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BACKGROUNDER

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Ensuring Success for the Air Force's Next Training Aircraft

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Abstract

The United States Air Force has done an extraordinary job of laying out the requirements for its next-generation trainer. The three aircraft finalists were all viable candidates, and final selection likely came down to cost and the risks associated with not only fielding this critical capability but sustaining the U.S. fighter aircraft industrial base. The clean-sheet design of the Boeing/SAAB platform certainly offers a level of near-term risk, but this award will reduce long-term risk to the United States while providing the Air Force with an extraordinary advanced trainer that will serve it well for decades to come.

The United States Air Force just awarded the Boeing Corporation a multi-billion-dollar contract to build an advanced flight school trainer aircraft to replace the T-38 Talon, which has been in service since the 1960s. Every fighter pilot who has received his or her wings since 1965 has flown this aircraft during the advanced phase of flight school. While very effective for the majority of its service life, the Talon's reliability and dated technology are now hampering pilot production. The jet's reliability rates, which were once well above 80 percent, have dropped into the low 60s, which means that nearly four out of every 10 T-38s on flight lines at training bases in the United States Air Force are not able to fly at any given moment.

The failing reliability of the T-38 is certainly an issue, but equally important are the capabilities within that platform that are falling short of need. The T-38 was designed to train pilots to fly second- and third-generation aircraft fielded during the same era. The sensors and turning performance of fourth- and fifth-generation fighter air-

Key Points

- The U.S. Air Force has done an extraordinary job of laying out the requirements for its next-generation trainer.
- Congress should use the current Air Force model for defining requirements for its next-generation trainer as a model for future programs of record.
- Like the F-35 and the KC-46, this program needs to move forward with a level of funding certainty that will make its fielding rapid and complete, with minimal risk.
- A fleet of 403 TX aircraft will deliver the capacity required to fill the 2,000-pilot shortfall as well as fill the cockpits of the additional flying squadrons the Secretary of the Air Force recently announced were needed to grow Air Force capacity to be ready for a near-peer fight.

This paper, in its entirety, can be found at **http://report.heritage.org/bg3366**

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craft (F-15, F-15E, F-16, F-22, and the F-35) require much more from the advanced trainer than the T-38 can deliver.

The time for the next generation trainer is long overdue—and delays in awarding the TX contract over the past year exacerbated the need. According to the Air Force, the contract award was based on the criteria of performance, cost, and risk.[1] The three submissions in the final competition were the Boeing/SAAB T-X, the Lockheed Martin/Korean Aerospace Industry's T-50, and Leonardo's T-100 aircraft. All likely met the minimum (threshold) performance requirements for the next-generation trainer, which likely left price and risk as the deciding factors.

Lockheed Martin/Korean Aerospace Industry's T-50 and Leonardo's T-100 have been flying for other nations for years, and the cost for acquisition and sustainment are well established. If Boeing was able to undercut the bids of the other two vendors, Boeing's bid still carries the caveat—and risk—that comes with systems that have yet to be fielded. The risks of cost overruns and delays in fielding inherent to new acquisitions are all-too-common and well understood, but the risk that likely contributed to this decision was one unique to the military: the risk to the industrial base.

Over time, the number of U.S. corporations that have the material and technological capacity, talent, and willingness to produce fighter aircraft under the burdensome U.S. federal acquisition system has dwindled to *two*. If Boeing had not won this contract, the risk that it would completely bow out of the fighter-production business would mean the associated industrial base would fall to just one company—Lockheed Martin—and that risk may very well have been a major factor in this competition.

The United States Air Force should include significant financial incentives—and penalties—in the TX contract with Boeing to ensure it delivers this critical capability on budget and on time because the need is great and long overdue.

Why Does the U.S. Need a New Advanced Trainer?

The T-38 was introduced as the Air Force's advanced pilot training aircraft in 1961 at a time when it was perfectly suited to train pilots for the Century Series aircraft (fighter aircraft with models between F-100 and F-106) and follow-on third-generation fighters produced during the same era. While it was incredibly effective in that role, aircraft capabilities and demands have changed considerably over the years, and the T-38 has become much more expensive to fly.

The Century Series fighters were state of the art in the late 1950s and early 1960s. Although designed for speed, their engines produced relatively low thrust, which meant the designs had to minimize the drag-producing elements on the aircraft, forcing engineers to minimize the size of the wings on a majority of fighters in that series. While these jets were fast, the lower-thrust engines, coupled with wing designs that favored speed, significantly limited the maximum G-forces these aircraft could sustain in air combat.

These jets also had very archaic avionics and limited weapons portfolios, and the mechanization required to operate those systems required pilots to remove their hands from the stick and throttle in order to do just about anything.

The T-38's throttle and stick were designed to more or less mirror the Century Series fighter cockpits student pilots would fly in follow-on assignments. The same was true for the cockpit dials and switches. Through the late-1990s, the T-38 had no screens or displays other than basic, round dials that gave the pilot engine performance cues and basic navigation aids. That changed somewhat with the T-38 Avionics Upgrade Program that incorporated hands-on throttle and stick controls, a heads-up display, and multi-function displays.[2] While a major improvement, the jet still fell short with regard to sensor and screen options, and it did nothing to improve the maneuverability of the Talon.

