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WINNING THE ATF

By Sherman N. Mullin

Mitchell Paper 9

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 the 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 and presentations on airpower and its role in the security of this nation.

ABOUT THE AUTHOR: Sherman N. Mullin was Vice President and General Manager of the Lockheed-Boeing-General Dynamics F-22 Team from 1986 to 1990. He retired as President of Lockheed Advanced Development Company, the Skunk Works, in 1994, after 35 years at Lockheed. He is a Fellow of the American Institute of Aeronautics and Astronautics.

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June 2012

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DEDICATION

Dedicated to my esteemed friends Richard Hardy of Boeing and D. Randall Kent of General Dynamics, the best team partners any aerospace program manager could ever have in a grueling 50-month competition. Together our F-22 Team won.

In Memoriam

Richard Abrams, master of flight testing

"There are some things which cannot be learned quickly, and time, which is all we have, must be paid heavily for their acquiring. They are the very simplest things." —Ernest Hemingway

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PREFACE

The objective of this paper is to cover important facts and issues not covered by other Advanced Tactical Fighter (ATF) written histories and to document selected important technical and management details which were significant elements of the F-22 Team victory in the ATF competition.

It is based primarily on my substantial personal collection of documents, a unique subset which is by no means comprehensive. However, I do not believe that a comprehensive set actually still exists. This paper also relies on my memory of several important program events and key program participants, particularly Richard "Dick" Hardy of Boeing and D. Randall "Randy" Kent of General Dynamics.

Design and development of a modern fighter aircraft is a very complex technical task. Organizing, staffing, and managing such a program is equally complex and demanding. Most histories of such programs are essentially cleaned up versions of how the task was accomplished. For example, consider the following three fairly important historical treatments.

The *Advanced Tactical Fighter to F-22 Raptor: Origins of the 21st Century Air Dominance Fighter,* written by Dr. David C. Aronstein, Michael J. Hirshberg, and Albert C. Piccirillo, provides an excellent history of the F-22 Raptor. However, it was not within its scope to cover the details of the establishment, operations, and key people of the Lockheed-Boeing-General Dynamics F-22 Team. The authors did not have access to any detailed historical papers of the team. It is a valuable book, but it represents a "cleaned up" version of the early years of the F-22 program history.

A two-part series of articles by *Code One* Magazine editor Eric Hehs provides an excellent technical history and includes many high quality graphics. Together, these two articles cover important F-22 aircraft configuration development history not included in any other publication and may be unmatched as a military aircraft configuration development history. However, they do not cover the pioneering F-22 avionics system or important program management and financial aspects of the F-22 Team operations.

And, a paper I wrote in August 1992 for the American Institute of Aeronautics and Astronautics' Wright Brother Lecture series—titled "The Evolution

of the F-22 Advanced Tactical Fighter"—is also very much in the "cleaned up" category. It was limited to 15 pages and contains virtually none of the major problems, personalities, and controversies involved in the program and has very little on the competitively important F-22 prototype avionics system architecture, hardware, and software.

These three documents carefully avoid the strong team emotional commitment, the essence of the competition, and the personalities of the key individuals. In contrast, this paper, in general, does not repeat information included in the three foregoing documents, rather it focuses on the flavor—the emotions and essence—of the competition environment.

The F-22 program was a unique odyssey by a large group of people—most had not met until November 1986. The Lockheed-Boeing-General Dynamics team developed a deep cohesive commitment; it was one of the reasons we persevered and won the ATF competition.

While the documents cited above make the program sound dry and ultra methodical, nothing is further from the truth. It was full of excitement, pain, frustration, joy, and ultimately, victory.

I am aware that this historical paper may be considered by some to be an ego trip. It is not. It is a sincere attempt to capture the accomplishments and unique commitment of a large team of people dedicated to developing the greatest fighter aircraft ever. It was one of the singular experiences of my life and career to be associated with them in this history making experience.

I thank Richard "Dick" Henderson for writing the section on the Engineering and Manufacturing Development proposal. He is probably the only person who ever understood the entire proposal in detail.

Sherm Mullin
2012

INTRODUCTION

This paper addresses how the Lockheed Skunk Works was one of the two winners in the first round of the competition for the US Air Force Advanced Tactical Fighter (ATF) program in 1986.

More importantly, it then covers how the Lockheed-Boeing-General Dynamics F-22 Team, from 1986 to 1990, won the final ATF competition, defeating the Northrop-McDonnell Douglas F-23 team.

From Nov. 3, 1986 to Dec. 31, 1990, the F-22 Team:

- Established a tightly knit, cohesive team, essential to F-22 program success.
- Designed, manufactured, and flight demonstrated two YF-22A prototype ATF aircraft, which had excellent performance, closely matching our analysis and predictions.
- Designed, prototyped, and demonstrated a completely new design integrated avionics system, including a pioneering active electronic steerable array radar and extensive prototype mission software. This system was first integrated and demonstrated in a ground laboratory and then in a Boeing 757 aircraft Avionics Flying Laboratory.
- Delivered systems engineering and design for the proposed production F-22 aircraft, known as the Preferred System Concept (PSC).
- Built a strong, cohesive three company management team to execute the next phase of the program, the multibillion dollar Engineering and Manufacturing Development (EMD) program.
- Developed a skilled, highly committed subcontract team whose performance demonstrated the subcontractors were capable of executing the EMD phase of the program on a low risk basis.
- Produced, for the EMD phase of the F-22 program, a complex seven-volume proposal, totaling 30,000 pages, in rigorous compliance with the Air Force Request for Proposal (RFP).
- Made a three company equally shared investment of $675 million to successfully complete the Demonstration/Validation program on Dec. 31, 1990.

All of this is now easy to say. It was very difficult to do. It was the result of 50 months of intensive work by a very large team—several thousand people at the peak of the effort—forged specifically to do this.

This paper attempts to capture what really happened during this odyssey, including who did what amongst the large cast of characters. This could be used as a case study, with the title “What aerospace program managers really do.” An alternate title would be “An aerospace melodrama, for adults only.”

WINNING THE ATF

Before the ATF

The first major Lockheed fighter program was the P-38 Lightning, which first flew in 1939. During World War II, Lockheed and Convair built nearly 10,000 P-38 aircraft.

Lockheed's Skunk Works had been involved with jet fighters since 1943, when it was founded by Clarence L. "Kelly" Johnson to design, build, and flight test the XP-80 prototype jet fighter for the Army Air Forces. Successful flight testing in early 1944 led rapidly to volume production of the F-80 Shooting Star. Over the next several years, the company designed and produced other subsonic fighter and trainer aircraft in amazingly large numbers.

The Skunk Works designed and prototyped the Air Force F-104—the first Mach 2 fighter—which achieved first flight in March 1954. Then, for the next decade and more, the Skunk Works focused on secret reconnaissance aircraft: the high altitude U-2 and the Mach 3 A-12 for the CIA, followed by the Mach 3 SR-71 Blackbird for the Air Force.

No significant work was done on a new fighter except a derivative of the CIA's A-12, the YF-12A (announced in 1964 by President Lyndon Johnson as the A-11). Lockheed built and flight-tested three YF-12A prototypes in the mid-1960s, but the Air Force at the time had no interest in producing an F-12 Mach 3 fighter fleet, so the program died.

The long series of Skunk Works fighter successes came to an abrupt halt on April 13, 1972, when USAF selected General Dynamics (YF-16) and Northrop (YF-17) to continue in the Lightweight Fighter Program. This was the biggest loss in Skunk Works history. It also marked an abrupt end of Kelly Johnson's role as a dominant designer of fighters for the Air Force. The ultimate winner was the General Dynamics YF-16. The GD F-16 became the most successful fighter program of the late 20th century. As of early 2012, more than 4,500 had been produced—with more orders to come—for worldwide customers.

In 1975 the Skunk Works had defeated Northrop in a classified Defense Advanced

Research Projects Agency (DARPA)-USAF competition to design a very stealthy technology demonstration aircraft. The program name was Have Blue.

Ben Rich, who had succeeded the legendary Johnson as head of the Skunk Works, led the stealth revolution at Lockheed, with a small, technically creative, risk taking team. The new Skunk Works team rapidly designed and built the two Have Blue technical demonstrator aircraft on a shoestring budget—about $30 million.

The first of this unique, odd-shaped faceted aircraft flew on Dec. 1, 1977. The second demonstrator flew in July 1978. The test results were astonishing. The measured radar cross section (RCS) showed that stealth was really achievable. In November 1978, based on the Have Blue test results, the Air Force awarded the Skunk Works a contract to develop the F-117 stealth fighter. It made its first flight on June 18, 1981.

The F-117 was a highly concurrent program, going directly into the production of eight aircraft per year, long before flight testing was completed. I became Vice President and F-117 Program Manager in February 1982. USAF achieved initial operational capability (IOC) in October 1983 at the highly classified Air Force facility near Tonopah, Nev. (USAF did not reveal the existence of the F-117 until November 1988.)

In the early 1980s, Lockheed Skunk Works began work on what would become the F-22 fighter. Capitalizing on its winning Have Blue/F-117 environment, Skunk Works had the money and talented imaginative people to jump start the program. It also had its traditional airtight organizational barrier that prevented other parts of Lockheed from having any involvement. This meant that the program was not open to marketers, finance managers, or a raft of corporate staff people. Lockheed CEO Roy A. Anderson and President Lawrence O. Kitchen were the primary protectors ensuring this “hands-off” arrangement.

Put simply, in 1985 the Skunk Works was flourishing. The F-117A stealth fighter was in production in the main hanger in Burbank, Calif., at eight per year, with rapidly decreasing costs and excellent profits. The TR-1 high altitude reconnaissance aircraft—really a U-2R aircraft—was being produced at four per year in Palmdale, Calif. In general, Lockheed, which was now out from under horrendous annual losses on the L-1011 Tristar aircraft program (terminated in December 1981), was in good financial condition and getting better. Consequently, the company had substantial resources available to vigorously pursue the ATF program.

And, the defense program environment was ripe. Ronald Reagan was President. Caspar Weinberger was Secretary of Defense. The Cold War was still intensely in progress. Reagan, Weinberger, and their lieutenants supported large annual defense budgets. So did Congress, on a bipartisan basis.

In the classified “black” world, USAF was successfully operating the F-117. Stealth was real. The Air Force, looking for a new fighter aircraft—one with stealth characteristics—to replace the F-15 Eagle, worked to make the Advanced Tactical Fighter (ATF) program a reality.

Lucky in Hindsight

Meanwhile, the Navy had embarked on a top secret carrier-based fighter program—one that indirectly but explicitly shut out Lockheed. In fall 1984, Secretary of the Navy John F. Lehman mandated that only four companies would be involved in the competition for the A-12 fighter program. Lehman established two teams: (1) General Dynamics and McDonnell Douglas, and (2) Northrop and Grumman.

The General Dynamics-McDonnell Douglas team won the classified competition, defeating the Northrop-Grumman team. Unfortunately for the winner, the A-12 program went on to become one of the biggest disasters in Navy and aerospace industry history. Defense Secretary Richard Cheney cancelled the program in early 1991. Not one aircraft was ever built.

The A-12 debacle ruined the careers of several senior Navy officers and several executives at General Dynamics and McDonnell Douglas. Cheney also fired Undersecretary of Defense for Acquisition John A. Betti who had failed to report serious technical, schedule, and cost problems engulfing the A-12 program after conducting a program review in early 1990. (See section titled Surviving Cheney's MAR, p. 43.)

Although Lockheed officials had been deeply unhappy at the time, it was extremely lucky that the Lockheed Skunk Works was kept out of the A-12 program and decided to focus intensely on the emerging ATF program. Lockheed CEO Roy Anderson, a strong supporter of the Skunk Works, emphatically endorsed this priority.

We had six competitors for the ATF: McDonnell Douglas, General Dynamics, Northrop, Boeing, Rockwell-North American Aviation, and Grumman.

As noted earlier, the Skunk Works had been doing some preliminary design work on the ATF since 1982. By early 1985 that work greatly intensified. So much so that Lockheed President R. R. "Dick" Heppe told me to start working half time on the ATF program. I had been managing the still top secret F-117 stealth fighter program. My deputy John J. Sheridan, a Lockheed veteran, and Jack Gordon, the program's chief engineer, took over most of the management of the F-117 program.

Design Challenge

The ATF was a very difficult aircraft design problem. The objective was to design the most formidable fighter aircraft in the history of the world, but to also make it clearly affordable. The Air Force focused on a system design that would make this new fighter clearly dominant in the early 21st century. The attributes would include range, endurance, maneuverability, survivability, lethality, and supportability. USAF wanted the ATF to have breakthrough new technologies integrated in the design.

In short, USAF wanted an enormous amount of capability in a single aircraft. Meeting the ATF requirements would be a very difficult task. It required supercruise: the ability to fly at supersonic speed, 1,000 mph or better, without turning on the fuel guzzling afterburners on the back of the jet engines. It required long range mission

capability using only internal fuel. This drove the size of the airplane up, making supercruise more difficult to achieve.

The service's current fighters got long ranges by using external fuel tanks, which looked like big slick bombs, and made excellent radar reflectors. For the ATF, USAF wanted excellent subsonic and supersonic maneuverability.

Along with these and many other requirements, the Air Force demanded a very stealthy airplane to make it one of the most survivable airplanes ever built. In 1985, this was the newest, most difficult, and most controversial requirement. We tackled this problem with great vigor, confident we could meet the very demanding requirements.

At this point we were competing to win one of three planned Demonstration/Validation (Dem/Val) contracts. No aircraft had to be built and flight tested. The objective was technology risk reduction, laboratory demonstrations, ATF weapon system simulation, more detailed paper aircraft design and analysis, and more accurate estimates of aircraft weight, production costs, and combat performance.

Achieving Stealth

Although many new technologies were relevant to meeting the ATF requirements, the newest and most fundamental was low observable (LO) capability. The historical trend was clear: Since the late 1930s ground and airborne sensors, particularly radar systems, were steadily and sometimes dramatically advancing and reducing the survivability of fighters and other military aircraft. LO technology—stealth—would provide the capability to fundamentally reverse this historic trend and to begin to reduce and ultimately emasculate the capability of an adversary's ground, shipboard, and airborne sensor systems.

In the case of ATF, the most fundamental improvements would come in two areas: (1) the ability to go through and/or fight above enemy surface-to-air missile (SAM) defenses and survive; and (2) to drastically reduce the range of enemy fighter onboard sensors, particularly their radar.

Largely because of my work on the F-117, I had focused intensely on LO technology, which to me was a revolutionary advance in military systems. I firmly believed it would provide a path for US air superiority deep into the 21st century. The issue was whether it could be done in a balanced and affordable manner. This was a very controversial position in 1985—and it still is. There are many disbelievers in stealth, more than a few of them truly technically ignorant and proud of it.

However, the relevant physics is embedded in the equations of electromagnetic radiation set forth by the great British physicist James Clerk Maxwell in 1864. His work was one of the great accomplishments in the history of science. His equations are not subject to amendment or reinterpretation—which may make them forever alien inside the Washington, D.C., beltway.

The End of the Part-timers

Oct. 8, 1985, was a defining day, in my mind, for the Lockheed ATF program. I came to work on that day in a bad mood—an unusual occurrence since my normal dis-

position is cheerful, say, 99 percent of the time (although some might say I'm irate 10 percent of the time). The reason for my bad mood: Progress in preparing our ATF proposal was not going well.

It was time to talk with Heppe, who, although President of the Lockheed California Company, was also the theoretical full-time ATF program manager. I bluntly told him that we were going to lose the ATF competition because we had way too many part-timers—including him and me—on the program. In my view, he had two choices: run the company full-time, picking someone else to manage the ATF program, or run the ATF program full time. Heppe was equally blunt in his response, before walking out in a huff. He said he was not going to turn the company over to someone else (ostensibly Lloyd Graham, the Executive Vice President) and told me to get back to work.

However, when I arrived at work the next day, I found a copy of a memo from Heppe to all ATF program participants on my desk. It stated, among other things, that "effective immediately Sherm Mullin will come to work on the program as acting program manager on a full-time basis."

I immediately ordered new business cards which read: Sherman N. Mullin, Vice President and General Manager, Advanced Tactical Fighter Program—no mention of "acting." Thus began probably the five-plus toughest years of my life—intense and demanding all the way.

The Heppe memo also filled leadership voids in engineering. He named William "Will" O'Neil III to lead systems engineering and Rudolph "Rudy" Burch for avionics engineering. They were both strong leaders, so their assignments delighted me.

Robert H. Blanchard, an old friend and Lockheed veteran, became my deputy on the ATF program. After graduating from the University of Massachusetts, he played pro football briefly for the New York Giants before a neck injury ended his career. In industry, he proved a tough business manager and one of the most competent, experienced subcontracting managers in aerospace. He was blunt, honest, loyal, and highly motivated. As honcho for our planning and scheduling, no important detail escaped Blanchard's notice. And, we worked well together, with unambiguous communications. Usually he addressed me as Mullin or Sherm, but when he called me "Sherman," I listened very carefully. We were in the office before seven every morning and often dumped our guts over the first cup of coffee.

I can honestly say that speed and clarity of communications and decisions were competitive imperatives. Later in the program, the frankness that Blanchard and I exhibited with each other and with our Lockheed managers startled our Boeing and General Dynamics teammates.

And, despite my seeming head-butt with Heppe over ATF personnel allocations, I consider him one of the true fathers of the F-22. His knowledge and experience in the development of supersonic aircraft was unmatched on the F-22 Team. He was a very demanding boss who set high standards for himself and everybody who worked for him. Over 30 years earlier he had a major role in developing the first Mach 2 aircraft, the F-104 fighter. In 1981, Heppe became Vice President and Assistant General Manager of the Skunk Works. Over the years, since I first started

working with him in 1969, he had selected me for a succession of jobs, including F-117 Program Manager—one of the best jobs of my career.

We had a very frank relationship and complemented each other to a significant degree. He was an internationally known aeronautical engineer and aerospace program manager. I knew about as much about aerodynamics as he knew about digital electronics. However, we both operated fundamentally the same way, rigorously accepting total responsibility and making things happen, not always smoothly.

Side Note: At this point, I also formally turned over the entire F-117 program to my deputy Sheridan, whose contribution to the success of the F-117 program had been enormous. Working with him since April 1982 had been one of the great pleasures of my career. He had come to Lockheed as a young man. He was a first-class, very practical aircraft design engineer, as well as a strong leader and very honest manager. In earlier years, I don't believe that Lockheed had treated him well, making scant use of his talents. He did an excellent job of running the F-117 program until his retirement in March 1988.

The Mating Dance

After much debate in early 1985, we concluded that Lockheed would have to team with one of its major competitors to win the ATF competition. We felt that we could win one of the first rounds without teaming, but could not win the final round single-handedly.

Heppe was the Lockheed point man in the teaming discussions, with me as his loyal and somewhat naïve lieutenant. Calling this a mating dance is accurate, not facetious.

