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AVIATION AFTERMARKET DEFENSE

Sustainment and Modernization

Fall/Winter 2024/25 Vol. 19, No. 2

EVOLUTION and REVOLUTION

Changes come to the defense aviation aftermarket

INSIDE:

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A Pivotal Moment

Looking back over the last century, it is estimated that World War I cost more than any previous war, in both expenditures and lives lost. World War II quadrupled the cost in dollars and doubled fatalities. And as technology has progressed to extraordinary levels of complexity, the relative expense of national defense and participation in armed conflicts has escalated, as has the human cost.

In this new year, with a controversial U.S. administration coming in and unprecedented worldwide turmoil, we find ourselves at a pivotal moment. We in defense aviation and related industries, planners and logistics managers, and personnel with feet on the ground and in the air, all await budget approvals, policy priorities, and corresponding allocations over this next year and beyond, decisions that will shape this nation's military, its supporting infrastructure, and much more.

Of course, we can make informed deductions, and, with today's computer modeling and the latest artificial intelligence, it is easy to believe we can even predict the future. But without the prescience of a functional crystal ball, there is no way to really know the outcome of forthcoming resource decisions and chosen approaches to the complex conflicts and challenges we currently face. Plus, on top of the myriad possible outcomes to known situations are complications yet unknown, abroad and at home.

Taking into account the amount that U.S. defense forces will have to work with, will investments go toward upgrading existing aircraft or developing new models? What aircraft types will be prioritized? Transports, helicopters, fighters, bombers? Manned or unmanned platforms? What part will climate-related and other 21st-century goals play? Will airlift, aerial surveillance, or armament take precedence? And where will we focus our manpower, equipment, and efforts?

The probable answer to most of these questions is that we will once again not place all of our eggs in one basket. With sustainment of current capabilities necessary to keep air defenses solid in the near future, planners are likely to spread monies across strengthening what we have in place. At the same time, they also know that we must continue to be proactive in developing diverse evolving technologies to ensure we always stay ahead of the ever-advancing innovations of our and our allies' adversaries.

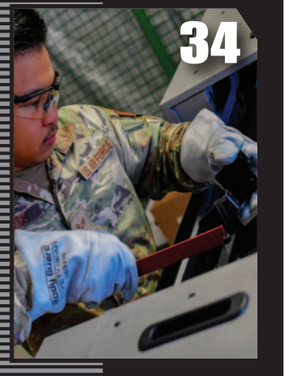
Some good news is that despite concerns we may have about available dollars and chosen directions, no matter what choices are made in terms of old versus new and different models and missions, both original equipment manufacturers and the aftermarket in all segments — aircraft and component producers; parts, service, and sustainment providers; and other industry players — are likely to have plenty of business and even experience growth. After all, the potential problems to be addressed are, if anything, increasing.

Possible good or bad news is that while we can advocate for what we view as the best decisions, it is up to those who lead us to take into account lessons learned from past conflicts, heed the sage counsel of insightful advisors, proceed with good judgement, and make wise decisions. In the geopolitical balancing act between national defense and foreign policy, we are on as precarious an edge as at any time in our nation's history. To quote Theodor Seuss Geisel, better known as Dr. Seuss, we must, "Step with care and great tact."

Ultimately, we can only hope that the investments in, decisions about, and the concerted efforts of our defense forces, and all those who fight, strive, and otherwise seek desired outcomes will decrease and de-escalate conflicts and reduce the numbers of lives ruined and lost in the days to come.

Laura Brengelman

Laura Brengelman
Editor



They also serve who only stand and wait®
John Milton, 1655

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By Valius Venckūnas

The Boeing E-4B "Doomsday plane," soon to be replaced by the new Survivable Airborne Operations Center (SAOC) based on Boeing's 747-8. (U.S. Air Force photo by Technical Sergeant Codie Trimble.)

SNC to Build New Doomsday Planes
A $13 billion contract to replace the U.S. Air Force's Boeing E-4B "Doomsday plane" was awarded to Sierra Nevada Corporation (SNC). The new aircraft, known as the Survivable Airborne Operations Center (SAOC), will serve as a mobile nuclear command outpost for the National Command Authority and carry U.S. top officials in the event of a nuclear conflict, a role that earned it the nickname "Doomsday plane."

The current fleet of four E-4Bs entered service in 1974, and is based on the antiquated Boeing 747-200. With the service life of the E-4Bs nearing its end, the U.S. Air Force began looking for a replacement in 2021 and eventually settled on the Boeing 747-8 as a platform of choice. However, the production run of this aircraft ended in 2019, necessitating procurement of a used airliner.

Initially, Boeing and SNC both offered bids to build the aircraft, but Boeing was eliminated from the bidding, reportedly due to disagreements over contract terms. Since being selected, SNC purchased five Boeing 747-8 wide-body airliners, which are set to be converted and enter operations as the new SAOCs by 2036.

Artist's impression of a U.S. Air Force E-7A Wedgetail. (Image courtesy of Boeing.)

U.S. Air Force Commissions Wedgetail Prototypes
The U.S. Air Force awarded Boeing a $2.56 billion contract to deliver two prototypes of the E-7A Wedgetail airborne early warning and control (AEW&C) aircraft. The contract is a part of the rapid prototype program for E-7A aircraft that could inform a production decision by fiscal year 2026.

In 2022, the E-7A was selected to replace the Boeing E-3 Sentry, commonly known as the Airborne Warning and Control System (AWACS), which is marked for retirement. The program integrates existing E-7 aircraft with U.S.-based mission systems, paving the way for transition to the new model. Based on the Boeing 737 Next Generation (NG) series of commercial jets, the E-7 features an advanced active electronically scanned Array (EASA) radar, providing a significant step-up in capability.

Introduced in 2012, the E-7 has already entered operations with the Royal Australian Air Force, the Republic of Korea Air Force, and the Turkish Air Force. U.K.'s Royal Air Force also has ordered the aircraft, and it is slated to become a primary asset of NATO's Airborne Early Warning and Control Force. The first E-7 is planned to enter service with the U.S. Air Force in 2027.

U. S. Air Force's $12.5 Billion Infrastructure Modernization
In late August, the U.S. Air Force selected twenty-three companies to modernize, maintain, and operate network infrastructure at its bases across the world. The Base Infrastructure Modernization (BIM) contract includes wired and wireless components of both classified and unclassified networks at various locations, including U.S. Air National Guard and U.S. Air Force Reserve bases.

Forty-seven companies put forward proposals for the contract, with less than half selected. The list of awarded firms includes AT&T, CACI International, General Dynamics, Telos, and others.

Lockheed Martin Lands Crucial F-35 Contracts
Lockheed Martin has been awarded three contracts connected to further upgrades, development, and sustainment of U.S. Air Force F-35 Lightning II fifth generation fighter jets.

The largest contract, worth $3.9 billion, is for development, integration, testing, production, deployment, upgrades, and sustainment of training systems. Lockheed Martin will provide the training systems for F-35s flown by the U.S. Air Force, U.S. Navy, and U.S. Marines, as well as those operated by foreign countries.

Another contract, worth $1 billion, extends Lockheed Martin's engineering, maintenance, logistics, manpower, and material support services for F-35 laboratory facilities and test activities. It also covers testing and evaluation activities required by the U.S. military and foreign F-35 customers.

The third contract, worth around $194 million, covers continued provision of supplies to depots that support the deployment of F-35s across the world.

A Joint Direct Attack Munition GBU-31 is shown during an exercise. Bolt-on attachments, which convert a gravity bomb into a precision-targeted one, are visible. (U.S. Air Force photo by Senior Airman Koby I. Saunders.)

Boeing Receives JDAM Contract
In late May, the U.S. Air Force awarded Boeing a $7.5 billion contract to deliver Joint Direct Attack Munitions (JDAM) guidance kits and to provide spare parts and related repairs. The sole-source, fixed-price, indefinite delivery/indefinite quantity contract will run through the end of February 2030. Some of the kits will be transferred to the U.S. Navy and distributed to international allies.

Reports suggest that current conflicts in Ukraine and the Middle East have revealed a shortage of precision-guided munitions. Thus, while the exact number of kits was not specified, it is understood that the U.S. Air Force intends to "catch up" on JDAM production.

The kits consist of a collection of bolt-on parts that fit onto unguided gravity bombs, converting them into guided ones. Included are an inertial guidance system, laser seekers, and Global Positioning System (GPS) receivers. These upgrades can be installed on a wide range of bombs and are compatible with the full range of aircraft that carry them.

An F-35 production line at Lockheed Martin's facility in Fort Worth, Texas. (Photo courtesy of the Defense Contract Management Agency.)

Lightning II Deliveries Resumed

Following a year-long hold, Lockheed Martin resumed deliveries of F-35 Lightning IIs in late July. The first two F-53As were delivered to Montgomery Air National Guard Base, Alabama, and Nellis Air Force Base, Nevada, out of the stock of more than ninety aircraft accumulated by Lockheed Martin.

Deliveries of the F-35 were halted by the U.S. Department of Defense in July 2023, as a result of software problems with the Technology Refresh 3 (TR-3) upgrade, which is designed to improve the aircraft's operational capabilities by enhancing its computer systems and sensors. Issues with TR-3 have caused numerous delays and cost overruns since the early flight tests in 2023. A "truncated" version of the upgraded software is installed on the newly delivered F-35s, enabling the Joint Program Office to clear the deliveries with the expectation of implementing a fully functioning upgrade in the near future.

A Northrop Grumman B-21 Raider in flight. (Photo courtesy of Northrop Grumman.)

B-21 Price Ceiling Renegotiated

Northrop Grumman has negotiated a higher price ceiling for B-21 Raider strategic bombers. The renegotiation followed the company declaring a loss on the first batches of B-21s.

The next nineteen B-21s will have a higher price than the initial low-rate production run, which resulted in a $1.2 billion loss for the company. Despite the increased price ceiling, Northrop Grumman representatives say the manufacturer is on track to maintain an average B-21 unit cost of $550 million in 2010 dollars, which is around $700 million in 2024 dollars.

Beginning development in 2015, the B-21 performed its maiden flight in November 2023. The U.S. Air Force plans to eventually operate an estimated 100 B-21s by the 2040s, replacing both Rockwell B-1 Lancer and Northrop B-2 Spirit with the new stealth bomber, which Northrop Grumman calls "the first sixth generation military aircraft."

Honeywell Acquires CAES

Honeywell has acquired CAES Systems Holdings for $1.9 billion. The acquisition, which began in June, was completed in early September.

Based in Virginia, CAES manufactures mission-critical electronics equipment, such as antennas used on a variety of U.S.-made aircraft, including the F-15, F-16, F-18, and F-35.

By acquiring CAES, Honeywell is poised to significantly expand its offering of defense technology solutions, both growing its established production and introducing new platforms into its lineup. In particular, the company will be working on a SPY-6 naval radar, as well as various unmanned aerial platforms.

One of the former French Air Force Boeing KC-135 Stratotankers that will be used by Metrea to refuel U.S. and other nations' fleets. (Photo by Pedro Aragão, courtesy of Wikimedia.)

Metrea Buys French KC-135s

Metrea, a Washington DC-headquartered company, has acquired France's remaining fleet of fourteen Boeing KC-135 Stratotanker aerial refueling aircraft from the French Air and Space Force. The acquisition includes several variants of the aircraft.

Coupled with four KC-135s that Metrea previously purchased from Singapore, the acquisition makes the company the largest commercial operator of air refueling aircraft. In 2021, Metrea signed a contract with the U.S. Naval Air Systems Command (NAVAIR) to provide refueling support to U. S. Air Force, U.S. Marine Corps, and U.S. Navy aircraft, as well as NATO and allied nation fleets.

France began officially retiring its KC-135s in 2020, as a part of transitioning to the Airbus A330 Multi Role Tanker Transport (MRTT). Most of its KC-135s were in operation since the 1960s and underwent several rounds of modifications, serving as tankers, cargo, and troop carrier aircraft. The country plans to operate fifteen MRTT aircraft, with the majority already delivered.

The sixth prototype of the KF-21 during its maiden flight. Note the twin-seat cockpit. (Photo courtesy of Korea Aerospace Industries.)

South Korea's Native Jets Inbound

South Korea announced ordering the first batch of the KF-21 Boramae, its domestically produced fighter jet, after the country's Defense Acquisition Program Administration (DAPA) signed a 1.41 billion dollar deal with the jet's manufacturer Korea Aerospace Industries (KAI).

The KF-21 is advertised as a 4.5 generation fighter jet, featuring limited stealth capabilities, supercruise, and other staples of a fifth-generation fighter. Six prototypes of the aircraft are in various stages of completion. The initial production run began in early July 2024, and the first serial production model is expected to enter service in 2026.

The KF-21 is being developed in cooperation with Indonesia, although the Southeast Asian country's participation in the program involved years of disagreements with South Korea and has recently been reduced. In 2023, Poland expressed interest in joining the development program, along with purchasing a sizable fleet of KAI FA-50 light combat jets.

Boeing AH-64E Apache helicopters of the U.S. Army. Eight earlier generation Apaches will be transferred to Poland for initial training. (Photo courtesy of the U.S. Army.)

Poland Orders Apaches

Poland signed a Letter of Offer and Acceptance (LOA) for ninety-six Boeing AH-64E Apache attack helicopters. This largest attack helicopter order in the country's history will make Poland the second-largest Apache operator in the world, after the U.S. Army.

Poland selected the AH-64E in September 2022 as a part of Kruk, a program to procure a new attack helicopter fleet, where the Apache outcompeted the Bell AH-1Z Viper. Before 2022, the Polish Land Forces operated around thirty Soviet-made, heavily modernized Mil Mi-24 attack helicopters. A significant part of that fleet was donated to Ukraine.

The $10 billion contract for new Apaches includes ammunition, spare parts, a training package, and a logistics package, including maintenance equipment, airport and hangar equipment, and technical support. Poland will also receive eight earlier-generation AH-64Ds, on lease from the U.S. Army. The helicopters will be used to conduct training for Polish pilots and engineers, in preparation for the first shipments of AH-64Es, with delivery expected to begin in 2028.

An F-16 Fighting Falcon with Ukrainian markings. (Photo courtesy of the Ukrainian Air Force.)

Ukraine Flying Falcons

The Ukrainian Air Force is now flying F-16 Fighting Falcon fighters, the first Western-made manned combat aircraft in the nation's history. The jets have been showcased in a televised ceremony by Ukraine's president Volodymyr Zelensky and reportedly participated in an interception shooting down cruise missiles aimed at targets within the country.

Ukraine has not disclosed the number of aircraft received or the countries that donated them. But it is known that an estimated eighty-five F-16s have been pledged to Ukraine by Belgium, Denmark, the Netherlands, and Norway, with other countries saying they might contribute as well. The pledged jets were slated for retirement by their original operators and set to be replaced by Lockheed Martin F-35s.

While the discussions about providing Western-made aircraft to Ukraine started soon after the beginning of Russia's invasion in February 2022, training of Ukrainian pilots did not start until early 2024. It has been provided by a coalition of thirteen countries and conducted in Romania, with the participation of Lockheed Martin.

Before receiving the F-16, the Ukrainian Air Force's fighter fleet was primarily composed of a dwindling number of Soviet-era MiG-29 and Sukhoi Su-27 multirole fighters. Discussions about providing Ukraine with French-made Dassault Mirage 2000 and Swedish-made Saab JAS 39 Gripen are also taking place.

Concept art of a Hellenic Air Force F-35A Lightning II. (Image courtesy of Lockheed Martin.)