Fighter pilots executing air combat maneuvering or basic flight maneuvers (BFM) in the 1960s and 1970s were flying aircraft with significant limitations compared to today's fourth- and fifth-generation fighter platforms. In a turning fight, airframe

1. Lt. Gen. Emerson Gardner, "We Analyze the Air Force $16B T-X RFP," Hedgeye, January 4, 2017, https://app.hedgeye.com/insights/56334-we-analyze-the-air-force-16b-t-x-rfp (accessed October 2, 2018).
2. Michael P. Snow, Guy A. French, and Thomas A. Hitzeman, "Primary Flight Displays in the T-38C: When Do Differences Among Displays Become Inconsistencies?" Air Force Systems Command, ASC-03-0025 (January 8, 2003), p. 1, http://www.dtic.mil/dtic/tr/fulltext/u2/a430679.pdf (accessed October 6, 2018).

designs limited unrestricted[3] G-force loadings to less than 7 Gs. Beyond the initial turn, the G available (or the ability to make tight turns) was also limited by the amount of thrust their jet engines produced. In order to sustain a tight turn to either threaten another aircraft or deny a valid weapons shot by an adversary, pilots were forced to trade altitude for airspeed—or fight downhill. As their altitude decreased, so did available energy, and the fights would often end in slow speed, low-G stalemates at the bottom of the maneuvering area. While the training was (and still is) valuable, it missed a key aspect of modern dogfights as pilots executing maneuvers in relatively low-G fights were not forced to fight and think under nearly the *weight* pilots flying modern-day fighters endure.

The pressures pilots experience during BFM engagements is based on the relationship of G-force to weight. The average person's helmet-laden head weighs roughly 20 pounds under the earth's standard gravitational pull—or 1 G. When pilots need to maneuver their aircraft in tight (hard) turns, that G level goes up and pilots experience the same sensation riders on rollercoasters feel as they bottom-out of a big hill—but on steroids. In a turn that generates 9 Gs, that same helmet-laden head weighs 180 pounds.

Think about trying to do a rudimentary math problem with that much weight resting on your neck while trying to breath with an equal amount of pressure on your chest, and you begin to get an idea of the mental and physical demands associated with flying fourth- and fifth-generation fighters. It would be one thing to endure that for a moment or through an initial turn, but it is another entirely to fly an aircraft with the kind of thrust that can sustain that level of G-force throughout a dogfight—where a pilot's life literally hangs in the balance of the outcome.

The ability for an aircraft to sustain high G is based primarily on the amount of thrust a jet's engine(s) produces compared to the weight of the aircraft, also known as a jet's "thrust to weight ratio." In afterburner, a T-38's two jet engines produce a combined 6,600 pounds of thrust and, by the time a jet has taxied, taken-off, and flown out to a maneuver area, it weighs just over 10,000 pounds, giving it a thrust to weight ratio of 0.66. While the math is not pure at all altitudes, jets with thrust-to-weight ratios of 1-to-1 (1.0) or higher can generally sustain the maximum G for which the aircraft is rated.

Modern-day platforms like the F-16, F-15, F-22, and the F-35 can all generate nine Gs, and under certain conditions have thrust-to-weight ratios well above 1.0—and each can sustain that G-loading until the jet runs out of fuel. Merely staying conscious in that environment is a challenge, but the job requires much more than that. Pilots have to learn to keep track of all relevant friendly and enemy aircraft while employing one of the most complex weapon systems ever designed in situations where the outcomes are all important. Those weapons systems have a suite of electronics, sensors, and displays that dwarf those of earlier generation fighters.

The sensors and cockpit instrumentation of fighters fielded in the 60s and 70s were modern for their time but are archaic by fifth-generation fighter standards. The vast majority of cockpit gauges dealt with airframe, engine, and subsystem performance. Some fighters of that era incorporated radars and basic threat-warning displays, and the number of different switches pilots were required to move (the mechanization) and the location of those switches (ergonomics) made them challenging to employ. Conversely, the amount of useful information those sensors and associated displays delivered was quite small by today's standards.

The sensor suites in modern fighter aircraft incorporate information from onboard as well as offboard sensors from satellites, other aircraft, and teams on the ground in data streams that are both raw and synthesized. Asking a new pilot to process that information while maintaining situational awareness and employing a jet under seven, eight, or nine Gs can be overwhelming without an incremental approach to training—which ideally should begin in flight school.

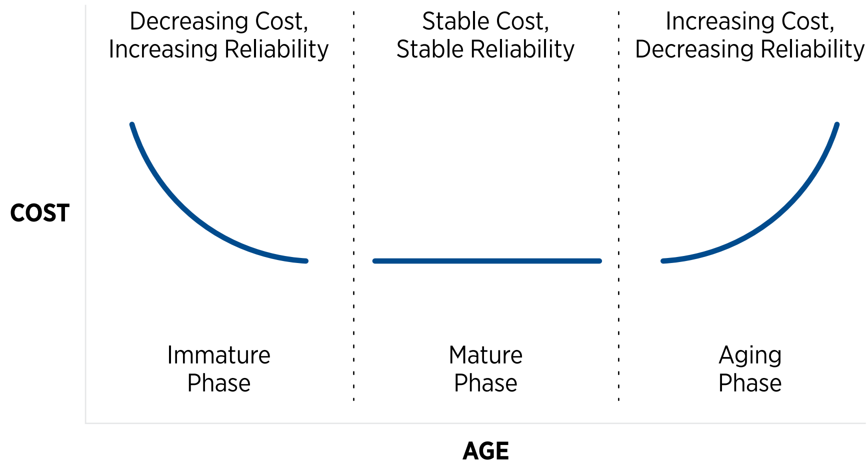
Since the arrival of the fourth-generation F-15 in the mid 1970s, pilots have been forced to develop those rudimentary skill sets and habit patterns only after they arrive at their fighter training unit as the

3. F-4 Phantom aircraft could withstand 8.5 Gs with no unsymmetrical (rolling) motion on the aircraft. However, there are very few movements in a turning fight against another aircraft in which there is no rolling moment/input placed on the jet. The unsymmetrical G limit on an F-4E with half-fuel and missiles was 7 Gs; however, its low thrust-to-weight ration would not allow it to sustain anything close to that loading. See *Flight Manual: USAF Series F-4E Aircraft*, TO 1F-4E-1, February 1, 1979, pp. 5–12, http://www.f4phantom.com/docs/F4Manual-1979-T-O-1F-4E-1-Flight-Manual-USAF-Series-F-4E-Aircraft.pdf (accessed September 5, 2018).