The two strong fighter aircraft incumbents were McDonnell Douglas with its F-15 Eagle twin-engine fighter and General Dynamics-Fort Worth with its low-cost single-engine F-16 Fighting Falcon fighter. Since Lockheed management had a very strong historic dislike of Northrop, we had no interest in them. We also had no interest in Rockwell-North American Aviation or Grumman. As to Boeing, we were ambiguous.

Our initial off-the-record discussions with McDonnell Douglas and GD were very cautious, with many meetings and much vague posturing. McDonnell was very cocky, almost arrogant. General Dynamics was systematic and down to Earth, but inconclusive.

Shortly into this effort, Lockheed Chairman Anderson retired, and Kitchen, who had been Lockheed President and Chief Operating Officer since 1976, became Chairman and CEO on Jan. 1, 1986. This tipped the scale slightly because Kitchen would make the final decision on the team, and he was not enthused about teaming with McDonnell.

Nonetheless, in early 1986, Heppe and I had a lengthy teaming discussion with McDonnell Aircraft President Donald Malvern and the McDonnell Vice President for ATF, J. J. Burns. Again, McDonnell was fairly cocky and largely noncommittal. At the end of the meeting, however, Malvern did say: "Only one thing is certain: We will

never team with Northrop." Six months later, McDonnell and Northrop teamed on the F-23 ATF program, with Northrop as prime.

In spring 1986, Boeing Vice President Charles F. Tiffany and Boeing ATF Program Manager Dick Hardy came to Burbank for some serious teaming discussions. I flew with them to our huge Skunk Works Helendale radar range, which had been essential to stealth aircraft development. Clearly the capability of this facility, located in the Mojave Desert near Victorville, Calif., had an impact on their teaming thinking. However, discussions with Boeing continued for months with no resolution.

Then we came up with the idea of a three company team: Boeing, General Dynamics, and Lockheed. Richard "Dick" Adams, Executive Vice President of General Dynamics, a man short on words and fast on decisions, instantly endorsed this approach. And, in late May, Lockheed promptly but courteously rejected a very aggressive late effort by McDonnell's Malvern to engage us in a teaming agreement.

Finally, in June 1986, the CEOs of Lockheed, Boeing, and General Dynamics approved the three company approach—the long mating dance was over. On June 27, 1986, we signed a memorandum of agreement. Basically, the three companies would continue to compete, but, if one company won, that company would be team leader and prime contractor, and we would split the work one third each by dollar value.

On Oct. 13, 1986, the three CEOs signed the formal Teaming Agreement. It was a 48-page document plus a nine-page appendix. Blanchard primarily orchestrated the agreement, leading a small team of business managers and lawyers from the three companies. The agreement was developed—surprisingly harmoniously—in one intense week in Seattle.

This unique effort had lasted 18 months. We were now happily mated. And, this team has stayed mated since 1986.

Looking back, forming this team in mid-1986 was probably the most important decision the three companies made in ultimately winning the competition. It proved to be a remarkably cohesive team at all levels, from the CEOs on down. The number of people who did not fit into the team effectively was small. The team removed those few individuals who proved unproductive or proved they couldn't take direction from outside their own company and replaced a few managers who proved they couldn't lead people outside their own company. On the whole, most people adjusted well and got on with the very difficult task at hand.

By far the closest relationship which developed was that of the Hardy, Kent, Mullin trio in the Team Program Office. We occasionally had differences but resolved them promptly. We marched together tightly for 50 grueling months. We did not tolerate anyone in the three companies trying to end run us. Can you imagine that?

A New Fighter Design

> "Development engineering work is a tough way for an engineer or scientist to make a living. It is a young man's type of work, requiring discontent with the past and unbounded optimism for improvement. Uncertainty is their con-

stant companion. Age brings a desire for stability, impatience with constant change, and a weakening of the imagination and creative urge."
—M.P. O'Brien, Dean Emeritus, College of Engineering, University of California, Berkeley, 1962.

Modern airplane designs evolve spasmodically and often slowly. Designing them is a complex, creative task. Computers help, but not anywhere as much as computer zealots proclaim. No individual engineer or team of engineers is brilliant enough to get the right answer on the first try. Kelly Johnson, one of the greatest aeronautical engineers, took 16 months in 1958-59 to evolve the preliminary design of the first Mach 3 airplane, the A-12, for the CIA. It was named A-12 because it took 12 tries to get an acceptable design.

When I took over the ATF program the Skunk Works engineering team headed by Bartley "Bart" P. Osborne had been working on an ATF design for three years. This was the second supersonic stealth fighter aircraft design the Skunk Works had ever attempted. The first one had been Johnson's YF-12A fighter-interceptor. It was way ahead of its time and had no competition, but, as I noted earlier, it never entered production.

Osborne, who was a 1956 graduate of Carnegie Institute of Technology (now College of Engineering under Carnegie Mellon University) in mechanical engineering and later received a master's in aeronautical engineering, was also an experienced and competent proposal writer, a rare talent among aeronautical engineers. He and his team had evolved a very promising design concept despite the fact that, from an aircraft design viewpoint, many of the requirements set forth by the Air Force conflicted with each other.

Among USAF's primary design requirements were:

- Long range first-look, first-shot, first-kill capability against any enemy aircraft
- Crew of one
- Very stealthy to ensure outstanding survivability in combat
- Excellent subsonic and supersonic maneuverability
- Up to Mach 2 (about 1,400 nautical miles per hour)
- Supercruise, flying at supersonic speeds without using jet engine afterburners
- Carry all missiles internally to stay stealthy
- Carry all fuel internally to stay stealthy (no radar reflecting external tanks)
- Totally new integrated modular digital avionics system

The number of engines was not specified, but it was immediately obvious that one engine would not do the job. The Air Force had already selected General Electric and Pratt & Whitney to develop new supercruise-capable jet engines.

After three years of intense design and analysis, Osborne's team had completed the preliminary design and analysis for the Lockheed ATF. One of the most important objectives of our proposal was not only to describe our design but also to convince the Air Force that this was the best design approach to meeting their

ATF weapon system requirements. Our proposal also had to cover our approach to the electronics and software system design to meet the combat mission requirements.

Revolutionary Avionics System

In the Skunk Works in 1985 we considered our proposed ATF avionics system design to be of high importance competitively. Several of the veteran Lockheed avionics engineers, including me, came into the program with some very firm system architecture and system design ideas and conclusions based on past experience. All these ideas were included in the first Lockheed Skunk Works ATF proposal submitted in February 1986.

The Air Force wanted a totally new design avionics system that would eliminate the known operational, reliability, maintenance, and logistics support problems of existing systems. At the best of times, putting electronic equipment in fighter aircraft is a tough engineering design problem because of severe constraints: volume (size), weight, limited electrical power, cooling, the high vibration operating environment, and others. For the ATF, we gathered a large data base on all of the current systems: not the design engineering data but the real world data based on what operational Air Force fighter squadrons were experiencing. They keep good records, including maintenance actions for each piece of equipment.

There were numerous problems with existing avionics systems. Reliability was not good primarily due to inadequate cooling of electronics modules. The large number of different electronics module types in each aircraft drove up the cost of spare parts and ground support equipment to test and diagnose failed modules. And, many of the modules themselves were packaged together in so-called black boxes, so that when any part on any module failed the whole black box had to be removed and taken to the repair shop. Nonetheless, it was a long-standing design approach. We were determined to start with a clean sheet.

We made some fundamental decisions:

First, we realized that high reliability was not achievable using forced air cooling. High speed fans blowing air through every avionics black box had been the primary approach for decades, but the results were marginal at best. We planned to employ a liquid-cooling system, which many considered a radical approach.

Second, we said there would be no removable black boxes. The physical architecture of the system would allow the test, diagnosis, removal, and replacement of individual failed modules within the aircraft. This approach had been used successfully to a significant degree in the Navy P-3C maritime patrol aircraft, but it had never been done in a fighter.

Third, we would rigorously limit the number of avionics modules. We wanted to avoid the logistical nightmares inherent in earlier systems, such as the Navy's S-3A Viking aircraft, developed by Lockheed, that probably set the record with 1,200 module types. There were many other aircraft avionics system designs with 500 or more module types.

Consequently, we proposed to employ:

- Electronic installation packaging that would enable individual removal of malfunctioning modules.
- A common module design for all subsystems, so that the number of different avionics module types would be well under 100.
- Refrigerated liquid cooling to greatly improve reliability.
- A designed-in system self test and diagnostic capability to automatically identify a malfunctioning electronics module so an Air Force maintenance technician could quickly find, remove, and replace it.

This system design approach was based not only on clear technical thinking but also on strong emotional feelings of the experienced avionics engineers involved who had lived through decades of criticism about the old back box avionics approach. We did not intend to back down if challenged by defenders of the status quo.

Our avionics design also had many other innovative features, including integrated displays and controls in the cockpit.

To meet the Air Force requirements, we had to design and develop a mammoth amount of new software. We ensured that our proposal contained the preliminary functional design for all this software, which would be loaded into the many very high speed digital computer modules in the airplane. It was the most software intensive fighter aircraft design in history, but it would provide complete real time support to the pilot in combat. We believed our system design to be highly creative, truly unique, but also a realistic way of meeting the very demanding requirements.

Later our F-22 Team assembled a group of excellent avionics subcontractors strongly committed to our unique system design. The design called for all these companies to use common modules, many built by their competitors. We believed our unique design had enormous potential to provide better system performance and improved reliability but at lower cost. Our team deeply believed in this fresh approach, one that put us in a strong competitive position.

Grinding Out Our Initial ATF Proposal

The Air Force dictated the specific content and page count—volume by volume—that should appear in each company's draft Dem/Val proposal. Writing a first rate proposal is one of the most difficult and painful jobs in the aerospace business. Most engineers do it poorly, even though it is one of the most important things you can do for your company. The first written draft of our proposal, completed in mid-1985, was unusually mediocre.

In late September 1985, Lockheed brought in Alton "Al" D. Slay, a retired Air Force four-star who had led Air Force Systems Command and was now head of Slay Enterprises, to perform an in-depth review of that draft. Slay and his hand-selected Red Team were ruthless. And, during a subsequent two-hour debrief, they critically dissected our draft proposal page by page. There was blood on the floor. The Systems Engineering volume, in particular, got horrendous criticism.

Both Lockheed CEO Anderson and President Kitchen were in attendance, and it was the only time I ever saw Anderson really lose his temper. Red-faced, he chewed out all of us, including Kitchen, for not having more competent people working on the proposal. In no uncertain terms he ordered the senior management to bring several of the best systems engineers in Lockheed into the ATF program immediately.

Literally overnight we brought some aggressive new first-rate systems engineers into the program. They started arriving at Burbank airport the morning after the Slay debrief. When they checked in with me, they all said, "I'll be here until you release me." We did a complete rewrite of the proposal, working seven days a week.

Leading this new group was O'Neil, who served as Chief Systems Engineer on the program from 1985 to 1987. He and his team quickly wrote a new, first-rate Systems Engineering volume.

I personally took over the writing and editing responsibility for the Executive Summary volume. Heppe, a master of proposal writing and illustrating, spent much of his time painstakingly reviewing our latest draft. Nearly half the proposal content was in graphic form, and each illustration was reviewed in detail by a host of folks, including me, Heppe, Osborne, O'Neil, Burch, and Richard "Dick" Henderson, who would become our Director of Proposal Management.

By late November, we were starting to see daylight. It looked like we would be able to deliver a very good proposal to the Air Force, as requested, on Dec. 10, 1985.

Then the Air Force called a halt to the Dem/Val proposal effort while it worked out a major change. On Dec. 16, the service issued that change, altering the low observable requirements. The Air Force had decided—correctly—that it needed a much, much stealthier aircraft. We were elated by this change, believing it would greatly improve our competitive position.

USAF slipped the proposal submittal date into 1986. We locked up our ATF program building on Dec. 23 and took a long Christmas holiday. Our proposal team came rolling in Jan. 2 and charged down the homestretch in early 1986 with great enthusiasm.

On Feb. 18, we delivered our proposal to the Air Force. We were exhausted and cautiously optimistic that we would be one of the three winners. However, this was soon followed by another unplanned event: The Air Force restructured the whole ATF program.

Packard Commission Fallout

In late 1985, President Ronald Reagan commissioned David Packard, co-founder and chairman of Hewlett Packard, to lead a Blue Ribbon panel and make policy recommendations on how to improve the defense acquisition system. Packard, who had served as Deputy Secretary of Defense from 1969 to 1971 during President Richard Nixon's first term, had strong views on defense acquisition policy and was fearlessly independent. In 1969 Packard was not impressed by the way defense acquisition was being done. In 1986 he was even less impressed. One of Packard's main recommendations was that new, complex systems should first be prototyped,

Al Slay, Proposal Red Team Grand Master

At Lockheed our principal outside consultant throughout the ATF competition was Alton "Al" D. Slay, retired USAF four-star and former head of Air Force Systems Command. His leadership, intellectual power, and persistence were awesome.

It is prudent for any company in the aerospace business to have its major proposals critically reviewed by an independent group, usually called the Red Team, and Slay is the greatest Red Teamer I have ever met. We would have never won the tough ATF competition without the contributions of Slay and his team.

Slay, who had joined the Army as a private in 1942, retired from the Air Force as a four-star general in 1981. During his long career, he flew every Air Force fighter from the World War II P-40 single piston-engine fighter to the F-15C Eagle twin-engine jet. On his last assignment, as AFSC Commander, he was responsible for all research, development, and acquisition. He supervised the spending of many billions of dollars. He was a mighty Cold Warrior for many years. He mastered the design and acquisition of new weapons systems at every level of detail. His memory was legendary. He was an intense workaholic, but was also always in outstanding physical condition. This work and healthy ethic continued when he retired and established his own independent consulting business.

Slay's approach to writing a winning proposal was simple to state but hard to do:

1. Clearly define your strategy and themes and stick to them rigorously.

2. Precisely comply with every single requirement of the customer's Request for Proposal. This sounds like a platitude, but it is not. It forces you to very systematically evaluate the responsiveness of your draft proposal to every single sentence in the RFP.

Al Slay and his associates had perfected a detailed methodology for Red Teaming proposals that they employed rapidly and effectively. From the summer of 1985 to July 1986, Slay's incredible team contributed strongly to making our Dem/Val proposal excellent by all measures.

They succeeded according to Robert A. Fuhrman, Lockheed President and COO (1986-1988), who stated, "This proposal sings."

to demonstrate feasibility, before proceeding with the production design of the system.

The Packard Commission report, dated Feb. 18, 1986, stated:

> "A high priority should be given to building and testing prototype systems and subsystems before proceeding with full scale development. This early phase of research and development should employ extensive informal competition and use streamlined procurement processes. It should demonstrate that the new technology under test can substantially improve military capability, and should as well provide a basis for making realistic cost estimates prior to a full scale development decisions."

Based on the Packard Commission recommendations, the Air Force drastically changed the ATF Demonstration/Validation program. In May 1986, the service issued two new major requirements. First, competitors would design, build, and flight-demonstrate two prototype aircraft. Second, competitors would design and demonstrate their new prototype avionics systems—hardware and software—in a ground laboratory.

In June 1986 we began working day and night to prepare our revised proposal.

During this time, I had another blunt argument with Heppe, who was insisting that we should use conventional metal materials—primarily aluminum and titanium—in the prototype aircraft since this was the low-risk approach. I was adamant that to win the competition we would have to use a significant amount of the new, lighter-weight non-metallic composite materials. I yelled this out to him in a large meeting and then walked out. (My view prevailed: Our new proposal committed us to using a large percentage of advanced composite structural materials.)

We submitted our revised proposal in July 1986. Our somewhat optimistic estimated cost for the Dem/Val program was $1.1 billion. Since the government funding at that time was $691 million for a fixed-price contract, our team investment would be more than $400 million if we won. Kitchen wasted no time in making the decision in early July to accept the $691 million fixed-price contract. (This would never happen in today's defense budget environment.) Since we were all still in competition, we did not consult our two team partners on this decision.

Round One Winners: Lockheed and Northrop

On Friday, Oct. 31, 1986, the Air Force announced the two winners of the first round of the Advanced Tactical Fighter competition: Lockheed and Northrop.

I climbed up on a desk and shouted the good news to our program team. It was a big win. Lockheed was back in the fighter business. I did a long telephone interview with a *Los Angeles Times* reporter, predicting a very bloody competition yet to come with Northrop.

We were all so worn out we didn't even bother to celebrate. I went home early for once, tired, but happy. I called Slay, the hard-assed leader of our proposal Red Team, to thank him for his great contribution to our win.

Our victory was front page news in the Nov. 1, 1986, *Los Angeles Times.*

Over the next several months we tried to determine the results of the competition. Our best estimate was: (1) Lockheed; (2) Northrop, very close; (3) Boeing; (4) General Dynamics; and then the also-rans: McDonnell Douglas, Rockwell-North American Aviation, and Grumman. Neither of the two fighter incumbents had finished in the top three. The two leaders in stealth technology had won. Bottom line: The Lockheed-Boeing-General Dynamics Team was in the final round of the ATF competition.

Beginning the Final Round

"An adequate national defense cannot be assured except by an aerial force

capable of achieving command of the air." —Guilio Douhet, Italian pioneering airpower strategist, 1921

While Douhet wrote of "command of the air," the US Air Force used the term "air supremacy." And that's what the service wanted the Advanced Tactical Fighter to provide in the 21st century.

With that firmly in mind, the Lockheed-Boeing-General Dynamics Team began work at the crack of dawn on Monday, Nov. 3, 1986. I was now running a powerful team, and although we hardly knew each other that changed quickly. I was determined to use Skunk Works program management methods as much as possible in this complicated team lash-up.

USAF designated our team's ATF the F-22 and the Northrop team's airplane the F-23. The Dem/Val round of the competition was set to last 50 months and end Dec. 31, 1990.

The broad Air Force requirements were well thought out, focused, comprehensive, and extremely demanding. The average production cost was not to exceed $35 million per airplane. The maximum gross takeoff weight was not to exceed 50,000 pounds. The aircraft was to be very stealthy, be able to supercruise, have excellent maneuverability, and have a very advanced integrated avionics system. It was to be superior to the F-15 Eagle by a large margin: more reliable, easier to maintain, and far easier to support when operating deployed anywhere on Earth. Other than that, we could do anything to the design we thought was the right engineering thing to do. The airplane was to be a "clean sheet of paper" design. Everything in it would be new. This turned out to be very hard work—sometimes almost unbearable, but sometimes joyous.

The prototyping of the aircraft and avionics system were "best efforts" programs, aimed at reducing risk in the production phase of the program. There were no detailed contract specifications, just a general statement of requirements. One exception was the maneuvering capability, which USAF specified in more detail than any other performance requirement. It was clear that the Air Force was insisting on outstanding fighter combat maneuvering performance and would not allow it to be compromised to achieve the demanding stealth objectives. This did not change during the four-year competition.

