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THE VANISHING ARSENAL OF AIRPOWER

By Rebecca Grant

Mitchell Paper 4

Brig. Gen. Billy Mitchell

On September 12, 1918 at St. Mihiel in France, Col. William Mitchell became the first person ever to command a major force of Allied aircraft in a combined-arms operation. This battle was the debut of the US Army fighting under a single American commander on European soil. Under Mitchell's control, more than 1,100 allied aircraft worked in unison with ground forces in a broad offensive—one encompassing not only the advance of ground troops but also direct air attacks on enemy strategic targets, aircraft, communications, logistics, and forces beyond the front lines.

Mitchell was promoted to Brigadier General by order of Gen. John J. Pershing, commander of the American Expeditionary Force, in recognition of his command accomplishments during the St. Mihiel offensive and the subsequent Meuse-Argonne offensive.

After World War I, General Mitchell served in Washington and then became Commander, First Provisional Air Brigade, in 1921. That summer, he led joint Army and Navy demonstration attacks as bombs delivered from aircraft sank several captured German vessels, including SS *Ostfriesland*.

His determination to speak the truth about airpower and its importance to America led to a court-martial trial in 1925. Mitchell was convicted, and resigned from the service in February 1926.

Mitchell, through personal example and through his writing, inspired and encouraged a cadre of younger airmen. These included future General of the Air Force Henry H. Arnold, who led the two million-man Army Air Forces in World War II; Gen. Ira C. Eaker, who commanded the first bomber forces in Europe in 1942; and Gen. Carl A. Spaatz, who became the first Chief of Staff of the United States Air Force upon its charter of independence in 1947.

Mitchell died in 1936. One of the pallbearers at his funeral in Wisconsin was George Catlett Marshall, who was the chief ground-force planner for the St. Mihiel offensive.

ABOUT THE MITCHELL INSTITUTE: The General Billy Mitchell Institute for Airpower Studies, founded by the Air Force Association, seeks to honor the leadership of Brig. Gen. William Mitchell through timely and high-quality research and writing on airpower and its role in the security of this nation.

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Industrial base studies nearly always cite the present moment as a critical period in which one faces decisions fraught with consequences. They are not always right about this, but, in the case of the industrial base supporting American airpower today, they are dead on. Momentous change did in fact occur in the year 2009, and that meant the United States military faced decisions fraught with consequences.

Back in 2008, a report from members of the blue-chip Defense Science Board outlined a coming crisis that would be felt across the defense industrial base. The central danger of that postulated crisis was that, “while competition still occurs between a few firms in each sector,” the US federal government “can no longer benefit from a highly competitive defense market.”[1]

And that warning was issued well before Black Monday, April 6, 2009. On that date, the Defense Department announced a set of decisions affecting the Fiscal 2010 defense budget. These amendments called for termination of several critical defense aerospace programs, including the F-22 fighter, the C-17 airlifter, and the so-called Next Generation Bomber.

With these moves, the aerospace industry’s top customer more or less decamped from a significant share of the fixed-wing military aircraft market. As a result, major risk now suffuses the entire aerospace industrial base. The question is to what extent the nation can manage that dramatically enlarged risk and keep it from doing serious harm to future national security.

Consider the changes that now are in store:

- By 2012, the United States will have in operation just one fifth-generation fighter line—the Lockheed Martin F-35 facility in Fort Worth, Tex.
- Pratt & Whitney could be the only US engine house producing advanced fighter engines.

- When the C-17 line in Long Beach, Calif., closes—and that appears to be a matter of a few years, at best—the Lockheed Martin C-130J facility in Marietta, Ga., will be the sole US military airlifter plant.

- If the US is lucky and finally gets an aerial tanker program off the ground, the nation will have a production line for these vital types of airplanes.

- Medium- and high-altitude unmanned aerial vehicles, used for combat and sensor operations, will be built by a relative handful of specialized firms. A few will manufacture small UAVs.

The reality could not be clearer. The American arsenal of airpower, once a massive and thriving entity, has passed through a permanent transformation. This fact of life will exert an outsized impact on the Air Force, not to mention the Navy, Marine Corps, Army, and allies, as more and more aerospace workers exit the industry.

This paper assesses the impact of a collapsed industrial base as it affects the US Air Force in particular.

A SHOCKING TURN

The foul-weather forecast is a shocking turn, not least because the expected decline in military sales is taking place within an industry that appeared to be thriving after 2001 and is still posting relatively good quarterly results.

In the year 2008, total sales of US aerospace products and parts reached $257 billion, an increase of 3.4 percent over 2007 (not, however, adjusting for inflation). True, there was a drop in after-tax profits and in exports, two bleak developments which foreshadowed the toughening economic climate which began in late 2008. Even so, the Department of Commerce characterized the business activity of the period 2001-08 as "the largest upturn in the US aerospace market since World War II."[2]

Contained within that aerospace industrial surge, and helping to cause it, were the requirements generated by a fast-rising defense budget. Note, for example, that in the five-year stretch from Fiscal 2001 (with the onset of the Global War on Terrorism) and Fiscal 2006, awards to prime Defense Department contractors more than doubled, rising from $144 billion to $294 billion.[3]

However, this massive upsurge in military spending was not all that it appeared to be. During this time, several major programs approached the end of their production runs prior to full recapitalization. In addition, few new-start programs survived. Wartime supplementals funded some aviation procurement for airlift and unmanned vehicles, but not much.

By its nature, the huge Bush Administration defense "spending spree" of the early 2000s did little to stimulate development of the next generation of military aircraft. Military spending was focused heavily on the here and now—the re-equipping and re-supplying of forces, including air forces, fighting in Iraq and Afghanistan. It was money that was expended, intentionally, on the present, not on the future. Indeed, Defense Secretary Robert M. Gates criticized the latter kind of spending as being symptomatic of "next-war-itis," a disease he defined as "the propensity ... to be in favor of what might be needed in a future conflict."[4]

The dwindling away of major programs will unravel the decades-long process used to sustain US airpower. It is not simply a matter of running fewer programs for a smaller force. Major programs lie at the heart of everything from design innovation to training and seasoning of engineers and production specialists to sustaining company profits and investment. They provide the core of design teams, highly skilled production workers, and line managers who know how to move projects from computer screen to flight line and who constitute the most precious resource of the industry. The loss of major programs—and the people who work on them—creates a new level of uncertainty about whether the core elements driving the industry will even survive.

The experience of the aerospace industry over six decades provided a relatively rich pool of talent from which the industry could always find individuals ready to conquer the next technological challenge and to deliver better and better aircraft on schedule, or nearly so. This may no longer be the case.

Of course, airpower goes beyond fixed-wing aircraft. Airpower as defined most broadly includes those capabilities designed to dominate the linked domains of space and cyberspace. There, the outlook is much brighter.

The space industrial base is small and specialized. Yet a thriving commercial market provides robust earnings and prospects for innovation in this field. Space capabilities are not so heavily dependent on the defense budget, either. The cyberspace "industrial base" is a creature even more remote from Rosie the Riveter. It does contain truly industrial types of components such as machinery that generates electricity for, or the cooling of, server farms. Yet the signature capacity of cyberwar lies in the knowledge base and innovation of software applications, encryption, and integration of data. Exploitation of the cyber domain is a quintessentially human business. In these areas, the industrial base has experienced rapid growth through development and sale of commercial products. Few would say there is a crisis in the cyberspace "industrial base."

In addition, offshore capacity can help fill in for losses in American aerospace infrastructure. A portion of the airpower arsenal long has come from outside the US. Prominent prime contractors and suppliers from other nations have formed an indispensable part of major military aircraft programs. The first viable jet engine designs tested in America came from Britain. Global suppliers contribute to the massive Lockheed Martin F-35 program as they do to the Boeing 787 airliner. Wartime supplementals of recent years have been used to buy aircraft and helicopters from Italian consortia, to name just one foreign contributor.

For all these caveats, though, one cannot fail to see the difficulty that looms. The crisis is coming to a head. The core of the airpower arsenal rests with major fixed-wing military aircraft programs. There, investment is down, and the old model of reliance on a large number of thriving prime contractors and major suppliers has nearly vanished.

US AEROSPACE INDUSTRY

The 2009 decisions, taken in an effort to reshape the US military, are on track to squeeze the aerospace industrial base for military programs by destroying major programs and, perhaps, causing the exit of one or more of the few remaining large manufacturers.

Just what is this much-discussed "aerospace industry" that we refer to as the arsenal of airpower? And how has it developed over time?

The subject is complicated. There is no doubt that discrete industrial advances and techniques at times have played critical roles in the development of the postwar US military "economy." However, a large part of such development is unplanned and seems to come about almost by accident. The Labor Department, in a 2001 report on the American workforce, observed, "Our economy has evolved as much in response to social, political, and economic factors, such as wars and depressions, as it has to specific technological innovations."[5] One could reach the same conclusion about the aerospace industrial economy itself.

