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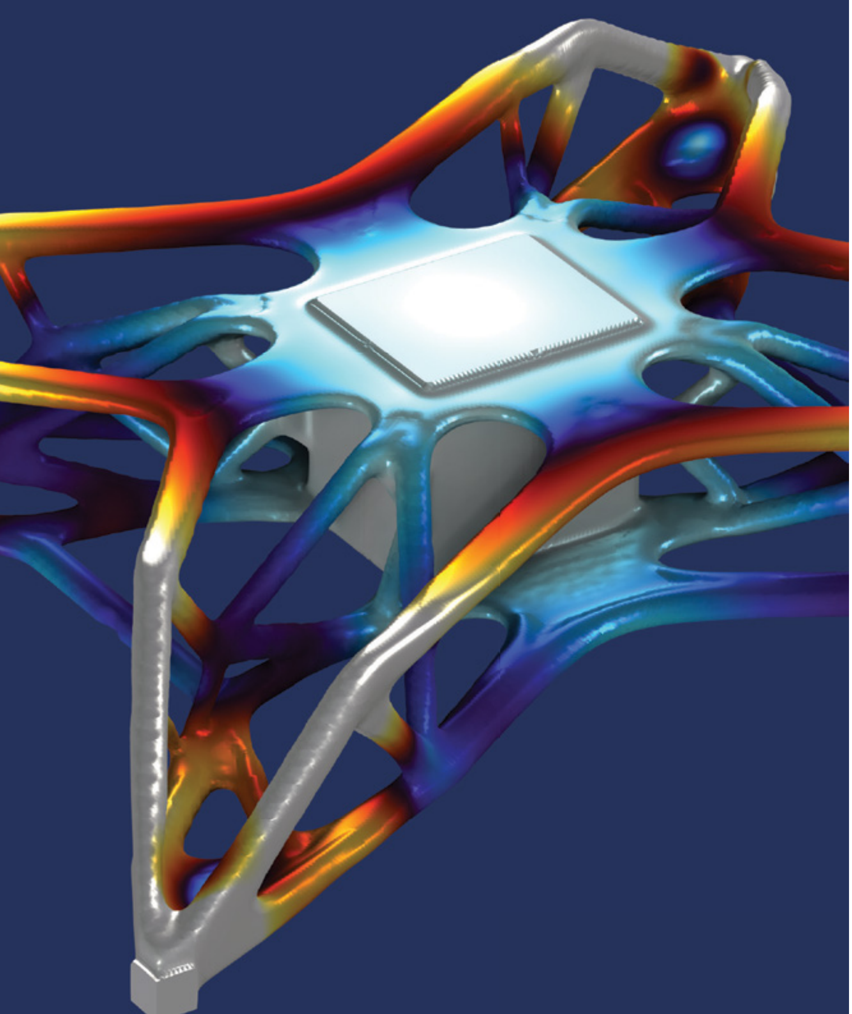

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April 2024

AEROSPACE & DEFENSE TECHNOLOGY™

The Engineer's Guide to Design & Manufacturing Advances

SAE INTERNATIONAL®

10 New Unmanned Ground Vehicles

Advancing Multi-UAV Operations

COM Express: Future Embedded Architecture of Robotics

RF-Cyber for Counter-UAS

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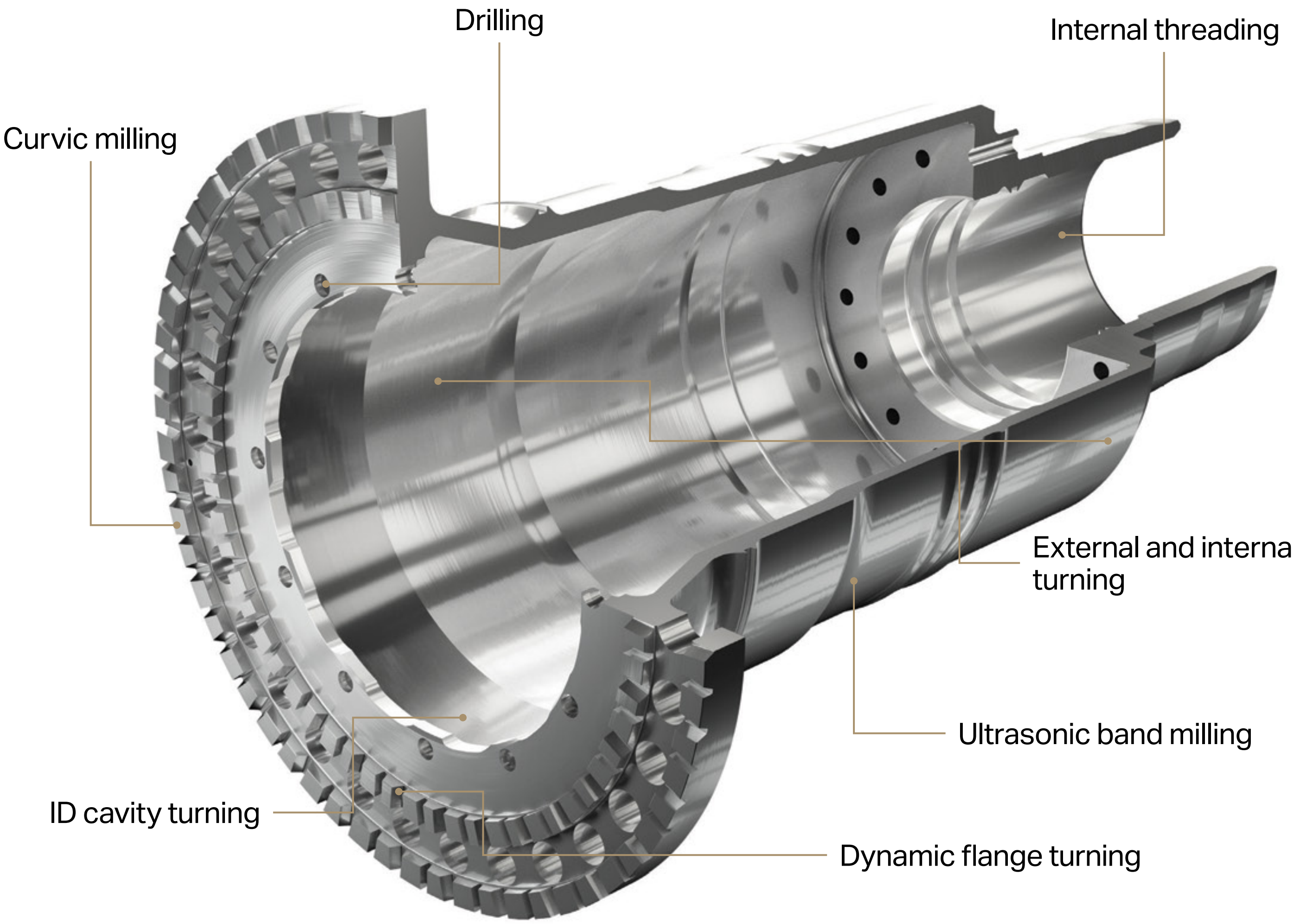
Drilling
Internal threading
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ID cavity turning
Dynamic flange turning

