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U.S. Air Force Should Adjust Tanker Acquisition Strategy to Support Strategic Competition with China

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KEY TAKEAWAYS

The Air Force is retiring aging tankers without suitable replacements and basing its tanker capacity requirements on regional rather than peer-level threats.

The Air Force needs to move immediately to strengthen the path to recapitalization of its fleet of strategic air refueling aircraft.

The USAF should increase its air refueling requirement from 479 to 691 aircraft, stop retiring viable tanker aircraft, and incentivize corporate competence.

Since 2002, the United States Air Force has been on a fitful path to recapitalization of its fleet of air refueling aircraft, which now average 55 years old.[1] In an effort to save money, it has reduced its fleet size by retiring aging tankers without suitable replacements. It also has based its future tanker capacity requirements on regional rather than peer-level threats. As it continues to wrestle with a replacement tanker that has experienced considerable delays, the service should:

- Forgo retirements of viable platforms until mission-ready KC-46 replacements are in place,
- Strive to align air refueling capacity requirements for a peer-level fight, and

- Incentivize performance within the tanker industrial base through open competition.

Background

The Air Force began a process to replace its fleet of KC-135 and KC-10 tankers in 2001 with a controversial sole-source proposal that involved both buying and leasing new aircraft from the Boeing Corporation. That program was terminated in 2005 after corruption related to Boeing's lease proposal was uncovered.[2]

Following that inauspicious start, in 2006, the Air Force issued a request for proposals (RFP) for a highly capable, medium-sized, low-risk, and low-cost tanker to replace the oldest KC-135s in the inventory.[3] The two vendors that submitted proposals were the Boeing Corporation and the European Aeronautic Defence and Space Company (EADS), the parent of Airbus at the time, in partnership with Northrup-Grumman. EADS won the contract, but shortly after the award, Boeing filed a formal protest.[4] Many in Congress voiced their concerns to the Office of the Secretary of Defense about the award of a major weapons system to a foreign company,[5] and in 2008, Secretary Robert Gates terminated the program.[6] After a cooling-off period, the Air Force revised the requirements and requested a new set of proposals for its next tanker.

The cost of Boeing's submission in that round of competition reportedly was less than the cost of the EADS submission, and in 2011, the Air Force awarded Boeing a contract to modify its already successful 767 airliner into the KC-46A air refueling platform and deliver a total of 179 tankers in a program that would become known as KC-X.[7] The first seven jets were to be delivered in 2015; 18 were to achieve initial operational capability (IOC) by August 2017;[8] and the last six were to be acquired in 2027.[9]

Over the years, the initiative to replace the tanker fleet has morphed into three incremental acquisition programs known as KC-X, KC-Y, and KC-Z. KC-X acquisition will be completed with the last KC-46A delivery; KC-Y, also known as the Bridge Tanker, was initially intended to replace the KC-10s and a tranche of older KC-135s beginning in 2029; and the KC-Z will replace the remaining KC-135s at some point in the future.[10]

The KC-X program has suffered several technical and production challenges, and the Air Force is now on track to accept the last of the KC-46s in 2029 after a three-year delay. To continue the seamless replacement of its aging tankers, the service intends to solicit proposals for KC-Y by the end of 2022 with the intent of receiving the first of as many as 160 tankers in 2029.[11]

The KC-46 was designed to refuel both Air Force and Navy/Marine Corps aircraft, and the difference between these two systems are significant.

- Air Force refueling systems use long, rigid, telescoping fuel-transfer tubes or probes known as booms that are guided by boom operators (boomers) located inside tanker aircraft. The boomer guides the pilots of receiving aircraft into position using a series of direction-guiding lights underneath the tanker. Once the receiving aircraft stabilizes, the boomer extends the boom and guides it into a small air refueling receptacle on the receiver aircraft. That process can pass fuel very rapidly but relies on visual cues and depth perception by both the boomer and the receiver aircraft pilot as no automated process has yet been fielded.

- Navy systems use a basket-and-probe system in which the air refueling platform extends a long fuel hose with a drogue/basket on the end that contains a refueling receptacle. Pilots of receiver aircraft maneuver behind the refueling platform and then fly their jet's air refueling probe directly into the basket. The basket-and-probe system was designed so that Navy fighter aircraft can be configured with extra fuel tanks and a drogue/basket system to refuel other fighter aircraft. While the system requires no guidance or help from within the tanker platform, fuel flows are slower, increasing the time needed to refuel. A four-ship formation of Air Force F-35As requires about 20 minutes to refuel with an Air Force boom system, whereas four Navy F-35Cs refueling with a drogue/basket system require more than 60 minutes to take on the same amount of fuel.[12]

Air Force tanker booms can be configured to fly with a drogue/basket (only) to refuel probe-equipped aircraft, or they can fly with two additional drogue/basket pods mounted on the wings, allowing the tanker to refuel either type of aircraft on the same mission. C-130s can be configured with drogue/basket systems to refuel probe-equipped aircraft, but their offload capacity is much lower because the airframe is smaller and therefore carries less fuel.