Greece Invests in Fighter Fleet

Greece has signed a contract to acquire twenty Lockheed Martin F-35 Lightning II fighters. Deliveries of the aircraft are set to begin in 2025, end in 2033, and consist entirely of F-35As, the conventional take-off and landing variant of the jet.

The new aircraft will supplement Greece's Hellenic Air Force (HAF) fleet of F-16 Fighting Falcons and Dassault Rafales. It will also streamline the HAF's fighter lineup, enabling retirement of antiquated F-4 Phantom, Mirage 2000, and older F-16s, all of which Greece still operates.

First evaluating the F-35 in 2019, Greece expressed an interest to eventually purchase up to forty F-35s, and it was cleared to do so by the U.S. Department of Defense. The current order of twenty aircraft is valued at $8.6 billion, with the deal including additional parts such as engines, electronics, and communications equipment, plus logistics support.

This purchase is significant in the context of the tensions with Turkey, Greece's neighbor and longstanding rival. Turkey was a member of the Joint Strike Fighter program, but was eliminated following its controversial purchase of a Russian-made S-400 air defense system.

The C-17 Globemaster, one of the largest military transport aircraft in service, is shown here refueling via a flying boom. (Image courtesy of Boeing.)

THE EVOLUTION OF AERIAL REFUELING

Operators aim to increase the flexibility, efficiency, and autonomy of their tanker fleets.

By Jeff Blundell

There is a popular saying in military aviation circles. You see it on hats, t-shirts, and even a few tattoos: "Nobody kicks ass without tanker gas."

While the idea that aerial refueling is essential for bringing the fight to the enemy is well established, methods for doing it continue to evolve. Major changes on the horizon, aimed at maximizing fleet readiness, increasing efficiency, and reducing the overall cost of refueling, involve new transports, systems, and even unmanned aerial vehicles (UAVS).

John B. Sams, Jr., has been in the middle of the evolution of this vital procedure for more than 50 years. As the retired U.S. Air Force Lieutenant General recalls, "In 1972, I was a B-52 aircraft Commander. Part of certification is you've got to be able to take on a prescribed amount of fuel, and that meant hanging on the boom for 20 minutes without a disconnect." A few years later, he was part of a record-setting refueling exercise.

"As the Strategic Air Command test pilot, one of the requirements was that our E-4B be able to stay airborne for 30 or more hours," Sams explains. "The idea was that you need to stay airborne, in case the landing airfields are destroyed in an attack. And so that you always have an airborne national command post capable of launching all the missiles and executing the war plan in the event that your ground-based facilities are incapacitated early on." During that 30-hour flight, Sams refueled his airplane ten times with 60,000 pounds offloaded from an aerial tanker in each refuel.

In the years since Sams retired from active service, he worked for a time with Boeing before becoming chairman and chief executive officer of ARSAG (Aerial Refueling Systems Advisory Group) International, headquartered in Solon, Ohio. Chartered by the U.S. Department of Defense, ARSAG establishes standards for the equipment involved in aerial refueling and provides those guidelines to the U.S. defense services and those of other North Atlantic Treaty Organization (NATO) member nations.

The goal is to ensure that a tanker built by Boeing, Airbus, or another major manufacturer can refuel a British Eurofighter Typhoon, Lockheed Martin F-35, or any other essential allied aircraft. Creating this mutually agreed-upon set of standards is essential for collaboration among allied nations involved in joint missions around the world.

John B. Sams, Jr., Lieutenant General, U.S. Air Force, Retired, is currently chairman and CEO of ARSAG (Aerial Refueling Systems Advisory Group) International. (Image courtesy of ARSAG International.)

OUT WITH THE OLD, IN WITH THE NEW (GRADUALLY)

The U.S. Air Force is in the process of replacing its aging fleet of KC-135 tankers with the newer, more capable KC-46 Pegasus. Recently, the force demonstrated the capabilities of the KC-46 by conducting a

"The idea was that you need to stay airborne, in case the landing airfields are destroyed in an attack..."

A Boeing KC-46 refuels a C-17. (Image courtesy of Boeing.)

A Boeing KC-46 Pegasus uses a boom to refuel a U.S. Air Force F-16 built by Lockheed Martin. (Image courtesy of Boeing.)

U.S. Navy fighters such as the F-18 are designed to receive fuel through a probe-and-drogue system. (Image courtesy of Boeing.)

westbound circumnavigation endurance flight known as Project Magellan. Between June 29 and July 1, 2024, an Air Force crew successfully flew a Pegasus for 45 hours nonstop, starting and finishing at McConnell Air Force Base in Kansas. That impressive endurance is just one reason the Air Force is making the switch.

"The roles and missions have expanded in the years since the KC-135 first came online," explains Sams. "It was specifically designed and built to be capable of refueling B-52s and B-47s. What has changed over the years is we have fewer and fewer bombers in inventory, and, although diminished, we have a large number of fighter-type aircraft needing air refueling."

Sams says KC-46s offer a wide range of advantages over KC-135s. "You get slightly more fuel. You get lower cost of operation, because they have two engines versus four, and you get a higher rate of fuel transfer to receivers. And that's just the beginning." He continues, "The KC-46 is fitted with a drogue pod on each wingtip, so it can be used to refuel both U.S. Air Force and U.S. Navy aircraft, even refueling two planes at the same time. This is in addition to its always available centerline air refueling drogue system."

Outlining the aircraft's added capabilities, he notes, "The KC-46 has a cargo door and a freighter floor installed, so if you decide to use it to deploy fighters to an overseas base, it can double as a cargo airplane. You can put eighteen pallets on a KC-46, where you can only put about five on a KC-135. Additionally, every KC-46 carries an installed aeromedical evacuation suite, so that without adding or removing equipment, you can turn it into a medical evacuation airplane."

Such incredible flexibility has quickly made the big bird a darling for mission planners. Crews, meanwhile, are most excited about its increased self-defense and communication capabilities, enabling it to work in concert with advanced fighter jets.

"F-35s and F-15EXs have more communication and information sharing capabilities than any earlier aircraft," Sams explains. "The KC-46 has the ability to be an integral part of that sharing network, so it can be used to spot threats and be immediately informed of those threats."

Lastly, maintenance crews will have lighter workload keeping the KC-46s aloft, as compared to older aircraft such as KC-135s. "Modern engines result in longer time between overhauls. Also, because the KC-46 is an FAA (Federal Aviation Administration) certified airplane, it can go through the standard depot system that commercial airliners use."

As much as Sams is impressed by all the things the KC-46 can do, he is adamant that it is not the perfect choice for every user. "Some nations may not have the budget or the need to purchase a fleet of KC-46s or Airbus KC-30s (often called multi-role tanker transports or MRTTs). A better choice to meet their refueling needs might be a somewhat smaller aircraft, perhaps with less capacity or capabilities but costing less, such as an Embraer C-390 transport."

A small airplane equipped with Northstar's aerial refueling system has the ability to match airspeed with other small planes, various UAVs, and helicopters. (Image courtesy of Northstar.)

BIGGER IS NOT ALWAYS BETTER

Taking into account such differences in refueling requirements, some companies are specifically focusing on a second tier of the refueling industry: low-volume, low-speed refueling. In fact, this niche may be the fastest growing segment of the industry.

"Recently, we designed a small pod, which we mounted on a prototype aircraft," says Mike Bandak, president of Northstar, a privately owned aerial refueling manufacturer based out of Rancho Cucamonga, California. The company also provides services, upgrades, and after-market support for the larger systems.

For this project, Northstar, together with Victory Aviation Supplies out of Texas, has used a Thrush aircraft. These are most

It took Northstar just eight months to develop the KC-9, a versatile refueling system for small aircraft. (Image courtesy of Northstar.)

Mike Bandak founded Northstar in 1975. The California company continues to be an innovator within the aerial refueling industry. (Image courtesy of Northstar.)

MEANWHILE IN CANADA

Two of the Royal Canadian Air Force's new CC-330 tankers are already in service, and the full fleet is expected to become operational by 2028. (Image courtesy of the Royal Canadian Air Force.)

The Royal Canadian Air Force's CC-330 Husky fleet will be equipped with capable avionics, flight control, navigation, communication, and mission systems that have specific requirements to enable extreme cold weather operations. (Image courtesy of the Royal Canadian Air Force.)

The Royal Canadian Air Force is in the midst of their Strategic Tanker Transport Capability Project. It involves acquiring nine CC-330 Husky aircraft. Eight will be used as tankers, while the ninth will be designed as a VIP transport. (Image courtesy of the Royal Canadian Air Force.)

The Royal Canadian Air Force (RCAF) has the responsibility of patrolling an enormous swath of territory that is among the most sparsely populated and remote in the world. That reality makes them heavily dependent on their aerial refueling program. They also have some specific technical concerns related to flying in extreme environments.

"Performing the NORAD (North American Aerospace Defense Command) mission in the far reaches of Canada's northern territories requires an aircraft with several unique characteristics," says Kened Sadiku, a spokesperson for the RCAF. "Not only must the aircraft be capable of startup, take-off, and landing in extremely cold temperatures (–31°F/–35°C), but it must be able to safely navigate in the polar regions, communicate over secure networks with other aircraft also operating in those regions, and then effectively perform its core air-to-air refueling tasks."

"Since 1992, the CC-150 Polaris aircraft and its crews have provided outstanding service to Canada. However, the fleet is nearing the end of its life and must be replaced. In addition, both NATO and NORAD have formally requested that Canada increase its air-to-air refueling capability," says Sadiku.

With that in mind, the RCAF has embarked on the Strategic Tanker Transport Capability Project. This effort will see them replace their current fleet of five Airbus CC-150 Polaris aircraft with nine Airbus CC-330 Husky aircraft. Four of these will be built new by Airbus, while the other five will be purchased used from the commercial market. One of the Huskies will be configured as a VIP transport.

"The intent is to retire the Polaris in a phased approach, as the new CC-330 Husky fleet is integrated and becomes fully operational," says Sadiku.

Two of the new tankers are already in service, and the full fleet will be operational by 2028. They will carry 245,000 pounds of fuel, enough to ferry six RCAF McDonnell Douglas CF18 Hornet multi-role fighters across the Atlantic Ocean. The tankers will be equipped with both probes and drogues, plus flying boom refueling equipment, making them capable of refueling any NATO or allied aircraft.

"The CC-330 Husky fleet will be equipped with avionics, flight control, navigation, communication, and mission systems that have specific requirements that will enable cold weather operations, safe navigation, and effective communication in the far north," concludes Sadiku.

▲ The Brazilian Air Force currently uses a KC-130 to refuel their helicopters. (Image courtesy of Northstar.)

commonly employed for aerial spraying, such as crop dusting. But in this case, Northstar is using a military version, a plane they have dubbed KC-9.

"What we have is the first small tanker in the world. Because it can fly at lower speeds, it can be used to refuel small aircraft, helicopters, and UAVs," Bandak explains. In fact, the highly modified Thrush can carry up to 1,000 gallons of fuel, enough to fuel a couple of helicopters.

"Right now, the only option for refueling helicopters is a KC-130," says Bandak. "If you look at buying a KC-130J, the approximate price is $90 million, and they are costly to operate. Our system is a lower cost option." To that he adds, "Because of the aircraft we're using, the parts are available off-the-shelf, making maintenance and support of that aircraft less costly."

Such economies are appealing to organizations that use helicopters for long-range patrols. While the planes might be relatively slow, development of their refueling capability has been fast. A small and nimble company, Northstar was able to develop and flight-test its new system in just eight months.

Northstar's system also may be useful for any organization flying a squadron of drones. "We're looking at finding sensors for navigation and logic control to control the refueling of manned-to-unmanned aircraft, as well as unmanned-to-unmanned, because that is the future," says Bandak.

THE FUTURE HAS NO CREW

Many agree with Bandak that autonomous aircraft are going to play a prominent role in the U.S. Air Force, along with other nations' forces, in the relatively near future. Yet while drone technology is rapidly evolving, methods for refueling them on the fly, as well as using them for that task, has not yet caught up.

"Boeing and Airbus have been developing the capability from both ends: to be able to autonomously

"We're looking at finding sensors for navigation and logic control to control the refueling of manned-to-unmanned aircraft, as well as unmanned-to-unmanned, because that is the future"

REFUELING IN SPACE

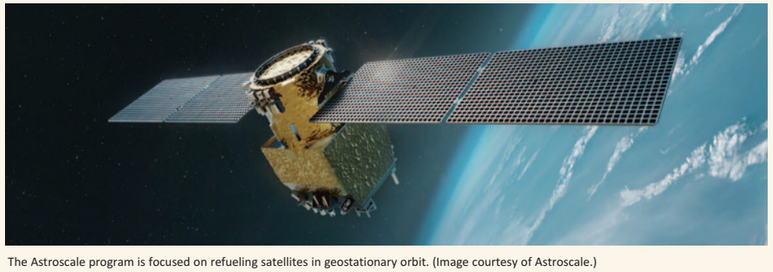
Aerial Refueling is almost exclusively focused on aircraft. But there is an even higher level of military assets that also needs extra fuel to extend their effectiveness: satellites.

Last year, the U.S. Space Force awarded large contracts to two companies developing systems to service satellites. Astroscale, based in Japan, received $25.5 million to develop an on-orbit refueling vehicle. At the same time, the U.S. company Starfish Space was awarded $37.5 million to develop, launch, and operate an on-orbit servicing satellite. These companies also have private investors involved in helping make development of these outer space service vehicles a reality.

Both groups are considering the best approaches to extending the life of satellites in geostationary orbit. That is where the large, school-bus-sized, GPS satellites are flying. These assets are particularly expensive to develop and launch, so finding a way to give them a full tank of fuel, rather than abandoning them to become space debris, with the subsequent need to then send up even more costly replacements, is a priority. Such technologies ultimately are bound to support satellites deployed to serve both commercial and national interests.

Astroscale is developing a satellite refueling system to help keep large, expensive satellites in orbit and operational for much longer, both saving money and reducing new space debris. (Image courtesy of Astroscale.)

Astroscale recently received a $25.5 million contract from the U.S. Space Force to develop an on-orbit refueling vehicle. (Image courtesy of Astroscale.)



The Astroscale program is focused on refueling satellites in geostationary orbit. (Image courtesy of Astroscale.)

The Boeing MQ-25 Stingray aerial refueling drone is designed to operate from U.S. Navy aircraft carriers. Here, it is shown refueling an F-35C. (Image courtesy of Boeing.)

The MQ-25A Stingray autonomous tanker has a 75-foot wingspan in flight but is designed to be stored in a hangar on board aircraft carriers such as the U.S.S. George H. W. Bush. (Image courtesy of Boeing.)

receive fuel and to be able to autonomously transfer fuel with no pilots in either one of the airplanes," says Sams. He describes a notable example of the need for the latter.

"Presently, whenever the U.S. Navy is recovering fighters on a carrier deck, they have to have a tanker airborne, in case one of those returning airplanes can't land on the first or second attempt and needs a quick refueling to add more fuel to keep making additional circuits," says Sams. "Presently, they use an F-18. They put three external fuel tanks on it and use it as a tanker." The problem is that this means one of the Navy's fighters is not available to serve its intended and best use.

Boeing's MQ-25A Stingray is an autonomous tanker that is being procured by the U.S. Navy to solve this very problem. Measuring roughly 50 feet long, with a 75-foot wingspan, the MQ-25 can carry approximately 15,000 pounds of fuel. While it boasts a range of 500 miles, it likely will spend most of its operational life circling above an aircraft carrier.

Captain Daniel Fucito, Program Manager for the U.S. Navy's Unmanned Carrier Aviation Program, states that the MQ-25A Stingray will be their first operational, carrier-based unmanned aircraft. Flight tests have been taking place, deploying from the U.S.S. *George H. W. Bush*. According to Fucito, "These successful test events and improved production line progress are steadily moving us toward first flight and entrance into developmental testing next year."