Equally complex is the task of simply defining who is in, and who is out, in the aerospace industrial base.

Since the 1810 US census, the nation has collected data on manufacturing in America. Use of organized statistical data came into its own in World War I. It was in the depths of the Great Depression that President Franklin D. Roosevelt authorized a central statistical bureau which has evolved today in the North American Industry Classification System. Defense work within the aerospace industry has never been treated as a separate element. Commentators on industrial policy may talk about "the industrial base," but there is no absolute, agreed upon definition of what that it is. Military and civil work blend together in official reporting of statistics on earnings or labor metrics.

As of 2008, according to government labor statistics, the aerospace production work force (including those engaged in work on civil aircraft, space systems, and missile systems) was made up of about 490,000 jobs.

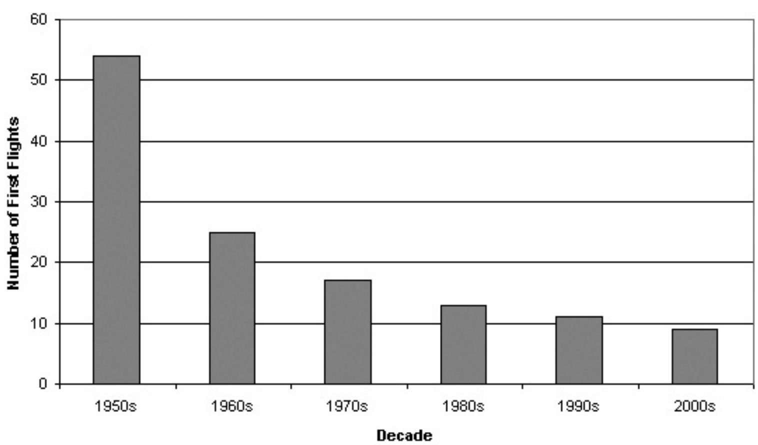
US aerospace workers are a special group. They are among the highest-paid in the US manufacturing sector. The Bureau of Labor Statistics does not separate military from commercial programs, but its findings on the workforce are insightful. As any program manager will attest, these people are the most important element of the military aerospace industrial base.

Production and related work—such as installation, maintenance, and repair—accounted for about 40 percent of the overall labor recorded in this sector.[6] (Other categories were professional—including aerospace and industrial engineers—management, financial, administrative support, and sales.) The average aerospace production worker logged a 43.8-hour week. Workers in other manufacturing jobs worked 41.1 hours, while the average for all industries was 33.9 hours. Aerospace workers were also well-compensated. The BLS found that, in 2006, weekly earnings for production workers manufacturing aerospace product parts averaged $1,153, compared with $691 in all manufacturing and $568 in all private industry.

Further, BLS noted, "Above-average earnings reflect, in part, the high levels of skill required by the industry and the need to motivate workers to concentrate on maintaining high-quality standards in their work."

Aerospace workers were also generally well-educated and well-trained. This is not a "nice to have" attribute, but one in which the industry invests heavily. "Because employers need well-informed, knowledgeable employees who can keep up with the rapid technological advancements in aerospace manufacturing, the industry provides substantial support for the education and training of its workers," noted the BLS. The consolidation of aerospace companies in the 1990s changed the face of the industry, pushing them more and

The Number of First Flights by Decade



more into large corporations. More than 60 percent of all aerospace workers are employed in companies with more than 1,000 employees apiece.

However, consolidation did not eliminate small businesses. According to the latest official statistics, the aerospace industry in 2006 included about 2,900 firms which manufactured aircraft and spacecraft of all types, plus guided missiles.[7] From work on the unmanned airplanes to support for new rockets, all fit within the aerospace industry. Many aerospace industry firms employ fewer than nine workers.

The industry is not moribund. Writ large, it is still a vital element of the American economy. According to data compiled by the Aerospace Industries Association, annual aerospace net sales, receipts, and operating revenues totaled more than $241 billion in 2008, up from nearly $229 billion in 2007.[8] The problem is the concentration of industry into just a relative handful of companies. Aerospace and defense ranked fourth when the sum of revenue was divided by the number of companies creating it.

The years ahead could hit the aerospace industrial base—the arsenal for airpower—harder than any changes of the past 60 years. Two major changes are in motion. First, the number of major fixed-wing aircraft programs will fall as production lines close. Second, there are few plans for new starts, which will curtail the number of programs reaching “first flight” in the 2010-19 decade.

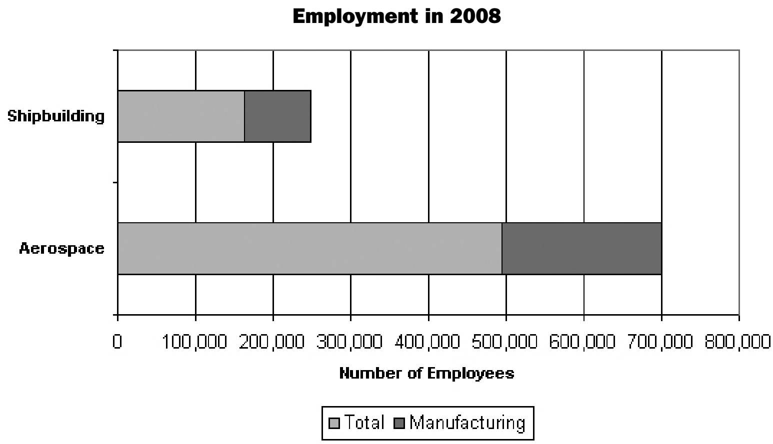
Together these facts will significantly reduce capacity and output across the industry. They lead inexorably to a decline in number of programs, and programs are key. Programs engage prime manufacturers as well as a range of partners and suppliers in large, productive ventures.

To view the industry from the standpoint of its programs is to gather the elements for success: customer demand and manufacturer supply. As programs diminish, jobs will also be lost and, with them, capacity. Major programs provide the primary conduit for extensive new hires of both professional and production personnel. Fewer programs will mean that fewer aerospace engineers and production specialists will be trained and gain the years of experience needed to generate new designs and run production lines efficiently. Education in science, technology, engineering, and math is an important part of this development, but equally critical is what happens to the individual worker long after he or she has left high school.

This dimension deserves examination, for it is central to the claim that a lack of major programs could be catastrophic.

BOOM AND BUST

Over the century of US military aviation, business activity has been cyclical, with certain patterns coming, going, and then coming back again. However,



Source: Bureau of Labor Statistics 2006 Annual Survey of Manufacturers, released 11/18/2008

the market has not seen indicators of a down cycle of this magnitude since 1920. That cycle lasted for some two decades, and finally ended only with the onset of World War II and its demand for vast numbers of military aircraft. Simply put, the model which has produced the American edge in airpower from P-51s to F-22s will start going out of business in 2011. Barring new serious and unforeseen threats, the program-driven model of innovation is unlikely to return.

The traditional model—innovation by competing major programs—actually evolved out of a pre-World War II period of aircraft development. As much as Americans love airplanes, the funding of aerospace programs has often been difficult to acquire and sustain. The federal government has taken immense risks with the aerospace industrial base before, and none more so than in its first decades.

The United States government, simply put, showed scant interest in military aviation. David R. King, a USAF officer whose doctoral dissertation was on the aerospace industrial base, wrote in *Air & Space Power Journal*, "Due to short-sightedness, the United States, despite having pioneered manned flight in 1903, found that by World War I its industrial base lagged that of other nations."[9]

The US Army was the first airplane customer, and government direction for military aviation began before the US entered World War I when Congress chartered the National Advisory Committee for Aeronautics in 1915.

The boom and bust cycle commenced almost immediately. According to historian Walter Boyne, cash allocations for the Air Service rose from $801,000 in 1916 to $18,681,666 in 1917 before soaring to $952,304,758 for 1919.[10] (While that was after the Nov. 11, 1918, armistice, the Allies had been gearing up for a big war-winning offensive in 1919 if needed.)

This immense and costly industrial surge came too late. Most US pilots flew French or British airplanes during the war.

By 1920, alarm about the scope of aviation spending had become intense. The first order of business for Congress after the war was to cut military spending. As a result, the first order of business for aircraft manufacturers was to cool off and reset to peacetime production levels.

However, the government went too far. Spending plummeted to just $26 million in 1920. By 1924, that already sickly budget was halved again, to $12 million. By the mid-1920s, the industry was foundering. "Of the pitifully small amounts of the budget remaining for aircraft, the majority was spent on the purchase of observation types for reconnaissance," wrote Boyne.

Leading airmen of the day had no beef with scaling back the near-outlandish wartime production. They just did not want to cut the fledgling industry to pieces. It was in the context of this air budget freefall that Billy Mitchell emerged as the loudest voice for preserving airpower and for wiser allocation of resources. "The present American industry is but a shadow of that which existed at the time of the armistice," lamented Mitchell in 1925.[11] He and others had hoped that civilian aircraft production would keep up the pace, but it didn't.