For the purposes of this paper, C-130s are referred to as tactical air refueling systems, and KC-135, KC-10, KC-46, and KC-Y systems are referred to as strategic air refueling systems/tankers. Before the service begins the selection process for the KC-Y, it is important that the status of the KC-X program and the challenges that have characterized deliveries of the KC-46A be understood.

Problems with the KC-X

To date, more than 60 KC-46s have been delivered, but even at the most basic level, the program has been marred by a string of system design problems and production faults. The KC-46 design incorporated the concept for a Remote Vision System (RVS) that molds video from multiple cameras at the rear of the plane to create a two-dimensional and three-dimensional (2D/3D) vision system, allowing the boom operator to sit in the main cabin and refuel the aircraft remotely.

During flight testing in 2016 and 2017, aircrew identified several major issues with the RVS and the aircraft's refueling boom that inhibit the KC-46A from executing its primary mission: refueling other aircraft.[13] The jet's boom was too stiff, which proved to be problematic for fueling lighter aircraft like A-10s and F-16s.[14] Problems surrounding the RVS were first reported as issues surrounding a "sunlight glare" during certain times of the day, but the challenge is much deeper.

The RVS 2D/3D, black-and-white cameras are mounted at the rear of the KC-46, just behind the aircraft's boom. While the camera image can wash out during certain sun angles, even when paired with the jet's 3D goggles, the system does not give boomers the depth perception they need to conduct normal air refueling operations. Stunningly, the system often fails to capture or display the length of the telescopic boom as it extends to make contact with receiver aircraft.[15]

The alignment of the RVS cameras in relation to the air refueling boom's outer tube[16] effectively obscures or masks the last several feet of the telescoping portion of the boom,[17] including the refueling probe that makes contact with the refueling receptacles of receiver aircraft.[18] If the lighting/sun angle is right, the system can pick up the end of the boom's shadow on top of the receiving aircraft. This work-around gives boomers the opportunity to gauge the position of the tip of the boom before attempting to connect to receiving aircraft. However, it also assumes the best of conditions, and when viewed in context with current refueling procedures, its associated challenges become glaringly obvious.

The refueling receptacle for the F-16 is located several feet behind the cockpit and is not visible to pilots flying those single-seat fighters. Refueling procedures for the F-16 call for the pilots to fly to a position directly in line with the end of the tanker's boom and then move forward directly toward the end of the probe. As the distance between the end of the boom and the jet's canopy closes, the boomer uses his depth perception to judge when to move the boom around and then directly behind the F-16's canopy to

make contact with the jet's refueling receptacle. With questionable depth perception, no reliable ability to see the end of the boom, and no usable surface area in front of the canopy to catch the boom's shadow, attempting to refuel an F-16 with the KC-46's RVS system during daytime in clear weather conditions is challenging.

In addition, during heavy weather or clear-air turbulence, the tanker and receiver aircraft can move up and down rapidly without warning, often in opposing cycles. Attempting to make a refueling connection without relevant depth perception and without being able to see the end of the boom under those conditions elevates what would otherwise be a benign procedure to one that is mishap-prone, even with the most experienced boomers.

While the technical challenges with the boom and RVS are troubling, issues with basic workmanship are equally illuminating. In February 2019, an internal Boeing management memo noted that Air Force pilots were finding so much debris and so many loose tools throughout brand-new jets that "they will not fly [them] due to the FOD (foreign object debris) issues and the current [lack of] confidence they have in our product...."[19]

Boeing was able to win the KC-X contract primarily because it met three criteria: cost, preservation of the U.S. industrial base for tankers, and previous experience in building the KC-135. While noble in design, all three criteria have delivered poor outcomes for the KC-X acquisition program.

Boeing reportedly underbid EADS in a firm-fixed-price (FFP) contract that made it financially responsible for cost overruns. To date, the company has absorbed some $5.4 billion in cost overruns[20] that otherwise would have been borne by the government through a cost-plus-fixed-fee (CPFF) contract.