FIGURE 1

Aircraft's Life Cycle Applied to Its Operating Costs

In general, CBO expects aircraft operating costs to decline in the initial years of operation, plateau for a period, and then increase during a final (aging) phase.



SOURCE: Congressional Budget Office, "Operating Costs of Aging Air Force Aircraft," https://www.cbo.gov/system/files?file=2018-09/54113-aging_aircraft.pdf (accessed October 15, 2018).

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most advanced aircraft they would fly up to that point was the T-38. The T-38 has not met that need for quite some time and it has grown more costly to fly every year.

Operating Costs of Aging Aircraft

Most buyers are aware that the issues and risks that come with purchasing a clean-sheet design car in its first model year can be significant. Parts thought to be designed to last the life of a car suffer unexpected failures that often take several trips to a dealership to fix because the maintenance practices have yet to be refined. As production methods are improved during follow-on model years, the troubled parts and repair processes are also redesigned, and the cost to own and maintain that car drops significantly. Here, the car enters a healthy or *mature* stage of life. No matter what model year you purchase, if you hold on to a car beyond the 10-year point, annual maintenance costs begin to rise, and every year that passes beyond that 10-year point, buying a new car gets more affordable than sustaining the old one. These same three stages of life are true with high-performance aircraft.

The clean-sheet designs of the T-38, F-14, F-15, F-16, and the F-35 all suffered growing pains in their first model years, but the refinements that came with each year beyond led to significant improvements. Over time, operating costs decreased as the reliability of those systems improved and the aircraft systems moved into the mature phase. There, the costs and reliability are stable, and the associated pilots and maintainers within that system fall into a healthy rhythm. For most aircraft, the mature phase ends at about the 20-year point, at which time the aircraft enters the "aging" phase. From there, costs begin to grow dramatically and the cost per flying hour increases 7 percent to 8 percent every year.[4]

T-38s enjoyed quite a run during their mature phase. For more than 30 years they delivered exceptional aircraft utilization and mean time between failure rates.[5] The average T-38 is now well over 40 years old, and the availability rate of that system has dropped to just above 60 percent today, which means an average of just six of every 10 aircraft on any training flight line in the Air Force are available to fly any given moment. And the mechanical failures that system is now experiencing in the air are taking an ever-increasing toll. Over the past year, the Air Force has suffered the loss of *five* T-38s, causing multiple injuries and two fatalities. While cause has yet to be

4. Jeremiah Gertler, "Advanced Pilot Training (T-X) Program," Congressional Research Service *Report for Congress*, May 21, 2018, p. 1, https://fas.org/sgp/crs/weapons/R44856.pdf (accessed September 12, 2018).

5. William C. Widenhouse and Willam E. Romans, "A Forecasting Technique for Operational Reliability (MTBF) and Maintenance (MMH/FH)," U.S. Air Force Systems Command *Technical Report* ASD-TR-77-28, (December 1975), p. 107, http://www.dtic.mil/dtic/tr/fulltext/u2/a430679.pdfhttp://www.dtic.mil/dtic/tr/fulltext/u2/a430679.pdf (accessed September 19, 2018).

determined in three of those mishaps, the remainder were caused by mechanical failures.[6]

The Air Force is simultaneously suffering one of its most significant pilot shortages since it was established in 1947, and its production of critically needed replacement pilots relies on mission-ready aircraft. When you look at the performance, increasing cost, and ever-growing risks of the T-38, it is more than evident that it is past time for a new advanced trainer.

What Is Different About This Training Platform?

The operational and maintenance performance parameters spelled out within the TX Request For Proposal (RFP) are impressive,[7] and each is designed to progressively prepare pilots to make the transition into fifth-generation platforms (and those that follow) much easier. The requirements for this platform are categorized as either "threshold" or "objective," with "threshold" being a required or minimum capability within each of the vendor submissions and the desired capabilities stated as "objective."

The airframe and engine thrust-to-weight threshold requires the aircraft to be capable of withstanding instantaneous turns of at least eight Gs, and sustaining at least 6.5 Gs at 15,000 feet of altitude.[8] The cockpit must mimic that of a modern, fifth-generation platform with multi-function displays, situational awareness cues, and hands-on throttle and stick switchology. The handling characteristics, cockpit layout, heads-up display, and handling characteristics will certainly help pilots build habits that will stay with them throughout their careers, but there are other attributes of this jet that will further help them step up into actual fighter employment.

It must also have the inherent capabilities that allow it to serve as the primary platform for the introduction of fighter fundamentals where future fighter pilots are taught the basic skills and tactics they will rely on when they climb into their fighters. Each vendor's aircraft must have the ability to simulate air-to-air and air-to-ground weapons employment, as well as simulate threats and display those simulations visually and audibly. While the threshold requirement does not specify these aircraft have the ability to refuel in flight, the air frames must allow for future modification that will allow them to be refueled in the air.