Mitchell's core argument was that the US should retain a much smaller industry with a "satisfactory nucleus" that could advance aircraft design. "By a 'satisfactory nucleus' is meant a number of aircraft manufacturers, distributed over the country, operating on a sound financial basis, and capable of rapid expansion to meet the government's needs in an emergency," Mitchell explained.[12]

The argument fell on deaf ears. "For the United States, the experience gained so quickly and at such great expense in World War I became irrelevant after 1918 as military budgets were slashed for the next 20 years," Boyne observed. Wall Street threw money at civilian airplane manufacturers after Lindbergh's 1927 flight.[13] However, such heavy investment did little to advance military aviation. In Boyne's view, the failure of the Allies to keep up with aeronautics was the reason Nazi Germany, though prostrate in 1932, could become "intimidating by 1935 and brilliantly effective by 1939."[14]

For World War II, it was surge again. In 1939, the US produced a measly 5,865 aircraft. From January 1940 through Aug. 14, 1945, America produced 303,717 aircraft.[15] That stupendous growth gave birth to the aerospace industry of today, so it's worth pausing to consider how that rapid growth was achieved. In retrospect, it appears that the United States mostly got lucky.

First, the growth was led by strong government investment and clear-cut direction. Plans came from the top: it was President Roosevelt himself who gave the order, in a famous speech, for the US to begin producing 50,000 airplanes per year.[16]

Second, the technology of the day permitted rapid transfer of personnel from one metal-bending industry to the next. Much of the growth occurred by transferring engineers and production specialists from other disciplines and factory lines. Perhaps the most dramatic example was that all production of cars for civilians stopped in 1942.

Third, the American economy had ample unused capacity and therefore lots of room to expand rapidly. The storied production surge was possible in part because of the latent manufacturing capacity in the American economy. The late 1930s were still recession years with lower production. The US also had a much bigger population base than most of the other belligerents. “United States production in World War II was about what one should have expected, given the size of the prewar technological-industrial base, the population size (three times that of Britain, nearly twice that of Germany, and greater than that of the Soviet Union after Hitler’s conquests in 1941),” said Gropman.[17]

Fourth, aircraft producers were able to tap excess labor. The lingering effects of the Great Depression had kept unemployment at a relatively high level. The growing aircraft industry was able to absorb many of these workers. The aerospace industry also hired more than half a million women to fill out its workforce. Transferable skills and an ability to break jobs down into tasks for which workers could be trained quickly were key. Workers eventually rewarded their employers with significant productivity gains as hours required to manufacture aircraft types plummeted from 1943 onward.

The results were amazing. Gropman noted that aircraft production floor space increased from 13 million square feet in the prewar period, to more than 167 million square feet in 1943, and the value of the facilities mushroomed from $114 million prewar to almost $4 billion in 1944. He said, “In 1940, the United States had 41 engine and propeller plants; in 1943 it had 81, with five built in Canada with US funds (nearly all of the 40 new factories were of considerably larger size than those that existed in 1940).”[18]

Finally, the surge was led by airmen with deep experience and strong vision. It was not a faceless bureaucracy that generated this output. The success of wartime production depended on direct, personal involvement by senior generals of the Army Air Forces. Men like Maj. Gen. Oliver P. Echols served continuously in the Materiel Division (later the Materiel Command) for the US Army Air Forces. Echols was a World War I Army Air Service veteran who spent two years in France, then rose to assistant division chief in 1939 when plans for accelerated production were first laid out. During the war, he was essentially tied to the duties at Wright-Patterson AFB, Ohio, or in Washington D.C., representing air interests in wartime production allocation.

The best example of all was Gen. H.H. Arnold. Arnold had numerous aircraft development assignments over a 20-year period. He was unsurpassed in—to use modern lingo—acquisition and research and development experience. Indeed, he could be topped by very few senior officers even today.
In sum, structural conditions allowed the US to undertake the surge in production. Yet the key element remained the government customer. World War

II created an industry behemoth churning out numerous new types of aircraft as well as massive quantities of existing types. It helped set the baseline for what is still regarded today as the ideal state of the market: a dozen or more strong, prime manufacturers working simultaneously on several well-funded programs. Quantity brought efficiency as the number of hours required to produce aircraft plummeted under full-scale war production.

After stunning growth, the industry after war's end in 1945 crashed nearly as rapidly as it had risen. It barely survived the late 1940s before it could enjoy the long demand waves for commercial airliners and military jets that began in the 1950s.

In the end, the dangerous postwar gap had been bridged. What Mitchell termed a "satisfactory nucleus" of manufacturing plants remained to produce the airpower of today. The 1950s and decades beyond would prove that, while the structure was program-centered, the real nucleus of innovation lay in the accretion and transfer of knowledge among the men and women working on the programs.

MODEL OF COMPETING PROGRAMS

Production activity in World War II could be characterized as a manufacturing surge. What came next was different. The decades that followed elaborated a deliberate policy of fostering the advance of military aircraft technology. Under these conditions, major aircraft programs became the prime engine of innovation and production. Programs built and refreshed the arsenal of airpower and shaped the modern aerospace industry.

"As long as you have enough major programs, you maintain your innovation." Those words spoken by a senior aerospace executive in the summer of 2009 perfectly captured the prevailing wisdom about what the industrial base needs.

Volumes of empirical evidence illustrate the point. The edge in US military aircraft grew after World War II, when gains made in the 1940s were consolidated with fast-paced research on a wide variety of programs. Technologies such as jet engines that were pursued during the war matured in the 1950s and beyond.

After the industry's uncertainty and contraction in the late 1940s, the aerospace industrial base entered a 20-year period in which many firms competed on a wide variety of projects. In the 1950s, Bell, Boeing, Cessna, Convair, Douglas, Fairchild, Grumman, Lockheed, McDonnell, North American, Republic, and Vought all produced new designs. Some, such as the Bell X-15, were experimental and did not generate large production runs. Some were forgettable. Others, such as the Boeing B-52 bomber, became classics of airpower. The performance ranged from the venerable Cessna T-37 trainer to the still-unsurpassed North American X-15 aircraft.
There was some obvious specialization, as in the case of Boeing with its large aircraft successes. However, there was also striking diversity in the number and types of aircraft designs pursued by each individual major manu-

facturer. One case in point: Lockheed, which, in the mid-1950s, rolled out the C-130 tactical airlifter, the radically different Mach 2 F-104 fighter, and the unique, extremely high-flying U-2 reconnaissance airplane.

The last 100 or so major programs for military fixed-wing aircraft (for the Air Force and Navy) have much to tell about the workings of the industrial base. The list (p. 13) tallies military fixed-wing aircraft for the Air Force and Navy that made their first flights in 1950 or later. These programs included major designs and modified designs in which substantial alterations were made. For example, the F/A-18A/B/C/D, the F/A-18E/F, and the F/A-18G are posted separately. However, the F-16 is counted just once despite its numerous and highly effective block upgrades.

The chief criterion for inclusion was that the aircraft made first flight. Accordingly, the ill-fated Navy A-12 is absent, while the secret Tacit Blue aircraft is included because it made 132 test flights in the early 1980s. (Lockheed's A-12 precursor to the SR-71 is included.) Getting a new aircraft to first flight represents the prowess of a design team, notwithstanding the ultimate production decisions or the fact that many first-flight articles demanded months or years of additional work to achieve production readiness. Introducing new types is not the only goal for the industry. Other aims, such as controlling cost and executing maintenance and upgrades, are important. However, the fundamental measure of merit, over time, is the ability to innovate and meet new requirements. In this, programs are a valid measure.

Overall trends are dramatic. Of the last 129 programs, only 20 achieved their first flights in 1990 or later. Among these are standouts such as the C-17, the two Advanced Tactical Fighter competitors—the YF-23 and YF-22 (later F-22)—and the X-32 and X-35 (later F-35) duelists in the Joint Strike Fighter competition.

The trend after that is even worse. A mere nine of those 129 programs reached first flight in the 2000s, beginning with the two F-35 candidates (X-32 and X-35) in 2000 and ending with the Boeing P-8A Poseidon in 2009. There were four different companies represented in the 2000s, including relatively new entrant General Atomics.

Pan wide and it's easy to see why the lack of programs moving ahead worries so many. Distribution of work in the past spread a few new programs nearly every year among a base of more than a dozen companies. Top suppliers delivered a large number of new models. Grumman, for example, delivered 12 aircraft to first flight, from the derivative F9F-6 Cougar in 1951 to the X-29 in 1984.