FFP contracts work well for proven systems or for those with very high technology readiness levels (TRLs), but the design for the KC-46's RVS system met neither of those criteria. On the surface, Boeing's FFP contract for the KC-X effectively limited a great deal of financial risk to the government, but it also has caused a significant amount of operational risk. Forcing or even allowing a contractor to insert a low-TRL system under such an agreement can put contractors in dire financial straits, and the collateral effects within this effort have exposed the government to operational risks with enormous attendant costs.

Eleven years after the KC-X contract was awarded, the Air Force is accepting aircraft that are years away from having a viable operational capability, and the program remains anything but low risk. The new tanker is prohibited from supporting real-world contingency operations, and the jet's initial operating capability (IOC) date has slipped to fiscal year (FY) 2024 at the earliest.[21] By that time, the Air Force will have taken possession of some 103 KC-46s.[22]

The Air Force estimates that the fix for the boom and RVS should be ready by the spring of 2024,[23] but the shortcuts the service is taking to make that timeline are eye-opening. The problems with the current system were discovered during flight testing, yet the Air Force has decided not to assess or flight test the fully revised RVS before it accepts the design.[24] Problems discovered beyond that point could result in even more significant delays, and the costs for fixing the system will be borne by the Air Force.

Assuming the redesign goes as planned, retrofitting jets that the service has already accepted with the boom and RVS redesign will take several years, and the operational impact of that process will be significant: 103 strategic air refueling assets will be unusable in real-world operations in 2024. That number will grow to 110 jets in 2025, equating to 23 percent of the fleet that will be unable to fulfill operational taskings. Assuming that the design and retrofit stay on track, the numbers will slowly start to improve through 2029 when all KC-46s will be fully operational.[25]

Recognizing the gap in operational capability, Congress, through the FY 2022 National Defense Authorization Act (NDAA), directed the Air Force to slow or curtail the retirement of viable tanker aircraft until the KC-46 comes up to speed.[26] Unfortunately, that move has introduced still other challenges. As the service continues to accept new KC-46s, the squadrons and crews that transition to those jets are no longer available to fly the operationally capable KC-10 and KC-135 aircraft. The Air Force is studying methods for filling those cockpits and covering the operational gaps[27] by hiring private organizations/aircrews to maintain, operate, and fly the tankers the service is retiring. However, while this option may buy down operational risk, it will undoubtedly impose a significant financial burden on the Air Force.

Because crews that transition to the KC-46 need to continue training, the service moved last year to meet that need as well as to relieve KC-10 and KC-135 operational tempo where possible. The Air Force approved the KC-46A for stateside operations and refueling missions in support of U.S. Transportation Command (TRANSCOM); for aircraft that employ probe/drogue refueling (Navy/Marine Corps fighters); and for 11 Air Force platforms.[28] The list does not include the F-35, F-22, or B-2 because of the likelihood of the KC-46 RVS/boom system's errantly damaging the stealth coatings on those jets. Commanders may elect to waive that restriction during contingency or wartime operations, but they will have to accept the increased operational risk.

Boeing is at least seven years away from delivering 179 fully operational KC-46s, and risks to the service and its wartime mission between now and

2029 will be significant. It is important to keep those lessons in mind as the Air Force moves to acquire the next increment of tankers, particularly in light of recent events and the possibility that they might escalate into great-power conflict. Vladimir Putin's invasion of Ukraine has forced even the most dovish nations within NATO to revise their defense spending to ready their nations for a possible conflict with Russia,[29] and the Commander of Indo-Pacific Command has testified before the Senate Armed Services Committee that China could move on Taiwan by 2027.[30] The potential for great-power conflict is growing, and the United States needs to acquire the capacity to fight such a war.

The KC-Y

Later this year, the Air Force will release an RFP for the next increment of 150 strategic tankers. Both the Boeing Corporation and Lockheed Martin/Airbus are expected to submit proposals that are designed to capture the KC-Y contract. Boeing is expected to offer the KC-46A that is currently in production in the United States. The Airbus/Lockheed Martin KC-Y proposal, named the Lockheed Martin Next Generation Tanker or LMXT, will be a modified version of Airbus's A-330 Multi-Role Tanker Transport (MRTT).

The MRTT is already operational and has been certified to refuel every fighter aircraft in the U.S. Air Force and Navy inventories. It has a boom enhanced vision system (BEVS) with 3D, high-definition color displays that allow boomers to sit in the main cabin and remotely refuel other aircraft. BEVS was designed to enable automated air refueling (refueling without a boom operator) using machine vision algorithms. That sub-system is on track to be certified for automatic daytime refueling later in 2022 and nighttime refueling in 2023. Based on the Airbus A-330 airliner, the MRTT design will be modified to increase its fuel capacity.

