a reasonable, if sketchy, concept of operations for an air offensive against a near-peer competitor in the late 2030s.

First Phase: targets include military command & control (especially for air defense and space), long-range strike assets, political control nodes, power projection forces (air, sea, amphibious). Objectives are to degrade enemy’s ability to exercise political and economic control; reduce force projection capabilities (particularly air and missile), and opponent’s control of airspace outside his frontiers.

Strike sorties involve stealthy aircraft operating forward to find targets and direct strikes, generally by air-breathing missiles fired from a distance). That is, weapons would be mostly standoff: hypersonic missiles, and subsonic cruise missiles.

Objectives are to degrade enemy’s ability to exercise political and economic control; minimize force projection capabilities (particularly air and missile), and reduce enemy’s air control outside his frontiers.

Second Phase is intended to roll back enemy air control to permit operations by aircraft carriers and arsenal ships against forces operating (or preparing to operate) outside of the enemy homeland. Among other things, it’s intended to enable operations of non-stealthy aircraft, mated with stealthy aircraft, in previously contested air space.[9] It also aims to degrade the opponent’s energy production and distribution capabilities. There would undoubtedly be further phases for the campaign.

The forces implied by this concept of operations include the following building blocks, and could be a useful benchmark for force planning and acquisition:[10]

- Stealthy aircraft intended primarily to obtain and share situational awareness with other forces;
- Non-stealthy, “legacy,” weapons carriers;
- Specialized “weapons trucks” (e.g., upgraded F-15s);
- Arsenal aircraft (large weapons trucks such as B-52s);
- C4ISR assets, both airborne and in space;

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[9] A concept called the “Wolfpack” (Wynne, 2012).
[10] An approach recommended by Jumper et al. (2009) and others.

- Naval forces to include arsenal ships;
- Land combat forces capable of taking and holding island bases; and
- Lots of tankers.

Getting from where we are to that force involves substantial efforts at networking, upgrades to existing aircraft, continue aerial tanker modernization, and lots of new non-nuclear weapons—plus a new fighter, maybe. There's no guarantee that the entire package would be affordable.

What This Could Mean for Acquisition Professionals

The 6th-generation air combat is clearly something of a quandary for warfighters (and therefore to the requirements community). It also is something of a quandary for the acquisition community.

First, there are at least three reasonable answers to the question of how many new fighters should be in the DoD's portfolio of 6th-generation air combat capabilities, depending in part on views of the requirements. There is accordingly good reason to pay more attention to what the requirements community specifies. As the JCIDS instruction puts it, "Close collaboration between requirements and acquisition communities is a key aspect of ensuring that knowledge gained early in the acquisition process is leveraged to enable the setting of achievable risk-informed capability requirements, and the making of effective cost, performance, schedule, and quantity trade-offs" (CJCS, 2015). That's always been sound guidance, but it's becoming even more important. It's critical to understand not only the requirements pertaining to a particular platform type, but how it performs within a larger system ("ecology" or "complex"). How to do it is a difficult problem.

Second, the 6th-generation quandary might well be a watershed event beginning a new era in defense acquisition management. The DoD appears to be doing less acquisition of platforms (systems) and more acquisition of systems of systems. An interesting representation of this idea is shown in Figure 3.

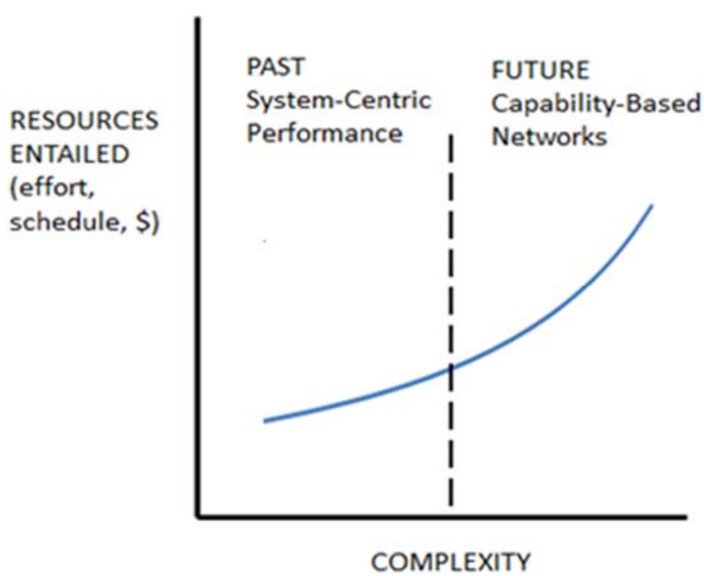

Figure 3. Changing Context of Defense Acquisition
(adapted from Angelis et al., 2008, p. 2)

Or as one DARPA official put it,

> The globalization of technology has made (previous practices) increasingly unsustainable. Potential adversaries are now able to access advanced technologies with relative ease and incorporate them quickly into military systems—sometimes accomplishing multiple upgrades during a U.S. weapon system's development and acquisition period. (Shaw, 2016)

Third, all of this likely means that Systems of Systems (SoS) Engineering will become a more important management method in the future acquisition enterprise. While we have no particular expertise in System of Systems Engineering, we think the following items are the key takeaways from System of Systems literature:

- SoS acquisition management is hard to do. Extant research (e.g., Angelis et al., 2008, esp. pp. 25, 29–30) strongly suggests that system of system acquisition programs are more likely to encounter cost and schedule difficulties.
- SoS research has identified causes for these difficulties (e.g., DeLaurentis & Ghose, 2008, p. 188; Huynh et al., 2011, p. 237). We take the central themes as being related to problems with coordination, organization, persistence of platform-centric management practices, and complexity (with emergent behavior of the system of systems).
- There have also been serious efforts to formulate methods and tools for dealing with SoS difficulties (e.g., Huynh et al., 2011; Shaw, 2016).
- Open-source reports indicate that those methods are not fully developed yet, or have yet to be fully applied (as discussed in the no-fighters rationale above).

In short, significant, ongoing changes in contemporary military affairs are driving the United States and its allies to networked, system-of-systems solutions to ever more difficult threats. However, acquiring systems is hard, and it's not clear that the tools available are up to the task of achieving good outcomes in such acquisition programs.

And it seems that the 6th-generation quandary poses significant problems for the operational, planning, and acquisition communities.

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