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ON THE COVER

The evolution of military aviation takes a revolutionary turn with the concept of Manned-Unmanned Teaming (MUM-T). The Collaborative Combat Aircraft (CCA) concept, also known as loyal wingmen, is poised to redefine the capabilities and presents immense potential for air forces worldwide. To learn more, read the feature article on page 10.

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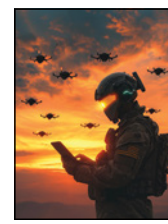

EXPERT Insight

What the Aerospace Industry Can Learn from the Automotive Sector

The correlation between the automotive and aerospace markets holds more similarities than people think, offering a valuable learning opportunity for the aerospace sector. One significant area of overlap lies in data – both sectors deal with assessing facility performance and equipment efficiency.

For Tech Briefs' *Expert Insight series, Darryn La Zar, Senior Business Development Director at ACS, provides perspective on how the aerospace industry can update its approach to facility and test equipment real-time data monitoring with a focus on product life cycles, obsolescence, and managing risk. La Zar also spoke with* Aerospace & Defense Technology (A&DT) *about the aerospace industry's need to embrace open architecture software.*

***Aerospace & Defense Technology:* What can aerospace engineers learn from how the automotive industry manages performance assessments of aging test facilities and equipment?**

Darryn La Zar: Automotive engineers have to design very flexible facilities from the start because their life cycle is different. They don't move to a new building every time they produce a new vehicle or variant. In aerospace, their volume life cycle is significantly longer.

Aerospace engineers need to look at more updates over time to stay current with regulatory and safety requirements over the life cycle of an aircraft. For automotive, we employ what we call an FEP or a front end plan.

It's a process that we've developed over our 30 years in business, and it reduces timeline and cost estimations. It gives you a much better target of where your funds need to be directed.

***A&DT:* What can aerospace companies learn from the automotive sector's approach to data acquisition for test facilities and equipment?**

La Zar: Within the automotive sector, there's been widespread adoption of off-the-shelf data acquisition hardware and open architecture software. Within the aerospace market that has not been the case.

There is traditionally a lot of proprietary equipment required for data acquisition in aerospace. Whereas automotive is constantly taking those technologies and opening up the architectures. That's the basis that we develop off of. While there was a time when it was necessary for proprietary architectures, today we can achieve the same goals with off-the-shelf solutions.

The other trend is enabling real-time health data monitoring of both the equipment and the building itself. If you can consistently analyze updates based on historical data, then you can ensure both are ready to execute as needed.

A&DT: Are there any new data acquisition technologies that have been embraced by the automotive sector that the aerospace industry can adopt?

La Zar: I think it's less about new technologies and more about how they're being applied. For example, faster communication rates are enabling deterministic real-time monitoring of data.

There's also a focus on establishing a more distributed I/O mechanism. That is a challenge for aerospace because most of the testing requires a significantly higher number of channels. Distributing that I/O evenly is critical and can reduce costs.

A&DT: What are some of the factors that challenge the aerospace industry's ability to update its approach to data acquisition in the way the automotive sector has?

La Zar: Life cycle is a major factor. The life cycle of an aircraft is significantly longer than the life cycle of an automobile. For example, the current 737 airframe is roughly 57 years old.

Funding is typically tied to a specific program in aerospace as opposed to being tied to research and development. Another major challenge is obsolescence. For example, you may have a test system that's required to be operational for 25 years.