Both the KC-46 and the LMXT have cargo[31] and passenger carriage capabilities and are designed to accept high-end command and control equipment to further the Air Battle Management System/Joint Air Domain Command and Control network efforts. However, those capabilities are secondary to the air refueling mission, and the RFP and follow-on acquisition decision process must prioritize those capabilities accordingly.

While the overarching tanker acquisition strategy has morphed over the years, the KC-Y Bridge Tanker program was initially designed to replace the KC-10, a jet that can carry significantly more fuel than the KC-135 carries. The distances and fuel offload capacity required to establish a

tanker bridge and sustain operations from the United States to the area of operations would be much greater in a peer fight with China than they would be in a fight with Russia. That fact, coupled with China's intent to target any tanker base within range of its air-to-surface missile systems, makes fuel offload capacity at range a critical capability. The KC-10 carries a maximum of 356,000 pounds of fuel, which is 70 percent more than either the KC-135 or KC-46 can carry, but it burns fuel at a much higher rate than the KC-135, KC46, or LMXT. The KC-135 has a capacity of 200,000 pounds, and the KC-46 can carry 211,000 pounds,[32] but the LMXT can carry 268,445 pounds.[33]

The operational effects of that additional capacity are not insignificant. In real terms, the LMXT could refuel seven more F-35s than the KC-46 can refuel when the offload point (Air Refueling Contact Point or ARCP) is 1,000 miles from the tanker's launch and recovery base, six more at an operating radius of 2,000 miles, and five more at 3,000 miles. The LMXT and KC-10 can offload the same amount of fuel at 2,500 miles, but from that point on, because of its more efficient engines, the LMXT can offload more than even the KC-10 is able to offload.[34]

The LMXT's increased capacity and proven track record make it a viable contender in this competition. Because the KC-46 is smaller than the LMXT, it conceivably could operate out of more bases in the Pacific region when both aircraft are loaded to their maximum gross weights. When both aircraft are loaded to the same gross weights, however, the LMXT can fly out of more airfields because of its more powerful engines. Assuming that the issues with its boom and RVS are resolved in due course, the KC-46 will be a serious contender, but it will take years for those issues to be resolved, and acquiring an additional 150 Pegasus platforms before the fix has been accepted would therefore be unwise. Delaying the KC-Y acquisition decision until the KC-46 becomes operational is an option, but such a delay would levy even more risk on an already strained tanker fleet.

Pressure from Members of Congress and industrial partners to embrace that risk and fall back on the same cost savings and buy-American criteria that got the service in trouble with the KC-X program will undoubtedly be high. Both sticker price and preservation of an organic American industrial base for tankers are important considerations, but as previously noted, the costs associated with filling the operational gaps created by the KC-46 RVS and boom issues are likewise important. Perhaps as a sign that Airbus/Lockheed Martin learned from their previous proposal, they now have plans to assemble the A-330 airframe in Mobile, Alabama, and modify it into the LMXT tanker in Marietta, Georgia.

Finally, the critical technology within the LMXT proposal is already operational and at work in dozens of fielded MRTT platforms, which means the risk associated with acquiring this system would be minimal. The Bridge Tanker acquisition decision is a critical one, and it will be important for the service to go through the acquisition process by the book and avoid the gaffes and resets that it suffered with the KC-X in the mid-2000s. The service needs as many operational booms as it can field for a possible fight with China—even more capacity than it currently is programmed to acquire.

The Real Tanker Capacity Requirement

By the end of the KC-X, KC-Y, and KC-Z acquisition programs, the Air Force will have replaced all KC-135 and KC-10 aircraft with new and more capable tankers while reducing the total number of strategic refueling platforms from 479 to 457. That number is woefully insufficient for a peer fight, based on the recent history of real-world operations as well as formal tanker requirement studies.

In both 1991 and 2003, the Air Force possessed some 600 KC-135 and KC-10 tankers.[35] When the service executed Operation Desert Shield and Operation Desert Storm, it employed some 271 tankers to support the airbridge to the Persian Gulf as well as combat operations in Iraq.[36] Twelve years later, during Operation Iraqi Freedom, the demand for Air Force tankers peaked at 319 and then leveled off to a continual demand of 280 (95 airbridge and 185 combat support)—a number that did not include tankers from sister services or allies.[37]

With today's inventory of 479 aircraft, that daily tanker support requirement for a regional war against a Third World adversary would consume 58 percent of our current fleet, and that number does not include combat losses, tankers required to defend the homeland or support deterrence operations in a second theater, or tankers held in reserve to support nuclear strike operations. According to a recent Hudson Institute study, this could mean an additional 325 tankers,[38] which, when combined with the sustained Operation Iraqi Freedom requirement of 280 tankers, equates to a capacity requirement of 605 strategic air refueling aircraft.