The aircraft itself is certainly the primary and most costly element within the vendor TX submissions, but it is the performance, cost, and risk of the whole system that must be analyzed and assessed.

Ground-Based Training

The TX RFPs required vendors to develop a complete package of aircraft and simulator hardware, software, computers, and academics to teach advanced pilot training students how to fly the high-performance aircraft and operate them within the Air Force system. This will enable the Air Force to quickly implement the entire system as soon as the new TX system arrives at each pilot-training location.

Student pilot training begins with instruction and courseware designed to teach students aircraft systems and ingrain flight rules and checklist procedures for start, taxi, takeoff, navigation, and instrument approaches—as well as other normal and emergency procedures. Designing the academic curriculum and blocks of instruction for this phase of flight school is very involved, as the Air Force did not merely ask the

6. See Jen Killin-Guadarrama, "T-38 Pilot Killed in Texas Crash Identified," *USA Today*, November 22, 2017, https://www.usatoday.com/story/news/nation-now/2017/11/22/t-38-pilot-killed-texas-crash-identified/890745001/ (accessed October 10, 2018); Kent Miller, "T-38 Talon Training Jet Crashes in Oklahoma," *The Air Force Times*, August 17, 2018, https://www.airforcetimes.com/news/your-air-force/2018/08/17/t-38-talon-training-jet-crashes-in-oklahoma/ (accessed October 10, 2018); Stephen Losey, "Gearbox Failures, Ejection Seat Setting Mistakes Led to Fatal T-38 Crash," *The Air Force Times*, August 24, 2018, https://www.airforcetimes.com/news/your-air-force/2018/08/24/gearbox-failures-ejection-seat-setting-mistakes-led-to-fatal-t-38-crash/ (accessed October 10, 2018); Kyle Rempfer, "T-38C Talon II Jet Crashes Outside Columbus AFB," *The Air Force Times*, May 23, 2018, https://www.airforcetimes.com/news/your-air-force/2018/05/23/t-38c-talon-ii-jet-crashes-outside-columbus-afb/ (accessed October 10, 2018); Tyler Rogoway and Joseph Trevithick, "Pilots Eject After Air Force T-38 Talon Jet Veers off Runway, 4th Talon Loss In 10 Months," The Warzone, September 11, 2018, http://www.thedrive.com/the-war-zone/23508/pilots-eject-after-air-force-t-38-talon-jet-veers-off-runway-4th-talon-loss-in-10-months (accessed October 10, 2018); and; Jennifer Leigh Oprihory, "47th Flying Training Wing Identifies Airman Killed in T-38 Crash at Laughlin," *Air Force Magazine*, November 14, 2018, http://www.airforcemag.com/Features/Pages/2018/November%202018/47th-Flying-Training-Wing-Identifies-Airman-Killed-in-T-38%20Crash%20at%20Laughlin.aspx (accessed November 15, 2018).
7. Requirements_Matrix.pdf found within "March 17, 2015 Package," https://www.fbo.gov/index?s=opportunity&mode=form&id=d269f42d1e71393420a00779e7d11b5d&tab=core&_cview=1 (accessed October 12, 2018).
8. Ibid., p. 1.

candidate vendors to update the T-38 block of instruction. The threshold requirement forced each to develop an all-encompassing ground-based system of instruction using the latest technology to not just teach students how to fly advanced aircraft, but to help transition those newly winged pilots into fifth-generation platforms.

Outside the classroom, students will be able to go through procedures with computer-based part-task trainers (smart tablets) that allow them to master switchology for individual cockpit components without the need for more expensive training platforms. The combination of academics and hands-on tablets with built-in training aids/home study will help them incrementally digest each aircraft subsystem, which will make their time in the simulators much more productive.

The threshold requirements specified three different types of simulators with levels of fidelity that will allow students to learn different skills and challenge student pilots with an ever-increasing series of tasks and work-load. The most basic level of simulation is the unit training device (UTD), where students move beyond piecemeal, subsystem operation to practice switchology, procedures, and instrument cross-checks required for engine start, normal ground and takeoff procedures, basic navigation, instrument approaches, and emergency procedures. The instrumentation, switches, and basic handling of the UTD are direct replications of the aircraft, but the visual displays are much more basic compared to the operational flight trainers (OFTs).

OFTs are high-fidelity simulators with screens that allow student pilots to practice visual flight patterns and landings, formation flying, low-level navigation, and other advanced operations associated with military aviation. One of the most novel and eye-opening aspects of an OFT is its ability to link a simulator with an aircraft flying in the local area. At first blush, this may appear to be an excessive requirement, but it is a huge additive.

Every student going through flight school flies "solo" sorties without an instructor in the cockpit or on the wing. Once they are on their own, there is little an instructor can do to help them return safely from the sortie beyond the instruction they have given up to that point. As a tradition, instructors peel their wings off and place them on the student's flight suit during this first solo hop, because if the student does not return, the instructor may well lose his wings. OFTs add a completely different dimension to this first sortie—and the sorties beyond.

The imbedded data link between the aircraft and an OFT allows instructors to virtually fly alongside the student's aircraft as a safety observer throughout those initial sorties. This is particularly valuable during in-flight emergencies in which students can become saturated with the simultaneous tasks of flying the aircraft and handling the emergency. The simulation and replication that come through the datalink allow instructors to "see" the student's aircraft as conveyed though the data link and simulation—everything from the terrain through which they are flying to where they are heading to the configuration of the student's aircraft. This system basically puts another set of eyes on the situation—eyes that can cross-check every aspect of the recovery. As it is now already apparent, the OFTs can introduce students to formation flying—their first steps into the world of multi-ship operations—without leaving the ground.