Employing the "best efforts" approach meant that our team had to decide what we would do and what we would not do. Example: We decided that one of our prototype aircraft would have missile launch capability, which was not required. In the case of the avionics system, our team and its subcontractors had to decide what avionics equipment and how much mission software to prototype. Early in the program we strenuously debated and rapidly resolved these issues. And, once resolved, they were not changed. (We later realized our team had made some very good decisions in 1987.)

Launching the F-22 Team

For about 100 key members of the Lockheed-Boeing-General Dynamics F-22 Team Nov. 3-7, 1986, was a memorable week, with some truly new experiences. The

team gathered in Burbank on Sunday evening, Nov. 2, ready for the kickoff meeting on Nov. 3. It was a unique experience for everyone, an all day long show and tell, with each company summarizing its own proposal.

On Thursday, Nov. 6, Eric "Rick" E. Abell, Technical Director (Chief Engineer) of the Air Force ATF System Program Office (SPO), gave the team management a formal debrief of the Air Force's assessment of the proposals that had been presented by each of the three companies. He specifically cited their strengths and weaknesses. It was clear that the Lockheed Systems Engineering volume and detailed risk reduction plans had been a significant factor in the Lockheed win. Abell impressed the F-22 Team with his straight forward approach, frankness, and objectivity. This impression of him would not change over the next 50 months.

As the Team Program Office General Manager, I had the Boeing, General Dynamics, and Lockheed Program Managers reporting directly to me.

Dick Hardy. Boeing Program Manager Hardy had come to Boeing as an aeronautical engineer directly out of MIT in 1959. He was tersely articulate, strong minded, very systematic, and, it turned out, very loyal. His will to win was very strong. Like me, he was a native Northeasterner who had become a permanent Westerner.

Randy Kent. Kent, the General Dynamics Vice President and F-22 Program Director, had been a combat infantryman in Europe in World War II. He was a veteran aerodynamicist, very analytical, and a very experienced engineer and manager. He had by far the most fighter aircraft development experience in our team program office and was out to win in this last competition of his career.

Jack Gordon. Gordon, who had been the Skunk Works Chief Engineer for the F-117A, became the Lockheed F-22 Program Manager. He had 23 years aerospace experience and a Stanford master's degree in mechanical engineering. He was a strong, confident manager, solid as a rock. He helped significantly in launching the F-22 program before he became Assistant General Manager of Skunk Works.

Bob Blanchard. Blanchard continued as Lockheed F-22 Vice President and the team's Assistant General Manager.

We became a very cohesive management team, working intensely together, with mutual respect and mutual support. Our emotional commitment to winning the competition was very strong.

As stipulated in the Teaming Agreement, the Team Program Office reported to a three company Executive Committee (ExCom), which would meet about every two months. The original F-22 ExCom included seven executives:

Chairman: John C. Brizendine, President, Lockheed Aeronautical Systems Group

R. Richard Heppe, President, Lockheed California Company

Lionel D. Alford, Corporate Senior Vice President, Boeing

Abraham M. S. Goo, President, Boeing Military Airplane Company

Charles F. Tiffany, Vice President-Advanced Systems, Boeing

Richard E. Adams, Corporate Executive Vice President-Aerospace, General Dynamics

Herbert F. Rogers, Vice President and General Manager, GD-Fort Worth Division

The ExCom membership changed over time, mainly due to retirements. The only member who served from 1986 to 1990 was Rodgers, which proved of great benefit to me and the entire Team Program Office. In November 1988, Kenneth W. Cannestra replaced Brizendine as President of Lockheed Aeronautical Systems Group and became ExCom Chairman through 1995.

My first order of business was to build a cohesive, competition-winning Lockheed-Boeing-General Dynamics team. Our second order of business was to develop a first class, equally cohesive subcontractor team. It turned out—for me in particular but also for the Team Program Office managers—that keeping these teams cohesive would continually be the first, and on some days, the only order of business.

Our team and the Air Force SPO had a stunning number of strong personalities. Self confidence turned out to be conspicuously abundant, although not always justified. Diplomatic skills turned out to be not widely available, but also not very sought after. It was a rough, tough competition in every sense of the word. Most days I loved it. On other days, the adolescent behavior of middle-aged men was depressing. My gin martini consumption was high during these years, usually about four every night, but I was in my office by 7 a.m. every morning, eager for action. All the key Air Force people and subcontractor managers knew they could reach me early, and often did. I usually left for home about 6 p.m.

Team Relationships

We ran the F-22 team as a tightly knit—really tight—joint venture. This is an easy statement to make. What made it a reality every day for the entire 50 months was the relationship of Hardy, Kent, and me. All decisions and direction were made by us jointly in real time—often only in verbal form. At Boeing in Seattle, General Dynamics in Fort Worth, and Lockheed in Burbank, the F-22 had separate, classified work areas with security guards. The Team Program Office managed all work, not local company management, although they sometimes rose up and had to be put down.

The ExCom repeatedly urged me to divorce myself from internal Lockheed operations—I did, but the withdrawal took awhile—to spend all my time and energy leading the team. In the last years of the competition, I did not go to any Lockheed staff meetings and refused to be involved in any Lockheed activities not directly related to the ATF competition.

Within the F-22 Team, we had our own simple operating policies and procedures, none of which were well documented or followed rigorously. However, our paramount driver was time—and we did not let anybody take it away from us.

As agreed in the Teaming Agreement, each company was to get one third of the work by dollar value, meaning that each committed to making 33 percent of the

investment. I did not attempt to use standard Lockheed subcontracting policies and procedures. And, there was no effort spent deciding who shot John when problems popped up that would cost money to fix. (There were plenty of them.)

The equal one-third split really helped build team cohesiveness. It also precluded having administrators and lawyers—generating piles of paperwork—fight over who was going to pay what bill. We each paid 33 percent of the total bill and that was that. The team had few paper shufflers—a damned delight.

Our goal was to have completely open relationships within the team and with the Air Force across all elements of the program: technical performance, detailed plans and schedules, budgets, and financial performance. This proved painful sometimes, but that was the way we operated.

Blanchard, by far the most experienced subcontracting manager in the Team Program Office, was the chief architect for the team approach to subcontracting, which was straightforward: Any company that won an F-22 subcontract would advance with us if the F-22 Team won. They needed that assurance since most subcontracts were fixed price, requiring the subcontractor to invest. The only catch: The subcontractor had to deliver in this final selection phase. This way the Air Force would get what might be called a package deal.

We maintained very close relationships with the major subcontractors at all levels, frequently violating policy by circumventing the management chain of command. However, we trusted them and they trusted us.

We also had very close relationships, at all levels, with the competing jet engine contractors—General Electric and Pratt & Whitney. Both were designing low observable engine exhaust nozzles to meet our specific requirements. We trusted them to protect our competitively sensitive information and vice versa. We developed very strong program management and engineering bonds with both engine companies.

As part of the F-22 Team operating mode, we made no effort to gather competitive intelligence and perform competitive analysis. We simply ignored the Northrop-McDonnell Douglas F-23 team. We had decided that the right strategy was to focus on what the Air Force wanted and, if possible, give it to them. There would be no gamesmanship, no political persuasion. We did briefly debate conducting a substantial advertising campaign, but both the ExCom and the F-22 Team Program Office saw no value in it.

The three company CEOs and the ExCom were critical in keeping the many non-ATF managers out of the F-22 Team's way. These top execs managed that nearly flawlessly throughout the program. One succeeded totally: Boeing CEO Frank A. Schrontz, who was the only CEO in office throughout the program, would ask me privately, whenever he saw me, if I was having a problem with anyone in Boeing; my answer was always no.

Fain in Charge

In December 1986, the Air Force assigned Col. James A. Fain Jr. to replace Col. Albert C. Piccirillo, who had served as ATF Program Manager in the early phases of

the program. Fain was lean and mean. He was a 1963 Air Force Academy graduate and had flown both bombers and fighters. He was also a graduate of the Air Force Test Pilot School and had spent a lot of time test flying aircraft at Edwards Air Force Base over the Mojave Desert. As a lieutenant colonel he commanded the A-10 attack aircraft combined test force at Edwards and had done intensive night high-precision ground attack test flying. Fain was the ultimate hard ass who could and did out swear everyone, even former Army Sergeant Mullin.

I had many frank conversations with Fain. Whether by telephone or face-to-face, these conversations often would singe the ears of aerospace neophytes, or even some veterans.

He hit the ATF program like a precision guided bomb. He was fearless and fast. For the next 49 months he ran the program with an iron fist. The Air Force promoted him to brigadier general in 1989, which surprised many people but not me. There is no doubt in my mind that without him the program objectives, particularly the schedule, would not have been met. He was a very tough guy to work with, particularly at first. Not everybody loved him, but the Air Force had picked the right person. He understood the most important part of his job: total responsibility. He delivered results, real results, on schedule.

Both the military and civilian people in his SPO, headquartered at Aeronautical Systems Division, Wright-Patterson AFB, Ohio, were inspired and very competent. His Technical Director (always referred to by the classical title of Chief Engineer) Abell, a member of the Senior Executive Service, was an engineer of great competence and confidence. I called him the sergeant major of the Air Force program office, because he had the voice of a British regimental sergeant major, used it, and brought discipline to our numerous meetings, some with more than 100 people in attendance. Abell also had great technical insight and was articulate, blunt, and decisive.

Fain's operational counterpart at Tactical Air Command, Langley AFB, Va., was Col. David J. McCloud, a skilled fighter pilot and master of many trades, who served as TAC's Director of ATF Requirements (Advanced Programs). I had worked with him since 1982 when, as a major, he was the F-117 program staff officer in the black hole in the Pentagon. Then for two years he was Deputy Director of Operations in the F-117 stealth fighter wing at Tonopah Test Range, Nev. He had flown many F-117 night training missions, and he was a deep true believer in stealth. An engineer by education and fighter pilot by choice, he was intense, bright, articulate, and decisive. Most of all he was a leader. He was smooth in the best sense of the word.

Piccirillo, Fain, Abell, and McCloud were among the true founders of the ATF program. It was a privilege to work with them. They and many others they selected provided the Air Force an eager, first class total program management team. Over the final phase of the competition, Fain led the charge every day

At a more senior level, two Air Force generals played major roles in making the ATF program happen. One was Joseph W. Ralston and the other was John E. "Jake" Jacquish. Brigadier General Ralston, who was Director of Requirements at TAC and McCloud's boss, was one of the fathers of the F-117 fighter program and had become a convinced and articulate believer in stealth. As the ATF program moved ahead,

he was promoted to major general and moved to the Pentagon as Director of Tactical Programs, replacing Major General Jacquish. Jacquish received a third star and became Deputy Assistant Secretary of the Air Force for Acquisition.

Engine Exhaust Nozzle Fiasco

Under Air Force direction, General Electric and Pratt & Whitney had begun competitive development of unique new jet engines for ATF in 1983. P&W worked on what became the F119 engine and GE the F120 engine. The engine efforts were limited to ground test programs only until May 1986 and the fateful Packard Commission fallout.

After USAF decided to build ATF prototype aircraft, it funded both engine companies to build six flight-certified engines—four for installation in F-22 and F-23 prototype aircraft plus two spares. So far, though, the engine program had ignored the need for a low observable exhaust nozzle.

When Fain learned of the exhaust nozzle issue in early 1987, he moved quickly. He put the screws to the F-22 and F-23 teams to spend $30 million each for the required exhaust nozzles and, very reluctantly, we did.

He also convinced Lt. Gen. William E. Thurman, his boss at Aeronautical Systems Division, to put the two engine programs under his direct control. (The engine program had been run by a separate SPO.) Indirectly this sent a message to everybody in the Air Force and industry: Jim Fain, in no uncertain terms, was going to run the total ATF program. We liked this. Nothing is worse than working with a program manager who does not take total responsibility, who is not decisive, and who does not make decisions stick, whatever it takes.

Exercise Blue Two

In early 1987, the Air Force launched an effort designed to fully immerse the competing teams in the operating and maintenance (O&M) problems—and subsequent lessons learned—it faced with its current fighter aircraft. USAF dubbed it Exercise Blue Two and purposely conducted it during the winter at three front line NATO air bases in West Germany. Brig. Gen. Frank S. Goodell led the group—10 people from the F-22 team, 10 from the F-23 team, and 16 others, including Fain and Abell. Goodell was the Special Assistant for Reliability and Maintainability to USAF's Military Deputy for Acquisition.

We went first to Spangdahlem Air Base, where, dressed in chemical-biological protective clothing, we worked for two days with the F-4 Phantom fighter aircraft wing. In its time the F-4 was an epic McDonnell Aircraft accomplishment. They built more than 5,000, more than any fighter since World War II. However, the aircraft contained an incredible amount of electronics and other equipment that made it difficult to maintain, largely because removal and replacement of malfunctioning equipment took so much time and effort. The thick concrete aircraft shelters where the maintenance troops worked were cold, damp, and gloomy. It was a sobering experience for all of us.

Our next stop was the F-15C Eagle fighter wing at Bitburg Air Base. The newer F-15

was a much more reliable and maintainable airplane than the F-4. However, it required a large array of ground support equipment, such as various carts for electric power, hydraulics, and much more. It was an endless task to maintain all this stuff. The wing had 72 combat airplanes and 3,500 people—not a good ratio.

Our last stop was Ramstein Air Base, where we spent two days working with the F-16C Fighting Falcon fighter wing, which also had the latest General Electric jet engines installed. Clearly the F-16 was the easiest aircraft to operate and maintain, but even here there were lessons to be learned. The avionics maintenance shop had a huge set of complex automatic test equipment and other ground support equipment, which was virtually impossible to relocate. The jet engines had a very thorough health monitoring system built in, but the health criteria came from ivory tower engineers with the result that good engines frequently would declare themselves unhealthy. After each flight a veteran master sergeant looked at the data and decided if the engine was healthy or not, often overriding the automatic system.

Our Strategy for Winning

For the first six months of 1987, we formulated, documented, and communicated to our team a very explicit, very aggressive strategy for winning the ATF competition. Since we were investing hundreds of millions of Lockheed, Boeing, and General Dynamics money, in addition to ultimately $818 million (FY90 dollars) of government funding, this strategy determined where we spent it. Designing a good fighter aircraft and building and demonstrating two flying prototypes was only a fraction of the effort.

On June 29, 1987, I gave a presentation to the Lockheed Board of Directors that summarized our team's competition strategy:

- Develop the best flying prototypes
- Deliver the most capable avionics/software demonstrated in the Boeing 757 aircraft
- Produce a very stealthy full scale aircraft pole model for Air Force to measure
- Create a producible design to meet $35 million per aircraft goal
- Meet reliability, maintainability, supportability objectives
- Develop Navy aircraft version which meets all major Navy objectives (see p. 38)
- Develop first class management team for production design phase

While these goals are fairly obvious, the job was to make all this happen by December 1990.

I also told the board that our three-company team would require an investment of $405 million to win: $135 million from each company. By the end of 1990, we actually invested $675 million—$225 million per company.

Amazingly, at the end of all this I got promoted, as did Hardy at Boeing. Kent ended his long, productive General Dynamics career on a high note and retired. Winning the ATF competition erased all the F-22 Team Program Office's sins, which fortunately have never been cataloged.

Dumping Our Design: The Great 90-Day Fire Drill

To say July 10, 1987, was our blackest Friday is no joke. On that day, we dumped our design.

We spent all day in an ExCom meeting at Fort Worth locked in a fierce debate, during which we reached a unanimous conclusion: Our F-22 aircraft design was not competitive.

It was not a winner for at least two very good reasons. On paper it weighed far too much, and it would meet few of the most important Air Force requirements. To be honest, the team had lost confidence in the design.

That led us to another painful conclusion: We needed a new chief design engineer. I had to replace my good friend Bart Osborne. Osborne had led the preliminary design effort at Lockheed and had brilliantly led the preparation of our winning technical proposal, including skillfully writing some of it and editing all of it. However, he had not been able to rigorously manage the collection of Lockheed, Boeing, and General Dynamics engineers who worked for him, some of whom were undoubtedly snotty prima donnas. We were all learning that managing in a three company team was not easy.

After the ExCom meeting, Heppe and I selected C. Richard "Dick" Cantrell, then Director of Engineering in the Lockheed Skunk Works, as the new F-22 Director of Design Engineering. Selecting Cantrell turned out to be a wonderful decision. He was quiet, diplomatic, tough, and decisive, and an aeronautical engineer to the core. Surrounded by a sea of epic engineering egos, he was able to conceal his, which, I must say, was as big as any of them and much more justified.

We decided to start over at the crack of dawn on Monday, July 13.Thus, the F-22 Advanced Tactical Fighter was born between July 13 and mid October—in a 90-day fire drill. Our team looked at every possible configuration of the aircraft we could imagine. We formed separate tri-company teams in Burbank to do preliminary design for each candidate aircraft and to estimate its weight, combat performance, and other characteristics. We absolutely refused to compromise in the area of low observability. Any candidate design which was not really stealthy was immediately dropped. We worked six- and seven-day weeks. Tempers often flared, but the work went on.

The options and decisions seemed endless. We debated such things as whether to go with two big tails or four smaller tails, or different engine air inlets, or different wings, or different internal weapons bays with different kinds of weapons bay doors. We worried over weight estimates and drag estimates. However, one thing did not change: The designs always included LO engine nozzles with pitch thrust vectoring. Our team continued to work intensely with General Electric and Pratt & Whitney to make this happen.

Heppe was one of the great aeronautical engineers of his generation, and, at 64, he demonstrated that one more time during that intense summer of 1987. He had been at Lockheed since 1947, after completing postgraduate work at the California Institute of Technology in Pasadena. He understood both supersonic aerodynamics and stealth in great depth. He personally made all the major decisions. The rest of

us supported him and Cantrell intensely. It was a summer of imagination, invention, and engineering achievement.

By Oct. 15, we believed we had converged on the best aircraft design we could conceive. It had the lightest weight and the best operational fighter performance. We froze the external geometry—known in the aircraft business as freezing the lines—and launched the very talented Lockheed-Boeing-General Dynamics YF-22A prototype design engineering team.

Our technical course to winning was set. However, three years of intense systems engineering and detailed design engineering of the F-22 production aircraft were still ahead.

And, the results of the great 90-day fire drill were not perfect. It was in April 1988, that Edsel "Ed" Glasgow, our Chief Flight Sciences Engineer and one of the true fathers of the F-22, told me that our prototype aircraft would not supercruise. He said that the supersonic aerodynamic drag at Mach 1.5 was too high. Shocked, I snapped at him, "Don't tell me our damned problems; tell us how to fix them." The next day he did.

Glasgow was one of the best aeronautical engineers I ever worked with. (He played a major role in the F-22 design, for which he never got proper credit, then or later.) To reduce the supersonic drag, the Skunk Works reshaped the fore-body and Boeing rapidly reshaped the aft fuselage—both of which were already being built. These late major design changes were painful, but they got done quickly and they worked.