While those numbers are significant, the airbridge and combat support requirements for a peer fight, particularly one conducted in the threat environment and over the vast distances associated with a fight with China, would likely dwarf that number. A U.S. Department of Defense Study completed in 2001 concluded that "500–600 KC-135R equivalents" were needed "to meet the National Military Strategy," and a 2005 Mobility Capabilities

Study "reportedly recommended the acquisition of 520–640 KC-135R model equivalents."[39] Both of those studies were conducted long before the 2018 National Defense Strategy (NDS) directed the services to prepare for great-power competition with China or Russia.[40]

Seven months after the 2018 NDS was released, the Secretary of the Air Force released "The Air Force We Need," a study examining the capacity the service would need to support that strategy. Based on thousands of war-game simulations, the study found that the service would need 14 more tanker squadrons than the 40 it had at the time,[41] which equates to a total of 691 strategic refueling platforms.[42]

Although the service has backed away from the study because of the associated cost, it remains the most accurate estimate we have for the tanker requirements associated with great-power competition. Other alliances with other nations may bring additional fighter capacity to such a fight, but almost every nation will need the strategic tanker support that only the Air Force can bring.

The Air Force should increase its capacity requirement to match the approximately 691 tankers recommended in "The Air Force We Need," and now is an excellent time to begin. As previously noted, the Air Force is studying methods for covering the operational gaps caused by delays associated with the KC-46. One option would be to shift "retiring" active-duty air refueling assets to the Reserve Component. This would undoubtedly be less expensive than a commercial option, and the assets and crews would have no geographic constraint on where they could fly in times of war.

Hiring private organizations/aircrews to maintain, operate, and fly the tankers the service is moving to retire might also be a viable option. While constraints on where those leased platforms could fly would be an issue, the option would allow the service to build the 691-tanker capacity requirement for a peer fight, satisfy congressional concerns, and allow the service to continue or even accelerate its programmed retirements of the KC-10 and KC-135 tanker fleets.[43]

What Congress and the Air Force Should Do

Congress should:

- Extend the prohibition on the retirement of KC-135 and KC-10 tanker aircraft to include all viable platforms until the service achieves a combined tanker fleet of 691 KC-135, KC-10, KC-46, and KC-Y platforms.

- Direct the Defense Department to sustain a minimum of 691 strategic air refueling platforms through the acquisition of the KC-Z acquisition program.

- Authorize the Air Force to increase its total aircraft inventory of tankers to 691 or lease additional tanker aircraft and aircrews from private American organizations to achieve that capacity.

For its part, the Air Force should:

- Structure the KC-Y request for proposals so that it incentivizes competition and encourages expansion of the U.S. air refueling industrial complex beyond its current single member.

- Consider multiple factors when awarding the KC-Y contract including the vendor's track record for minimizing risk and delivering quality on time and on or under budget, as well as the capabilities and offerings within the American defense industrial base.

Conclusion

The Air Force should move immediately to strengthen the path to recapitalization of its fleet of strategic air refueling aircraft through seamless competition, both to incentivize performance within and to expand the tanker industrial base. The Defense Department should maintain the current proposal and acquisition schedule for the KC-Y, and the award should prioritize proven performance and the minimization of risk. The retirement of viable tanker aircraft fleet should end until operational replacements are in place, and the Air Force should increase its air refueling capacity from 479 to 691 owned or leased tankers to ensure that it is better prepared for possible conflict with a peer competitor.