As components change, it's very difficult for the supplier of a component or subsystem to upgrade. Those upgrades are expensive because the data has to be aligned and authorization is required from the OEM.

A&DT: We're seeing more aerospace companies investing in the electrification of aircraft. Considering the advancements the automotive industry has already made, what can the aerospace industry learn from their introduction of new research and test facilities to develop new aircraft batteries and technologies?

La Zar: The learning can go both ways. While the automotive sector has made more progress, they're still in their early stages as well. The learning is going to be much more dynamic because electrification for both aerospace and automotive can happen at the same time and that's really important for both industries to know.

Overall, the biggest lesson aerospace can learn from the automotive sector is related to regulation and safety. Safety really is going to be identical in both, whether it's the current state of electrification or how they both advance. Both are invested in hydrogen and alternative fuels. There is limited regulation that covers those specifics in detail. So understanding that and taking industry best practices into account is critical. We're doing that today for customers in both industries.

Watch the full interview with Darryn La Zar

10 Unmanned Ground Vehicles *Being Developed and Tested* Around the World

Unmanned ground vehicles (UGVs), robot combat vehicles or autonomous vehicles, no matter what you call them, are increasingly being developed, prototyped and tested for future use in autonomous and teaming operations or scenarios with manned vehicles. In the U.S., the Army has expressed growing interest in UGVs, after recently selecting four companies to develop robotic combat vehicle prototypes for a variety of future use cases.

Interest in new UGV technology is also growing around the world. Last year, the U.K. Ministry of Defense (MOD) held its first ever trial of heavy UGVs, Estonia hosted a large international test of UGVs and Australia ended the year with several weeks of a major robotic combat vehicle exercise. This article provides updates on some of the latest prototyping, development, purchasing and deployment of 10 new military UGVs.

This article was written by Woodrow Bellamy, Senior Editor, SAE Media Group, (New York, NY).

(Image: Adobe Stock/Norlif)

General Dynamics Land Systems

TRX SHORAD

General Dynamics first unveiled the Tracked Robot 10-ton (TRX) Short Range Air Defense (SHORAD) variant in March 2023, prior to the Army selecting them as one of four companies/teams competing to win its Robot Combat Vehicle (RCV) contract that seeks to deploy UGVs teamed with manned vehicle units by 2028. The variant unveiled in March 2023 adds increased counter UAS (C-UAS) capability to the demonstrator that GDLS previously launched in October 2020. TRX SHORAD is also capable of autonomously launching and receiving small unmanned aircraft systems (UAS). The original non-SHORAD version of the TRX was selected for the first phase of the Army's RCV program, and GDLS is currently designing and building two prototypes of the modular TRX. GDLS describes the UGV as featuring "lightweight materials and a hybrid-electric propulsion system" that is being developed for several different use cases including indirect fire, autonomous resupply, complex obstacle breaching, C-UAS, and electronic warfare (EW) among others.

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HDT Global

WOLF-X

WOLF-X is the prototype UGV from a team that includes HDT Global as the lead vehicle developer, BAE Systems as the armament and situational awareness provider, and McQ Inc. — a Virginia-based defense electronics manufacturer — as the prime contractor. The 8×8 wheeled UGV is capable of being transported in a CH-47F. Powered by a hybrid diesel-electric system, WOLF-X also features a lithium ion battery and can be configured with an MK44 30 mm chain gun and enhanced armor. Team HDT is one of the four developers selected to participate in the Army's RCV program, with a WOLF-X prototype scheduled for delivery to the Army for test and evaluation this year.

Textron Systems Corp.

RIPSAW M3

Textron Systems is the lead developer of the RIPSAW M3, and also one of the four prototype vehicles selected for the Army's RCV program. The company partnered with Howe & Howe and Teledyne FLIR on the development of M3, a variant of the RIPSAW M5 system first launched by Textron in 2019. The Army has completed over 2,000 miles durability testing with the RIPSAW family since 2020, and describes all RIPSAW variants as featuring a basic flat-top deck configuration with an open architecture design and common chassis. RIPSAW is also designed with a size that fits inside of a CH-47F, and has 85 feet of deck space for payload configuration, and a 1,200-horsepower hybrid electric powertrain according to details released by Textron Systems. During AUSA 2023, Textron exhibited a version of the M3 demonstrator featuring a Kongsberg RS6 weapons system and a Javelin missile launching system. The company is developing a RIPSAW prototype for delivery to the Army later this year.

Oshkosh Defense, LLC

Oshkosh RCV

Oshkosh Defense is collaborating with Pratt Miller Defense and QinetiQ on the development of two different prototype robotic combat vehicles as part of the Army's RCV program. The company displayed both variants during the 2023 AUSA Conference. One of the variants was equipped with a Kongsberg RS6 remote weapon station, L3 Smoke Obscuration Module, LW 30x113 mm cannon, and a Switchblade 300 loitering munitions/UAS launcher system from AeroVironment. The second variant featured the Kongsberg CROWS-J equipped with an M2 .50 caliber machine gun and the Hoverfly Tethered Unmanned Aerial System (TeUAS). Oshkosh is on track to deliver two prototypes for testing to the Army in August.