Investing in Simulation Capability

Knowing that it would be ultimately responsible for the full weapon system simulation for the team, Lockheed had decided early on in the ATF contest that it could achieve a competitive advantage by building a totally new simulation center. Before the advent of the three company team, Lockheed invested $70 million to construct its new Weapon System Simulation Center (WSSC) at the Lockheed Rye Canyon laboratories facility in Santa Clarita, Calif. Lockheed believed this capability was essential to winning the competition and planned to leapfrog its competitors. Developing the WSSC was tough work as the company raced against the ATF program calendar. And, the original Lockheed WSSC managers were not up to the task so unfortunately had to be replaced.

Once completed, the WSSC provided a series of select Air Force fighter pilots the opportunity to realistically evaluate the F-22 system design and provide constructive feedback. The WSSC had two F-22 simulated cockpits that enabled air-to-air battles with actual and postulated enemy aircraft. Each successive system evaluation by the pilots resulted in recommendations for system design changes, particularly relating to the mission software.

Boeing also decided early on, long before we formed the F-22 Team, to build a large avionics system integration facility in Seattle that would include extensive capability for state of the art mission software development. Boeing's major strategic capital investment in this area greatly benefitted the F-22 Team. And, Boeing expanded the facility specifically for F-22 system development. Those added capabilities, includ-

ing building a radar tower, enabled the facility to conduct integration testing and demonstration of our complete F-22 prototype avionics system.

General Dynamics had the responsibility for developing and rigorously utilizing a high fidelity flight simulator for the YF-22A prototype aircraft. This simulation was critical to developing the flight control system software, also an important GD responsibility and one that was probably one of the finest technical accomplishments of the program. (The flight test program emphatically substantiated this claim. This software is critical to flight safety and aircraft performance of an aircraft with a fly-by-wire flight control system.)

The team also purchased engine simulators from General Electric and Pratt & Whitney. Our team's three test pilots—David L. Ferguson, Thomas A. Morgenfeld, and Jon S. Beesley—who spent a lot of time at GD's Fort Worth facility flying the simulated aircraft, concluded that the engine simulation was the best they had seen.

These facilities provided our team with capabilities of great significance in the ATF competition. The F-22 Team used them all intensely. And it used another important Boeing contribution, a 757 aircraft converted into an F-22 Avionics Flying Laboratory.

Correctly Orienting the Engineers

Many F-22 Team design engineers were not enthused with the task of systems engineering, either doing it themselves or contributing to work being done by another engineer. From 1985 onward, getting systems engineering right became a frequent and substantial issue.

The Air Force had emphasized that the ATF systems performance requirements were tentative and would be modified, if necessary, to achieve the $35 million, 50,000-pound airplane. This meant we had to conduct numerous systems engineering trade studies—looking at many different detailed design options—and, where necessary, recommend changes to USAF's requirements.

Many of our engineers wanted to treat the original requirements as carved in stone. They also wanted to do what they liked best: design a hot fighter airplane. We got them correctly oriented in early 1987 by many methods, some not so subtle—and occasionally had to repeat the cure.

In 1987, Albert L. Pruden replaced Lockheed Chief System Engineer O'Neil as the F-22 Team Director of Systems Engineering. Pruden had retired from the Air Force as a brigadier general in mid 1986 and joined Lockheed as Director of Tactical Air Requirements. I considered it mandatory to have someone in the systems engineering job that had extensive operational experience with fighter aircraft. Pruden filled the bill. He not only had an aeronautical engineering degree, he had flown many combat missions in F-4 Phantom aircraft, commanded an F-4 wing, and later flew the F-15 Eagle fighter.

Pruden's endless focus was to ensure—every day—that we were designing the best possible total combat aircraft system, not a "gee whiz" engineer's dream. He supervised all of our risk analysis, operational analysis, and many other tough tasks,

including many tradeoff studies. He was disciplined and persistent. We worked side by side throughout the competition and worked well together.

Slowly but surely in 1987 and 1988, we conducted more than 200 detailed technical trade-off studies to converge on the best design in every aspect of our F-22 airplane. These allowed us to gain confidence—based on objective analysis of many, many options—that we were evolving to the best possible aircraft design. If done right, we would win.

Some of these trade-off studies dealt with large issues, such as the number of air-to-air missiles that could be carried in the internal weapons bays and still comply with the weight constraints and the speed requirements. Others dealt with detailed technical issues, such as determining the "best" operating pressure for the hydraulic system, based on weight and cost comparisons. In many cases the subcontractors on our team were deeply involved in this work. For example, our Westinghouse-Texas Instruments team worked intensely on the radar system to get the best balance of combat performance, stealth, cost, and weight.

Over this two-year rigorous systems engineering work, despite Air Force instruction to modify requirements as necessary, many Air Force people were very reluctant to reduce any of the initial requirements. This was true for McCloud's fighter pilots and Fain's civil service engineers and loggies (Air Force logistic support specialists). It was becoming clear, though, that something had to give despite our hope to still meet the aircraft's weight goal of 50,000 pounds.

The SAB Challenge

In summer 1988, our avionics system design faced a serious challenge from the Air Force Scientific Advisory Board (SAB). Air Force Secretary Donald B. Rice and Chief of Staff Gen. Larry D. Welch had commissioned the SAB to look deeply into the technical feasibility of the F-22 avionics system design and its ability to meet all combat mission requirements. The SAB completed its draft study in August, citing several major problems.

The biggest issue the SAB raised was lack of clear connections between explicit combat mission requirements and the specific capabilities of our avionics system architecture, hardware design, and planned mission software. This was basic to competent systems engineering, and the SAB concluded we had not done the work.

Actually, the F-22 Team had done the work fairly well, but team engineers had failed miserably in communicating that to the SAB. Our engineers had been obsessed with describing our system design in exquisite technical detail, but had given short shrift to explaining why and how it would meet critical mission requirements. Consequently, we had a major problem on our hands.

We established a small three company task force, led by Ed Milkovich, Lockheed's foremost avionics systems engineer, to review our design over the course of many weeks of intense work. This task force recommended a few changes in the architecture, but the main result was clear tops down technical communication, the lack of which had created the problem in the first place. (Some avionics engineers have systems engineering couth and some do not. And, while I believe it is good to have

Avionics Revolution Confirmed

To help the F-22 team prototype the revolutionary new avionics system we had designed at Lockheed in 1985-1987, we competitively selected a very strong subcontractor team. These companies were willing to make substantial investments to assist our team in winning the Advanced Tactical Fighter competition, since that would guarantee them many years of avionics equipment production and new software development work in the future.

Lockheed conducted the competition for what we called the Common Integrated Processor (CIP). The CIP included the core systems architecture and two key common electronic modules to be used throughout the complete avionics system. Those two modules were the Data Processing Module, a 32-bit general purpose digital computer, and the Signal Processing Module, a special purpose programmable computer. Each weighed 1.2 pounds. The CIP development effort also included the real-time operating system, which is the complex software that controls the total avionics system that is critical to F-22 combat performance.

Hughes Radar Systems Group and IBM Federal Systems Division were the primary CIP competitors. Hughes won the competition with an outstanding design and a massive cost-sharing commitment. And, Hughes offered one pleasant surprise: It would employ a new Intel 32-bit processor chip.

The Air Force had been developing a unique 16-bit airborne computer for use in the ATF and other aircraft, but it was never used in the F-22 mission avionics system.

Hughes performed well and supplied CIPs for all the other avionics contractors. This was a key element of our team's firm commitment to maximum use of liquid-cooled common modules.

Prototyping Our Advanced Radar System

Boeing conducted the team competition for the F-22 radar system. The team had already decided that we would develop an Active Electronically Steered Array (AESA) radar. This was controversial with some Air Force generals and even a few F-22 team executives, who were convinced that AESA radars were not affordable.

Our team was united: We would aggressively prototype an AESA radar and ignore the critics. The critical issue was the production cost of Transmit/Receive (T/R) modules. A T/R module is a very small, very complex microwave electronics device. With each radar requiring a few thousand of these modules, the production cost per T/R module was critical.

The competitors for the radar system were a Hughes team and a Westinghouse-Texas Instruments team. Hughes had been a major supplier of high performance fighter aircraft radar systems for decades. However, Texas Instruments was the leading developer of a new highly automated production facility for low-cost T/R modules.

Boeing selected the Westinghouse-TI team. They performed well, producing a high performance prototype AESA radar system on a very tight schedule.

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Avionics Revolution Confirmed continued from page 33—

The Integrated Electronics Warfare System (INEWS) Saga

The Air Force and Navy had started the Integrated Electronics Warfare System (INEWS) technology development program as a joint project in 1983. By June 1986, the services had awarded two $48 million contracts, one to a TRW-Westinghouse team and one to a Sanders-General Electric team. The two teams were to develop prototype INEWS technology.

Unfortunately, both the military's objectives and the contractors' visions were extremely ambitious, just short of saving western civilization by electronic warfare alone. One initial system configuration weighed 800 pounds, which would be totally unacceptable for ATF aircraft.

General Dynamics conducted the F-22 team competition, looking for the right contractor to develop a rational subset of INEWS, skillfully tailored to meet realistic F-22 requirements. The Sanders-GE team won, accepting the terms but reality came to them slowly and painfully. It would take some enforced discipline before the Son of INEWS team got their feet firmly on the ground.

Integrated Communications, Navigation, and Identification Avionics (ICNIA)

In 1986, the Air Force had selected TRW to do advanced development of a very ambitious and complex new avionics subsystem, called the Integrated Communications, Navigation, and Identification Avionics (ICNIA).

F-22 team partner General Dynamics negotiated a contract with TRW to develop a prototype of a scaled-down ICNIA system that could be demonstrated as an element of our integrated avionics system.

Developing our Advanced Avionics Mission Software

One major avionics requirement was that all ATF software would be written in the new DOD standard computer language called Ada. In 1986, severe software development problems—technical, cost, and schedule—plagued many (probably most) important defense programs. DOD believed that Ada would have epic value in eliminating such problems. The transition began with nearly religious fervor.

We implemented the standardized Ada software support environments throughout our team, including major subcontractors, trained hundreds of software engineers to program in Ada, and displayed a true belief in the grand Ada crusade. We tolerated no heretics. Even so, I was stunned—and even depressed—at the huge amount of Ada source code we were producing. However, the younger members of our team happily set about filling up the vast memory in our prototype avionics system with computer machine code generated by an Ada source code compiler.

Luckily we had a large number of good programmers on our team, including our avionics subcontractors, because I agree with the great computer software pioneer Richard W. Hamming who once said when asked which computer programming language yielded the best software: "Good programmers produce good software efficiently. Lousy programmers produce lousy software inefficiently. It has nothing to do with which programming language is used."

Key F-22 Avionics System Subcontractors		
Subcontracting Company	**Subcontract From**	**Subsystem**
Hughes Aircraft El Segundo, Calif.	Lockheed	Common Integrated Processor
Westinghouse Baltimore, Md.	Boeing	Radar subsystem
Lockheed Sanders Nashua, N.H.	General Dynamics	Electronic Warfare Subsystem (Son of INEWS)
TRW Rancho Bernardo, Calif.	General Dynamics	Communications, Navigation, and Identification subsystem (Son of ICNIA)

both kinds, the SAB also rightly expected to converse with those with systems engineering couth. This painful fire drill was self inflicted.)

The task force presented its results to the SAB: Problem resolved. The changes required no additional common module types. Our prototype avionics team marched on vigorously.

The Air Force Generals Weigh In

In December 1988, Chief of Staff Welch decided he wanted a personal in-depth review of both the F-22 design and the F-23 design. I gave him a three-hour briefing, including my first chart with the title "What This Team Believes." This was the point at which I stated, for the first time, that the 50-000-pound takeoff gross weight objective was a problem. I told Welch that we simply could not meet the full set of Air Force requirements with a 50,000-pound airplane.

As I presented the results of several of our major systems engineering trade studies, Welch changed some of the requirements right in our meeting. In the end, we agreed that a 55,000-pound gross takeoff weight airplane was a more realistic objective.

This quick grasp of the issues and equally quick decision-making was typical of Welch, who was a fighter pilot with a lot of combat experience during the Vietnam War and who rose quickly through the ranks to the service's top job. He was analytical and surgically decisive and, certainly, did not waste words. He was also one of the most competent generals I ever met. Welch, who was Chief from 1986 to June 1990, remained deeply involved in the ATF program until the day he retired.

There were two other Air Force generals who played key roles in the ATF program—Lt. Gen. John Michael Loh, who commanded Aeronautical Systems Division from August 1988 to June 1990, and his boss Gen. Bernard P. Randolph, who led Air Force Systems Command from July 1987 to March 1990.

In early 1989, Loh conducted reviews of the avionics systems designs for both the F-22 and F-23 to judge if they were affordable. They were not. The Air Force fighter pilots and engineers and our own avionics engineers and avionics subcontractors

had gone bananas, proposing system designs that would cost $15 to $20 million per aircraft to produce.

Loh concluded that the ATF program must have a mandatory cost cap for avionics. He recommended to Randolph that USAF should limit the production cost for the total avionics system in each aircraft at $9 million. Randolph approved.

This was an excellent decision. And, after we performed major CPR on our engineers, they put together the best system possible for a production cost of $9 million. (See Avionics Revolution Confirmed, p. 33.)

A Sound Avionics Demo Plan

Our team—partners and subcontractors—formulated a very ambitious program plan for the F-22 electronics hardware and real-time software prototyping. And, we implemented it very aggressively.

First, we demonstrated each of the four subsystems independently in development laboratories. Second, we integrated them at Boeing's massive new avionics system integration center in Seattle. And, third, we conducted a weeklong demonstration for the Air Force. It went well.

Some people referred to this successful system demonstration as the "miracle in Seattle," but, in reality, it was a first rate piece of engineering—well planned and well executed. But we weren't done.

Finally, we installed our entire prototype avionics system in the modified 757 aircraft Boeing had provided. (I called it the software engineer's version of a fighter aircraft.) The aircraft accommodated up to 20 test engineers and software engineers for many weeks' worth of airborne system tests and demonstrations Boeing conducted over the western United States. The obvious objective was to show the Air Force that all elements of our system worked well together—that it really was an integrated system. The demonstrations were amazingly successful, leaving our team very optimistic.

In fact, I think we exceeded our expectations. In less than four years, we had designed, built prototype hardware and software, and demonstrated to the Air Force a robust prototype of the most advanced avionics system that the world had ever seen.

At the peak of this system prototyping effort in late 1988, our very competent team included 1,600 engineers at Lockheed, Boeing, General Dynamics, and our many subcontractors. The key had been a sound plan, inspired leadership, and first-rate people.

Leading the work was Chief Avionics Engineer Burch, who had come to Lockheed as a young electronics engineer in 1956 and advanced steadily. He was one of the most disciplined engineering managers I ever worked with. He planned; he scheduled; he delivered. His deputies—Michael O. "Micky" Michellich at Boeing and Larry Klos at General Dynamics—also delivered outstanding results.

By mid 1990, we felt very good about our competitive position in avionics.

Support From the Top

When Lockheed boss Kitchen retired at the end of 1988, Daniel M. Tellep replaced him as Chairman and CEO on Jan. 1, 1989. In that role, Tellep also chaired the quarterly F-22 Team CEO meetings that rotated among Burbank (Lockheed), Seattle (Boeing), and St. Louis (General Dynamics). He became a major contributor to the success of the F-22 Team.

Tellep had joined Lockheed in 1955 after receiving undergraduate and postgraduate degrees in mechanical engineering from the University of California, Berkeley. Working initially at Lockheed Missiles and Space Company, he became an outstanding engineer and then, in my view, the outstanding Lockheed employee of his generation. He was a man of integrity and great intelligence who was decisive and set very high standards. He had no real competition for the CEO position when the Lockheed Board of Directors made its decision in 1988. For me, it was a great pleasure to work for him from 1989 to early 1994.

The support provided me and the entire Team Program Office by Tellep, Schrontz at Boeing, and Stanley C. Pace, CEO at General Dynamics, was the stuff of every program manager's dreams. They were all demanding men, but very frank, fair, and decisive. And, they were quietly united as to their view on the responsibility and authority of Mullin, Hardy, and Kent.

Essentially, their view was that the Team Program Office leaders were a failure whenever we asked the CEOs to make an F-22 program decision or solve an F-22 Team problem. They were correct. This made quarterly team CEO meetings in 1989 and 1990 brief and to the point.

Launching IPTs, Unique SPO Stability

The Air Force convened an ATF Business Management Working Group on April 13, 1989. Discussions focused on an evolutionary management concept featuring Integrated Product Teams (IPTs) and an Integrated Master Plan (IMP) and Integrated Master Schedule (IMS).

The ATF SPO was among the first USAF programs to implement this concept, and it had already established a number of aircraft and support system IPTs. Each IPT centered on a major subsystem and comprised members of a functional organization such as design, manufacturing, logistics support, quality assurance, etc.

The Air Force conducted extensive training in-house with primes and major subcontractors to ensure understanding and compliance. The IPT concept proved to be highly successful on the F-22 and other major programs.

Although the ATF SPO had kept growing as time marched on, and by Nov. 1, 1989, included 261 military and civilian personnel, the expansion did not seem to have much impact on our F-22 Team. We dealt with SPO director Fain and his key lieutenants, all of whom seemed to have a passion for ignoring the Air Force bureaucracy at all levels.

Fortunately for the ATF program, the Air Force left Fain and all of his key people in place throughout the 1986-1990 Demonstration/Validation program. By late

1989, Fain and his key managers had reached peak effectiveness. That assessment covered Chief Engineer Abell, Deputy Program Manager Tom Graves, Assistant Program Manager Col. Tom Bucher, Director of Avionics Lt. Col. Michael Borky, Director of Logistics Tom May, Director of Program Control Ron Runkle, and also many others.

Without this management stability the program would not have been completed on schedule and the Request for Proposal for the EMD phase of the program would not have been issued on Oct. 1, 1990. (I don't know who orchestrated this stability of personnel assignments, but it was unusual in the Air Force.)

Creating the Prototypes

Under our Teaming Agreement, we split the design and manufacturing responsibilities for the two prototype aircraft as follows:

Designing an ATF for the US Navy

In 1987, Congress exerted strong pressure on the Navy to join the Advanced Tactical Fighter program. The ATF System Program Office (SPO) added $50 million dollars to the ATF contracts to do the preliminary design and analysis for the Navy ATF (NATF).

To do this competently we needed to hire a program manager who had the requisite knowledge to develop aircraft that would meet the tough requirements for operating from a modern nuclear-powered aircraft carrier. We were lucky. We hired Roy Buehler, a recently retired Navy Captain who had flown F-8 jet fighters from carriers and had extensive F-14 Tomcat flying experience and technical knowledge. If it went into production, the NATF would replace the F-14 fighter aircraft.

In his final Navy assignment, Buehler had done an excellent job as program manager of the A-6 Intruder attack aircraft. In that job he also had crossed paths with Navy Secretary John Lehman, whose machinations caused Buehler to elect early retirement. We had picked the right man to lead our NATF program. To me not being loved by Lehman was a major virtue.