In the 1950s, more than a dozen companies struggled to realize the visions of the late 1940s for products ranging from jet fighters to unmanned drones to reliable air transports. Memorable aircraft such as the F-94 fighter and the B-47 bomber had been tested late in the decade. In the 1950s, 54 new

Continued on p. 17

First Flights, 1950-2009

A cluster of successful types debuted from 1947 to late 1949, thus narrowly missing the cutoff for this table, which lists types with first flights in 1950 and later. These include the Fairchild C-123 Provider, Boeing B-47 Stratojet, North American F-86 Sabre, and Lockheed F-94.

Year of First Flight	Type	Maker	Nickname
1950	XA2D-1	Douglas	Skyshark
1950	XF-96A/XF-84F	Republic	Thunderstreak
1951	F9F-6 (F-9F)	Grumman	Cougar
1951	XQ-2	Ryan	Firebee
1951	X-1	Bell	
1951	X-5	Bell	
1951	X-7	Lockheed	(Ramjet research drone)
1951	XF3H-1	McDonnell	Demon
1951	F4D (later F-6A)	Douglas	Skyray
1952	X-2	Bell	
1952	X-3	Douglas	
1952	XA3D-1 (later A-3A)	Douglas	Skywarrior
1952	XA2J-1	North American	Super Savage
1952	S-2	Grumman	Tracker
1952	YB-60	Convair	
1952	F10F	Grumman	Jaguar
1952	XB/YB-52 (B-52)	Boeing	Stratofortress
1953	F2Y (later F-7)	Convair	Sea Dart
1953	X-10	North American	
1953	YF-100A	North American	Super Sabre
1953	YF-102	Convair	
1954	YF-102A (F-102)	Convair	Delta Dagger
1954	F-101A	McDonnell	Voodoo
1954	XA4D-1 (A-4A)	Douglas	Skyhawk
1954	RB-66A	Douglas	Destroyer
1954	C-130 (70 variants)	Lockheed	Hercules
1954	XF-104 (F-104)	Lockheed	Starfighter
1954	F11F (orig. XF9F-9)	Grumman	Tiger
1954	XFV-1	Lockheed	
1955	X-1E	Bell	
1955	X-13	Ryan	
1955	TF1 (later C1A)	Grumman	Trader
1955	B-66B	Douglas	Destroyer
1955	P6M	Martin	SeaMaster

Year of First Flight	Type	Maker	Nickname
1955	XF8U-1	Vought	Crusader
1955	U-2A	Lockheed	Dragon Lady
1955	YF-105A	Republic	
1955	T-37	Cessna	Tweet
1956	YF-105B (F-105B)	Republic	Thunderchief
1956	KC-135	Douglas	Stratotanker
1956	F5D-1	Douglas	Skylancer
1956	WF-2 (later E-1B)	Grumman	Tracer
1956	F-106	Convair	Delta Dart
1956	F-107A	North American	
1956	YB/RB-58 (B-58)	Convair	Hustler
1957	X-14	Bell	
1957	F-101B	McDonnell	Voodoo
1958	XQ-2C (BQM-34)	Ryan	Firebee (Lightning Bug)
1958	YA3J-1 (later A-5)	North American	Vigilante
1958	YF4H-1 (Navy F-4)	McDonnell	Phantom II
1958	T-2J-1 (later T-2A)	North American	Buckeye
1959	X-15	North American	
1959	X-18	Hiller	
1959	YT-38 (T-38)	Northrop	Talon
1960	A2F (later A-6A)	Douglas	Intruder
1961	P-3A	Lockheed	Orion
1961	E-2A	Grumman	Hawkeye
1962	A-12	Lockheed	
1963	F-4C (USAF version)	McDonnell	Phantom II
1963	YF-5A (MAP*)	Northrop	Freedom Fighter
1963	YF-12	Lockheed	
1963	X-19	Curtis-Wright	
1963	X-21A	Northrop	
1963	C-141A	Lockheed	Starlifter
1963	YAT-37D (A-37A)	Cessna	Dragonfly
1964	XB-70	North American	Valkyrie
1964	X-15A-2	North American	
1964	F-111A	General Dynamics	Aardvark
1964	SR-71	Lockheed	Blackbird
1964	C-2A	Grumman	Greyhound
1965	YA-7A (A-7)	LTV	Corsair II

Year of First Flight	Type	Maker	Nickname
1965	OV-10	North American	Bronco
1966	D-21	Lockheed	Tagboard
1966	X-22	Bell	
1967	U-2R	Lockheed	Dragon Lady
1968	C-5A	Lockheed	Galaxy
1968	EA-6B	Grumman	Prowler
1968	C-9	McDonnell Douglas	Nightingale
1968	Model 166 (BQM-34E/F/T)	Ryan	Firebee II
1970	F-14	Grumman	Tomcat
1970	X-28	Pereira/Osprey	
1972	YS-3A (S-3)	Lockheed-LTV team	Viking
1972	YA-9A	Northrop	
1972	YA-10 (A-10)	Fairchild	Thunderbolt II (Warthog)
1972	F-15A	McDonnell Douglas	Eagle
1973	E-4	Boeing	
1974	YF-17	Northrop	Cobra
1974	YF-16 (F-16)	General Dynamics	Fighting Falcon (Viper)
1974	B-1A	Rockwell	
1975	E-3	Boeing	Sentry
1975	F-4G	McDonnell	Wild Weasel
1977	EF-111A	Grumman	Raven
1978	Have Blue	Lockheed	
1978	F-18A (later F/A-18)	McDonnell Douglas	Hornet
1978	YAV-8B (AV-8B)	McDonnell Douglas	Harrier II
1979	C-20 (Gulfstream III)	Gulfstream	
1980	KC-10	McDonnell Douglas	Extender
1981	F-117	Lockheed	Nighthawk
1982	F-16XL	General Dynamics	
1982	F-20 (orig. F-5G)	Northrop	Tigershark
1982	Tacit Blue	Northrop	Whale
1984	X-29	Grumman	
1984	B-1B	Rockwell	Lancer
1985	C-5B	Lockheed	Galaxy
1986	F-15E	McDonnell Douglas	Strike Eagle
1986	RQ-2A	Pioneer UAV Inc.	Pioneer
1988	T-45	Boeing-BAE	Goshawk
1988	E-8	Northrop	Joint STARS

Year of First Flight	Type	Maker	Nickname
1989	B-2	Northrop	Spirit
1990	X-31	Rockwell	
1990	YF-22 (F-22)	Lockheed	Raptor
1990	YF-23	Northrop	Black Widow II
1991	C-17	McDonnell Douglas	Globemaster III
1994	RQ-1 (now MQ-1)	General Atomics	Predator
1995	F/A-18E/F	Boeing	Super Hornet
1996	Bird of Prey	Boeing	
1996	C-130J	Lockheed Martin	Super Hercules
1997	V-22	Bell-Boeing team	Osprey
1998	T-6	Raytheon	Texan II
1998	RQ-4	Northrop Grumman	Global Hawk
2000	X-32	Boeing	
2000	X-35 (F-35)	Lockheed Martin	Lightning II
2001	MQ-9	General Atomics	Reaper
2002	X-45	Boeing	
2003	X-47A	Northrop Grumman	Pegasus
2006	C-5M	Lockheed	Super Galaxy
2006	EA-18G	Boeing	Growler
2007	E-2D	Northrop Grumman	Advanced Hawkeye
2009	P-8A	Boeing	Poseidon

MAP = Military Assistance Program

Continued from p. 12

programs were shepherded to first flight by 15 separate companies. The KC-135 and C-130 entered production in the 1950s and remain mainstays today, with the C-130 still in production.

The 1960s were almost equally productive. Twelve companies introduced a total of 25 new aircraft. One strategic exit was made by Boeing, which thrived during the decade with sales of the KC-135 and a growing customer base for its 707 airliner. Lockheed and North American pushed the design envelope for supersonic aircraft with interceptors and a bomber capable of Mach 3+ flight. Unmanned vehicles such as the Firebee proliferated as solutions to reconnaissance problems.

In the 1970s, the US built on the lessons of Vietnam and made it the era of the fighter. The Air Force's F-15, F-16, and A-10, as well as the Navy F-14 and F/A-18 all debuted during this decade. The one bomber developed in this decade was the B-1A and it looked and flew like a fighter. Boeing briefly re-entered the market with sales of the E-3 Airborne Warning and Control System aircraft and the E-4, based on its wide-body types. Lockheed and Northrop spearheaded a race for stealth across several secret programs.

The decade of the 1980s will be remembered for its strong production of large quantities of 1970s aircraft. It also saw the debut of a new tanker/airlifter, two bombers, and two fighter-bombers. The arrival of the B-1B and the first flight of the B-2 recapitalized Air Force long-range aviation. Unfortunately, neither program unfolded according to plan, and their stumbles cast a long shadow on future aircraft procurement. The slow decline in primes began in this decade; eight firms brought new designs to first flight.