NOT SO STEALTHY

For fighters and reconnaissance aircraft, the past 25 years have been all about prioritizing stealth, and avoiding detection has been a key priority in the design of any new model. But that characteristic has been curiously absent from tankers, including those currently in development.

"Now, why do you need a stealth tanker?" Sams asks rhetorically. "Well, because many of our fighter airplanes are relatively short-ranged. So, you're going to have to refuel them closer to the battlespace than you did with a B-52 or a B-2."

The issue is that stealth is hard to achieve with a tanker, because regardless of the design, a boom is needed. "And when you put that boom down," Sams observes, "the boom has got to be designed in such a way that it has stealth properties. So far, I don't know that anybody has mastered that. I know from my conversations with the higher ups, the U.S. Air Force has looked at this. But they don't feel they're ready to step forward in the next iteration with a stealth tanker. They're not there yet."

So, while a stealthier approach to refueling might come eventually, for the foreseeable future, flexibility and efficiency are higher and more achievable priorities. Still, the one thing that remains constant amid all of this evolution is that refueling planes before and after they enter strategic air spaces is essential to mission success. And right along with the increasing challenges of today's battlefronts, more solutions are underway.

AAD

THE AVIONICS REVOLUTION

Advanced Materials are Driving the Future of Avionics
By Terry Lloyd

Aviation, by its gravity-defying nature, has always been dynamic. Even as the industry matures, significant innovations in fuels, propulsion (including hybrid and all-electric), and breakthroughs in aerodynamics are on the horizon. But these innovations cannot compare to what is occurring in the avionics segment. While new developments in aircraft design proceed at a relatively slow pace, given the high cost of research and development, advances in avionics technology are exponential by comparison.

Less than a generation ago, avionics could be defined as simply the electrical system of an aircraft, along with a few "steam gauge" instruments and some sensors. Now, areas included in the definition of avionics are extensive, encompassing air and fuel flow control; aircraft band, tactical, and other audio communications; antennas and couplers; auxiliary power units and battery chargers; emergency location transmitters and associated systems; flight controls; global positioning systems (GPS); inside and outside lighting; instruments and clocks; internal environmental control; inverters and converters; and transponders, altitude encoders, and serializers.

Add on layers for cyber security and encrypted communications for automation and command and control, and with rapid advances of artificial intelligence (AI) ever-present in the background, along with myriad challenges posed by the Internet, the complexity of the industry can be staggering. Yet one common "thread" throughout these numerous components is connectivity, which usually means cables and connectors.

While new developments in aircraft design proceed at a relatively slow pace, given the high cost of research and development, advances in avionics technology are exponential by comparison.

In this article, we will look at some developments in avionics components and infrastructure made possible by new materials and processes, focusing on advances in connectivity (cabling, fiber optics, and connectors). We also will share insider looks from avionics repair and technician training viewpoints. And we will discuss applicable trends in future materials and manufacturing processes in defense aircraft and spacecraft.

Mach 20, anyone? This illustration depicts the U.S. Defense Advanced Research Products Agency's (DARPA) Falcon Hypersonic Test Vehicle as it emerges from its rocket nose cone and prepares to re-enter the Earth's atmosphere. DARPA conducted two test flights of the vehicle; in the second, the Falcon HTV reached a speed of Mach 20 before losing control. The high temperatures and intense G-forces encountered at Mach 20 are a severe test for avionics connectivity components, including cabling and connectors. (Image courtesy of DARPA.)

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LATEST TRENDS IN ADVANCED MATERIALS AFFECTING AVIONICS

U.S. Air Force avionics technicians perform a phase inspection on an F-15 Eagle. Given the increasing tactical necessity to disperse forces in future conflicts, especially in the Indo-Pacific theater, reliability, durability, and ease of maintenance of fighter aircraft systems will be critical to ensure air assets are mission capable. (U.S. Air National Guard photo by Senior Airman Randy Burlingame.)

Emerging advances in materials for avionics components and conductivity (cable, wire, fiber optics, and connectors) include using new lighter materials, such as carbon fiber composites. The mix of the constituent materials making up such composites can be designed to meet the specific application, including a very high strength-to-weight ratio, reducing system size.

Aluminum-lithium alloys can provide excellent corrosion resistance and high strength. This makes them good choices for sensitive components that must withstand extreme conditions, such as high temperatures, again without adding much weight.

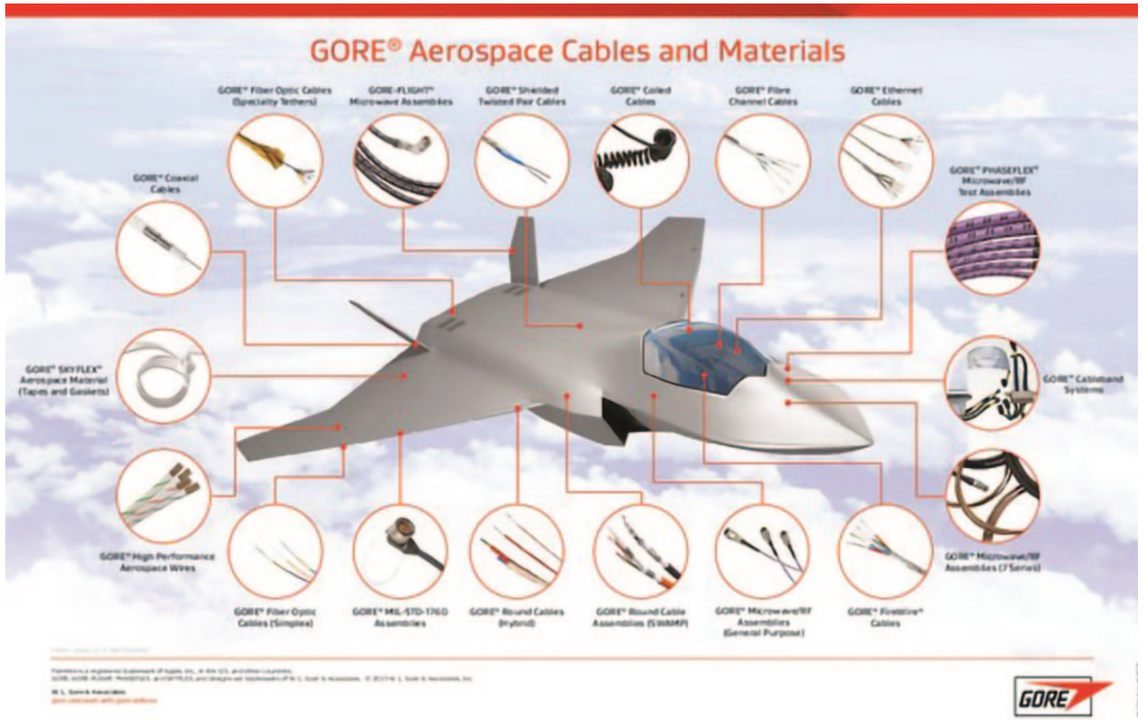
Smart materials, or shape memory alloys (SMA), can revert to a predetermined shape when exposed to specific stimuli like heat. In avionics, such properties can benefit actuators and sensors requiring minimal size and complexity.

Piezoelectric materials generate electrical energy when mechanically stressed, offering potential applications in self-powered sensors or actuators, where they can reduce power consumption by providing localized energy generation. Uses include vibration monitoring systems and condition monitoring of aircraft structures.

Nanotechnology includes the use of graphene, known for its exceptional electrical, thermal, and mechanical properties. These properties enable ultra-lightweight and strong parts, efficient thermal management, and improved electrical conductivity. Uses include batteries, next-generation sensors, and conductive coatings. Other nanomaterials are being integrated into nanocomposites to improve strength, reduce weight, and add thermal or electrical properties.

Other materials on the rise that will impact how aircraft and spacecraft, and particularly avionics systems, can be designed and built include:

- **Advanced ceramic materials** are suited for extreme, high-temperature applications, supporting more durable components.
- **Electrochromic materials** can change optical properties in response to electrical stimuli, a useful feature in avionics displays and adaptive optics.
- **Metamaterials** are engineered with properties not found in nature, and may enable more efficient antennas, radar systems, and advanced stealth technologies.
- **Self-healing materials** can repair themselves when damaged, improving reliability and reducing downtimes and maintenance costs.



▲ This shows a typical aircraft avionics systems using W.L. Gore & Associates's aerospace cables and materials. The industry leader is constantly exploring the use of innovative materials and methods for integration into its lineup of next generation products. (Image courtesy of W.L. Gore & Associates.)

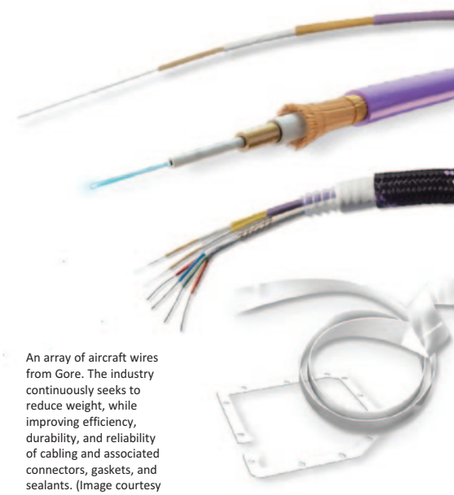
THE NEED TO BE BETTER, LIGHTER, AND MORE SUSTAINABLE

Advancements in avionics and connectivity, as with other aircraft improvements, tend to be focused on making lighter, more efficient, and more sustainable systems. Material developments include advances in metals, composites, materials with piezoelectric properties, and innovative alternatives.

A master at turning research and development into practical applications, W.L. Gore & Associates is probably best known for the development of Gore-Tex, a breathable, waterproof fabric that revolutionized outerwear, military, and firefighter clothing and accessories. While still a leader in these areas, the company also offers a dazzling array of products across industry categories, including advanced products integral to aerospace and aviation cabling and connectivity. Defense and civil aircraft and advanced air mobility are served by their aerospace lines of cabling products. And integrating advanced materials and processes into their products is top of mind for this forward-thinking company's world-class team.

"Advanced composite materials, new aluminum alloys, carbon nanotubes, next-generation insulation materials, and high-temperature semiconductors will be incorporated into future aircraft concepts and demonstrations. Gore is actively exploring and supporting broader use of these lighter-weight materials into its portfolio of aircraft sealants and wire," comments Brian Tallman, Global Aerospace & Defense Market Leader at the company.

One example of the company's



An array of aircraft wires from Gore. The industry continuously seeks to reduce weight, while improving efficiency, durability, and reliability of cabling and associated connectors, gaskets, and sealants. (Image courtesy of W.L. Gore & Associates.)

STINGRAY, GHOST BAT, VALKYRIE, FURY, AND BLACKFLY

The Boeing MQ-28 Ghost Bat Collaborative Combat Aircraft and the Boeing MQ-25 Stingray aerial refueling drone are two examples of the increasing reliance on autonomous aircraft to achieve air superiority in future contested airspace and augment piloted missions. The design requirements of such unmanned aircraft put to the test today's state-of-the-art avionics. (Image courtesy of Boeing.)

While this might sound like the lineup for a new comic book–based summer blockbuster movie, it is a roster of something more powerful, and maybe even "cooler."

As a result of recent battlefield lessons learned in past conflicts and looking forward to anticipated operations Indo-Pacific theater, the U.S. Defense Advanced Research Project Agency (DARPA) and other U.S. Department of Defense agencies are looking to unmanned aerial vehicles (UAVs) being developed for Advanced Air Mobility (AAM), as well as adding high-end automation to existing aircraft used for missions in contested areas. The reliance of these systems on advanced avionics is pushing the industry to develop and refine the components of avionics systems, especially cabling and wiring, for weight reduction, efficiency, and durability.

Among UAVs serving U.S. defense aviation is the Boeing MQ-25 Stingray aerial refueling drone capable of operating off aircraft carriers. The MQ-28 Ghost Bat is another Boeing program; already adopted by the Australian Air Force as a Loyal Wingman class stealth, multirole, unmanned combat aerial vehicle, it is being evaluated for U.S. Air Force use. Also under evaluation by the U.S. Air Force, as well as the U.S. Navy and U.S. Maritime patrol, is the Kratos XQ-58 Valkyrie.

Anduril's Fury and a design by legacy drone manufacturer General Atomics were selected by the U.S. Air Force in April 2024 as finalists for the autonomous fighter platform being explored under the Collaborative Combat Aircraft (CCA) program. At the same time, the U.S. Air Force Research Laboratory is evaluating Pivotal's BlackFly, an electric-powered vertical take-off and landing (VTOL) personal air vehicle that can fly in an autonomous mode and search for those in need of rescue,

Pivotal's BlackFly electric vertical take-off and landing, or eVTOL, aircraft, along with other electric aircraft, is shown being evaluated during Exercise AGILE FLAG 24-3, held in California in August. Tests were conducted in an unmanned configuration to better assess aircraft potential capabilities, including complex remote and autonomous systems controls. (Image courtesy of the U.S. Department of Defense.)

recovery, or medical evacuation. And the U.S. Marines and FedEx are involved in the development of Elroy Air's Chaparral, a runway-independent cargo drone capable of autonomously moving "a few hundred pounds across a few hundred miles" to meet battlefield logistics needs for supplies and equipment parts in remote locations.

"Meeting C2 (command and control) requirements are key for remotely piloted operations in terms signal availability, latency, etc.,"

A U.S. Marine Corps TRV-150 Tactical Resupply Unmanned Aircraft System aircraft prepares to release a payload during a tactical resupply demonstration near Yuma, Arizona, in 2023. The program places emphasis on operators' ability to change and charge batteries and conduct most maintenance in the field. (U.S. Marine Corps photo by Lance Corporal Ruben Padilla.)

Reliable Robotics, a U.S. Air Force Autonomy Prime partner under DARPA, takes off from Mojave Air and Space Port, California, in its autonomous Cessna 208B Grand Caravan, to deliver cargo to Travis Air Force Base, California, during Exercise AGILE FLAG 24-3 in August. (U.S. Air Force photo by Matthew Clouse.)

according to Clint Harper, a recognized Advanced Air Mobility Infrastructure & Community Integration advocate and consultant, who also served a career in the U.S. Air Force.

In addition to fully autonomous, uncrewed aircraft, DARPA is developing a "tailorable, drop-in, removable kit that would promote the addition of high levels of automation into existing aircraft, enabling operation with reduced onboard crew." Called the Aircrew Labor In-Cockpit Automation System (ALIAS) program, such programs address cargo, tanker, and bomber aircrew fatigue and in-flight emergencies—a significant concern going back to the Persian Gulf War in the 1990s, now of increasing concern with the distances characteristic of the Indo-Pacific theater. The system will incorporate advances in flight automation combined with proven remotely piloting technology, including capabilities for auto takeoffs and landings. Additional features will be developed for special operations.

advances in this segment, Gore's GWN3000 Series High Performance Aerospace Wires, received the 2021 Military & Aerospace Electronics Technology Innovators Award. These wires are optimized for electrification, ensuring reliability, safety, and reduced lifecycle costs in current and next generation aircraft. It is not necessary for an aircraft that operates in extreme environments, such as at high altitudes and/or high speeds, to suffer from wear and reliability issues. Reportedly, up to 70 percent of rotorcraft exhibit significant wire damage in some applications. The GWN3000 wires are designed to prevent such degradation.