Buehler's NATF team included Glenn J. Eckard for Boeing and David Palmer for General Dynamics. They worked well with the Navy NATF program office, headed by Capt. Roger "Burner" Burnett, and the technical staff at Naval Air Systems Command.

One of the most important features of a good carrier aircraft is landing speed. For safety and other reasons, the Navy loves a landing speed of around 120 to 130 miles per hour, not any faster. This may sound fast, but it is actually considered slow. Designing a supersonic aircraft that can fly at Mach 2 and also fly really well at 120 mph is a very difficult task. The way this problem was solved when Grumman designed the Tomcat in the 1960s was to have "swing wings." For carrier takeoffs and landings, the wings were swept forward. For high-speed flying they were swept way back. This was a practical solution. However, having swing wings increased weight, complexity, and cost.

- Lockheed: Overall design integration, forward fuselage and cockpit, low observable parts, final assembly, and ground test.
- Boeing: Wings and aft fuselage, including engine installation.
- General Dynamics: Center fuselage, all functional subsystems (electrical, hydraulics, etc.), vertical and horizontal tails.

We also set up a separate, small, three company program management team responsible for the planning, scheduling, design, subcontracting, and manufacture of the two prototype air vehicles. Serving as Program Manager for the YF-22A was Joseph A. Donaldson, a veteran Lockheed engineering manager and a self-starter at the peak of his career. He reported to me in the Team Program Office. Donaldson and his team delivered two excellent airplanes under intense pressure.

The team used CADAM (Computer-Augmented Design and Manufacturing) software

Getting an acceptable carrier landing speed was our biggest design problem on the NATF program. Hardy and his Boeing NATF team were virtually obsessed with using a fixed-wing aircraft design. Using wind tunnel models, they set out to show that the aircraft could achieve an acceptable carrier landing speed. Concurrently at General Dynamics, Kent's NATF team became convinced that a swing wing was essential. In the 1960s, GD had developed the F-111 fighter-bomber for the Air Force using the swing-wing approach very successfully.

As 1989 unfolded, we conducted an internal competition to see which way was best for us to win the NATF portion of the competition. We gave Boeing more time to make their fixed-wing design work better. Finally in August 1989, Buehler strongly recommended that we select the swing-wing design. Our F-22 Team Program Office approved.

The team, working hard on every detail of our NATF design in late 1989 and early 1990, produced a very stealthy swing-wing fighter that could supercruise. It was very suitable for carrier operations. Most of the advanced integrated avionics system was identical to the system we had designed and prototyped for the Air Force. We felt very good about the NATF proposal we submitted in December 1990.

However, in early 1991, the Navy bailed out of the ATF program. They put all their carrier fighter aircraft eggs in one basket—the F-18E/F Hornet. It was a 20th century airplane, jack of several trades, and master of none.

But by going with the F-18E/F, the Navy avoided risk. There is no doubt that the A-12 stealth attack aircraft program failure had scarred the Navy's thinking for a generation. Navy leaders had lost their courage after decades of successfully pioneering excellent new carrier aircraft. They would not have a revolutionary new carrier aircraft in the early part of the 21st century. (Note: The Navy still got a vote in the ATF competition, and, as we found out later for certain, it cast it for our F-22 team.)

for aircraft design and tool design. Dedicated IBM mainframe computers at Burbank, Fort Worth, and Seattle were interconnected through high speed secure digital data links. This mature computer aided design system architecture worked well. General Dynamics produced computer controlled high precision rugged steel tools for all the major mechanical interfaces (wing-center fuselage, center-aft fuselage, etc.).

Final assembly was done by the Skunk Works in Palmdale. The pacing item was the GD-built center fuselage. In fall 1989, GD was experiencing major schedule problems with the center fuselage, but the section arrived in Palmdale in mid-January 1990. From that point, final assembly proceeded rapidly. All the major assemblies went together smooth as silk.

That is not to say there weren't other issues. Tooling costs, for instance, went way outside the budget because all three companies had grossly underestimated the cost of designing and building fabrication and assembly tools, particularly for the composite structures. And, this investment in tooling was doubly painful, since these beautiful, expensive tools would be used only for the two prototype airplanes.

There was little we could do except swear, grit our teeth, and push for completion. These tools did produce very high quality parts and major assemblies, resulting in two excellent airplanes, particularly for prototypes.

The Air Force also required us to design, build, and rigorously test a full-scale, high fidelity "pole" model of the F-22 to demonstrate that it would meet the very demanding low RCS (stealth) requirements. At the radar measuring range, the model sits on top of a giant pole, hence they are known as pole models.

Lockheed Skunk Works engineer Gary W. Ervin, who was the LO engineering manager for the team, led this effort, which is a complex and demanding task since the pole models include a multitude of details, such as engine inlets, antennas, radome, canopy, all radar absorbing structures, and many others. The external geometry of the model must be a precise replica of the planned production aircraft.

Despite extensive pole model design and construction experience at the Skunk Works, we experienced a major budget overrun building the F-22 pole model.

As required, we had submitted our predicted test results in advance and then successfully completed our actual pole model testing in March 1990. Knowing that the pole model test data was a major competitive issue, we believed our data placed us in a good position.

On the prototype front also, I decided we had to make a change in our flight test team in April 1989. The prototype flight test program appeared in peril because the detailed technical planning was not going well. It was not a good sign that our flight test managers were letting the design engineers push them around. The flight test team acted more like followers than leaders.

I needed a forceful, hands-on manager—Richard "Dick" Abrams, the best flight test manager in the business. Abrams, who was running the F-117 stealth fighter flight test program with great effectiveness since 1981, was a first class aeronautical en-

gineer who had gone into flight test engineering in 1960 for the Air Force at Edwards Air Force Base, fresh out of California State Polytechnic University. Over the years he had become a master of the trade. And, in addition, three of the YF-22A test pilots—Ferguson, Morgenfeld, and Beesley—had worked long, hard, and effectively on the F-117 program with Abrams.

My old boss and Skunk Works leader Ben Rich agreed to release Abrams, who took over the YF-22 flight test program in May 1989. Our problems in flight test rapidly disappeared. (I worked with Abrams from 1982 to 1994, and, in my view, he was one of the greatest flight test engineers of his generation, holding one of the best flight safety records in aviation history.)

Evolving the PSC

Meanwhile, we had continued evolving our Preferred System Concept (PSC)—the F-22 production aircraft design—working in parallel with the detailed design of the YF-22A prototype aircraft. The effort included the never-ending drive to reduce weight and improve combat performance.

The $9 million cost cap on the production avionics system helped. We eliminated the infrared sensor and two radar side arrays on the forward fuselage.

We also made three major configuration changes: (1) reduced the length of aircraft from 64 feet to 62 feet; (2) changed the wing leading edge sweep from 48 degrees to 42 degrees; and (3) changed the wing span from 43 feet to 44.5 feet. Each new configuration required considerable time and effort to conduct extensive analysis involving subsonic and supersonic performance, empty weight, takeoff gross weight to meet mission radius requirements, RCS over a wide range of frequencies, and many other areas.

And, we systematically addressed potential and actual changes to specific structural material selections. The team objective continued to be maximum use of non-metallic composite materials to reduce weight, which remained a major area of debate by the team's structural engineers.

By the end of 1989, this intense effort had produced a PSC that was an excellent fighter aircraft. However, we were still not convinced that it could win the competition. We based this view not just on data and numbers but also on engineering and program management judgment.

In Seattle in January 1990, during perhaps the most painful meeting the Team Program Office had with the CEOs of the three companies, we had two major agenda items.

First, we requested an additional investment of $30 million to do one last detailed design cycle for the PSC. We, the TPO leaders, believed this extra work was essential to winning the competition. After agonizing discussion, the three CEOs approved the additional investment.

Second, Hardy and his Boeing F-22 program organization wanted to have total control over mission software development during the next phase of the program. How-

ever, the Lockheed crew wanted to split the task, with Lockheed doing the software directly related to the pilot-vehicle interface and Boeing doing all the rest. After a brief discussion between Lockheed's Tellep and Boeing's Schrontz, Schrontz concurred with the Lockheed position.

From February to August 1990, the F-22 Team developed the final iteration of the PSC design, which would lead to our formal technical proposal.

Concurrently, work on the detailed contract specification for the F-22 Full Scale Development—or, using the subsequent terminology, the Engineering and Manufacturing Development—production aircraft was underway. However, as the weeks went by, the Team Program Office continued to see specifications and other docu-

The Tellep Restructure

Lockheed had reorganized in September 1987, creating Lockheed Aeronautical Systems Company (LASC) out of what was left of the Lockheed California Company in Burbank, Calif., the Lockheed Georgia Company in Marietta, Ga., and the Skunks Works in Burbank and Palmdale. LASC had huge old facilities operating at 30 to 40 percent of capacity. And, its three cultures refused to mix no matter how Lockheed drew the organization chart or who it put in the top box.

By fall 1989, Lockheed management realized that, basically, still having three separate aircraft organizations—often engaged in intramural battles—was unacceptable. The Cold War was over. Business was down.

In April 1990, at the culmination of eight months of study and analysis by LASC senior managers, Lockheed CEO Daniel M. Tellep and Lockheed Aeronautical Systems Group President Kenneth W. Cannestra faced a sea of paper outlining seven different potential plans of action. The plans had updated financials but were useless warmed over versions of earlier unacceptable plans that, quite literally, were a desperate substitute for lack of insight and judgment. Tellep then made some major decisions that permanently changed the aircraft sector of Lockheed.

He rejected all the study data, deciding instead to make the Skunk Works a separate company consolidated in Palmdale and to move everything else as LASC to Marietta, shutting down the original Lockheed plant in Burbank. He had all the staff studies of the past eight months put in the shredder.

Tellep had asked me how I felt about doing the F-22 ATF program in Georgia, if we won the ATF competition. He expected me to strongly oppose a shutdown of the Burbank plant. My answer was that the Lockheed's one-third of the ATF program could not carry Burbank. I further stated that the only way to solve the Burbank bureaucracy, overhead cost problem, and aging plant issue was to permanently and totally eliminate it.

The Lockheed Board of Directors approved the Tellep plan on May 9, 1990. The company rapidly implemented it. Some 1,000 Californians going to Georgia migrated there in early 1991. The last Lockheedians left Burbank in May 1994, on their way to the Lockheed Skunk Works at Palmdale. (I was personally responsible for the shutdown of the Burbank plant.)

ments containing TBDs, or things yet To Be Determined. We launched a vigorous campaign to eliminate the raft of TBDs and wrapped up the PSC effort as summer ended.

Surviving Cheney's MAR

In the midst of our fully engaged Dem/Val efforts and initial EMD planning, Defense Secretary Cheney decided to conduct a Major Aircraft Review. Cheney expected the review, which he initiated in January 1990, to determine if the country could afford to continue developing several very expensive new military aircraft. The Air Force had three programs under scrutiny: the B-2 stealth bomber, C-17 transport, and Advanced Tactical Fighter (both the F-22 and F-23). The Navy had one program: the A-12 stealthy carrier attack aircraft.

DOD Acquisition Chief Betti, former senior executive of Ford Motor Company, led the review. He first brought a team of senior civilian officials, generals, and admirals to California to conduct formal half-day reviews each on the B-2, C-17, F-22, and F-23 programs. They then went to Texas to look over Navy A-12 stealthy carrier attack aircraft program.

The F-22 Team held the F-22 review in the Skunk Works flight test hanger in Palmdale, where we were assembling our two YF-22A prototype aircraft. I gave a two-hour briefing, relaying primarily that we would complete the flight testing and the avionics systems demonstrations by the end of 1990 and that we were totally prepared to start the EMD of the F-22 production airplane in 1991, as planned. Over the course of another hour, Betti and his reviewers looked at the two airplanes. Lockheed chief test pilot Ferguson gave them his briefing while sitting in the cockpit of our first YF-22A aircraft.

The review team's questions were few and not very penetrating. I came on strong, displaying the belief and emotional commitment that I deeply felt.

In late March Betti reported to Cheney that all the aircraft programs were right on track and should proceed into production. (Note: Betti's conclusions on the Navy A-12 aircraft were pure baloney—see section titled Lucky in Hindsight, p. 11.) Cheney promptly reported the results of the review to the appropriate Congressional committees, whose members did not challenge the respected former Congressman from Wyoming.

The ATF program survived the MAR and so did I. We did not peddle baloney to anyone. Having two real airplanes to show the naive Betti and his entourage was a lot better than 100 beautiful color viewgraphs and a stream of soothing rhetoric. Actually, we also had some good viewgraphs, which I presented with rare brevity.

The ATFs Fly

Throughout the Dem/Val and Cheney's MAR, the intense ATF competition with the Northrop-McDonnell Douglas team continued seven days a week. And, it was the Northrop-McDonnell team's ATF prototype that flew first. Northrop chief test pilot Paul Metz made the first flight of the YF-23, powered by Pratt & Whitney YF119 engines, on Aug. 27, 1990.

On Aug. 29, the F-22 team rolled out the YF-22A Prototype Air Vehicle (PAV)-1, powered by General Electric YF120 engines, at Lockheed's Palmdale facility.

On Sept. 29, 1990, my friend "Fergie" Ferguson taxied the YF-22 PAV-1onto the runway at Palmdale, ready to takeoff. He would sit there for 30 long minutes because the Ridley ground control center at Edwards Air Force Base could not receive the aircraft's telemetry signals— a mandatory requirement for the test flight.

Ferguson had been an Air Force test pilot for many years, after flying numerous combat missions in Vietnam. He had retired from the Air Force as a lieutenant colonel and joined the Skunk Works as a test pilot on the F-117 aircraft program. Instead of a white scarf, he had gray hair.

I was standing on the north side of the runway with Maj. Gen. John P. Schoeppner Jr., Commander of the Air Force Flight Test Center at Edwards, and ATF Program Manager Fain waiting for resolution of the telemetry problem. Fortunately no one was near us or they would have heard every profane and obscene word in the English language used emphatically, some more than once. Finally, technicians found and fixed the problem at Ridley.

Immediately Ferguson took off in front of a wildly cheering crowd, landing at Edwards about 30 minutes later. Our YF-22 flight test was underway.

On Oct. 30, 1990, Morgenfeld, a former Navy F-18 and Skunk Works F-117 fighter test pilot, made the first flight of PAV-2, our second YF-22 aircraft, powered by two Pratt & Whitney YF119 engines. Three other excellent test pilots shared the flying at Edwards: General Dynamics' Beesley (another former Air Force F-117 test pilot), and Air Force test pilots Lt. Col. Willie Nagle, with the Air Force Operational Test and Evaluation Center, and Maj. Mark D. Shackelford, with the ATF Combined Test Force.

Between Sept. 29 and Dec. 28, our team, with Abrams leading the charge, conducted one of the most intense and successful flight test programs in the history of aviation. This is what our team did:

- Flew 74 test flights
- Accumulated 92 flight hours
- Demonstrated and used in-flight refueling extensively
- Demonstrated supercruise (at about 1,000 miles per hour) with both airplanes
- Flew at speeds up to Mach 2 (about 1,400 miles per hour)
- Demonstrated engine thrust vectoring
- Demonstrated super maneuverability, from low speed to supersonic speed
- Demonstrated high speed maneuvers over 7 Gs
- Launched two types of air-to-air missiles from internal weapons bays

Friday, Dec. 28, was another epic day, both in performing flying and collecting test data. The Air Force provided a gas station in the sky, an Air Force KC-135 tanker that flew all day above Edwards. Morgenfeld flew aircraft No. 1, conducting numerous in-flight refuelings and supersonic performance testing, both at supercruise and at

The Financial Aspect of Dem/Val

It is not clear who in the Air Force, in May 1986, decided that the Dem/Val contracts would be a fixed price of $691 million for each contractor. We don't know whether this number was based on incompetent estimates or just a Pentagon fantasy. In any case, USAF set this price after also deciding to restructure the program to include two prototype aircraft and a prototype avionics system.

And, just to ensure that we did not spend all the money on the two prototype aircraft, the contract stipulated that $293.5 million would be spent on avionics. (Note the idiotic precision of this number.)

In July 1986, after Raymond G. Stuber, a veteran Lockheed financial manager, conducted a cost estimate for the restructured program, he and I met with Lockheed CEO Kitchen and selected senior corporate officers. We went through the program content in depth, and then covered the cost estimates. They were: minimum $1 billion, target $1.1 billion, and more likely $1.2 billion.

At those costs, the company investment would be $300 million to $500 million. But, with a three company teaming arrangement, we estimated the cost per company at about $100 million to $170 million.

In 1987, after we had fully established the F-22 Team, we settled on a plan to invest $135 million per company. However, that proved unrealistic.

When it added the Navy ATF program, the government provided an additional $50 million. (We did not invest any team funds in the NATF.) The contract total then was some $818 million in FY90 dollars.

In the end, the Lockheed-Boeing-General Dynamics team spent about $225 million per company. Writing off the investments as incurred, we buried the costs in financial reports from 1987 to 1990, thus causing no hiccups on Wall Street. I don't believe the company boards criticized any of the three CEOs for making this major investment.

We did not require our major subcontractors to provide a summary of how much they invested, but a good estimate is that our F-22 Team subcontractors, as a group, invested about $200 million from 1987 to 1990. Like Lockheed, Boeing, and General Dynamics, the subcontractors wrote off the investment as it occurred. Again, we noted no adverse impact on earnings either with Wall Street analysts or financial press. Fortunately all of our subcontractors were financially healthy.

This is the breakdown of costs and the funding sources for the F-22 Dem/Val program:

Government funding	$818 million
Team investment	$675 million
Subcontractor investment	$200 million
Total	$1.7 billion

However, these program costs do not include capital investments each company made to try to ensure a strong competitive position. A good approximation would be $100 million for each of the three F-22 team companies. Collectively, the major F-22 subcontractors also probably made $100 million in capital investments.

maximum speed, using the engine afterburners. Nagle, the operational fighter pilot, flying aircraft No. 2 also refueled several times and demonstrated many different high performance maneuvers.

The sky was clear and the sun was very bright above the Mojave Desert. The aircraft flew at altitudes up to 50,000 feet and sent many supersonic booms rattling across the Antelope Valley, which was music to the ears of the 200,000 desert rats that lived there.

This was the last day of "sealed envelope" testing. In June 1990, at Fain's direction, we had turned in our analytical predictions of all the measurements we would make during the flight test program. They were in a sealed envelope turned over to the Air Force. F-22 Chief Flight Sciences Engineer Glasgow supervised the work done on the analytical predictions contained in the sealed-envelope data.

The flight test data measured during the YF-22 flight demonstrations was virtually identical to our team's analytical predictions, which really impressed the Air Force.

At 4 p.m. on Dec. 28, Abrams, Ferguson, and I, sitting in the real-time ground data center, decided that this incredible flight demonstration program was over. Morgenfeld and Nagle flew back to Edwards and landed. It was one of the great afternoons of our lives. The troops parked our two beautiful prototype fighters and locked the place up.