The weapon systems trainers (WST) are OFTs with even greater faculties and are designed to transition newly winged pilots into the world of fighter tactics. This intermediary course of instruction is known as the Introduction to Fighter Fundamentals (IFF) and spins pilots up into tactical formation, basic fighter maneuvers (dogfighting), air combat maneuvering, as well as bombing and bomb-range procedures. The AT-38 (the tactical version of the T-38) has been used for the IFF program for more than 50 years, and the same simulators used in flight training support that jet and have no tactical application, leaving the whole of IFF training to actual time in the AT-38 cockpit.

The new computers and imbedded programs of the WSTs, on the other hand, will allow pilots to learn how to employ radars, targeting pods, and threat-detection systems without ever leaving the ground. WSTs also allow pilots to virtually air refuel, fight, react to simulated threats, and employ air-to-air and precision air-to-ground ordinance through very advanced simulations. Fidelity here is all-important, as pilots fighting or maintaining formation on another aircraft judge distance, closure, and maneuverability based primarily on visual cues. This is one of the many reasons why visual fidelity in these simulators is a critical performance parameter. Having enjoyed the methods and mechanisms associated with the T-38 and AT-38 aircraft for fighter lead-in training, it was eye-opening to experience the entire TX system of one of the vendor finalists.[9]

9. T-50 Flight took place on May 18, 2017, at the Donaldson Center Airport, Greenville, South Carolina.

Flying a TX Trainer Is Believing in Both Need and Concept

The detailed specifications laid out in the RFP, coupled with each vendor's history, make it very likely that all three trainer offerings met the threshold performance requirements. Having the opportunity to fly (just) one of the three still provided great insight as to what the Boeing/SAAB TX aircraft should bring to the Air Force.

At first glance, the exterior of the T-50 closely resembles a smaller version of Lockheed Martin's F-16. The 30-degree tilt-back angle of the ejection seat and side stick controller furthered that impression. The mission was flown as a two-ship, and the configuration of the wingman's jet was markedly different from the leader's in that it had a refueling "kit" on the dorsal area between the cockpit and vertical stabilizer. The kit has a fully operational door and tanking system that allows this jet to actually accept fuel from an air-refueling tanker and use that fuel in flight.

The large, multi-functional displays are visually sharp, and paging through the display options is both easy and intuitive, as are the hands-on controls on the stick and throttle. At the maximum power setting (without use of the afterburner), the takeoff roll was incredibly short, and the thrust made for an impressive formation takeoff. Cockpit visibility was excellent.

Once established in the area, the pilot put the aircraft through a series of basic maneuvers that reinforce a sense of the aircraft's responsiveness and ease of handling throughout the flight training airspeed envelope. The large screens/multifunctional displays made area orientation and staying within the confines of our military operating area a snap. Once we had burned down approximately 30 percent of the jet's internal fuel, the pilot selected afterburner at 15,000 feet and 450 knots indicated airspeed and entered a 7.5 G turn and held that G through 360 degrees with a negligible loss of altitude. The threshold requirement for that same maneuver is 6.5 Gs.

From there, the pilot selected the air-to-ground mode of a real jet, and the center display depicted a crisp image from the jet's simulated targeting pod of a bridge that was actually 20 miles ahead. Zooming in on one end of the bridge, the targeting pod displayed the image of a Russian SA-6 surface-to-air missile system as the target. The simulation allowed the pilot to zoom in and move the targeting pod cursor to a specific designated point of impact on the target. From there, every aspect of employment was perfectly replicated. The countdown to weapons release was displayed in the heads-up display, and once the simulated weapon was released on the bridge, countdown to impact began to timeout.

One of the errors pilots can make while employing a targeting pod is over-banking the aircraft to the point where parts of the aircraft block out or mask the target image as viewed from the pod. Even that aspect was well replicated in this simulation. As we approached the bridge, the surface-to-air missile system target acquired and launched a missile at our jet, and the simulated threat-warning system delivered all of the visual and oral displays associated with an actual fighter in an actual launch situation.

Following the air-to-ground simulation, the pilot selected the air-to-air mode and (virtual) air-to-air radar, and targeting pod displays appeared on the cockpit screens. The programmed threats within the aircraft's simulation package displayed an aircraft 30 miles in front of the aircraft on the (virtual) radar screen. Once that aircraft was designated as a target through the hands-on throttle and stick switchology, the closure rates, target aspect, airspeed, missile shoot queues—everything found in a real fighter cockpit—were clearly displayed. The pilot maneuvered our aircraft to perform a beam-to-trail intercept, and the virtual radar and targeting pod displays depicted the simulated intercept in lockstep with what happens in the real world.

The pilot then turned the aircraft toward our wingman, who was flying in a separate part of the area, and as he moved to intercept that aircraft, the displays responded just as they had on the simulated target. As the aircraft came within visual range, it was startling to see how the virtual-targeting pod displayed a live aircraft exactly as we were seeing in flight. The aspect angle and look down/up perspectives were identical to what was happening outside the cockpit.

Flying the recovery back to the home field in South Carolina, it was easy to see and feel the handling similarities between this trainer and the F-16, with the sole exception of the landing. The manufacturer had widened the landing gear, making the touchdown phase of landing this aircraft much more forgiving than landing its older sibling.