The 1990s was a decade that saw the second significant slowing in the introduction of new types of aircraft. At the same time, the Air Force held back in its fighter acquisition while pressing for the development of new stealth fighters. Boeing re-entered the military aircraft business through partnership on the F-22 Raptor and even more important, with major strategic acquisitions taking over the C-17 and F/A-18 programs. Privately held General Atomics reaped success with the operational use of its Predator unmanned airplane late in the decade. Northrop Grumman first flew its new high-altitude Global Hawk in 1998.

In the 2000s, first flight programs tapered off, and the Defense Department held only one major successful competition: the Joint Strike Fighter. (USAF held a competition for a new tanker, but a successful protest prompted a restart that DOD aborted in late 2008; USAF began the process again in September 2009). General Atomics capitalized on its Predator success with a larger, hunter-killer version, the Reaper. With a scant nine first flights (including the two JSF contenders) for military aircraft, the first decade of the 21st century looked a bit like the period 1903 to 1910.

The diminished number of first flights represented the culmination of several trends. Without question, one was the increasing sophistication of aircraft like the F-35. Another was the importance of space and cyberspace. Still another trend not fully captured by these criteria was the uptick in unmanned airplanes, especially the short-range, low-altitude craft that don't even find a place on this first-flight list.

The impact of this dramatic slowdown can be seen by reviewing one of the most successful program-based rivalries of all time.

CASE STUDY: NORTHROP VERSUS LOCKHEED

In 1981, the B-2 stealth bomber program was awarded in great secrecy to a self-described dark horse—a contractor that had not built a bomber since it produced a few prototypes of the YB-49 Flying Wing in the 1940s. That company was Northrop, which beat out Lockheed, a company that had an equally secret stealth demonstrator already flying. The initial contract was for $9 billion. Production of the B-2 would stimulate computer-aided design, composite fabrication, and a host of other developments across the aerospace industry.

The award was not a fluke but the result of careful investment and policy decisions reaching back a decade and spanning several presidential administrations. Those decisions stimulated research and development and production through specific and ambitious requirements for major programs.

From the early 1970s through today, those two firms—Lockheed and Northrop—have squared off against each other in highly directed competitions. They dominated the race until Boeing re-entered the fray in the mid-1990s. The B-2 bomber was just a waypoint on the path of this contest. The competition started with the first prototype stealth fighter in the 1970s and has continued with concepts for a next generation bomber for 2018 and beyond. Along the way, the two medium-size aircraft manufacturers founded prior to World War II became two behemoths, Lockheed Martin and Northrop Grumman.

These titans of industry pitted their experimental designs against each other in a series of competitions from the early 1970s through this decade. Keeping them as competitors was deemed so important that the US government nixed their merger in 1998. The competition between these two leaders of advanced aircraft development has illustrated the key role of program-based competition in the health of the aerospace industry.

HARNESSING STEALTH

Radar cross section reduction for aircraft became a goal as soon as Britain and Germany put early warning radar systems in place during World War II. The Germans in particular experimented with both designs and coating material, but it was British development of radar-obscuring chaff that proved the most effective counter during the war. Aerospace engineers had decades of work ahead of them to make stealth viable and then to extract from it high performance.

In the 1950s, technologists returned to experimental concepts for minimizing radar cross section for aircraft and missiles. At the same time, evaluation of smooth shapes for missile re-entry vehicles and for cruise missiles helped push the art further. During the early 1960s, experiments with missiles such as Hound Dog and aircraft such as the Lockheed A-12 and SR-71 added radar cross section reduction as a design parameter. However, it was the burgeoning of Soviet-made air defenses that forced serious investment in stealth aircraft.

The idea of stealth began to jell in the early 1960s in various forms. Small-scale government contracts were let to maintain small teams of engineers who studied the radar cross sections of known objects such as airliners and missile nosecones. Most were experts in radar phenomenology. Their research focused on how radar worked and how to enhance its performance. Occasional studies of how to evade it helped create an initial basis for what became stealth engineering.

Glimpses of promising stealth technologies led the Air Force and the Pentagon's Advanced Research Projects Agency to open up a competition that would help both government and industry break barriers and assess the feasibility of stealth aircraft. Entry into what became the business of stealth depended heavily on whether an aircraft company had a nucleus of a stealth design team. The government cast a wide net among companies to see who could develop the technology. ARPA famously sent a letter to five companies who manufactured fighters—and just as famously forgot Lockheed, which had an extensive secret history of stealth development for CIA spy aircraft.

Thus began the fascinating tug-of-war between Lockheed and Northrop. The government encouraged each contender through ongoing contracts and a steady pace of new program work. It was a crucial step, as the best long-term approach to radar cross section reduction was not yet clear.

Lockheed made early strides with faceted aircraft such as the concept demonstrator that became the F-117. Northrop started with curved shapes that owed much to the design team's background in radar phenomenology and cruise missile shape reduction. Setting up a competition of facets versus curves greatly oversimplified the problem but led to different approaches in significant features such as airframe design and application of radar absorbing materials.

ENTER THE B-2 BOMBER

The competition did not stop after Lockheed beat Northrop for the F-117 program. Northrop continued to work on a government contract for a battlespace control aircraft later named Tacit Blue. Each company had one win under its belt and felt it had narrowly lost to its rival when they squared off for a stealth bomber design.

An engineer on the winning Northrop team specifically credited the previous years of work as preparation for the victory. "We knew more about predicting radar cross section of three-dimensional shapes than anybody in the world because of the Air Force contracts experience," he said.[19]

An equally important foundation for the advanced technology race of the mid-1970s had been laid in the 1950s with the large number of fighter programs spread across the industrial base of that era. "Almost every company in the industry built some, including Douglas, Grumman, Lockheed, McDonnell, North American, Northrop, Republic, and Vought," one historian pointed out.[20] In turn, these companies were still moving forward, based in large part on their World War II experience in designing and producing manned aircraft.

What that meant specifically for the B-2 was that while Northrop had not recently built a bomber, it had fighter experience. In a sense, the fighter business had left Northrop with the management, expertise, and the cash to get into the new market for stealth being created by ARPA and the Air Force. Northrop transferred its current F-5 fighter program manager to run the bomber proposal team. Northrop's chief executive officer, T.V. Jones, also had the wisdom to team fast with Boeing to build major sections of the bomber.

Fighter work in the 1950s and radar cross section work in the 1960s turned out to be key elements of the skill set for highly innovative design of stealth aircraft in the 1970s and 1980s. A wide base of experience narrowed to the specific point necessary to produce the B-2 design and execute the first pole models.

In the end, the Lockheed and Northrop bomber designs were distinct, just as intended. Lockheed gambled on a medium-size aircraft while Northrop committed to a big, long-range bomber and in those choices lay a key discriminator. "Because our airplane was designed to be smaller, the control surfaces on the wing were smaller, too, which meant we needed a small tail for added aerodynamic stability," Lockheed Skunk Works honcho Ben Rich later explained. "Northrop had larger control surfaces and needed no tail at all," Rich said, and that helped propel them to victory.[21]

BATTLE OF THE STEALTH FIGHTERS

The momentum of competing design teams with nearly a decade of experience made it possible to take on the immense challenge of a supersonic stealth fighter.

The Advanced Tactical Fighter was by far the toughest program in the stealth family. Both Lockheed and Northrop had studied the problem of a supersonic, stealth fighter in the late 1970s and found it to be extremely demanding. However, the Air Force took the plunge. In the early 1980s, it funded work on an ambitious set of requirements for the program later known as the F-22.

Industry was strong enough to handle it. The 1990 flyoff between Lockheed's YF-22 and Northrop's YF-23 again pitted two different aircraft against each other. Lockheed's fighter emphasized maneuverability. Northrop's elongated YF-23 offered significant stealth and range. In a mirror image of the airframe competition, the Air Force also tested a Pratt & Whitney engine against a General Electric engine. Both prototypes achieved supercruise with each engine type.

The Air Force customer was left with a pleasant choice of aircraft with superb capabilities representing two rather different design philosophies. Both had the indispensable element of supercruise and both did well in flight tests. Ultimately, the YF-22 was chosen in April 1991. It was far from a mature system, and Air Force Secretary Donald B. Rice knew major challenges lay ahead. He summoned the CEOs of Lockheed and partners Boeing and Pratt & Whitney to a meeting where he threatened to transfer the building of the F-22 to the government if the prime contractors failed to meet design goals and cost criteria. In the end, the first production F-22 flew in 1997.

By that time, the government was attempting to duplicate the successful competition on an even larger scale with the Joint Strike Fighter. Senior leaders had technology innovation in mind when they funded work on the Joint Advanced Strike Technology (JAST) program in 1994. The initiative was a turning point for the aerospace industry. It was born after cancellations of the Air Force's multirole fighter and the Navy's stealthy attack aircraft program. The Air Force had the F-22 heading to production, and the Navy was at work on the F/A-18EF Super Hornet, which made its first flight in 1995. A separate effort involving Britain was researching the next step for vertical takeoff and landing aircraft to replace the Harriers used by the Marine Corps.