At dusk we all headed home for a four-day New Year's weekend. When I got home to Glendale that night, I said to my wife Judia: "Make me a big martini. We've won." That was the first martini, not the last.

Crafting the Final Proposal

As we had proceeded through the Dem/Val phase, pushing toward prototype flight testing, the F-22 Team also had begun planning for the EMD phase and developing our formal proposal. I confess that our team did not get off to a good start with Fain in planning for this next phase.

Specifically, we encountered a big problem when Raymond G. Stuber, F-22 Team Business Manager, and I went to Wright-Patterson Air Force Base for a working, informal kickoff meeting with Fain and a few of his people. The SPO had patched together a big master schedule—some SPO members dubbed it the Dead Sea Scrolls—from segments of several earlier programs.

As the meeting went on, Stuber politely shot down most everything Fain proposed. After about an hour, Fain stood up and said, "Mullin, I want you and this guy Stuber off this base immediately." We drove over to the Air Force Museum, had a leisurely lunch, and flew home to Los Angeles.

Assistant Program Manager Bucher called me at home that night and said Fain would call me in the morning to direct me to get rid of Stuber. Bucher urged me, on behalf of the SPO senior managers, to stick with Stuber. Fain did call, but I kept Stuber on the program. He was a major contributor to our victory.

We spent most of 1990 planning for the EMD phase and working on our formal

competitive proposal to the Air Force. Our idealistic objective was to beat the Northrop-McDonnell Douglas F-23 team in every element of the competition, including every volume of the proposal. As I noted earlier, proposals are always tough, and this one was very complex, despite a sincere effort by the Air Force to simplify it. We expected the release of an RFP for EMD production by mid-1990, so we had launched program and proposal planning activities more than a year earlier.

We established our team Proposal Management organization in March 1989 with Henderson as Director of Proposal Management, reporting directly to me. Henderson was a 37-year Lockheed employee with experience in systems engineering, business management, advanced programs development, marketing, and program management. He had worked for several years in each of the three largest Lockheed companies, the corporate Washington office, and the Skunk Works. In addition to his "regular" jobs, he often served as an author, reviewer, or coordinator for major proposals throughout the corporation.

Joining Henderson were Ted Heikell for Boeing and Fred Kelly for General Dynamics. We also had Al Slay and his Slay Enterprises team to again serve as proposal Red Team.

We had many volumes to write: technical, management, plans and schedules, cost, executive summary, and others. We assembled a potent proposal team of the best Lockheed, Boeing, and General Dynamics people we could find. The process was often painful. The Air Force sent us a draft RFP for review, which we did in detail and recommended revisions to it.

The government required simultaneous submittal of two proposals: the F-22 EMD/

Final EMD Proposal Contents/Pages

Proposal Volume	*Author*	*Number of Documents*	*Number of Pages*
I. F-22/NATF Executive Summary	Al Pruden	1	15
II. F-22 Technical Proposal	Don Herring	8	150
IIA. NATF Technical Proposal	Don Herring	36	2,000
III. F-22/NATF Management Proposal	Rudy Burch	2	300
IV. F-22 Cost Proposal	Dave Golem	14	6,250
NA. NATF Cost Proposal	Dave Golem	4	1,210
V. Past Performance	Gary Johannesson	2	25
VI. Model Contract	Roy LeCroy	86	17,490
VII. IMP/IMS Guide	Roy LeCroy	1	15
Corporate Financial Information		1	60
Project 3100/3200 Supplements		7	1,315
Project 3212 Supplements		3	725
Totals		**165**	**30,555**

Production proposal and NATF Dem/Val III proposal. This complicated the technical and proposal development efforts because we had to coordinate parallel design activities and produce a greater number of proposal documents. We successfully persevered with both products using special organizational and procedural approaches.

After we wrote our first draft, Slay and his Red Team reviewed it, generating many detailed requirements for revision.

USAF formally issued its Draft EMD Request for Proposal on Aug. 18, 1989. Our F-22 team used a proprietary computer program to parse the Draft RFP into an extensive list of individual requirements, each of which we then assigned to an author for a response. As proposal preparation and reviews progressed, we audited each requirement to ensure that we achieved full, competitive compliance.

USAF issued a revision to the Draft RFP on April 23, 1990, that triggered a rapid escalation of proposal activities. Among them, we established proposal themes in May, conducted author training in May and June, and held a monthly series of in-process reviews with the SPO during May through August.

Volume and section authors did an outstanding job. Many of them wore two hats—one as a key manager or specialist in a functional organization and the other as an author. They were often pulled in two directions—first to their design, test, and support responsibilities and, in the wee small hours, to spelling out on paper how and why their technical effort clearly offered the best competitive choice.

Various review teams were a fundamental part of our proposal preparation process. We had a Gold Team review completed on July 3, a Pink Team review on Sept. 12, and two Red Team reviews, one on Oct. 26 and one on Dec. 4. Slay chaired these review teams, which included highly qualified company and retired military personnel, none of whom were involved as proposal authors, but each of whom understood the requirements and issues surrounding the ATF/NATF procurement.

The review teams scored each proposal section for compliance with RFP requirements, demonstrated expertise and competence, and effectiveness of presentation. The reviewers provided deficiency reports and clarification requests to authors for their resolution. The review teams also provided a final debrief for authors, team management, and company management. They emphasized strengths, weaknesses, risk areas, and required corrective action.

The Air Force issued its final EMD RFP on Nov. 1, 1990.

We had established Proposal Support Centers, located at each company, to be the focal points for receiving, tracking, producing, distributing, and maintaining the status of proposal text and graphics to post on an up-to-date review “wall” chart.

The Lockheed Support Center, managed by Lynn Blue, integrated team inputs and conducted the final composition, printing, binding, and preparation for delivery. We had detailed instructions for preparation, formatting, and editing.

Security classification also had a major impact on proposal preparation. Our final submittal contained more than 8,000 classified pages—most at Top Secret Special

Access Level III. Team members had to use a secure Video Teleconferencing network to conduct much of their coordination. The preparation, transmittal, and review of classified proposal text and graphics followed rigorous guidelines to ensure the complete maintenance of tight security.

During December 1990, we maintained very tight schedule controls for every volume. Red Team reviews were completed, followed by author fixes, editing, follow-up review, classification check, management review, final fix and proofread, printing and binding of multiple copies, QA check, packing, and preparation for transport.

We had chartered a cargo transport plane to deliver our proposal—securely boxed and comprising several wooden pallets—to the Aeronautical Systems Division at Wright-Patterson. The plane left Burbank late in the evening of Dec. 30 with two security personnel riding shotgun. Henderson and Bill Schaff of Lockheed's Dayton Office met the airplane early on Dec. 31 with a forklift and truck. They completed delivery to ASD by midday Dec. 31, 1990.

I stayed totally immersed in the F-22 advanced tactical fighter program until we finished flight testing and delivered our proposal. I led our team in giving the formal oral summary of our proposal to the Air Force at Wright-Patterson on Jan. 3, 1991—my last day on the F-22 program. I was very confident we would win.

The F-22 Team Wins

On April 23, 1991, Secretary of the Air Force Donald B. Rice announced the winner of the ATF competition: our Lockheed-Boeing-General Dynamics F-22 team. He also announced that Pratt & Whitney won the ATF engine competition.

The F-22 team had defeated the Northrop-McDonnell Douglas F-23 team. And, P&W had defeated General Electric.

Addendum: Why Was the F-22 Team ATF Team Successful?

F-22 Team General Manager Sherm Mullin—

Leading the F-22 Team taught me many new lessons, some of which I included in my Wright Brothers Lecture in Aeronautics, delivered on Aug. 24, 1992, for the American Institute of Aeronautics and Astronautics. I titled it "The Evolution of the F-22 Advanced Tactical Fighter." Quoting from that presentation:

> "In the current age of overspecialization and unwillingness to take risk, Orville and Wilbur Wright will forever loom far above the crowd, as they did in 1903. Aeronautical engineering was not meant to be a profession for those engineers obsessed with very low risk and not avid in developing and applying new technology. Now we have risk adverse types of engineers in abundance, and they are greatly impeding our efforts." …
>
> "The F-22 is a truly revolutionary airplane, designed in a unique team environment. We succeeded because we were willing to take the necessary technical risks. To succeed as a team, cohesion of the highest order is mandatory. With cohesion you can solve problems rapidly; without it, the process bogs down. We gave the highest priority to achieving and maintaining team cohesion, which we succeeded in doing." …
>
> "We have unlimited opportunities as we march into the 21st century. The ATF was one of the last opportunities of this century, and we met the challenge. The question is will we continue to do so in aeronautics. There is no such thing as a low risk future program in advanced aeronautics. Yet this oxymoronic phrase is heard with increasing frequency. We must continue in the tradition of the Wright Brothers or we will slowly wither away." …
>
> "In summary, this work was accomplished by my esteemed colleagues, the total F-22 Team."

Boeing F-22 Program Manager Dick Hardy—

I have been thinking about our success and have come to the following conclusions:

1. We kept the team glued together, and Sherm Mullin gets most of the credit for that. Randy Kent and I did OK supporting his leadership.

2. We used the best ideas from the whole team. Heppe, Mullin, and engineering leaders, like Rudy Burch, get a lot of credit for having technically open minds.

3. We figured out the production configuration and made the design compromises during the Dem/Val phase.

4. We built a prototype aircraft of the production configuration, so we demonstrated the high-risk areas like missile bays and launch, high angle of attack, and signature.

5. The competition—the Northrop-McDonnell Douglas Team—did not do well in those areas. Northrop and McDonnell Douglas fought with each other, and their prototype aircraft was a low signature device that had the missile bays in the wrong place and was angle of attack limited.

General Dynamics Program Director Randy Kent—

The make-up of our team represented the best our industry had to offer:

- Lockheed: Stealth experience, excellent system engineering capability, and masterful program management capability.
- Boeing: Complex avionics integration experience, industry-leading in materials and manufacturing, and a well-deserved reputation for delivering what it promised.
- General Dynamics: A well-recognized capability for modern fighter aircraft design and three decades of supporting USAF operations worldwide.

Our top-level management structure was successful in establishing procedures that recognized the best ideas, regardless of which company they emanated from. This also involved dealing with giant egos present in all three companies. The upper management challenge was to use these ideas, endure the ego trips, and settle disputes rapidly. Our approach to this situation was to instruct all personnel that in the event of a conflict of ideas, the combatants must immediately alert their company leader, then put the matter before the Mullin-Hardy-Kent trio for resolution and direction. Long-term festering of problems was thus avoided.

Finally, but most importantly, the key factor in winning was that we had the most capable Program Manager in industry: Sherman Mullin. His ability to draw the best out of his team (by calm, explosions, and finesse) and to sustain the confidence of the Air Force in our efforts was the single most important factor in our win.

Appendix A: Chronology of the ATF/F-22 Team Program

1981

May-June: The Aeronautical Systems Division (ASD) at Wright-Patterson AFB, Ohio, issues a draft Request for Information (RFI) for the Advanced Tactical Fighter (ATF), seeking responses from nine companies (Boeing, Fairchild, General Dynamics, Grumman, Lockheed, McDonnell Douglas, Northrop, Rockwell, and Vought).

November: ASD issues the formal RFI for the ATF program.

1982

May: ASD receives seven RFI responses (Boeing, General Dynamics, Grumman, Lockheed, McDonnell Douglas, Northrop, and Rockwell).

1983

May: ASD issues the concept definition Request for Proposal (RFP) for the ATF program.

September: The Air Force issues $1 million concept definition contracts to seven airframe companies (Boeing, General Dynamics, Grumman, Lockheed, McDonnell Douglas, Northrop, and Rockwell).

September: The Air Force awards Demonstration/Validation (Dem/Val) contracts to General Electric and Pratt & Whitney to design and build ATF engines—USAF designates F119 for P&W and F120 for GE.

October: Air Force Systems Command (AFSC) formally establishes the ATF System Program Office (SPO), headed by Col. Albert C. Piccirillo, at the Aeronautical Systems Division.

1984

Unknown: Lockheed assigns Bartley P. Osborne as Skunk Works Chief Engineer for the ATF.

May: ASD holds Acquisition Management Panel to seek ASD Commander's approval for the Dem/Val phase acquisition strategy.

May: The seven companies deliver results of their concept definition studies.

June 1: Lockheed California Company taps R. Richard "Dick" Heppe as President.

August: AFSC's Business Strategy Panel approves the acquisition strategy for the ATF Dem/Val phase.

October: ASD issues draft RFP for the Dem/Val phase of the ATF program.

1985

January: Sherman N. Mullin, Lockheed Skunk Works F-117 Program Manager, joins Lockheed's ATF program part time.

March: Robert H. Blanchard becomes Deputy Program Manager, Lockheed ATF program.

Oct. 8: ASD issues the final RFP for the Dem/Val phase to the seven competitors, with proposals due Dec. 31, 1985.

Oct. 9: Mullin becomes acting ATF Program Manager (not publicly announced).

October: Lockheed Red Team rates Lockheed's Dem/Val proposal draft systems engineering volume grossly deficient.

October: William D. “Will” O’Neil becomes the Lockheed ATF acting Chief Systems Engineer.

November: The Air Force establishes far more stringent low observable (LO)/stealth requirements and extends Dem/Val proposal submittal date by six weeks to Feb. 18, 1986.

Dec. 23: Skunk Works ATF team shuts down for the Christmas holidays.

1986

January: Lawrence O. Kitchen becomes Lockheed Chairman and CEO, succeeding Roy Anderson, CEO from 1977 through 1985.

Feb. 18: Lockheed submits its proposal for the ATF Dem/Val phase.

April 7: Brig. Gen. Albert L. Pruden Jr., USAF (Ret.), joins Lockheed as Director of Tactical Air Requirements.

May 28: The Air Force drastically restructures ATF Program, adding requirements for two prototype aircraft and a prototype avionics system.

June 3: Lockheed hosts prospective subcontractor conference: “Join the Winning Team.”

June 27: Company officials sign a Memorandum of Agreement at Boeing’s plant in Wichita, Kan., forming the Lockheed-Boeing-General Dynamics ATF Team.

June 30: Lockheed and several major avionics suppliers agree to the ATF avionics system architecture and to jointly implement the Lockheed avionics common module initiative.

July 7: Lockheed CEO Kitchen agrees to accept USAF’s fixed price contract and major cost sharing arrangement.

July 28: Lockheed submits its revised Dem/Val proposal, adding the two prototype aircraft, a prototype avionics system, and an avionics flying test bed and provision for the major cost sharing aspect of the program.

August: Robert B. Ormsby retires as President of Lockheed Aeronautical Systems Group. John Brizendine, retired President of Douglas Aircraft Company, replaces Ormsby.

Oct. 13: Company officials sign a formal Lockheed-Boeing-General Dynamics ATF Teaming Agreement; it is an enduring agreement, not changed over the next several years.

Oct. 31: Lockheed and Northrop each receive ATF Dem/Val-Prototype Fixed Price Prime Contracts for $691 million. (USAF assigns F-22 to the Lockheed ATF and F-23 to the Northrop ATF.)

Nov. 3: Lockheed, Boeing, and General Dynamics activate their F-22 ATF program team.

December: Col. James A. Fain Jr. becomes ATF Program Director, replacing Piccirillo, who had led the ATF SPO since 1983.

1987

February: The F-22 Team resolves the engine exhaust nozzle stealth debacle with the Air Force, General Electric, and Pratt & Whitney. USAF puts engine development programs under ATF SPO Director Fain.

March 1-6: Company and USAF representatives participate in Exercise Blue Two visit to three USAFE fighter bases.

May 4: Robert V. Sallada, former Navy pilot, joins Lockheed as its Navy ATF (NATF) Program Manager.

May: F-22 Team conducts a weeklong Systems Requirements Review (SRR) for USAF representatives; Osborne is the primary presenter.

June 29: Mullin makes formal F-22 program presentation to the Lockheed Board of Directors.

July 6: Lockheed dedicates new $70 million Weapon System Simulation Center at their Rye Canyon, Calif., development complex.

July 10: F-22 Team hosts an all-day F-22 Team Executive Committee (ExCom) meeting in Fort Worth, Tex.

July 13: Heppe leads launch of new design for the F-22; Lockheed appoints C. Richard Cantrell new Director of Design Engineering.

July 30: F-22 Team announces award of Common Integrated Processor (CIP) avionics architecture, hardware, and software subcontract to Hughes.

Sept. 3: Lockheed forms the Lockheed Aeronautical Systems Company (LASC) and disestablishes Lockheed California Company, Lockheed Georgia Company, and Lockheed Aircraft Service Company; John Brizendine becomes first LASC President.

October: F-22 Team completes new preliminary design and initiates YF-22A prototype detailed design.

1988

Jan. 7: Lockheed names Donald Herring Chief Engineer for the ATF Preferred System Concept (PSC), the F-22 production airplane.

Feb. 2: Lockheed names Maj. Gen. Fred A. Haeffner, USAF (Ret.), its new Director of Tactical Air Requirements.

April: Wind tunnel tests show the current F-22 design will not supercruise; F-22 Team makes rapid design changes to forward and aft fuselage to reduce supersonic drag.

June 21: Lockheed appoints Roy Buehler, a retired Navy Captain who had been the Navy's Program Manager for its new A-6 attack aircraft, as its new NATF Program Manager, replacing Sallada.

July 14: Lockheed appoints S.B. "Bud" Ohrenstein its Chief Engineer for the YF-22A ATF prototype aircraft.

Sept. 7: Boeing appoints Michael Manka its Chief Engineer for the F-22 PSC.

Sept. 15: Lockheed names Steve Honig, former Grumman engineering manager, Chief Engineer for the NATF.

Nov. 11: Kenneth W. Cannestra succeeds Brizendine as President of the Lockheed Aircraft Systems Group and Chairman of the F-22 Team ExCom.

December: USAF selects Col. James A. Fain for promotion to brigadier general.

Dec. 31: Heppe retires but continues as a consultant to Mullin through December 1990.

1989

Jan. 1: Daniel M. Tellep becomes Lockheed Chairman and CEO, succeeding Kitchen.

Jan. 19: James A. "Micky" Blackwell becomes Lockheed Vice President and Assistant General Manager for the F-22 program, succeeding Blanchard.

Jan. 19: Ohrenstein becomes Director of F-22 Design Engineering, succeeding Cantrell.

March 17: William D. "Bill" Buntin replaces Gerald C. Murff as General Dynamics F-22 Chief Engineer.

May 22: Lockheed names Richard "Dick" Abrams YF-22A Flight Test Program Manager and Team Site Manager at Edwards AFB, Calif.

Aug. 15: Government and industry officials hold ATF Combined Test Force Facility ribbon cutting ceremony at Edwards.

Aug. 18: ASD issues draft RFP for the ATF Full Scale Development (FSD)/Engineering and Manufacturing Development (EMD) phase of the program.