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Endnotes

1. Table, "Equipment: Aircraft Total Active Inventory (As of Sept. 30, 2020)," in "Air Force & Space Force Almanac," *Air Force Magazine*, Vol. 104, Nos. 6 and 7 (June/July 2021), p. 73, https://www.airforcemag.com/app/uploads/2021/06/Almanac2021_Fullissue-1.pdf (accessed March 7, 2022).
2. Christopher Drew, "Boeing Wins Contract to Build Air Force Tankers," *The New York Times*, February 24, 2011, https://www.nytimes.com/2011/02/25/business/25tanker.html (accessed March 7, 2022).
3. GlobalSecurity.org, "KC-X Tanker Replacement Program," last modified July 7, 2011, https://www.globalsecurity.org/military/systems/aircraft/kc-x.htm (accessed March 7, 2022).
4. Christopher Hinton, "Boeing Files Protest Over Lost U.S. Tanker Deal," MarketWatch, March 11, 2008, https://www.marketwatch.com/story/boeing-files-protest-over-air-force-tanker-award (accessed March 7, 2022).
5. Press release, "Hunter Statement on Secretary of Defense Decision to Cancel Current KC-X Aerial Refueling Tanker Acquisition Program," Committee on Armed Services, U.S. House of Representatives, September 9, 2009, https://republicans-armedservices.house.gov/news/press-releases/hunter-statement-secretary-defense-decision-cancel-current-kc-x-aerial-refueling (accessed March 7, 2022).
6. Jim Garamone, "Secretary Gates Cancels Air-Refueling Solicitation," U.S. Air Force, September 10, 2008, https://www.af.mil/News/Article-Display/Article/122487/secretary-gates-cancels-air-refueling-solicitation/ (accessed March 7, 2022).
7. John A. Tirpak and Michael C. Sirak, "Boeing Wins KC-X Contest," *Air Force Magazine*, February 25, 2011, https://www.airforcemag.com/boeingwinskc-xcontest/ (accessed March 7, 2022).
8. Jonathan Derden, "AFRES KC-46A Candidate Bases Announced," SOFREP [Special Operations Forces Report], April 20, 2015, https://sofrep.com/fightersweep/afres-kc-46a-candidate-bases-announced/ (accessed March 7, 2022).
9. Table, "Annual Funding 3010 | Procurement | Aircraft Procurement, Air Force," in U.S. Department of Defense, *Selected Acquisition Report (SAR), KC-46A Tanker Modernization (KC-46A) as of FY 2018 President's Budget Request*, December 2016, p. 30, https://man.fas.org/eprint/KC-46-2018.pdf (accessed March 7, 2022).
10. GlobalSecurity.org, "Bridge Tanker / KC-Y – KC-10 Replacement," Global Security, last modified September 18, 2021, https://www.globalsecurity.org/military/systems/aircraft/kc-y.htm (accessed March 7, 2022).
11. Gareth Jennings, "US Air Force Launches KC-Y Tanker Competition," Janes, June 17, 2021, https://www.janes.com/defence-news/news-detail/us-air-force-launches-kc-y-tanker-competition (accessed March 7, 2022).
12. Based on each aircraft requiring 6,000 pounds of fuel. Boom system fuel flow is 1,200 pounds per hour, and Drogue/basket system fuel flows are roughly 400 pounds per hour.
13. Bill Carey, "U.S. Air Force Will Test KC-46 to Assess Boom-Scraping Issue," AINonline, September 22, 2017, https://www.ainonline.com/aviation-news/defense/2017-09-22/us-air-force-will-test-kc-46-assess-boom-scraping-issue (accessed March 7, 2022).
14. U.S. Government Accountability Office, *KC-46 Tanker: Air Force Needs to Mature Critical Technologies in New Aerial Refueling System Design*, GAO-22-104530, January 2022, pp 11, https://www.gao.gov/assets/gao-22-104530.pdf (accessed March 7, 2022).
15. Brian W. Everstine, "Inside a KC-46 Refueling Flight," *Air Force Magazine*, May 26, 2021, https://www.airforcemag.com/inside-a-kc-46-refueling-flight/ (accessed March 7, 2022).
16. Figure 1 in Moshe Barsheshet, Yoav Herzig, Elie Koskas, Michael Litvak, and Daniel Frydman, "Tip with Nozzle Load Sensing and Wireless Communication Functionality for Refueling Boom," U.S. Patent Application No. US9840336B2, December 12, 2017, https://patents.google.com/patent/US9840336B2/en (accessed March 7, 2022).
17. Air Force Test Center, "July 12, 2016: Pegasus Refuels Globemaster III," July 13, 2020, https://www.aftc.af.mil/News/On-This-Day-in-Test-History/Article-Display-Test-History/Article/2224692/july-12-2016-pegasus-refuels-globemaster-iii/ (accessed March 7, 2022).
18. Tyler Rogoway and Joseph Trevithick, "This Is What the Boom Operator's Station on the New KC-46 Tanker Actually Looks Like," The War Zone, April 2, 2019, https://www.thedrive.com/the-war-zone/27268/this-is-what-the-remote-boom-operators-station-on-a-kc-46-tanker-really-looks-like (accessed March 7, 2022).
19. Dominic Gates, "Boeing Tanker Jets Grounded Due to Tools and Debris Left During Manufacturing," *The Seattle Times*, February 28, 2019, https://www.seattletimes.com/business/boeing-aerospace/boeing-tanker-jets-grounded-due-to-tools-and-debris-left-during-manufacturing/ (accessed March 7, 2022).
20. Valerie Insinna, "Boeing Racks up $402M Cost Overrun on KC-46 Tanker," *Breaking Defense*, January 26, 2022, https://breakingdefense.com/2022/01/boeing-racks-up-402m-cost-overrun-on-kc-46-tanker/ (accessed March 7, 2022).
21. "KC-46 Pegasus," *Air Force Magazine*, https://www.airforcemag.com/weapons-platforms/kc-46/ (accessed March 7, 2022).
22. Figure 8, "Actual and Planned Aerial Refueling Tanker Fleet Size in the Air Force," in U.S. Government Accountability Office, *KC-46 Tanker: Air Force Needs to Mature Critical Technologies in New Aerial Refueling System Design*, p. 29.
23. Joseph Trevithick, "Plan to Fix Troubled KC-46 Tanker Risks Making Same Mistakes New Report Says," The War Zone, January 27, 2022, https://www.thedrive.com/the-war-zone/44046/air-force-risks-repeating-its-mistakes-when-it-comes-fixing-its-kc-46-tanker-new-report-says (accessed March 7, 2022).