Following a quick debrief, the pilot walked us through the simulator building where are all three simulators (UTD, OFT, and WST) were in operation.

One of the many things that was demonstrated during the tour was the air-refueling capability of the WST. Each of the vendors' weapons training simulators must allow student pilots to practice air refueling—as currently there is no capability for newly winged pilots heading to fifth-generation platforms to gain that experience in flight without being trained in another fighter like the F-16. The AT-38 does not possess an air-refueling capability, and there are no two-seat versions of the F-35 and F-22, which means the very first time a new pilot flying either one of those jets attempts to receive fuel from an airborne tanker, he or she does it without an instructor in the jet. Having that capability in the WST is essential, and having the optional ability to add air-refueling capability to each of the aircraft at some point in the future is much more than merely a useful option.

Each of the simulators specified in the RFP, along with the other learning tools like the desktop flight simulator and electronic notebooks, were available for hands-on exploration. It was readily apparent that the specifications and requirements laid out by the Air Force are exceptionally well thought-out and will provide next-generation pilot training students incredible advantages and systematic growth over previous flight school and IFF students. The details within the RFP define a system that will help students master fifth-generation fighter platforms much faster than the T-38. Unfortunately, those qualities will *not* lead to a demand for a markedly smaller number of aircraft.

How Many TX Trainers Should the Air Force Buy?

The Air Force currently has 438 T-38s in the active-duty inventory whose sole mission is to train student pilots. The current TX purchase plan limits initial acquisitions to just 350 aircraft—88 below the number currently filling the advanced training and IFF demand.[10] Numbers matter here, and limiting this purchase order based on assumed higher aircraft availability rates and projected programmed efficiencies may not be in the Air Force's best interest for several reasons.

Since 1994, the average graduation rate for student pilots entering flight school in the Air Force is above 95 percent. That figure is up from below 80 percent (a 20 percent washout or *screening* rate) in the 1980s, without any perceivable change in the quality of instruction, the number or quality of students who apply for flight school, or the selection/screening process beyond. While some claim that standards have not fallen, at best the graduation rates bring quality control into question.

The Air Force is currently 2,000 pilots short of the manning required to fill every cockpit and staff position requiring a pilot in the service. In a move to fix that deficit, the service is now attempting to incrementally increase pilot production from 1,200 pilots a year to 1,400 pilots. Several things factor into the Air Force's ability to produce pilots. Possessing training aircraft with high availability rates is certainly a driver, and the T-38's recent availability numbers have dropped off to the point at which only six of 10 Talons are available at any given moment in time. The RFP stipulates that Boeing's T-X will bring that number up to the point at which at least eight out of 10 will be available. That will certainly enable a greater throughput, but it will not be sufficient to meet the requirements for quality pilot production for the challenges that lay ahead.

If the math were pure and the environment pilots fly in did not create a greater demand for quality coming out of the pipeline, then the difference between 60 percent availability of the T-38 and 80 percent availability of the TX aircraft might fix the pilot production problem, making the 350 aircraft acquisition number at least feasible. That would be particularly true if the number of annual graduates did not need to grow beyond the need to fill the current deficit. Unfortunately, this is no longer the case.

During the 2018 Air Force Association's annual convention, the Secretary of the Air Force, The Honorable Heather Wilson, stated that the Air Force is too small and needs to add another 74 squadrons to its roster—at least 27 of which are flying squadrons. In raw numbers, that would add 457 aircraft to the inventory, creating a requirement for more than 900 additional pilots. The environment in which those pilots would be required to fly is also changing.

The National Defense Strategy recently changed the focus of the services from low-intensity campaigns to high-intensity conflict against near-peer competitors, which changes the environment and the demands that will be placed on those pilots significantly. For the past 27 years, pilots have flown over

10. Gertler, "Advanced Pilot Training (T-X) Program: Background and Issues for Congress.," p. 1.

Iraq, Afghanistan, and Syria at medium altitude, well above a benign, low-threat environment.

The challenges and engagements that will come with fighting near-peer competitors include the most capable surface-to-air missiles and high-end fighter aircraft that we have faced anytime in our nation's history. Our nation's previous high-intensity conflicts (and those of other nations) have demonstrated time after time that the nations that screen more thoroughly, demand higher levels of performance, and offer pilots greater opportunities to train always come out on top.

In the 1980s, screening rates at U.S. Air Force flight schools and the follow-on specialty training programs were high, and the number of sorties and hours pilots were given to hone their skills dwarfed those enjoyed by Soviet pilots. Today Chinese fighter pilots fly at rates nearing those our pilots enjoyed during the Cold War, while Air Force flight schools have all but eliminated screening, and its pilots are relegated to nearly the same sortie rates and hours Soviet pilots endured during the years when U.S pilots scoffed at their readiness.[11]

Confidence comes with the feeling of being elite, and that feeling is lost when virtually anyone can become part of your profession. In order to reinstitute quality and prepare our pilots for the high-end conflict on the horizon, screening needs to be factored back into every facet of the training pipeline. That pipeline begins in flight training, and having only 350 TX platforms will not allow the Air Force to increase the quality of its graduates while expanding pilot production to 1,400 pilots a year (which itself is still insufficient). The Air Force should acquire enough trainer aircraft to increase the screening rate to ensure superbly qualified pilots arrive at gaining units and to ensure that there is enough excess capacity to cover what will likely be demanded during an extended high-end confrontation with a near-peer adversary—a minimum capacity of 1,500 students a year. To ensure that capacity, the Air Force needs to acquire 403 TX training aircraft.