Team Lynx

XM30

Team Lynx is led by American Rheinmetall Vehicles (ARV), and includes Alison Transmission, Anduril Industries, L3 Harris, Raytheon and Textron Systems. The group was selected to design in July 2023 the prototype XM30 Mechanized Infantry Combat Vehicle to serve as the U.S. Army's Optionally Manned Fighting Vehicle. XM30 will replace the M2 Bradley Fighting Vehicle and is the Army's first ground combat vehicle designed using new digital engineering tools and techniques. XM30 is not expected to be operational as a fully unmanned vehicle in its initial deployment, according to a June 2023 media briefing given by Army acquisition leader Doug Bush. According to details about the XM30 released by Raytheon, the vehicle is being designed to be operated with two crew members and a third "virtual crew member, who will scan an area, identify potential threats and notify the crew." The Army is now in the third phase of prototyping for the XM30 program and estimates its first unit could be equipped with a field-ready XM30 by 2029.

Milrem Robotics

THeMIS

Established in 2013, Milrem Robotics is a Tallinn, Estonia-based robotics supplier that first introduced its THeMIS UGV in 2019, when the prototype was subsequently acquired for testing by Thailand's Army and Defence Technology Institute. THeMIS is eight feet long and has a height of three feet with a chassis that can carry up to 1.3 tons. Milrem's power options for THeMIS include a diesel engine and electric generator as well as a lead acid or lithium-ion battery. Its run time on electric power is up to 1.5 hours, and Milrem has developed logistics, combat, ISR and EOD configurations of THeMIS. The U.S. is one of 16 total countries that have acquired the THeMIS UGV for testing and evaluation purposes. The company has also delivered 15 THeMIS UGVs to Ukraine to support logistics, casualty evacuation and route clearance operations.

Israel Aerospace Industries

Rex MK II

First unveiled by Israel Aerospace Industries (IAI) subsidiary ELTA Systems Ltd. (ELTA) in September 2021, REX MK II is an all-wheel drive hybrid electric powered UGV that can carry up to 1.3 tons. According to IAI, Rex MK II also features remotely controlled weapons systems, including a 7.62 mm machine gun and a .50 caliber heavy machine gun. The multi-mission vehicle can operate completely autonomously with command and control or remotely controlled by an operator. IAI also notes that two Rex vehicles can be transported inside of a single V-22 Osprey. One of the most recent updates around Rex MK II came when it demonstrated manned-unmanned teaming capability in an exercise with BAE Systems last year. The U.K.'s MOD is one of several international customers that has purchased the Rex MK II.

Elbit Systems

ROBUST

Jointly developed as a technology demonstrator by Elbit Systems and the Israel Ministry of Defense, the Robotic Autonomous Sense and Strike (ROBUST) UGV was first unveiled in October 2022. The 6×6 vehicle is equipped with a 30 mm autonomous turret, an active protection system, a robotic autonomy kit, and a built-in robotic arm for receiving and launching drones. Last year, ROBUST began testing and demonstration exercises including a trial organized by the U.K. MOD's Defence Equipment and Support (DE&S) division for UGVs weighing over 5.5 tons. The vehicle can be remotely controlled and has a turret equipped with a 12.7 mm heavy machine gun and pintle-mounted 7.62 mm machine gun, according to details released by Elbit. No timeline has been provided by Elbit for when ROBUST will be ready for deployment and operation.

Rheinmetall

Autonomous Combat Warrior Wiesel

German aerospace and defense manufacturer Rheinmetall unveiled the Autonomous Combat Warrior variant of its Wiesel ground vehicle in December 2021. The vehicle can be remotely controlled by a tablet, and the company added the unmanned capability to its Wiesel family of ground vehicles using its "PATH A-Kit." According to Rheinmetall, the A-Kit is a navigation system that enables full autonomous navigation through a combination of advanced sensors, algorithms, and real-time data analysis. The vehicle's autonomous mode is enabled by programming waypoints for it to navigate between on a tablet. Rheinmetall has released very few details about the robotic vehicle since its 2021 launch, although it did participate in the U.K.'s 2023 heavy UGV trial.

Hanwha

Arion-SMET

Korean aerospace and defense manufacturer Hanwha's Autonomous and Robotic Systems for Intelligence Off-road Navigation – Small Multi-purpose Equipment Transport (Arion-SMET) is a six-wheeled all-electric vehicle that can drive up to 62 miles and carry up to 1,200 pounds in payload. Hanwha developed Arion-SMET to support infantry operations, such as ammunition transport, medical evacuation, reconnaissance, and fire support. In December 2023, the U.S. Army, Marine Corps, and Ministry of National Defense of the Republic of Korea participated in a Foreign Comparative Test (FCT) to evaluate the Arion-SMET's ability to navigate over a variety of terrains, heavy equipment transportation, soldier following and remote-controlled driving. The Marine Corps has not yet fielded a UGV, and is currently defining its requirements for the technology.

Advances in Multi-UAV Operations

Manned-Unmanned Teaming, Swarming and Synchronized Flying

In the ever-evolving landscape of unmanned aerial vehicles (UAVs), the use of multi-UAV operations stands at the forefront of technological innovation. The contemporary operational environments underscore the critical importance of harnessing not only the capabilities of individual UAVs and coordinated operations but also their collaborative flights with manned aircraft as loyal wingmen in complex and heavily contested areas.