According to Tallman, fiber optics is playing an ever-increasing role across the aerospace industry, due to its lighter weight and greater efficiency in data transmission as compared to traditional copper wire. Notably, increased electrification in aircraft comes with a need for higher voltages in systems. "This shift requires increased robustness of insulation systems that can handle higher voltages, while meeting higher environmental requirements (such as altitude and temperature)," says Tallman. Not surprisingly, Gore has been addressing these new requirements as well. In 2020, its fiber optic cables received a platinum award. This follows its ethernet cables receiving gold honors in 2017.

NEW TECHNOLOGIES AND RISING COSTS SPUR INDUSTRY COLLABORATION

Other companies and research centers also are collaborating to address the challenges of standardization, at least within the European Union, of high-voltage systems for electric aircraft propulsion. As part of the European Union's Clean Aviation HECATE project, Collins Aerospace has achieved Preliminary Design Review (PDR) for new high-voltage distribution technologies to be used in future hybrid-electric aircraft. The announcement was made in July at the

"FLY BY LIGHT"

A Japan Maritime Self-Defense Force P-1 patrol aircraft takes off from U.S. Marine Corps Air Station Kaneohe Bay, Hawaii, during Exercise Rim of the Pacific (RIMPAC) 2024. The Kawasaki P-1 is the currently the only production military aircraft that uses a fiber optic "fly-by-light" flight control system. (Japan Maritime Self-Defense Force photo by Petty Officer 2nd Class Atsushi Mashima.)

Aircraft have evolved from using steel cables to translate pilot input to flight controls to fly-by-wire technology incorporated in the 1970s. Now, advanced fiber optic cabling is a candidate to replace fly-by-wire, in an application called "fly by light" (FBL).

The advantages of fly-by-light (FBL) include higher bandwidths to transmit more data at higher speeds, and immunity to electromagnetic interference, an important capability in military aircraft. Plus replacing bulkier metal wiring achieves a notable weight reduction.

So far, the Kawasaki P-1, a four-engine jet maritime patrol aircraft in use by the Japanese military, is currently the only production military aircraft known to use an FBL flight control system. The People's Liberation Army Air Force of China is reportedly looking at FBL technology in the development of its Gen 6 fighter aircraft prototypes.

United Kingdon's 2024 Farnborough Air Show.

By providing a framework of standardized reviews, PDRs promote the development of interoperable systems, allowing different components and technologies to work seamlessly together. The standardized PDR process ensures that operational and safety considerations are thoroughly evaluated early in the design phase, identifying and addressing potential design flaws before they become critical issues. The end result is more dependable, safer, high-voltage distribution systems.

Other companies in the HECATE project include Airbus Defense and Space and Leonardo. Collins Aerospace, through its Applied Research & Technology organization and Power & Controls business, is on the HECATE steering committee.

Collins is also recognized as a leader in developing lightweight thermoplastics materials, currently being incorporated into aircraft structural components, such as engine nacelles. Their high durability, flexibility, insulating properties, and resistance to harsh conditions and high temperatures, also make these materials ideal for protecting sensitive electronic components, sheathing and insulating cables, and enhancing printed circuit boards (PCBs) and connectors in avionics systems.

Other companies also are making moves to provide even more robust and environmentally resistant cabling and connectors to support the increasingly extensive and interconnected systems vital to today's state-of-the-art aircraft. In May 2024, Amphenol Corporation — one of the world's largest designers and manufacturers of electrical, electronic, and fiber optic connectors and interconnect systems; antennas, sensors, and sensor-based products; and coaxial and high-speed specialty cabling — announced it had completed acquisition of the Carlisle Interconnect Technologies (CIT) business from Carlisle Companies.

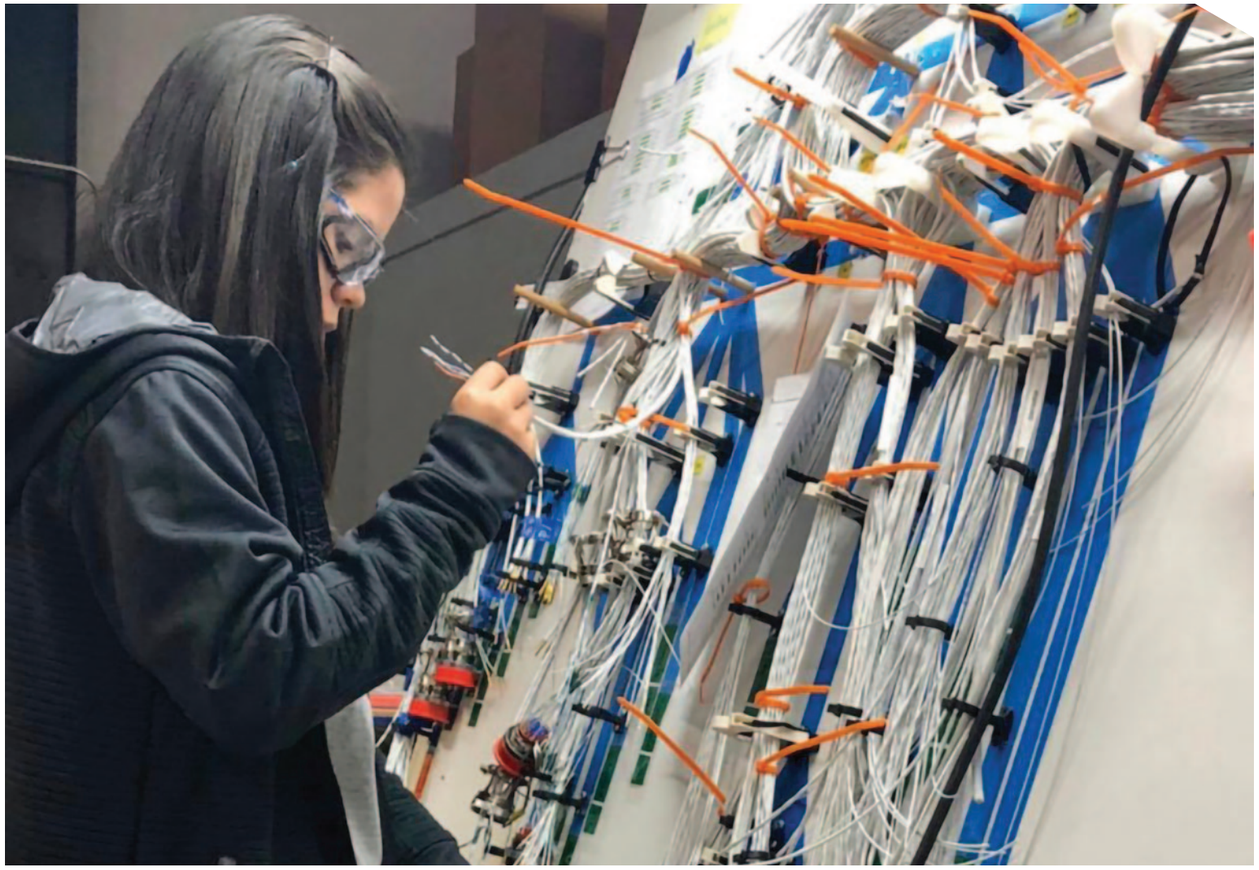
"The acquisition of CIT enhances Amphenol's product offerings for highly engineered harsh environment interconnect solutions and will enable us to deliver a more comprehensive technology offering for our customers in the commercial air, defense, and industrial markets," states Amphenol president and chief executive officer, R. Adam Norwitt.

The company's LITEflight fiber optic cable is designed for aerospace, military, industrial, and other heavy-use applications. Particularly advantageous for aircraft, such fiber optic cable typically weighs in at only about 15 pounds per mile of cable, even with its outer protection, making it much lighter than copper wire cables. In June 2024, Amphenol/CIT's facility in Nogales, Mexico, earned accreditation for electronics, specifically cable and harness assemblies, from the National Aerospace and Defense Contractors Accreditation Program.

IMPLICATIONS OF ADVANCED MATERIALS FOR MAINTAINERS

Given the rapidly changing scope of components and materials in avionics cabling and connectors, and the continuing deep deficit in skilled employees across the aviation industry, training technicians to perform field and backstop maintenance can be a daunting challenge. In addition, training must be conducted in accordance with federal regulations, and in avionics, comply with Federal Communications Commission and industry standards. If these regulations do not keep pace with emerging materials and manufacturing technology, that causes a quandary for trainers, who are "pulled" by the industry to provide comprehensively trained technicians.

The cost of acquiring new tools, some for specific systems, is also a consideration. At the same time, use of artificial intelligence (AI) to guide



U.S. Air Force avionics technicians perform a phase inspection on an F-15 Eagle. Given the increasing tactical necessity to disperse forces in future conflicts, especially in the Indo-Pacific theater, reliability, durability, and ease of maintenance of fighter aircraft systems will be critical to ensure air assets are mission capable. (U.S. Air National Guard photo by Senior Airman Randy Burlingame.)

training and advanced 3D modeling, such as the use of a digital twin of a component or system, can help enhance the efficiency of training programs and reduce operating costs.

Ashley Mercado, vice president and chief operating officer of Avionica USA, notes, "I rely on the guidance provided by the manufacturers and the standards issued by the FAA (Federal Aviation Administration) to ensure we are providing quality repairs and installations to our Repair Center customers. That experience then informs our constant review and revision to our technician training curriculum. It is a real challenge to stay ahead of all the changes, and being an instructor as well helps me to implement changes as they are needed."

Avionica USA has avionics technician training schools, FAA-certified avionics repair stations, and marine electronics installation and repair locations throughout Florida and Puerto Rico. In Florida, Avionica USA's programs are certified for continuing education credit by the University of Central Florida (UCF). Located in Orlando, UCF partners with Lockheed Martin, Siemens, and NASA to offer some of the top aerospace degree programs in the country.

ACCELERATING ADVANCEMENTS

The pace of advances in avionics is likely to accelerate as new materials and technologies mature and become more cost-effective, even with inherent challenges to implementation. With so many areas, such as nanomaterials and nanocomposites, demonstrating the potential to dramatically improve performance, reduce weight, enhance safety, and increase the efficiency of modern avionics systems, the possibilities seem endless.

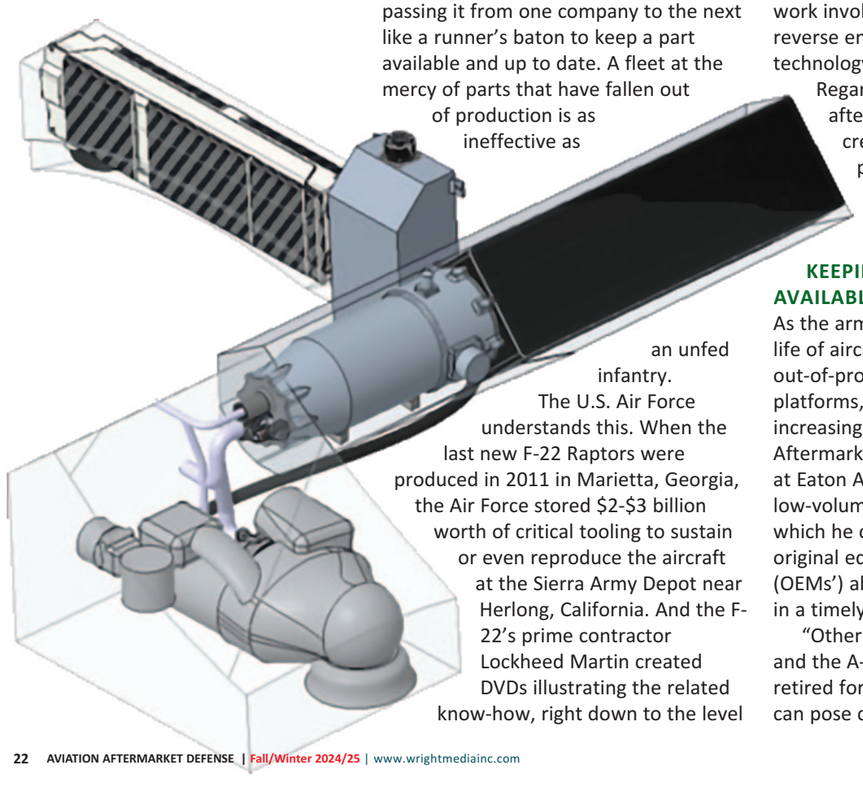
AAD

FLYING ON IP

Aftermarket Companies are Acquiring Intellectual Property (IP) to Make the Old New, and Better, Again

By Paul McDonnold

Long ago, Napoleon Bonaparte said that an army marches on its stomach. What is equally true is that today's military aircraft fly on a sophisticated web of mechanical and electronic components, from airframes to radar and weapons systems. And with so many older platforms still in service, it is critical to preserve the intellectual property (IP) necessary to sustain and upgrade their performance, if needed passing it from one company to the next like a runner's baton to keep a part available and up to date. A fleet at the mercy of parts that have fallen out of production is as ineffective as an unfed infantry.



Eaton Aerospace's innovative battery-powered solution, the Electric Primary Recovery System (ePRS), offers a safer and more efficient way to replace hydrazine on the F-16. (Image courtesy of Michelle Lutrick, Eaton Aerospace Group.)

The U.S. Air Force understands this. When the last new F-22 Raptors were produced in 2011 in Marietta, Georgia, the Air Force stored $2-$3 billion worth of critical tooling to sustain or even reproduce the aircraft at the Sierra Army Depot near Herlong, California. And the F-22's prime contractor Lockheed Martin created DVDs illustrating the related know-how, right down to the level of how to correctly hold a tool.

Not all platforms are so well provided for. But that creates opportunities in the aftermarket for firms seeking to acquire and utilize the IP necessary to manufacture parts that go out of production. That information and the rights to use it may take the form of patents, copyrights, or shared trade secrets. Or, in some cases, legacy parts re-creation simply comes down to the work involved in good old-fashioned reverse engineering, though today's technology can streamline that process.

Regardless, many aviation aftermarket companies are finding creative and profitable ways to produce the parts needed by those who work to keep old birds flying.

KEEPING "STRANGER" PARTS AVAILABLE

As the armed forces extend the service life of aircraft, the challenge of supplying out-of-production parts for aging platforms, such as the B-52, is becoming increasingly urgent. Lane Taber, Aftermarket Product Strategy Manager at Eaton Aerospace Group, says that a low-volume demand for those parts, which he calls "strangers," affects the original equipment manufacturers' (OEMs') ability to support legacy aircraft in a timely and efficient manner.

"Other aging platforms, like the C-5 and the A-10, have been at risk of being retired for a long time," Taber says. "This can pose challenges for the suppliers to be able to quickly ramp-up production on these platforms, as the supply base has likely changed, and tooling/equipment may need to be revitalized since [parts were] last manufactured."

In some cases, it is simply a matter of sustainment. In others, the focus shifts to evaluating alternatives to mitigate obsolescence. For example, Taber adds, Eaton's team not only replaces old parts, they also scrutinize the repairs, overhauls, and reasons for replacing those parts in order to identify ways to improve them. This includes analyzing wear and other failure conditions of the units received, and then discovering design changes that hopefully will help extend the service life of the unit at the component level.

In addition, Taber points out that low, inconsistent, and non-forecasted volumes can make it difficult for OEMs to generate solutions to obsolescence within the timelines customers require. Eaton's strategy for dealing with this challenge can take many forms: evaluating different sourcing options (buying versus making the parts), partnering with existing or new suppliers (including smaller firms that may work to produce parts in a quicker timeframe), or leveraging alternate business models. All viable paths are considered and explored when it comes to solving the complex challenge of ensuring the continued delivery of high-quality, yet affordable parts that their customers, particularly the U.S. defense forces, need to keep aircraft flight-ready.