The math supporting 403 TX trainers is based on the need to increase student capacity from 1,200 to 1,500 a year (a 25 percent increase). The Air Force has 430 T-38 aircraft that have an operational availability rate of 60 percent,[12] meaning only 258 are available to fly at any given moment. If 258 aircraft must be available to produce the T-38's current share of training 1,200 pilots a year, the platforms required to train 1,500 pilots a year would demand 322 be available all the time. The TX RFP requires the selected aircraft to have an operational availability of 80 percent or greater,[13] and providing a real availability of 322 aircraft at 80 percent operational ability would require an actual fleet of 403 aircraft. This number does not include the additional aircraft that would required should the Air Force revert back to a single pilot-training track that requires every student to fly the advanced trainer.

The Deciding Factors for Boeing/SAAB T-X Selection

The quality associated with the three finalists for the Air Force TX trainer bring several positive thoughts into focus. The first is that the Air Force has done an extraordinary job defining the requirements for this trainer. The three finalist platforms likely met all the performance threshold requirements defined by that process, and having the pick of that litter must have made the final award a challenging one that came down to cost and risk.

The track records of the T-50 and T-100 are solid. Each has flown through the costly and episodic cycles associated with the immature phase of an aircraft's life cycle—a risk period Boeing/SAAB's T-X has yet to weather.

Boeing/SAAB Team

Boeing and SAAB have been manufacturing fighter aircraft as independent corporations for many years. Each company produces fighters that are currently rolling off production lines in both Sweden and the United States. Designing and building high-performance, fourth-generation aircraft are in their wheelhouse, and their respective track records are solid. The Boeing/SAAB team elected to go with a clean-sheet design

11. Michael Auslin, "U.S. Air Force Pilots Fly Less than China's Do," *National Review*, December 20, 2013, https://www.nationalreview.com/corner/us-air-force-pilots-fly-less-chinas-do-michael-auslin/ (accessed October 10, 2018).

12. Gertler, "Advanced Pilot Training (T-X) Program: Background and Issues for Congress", p. 8.

13. "Advanced Pilot Training (APT T-X) Concept of Operations," U.S. Air Force *Solicitation*, Requirements_Matrix.pdf found within "March 17, 2015 Package," https://www.fbo.gov/index?s=opportunity&mode=form&id=d269f42d1e71393420a00779e7d11b5d&tab=core&_cview=1 (accessed September 21, 2018).

for this competition, which allowed them to build an aircraft from the ground up that was designed to meet the specifications associated with the RFP. The lessons each company has learned with regard to operating and maintaining aircraft have been incorporated into this trainer. The airframe design itself incorporates a single afterburning engine with a high-visibility cockpit.

While few if any outsiders have experienced the capabilities of this aircraft in flight, there is little doubt the aircraft will meet the threshold requirements laid out within the RFP, and it could tailor that design to capture additional credit/Air Force consideration for exceeding those performance threshold requirements. Unlike the well-established production line costs of the T-50 and T-100 aircraft, estimates for Boeing/SAAB's T-X are based on the production of two full-scale demonstrators.

Cost

Initially the Air Force estimated it would cost more than $19 billion[14] to buy a complete TX advanced pilot training system with 350 aircraft and 40 simulators. Boeing's reported bid of $9.2 billion[15] equals to a price of $25.26 million per aircraft.[16] If accurate, Boeing's bid came under the Air Force estimate by more than half—and likely came in well below the other two competitors. The firm fixed-price nature of the contract will mean the majority of the risk inherent in that bid will be absorbed by Boeing—but the risk beyond must also be understood.

Risk

Almost every clean-sheet design aircraft the Air Force has acquired to date has suffered design, test, and production delays and flight line availability issues that are inherent to an aircraft's first years of production. Even with a 767 baseline platform, Boeing's KC-46 is a new aircraft system that is now well behind that aircraft's delivery schedule.[17] The risk of the T-X suffering the same birthing pains will be present throughout this jet's formative years.

The Air Force is already 2,000 pilots short of what it needs to fill the cockpits and staff positions throughout that service. The ambitious growth laid out by the Secretary of the Air Force's vision of "The Air Force We Need" will likely add the demand for another 900 pilots to that deficit over the next 10 years.[18] If the Air Force is going to climb out of that hole while moving to a position of higher readiness, this advanced trainer must be fielded without a significant technical glitch or manufacturing delay. Two of the many issues that could get in the way of that goal are the Air Force changing the requirements and/or attempting to execute an imbedded RFP option beyond the contract award.

As previously noted, a unique threshold objective is the requirement that each candidate aircraft either possess or be able to be modified to possess an actual air-refueling capability that allows it to take fuel from an airborne tanker (like the KC-46) in flight. Giving recently winged pilots refueling experience in the TX with an instructor pilot would be a huge advantage. While the Boeing/SAAB T-X trainer can modified to accept a refueling probe and take on gas, the Boeing/SAAB T-X trainer does not *currently* possess an air-refueling capability. Historic design and manufacturing experience have created rough guidelines for incorporating capabilities into a platform at varying stages of design or production, and those costs can be significant.