The evolution of military aviation takes a revolutionary turn with the concept of Manned-Unmanned Teaming (MUM-T). The Collaborative Combat Aircraft (CCA) concept, also known as loyal wingmen, is poised to redefine the capabilities and presents immense potential for air forces worldwide. The development of a CCA mission involving an 'attritable' UAV fleet requires meticulous planning, cost considerations, and the establishment of organizational structures. These kinds of operations are designed to be more cost-effective than traditional manned aircraft due to their reduced reliance on aircrews, which, above all, is key to avoiding the loss of lives in high-risk missions. However, it is mainly due to the new design and manufacturing paradigms employed.

Attritable UAVs are designed to be reusable but, if necessary, affordable enough to be sacrificed during combat missions, with some CCAs even designated as completely expendable. These autonomous wingmen, designed to complement and accompany manned aircraft, introduce a new doctrine in aerial missions, ranging from target strikes to intelligence, surveillance, reconnaissance, and electronic warfare operations. This new innovative approach is presented to enhance avi-

(Image: Adobe Stock/Fukume)

ation capabilities and achieve mission success while reducing human risk and operational costs.

This state-of-the-art operational framework makes it evident that the fusion and synchronized dance of manned-unmanned teaming, multi-UAV, temporal trajectory control, GNSS-denied operation and advanced AI flight systems concepts are reshaping the narrative of aviation. The challenges and opportunities inherent in these advances propel us toward a future where unmanned and manned assets operate seamlessly, fostering a new era of efficiency, safety, and mission success in the skies.

The Collaborative Combat Aircraft (CCA) concept. (Image: UAV Navigation-Grupo Oesía)

The Future of Military Aviation with Manned-Unmanned Teaming (MUM-T)

The evolution of military aviation is undergoing a paradigm shift with the integration of unmanned aircraft into combat scenarios. MUM-T represents a transformative approach to enhance flight operation capabilities and achieve mission success. The autonomous CCAs, or Loyal Wingmen, are designed to accompany and complement next-generation fighter aircraft, fulfilling a spectrum of missions, including target strikes, intelligence, surveillance, reconnaissance, and electronic warfare operations.

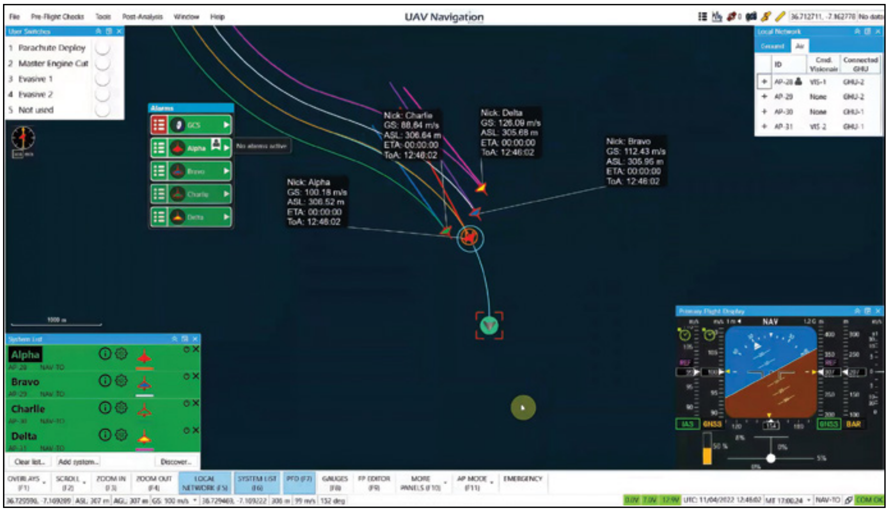
The future of MUM-T visualizes a diverse array of UAVs of varying sizes and capabilities, responding to specific mission requirements. From agile small UAVs to larger and weighted platforms, the flexibility of the CCAs concept allows for tailored solutions in modern military strategies.

However, this new operational scenario brings with it new important challenges to ensure flight safety, such as the human-machine interaction and the need for advanced flight control systems that are capable of managing an autonomous operation, including multiple unmanned aircraft with a manned aircraft in close formation.

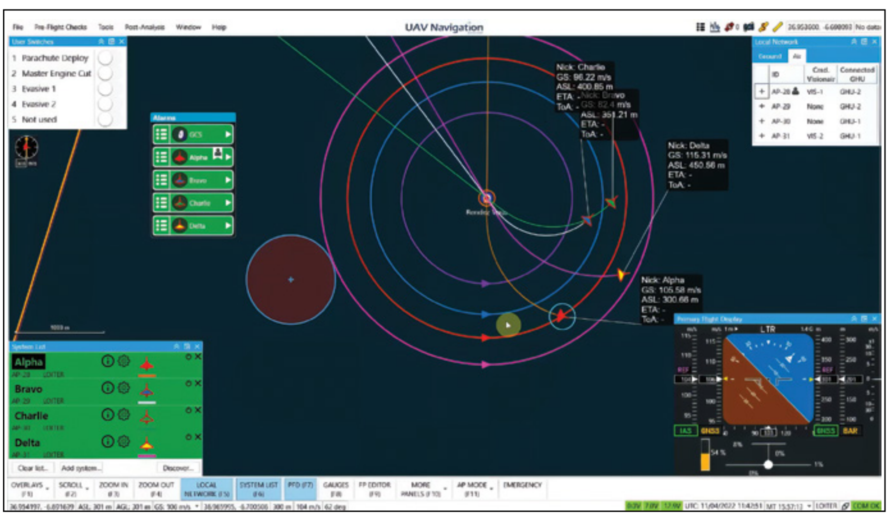
Two UAVs executing the same flight plan and being commanded from the same ground control station software. (Image: UAV Navigation-Grupo Oesía)

In addition to technological advances, air forces must lay the groundwork for the organizational structure to operate and maintain these advanced aircraft in a safe and coordinated ecosystem. The formation of specialized units and comprehensive training programs for airmen are critical aspects of this transformative process. These programs equip airmen with the necessary skills to seamlessly integrate manned and unmanned assets, fostering operational synergy on the battlefield.