UPGRADING LEGACY PART PERFORMANCE

As in so many fields, advanced technology offers the potential of not only maintaining but also improving operational performance in ways that would have been hard to imagine in the past. Taber mentions that when the F-16 was being designed in the 1960s, the only way to create a monopropellant to drive an emergency system was with the use of a material called hydrazine, which is both difficult to obtain and highly toxic, requiring maintainers to wear full hazmat gear when servicing the system. Advances have enabled Eaton to replace the hydrazine with a battery-driven system that is quicker, safer, and less costly to service.

Advances in 3D printing are also changing the product landscape in helpful ways. Kyle Spieles, Eaton Aerospace's Senior Engineering Manager for additive manufacturing, says that maintainers of some legacy platforms, such as the F-15 and B-52, have faced challenges in getting parts due to the closing of U.S. foundries. Rather than re-starting the casting process or making new tooling to meet an order from the U.S. Air Force, directly printing parts can be a potential solution.

Spieles does point out that one difficulty faced when using additive manufacturing as the new production process is that it generally means using not only a different manufacturing process but also a different material than the original part. This requires a new drawing, new identifier, and new validation at the assembly level, which can become a protracted procedure.

▲ Lane Taber, aftermarket product strategy manager at Eaton Aerospace Group. (Image courtesy of Michelle Lutrick, Eaton Aerospace Group.)

In some cases, it is simply a matter of sustainment. In others, the focus shifts to evaluating alternatives to mitigate obsolescence.

To face such obstacles, Eaton is working with government, academic, and industry partners to make the process more efficient, which Spieles says would help with sustainment of not only military but commercial fleets around the world. In the meantime, the further development of additive manufacturing and the leveraging of artificial intelligence is increasingly likely to help 3D printers create parts that are better than they have ever been.

▲ Kyle Spieles is Eaton Aerospace's senior engineering manager for additive manufacturing. (Image courtesy of Michelle Lutrick, Eaton Aerospace Group.)

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This C-130J cooling turbine is being set up for a test at AeroKool. (Image courtesy of Jon Silva, AeroKool Aviation.)

CHALLENGES FOR SMALL-TO-MIDSIZE FIRMS

In Hialeah, Florida, maintenance, repair, and overhaul (MRO) provider and manufacturer AeroKool Aviation approaches IP as a midsize firm that has taken on recreating parts that large OEMs have walked away from.

AeroKool's president, Jon Silva, has an atypical, and possibly even unique, background for someone in his position. After finishing a Ph.D. in history, he taught at Ohio State University, before deciding to take a job with Grimes Aerospace, which at the time was owned by Allied Signal (now Honeywell). Success in that role eventually led to his position at AeroKool. Today, Silva remains a member of the American Historical Association and says he continues to use his education every day.

"Historians tend to ask different kinds of questions than other people," he notes. "We want to know what makes things tick. What made Ancient Rome work? What makes America work? What makes a market work?" To answer such questions, the historian follows an evidence-based approach. And based on what Silva has seen, he concludes that the challenges involved in keeping an aging fleet of military aircraft flying are on the rise.

"The military airplanes that catch everyone's attention are the new ones," he says. "But the backbone of the U.S. Air Force is relatively old: 707s, KC-135s, E-8s, E-3s, C-130s, T-38s, F-16s. The Air Force has to maintain them, and that has become problematic."

In stepping up to fill the need, small-to-midsize firms are particularly challenged by some obstacles that may not be as detrimental to large OEMs, which can better absorb upfront costs for projects that do not pan out. For instance, preliminary investments in IP can go for naught if the requisite approvals are ultimately not coordinated and procured.

As an example, Silva mentions a part used in environmental control systems in both U.S. Air Force F-16s and U.S. Navy F-18s. When AeroKool proposed to reverse engineer this part, the Air Force accepted their plan, but the Navy did not. This meant neither branch could buy it.

Such arcane interagency protocols are a fact of life in dealing with the U.S. Department of Defense. Compared to the parts manufacturer approval (PMA) process on the commercial side, Silva says the defense aftermarket requires more coordination between different decisionmakers on the demand side of the market equation, coordination that can be difficult to arrange, especially for smaller firms.

"With the military, you really have to get their buy-in before you can even start to reverse engineer or develop something for them," Silva explains. "So, the first part of the problem is getting the U.S. Air Force, and I mean all parts of the Air Force—contracting, engineering, operations—on the same page. Everybody has to agree."

Nonetheless, he is hopeful that the U.S. Department of Defense will more effectively address such issues—which he says have developed because of a decades-long, "OEM-centric" focus on working with prime contractors—to streamline the approval process going forward. In the meantime, he says smaller aftermarket manufacturers must be "diligent and a little relentless" in working with the Department of

An AeroKool technician balancing the shaft of an air cycle machine (ACM). (Image courtesy of Jon Silva, AeroKool Aviation.)

Defense to acquire the approvals needed to pick up where the OEMs have left off.

When AeroKool does get the go-ahead on a particular part, in many cases, they can create their own IP essentially from scratch. Using as an example a small turbine wheel that fits in the air cycle machine of 737s, for which Honeywell is the OEM, Silva says his firm first buys several copies of the part.

For both commercial and military components, "We're going to take hundreds of measurements across all the critical dimensions. We're going to cut one of them up and get lab samples, so we know the material's properties and chemistry." From there, AeroKool can produce drawings and manufacture a part for inspection and testing. Once AeroKool is satisfied with the testing, all that data is put into a Source Approval Request (SAR) package to be sent to the cognizant engineer for military applications.

For a commercial application, the data is used to create a PMA package which goes to the FAA's Aircraft Certification Office (ACO). Once the ACO approves, the application is sent to the Manufacturing Inspection District Office (MIDO), which then comes on site to audit the manufacturing process.

Either way, the resulting part is identical to the original but features an AeroKool part number. In the commercial arena, this end-state is referred to as having Parts Manufacturing Authority. For approved military applications, the U.S. Department of Defense grants its own version of this authority, which is known as Source Approval.

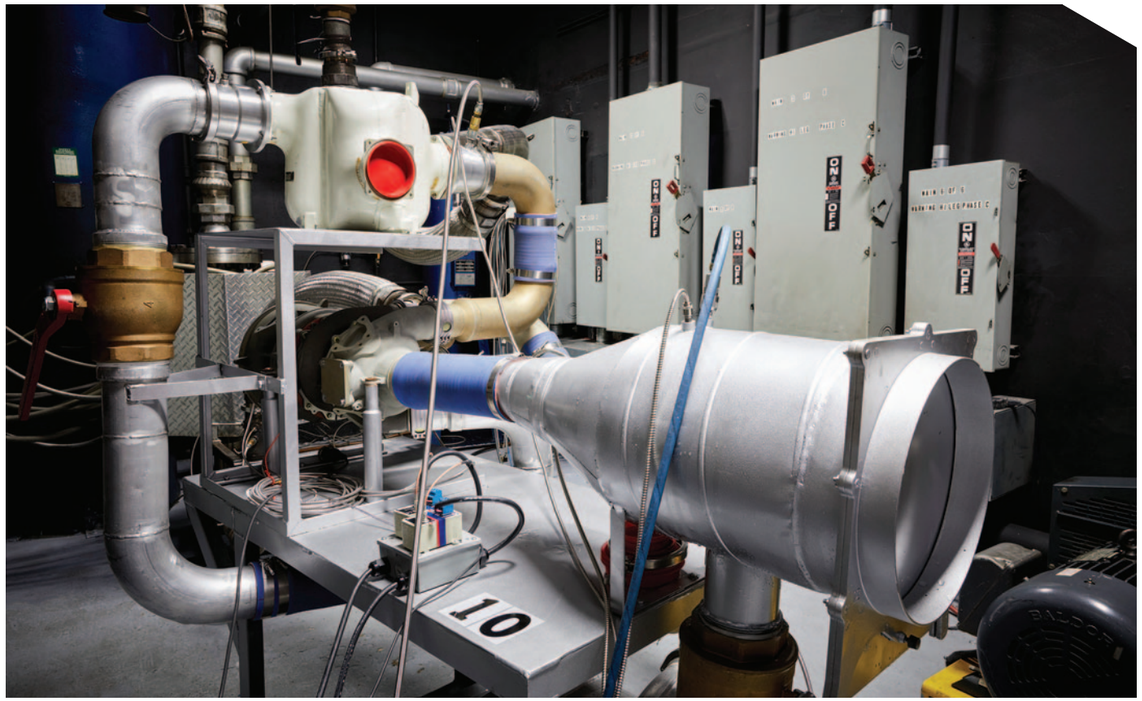
This all becomes more complex when incorporating a modification or upgrade to the part. Silva's guiding principle in these cases is similar to a physician taking the Hippocratic Oath to "do no harm." This means that incremental improvements in a part are not worth sacrificing past functionality. Therefore, to ensure that no functionality is compromised by making an upgrade, a revised part will go through even more rigorous testing and hurdles than a part aiming for straight identicality. This all translates into even costlier IP.

In some cases, Silva has found that advances in additive manufacturing are making it easier to create identical but better parts. He specifically mentions a part for the Airbus A-320, which previously required different components to be manufactured separately before being assembled. Thanks to the complex structures possible in 3D printing, it now can be printed as a single unit with all of the necessary internal features, both streamlining manufacturing and improving the accuracy of the resulting part.

THE NONPROFIT APPROACH

If any organization understands IP, it is SRI International, which began in 1946 as the Stanford Research Institute. Independent from Stanford University since 1970, SRI is a nonprofit organization, specializing in research and development in support of both government and industry. Headquartered in Menlo Park, California, it has played a role in the evolution of technology from the computer mouse to Apple's voice assistant Siri.

With offices and labs across the



A commercial air cycle machine (ACM) undergoing testing at AeroKool. (Image courtesy of Jon Silva, AeroKool Aviation.)

United States and one in Tokyo, SRI's staff of 1,500 works on what the organization calls "some of the world's hardest problems." Its Princeton, New Jersey, location—which played a pivotal role in the development of television as the onetime research facility for the Radio Corporation of America (RCA)—is where SRI helps the U.S. Department of Defense deal with obsolescence in microchips found in weapons systems on platforms such as the F-16. SRI's approach is not to reproduce these components per se, but to "emulate" them, as the performing contractor of the U.S. Defense Logistics Agency's (DLA) Generalized Emulation of Microcircuits (GEM) program.

"If you look at military systems, we're using them over a much longer time period and, in the case of aircraft, flying over a much greater number of years," says Saj Ishaq, vice president of SRI's Microcircuit Emulation Center. "So typical lifetimes are going up, and one of the prime failures is the electronics."

These long service lives mean that some chips used in aircraft inevitably fall out of production, whether due to declining demand from the commercial sector or outsourcing to foreign manufacturers. Ishaq points out that since the commercial sector comprises the vast majority of demand for microchips, defense force needs can become secondary concerns to commercial manufacturers focused on the profitability that comes with high-volume production.

Such chips may be over 30 years old and may have involved the work of several different OEMs. Rather than copying their IP, Ishaq says SRI emulates the part, by first understanding the chip's original function and electrical parameters. This necessitates acquiring as much technical data as possible related to the chip's electronic behavior under typical and atypical conditions, including different temperatures and other varying final use conditions. The end result is a high-reliability, military-grade form, fit, and function chip that is supplied to the exact same specifications as the original device and is interface-interchangeable. No parts list, maintenance, repair, or documentation changes are required.

"We don't copy anybody's design or infringe on anybody's IP, because we're basically making a part that will meet the final procurement specification. The DLA GEM program delivers a chip that has the same physical dimensions and the same electrical properties. The new part is a direct, drop-in replacement, and not a copy of the original part."

It is one thing to do the intellectual work to emulate obsolete chips, but another to manufacture them. Ishaq says one of the major challenges facing SRI and the United States overall is a lack of a strong domestic manufacturing ecosystem. "Today, there are not a lot of facilities that will build chips or microcircuits in the United States for military applications."

Saj Ishaq is vice president of SRI's Microcircuit Emulation Center. (Image courtesy of Saj Ishaq, SRI International.)

Microchip manufacturing is performed in SRI's cleanrooms in Princeton, New Jersey. (Image courtesy of Saj Ishaq, SRI International.)

"The reason we exist is to provide a continuous and permanent manufacturing source," he explains. "All GEM chips are marked with the SRI CAGE code and are sourced through the DLA GEM Program Office or directly from SRI International only. Using the DLA GEM program avoids purchasing obsolete microcircuits on the gray market and eliminates the threat of counterfeit chips in military systems. Obviously, we don't want China and Chinese companies controlling this market, so we are all about U.S. manufacturing. That allows us to maintain security, which is really critical in today's world."

Additive manufacturing is starting to offer some help in this cause. A microchip in the GEM world is typically built on silicon, but with a ceramic "package" around it. Ishaq says that SRI has been working with Rutgers University to develop the capability to print ceramic packages, and hopes to bring this capability in-house in the near future. In the meantime, he says the actual microcircuits are still too tiny for current additive manufacturing capabilities to handle.

Beyond that, Ishaq says the U.S. Defense Production Act, which has in the past provided some advantages to domestic procurement for military purposes, is not assisting sufficiently with procuring needed materials such as silicon and special gases. This is despite the fact that SRI is creating microcircuits going into critical defense platforms, such as the F-15.

"We literally have to compete with the largest chip manufacturers for procurement. And that makes it difficult for somebody like us to get critical materials." He concludes, "This is where we need more support from the U.S. government that will enable us to be at the front of the line, so we can maintain U.S. military weapons systems and readiness."

GOOD ADVICE FOR ASPIRING SUPPLIERS

Looking ahead, changes to the U.S. Defense Production Act to facilitate procurement would help the aftermarket effectively supply, modify, and upgrade the legacy parts necessary to keep our military in the air. Changes in the U.S. Department of Defense's approval process would also make it easier for small-to-midsize firms to work with them. And ongoing advances in applicable technologies, such as 3D printing, are expected to further advance this important industry segment.

For now, aftermarket suppliers will continue to find ways to acquire the IP necessary to make legacy parts available when needed, as well as to upgrade those parts when feasible. For firms wanting to be involved in this critical activity, the best advice for acquiring and using IP is probably, as AeroKool's Silva says, to be "diligent and a little relentless," just like the warfighters themselves.

AAD

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An F-22 Raptor performs a flyover and air demonstration during noon meal formation at the U.S. Air Force Academy in Colorado Springs, Colo., April 12, 2023. Events such as these aim to cultivate warrior ethos, a future-focused mindset and supplement existing character, leadership and officer development efforts with the cadets. (U.S Air Force Photo by Trevor Cokley.)

U.S. Air Force F-22 Raptors assigned to the 27th Expeditionary Fighter Squadron, conduct Dynamic Force Employment operations at I Gusti Ngurah Rai Air Force Base, Indonesia, in August 2024. (U.S. Air Force photo by Senior Airman Mitchell Corley.)

THE STEALTHY RAPTOR

The F-22 Continues to Improve Despite Threats to Retire the U.S. Air Force Fleet
By Donna Kelly

The Lockheed Martin F-22 Raptor is considered to be one of the finest stealth fighter aircraft in the world. It is an amazing weapons platform that gets the job done, in most cases without even revealing itself to the enemy. Much has been learned from its 25 years of operation, especially in the areas of stealth, advances in design, materials, and applications, and various maintenance techniques and time savers.

Additionally, invaluable lessons have been learned from its pilots about how best to use a highly valuable stealth asset. While relatively few F-22 aircraft were built, it is a credit to U.S. Air Force airmen that they continue to use them so successfully, serving in so many ways.