24. The list of Air Force Aircraft now includes the C-17, B-52, KC-46, AC-130J, HC-130J , MC-130J, C-5M, E-3G Sentry, F-15, F-15E, and F-16C. U.S. Government Accountability Office, *KC-46 Tanker: Air Force Needs to Mature Critical Technologies in New Aerial Refueling System Design*, pp. 28–29.
25. The number of operationally constrained platforms drops to 77 in 2026, 44 in 2027, and 11 in 2028. Figure 8, "Actual and Planned Aerial Refueling Tanker Fleet Size in the Air Force," in ibid., p. 29.
26. The 2022 NDAA prohibits the Air Force from retiring more than 18 KC-135s in FY 2023 to ensure that those fully capable strategic tankers remain in the inventory to sustain some level of operational readiness. S. 1605, National Defense Authorization Act for Fiscal Year 2022, Public Law 117-81, 117th Cong., December 27, 2021, Section 137, https://www.congress.gov/bill/117th-congress/senate-bill/1605/text (accessed March 8, 2022). The Subcommittee on Seapower and Projection Forces of the House Committee on Armed Services had previously "backed the Air Force's request to retire 14 KC-10A tankers in fiscal 2022," shrinking "the Extender fleet to 36 aircraft—but no further—by October 2022," and to "keep at least 24 KC-10As in its main inventory in fiscal 2023." Rachel S. Cohen, "Gradual Retirement for Tanker Jets Endorsed by House Lawmakers," *Air Force Times*, July 28, 2021, https://www.airforcetimes.com/news/your-air-force/2021/07/28/gradual-retirement-for-tanker-jets-endorsed-by-house-lawmakers/#:~:text=Under%20the%20subcommittee's%20version%20of,than%2012%20jets%20that%20year. (accessed March 8, 2022).
27. Air Mobility Command (AMC) expects the final report from that study to be completed in mid-2023 at the earliest. U.S. Government Accountability Office, *KC-46 Tanker: Air Force Needs to Mature Critical Technologies in New Aerial Refueling System Design*, pp. 32–33.
28. Air Mobility Command Public Affairs, "AMC Approves 4th KC-46A Pegasus ICR Milestone," U.S. Air Force, December 8, 2021, https://www.af.mil/News/Article-Display/Article/2863942/amc-approves-4th-kc-46a-pegasus-icr-milestone/ (accessed March 8, 2022).
29. Christopher F. Schuetze, "Russia's Invasion Prompts Germany to Beef up Military Funding," *The New York Times*, February 27, 2022, https://www.nytimes.com/2022/02/27/world/europe/germany-military-budget-russia-ukraine.html (assessed March 8, 2022).
30. Adela Sulman, "China Could Invade Taiwan in the Next 6 Years, Assume Global Leadership Role, U.S. Admiral Warns," NBC News, March 10, 2021, https://www.nbcnews.com/news/world/china-could-invade-taiwan-next-6-years-assume-global-leadership-n1260386 (accessed March 8, 2022).
31. The KC-46 can carry three times as much as the LMXT. However, all of that cargo is on the upper deck, and specialized equipment is required for the loading and offloading of all cargo. All LMXT cargo is in the lower lobe and can be loaded and offloaded with a simple forklift.
32. Stewart Welch and David Leroy, "The Case for a Three-Tanker Air Force," War on the Rocks, October 11, 2019, https://warontherocks.com/2019/10/the-case-for-a-three-tanker-air-force/ (accessed March 8, 2022).
33. Figure 26, "Tanker Options to Complement the KC-46A," in Timothy A. Walton and Bryan Clark, *Resilient Aerial Refueling: Safeguarding the U.S. Military's Global Reach*, Hudson Institute, Center for Defense Concepts and Technology, November 2021, p. 51, https://s3.amazonaws.com/media.hudson.org/Walton%20Clark_Resilient%20Aerial%20Refueling.pdf (accessed March 8, 2022).
34. Walton and Clark, *Resilient Aerial Refueling: Safeguarding the U.S. Military's Global Reach*, p. 54. See also Figure 27, "Single Tanker Fuel Offload Capacity," in ibid., p. 52.