1990

Jan. 13: F-22 Team starts final assembly of the first YF-22A prototype at the Skunk Works in Palmdale, Calif., with arrival of center fuselage from Fort Worth as the pacing item.

March 1: Gen. Larry D. Welch, USAF Chief of Staff, visits Palmdale for F-22 program discussions.

March 5-9: Undersecretary of Defense for Acquisition John A. Betti and his DOD team conduct Major Aircraft Review (MAR) directed by Secretary of Defense Richard Cheney for the Air Force's C-17, F-22, and F-23 programs and the Navy's A-12 program.

March 8: Betti's MAR team reviews the F-22 program in the morning at Palmdale, and the F-23 program in the afternoon at Edwards Air Force Base.

March: Program officials complete testing of the F-22 full scale low observable (LO) model at the Skunk Works Helendale, Calif., radar range.

April: Final assembly of the second YF-22A prototype begins.

May 9: Lockheed announces reorganization of Lockheed Aeronautical Systems Group that shuts down the Burbank, Calif., plant and, if the F-22 Team wins, would move F-22 production to Marietta, Ga., plant.

July 11: F-22 Team successfully completes final avionics architecture demonstration at the Hughes facility in El Segundo, Calif.

Aug. 29: F-22 Team conducts the formal rollout of first YF-22A ATF prototype at Palmdale.

Sept. 29: First flight of YF-22A Prototype Air Vehicle #1 (PAV-1) takes place, with Lockheed test pilot David L. Ferguson flying it from Palmdale to Edwards. General Electric F120 engines power PAV-1.

Oct. 25: Maj. Mark Shackelford becomes the first Air Force pilot to fly the YF-22A, taking the aircraft for the first time to supersonic speeds.

Oct. 26: A Boeing KC-135 tanker makes the first aerial refueling of the YF-22A.

Oct. 30: First flight of YF-22A Prototype Air Vehicle #2 (PAV-2) takes place with Lockheed test pilot Thomas A. Morgenfeld flying it from Palmdale to Edwards. Pratt & Whitney F119 engines power PAV-2.

Nov. 1: ASD issues the formal RFP for the EMD phase of the ATF program.

Nov. 3: The YF-22A PAV-1 demonstrates its supercruise capability.

Nov. 15: The YF-22A PAV-1 demonstrates the thrust-vectoring capability of its General Electric F120 engines.

Nov. 23: The YF-22A PAV-2 demonstrates its supercruise capability.

Nov. 28: General Dynamics test pilot Jon S. Beesley, flying PAV-2, fires an AIM-9 Sidewinder over the range at the Naval Weapons Center at China Lake, Calif. It is the first live missile firing in the ATF program.

Dec. 3: Lockheed elects Mullin as President of Lockheed Advanced Development Company, the Skunk Works.

Dec. 1: The YF-22A PAV-2 demonstrates the thrust-vectoring capability of its Pratt & Whitney F119 engines.

Dec. 10: High angle-of-attack testing begins, using PAV-1, which has a spin recovery chute.

Dec. 17: The YF-22A completes high angle-of-attack testing, having attained an unprecedented 60-degree angle-of-attack attitude while remaining in full control.

Dec. 20: Lockheed test pilot Morgenfeld fires an unarmed AIM-120 missile from PAV-2 over the Pacific Missile Test Range at Pt. Mugu, Calif.

Dec. 28: F-22 Team completes theYF-22A flight test program at Edwards AFB, Calif. Also on this day, the YF-22A achieves a maximum speed greater than Mach 2.

Dec. 31: F-22 Team submits its proposal for the EMD phase of the ATF program.

1991

Jan. 1: Blackwell becomes Vice President and General Manager, F-22 Team Program Office, succeeding Mullin.

Jan. 3: F-22 Team makes verbal formal proposal summary presentation to the Air Force.

Feb. 28: Operation Desert Storm, the Gulf War, ends. F-117 Nighthawk stealth fighters had completed 1,271 night attack missions with no losses or combat damage, proving stealth works in combat.

April 22: Secretary of the Air Force Donald B. Rice announces that budget considerations have led USAF to reduce the number of ATFs to be purchased from 750 to 648 aircraft.

April 23: Air Force Secretary Rice announces that the Lockheed-Boeing-General Dynamics F-22 Team has won the ATF competition, defeating the Northrop-McDonnell Douglas F-23 team. He also announces that the Pratt & Whitney's F119 engine has won the engine competition over General Electric's F120 engine.

1993

March 15: Lockheed purchases the Fort Worth Division of General Dynamics for $1.5 billion, giving Lockheed 67 percent of the F-22 program with Boeing still at 33 percent.

Appendix B: Key Participants in the ATF/F-22 Team Program

Lockheed-Boeing-General Dynamics F-22 Team

Abrams, Richard—Lockheed
Site Manager and Program Manager, YF-22A Flight Test at Edwards AFB, Calif., 1990; Skunk Works Director of Flight Test, 1991. Born in 1938. Aerospace engineering degree from California Polytechnic State University. F-117 stealth fighter flight test program manager; flight tester with USAF, Rockwell-North American Aviation, and Lockheed Skunk Works. ***Author Assessment:*** F-22 flight test leadership effective beyond simple description; long time close associate of YF-22 test pilots Ferguson, Morgenfeld, and Beesley.

Adams, Richard—General Dynamics (GD)
GD Executive Vice President; formerly Vice President (VP) and General Manager (GM) of GD's Fort Worth Division. Retired early in F-22 program but particularly notable for quick decision to approve the three company team. ***Author Assessment:*** tall, lean, strong, quiet, and decisive engineer; a seasoned aerospace manager of the old school—pragmatic, accepting responsibility calmly.

Alford, Lionel—Boeing
Boeing Senior VP, member F-22 Team Executive Committee. ***Author Assessment:*** Often grumpy; not well loved within the team; Alford and Boeing F-22 Program Manager Richard Hardy tolerated each other. Replaced by B. Daniel Pinnick, who was a calm, but quite forceful manager.

Anders, William—General Dynamics
GD Chairman and CEO, succeeding Stanley C. Pace in 1989. Ex-Apollo astronaut, formerly VP of General Electric. Sold GD's Fort Worth Division to Lockheed in February 1993. ***Author Assessment:*** No major impact on F-22 program.

Anderson, Roy A.—Lockheed (1920-2003)
Chairman and CEO September 1977 to December, 1985. In 1985 gave much personal attention and support to aggressively competing for the ATF program; strong backer of R. Richard Heppe; advocated termination of the L-1011 Tristar commercial aircraft program in 1981 as essential to restoring Lockheed's financial health. ***Author Assessment:*** One of the greatest executives in Lockheed history. Once a farm boy, he wrote by hand to Mullin in 1988: "Now you have to bring home the bacon."

Beesley, Jon S.—General Dynamics
Company test pilot and former USAF F-117 test pilot who resigned his commission to become civilian test pilot at GD; one of the YF-22 test pilots; later Lockheed Martin Chief Test Pilot for F-35 Joint Strike Fighter. ***Author Assessment:*** One of the best test pilots of his generation in the world.

Blackwell, James A. "Micky"—Lockheed
VP and Assistant GM, Team Program Office, 1989-1990. No previous major program management experience. Born in 1941. Aeronautical engineering degrees from the University of Alabama (bachelor) and University of Virginia (master). With Lockheed 1969-1999, primarily at Marietta, Ga. Succeeded Mullin as F-22 Team GM in December 1990. Was President of Lockheed Martin Aeronautical Systems Sector, 1995-1999.

Blanchard, Robert H.—Lockheed
VP and Team Assistant GM. Born in 1932. Business management degree from the University of Massachusetts. Former Director of Military Subcontracting. ***Author Assessment:*** A big, rugged manager of the old school; fearless, blunt, and focused on basics: plans, schedules, and budgets. Selected by Heppe and Mullin: complemented each other and had deep

mutual trust. Master behind the scenes operator; respected by subcontractors for honesty, trust, and loyalty.

Brazier, Michael—General Electric (GE)
Program Manager, GE's F120 engine program. English born and educated mechanical engineer. Earlier employed by Boeing and Pratt & Whitney. ***Author Assessment:*** Provided strong support to F-22 team, delivering engines for first YF-22 aircraft that performed as advertised, a major accomplishment.

Brizendine, John—Lockheed
President, Lockheed Aeronautical Systems Group and Chairman, F-22 Team Executive Committee, 1987-1988. Former President, Douglas Aircraft Company. World War II Navy veteran.

Buehler, Roy—Lockheed
Program Manager, Navy Advanced Tactical Fighter. Retired from the Navy as a Captain. Served as an aviator; commanded the Navy Plant Office at Grumman Aircraft, also serving as F-14 production test pilot; served as Program Manager for A-6 attack aircraft. ***Author Assessment:*** Disciplined, effective, forceful, experienced leader; respected by Navy personnel at all levels.

Burch, Rudolph "Rudy"—Lockheed
F-22 Chief Avionics Engineer, 1985-1990. Veteran avionics engineer, involved in F-104, S-3A Viking, and other programs. Led preparation of management proposal for Engineering and Manufacturing Development phase of ATF program; pioneered Integrated Product Teams. Later Program Manager in the Skunk Works. ***Author Assessment:*** No nonsense leader; a force of nature never deflected by unpredictable egotistical technologists. Looked like Pancho Villa, but was slightly gentler.

Cannestra, Kenneth W.—Lockheed
Group President, Aeronautical Systems Group, 1988-1995, replaced John Brizendine in November 1988. Chairman of F-22 Team Executive Committee, 1988-1994. Electronics engineering degree from the University of Michigan. Had space systems background. Was Navy veteran. ***Author Assessment:*** Skilled delegator; never involved in F-22 program management details.

Cantrell, C. Richard—Lockheed (1924-2004)
F-22 Director of Design Engineering, 1987-1989. Master's in aeronautics from the California Institute of Technology. Skunk Works veteran; Director of Engineering, 1984-1987. World War II Navy veteran. ***Author's Assessment:*** Calm and stable; an engineer's engineer; master of aerodynamics; mentor of young engineers.

Christensen, Larry R.—Lockheed
Program Manager, Advanced Systems Avionics. Born in 1943. Digital systems engineering degree from Brigham Young University. Leader of initial F-22 avionics architecture creation and definition, 1984-1986. Later manager of classified avionics projects. ***Author Assessment:*** Never given proper recognition for contributions to defining the F-22 avionics system architecture and skillful interface with Air Force avionics leaders.

Donaldson, Joseph A.—Lockheed (1932-2007)
Program Manager, YF-22 prototype aircraft, 1987-1990. Mechanical engineering degree from Ohio State University. Experienced Lockheed design and flight controls engineer. ***Author Assessment:*** Low profile manager who delivered excellent results under enormous pressure; long on pragmatism, short on rhetoric, enemy of bullshit.

Ervin, Gary W.—Lockheed
Manager, F-22 Low Observable Engineering. Born in 1958. Bachelor's degree in mathematics systems science from University of California, Los Angeles. Later, at Northrop Grumman, Corporate VP and Aerospace Systems President. ***Author Assessment:*** Youngest manager on the team, major contributor to team win. Repeatedly contradicted Leo Durocher's assertion that "Nice guys finish last." Elected a Pioneer of Stealth in 2006.

Ferguson, David L.—Lockheed (1938- 2011)
Chief test pilot, YF-22; made first flight Sept. 29, 1990. Former Skunk Works F-117 test pilot. Served as Lockheed Director of Flight Test, retiring in 1999. Retired from USAF as lieutenant colonel; Vietnam War fighter pilot; USAF test pilot. ***Author Assessment:*** A career fighter/test pilot; never drove a desk full time.

Glasgow, Edsel "Ed"—Lockheed
F-22 Chief Flight Sciences Engineer. Born in 1940. Received mechanical engineering degrees from Purdue University (bachelor) and Stanford University (master). Later VP of Engineering and Advanced Programs in the Skunk Works. ***Author Assessment:*** Aerodynamicist of the first rank. Major contributor to F-22 design and performance analysis. Articulate communicator with the Air Force. Calm and stable even when confronted with assertive, egotistical engineers.

Hardy, Richard "Dick"—Boeing
Member of Team Program Office and Boeing F-22 Program Manager, 1985-1990 and beyond. Received bachelor's degrees in aeronautics and astronautics and mechanical engineering and a master's in aeronautics and astronautics from MIT. Joined Boeing in 1959. Later VP and GM, Boeing Military Airplane Division. Resigned in 1996. Co-recipient, 1992 American Institute of Aeronautics and Astronautics (AIAA) Aircraft Design Award. ***Author Assessment:*** High integrity, logical, terse, frank, loyal, focused manager.

Henderson, Richard—Lockheed
Director of Proposal Management, 1989-1990. With Lockheed 1951-1991. Born in 1929. ***Author Assessment:*** Skillfully led the development of the massive proposal for F-22 Engineering and Manufacturing Development phase of ATF program. Seasoned, astute Lockheed manager whose contributions to F-22 Team win were enormous but not widely recognized, then or later.

Heppe, R. Richard "Dick"—Lockheed
President, Lockheed California Company, 1984-1987. At Lockheed 1947-1988. F-22 Consultant, 1989-1990. Born in 1923. Received bachelor's and master's degrees in engineering from Stanford University and a master's in aeronautical engineering from the California Institute of Technology. Fellow, AIAA, member, National Academy of Engineering, and many other honors. ***Author Assessment:*** Authority on supersonic aerodynamics. Prime contributor to F-22 program, 1984-1990. Led the great 90-day aircraft redesign fire drill in 1987. One of the great engineers in Lockheed history, skilled proposal leader, often controversial, never ambiguous.

Herring, Donald—Lockheed
Chief Engineer, Preferred System Concept (F-22 production aircraft), 1988 -1990. Received engineering degrees from Auburn University and Georgia Institute of Technology. VP and F-22 Air Vehicle Integrated Product Team Manager at Marietta, Ga., from 1991. ***Author Assessment:*** Came up through the seniority stifled ranks at Lockheed Georgia, 1961-1988. Major contributor to F-22 production aircraft design and the winning December 1990 Technical Proposal.

Kent, D. Randall "Randy"—General Dynamics
Member of Team Program Office, GD VP-F-22 Program Director. Born in 1926. Received bachelor's degree in mechanical engineering from Louisiana State University and master's in engineering from Cornell University. With GD 1949-1991. Involved in F-16 from 1971, with GD team that won USAF light weight fighter competition. VP F-16 Engineering 1979-1980. World War II Army infantry veteran, Europe. Co-recipient, 1992 AIAA Aircraft Design Award. ***Author Assessment:*** Calm, logical manager, most experienced aircraft engineer and manager in Team Program Office.

Kitchen, Lawrence O.—Lockheed
Lockheed Chairman and CEO, 1986-1988. Born 1923. No college degree. Joined Lockheed in 1958. Previously Lockheed President, 1976-1985. Earlier President of Lockheed Georgia

Company. Approved forming three company F-22 team in June 1986. Rapidly authorized significant ATF cost sharing in July 1986. USMC veteran of World War II.

Michellich, Michael O. "Mickey"—Boeing
Boeing F-22 Avionics Program Manager; later assigned to Team Program Office. ***Author Assessment:*** High energy manager, frank, highly competitive. Not the smoothest guy in town but made things happen. Solid contributor to F-22 Team win.

Morgenfeld, Thomas A.—Lockheed
Lockheed Skunk Works Test Pilot, made first flight of YF-22 #2, Oct. 30, 1990. Joined Lockheed in December 1979. Graduated from the US Naval Academy. Former Navy fighter pilot; Vietnam veteran; Navy test pilot. Graduated first in class from the Empire Test Pilots School in the United Kingdom. Retired as a Captain in the US Naval Reserve. Former Skunk Works F-117 test pilot. Later Chief Test Pilot during Joint Strike Fighter competition.

Mullin, Sherman N.—Lockheed
VP and GM, F-22 Team Program Office, 1986-1990. Previously VP and Program Manager for the F-117 stealth fighter program, 1982-1985. Born in 1935. Princeton University dropout. Non-degreed electronics engineer with Lockheed, 1959-1994. After ATF (1990-1994), President of Lockheed Advanced Development Company, the Skunk Works. Fellow, AIAA; 1992 AIAA Wright Brothers Medalist-Lecturer in Aeronautics. Elected Pioneer of Stealth, 2002.

Murff, Gerald C.—General Dynamics
Chief GD F-22 Design Engineer from 1986 to 1989. Born in 1939. Received bachelor's degree in mechanical engineering from Texas Tech University. Worked first with Boeing, then joined GD in 1963 and by 1970 was a lead engineer on the YF-16 prototype. Later was Product Manager for the Joint Strike Fighter program. ***Author Assessment:*** Talented and aggressive; made a major contribution to the detailed design of the F-22.

Ohrenstein, S. B. "Bud"—Lockheed
Chief Engineer, YF-22 prototype aircraft, 1988. F-22 Director of Design Engineering, 1989-1990. With Lockheed since 1966. Born in 1933. Received aerospace engineering degree from UCLA. ***Author Assessment:*** Seasoned, stable, high integrity engineer, highly disciplined manager.

O'Neil, William "Will" D. III—Lockheed
Became Chief Engineer, F-22 System Engineering, 1985-1987. Led writing of Systems Engineering volume, rated excellent by USAF, for ATF Demonstration/Validation phase. Later, Lockheed Corporate Director of Strategic Planning. Born in 1938. Received bachelor's and master's degrees at UCLA, where he studied mathematics, engineering, economics, and operations analysis. Worked as a senior level DOD civil servant, 1973-1984. Leaving Lockheed in 1991, became a VP of the Center for Naval Analysis (CNA) and, in 2000, began serving as CNA Chief Scientist. Served as a Navy surface warfare officer in the early 1960s and continued in the Naval Reserve, retiring as a Captain. ***Author Assessment:*** Highly articulate, literate, intellectual engineer.

Ormsby, Robert B. Jr.—Lockheed
First Group President, Lockheed Aeronautical Systems Group, retired 1986. Received bachelor's degree in aeronautical engineering from Georgia Institute of Technology. Approved June 1986 F-22 teaming agreement memorandum. ***Author Assessment:*** No major impact on ATF program.

Osborne, Bartley P. Jr.—Lockheed
Chief Engineer, Design and Technology, 1984-1987. Leader of winning Feb. 18, 1986, and July 28, 1986, ATF technical proposals. Replaced by C.R. Cantrell July 13, 1987. Born in 1934. Received a bachelor's degree in mechanical engineering from the Carnegie Institute of Technology. Career included 27 years at Lockheed, nine at North American Aviation, and four with DOD. Formerly Skunk Works Chief Engineer, Advanced Design. Later VP of Engineering at Lockheed Aeronautical Systems, Marietta, Ga. ***Author Assessment:*** Never given proper credit for Lockheed win in 1986.