The cost of adding a capability begins with the baseline cost of incorporating the capability during the specification requirements—before the original aircraft is actually designed. The cost of adding an air-refueling capability during the requirements phase of development is considered one unit. In this case, that unit would be the basic cost for building in the

14. Michael Bruno and Steve Trimble, "Is Boeing's 'Eye-Watering' T-X Bid a Game-Changer?" *AerospaceDaily & Defense Report*, September 28, 2018, http://aviationweek.com/defense/boeing-s-eye-watering-t-x-bid-game-changer?NL=AW-05&Issue=AW-05_20181001_AW-05_294&sfvc4enews=42&cl=article_1&utm_rid=CPEN1000002223577&utm_campaign=16721&utm_medium=email&elq2=2a4dad08f68e47f6889905ad2105f40f (accessed October 1, 2018).

15. Ibid.

16. Cost assumptions: Simulators: 40 total (UTD, OST, and WST) ground trainers at $2 million each equals $80 million. A $9.2 billion total bid, minus cost of simulators, equals $9.12 billion. This $9.12 billion divided by 351 aircraft equals $25.98 million per aircraft. The cost of simulators varies significantly, but this number includes an intentionally generous $2 million price for each of the 40 simulators.

17. Samantha Masunaga, "Delivery Delays of the KC-46 Tanker Catch Heat from the Air Force," *The Los Angeles Times*, April 11, 2018, http://www.latimes.com/business/la-fi-kc-46-boeing-20180411-story.html (accessed October 2, 2018).

18. David Deptula, "SecAF Wilson Takes Charge, Calls For 24 Percent Boost in Squadrons," *Breaking Defense*, September 17, 2018, https://breakingdefense.com/2018/09/secaf-wilson-takes-charge-calls-for-24-boost-in-squadrons/ (accessed October 10, 2018).

refueling doors, receptacle, plumbing electronics, and flight control coding into the jet at the outset of the project. For the purpose of this paper, that cost is referred to as the original component price (OCP). The cost of adding that same refueling capability in the design phase costs *three to eight times* the OCP. After manufacturing has begun, the cost is *seven to 16 times* OCP. At the integration and test phase, the cost is *21 to 78 times* OCP. And, at the operations phase, the cost to add or fix the requirement ranges from *29 to 1,500 times* the original cost of the component.[19]

If the government executes the option to add a refueling capability to this jet, whatever estimate the Boeing/SAAB team provided to the government for initial T-X acquisition cost will likely grow considerably, as will the complications associated with fielding. With that, the Air Force needs to do everything it can to ensure this new trainer meets or exceeds every threshold requirement established in the RFP on time and under budget. To ensure that takes place, the Air Force should lock down the requirements and include the right incentives and penalties in the final T-X contract to make sure the Boeing/SAAB team stays on track. While that cumulative, short-term risk may seem substantial, the turbulence will subside with time, and the potential for that risk will likely take a back seat to the long-term implications of selecting one of the other two vendors.

The incredible advances in combat systems and aircraft technology have accelerated in recent years. Those, coupled with the art associated with manufacturing truly stealth platforms, all but preclude new companies from entering the fighter production business, and there are only two companies left in the U.S. capable of really competing in that market. Over the course of the past 95 years, the industrial base for fighter production in United States has gone from more than a dozen companies[20] to just two: Boeing and Lockheed Martin. Lockheed Martin won the last two major fighter programs (F-22 and F-35), putting the Boeing Corporation's St. Louis, Missouri, facility on the precipice of going out of the fighter-aircraft business.

Given time, any company worth its salt could create new plants to produce fighters in the numbers required to meet U.S. requirements, and if Boeing had not been selected and ultimately bowed out of the U.S. fighter industrial base, Lockheed could undoubtably have covered future need. However, the loss of competition dilutes every aspect of performance. There is no reason to out-run, out-climb, out-perform, or under-bid another company if there is no one else on the track competing against you.

While the risks associated with fielding the clean-sheet design of the Boeing T-X program are likely higher than the other two candidate companies, the strategic risk to the United States of squeezing Boeing out of this business would have been much higher. That thought, coupled with the performance and relatively low cost of the Boeing/SAAB T-X system, make it a compelling choice for the Air Force.

Recommendations

The United States Air Force has done an extraordinary job of laying out the requirements for its next-generation trainer. The three aircraft finalists were all viable candidates, and final selection likely came down to cost and the risks associated with not only fielding this critical capability but sustaining the U.S. fighter aircraft industrial base. The clean-sheet design of the Boeing/SAAB platform certainly offers a level of near-term risk, but this award will reduce long-term risk to the United States while providing the Air Force with an extraordinary advanced trainer that will serve it well for decades to come.

To ensure the best possible outcomes from this purchase, Congress should:

- **Use the United States Air Force model for defining the requirements and creating the competition for the next-generation trainer as a model for future programs of record**; and

19. Jonette M. Stecklein, "Error Cost Escalation Through the Project Life Cycle," NASA *Conference Paper*, June 19, 2004, p. 1, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100036670.pdf (accessed September 21, 2018).

20. "Aircraft from 1920 to 1929," The Military Factory, 2018, https://www.militaryfactory.com/aircraft/aircraft-1920-1929.asp (accessed October 2, 2018).

- **Fully fund the acquisition of 403 TX trainers and a ground training system with a complementary capacity.**

For its part, the Air Force should:

- **Establish the TX program as number four in its list of acquisition priorities (behind the F-35, KC-46, and the B-21).** Like the F-35 and the KC-46, this program needs to move forward with a level of funding certainty that will make its fielding rapid and complete, with minimal risk.
- **Increase the TX contract from 350 to 403 aircraft and the associated TX system components to provide training for 1,500 annual flight school graduates.**
- **Include financial incentives and penalties in the final contract that will ensure the Boeing/SAAB team meets or exceeds the performance thresholds laid out within the RFP, and field this aircraft on time and on budget.**

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