Looking ahead, there were fears that the services could not pay for multiple new-start programs due to cuts in the defense budget. Keeping some technology research alive by funding various study teams was the interim solution. JAST was originally chartered in January 1994 as a technology development program to nourish research without necessarily dictating the final product. Its official mission was to define and develop aircraft, weapon, and sensor technology that would support the future development of tactical aircraft.

A handful of research and development programs were canceled with the intent that JAST would explore many facets of strike technology, from airframes to sensors and subsystems. In December 1994, for example, the Pentagon announced awards of 24 contracts. They ranged from $20 million-plus deals with prime manufacturers for joint strike weapon system concept design research on air vehicles, to smaller contracts for EO/IR sensors, scalable processors, and on-board, off-board information fusion.[22]

Just as important, early JAST work was spread across several companies. The JSF program demonstrator bid was one of the last from an independent McDonnell Douglas. By 1996, just two teams led by Lockheed Martin and Boeing were flying their demonstrators. This time, Northrop Grumman had joined the Lockheed team.

The Joint Strike Fighter program opted for an aircraft design based on far more mature technologies. Where the F-117, B-2, and F-22 leaped over significant hurdles, the JSF requirements were controlled to contain cost. The three variants—conventional takeoff and landing, carrier, and short takeoff/vertical landing—of the F-35 relied on enough common or cousin parts to share a production line and to ensure that every buyer could benefit from the learning curve of full-rate production.

This was a first in stealth aircraft development. One thing the stealth competitions had not done was to create production lines controlled for cost. The small quantity purchases were the main reason. Early program cancellations defeated attempts to achieve economic order quantity (EOQ). For example, the F-22 line was set for EOQ of 32 aircraft per year, but never topped 24 aircraft per year due to budget constraints. Not until commitments were made to scale the Joint Strike Fighter up to a potential for 3,000 or more units was there even a chance of achieving economies.

END OF THE MODEL?

It is far from certain that this time-proven system of keeping skilled competitors in the game will continue. In the 2000s, Lockheed Martin, Northrop Grumman, and Boeing dedicated resources for initial work on unmanned airplanes and long-range bomber concepts. All three spent their own corporate funds for research and development in addition to working on government contracts.

All contenders continued to draw on the deep experience of their teams as cultivated over the decades. Lockheed's Skunk Works meanwhile sharpened its skills by flying a separate demonstrator known as Polecat. Northrop faced off with Boeing over an experimental, stealth unmanned airplane. First Boeing, then Northrop Grumman (teamed with Lockheed Martin) came out ahead in the program that became the Navy's Unmanned Combat Air System (UCAS) demonstrator. "Here's a program we lost to Boeing in 1999 and took back from Boeing in 2007," said one Northrop engineer of the UCAS work.[23] The early loss motivated the company to spend some of its own money to do better. "We cobbled together this thing called Pegasus based on work we'd done over the years on different airplanes and ideas and thought, 'This could probably work,' " the engineer explained.

Effective program competition proved itself as a formula for ongoing innovation. What will replace it—if anything—is at this point unknown.

MARKET FORCES

In the view of the Aerospace Industries Association, the trade group of aircraft manufacturers, "A significant gap has developed between DOD's view of industry as an always-ready supplier of military capabilities and how industry actually makes decisions on what capabilities to offer. And that gap is widening."[24] AIA could just as have said the industry's capacity—not just the decisions—has been undercut.

What led to the high-level Pentagon decisions that knocked off major aircraft programs? Despite the dramatic moves of 2009, the process has actually unfolded over a long period. The pruning of the industrial base does not appear to be a result of deliberate, national policy. In fact, it more closely resembles the default outcome created by unforeseen events and by the different policy priorities of the Clinton, Bush, and Obama Administrations. The net effect of these policies has been to decrease funding for procurement, increase funding for operations and maintenance, and in the process suspend a big chunk of aircraft recapitalization—perhaps permanently.

The unintended confluence of these policies created the financial conditions that led to the winnowing of major programs and, with it, the earthquake in the industrial base. How it happened turns in part on different characterizations of the defense market and what motivates it.

First, it is important to understand that the "market" for military aerospace products flows from government policy, nothing more. There is agreement on one point. "The federal government traditionally has been the aerospace industry's biggest customer," noted an official report from the Bureau of Labor Statistics.[25]

The consensus ends there. According to a Defense Department report to Congress, "The industrial strategy of the Department of Defense is to rely on market forces to the maximum extent practicable to create, shape, and sustain those industrial and technological capabilities needed to provide for the nation's defense."[26] The official Pentagon view ran directly counter to some of its experts on the Defense Science Board. They noted, in contrast: "Market forces alone are unlikely to achieve the government's desired objectives in industrial or military capability, capacity, and future investment."[27]

As the preceding survey of the last 100 or so programs makes clear, market forces in the aerospace industrial base are not the same as those created by commercial sales. Three stages in demand creation stand out.

First, the steadiest generator of "market forces" for major military aircraft programs comes from the requirements of the armed service components. These, in turn, stem from a mix of technology forecasts, operational experience and gaps, and long-term plans for recapitalization. The "market" is put on display within the service's 30-year plans or visions. The single best example of this is the Navy account known as SCN for Shipbuilding and Construction. It lays out projected ship purchases by type some 30 years into the future and takes into account aging, retirement, and development of new types to meet anticipated requirements. Services build up the plans over time and trim them to fit anticipated funding levels. The most mature part of the plan is contained in the Future Years Defense Program. However, it is safe to say that any system in the FYDP got there through a long process of verification of the "demand" for the program—a competitive process that eliminated other types and programs along the way.

Second, there is a different layer of market forces that swings into action with review of service programs by the Office of the Secretary of Defense (OSD).

One could further make the case for a third layer, consisting of Congressional authorization and appropriation.

Action within the second and third layers often focuses on near-term program changes made by deleting or adding funding in specific years. It affects the final “sale” but has less impact on the creation of the program in the first place. This is why the budget decisions for Fiscal 2010 were so devastating in terms of the future of the industry. They carried both instant penalties and opportunity costs.

Cancellation of programs represents the biggest disruption to the “market.” Not only does budget authority vanish; the cancellation of a system wipes out the value of other choices made in previous budgets over years or even decades. Research and development investments yield less “return on investment” in a nonrecoverable process. The closer a system is to full-rate production, the greater the waste of capital. Developing a system and failing to see it through imposes immense and unrecoverable opportunity costs.

Opportunity costs ripple back through the industrial base, too. One is truncating a program at a low level of production after it has already drawn resources away from other programs at early milestones.

COSTLY SAVINGS

Decisions to cancel programs are not taken lightly. They stem from a strategic shift of course, a change in the financial climate within the wider defense “market,” or both. What conditions led to the disruption of recapitalization programs? By 2009, the answer was “a change in strategy.” However, so much of the damage was already done by that date that this answer alone falls far short of sufficiency.

It is necessary to examine budget decisions made prior to the strategy change. Here, the ballooning of operation and maintenance costs stands out. In 2007, the Defense Science Board flagged “resource shifts from equipment to personnel, O&M, and homeland security” as one of a dozen major changes that were transforming national security.[28]

The defense budget balances procurement, operation and maintenance, personnel costs, and a fourth major category, known as research, development, test, and evaluation. Significant funding for aerospace programs can be found in three of the four categories (personnel being the exception). For example, O&M comprises funding for major repair and overhaul, totaling billions per year. O&M funding also can include innovative system upgrades. However, major program funding for new systems is usually found only in the procurement budget line. Innovative research to develop systems resides in RDT&E. When operation and maintenance costs rise, it is often procurement that is tapped to bring the budget back to a desired topline. These decisions take the shape of specific fiscal targets for cuts handed to each service to adjust within its budgets. At other times, as was the case in April 2009, the cuts go directly to named programs.

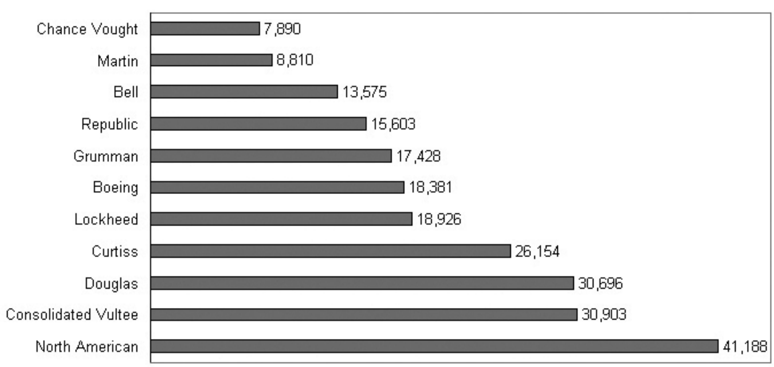
Recent high spending on operation and maintenance has distorted the "market" for procurement programs. Spending on the wars in Iraq and Afghanistan and on other categories such as military health care and space and intelligence systems recast the budget over the decade from 1999 to 2009. Total defense budgets rose faster than at any time since the Korean War. However, investment in new systems was deferred, delayed, and finally, cut.