While this legacy fighter is approaching its end of service life, landmark attributes and vital upgrades keep it flying. At this juncture, it is worth reviewing what is working for and happening with the Raptor, as well as taking a look at what is ahead for this capable fighter.

STEALTHY SKINS

When it first took flight in September 1997, the Raptor was covered in the newest types of stealth coatings for that time. While a marvel of invisibility, the innovative coatings were still largely untested under the harsh and widely varying conditions in which the F-22 would operate. Accordingly, based on the real-world data gathered through numerous mission flight hours, stealth coatings have continued to evolve, with Raptors benefiting from multiple upgrades.

Stealth coatings are referred to as radar absorbing materials (RAM). Extremely delicate, these materials have many natural enemies, including mechanical stress, excessive heat, freezing temperatures, and prolonged exposure to sunlight, moisture, salt, and dust. All can cause cracking, peeling,

U.S. Air Force Colonel Brandon Tellez, 1st Operations Group Commander, inspects the 71st Fighter Squadron guide-on during the unit's reactivation at Joint Base Langley-Eustis, Virginia, in 2023. (U.S. Air Force photo by Airman 1st Class Olivia Bithell.)

Captain Samuel Larson, F-22 Raptor Demonstration Team Commander, cruises at high airspeeds during the Air Power over Hampton Roads Air Show at Joint Base Langley-Eustis, Virginia, in 2023. The Raptor has a sleek aerodynamic design and increased thrust, allowing the aircraft to cruise at supersonic airspeeds without using afterburner, otherwise known as "supercruise." (U.S. Air Force photo by Airman 1st Class Mikaela Smith.)

This photo shows the wreckage of an F-22 Raptor fighter jet that crashed on May 15, 2020. The cause of the crash was a small piece of tape left on the aircraft after it was washed. The tape covered a sensor, causing the aircraft to receive faulty information. This underscores the miniscule attention to detail that must go into maintaining these stealth fighters. (U.S. Air Force Times image via the Freedom of Information Act, courtesy of the U.S. Air Force.)

fading, and other corrosion of the stealth coating.

But the most common way an F-22's stealth coating is disrupted is when maintenance is performed that requires the opening of its panels. According to Lockheed Martin, about 50 percent of the maintenance performed on an F-22 is related to repairing the low observable (LO) stealth coatings that become damaged when the aircraft is opened up for routine maintenance.

To solve this problem, this original equipment manufacturer (OEM) implemented two programs. The "Mighty Tough Boot" is a modification that increases the strength of the "boots," that is, the material that forms the seams between the aircraft panels. This upgrade decreases damage to the seams and the LO coating when panels are removed and reinstalled. Another initiative, known as "Form-In-Place," a concept that builds on the Mighty Tough Boot, involves making specific improvements to the panels themselves, so that it is easier for maintainers to remove and replace them without damaging the LO stealth coating.

OTHER COATING CHALLENGES

In addition to stealth materials, various performance coatings are used on other areas exposed to extreme environments, such as the insides of the long engine air intakes. The tedious and painful job of applying this material used to be accomplished by hand, a task that reportedly took an estimated 1,600 hours to complete. Maintainers were required to wear protective suits and respirators while crawling around in the cramped intakes for hours on end. Not surprisingly, many of those workers developed related shoulder injuries.

All that is history now, as robots produced by Aerobotix of Madison, Alabama, installed at Hill Air Force Base in Ogden, Utah, have been employed to take on this task. In 2016, a $1.5 million contract with the U.S. Air Force enabled Aerobotix to develop a complex, multi-axis system with a long carbon fiber arm designed to reach deep into the engine inlet ducts.

When human workers performed this task by hand, it was nearly impossible to ensure that the coatings were applied at consistent speeds and

Among new capabilities being prepared for the F-22 Raptor are the still-classified AIM-260 Joint Advanced Tactical Missiles, designed to attack targets beyond visual range, and needed to counter China's next generation PL-15 weapons. (Photo courtesy of U.S. Air Force.)

thicknesses. Speed is an issue because such coatings have short pot lives. (Pot life is the time in which the viscosity of a paint will double from its initial viscosity.) When the special coatings are applied by robots, the process is far faster, and the layer is more even, greatly reducing loss of these highly engineered coatings, which cost around $1,000 per gallon.

Robots now complete the job in 600 hours, with improved accuracy and quality control of the process. Project manager Bret Benvenuti, a senior robotics engineer at Aerobotix, points out, "That's a labor saving of around 80 percent, so it really helps solve the challenge of getting these aircraft back into service quicker. We estimate that since 2016, we've helped the U.S. Air Force save $8.8 million, $220,000 per aircraft, in maintenance costs."

There is still an aspect of intake coating maintenance that remains difficult. Before the robots can do their job of reapplying new coatings, the old coatings must be removed, and this still requires human labor. According to Technical Sergeant Justin Daywalt, Low Observable/Structures Integrated Support Manager for the F-22 System Program Office at Hill Air Force Base, "The actual removal of coatings from the F-22 inlets remains a manual process, where maintainers go inside the intakes and strip the coatings using hand tools. The coatings removal process remains a labor-intensive task, as automated process has not yet been qualified."

OTHER SPECIAL FEATURES AND UPGRADES

Special coatings are only one part of the Raptor's stealthiness. New stealthy external fuel tanks were spotted on the F-22 when it recently underwent testing at the Mohave Air and Space Port, in Mojave, California, and at an annex of the U.S. Air Force Flight Testing at Edwards Air Force Base, located in Palmdale, California. Officially referred to as the Low Drag Tank and Pylon (LDTP), the new design incorporates even more surreptitiousness than the previous tank design, as it is more aerodynamic. In addition, the LDTPs are equipped with "smart rack pneumatic technology" to ensure a proper ejection sequence, while minimalizing drag in flight.

Other new technology being tested on the F-22 includes stealthy InfraRed Search and Track (IRST) sensors developed by RTX (formerly Raytheon Technologies) of Arlington, Virginia. This equipment is contained in another stealthy pod, because there was no room for it inside the Raptor. Spares and support equipment are included in RTX's upgrade package. Once testing is completed, the IRST upgrade will be performed on all U.S. Air Force F-22s at the RTX facility in McKinney, Texas, with this work expected to be completed by May 2029.

In 2023, BAE Systems of Falls Church, Virginia, was awarded a $1 billion, 5-year sustainment contract for the AN/ALR-94 advanced digital electronic warfare (EW) system. This system is

A U.S. Air Force F-22 Raptor assigned to the 199th Fighter Squadron sits on the flightline at Yokota Air Base, Japan, in May 2024, during the Japanese-American Friendship Festival fireworks display. (U.S. Air Force photo by Yasuo Osakabe.)

Two F-22 Raptors fly a training mission over Alaska. The aircraft are from the 3rd Wing at Elmendorf Air Force Base, Alaska. (U.S. Air Force photo by Tech. Sgt. Mikal Canfield.)

capable of geolocating radar threats from significant distances, allowing the F-22 to limit its radar emission, which could compromise its own location. BAE, the OEM for this critical system upgrade, also will supply spares, repairs, upgrades, assistance with supplier logistics, test equipment, and engineering support.

THE RAPTOR FLEET

With these new contracts and more devoted to F-22 sustainment and upgrade, the end of the line for the Raptor keeps moving farther into the future. However, for the past several years, the U.S. Air Force has wanted to retire the earliest F-22s, the Block 20s, from their inventory to save money and make way for the Next Generation Air Dominance (NGAD) program and development of a hypersonic missile. The U.S. Congress and the Government Accounting Office (G.A.O.) deemed this plan unacceptable, because it left too many glaring inadequacies in the Air Force's ability to maintain air dominance.

Currently, the U.S. Air Force has 120 Block 30/35 combat capable Raptors. While thirty-seven Block 20 Raptors have received extensive upgrades to align them with the Block 30 standards, Air Force officials are still seeking to divest the fleet of thirty-two additional Block 20s.

Block 30/35 aircraft possess many enhancements that are absent in their Block 20 counterparts. Thus, until recently, the Block 20 aircraft were only used for training. This has been problematic, because pilots training on Block 20s do not have access to all the bells and whistles found on Block 30/35 models. So, when they completed their training and went on to an active combat squadron, they had a lot more to learn and master before becoming mission-capable crew members.

"The differences between them (Block 20 compared to Block 30/35) are getting greater and greater over time, because we keep putting more capability on the operational Raptors," explains U.S. Air Force Lieutenant General David S. Nahom, Deputy Chief of Staff for Plans and Programs. Due to this widening gap, it has been estimated that it would cost too much to upgrade the earlier Block 20 models, referring to the thirty-two that the Air Force wants to divest.

ADDRESSING THE TRAINING PROBLEM

The U.S. Air Force did decide to take some of the Block 30/35 aircraft from operational squadrons and repurpose them in a training capacity. Plus, in 2022, training for aircrews that had been held at Tyndal Air Force Base, in Florida, was moved to Joint Base Langley Eustis in Hampton, Virginia, with the reactivation of the 71st Fighter Training Squadron and its supporting maintenance squadron.

Langley Air Force Base has traditionally hosted three flying squadrons. The 27th Fighter Squadron and the 94th Fighter Squadron have been operationally flying the Raptor since 2005. And with the reactivated 71st Fighter Training Squadron, the three squadrons at Langley Air Force Base fly and maintain half of the U.S. Air Force's inventory of F-22s.

Using the newer Block 30/35 aircraft for training does have the downside of reducing the number of Raptors available for combat operations. But graduating pilots are emerging with higher skills and abilities and need less training upon arriving at their first mission assignment.

A TEMPORARY BUT USEFUL REPRIEVE

Since the Raptor has been given a temporary reprieve from retirement with its many new upgrades and enhancements, additional plans have been in the works to keep these fierce fighters flying. The current F-22 improvement strategy calls for $7.8 billion to be invested in the airplane before 2030, including $3.1 billion for research and development and $4.7 billion in procurement. Part of the rationale behind this significant investment in limited-life airframes is that using and testing new sensors and other upgrades on the Raptor will serve as a stepping stone in the U.S. Air Force's preparation for the forthcoming NGAD aircraft, in the hope that this technology can be fielded more quickly on the next model.

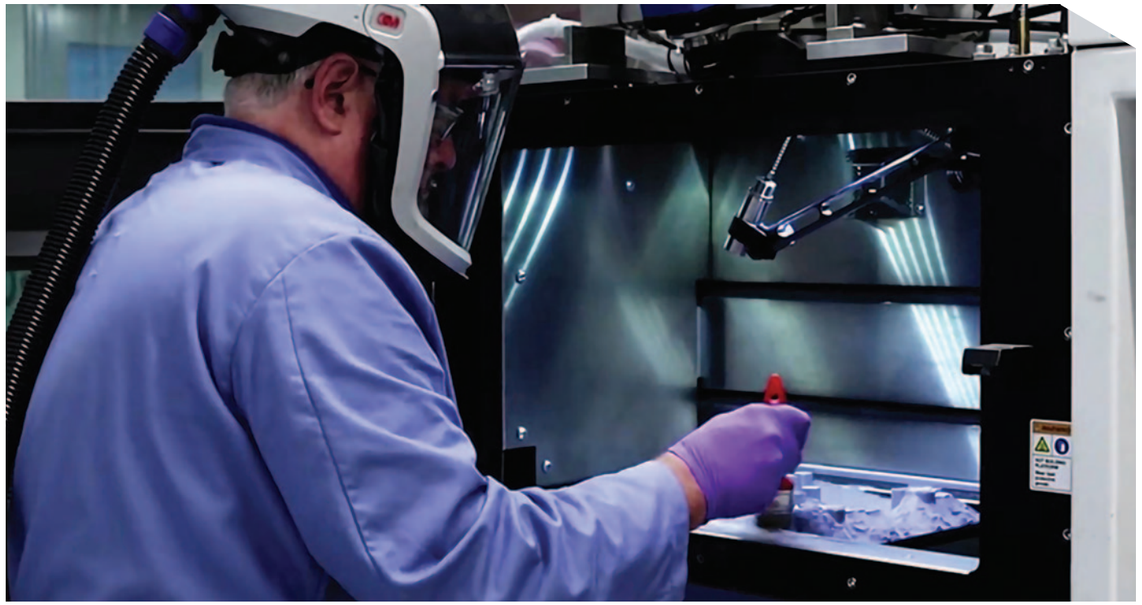
U.S. Air Force Fighters and Advanced Aircraft Program Executive Officer Brigadier General Jason D. Voorheis states that the end of the Raptor's service life is uncertain, but concludes, "What I can tell you is that we are hyper-focused on modernization to sustain that air superiority combat capability for a highly contested environment for as long as necessary."

TOO FINE A JET TO PUT DOWN

The Raptor continues to prove itself as a premiere stealth fighter and a valuable component of the U.S. Air Force's arsenal. Currently deployed in several of the world's most troublesome places, the F-22 performs its myriad tasks while shielding its presence from the enemy. As upgrades and modifications continue to make the jet even more capable in combat, valuable lessons continue to be learned, as testing of new weapons and systems provides knowledge for the future of maintaining air superiority on the global scale.

AAD

A U.S. Air Force pilot assigned to the Hawaiian Raptors Squadron, comprised of the 199th and 19th Fighter Squadrons, poses for a photo at Kadena Air Base, Japan, after a flight in March 2024. (U.S. Air Force photo by Senior Airman Sebastian Romawac.)



A Pratt & Whitney technician operates a 3D printing machine. The face shield protects the user from the materials used, which can come in the form of fine powders. (Photo courtesy of Pratt & Whitney.)

U.S. MILITARY EMBRACES AIRCRAFT 3D PRINTING AND ADDITIVE MANUFACTURING

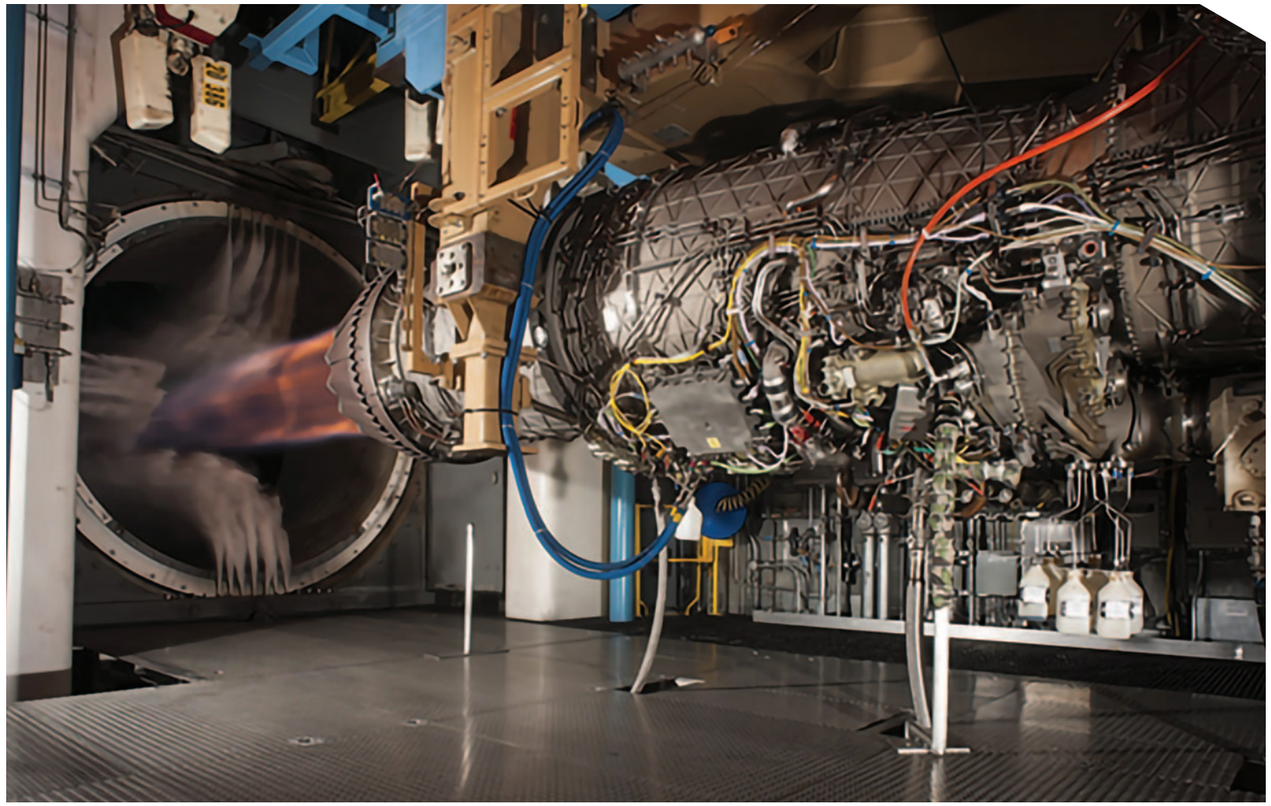
By Tracy Martin

MILITARY 3D PRINTING AND ADDITIVE MANUFACTURING

Since 2012, U.S. defense forces have been involved with additive manufacturing (AM) and 3D printing, exploring and gradually expanding use of these processes by the U.S. Air Force, U.S. Army, U.S. Marine Corps, U.S. Navy, and various U.S Department of Defense (DOD) contractors. But it was not until 2016 that it truly gained momentum. While the terms additive manufacturing and 3D printing are often used interchangeably (see sidebar), the latter is more prevalent, so it will be primarily used in this article.