As air forces embark on this transformative journey, they face the critical



UAV Navigation-Grupo Oesía's mission control software, Visionair, showing a multi-UAV flight following a leader and the remaining UAVs in open formation. (Image: UAV Navigation-Grupo Oesía)



Synchronized UAVs breaking formation autonomously after reaching the same waypoint at the same time. (Image: UAV Navigation-Grupo Oesía)

challenge of refining human interaction with UAVs. Envisioned as a fleet of UAVs directed by an air battle manager operating from a nearby platform, the focus is on optimizing self-awareness, control mechanisms and communication protocols between manned and unmanned assets. The effective coordination between human operators and autonomous capabilities will be vital to ensure successful missions.

For this reason, exploring different operational configurations is essential for the success of these missions, both using a single operator setup featuring reduced staff and hardware simplicity but intensified operator workload and multiple operator configurations distributing tasks among interconnected ground control stations, necessitating clear communication protocols.

Therefore, the development of advanced UAV mission control software and Ground Control Stations (GCS) has become a critical element. GCS software will need to be robust but also flexible to be able to display all the required information precisely, effectively and efficiently, allowing self-awareness and deep situational understanding. In this sense, the visual and rapid presentation of critical information such as positioning, flight altitude, airspeed, and surrounding traffic to increase the pilot's situational awareness or the Estimated Time to Arrival (ETA) to a specific "waypoint" (WP) of the different aircraft becomes crucial.

When operating multiple unmanned aircraft in formation and performing synchronized maneuvers, time becomes a critical variable. The coordination of arrival times at different points on the flight route enhances the efficiency of UAV operations, mitigating the risk of collisions. Most guidance and control systems in the last decade have incorporated the capability to create complex flight plans and manage operations, wherein unmanned aircraft follow predefined routes defined by multiple waypoints. However, the integration of temporal constraints — hence also known as 4D trajectories — now becomes indispensable, especially in operations involving multiple UAVs.

A notable facet of unmanned aviation involves the synchronized operation of Unmanned Aerial Target Drones (UAT) in mission-critical scenarios. Consider a mission example where two UATs emulate a penetration attack over a coastline. At a designated moment, both aircraft execute a coordinated evasive maneuver in response to an interception action initiated by the defending party. The success of such missions hinge on understanding how the UAV guidance, navigation and control systems, also known as autopilots, command and manage synchronized operations without the need for manual intervention.

Enhancements in Flight Control Systems

Achieving seamless control and coordination between manned fighter aircraft and unmanned wingmen, as envisioned in the collaborative combat aircraft concept, requires the deployment of advanced flight control systems. The ability to account for diverse and dynamic flight characteristics of both manned and unmanned assets demands intricate algorithms, sensor data, and real-time decision-making capabilities. With a high level of autonomy and adaptability, these sophisticated flight control systems become critical for future Collaborative Combat Aircraft fleets, ensuring smooth interactions between human operators and their UAV wingmen, even in the most challenging environments. In this scenario, UAV Navigation has taken important steps to improve the concept of flight control system and take it to another level.

The latest improvements included in the UAV Navigation-Grupo Oesía's VECTOR-600 autopilot system empower UAVs to cooperate during autonomous missions by seamlessly sharing state information. This level of cooperation facilitates swarm operations, coordinated flights, and open formation UAV flights, significantly enhancing the situational awareness of operators.

The advanced capabilities allow operators to visualize the status of every aircraft during multi-UAV operations, providing a comprehensive overview of the mission. This includes real-time surrounding traffic display capabilities and automatic collision avoidance with autonomous replanning algorithms. These features create a cooperative framework that not only eases the performance of advanced autonomous UAV missions, but also ensures the safe incorporation of unmanned aircraft into manned airspace.

Operators using UAV Navigation-Grupo Oesía's technology have already taken steps in realizing the vision of collaborative manned aircraft with remotely controlled unmanned systems. Leveraging their expertise in advanced flight control systems, they have already successfully executed multiple operations where a UAV target drone was controlled by a dedicated crew aboard a manned aircraft. By combining sophisticated algorithms and state-of-the-art sensors, the flight control system demonstrated the flexibility required to accommodate complex configurations while ensuring efficient and secure communication between the manned platforms and their UAV counterparts. This achievement showcases the immense potential of collaborative aviation, setting a precedent for the future integration of unmanned aircraft into modern air forces.

As we have seen in this article, the future of aviation is undeniably being shaped by the integration of unmanned aircraft into manned operations. The exploration of creating a collaborative aircraft framework, where UAV wingmen are remotely controlled from nearby manned platforms but also have the capability to execute complete autonomous missions, represents a groundbreaking leap in defense.