This decline in the aircraft procurement funding stream has been perhaps the single biggest factor leading to the recent narrowing of the aerospace industrial base. Beyond this, it illustrates that market forces are not given a free rein in determining procurement priorities.

The second factor that has undermined the power of market forces is the time lag from strategy development to program execution. In theory, national defense strategy drives spending (and shapes the market). In practice, there are more steps to the process, which takes more time, and they are critical to segments of the aerospace industrial base.

By the time programs reach production, national strategy often has become a blunt instrument to cut or curtail the program. The effect of termination is almost uniformly negative. Money and control dissipate. Program termination typically involves a contractual liability to pay fees to the prime contrac-

Eleven Prodigious World War II Aircraft Companies



Source: Air Force Magazine, "Chart Page: Who Built the Airplanes?" October 2009, p. 36.

tor to defray costs. Cutting production short can involve similar contractual obligations. Termination frees up money, but it is typically production money that, by law, must be spent on production for other systems, sometimes in a very short time frame. In this case, there is little chance of taking large sums budgeted for production and transferring them to R&D accounts, for example. Unless there is something else to buy right away—a mature program at a good production rate—program termination squeezes budgets back under their toplines but does very little for shaping future policy.

Finally, it is important to note that this unusual "market" delivers not only aircraft but a second, vital byproduct. That byproduct is made up of the engineers, production workers, and experienced managers trained on a career of moving from one large program to the next.

THE MARKET AHEAD

Decisions under way will make it very difficult for the government to again compete two "dark titans" against each other to pursue distinct, innovative approaches to aircraft design. The problem is not just that firms may exit a market. Companies have moved in and out of fighter and bomber and transport production before. But the reason they could shift gears rested in part with having a pool of seasoned aerospace workers close to hand. Already, this capacity has shriveled.

Aerospace workers have few options for moving from program to program as they once did. In Southern California in the 1970s and 1980s, an aerospace worker could move from space shuttle final assembly in Palmdale to a secret bomber program in Pico Rivera or an airliner or tanker in Long Beach. Few remnants of that industry remain.

Layoffs and retirements will shred much of the workforce, and major changes will start soon. Take the case of the C-17 production line in Long Beach, Calif. The line began in 1993 and has continued with constant improvements since. Much of the old tooling has been replaced, and just as important, workers continually evaluate better ways to accomplish tasks. The average worker on the C-17 line is more than 50 years old, with 20 years' experience in aircraft production. Layoffs will begin as C-17 production winds down, and those C-17 workers looking for jobs after 2011 will not have the choices available to their West Coast counterparts of earlier decades. Military production on UAV lines continues at Northrop Grumman, General Atomics, and others. Commercial aerospace work is under way on the 787 in Seattle. But for most, the options are limited. A permanent share of capacity will be lost as these experienced workers move on.

This is what makes the impending end of production lines and the dim forecast risky.

ASSURING INNOVATION?

The real question, then, is whether the narrowed aerospace industrial base will devise new methods for continuing innovation once the model of competition and major programs comes to a halt. On this count the news may not be all bad. It depends on a deeper understanding of the complex dynamics of technological innovation and what a drastically reshaped industry will have to do to carry those over.

Success after decline depends on the essential model of innovation in the first place. As previously discussed, the broad capacity embodied in major programs and a big, skilled, constantly learning workforce will not be the way ahead. So, what was it about that model that must be extracted and encouraged going forward?

One theory looms large. It is that a larger number of firms will lead to more competition and greater innovation through diverse approaches to an Air Force goal. The ideal as drawn from postwar industry is to issue a request for information and have a dozen agile responses. Received wisdom equated many competitors with the best solutions. (For a contrary view, consider the very first airplane competition. More than 40 bidders responded to the Army Signal Corps request for flying machines but only one firm, Wright, produced a flyable prototype.)

The biological-diversity slant may not be a perfect model for science and engineering disciplines. One of the problems is the assumption that technical agility and financial stamina exists in a vacuum, ready and waiting for the government's fax or e-mail.

Getting a successful response (or any responses at all) is much more complicated and reliant on a longer history of related work. Advanced work on critical technologies generally requires sustained research and development efforts by many individuals over a period of time. What is more critical in this vein is to present engineering teams with challenges that allow them to continue to push knowledge and application forward. The expertise for breakthrough technologies may come from a relatively small pool of highly talented, experienced (though often young) engineers. In looking back, they often share formative professional experiences at the same firm or on the same projects, or perhaps as disciples of the same mentor. Whether they reside across many firms or a few is less important than the accretion of research and experience.

The major challenge for the consolidated defense industry lies in whether primes can carry out two functions at once: planning for sustaining technologies and capitalizing on disruptive technologies.

In fact, the history of the aerospace industry could be read as a struggle between these two objectives. The goal of any company is to grow revenue and profit in order to stay in business. A "going concern" gravitates naturally toward products its customer likes and ways to add on to them—known from a business angle as sustaining technologies. Within the defense market, sustaining technologies have been wildly successful. A case in point is the F-15E. This derivative appeared a decade-and-a-half after the first F-15s entered service. Its advanced avionics and greater range and bomb-carrying capacity made it the star and workhorse of air campaigns from Operation Desert Storm in 1991 right through to its constant role in Afghanistan today, where it is forward based.

Contrast the wild success of this "sustaining" technology with the F-22. As described earlier, Northrop and Lockheed both ruminated about a supersonic stealth fighter in the late 1970s but concluded it would still be extremely difficult to achieve the needed technologies. They were right. The first production-representative F-22 flew in 1997—nearly 20 years after engineers tossed the idea around—and suffered all the difficulties of a disruptive technology.

Embracing disruptive technologies requires a crucible of some type. It may be war, or a force-feeding akin to the race for stealth. This crucible must bound the financial risk, offer an upside, and sustain initial research in what might be called the wind-tunnel phase. Here is where large companies can choke on disruptive technologies.

Corporate motivations for allocation of talent and resources can be very mixed indeed. The path to profit with a disruptive technology is generally unclear. In fact, most corporations that successfully brought disruptive technologies into the active Air Force inventory were also working on aircraft with direct market application and hence, customer encouragement. Northrop committed to the B-2 while at the peak of its F-5 sales. It invested in Global Hawk in an era rich with work on B-2 modifications and with F/A-18 work as a major supplier. Lockheed saw the F-22 through while maintaining a robust F-16 line. The number one disruptive aircraft of late—the MQ-1 Predator—emerged from a solid base of sales to a non-USAF client but was also achieved by one of the very few remaining privately held companies in the industry, General Atomics. Not that the senior management of General Atomics was blind to profit-and-loss considerations. But their diversified corporate structure and ability to invest and aggressively market the MQ-1 and later the MQ-9 more closely resembled the 1930s aerospace innovators.

From these examples, it is apparent that the tension between disruptive innovation and sustaining technologies is a major characteristic of the industry. It is also the breach into which the government customer must step with a balanced agenda of 75 percent solution upgrades and, yes, "exquisite" research programs that will advance the state of the art.

There are positive structural conditions going forward. Industry consolidation may have been helpful in tucking disruptive innovators into large, going concerns. For example, the last remaining major primes all take pride in advanced research and development. This may leave the rump aerospace industry in a viable position to move forward—providing that smooth signals from the Defense Department "market" keep coming.

An example from outside the industry illustrates the point. While Intel, the giant microchip-maker, was losing market share in DRAM—for "dynamic random access memory"—technology, a small group within the company had invented a microprocessor. The incorporation of this 286K chip in IBM personal computers was almost a ho-hum event, because profits and senior management attention at the time focused on DRAM. Yet it became a source of phenomenal growth.[29]

These examples suggest that from the viewpoint of corporate structure, flying "under the radar" of sustaining technologies and major corporate strategy may in fact be a good place for innovators to be—every bit as good as out in the garage. At a minimum, the necessary processes are closer to hand. There is talented management, some access to capital, and a way to show the idea to customers and get their feedback.

LEVERAGING MRO

Of course, unless the government plans to in-source all aircraft development, it will be necessary for the remaining companies to stay financially healthy as they bridge the ever-longer gaps between major programs and contend with variable funds for research and development. A healthy industrial base requires plenty of "going concerns," defined as companies that are expanding, recording profits, and maintaining the environment where the disruptive innovators can work.

One contributing factor will most likely be maintenance, repair, and overhaul—known as MRO.