The use of 3D printing in the military enables it to be more self-sufficient. This approach to parts replacement allows for on-demand manufacturing, whether at production facilities or forward-operating mission locations, particularly in conflict scenarios where time is of the essence and traditional supply chains are disrupted. Other advantage of using 3D printing for aircraft parts include accelerating the time from prototyping to manufacture of new parts, enabling low-volume production of replacement parts for legacy aircraft, and lowering costs due to less waste in high-cost materials. Thanks to structures made possible by the process, there also is the potential for reducing both the number of separate components and weight—always a plus for aircraft parts.

In 2012, the DOD introduced the *Department of Defense Additive Manufacturing Strategy* (see sidebar). This roadmap aimed to position 3D printing as a key technology to develop new and improved products, enhance logistics, and boost material readiness for the U.S. military. Since its



Testing an F135 engine at the Arnold Engineering Development Complex, located on Arnold Air Force Base in Tullahoma, Tennessee. (Photo courtesy of the U.S. Air Force.)

introduction, adoption of additive manufacturing has expanded considerably. What began with smaller part prototyping has progressed to the production of an ever-increasing range of end-use components for aircraft, ground vehicles, weapons, gear, shelters, and more.

Following are some examples of how the U.S. military, specifically in areas related to aviation defense, has been or will be using 3D printing and additive manufacturing. Based on our conversations with those in the know, it is clear that the evolution of this technology will be key to future aircraft and warfighter support.

A SMARTER WAY OF DOING BUSINESS

Pratt & Whitney is advancing aerospace manufacturing methods with a bold move into 3D printing. This innovation is changing the way the company produces select components for its high-performance engines, including the F135 and TF33.

Since 2018, Pratt & Whitney has been using 3D printing to enhance the F135 engine, which powers the F-35 Lightning II fighter jet. One notable application is the Turbine Exhaust Case (TE) box, a critical part that directs engine exhaust gases. Formerly made using hydroforming — a production process, utilizing high-pressure fluids to shape metal, that usually was outsourced—the TE box now benefits from efficiencies of 3D printing, including enabling Pratt & Whitney to form and finish these components in-house. Also, as 3D printing enables more complex structures, some number of multiple parts that previously were produced separately and joined after production can now be manufactured as one part.

Jesse Boyer, Senior Fellow–Additive Manufacturing at Pratt & Whitney, highlights key advantages of the project. “Unitization saves costs by reducing our part count, and it also improves our lead time, because you’re simplifying the supply chain. Additive really gives us that opportunity. Simply put, it’s a smarter way of doing business.”

The impact of AM extends beyond the F135 engine, as Pratt & Whitney’s team is also applying 3D printing to supporting long-term sustainability of legacy military aircraft. For example, their work on the TF33 engine, which

WHAT'S IN A NAME?

3D printing and additive manufacturing are terms so often used interchangeably, that there is some confusion about their distinct meanings. While 3D printing uses an additive approach to create objects, it does not always encompass the full scope of additive manufacturing. Conversely, all additive manufacturing processes can be considered 3D printing.

3D printing specifically involves creating a three-dimensional object from a digital model, such as a CAD design. The process involves feeding this model into a 3D printer, which effectively slices the design into thin layers that it builds it up layer by layer to form the final product. This method is typically used for small-scale or individual projects and may not describe the extensive operations seen in larger manufacturing workflows.

Additive manufacturing, on the other hand, is a broader term that can be used to encompass modeling (CAD drawings), material traceability, workflow management, post-processing (such as painting, polishing, and heat treating), quality control, and 3D printing.

In summary, additive manufacturing covers a wide range of related processes, while 3D printing refers more specifically to the act of building objects layer by layer. 3D printing may apply to smaller, or one-off projects, whereas additive manufacturing is more likely to refer to larger-scale or industrial production, including aviation parts.

Pratt & Whitney produced a loop bracket for the TF33 engine conventionally (at left) and used additive manufacturing (at right) to redesign and produce it for installation on a U.S. Air Force B-52H Stratofortress. (Photo courtesy of Pratt & Whitney.)

powers the B-52H Stratofortress, demonstrates how AM can address the challenges of sourcing spare parts for aircraft with service lives stretching over decades.

Joe Ott, TF33 and F100 Technology Manager for Operational Military Engines at Pratt & Whitney explains, "A lot of the parts haven't been made in over 20 years, and most of the original prints and design assumptions are lost to time. The suppliers that used to make them — many don't even exist anymore." Additive manufacturing addresses this shortfall by streamlining reverse manufacturing involving 3D modeling and supporting limited-run parts production.

A LEAP IN PRODUCTION CAPACITY

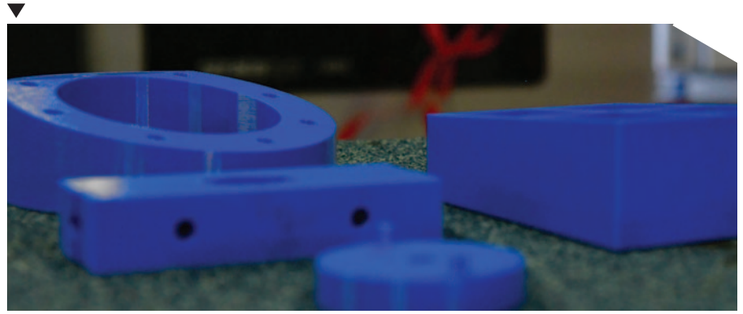
The 31st Maintenance Squadron (MXS) at Aviano Air Base is exploring the future of aircraft maintenance with a major upgrade to its 3D printing capabilities. Since adopting 3D printing in 2019, the squadron has benefited from its application, and a recently acquired Stratasys F900 3D printer is enabling a significant leap in production capacity.

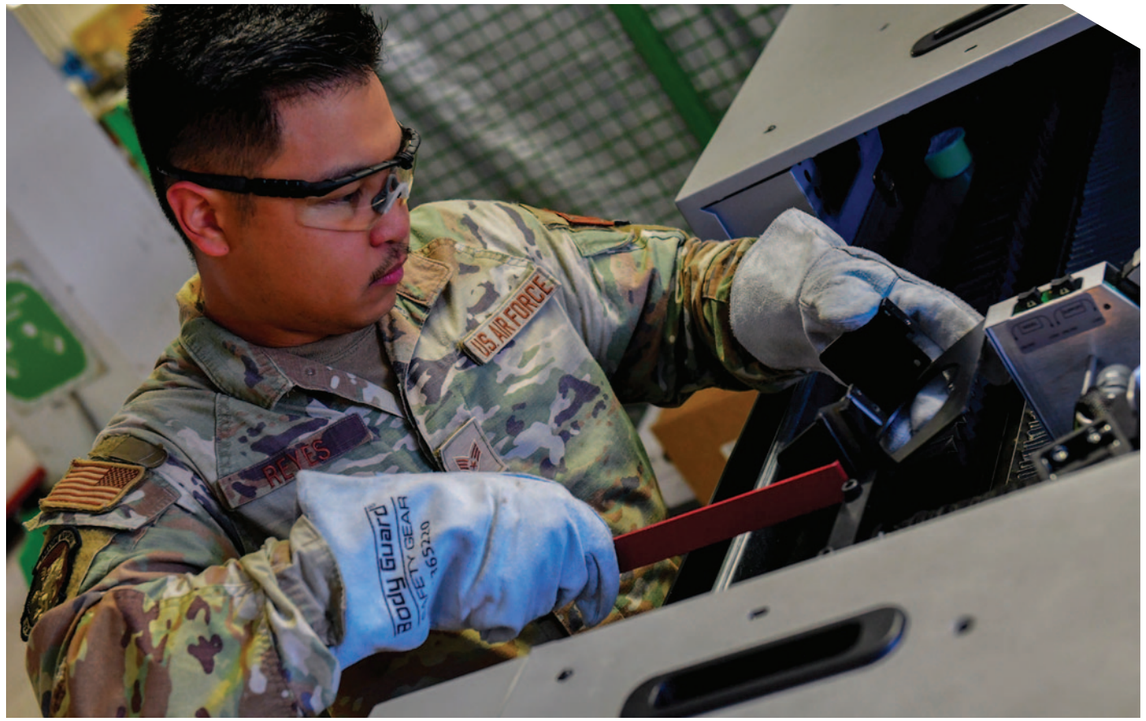
Among the enhanced capabilities of the F900 is an increase in the size of printable parts from the previous limit of 25 x 25 cm (just under an inch by an inch) to 91 x 91 cm (about 3 feet by 3 feet). So, the squadron can now produce larger and even more complex components.

"This new capability allows us to use the 3D printer as an additive manufacturing tool to create prototypes, before we proceed with making subtractive parts for the aircraft," explains Staff Sergeant Zachary Espinosa, an Aircraft Metals Technician Craftsman with the 31st MXS.

Applicable subtractive processes for forming metal parts may involve lathe-turning, milling, drilling, sawing, thread- and gear-cutting, and other machining. Using 3D printing both

3D-printed components from the 31st Maintenance Squadron metal shop's Stratasys F900 3D printer. (U.S. Air Force photo by Staff Sergeant Heather Ley.)





U.S. Air Force Senior Airman Abram Reyes, 31st Maintenance Squadron Aircraft Metals Technician Journeyman, checks maintenance parts made with the 31st MXS metal shop's Stratasys F900 3D printer at Aviano Air Base, Italy. (U.S. Air Force photo by Staff Sergeant Heather Ley.)

streamlines prototyping and enhances the squadron's overall operational capabilities.

Currently, the squadron's fabrication produces around sixty-three tools for local use and over 350 minor aircraft components each year. With the efficiency gains and material savings provided by the F900, its members anticipate not only a marked boost in production numbers, but also a notable improvement in their bottom line over the next year.

3D PRINTING MATERIAL REVOLUTIONIZES REPAIRS

When a C-5M Super Galaxy landed at Charleston Air Force Base in South Carolina, routine inspection uncovered a major issue: a part of the aircraft's aerodynamic fairing panel was missing. This fairing, crucial for reducing drag by covering a wing splice, relies on internal blocks and wedges—components that had started to crack and split, rendering the aircraft non-mission capable. Clay Elliott, a structural engineering expert for the C-5M, describes the situation "The technicians discovered a massive delamination of the phenolic blocks while inspecting the wing."

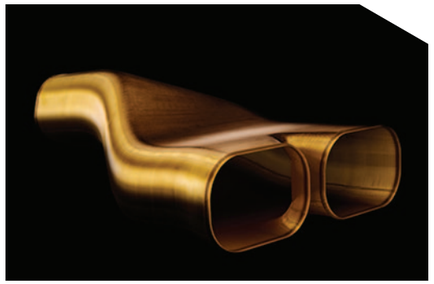
To address the problem, Elliott recommended using 3D-printed replacements made from Antero 800NA, a state-of-the-art thermoplastic known for its durability and resistance to environmental factors, making it a good choice for such critical applications. It can be used for aircraft components exposed to jet fuel, oils, hydraulic fluids, other chemicals, and it works well for applications that demand low outgassing.

This solution yielded impressive results. As Elliott notes, "We haven't had any issues with the aircraft we've repaired using this material and processes."

Todd Hicks, Aircraft Structural Maintenance Supervisor at the 60th Maintenance Squadron, emphasizes the advantages of this technology. "Traditionally, spare parts for the C-5M were costly and time-consuming to produce, due to specialized tooling and long lead times. 3D printing has streamlined the process, allowing us to produce parts on demand. This has significantly sped up maintenance and repair, leading to quicker turnaround times and cost reductions." These gains in efficiency help ensure the C-5M Super Galaxy can continue to operate at peak performance with minimal downtime.

3D PRINTING TAKES FLIGHT

The U.S. Marine Corps recently made another notable stride forward by



This aircraft component was made with the Antero 800NA thermoplastic material developed by Stratasys, an American-Israeli company specializing in 3D printers, software, and materials. (Photo courtesy of Stratasys.)

Pratt & Whitney produced a loop bracket for the TF33 engine conventionally (at left) and used additive manufacturing (at right) to redesign and produce it for installation on a U.S. Air Force B-52H Stratofortress. (Photo courtesy of Pratt & Whitney.)

demonstrating that 3D printing can be effectively carried out in flight. A groundbreaking test, conducted by the Consortium for Additive Manufacturing Research and Education (CAMRE) at the Naval Postgraduate School (NPS), in collaboration with the Marine Innovation Unit (MIU) and Marine Aircraft Group (MAG) 39, was carried out aboard a Marine Corps MV-22 Osprey tiltrotor aircraft.

During the demonstration, a custom medical cast was 3D-printed while the Osprey was in various flight modes, including taxi, takeoff, and in-flight maneuvers. The process began with a 3D scan of a U.S. Marine's arm, which was used to design the cast utilizing generative design software.

The test employed the Advanced Manufacturing Operational System (AMOS), a 3D printing system developed by Spencer Koroloy from the Naval Information Warfare Center (NIWC) Pacific in San Diego, California. AMOS is designed for speed, reliability, and durability, making it suitable for use in the demanding conditions of defense operations. While this test focused on a medical cast, it highlights the potential for 3D printing to provide on-the-spot solutions, including critical aircraft components, promising a future where 3D printing can offer flexible, on-demand production capabilities, even in the air.

As Lieutenant Colonel Michael Radigan, a liaison to the Naval Postgraduate School from the MIU, states, "We are just scratching the surface on the capabilities that will come from being able to 3D print in flight. Dozens of printers being installed in a modular fashion aboard aircraft brings the ability for mobile production at a scale we have not experienced before."