As technology matures and operational concepts evolve, MUM-T missions, synchronized flights, and the corresponding required advances in UAV flight control systems will undoubtedly become cornerstones of modern military strategies.

This article was written by Miguel Ángel de Frutos Carro, CTO, UAV Navigation-Grupo Oesía (Madrid, Spain). **For more information, visit www.uavnavigation.com.**

COM Express

The Architecture to *Support the Future* of Robotics & Unmanned Systems

(Image: Adobe Stock/Gorodenkoff)

Embedded computing systems to support robotic applications – particularly in aerospace and defense environments – demand special considerations including robust I/O, enhanced processing capabilities, vibration tolerance, and reduced footprint. Capitalizing on proven COM Express architecture allows for integration with existing systems as well as expansion using the most advanced peripherals available for reliable performance.

COM Express is a family of modular, small-form-factor computer-on-module (COM) specifications. The COM Express specification is one of many developed by PCI Industrial Computer Manufacturers Group (PICMG), whose goal is to translate desktop PCI standards to industrial applications. PICMG is a nonprofit consortium of companies and organizations, that collaboratively develop open standards for high-performance telecommunications, military, industrial, and general-purpose embedded computing applications.

The goal of all the different COM Express specifications is to fill the computing gap between high-cost, high-performance devices like VPX and COM-HPC, and lower-cost, Raspberry Pi-like devices. This modular system allows mid-range processing and networking capabilities that can be applied to aerospace, defense, robotics, autonomous systems, transportation, and other technology-driven markets.

COM Express is inherently flexible, allowing designers and engineers to select and combine individual modules to create custom hardware configurations. This can help meet specific application requirements and optimize system performance and any SWaP-C2 requirements. When using COM Express architecture, the computer-on-module has connectors that are soldered directly to the carrier board, and the enclosure is then built around the board.

A primary feature that separates COM Express boards from traditional single-board computers is the flexibility to mix and match various off-the-shelf modules. The COM module provides the high-speed computing functions that are common to most applications including the CPU, memory, graphics, Ethernet and

USB communications, SSD interface, and expansion buses. The carrier board is then designed to meet the application's I/O or subsystem requirements.

Faster, Better Design and Deployment with COM

By utilizing a two-board system – the carrier board with dedicated I/O and required subsystems and the COM Express processor module containing the CPU and other processing components – engineers can develop, design, prototype, and test rapidly for faster time to market. Estimates suggest that the time to design a custom carrier board is approximately half that of a traditional, full-custom OEM board.

The modularity of the platform allows designers and engineers to focus on developing the core functionality of the system, namely those housed in the carrier board. Perhaps the most beneficial element of COM Express architecture is the ability to optimize the carrier board to include the specific I/O for the application. The signals necessary to interface the I/O are brought down from the COM Express board via mating connectors, and the carrier board's functionality and mechanical footprint can be tailored to the application.

COM Express architecture allows manufacturers and integrators to rapidly respond to market fluctuations, competitive forces, and new technologies. They can quickly and efficiently modify existing designs, inexpensively broadening their product portfolios through the plug-and-play nature of COM modules and carrier boards.

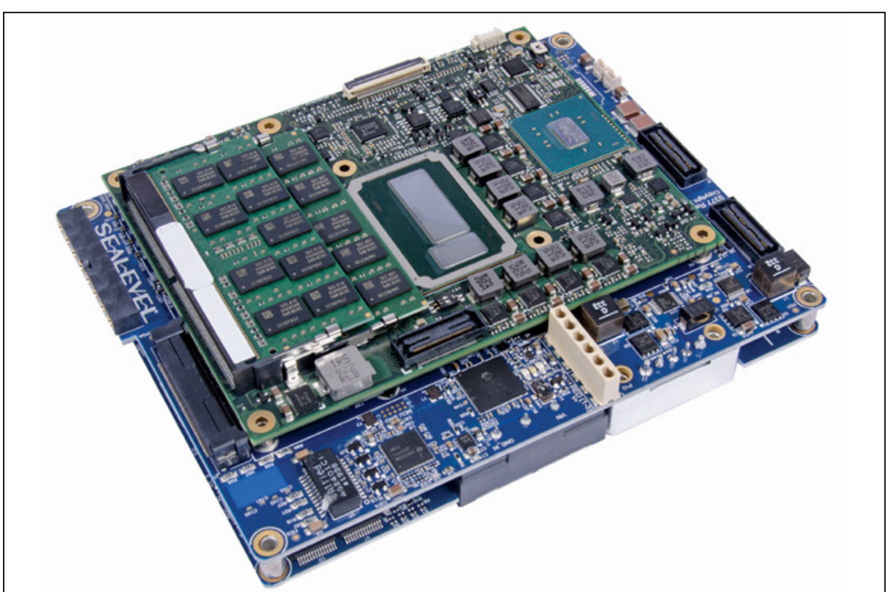
Meeting Environmental and SWaP-C2 Requirements

Another advantage of COM Express/custom carrier board architecture is the absence of cabling from the system. Utilizing COM Express allows a custom carrier board to be designed to the exact mechanical dimensions to allow I/O connectors to be soldered directly to the PCB in such a way as to allow external access without internal cables. The mounting of all connectors directly to the carrier board eliminates internal cable connections – removing a common point of failure. This makes COM solutions ideal for use in high shock and vibe environments, specifically those found in autonomous drone deployments for sea, air, and ground.