35. Figure 5, "Evolution of the US Air Force Tanker Fleet," in ibid., p. 18.
36. Walton and Clark, *Resilient Aerial Refueling: Safeguarding the U.S. Military's Global Reach*, p. 20.
37. Ibid., p. 21.
38. Figure 19, "Representative Tanker Wartime Requirements," in ibid., p. 41.
39. Christopher Bolkcom, "Air Force Aerial Refueling," Congressional Research Service *Report for Congress* RS20941, updated March 20, 2007, p. CRS-6, https://sgp.fas.org/crs/weapons/RS20941.pdf (accessed March 8, 2022).
40. James Mattis, Secretary of Defense, *Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge*, U.S. Department of Defense, https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf (accessed March 8, 2022).
41. U.S. Air Force, "The Air Force We Need: 386 Operational Squadrons," September 17, 2018, https://www.af.mil/News/Article-Display/Article/1635070/the-air-force-we-need-386-operational-squadrons/ (accessed March 8, 2022).
42. The numbers of total aircraft inventory (TAI) and combat-coded aircraft for the active-duty Air Force were derived through review of the U.S. Air Force's FY 2022 budget overview and the 2021 edition of the International Institute for Strategic Studies annual *Military Balance* study. Where the two publications were in conflict for TAI, the USAF numbers were generally adopted. Neither document specifies the number of active-duty combat-coded aircraft. That number was derived by tallying the total number of aircraft by type and dividing that number by the total number of active-duty squadrons flying those types of aircraft. The numbers and types of aircraft associated with Weapons Instructor Course Squadrons, Test, Operational Test & Evaluation, and other units are not standard/determinable and could not be assessed. The associated error is minimized by totaling all like aircraft (KC-135, KC-10, etc.); dividing them by the total number of squadrons flying those aircraft; and spreading the error equally across all operational and training units. While the number of aircraft in any one of those categories varies from unit to unit, there are approximately 15 tankers, in each squadron. Fourteen squadrons equates to 210 aircraft. When added to the 481 the Air force had in the inventory in 2018, that equates to total requirement of 691 tankers. See U.S. Department of the Air Force, *Department of the Air Force Fiscal Year 2022 Budget Overview*, https://www.saffm.hq.af.mil/Portals/84/documents/FY22/SUPPORT_/FY22%20Budget%20Overview%20Book.pdf?ver=SMbMqD0tqIJNwq2Z0Q4yzA%3D%3D (accessed March 8, 2022); International Institute for Strategic Studies, *The Military Balance 2021: The Annual Assessment of Global Military Capabilities and Defence Economics* (London: Routledge, 2021), pp. 56–59; and Table, "Air Force Total Aircraft Inventory (TAI)," in U.S. Air Force, *United States Air Force Fiscal Year 2018 Budget Overview*, p. 46, http://www.saffm.hq.af.mil/LinkClick.aspx?fileticket=m3vZOmfR368%3d&portalid=84 (accessed March 8, 2022).

43. Surprisingly, the 2021 mission-capable rates for the KC-10, KC-135R, and KC-135T fleets were 79 percent, 71 percent, and 70 percent, respectively. Those rates match or even exceed the KC-46 MC rate of 71 percent. Table, "FY21 Mission-Capability Rates," in Rachel S. Cohen and Stephen Losey, "U.S. Air Force Fleet's Mission-Capable Rates Are Stagnating. Here's the Plan to Change That," *Air Force Times*, February 14, 2022, https://www.airforcetimes.com/news/your-air-force/2022/02/14/us-air-force-fleets-mission-capable-rates-are-stagnating-heres-the-plan-to-change-that/ (assessed March 8, 2022).