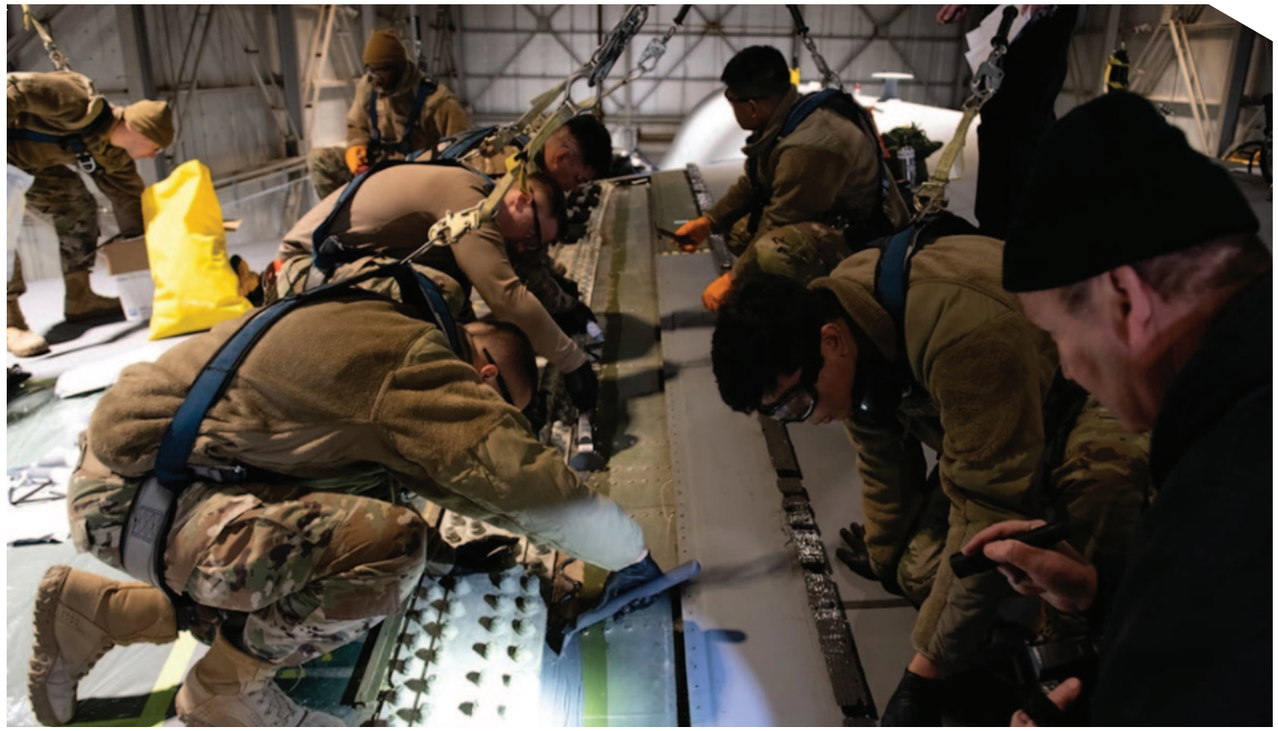
THE STRATEGY

In 2021, the U.S. Department of Defense (DOD) further advanced its commitment to additive manufacturing (AM) with the publication of the *Department of Defense Additive Manufacturing Strategy*. This document outlines how AM supports the nation's defense dominance in three ways:

1. Modernizing national defense systems to improve performance using AM-designed equipment,
2. Increasing materiel readiness to rapidly prototype and produce direct parts, thereby reducing the risk of obsolete hardware, and
3. Enabling warfighters to employ innovative solutions on the battlefield through AM capabilities.

Additive manufacturing is still an emerging technology, and while there has been growth in its use across the defense industrial base, its full potential is still being realized. The official strategy outlines five goals to achieve broad adoption of AM in the defense sphere:

1. Integrate AM into the DOD and both organic and commercial industrial bases.
2. Coordinate AM activities across the DOD and with external partners.
3. Promote and advance the agile use of AM.
4. Enhance workforce proficiency through quality training and best practice sharing.
5. Safeguard the cybersecurity of AM processes within the DOD and its supply chain.



Maintainers from the 60 MXS and 349 MXS are shown modifying an aerodynamic fairing over a wing splice of a C-5M Super Galaxy incorporating newly printed 3D parts known as blocks and wedges. (U.S. Air Force photo by Lan Kim.)

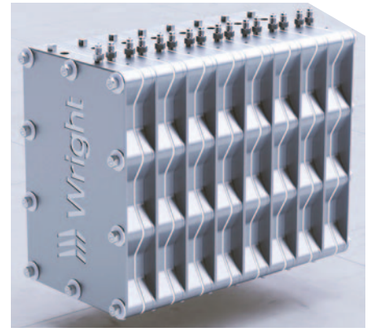
BATTERIES BREAKING BOUNDARIES

Fostering innovation, the U.S. Air Force greenlit Wright Electric's ambitious plan to develop next-generation batteries using cutting-edge additive manufacturing. This Phase 1 Small Business Innovation Research (SBIR) contract, awarded this past year, set the stage for testing Wright Electric's advanced thermal batteries in multirotor drones.

Wright Electric is on a mission to create megawatt-hour batteries that boast an impressive 1,000 watt-hours per kilogram at the pack level. For context, these new batteries would provide four times the energy density of the lithium-ion batteries powering today's electric vehicles. This could be a game-changer for electrifying large, hard-to-decarbonize vehicles, such as electric aircraft.

The crux of this initiative is to replace the single-use batteries currently in service with the U.S. military with Wright Electric's 3D-printed versions. These new batteries promise not only to be more sustainable, but also to improve performance and cost-effectiveness. Wright Electric's thermal batteries are said to provide high power availability and ultra-fast delivery rates — exactly what is needed in critical, in-theater operations.

The U.S. Air Force's backing is a nod to the growing importance of energy resilience and operational efficiency. Of interest to other aftermarket players is that this partnership could streamline Wright Electric's path to



Artist rendition of a Wright Electric 3D-printed battery. (Photo courtesy of Wright Electric.)

commercialization. Collaboration with the Air Force could help such companies navigate some of the lengthy Federal Aviation Administration (FAA) approval processes typically involved in aircraft component manufacturing.

THE FUTURE OF ADDITIVE MANUFACTURING

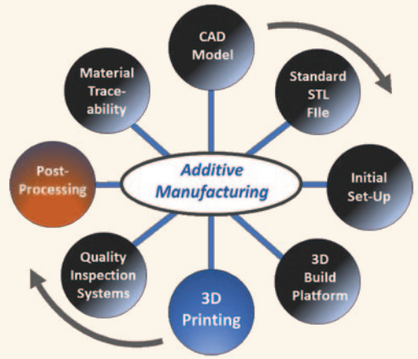
Aerospace manufacturing is an ever-evolving field, and staying competitive requires companies to adapt to industry changes, particularly by integrating cutting-edge technologies to enhance operational efficiency. Additive manufacturing and 3D printing enables U.S. defense forces, original equipment manufacturers, and aftermarket companies to create and test multiple versions of a product during development at a fraction of the cost of conventional manufacturing processes, transforming how products supporting defense aviation are developed and refined.

These technologies also align with other emerging trends, such as sustainability. With a growing emphasis on recyclable and reusable products, manufacturers are increasingly exploring ways to minimize waste, while producing efficient and effective parts. Additive manufacturing processes offer the advantage of producing parts in precise quantities to match demand, reducing surplus inventory and storage needs.

The concept of mass-producing aircraft components using 3D printing is no longer a futuristic idea. It is actively being utilized in military and aerospace manufacturing today. As more defense suppliers, maintainers, and fleet operators embrace this technology, it is expected that its progress and implementation will continue to accelerate rapidly.

AAD

ADDITIVE MANUFACTURING WORKFLOW



Additive Manufacturing workflow involves multiple processes, including 3D printing and post processing of the part. (Graphic created by Tracy Martin.)

The additive manufacturing process for metals, plastics or other material follows the same basic, five-part workflow defined in the *Machinery's Handbook, 32nd Edition* (Industrial Press, 2024; books.industrialpress.com).

1. A solid model of the component is created in, and imported from a computer-aided design (CAD) file. This model may be for an original part or it may have been reversed engineered from an existing design.
2. CAD software outputs a Standard Tessellation Language (STL) file that represents the solid part, without gaps or overlaps, with interconnected triangles.
3. During initial set-up, the STL file is oriented electronically on a 3D printer build platform, and the build file is separated into virtual slices. Intersecting points are identified, outlining the cross-sections to be printed in 2D layers.
4. The software in the AM machine converts the cross-sections of each layer into machine instructions that control the motion of a 3D printer. Various processes may include an extrusion head that deposits layers that make up the cross-sections of the part or a laser beam to selectively fuse deposited metal powder into a solid layer.
5. Once the part is completed and removed from the build plate, it may undergo such post-processing as heat treating or hot isostatic pressing to close up surface porosity. Precision fit parts may be machined, ground, sanded, shot-blasted, or coated with specialized surface materials. In accordance with aircraft standards, the entire process is subject to material traceability.

Key sources for more information about additive manufacturing include the product descriptions and detailed instructions provided by 3D print system and material manufacturers, an increasing number of focused industry standards (the *Machinery's Handbook* includes a list of these), and such dedicated groups as the National Additive Manufacturing Association (additivemfg.org) and the U.S. Department of Defense Manufacturing Technology Program's National Additive Manufacturing Innovation Institute, also known as America Makes (americamakes.us).

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(U.S. Air Force photo by Tech. Sgt. Kristen Pittman.)

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A C-130 Hercules from the 910th Airlift Wing C-130 sprays parts of New Orleans with a pesticide to suppress the growth of disease-spreading insects in September 2005. (Image courtesy of the U.S. Air Force.)

HERCULES VERSUS BITING BUGS

By Patrick J. Walsh

Moving methodically from one repair to the next throughout the difficult days following Hurricane Katrina and Hurricane Rita in Autumn 2005, linemen struggling to restore electrical power across large swaths of Louisiana and Texas found themselves confronted by an unexpected problem. They were under constant attack by swarms of insects.

Sustaining as many as 200 mosquito bites a minute while trying to stay focused on repairing the area's critical electrical infrastructure, they were clearly in need of help on a large scale. It soon arrived, in the form of C-130H Hercules aerial sprayers flown by the U.S. Air Force Reserve's 910th Airlift Wing.

The unit's specially trained crews targeted 2,880,662 acres of land in Louisiana and Texas with a barrage of insecticides that brought the rampant post-storm growth of mosquitoes and "filth flies" (a small fly known for its affinity for waste products) under control, vastly reducing the insect hazard and hastening the area's recovery. This effort set a new benchmark as the largest aerial spray mission in the history of the U.S. Air Force Reserve Command.

Based at Youngstown Air Reserve Station in Ohio, the 910th is the only U.S. Air Force unit designated by the U.S. Department of Defense to provide fixed-wing aerial spraying for applications of 5,000 or more acres. In addition to flying disaster relief missions such as the 2005 hurricane recovery flights, the 910th also supports large-scale pest and vegetation control operations at military installations and on federally owned lands. The unit also maintains the capacity for aerial spraying of dispersing agents, used for the first time in 2010, when it participated in cleanup of the massive BP Deepwater Horizon oil spill in the Gulf of Mexico.

Sources

"Aerial Spray Mission," Youngstown Air Reserve Station Fact Sheet, youngstown.afrc.af.mil; Campbell Robertson and Clifford Krauss, "Gulf Spill Is the Largest of Its Kind, Scientists Say," NY Times, August 2010.; Ed Runyan, "YARS commander describes missions," *Warren (OH) Tribune Chronicle*, April 2022.

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A group of retired Lockheed P-3C Orions at Davis-Monthan Air Force Base in Arizona, March, 2015. (Image courtesy of the U.S. Navy.)

THE P-3S THAT "UN-RETIRED"

By Patrick J. Walsh

When an aircraft is sent to the 309th Aerospace Maintenance and Regeneration Group (309th AMARG) at Davis-Monthan Air Force Base in Tucson, Arizona—the facility commonly known as "The Boneyard"—it is generally assumed that the airframe has seen the last of its days as a viable military asset. In some cases, though, the care of the 309ths, and perhaps some modernization, is all an aircraft needs before it finds its way back into the sky in a new role.

When South Korea decided in 2004 that it needed to strengthen its anti-submarine warfare (ASW) and maritime surveillance capabilities, the best option for doing so seemed obvious. The Republic of Korea Navy (RoKN) would add to its complement of Lockheed P-3 Orions.

The RoKN has fielded the P-3 since 1982, when it activated its initial group of eight Orions as Patrol Squadron 615. In order to outfit its ally with additional P-3s, the U.S. Department of Defense initiated the steps to facilitate a foreign military sale and searched its inventory for the nine aircraft that would ultimately be sold to the Republic of Korea (eight operational and one that was used for spare parts and later scrapped).

The P-3s involved were all stored at Davis-Monthan. Each airframe had been moved to the base after its initial service with the U.S. Navy had come to an end. The first arrived in 1991, with seven more of the nine retired Orions in storage at the base by mid-1994.

The P-3s were among the 10 percent of aircraft received by AMARG designated for "Type 1000" storage. This classification ensures they will be kept flight worthy in the event of an opportunity for further use. Thanks to the expert work of the 309th maintainers, who include many active-duty veterans with long experience with various aircraft, the former U.S. Navy P-3s were prepped and flown to the Waco, Texas, branch of L3 Communications (subsequently known as the L3 Platform Integration Division of L3Harris Technologies, Melbourne, Florida, following the 2019 merger of L3 Technologies and Harris Corp.). There, they received systems and service life extension upgrades as part of a $300 million 2005 contract awarded to L3 by Korea Aerospace Industries (KAI, headquartered in Gyeongsangnam-do, South Korea).

Following a series of additional modifications by KAI, the RoKN took delivery of the first of the refurbished Orions in February 2010, more than 18 years after the first of the group settled into storage at the Boneyard. This aptly demonstrating both the resiliency of the venerable P-3 and the admirable capabilities of the 309th AMARG.

Sources
"Lockheed P-3 Orion—South Korea," amarcexperience.com; John A. Tirpak, "Living Boneyard," *Air and Space Forces*, February 2013; Yonhap, "Navy aircraft unit reaches 40-year accident-free milestone," *The Korea Herald,* February 2022.

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Fatigue Technology 206-246-2010
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Flight Data Systems LLC 941-756-9394
6497 Parkland Drive, Suite J, Sarasota, FL 34243 U.S.A.

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Fokker Techniek B.V. +31(0) 622 855 430
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General Dynamics Ordnance and Tactical Systems 727-578-8100
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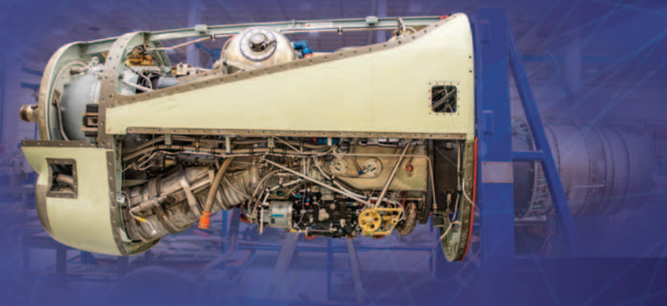

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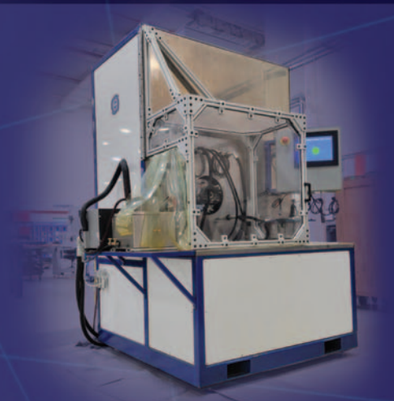

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