Vastly overlooked is the role of MRO in the viability of the industry. From a financial perspective, MRO is important and profitable. Compare the case of the local car dealership which may not be selling as many new models but sustains profit and workforce with the repair shop operations. The OSD-level view and the nascent nature of industrial policy have tended to discount the financial criticality of MRO for firms of all sizes.

MRO is an important source of work and profit. The past decade has seen a major rise of so-called performance-based logistics. According to the Department of Commerce, the global market value of MRO returned to growth in 2004, has been up ever since, and should increase by at least 50 percent over the next decade.[30] Much of the data from the Department of Commerce centers on the airline industry. However, it highlights a question worth evaluating: How will the reduction in military aircraft fleets and the retention of more legacy systems affect the MRO segment?

The second reason for linking MRO and industrial policy is that it directly addresses a key service consideration: life-cycle cost. The discussion of operation and maintenance costs in the defense budget showed that there will be an ongoing squeeze on procurement and research and development. More focus from industry and customer alike on life-cycle costs is a welcome outcome of the information revolution that allows developments such as autonomic logistics. Better tools than ever are in place to manage life-cycle costs. Using them to maximum effect will be essential to keeping legacy aircraft flying and making room for innovation.

Consequently, an additional factor for the defense aerospace industry is the balance of MRO work performed commercially and by the government depots and air logistics centers. Here, policy is a huge force in shaping the market, and the policy winds may be about to shift away from outsourcing and reverse course—at least to some extent—into a greater return of work to government-run depots.

Senior leaders would do well to consider the full picture of the need to maintain innovation as they assess outsourcing policies.

Outsourcing constitutes an important segment of revenue. In an industry dominated by large primes, the relationship of profit in this segment to the overall health of the company cannot be overlooked. Simply put, a thriving MRO business can be a pillar of steady earnings that may facilitate greater corporate patience with and investment in research and development. In a decade with few major programs, the relationship of the remaining constituent parts will become even more important.

THE SPUR OF COMPETITION

There is one more source of potential churn in the aerospace industry: a competitive threat. As the US military aircraft industry changes, it will not do so in a vacuum. China and Russia have both announced their plans to build up aerospace manufacturing for civil and military markets. China and Russia both aim to develop aircraft types for their domestic markets and for export.

No forward look at US aerospace manufacturing would be complete without assessing the role of new global rivals. While firms in Europe and Japan have long driven competition with the US, Russia and China were nonentities in decades past. Both nations have plans to dominate a much larger share of their own domestic markets and, in turn, the global market.

According to the Department of Commerce:
The largest and potentially most influential consolidation, however, is Russia's United Aircraft Corporation (UAC). UAC is a Russian government-owned joint stock company that consolidates the scientific and production potential of the Russian aircraft industry as well as the intellectual, industrial, and financial re-

sources for new aircraft development into a single state-owned and -controlled entity. UAC has already negotiated design and production agreements with a number of US and European aerospace companies, and UAC senior leadership has set a goal of becoming the world's third largest aircraft manufacturer by 2015.[31]

Russia has suffered its own economic setbacks with the volatility of oil prices. However, none doubt that Russia has the talent base to succeed. It will depend, of course, on state-directed investment and on whether Russian industry can attain the talent levels needed in its pool of aerospace workers.

China is also a factor. A concept airliner called the C919 was unveiled at a September 2009 aerospace trade show. Long a fan of reverse engineering for military systems, China, through its government-backed Comac consortium, announced plans to "beat Boeing and Airbus to market with a next generation narrowbody" airliner offering the latest technology and reduced operating costs, according to Scott Thompson, of PricewaterhouseCoopers, who noted that China has some formidable advantages on its side.[32] These include "huge financial reserves" along with guaranteed domestic market access—to its own home market. It goes without saying that low manufacturing costs are a given. Still, in Thompson's words, China's Comac "has no experience developing a large, technically advanced airplane" and faces "more than a decade to become competitive" in this market.

This is proof positive that making a solid handoff from one program to the next is a better way to build the next aircraft. Let's hope that struggling with the next technical leap and an inexperienced workforce is a situation American aerospace executives will never face.

SUMMING UP

In 1947, the Army Chief of Staff, Gen. Dwight D. Eisenhower, testified to Congress that America should have an independent Air Force because of "the paramount influence of airpower upon modern warfare."[33] For the next six decades, a robust though changing arsenal for airpower remained in place, even as it branched into space and cyberspace. Strong appreciation for the role of airpower in national defense crystallized in Eisenhower's time, as did the foundations of the industry that continues to create today's hardware and software.

One cost of recent vacillation about the role of airpower has been unwitting erosion of the industrial base. Now, as the industry enters a period of potential crisis, some lessons stand out. The cases examined show that the most successful major programs have in common a high degree of direction from the customer: the service.

It is easy to criticize the Pentagon's approach to industrial policy. The fact is that the Air Force (and sister services) are in the best position to shape policy to ensure a satisfactory nucleus of manufacturing capacity in their core competencies. It is the service that watches trends through the National Air and Space Intelligence Center or the Office of Naval Intelligence. Likewise, the services are the first to notice when maintenance trends become worrisome. They take note when air campaign plans are constrained by factors such as roaming surface-to-air missiles. They see the heavy demand for scheduling of ISR (intelligence-surveillance-reconnaissance) assets. Most of all, the services understand the close fit between their concepts of operations and the emerging technology trends and balances emanating from intelligence reports.

The Air Force should be encouraged to resume an active role in assessing the status of the aerospace industrial base and determining how to sustain it. Industry profits, the number of firms, and even the overall level of investment are not sufficient metrics for evaluating whether the raw core needed for progress and to meet future emergencies is in good shape or not.

Strengthening industrial policy monitoring within the Air Force is a philosophical shift. For decades, the focus has been on controlling and reining in programmatic and requirements decisions. (Often these are pejoratively referred to as "appetites," as though desire for superior systems equates with unchecked gluttony.) Defense reforms of the past two decades have focused on sharpening the requirements process for major weapons systems by adding layers of authority outside the services. The goal was to balance Defense Department investment by providing a joint or cross-service look at priorities. A second-level goal of joint requirements oversight was to improve interoperability. The establishment of the Joint Requirements Oversight Council in the 1990s was modified in the 2000s with a broader context of joint capability areas and a stronger voice for US Joint Forces Command.

Lost in the process was the core task of innovation and all that it entailed, such as sustaining experience among the workforce.

The level of employment and number of major programs assured that a trained workforce and viable commercial ventures would be in place for system development in the next decade or beyond. The lack of programs has now put that assumption in doubt. While it is far too early to declare the industry to be in a death spiral, it is time to take a firmer hand in extracting the seeds of innovation from a much narrower base.

Ultimately this requires a focused look with objectives that go beyond the current OSD policy mandate. While a policy function should continue to reside within OSD, there should be a far more market-focused core of industrial policy within the Air Force.

THE NEXT JET AGE

The best way to illustrate this is to conclude with a final story—an important one. It concerns the dawn of the jet age.

The jet age. ... It has shaped military and commercial aviation more than perhaps any other single development since the Wright brothers took off on the morning of Dec. 17, 1903. Today, the advances of jet propulsion have definitively separated American fighters such as the F-22 from Russian or Chinese rivals, pushing US aircraft far ahead.

Yet the early history of the jet engine in America was a difficult one. The most advanced research took place in Germany and Britain. Research began in earnest on the eve of World War II. Germany had pulled far ahead and managed to fit jet engines on the Me 262 before the end of World War II. Desperate efforts to halt German jet fighter production drove US planners to strike at some of the toughest targets of the strategic bombing campaign in the European Theater of Operations. The US had secret prototype jet aircraft, yet no American-made jets flew in combat in that war. Basically, the jet engine was still so complex and raw that there was doubt about investing in it, given the wartime needs for immediate production.

Had airmen adhered to the standards of investing only for "the wars we are in," as is the case today in the Robert M. Gates-led Pentagon, would the considerable research and development for the jet age have continued? While propeller-driven fighters like the P-51 and the Marine Corps F4U Corsair saw service in Korea, it was the F-86 that matched the nimble MiG-15s over the Yalu River. War is a mighty driver of innovation, yet it is not the only litmus test of sound aeronautical development. It takes a longer view of technology and military requirements to set a successful research and development program. That view resides naturally at the point closest to the customer. In today's Pentagon, that location is in the various armed services.

The aerospace industry in its military components thrives on a closer relationship with its customers. The 100-year history of the military industrial base for airpower is filled with breathtaking periods of boom and bust. Across the entire century, however, its best achievements in military programs resulted from cooperation with airmen—the customers. The only time the aerospace industry truly "went it alone" was during its birth in Dayton, Ohio, from 1901 to 1908. Since then, government policy and the relationship between the military customer and industry have waxed and waned.

It took airmen to push the promise of the jet age, and it will take airmen to set the course for revolutions of the future. ■

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About the Air Force Association

The Air Force Association, founded in 1946, exists to promote Air Force airpower.

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