Pace, Stanley C.—General Dynamics
Chairman and CEO, GD, 1986 -1990. Delegated F-22 responsibility and authority to Herb Rogers. Led TRW until 1985. Born in 1921. Graduated from the US Military Academy in 1943. Received master's degree from the California Institute of Technology. Served as B-24 bomber pilot during World War II. Retired from USAF as a colonel in 1954. ***Author Assessment:*** Solid diplomatic supporter of the program and Team Program Office; a gentleman.

Pruden, Albert L.—Lockheed
Director, Tactical Air Requirements (business development) 1986-1987. Director, Systems Engineering and Requirements, 1987-1990. Born in 1934. Received bachelor's degree in aeronautical engineering from North Carolina State. Served as USAF fighter pilot, flying 233 combat missions during Vietnam War; operational test pilot; fighter wing commander. Retired as brigadier general in April 1986. ***Author Assessment:*** Brought a fighter combat capability focus to the team systems engineering work. Quiet, systematic, effective.

Rogers, Herbert F.—General Dynamics
VP and GM, GD Fort Worth Division, later President of GD Corp. Received bachelor's degree in aeronautical engineering from Purdue University. Joined GD in 1949. Key member of F-22 Team Executive Committee. Major contributor to F-22 team victory, strong supporter of D. Randall Kent and Raymond Stuber. ***Author Assessment:*** Not impressed by provincial managers, his own or anybody else's. A seasoned, decisive aerospace executive of the first rank, a true team player. Respected by all.

Shockey, P. David—General Dynamics
F-22 Deputy Program Manager. Born in 1937. With GD from 1961. Worked in Team Program Office in 1990, planning for EMD phase of the program and the proposal. ***Author Assessment:*** Hard worker; handled lots of details for Kent; a solid team player.

Schrontz, Frank A.—Boeing
Chairman and CEO (1986-January 1997). Born in 1931. Received law degree from University of Idaho and MBA from Harvard. Joined Boeing in 1958. Left in 1973, serving in senior level DOD and Air Force positions. Returned to Boeing in 1977. ***Author Assessment:*** Terse and explicit. Strong supporter of F-22 team. Mr. calm and stability. Solid backer of Hardy, Mullin, and Stuber. Backed the Team Program Office to the hilt. A true team player, respected by all. Major contributor to team victory.

Slay, Alton D.—Lockheed consultant
President, Slay Enterprises. Principal Lockheed consultant to F-22 Team (1985-1990), including organizing and leading F-22 proposal "Red Teams." Born in 1924. Received a degree in mathematics from The George Washington University. Retired from USAF in 1981 as four-star general, leading Air Force Systems Command; fighter pilot with 181 combat missions in Vietnam War. ***Author Assessment:*** Major contributor to F-22 Team victory. A brilliant man with a legendary memory.

Stuber, Raymond G.—Lockheed
F-22 Team Business Manager. Born in 1937. Veteran Lockheed financial manager. Later VP. ***Author Assessment:*** Emerged as one of most important leaders of F-22 Team. Over time gained full confidence of senior management at Boeing and GD, as well as USAF ATF SPO. Delivered results; played no favorites; feared nobody. A thinker, not just a bean counter.

Tellep, Daniel M.—Lockheed
Lockheed Chairman and CEO (1989-1995). Born in 1931. Received bachelor's and master's degrees in mechanical engineering from the University of California-Berkeley. With Lockheed from 1955. Deeply involved on F-22 program from 1989 to 1990 and later. First Chairman-CEO of merged Lockheed Martin, 1995. ***Author Assessment:*** Intensely focused. Major personal contributor to F-22 Team victory.

Tiffany, Charles F.—Boeing
VP, Advanced Systems, Boeing Military Airplane Company. Leader of Boeing ATF teaming

explorations in early 1986. Retired early in ATF program. ***Author Assessment:*** Veteran aircraft structures engineer, logical and systematic. Promoter of three company team concept.

United States Air Force Team

Abell, Eric E.
Technical Director (Chief Engineer), ATF System Program Office (SPO) (1986-1990). Born in 1941. Received bachelor's and master's in mechanical engineering from the University of Cincinnati; master's in management from Stanford. Began long civil service career as propulsion engineer. Member of Senior Executive Service from 1982. ***Author Assessment:*** A Chief Engineer of the old school: impeccable integrity, blunt, terse communicator, skilled leader of troops, respected by all. The sergeant major of ATF program, with the voice and brevity that required. Avoided trivia with a passion. One of the great US Civil Servants of his generation.

Borky, Lt. Col. John Michael
Director, ATF avionics systems. Promoted to colonel in 1989. Received electrical engineering degrees from The Catholic University of America (bachelor), MIT (master), and University of Michigan (PhD.). His 25-year Air Force career included commanding Rome Laboratory in New York. After retiring from USAF in 1992, worked with three major aerospace firms, helped found a defense consulting firm, and served for seven years on the Air Force Scientific Advisory Board. ***Author Assessment:*** Technically brilliant and articulate; electronics systems engineer of the first rank.

Fain, Col. James A.
ATF SPO Director (1986-1992). Promoted to brigadier general in 1989. Born in 1941. Received bachelor's degree in engineering science from Air Force Academy; master's in systems management from University of Southern California. Flew B-52 and F-4 and served as a test pilot before turning to system program management. Commanded Aeronautical Systems Center and, before retiring in 1995 as a lieutenant general, was Assistant Vice Chief of Staff of the Air Force. ***Author Assessment:*** Highly competent, blunt, goal focused. Widely respected but not well loved; feared by some. Respected for his honesty, decisiveness, and for keeping outsiders from having any impact on the program: He delivered.

Jaquish, Maj. Gen. John
Director, Tactical Programs, Office of the Assistant Secretary of the Air Force for Acquisition (February 1989-May 1990). Promoted to lieutenant general in June 1990. Born in 1937. Received bachelor's degree in economics from Rutgers University. Flew F-102, F-106, and F-4, and participated in the F-15 follow-on test and evaluation program. Commanded the Tactical Air Warfare Center at Eglin AFB, Fla. Before retiring in 1993, was Principal Deputy for Acquisition. ***Author Assessment:*** Assertive and influential, tough when required.

McCloud, Col. David J. (1945-1998)
Director of ATF Requirements (Advanced Programs), Tactical Air Command (August 1987-August 1989). Received bachelor's degree in engineering from California State University-Northridge; master's in management and supervision from Central Michigan University. Flew most USAF fighters, including F-117 stealth fighter. Commanded several wings; was USAF director of operational requirements; Joint Staff director of force structure; and, by then a lieutenant general, was head of Alaskan Command at the time of his death. ***Author Assessment:*** Very competent and very influential; highly respected. One of the true fathers of the F-22.

Nagle, Lt. Col. Willie
YF-22A operational test pilot. Hand selected veteran fighter pilot serving with Air Force Operational Test & Evaluation Center. ***Author Assessment:*** Gave the YF-22 a very rugged workout. Not a white scarf type; first rate pilot.

Piccirillo, Col. Albert C.
ATF Program Manager (1983-1986). Retired from USAF in 1987. Received bachelor's degree

in aeronautical engineering from Pennsylvania State University; master's in aerospace engineering from Air Force Institute of Technology. Flew F-4 combat missions during Vietnam War; led Air Force Flight Test Center engineering team working on unmanned aerial vehicles; worked on various advanced development projects; was Chief of the Tactical Systems Division on the Air Staff. Later worked as aerospace engineer and consultant, including at ANSER Inc., leading analytical efforts for the Joint Strike Fighter. ***Author Assessment:*** One of the unheralded fathers of ATF program. Kept things organized and moving forward, despite numerous major changes mandated by others, including the Packard Commission.

Ralston, Brig. Gen. Joseph W.
Director of Requirements, Tactical Air Command (1987-1990). Born in 1944. Received bachelor's degree in chemistry from Miami University in Ohio; master's in personnel management from Central Michigan University. Flew F-105, including Wild Weasel missions in Southeast Asia, and F-4. Previously served as requirements/project officer on F-15 and lightweight fighter programs at Headquarters TAC and as special assistant for low observables technology on Air Staff. Retired in 2003 as four-star, after serving as head of US European Command and Supreme Allied Commander Europe. ***Author Assessment:*** Amazing mix of smart, articulate, tough, and smooth. A true leader.

Shackelford, Maj. Mark
YF-22 project test pilot, one of five (March 1989-January 1991). Received bachelor's degree in aeronautical engineering from Air Force Academy. Flew F-4 and F-16 and served as an F-16 experimental test pilot at Edwards AFB, Calif. Led F-22 SPO's Cockpit Integrated Product Team (1991-1993). Retired in 2011 as a lieutenant general, serving as Military Deputy for Acquisition. ***Author Assessment:*** Youngest test pilot; hand selected by USAF.

Welch, John J. "Jack" (1930-2010)
Assistant Secretary of the Air Force for Acquisition (1987¬-1991). Received bachelor's degree in engineering from MIT. Worked with Vought Aerospace/LTV (1951-1987), rising to Senior VP, LTV Aerospace Co. Served as Air Force Chief Scientist from 1969-1970. After retiring from LTV, nominated for top Air Force acquisition post. ***Author Assessment:*** Major player in making ATF a reality. Had strong emotional commitment. Skilled stealth aircraft advocate. One of the true fathers of the ATF program.

Welch, Gen. Larry D.
Chief of Staff, US Air Force (July 1986 – July 1990). Born in 1934. Received bachelor's degree in business administration from University of Maryland; master's in international relations from The George Washington University. Started career as enlisted National Guardsman; entered USAF as aviation cadet. Flew F-4 combat missions during Vietnam War. Served as Commander in Chief of Strategic Air Command before becoming CSAF. Later longtime President of Institute for Defense Analyses. ***Author Assessment:*** Major advocate of ATF. Strong, quiet backer of ATF Program Manager Fain. Brilliant, deep thinker, forceful, tersely articulate. Exuded competence and authority.

Appendix C: References (Selected Published Documents)

Abrams, Richard, "YF-22A Prototype Advanced Tactical Fighter Demonstration/Validation Flight Test Program Overview," Lockheed Advanced Development Company, 1991.

Author Assessment: The authoritative unclassified technical report on the intense YF-22A flight demonstration program conducted at Edwards AFB, Calif., from Sept. 29 to Dec. 28, 1990.

Abrams, Richard, and Miller, Jay, Lockheed (General Dynamics /Boeing) F-22: Advanced Tactical Fighter Unveiled! Aerofax Extra Series No. 5 (Arlington, TX: Aerofax, Inc., 1992).

Author Assessment: A well illustrated, technically detailed 40-page publication, written after the F-22 team had won the ATF competition, and the Lockheed F-22 ATF program had moved from California to Georgia.

Aronstein, David C., Hirshberg, Michael J., Piccirillo, Albert C., Advanced Tactical Fighter to F-22 Raptor: Origins of the 21st Century Air Dominance Fighter (Reston, VA: American Institute of Aeronautics and Astronautics, 1998).

Author Assessment: An excellent history, written from an Air Force point of view, with very little access to F-22 team internal documents. Very little coverage of the F-22 avionics system prototype hardware and mission software.

Aronstein, David C. and Piccirillo, Albert C., Have Blue and the F-117: Evolution of the "Stealth Fighter" (Reston, VA: American Institute of Aeronautics and Astronautics, 1997).

Author Assessment: A detailed history authorized by the Air Force, which declassified a huge number of key documents to enable its publication. Essential background information to understanding how the Lockheed Skunk Works got back into the tactical aircraft business in the late 1970s and laid the groundwork for its approach to the ATF competition, including developing pioneering stealth technology.

Boyne, Walter J., Beyond the Horizons: The Lockheed Story (New York: Thomas Dunne Books, 1998).

Author Assessment: The authorized history of the Lockheed Corp. from 1913 to 1998 by a distinguished aerospace historian. Covers F-22 development at a summary level, putting it into the context of Lockheed corporate history.

Hehs, Eric, "F-22 Design Evolution, Part 1," Code One Magazine, April 1998, Vol. 13, No. 2 and "F-22 Design Evolution, Part 2," Code One Magazine, October 1998, Vol. 13, No. 4 (Fort Worth, TX: Lockheed Martin Tactical Aircraft Systems).

Author Assessment: Excellent detailed exposition, with outstanding illustrations. Makes clear the complexity of modern military aircraft design, including more on trial and error than normally admitted. No significant coverage of avionics system design, prototyping, laboratory demonstrations, and flight demonstrations.

Miller, Jay, Lockheed's Skunk Works: The First Fifty Years (Arlington, TX: Aerofax, Inc., 1993).

Author Assessment: The authorized history from 1943 to 1993, by a well known aerospace historian. Includes much previously classified Air Force and CIA information. Includes a detailed technical chapter on the F-22.

Mullin, Sherman N., "The Evolution of the F-22 Advanced Tactical Fighter," paper to accompany a lecture on Aug. 24, 1992, at Hilton Head Island, S.C., for the American Institute of Aeronautics and Astronautics (AIAA) Wright Brothers Lecture in Aeronautics, AIAA Paper 92-4188.

Author Assessment: A 15-page summary, very diplomatic, with no discussion of the Air Force and F-22 team cast of characters. Little on the F-22 avionics system.

Mullin, Sherman N., "Into Digital Computing Through the Back Door," IEEE's Annals of the History of Computing, Volume 25, No. 3, July-September 2003.

Author Assessment: How a non-degreed electronics engineer evolved into an aerospace digital systems engineer and manager from 1957 to 1990. Contains technical details of specific airborne digital computers embedded in P-3C Orion, S-3A Viking, F-117 Nighthawk, and F-22 Raptor aircraft.

Stevenson, James P., The $5 Billion Misunderstanding: The Collapse of the Navy's A-12 Stealth Bomber Program (Annapolis, MD: Naval Institute Press, 2001).

Author Assessment: A long litany of the disintegration¬—and ultimate cancellation in 1991—of the Navy A-12 carrier stealth aircraft program, conducted concurrent with the Air Force ATF Dem/Val program by a General Dynamics¬-McDonnell Douglas team.

Teaming Agreement among The Boeing Company, General Dynamics Corp., and Lockheed Corp. regarding the Advanced Tactical Fighter, Oct. 13, 1986, 48 pages plus nine page Appendix A. Signed by Frank Schrontz (Boeing CEO), Stanley C. Pace (GD CEO), and Lawrence O. Kitchen (Lockheed CEO). Major provisions of the agreement: The team will split all work one third by dollar value to each company for the life of the program. Each company will provide one third of the team investment required to accomplish the Demonstration/Validation/Prototype program.

Author Assessment: Clearly this agreement was a bold, high risk initiative by the three CEOs. There is no documented evidence that they got much credit for this in 1986 or later when the team won the ATF competition in 1991.

As the legendary Navy civil service aeronautical engineer George Spangenberg stated at the end of his long career: The sixth and final major step in every successful military aircraft program is to "reward the nonparticipants."

Appendix D: F-22 Team and ATF Organizations

F-22 Team Program Management Organization (As of January 1990)

F-22 ATF Team Program Office

General Manager	Sherman N. Mullin
Assistant General Manager	James A. Blackwell
Boeing Program Manager	Richard Hardy
General Dynamics Program Director	D. Randall Kent
Director of Operations	Robert H. Blanchard
Director of Business Management	Raymond G. Stuber
Director Program Planning	P. David Shockey, General Dynamics
Director Proposal Development	Richard Henderson
Director Avionics Systems	Michael Michellich, Boeing
Director Test and Evaluation	Karl Lang, Boeing
Program Manager Navy ATF	Roy Buehler

Boeing F-22 Program Organization

Program Manager	Richard Hardy
Chief Engineer, Airframe	Douglas K Gould
Manager, Avionic Systems	Rick S. Edelman
Manager, Preferred System Concept	R. Michael Foley
Manager, Operations	R. D. Seymour
Business Manager	Fred B. Whitney
Manager, R, M, and Support	Richard V. Gidner
Manager, Projects	Lloyd B. Eldrenkamp
Manager, Quality Assurance	W. E. Strobelt
Manager, Navy ATF	Glen J. Eckard

General Dynamics F-22 Program Organization

VP and Program Director	D. Randall Kent
Deputy Program Director	P. David Shockey
VP Design Engineering	William D. Buntin
Manager, System Engineering	William J. Moran
Manager, R, M, and Support	Chester A. Hardy
Manager, Manufacturing	Richard M. LaSalle
Project Manager, YF-22A	Gordon K. Smith
Project Manager, Avionics	Larry C. Klos
Project Manager, Navy ATF	David F. Palmer
Business Manager	J. F. Oppie
Manager, Plans and Controls	H. J. Durham
Manager, Material	J. R. Chambers
Manager, Quality Assurance	G. M. Croy
Manager, Security	A. P. Carter
Manager, Test and Evaluation	M. K. Johnson
Project Pilot	Jon S. Beesley

Lockheed F-22 Program Organization

VP and Program Manager	James A. Blackwell
Director Business Management	Raymond G. Stuber
Director Design Engineering	Donald G. Herring
Chief Avionics Engineer	Rudolph L. Burch
Director System Engineering	Albert L. Pruden
Director, R.M. and Support	Robert R. Humphrey
Director Manufacturing	John O. Stanley
Director Quality Assurance	Bryan G. Carl
Director Materiel	Michael Rollins
Program Manager YF-22A	Joseph A. Donaldson
Program Manager Flight Test	Richard Abrams
Project Pilot YF-22A	David L. Ferguson
Program Manager Adv Technology	Larry Christensen
Program Manager Adv Materials	Richard Circle
Chief Program Coordination	Michael Fair
Director Management Systems	Edward Fazio
Manager Computing Services	Phillip Hemberg
Manager Program Security	Jan Weigel
Coordinator, Human Resources	Robin Metcalfe

Air Force ATF System Program Office (As of Nov. 1, 1989)

Total personnel: 261

Program Director	Brig. Gen. James A. Fain Jr.
Deputy Program Director	J. Tom Graves
Asst. Program Director	Col. W. Tom Bucher
Program Manager, Navy ATF	Capt. Roger Burnett, USN
Technical Director	Eric E. Abell SES
Chief, Flight Systems	Herbert S. Hickey
Chief, Propulsion	Jon Ogg
Chief, Avionics	Christopher Blake
Chief, Support Systems	Donald Chislaghi
Chief, System Engineering	Ajmel Dulai
Director, Avionics	Col. J. Michael Borky
Director, Engine Management	Col. Peter Smith
Director, Acquisition Logistics	Col. Thomas May
Director, Test and Evaluation	Lt. Col. Jay Jabour
Director, Manufacturing	Ronald Vanatsky
Director, Acquisition Support	Lt. Col. Robert Kayuna
Director, Program Control	Ronald Runkel
Director, Contracting	Paul Weiser
Director, System Safety	Maj. Eldon Bertran
Program Manager, YF-22	Lt. Col. Gerald L. Christeson
Program Manager, YF-23	Lt. Col. Robert Forbes
Chief, Management Operations	Jacqueline Penrod

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ADVOCATE for aerospace power and STEM education; and

SUPPORT the Total Air Force family and promote aerospace education.

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