COM Express specifications are also intentionally architected to support rugged computing in diverse, potentially harsh, environments, where temperature poses a barrier. In these environments, computers must be able to withstand extreme operating temperatures. Further, since external thermal conditions cannot be controlled, engineers must design devices with minimal heat production. A wide variety of COM modules have a -40 °C to +85 °C operating temperature – and up to a 15-year lifecycle guarantee. Pairing these COM modules with a carrier board specifically designed to meet the same diverse environmental conditions allows for fanless, solid-state operation in many applications.

Specifically, as UAVs become more complex, they require more processing power and often include data communications networking hardware. The range and capability of these platforms are, ultimately, limited by size and weight; fuel costs increase as the size and weight of the UAV increase. COM Express solutions expand or reduce on a horizontal plane to meet the available footprint and achieve the necessary SWaP-C2 optimization.

COM Express Mini Type 10 Carrier Board used in a hyperspectral imaging UAV platform. (Image: Sealevel Systems, Inc.)



COM Express Compact Type 6 Carrier Board and daughter board assembly used in AR mapping and recording UAV platform. (Image: Sealevel Systems, Inc.)

Specific Unmanned & Robotics Use Cases

Hyperspectral Imaging for UAVs

A leading manufacturer of hyperspectral imaging systems deploys solutions for use in military applications including remote surveillance, target tracking, and missile and mine detection. Among these solutions is a system for unmanned aerial vehicles (UAVs). This system is particularly susceptible to SWaP-C2 constraints as well as extreme vibration and shock tolerance.

After performing a detailed analysis of the mechanical and environmental requirements, the company's partner engineering firm specified a COM Express Mini Type 10 carrier board. However, due to the unique enclosure of the end product and expansive I/O, they ultimately proceeded with a two-carrier board solution.

Driving factors for the use of COM Express in this design included the need to meet a constricted timeline, a unique available footprint, and the ability to tailor the product to meet very specific I/O requirements. The project was completed in 11 weeks from initial prototyping to full production. With the capability to integrate two boards, connected at a right angle, the design team was able to maximize the processing capabilities while including the application-specific I/O.

AR Mapping and Geospatial Recording

As their business grew, one solutions provider saw an increasing number of their AR mapping and geospatial recording systems being deployed in military UAVs for the display of live video of ground-based targets, overlaid with real-time data. For the next generation of their systems, they sought a computing platform that would strategically move them from low-volume, hobbyist production to a full-scale, industrial, widely available product.

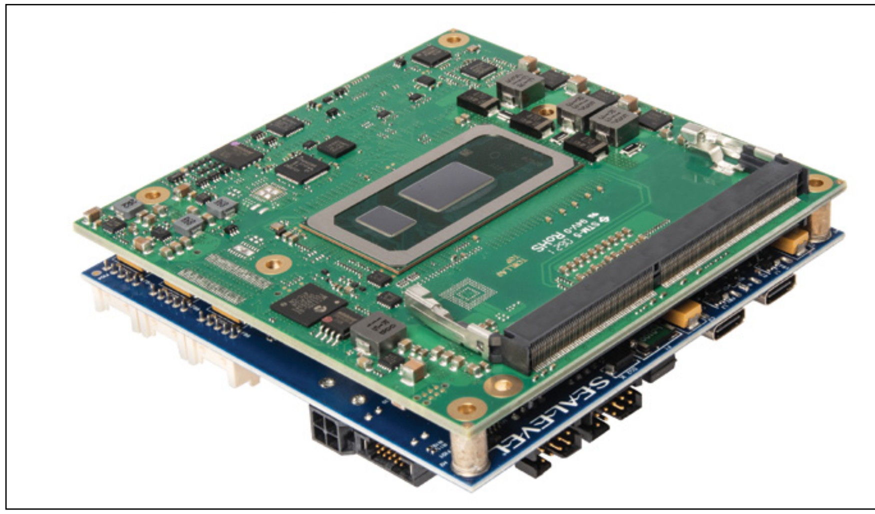
This application necessitated high-performance processing onboard the deployed system. Combined with size restraints and dense I/O requirements – and the aforementioned desire for an industrial, high-volume solution – COM Express quickly emerged as the preferred architecture for the redesign. By utilizing a Compact Type 6 carrier and daughter board, the product met all of the SWaP-C2 requirements and facilitated the integration of the robust I/O mix including Gigabit Ethernet, USB 3.0, composite and component video, DisplayPort, HDMI, SDI, CAN, ARINC, RS-232, RS-284, PS/2, differential audio, GPIO, A/D inputs, and D/A outputs.

Robotic Exoskeleton Control

A not-for-profit research institute developed a powered exoskeleton to provide increased mobility and independence to people with lower limb paralysis. The exoskeleton allows users to stand up and walk through a variety of environments, including up and down stairs and ramps, and across both flat and bumpy terrain. The exoskeleton utilizes powered actuators located in the hip, knee, and ankle to provide users with a smooth and natural walking motion.

After a thorough prototyping process with a Raspberry Pi-based computer, the institute partnered with an engineering and manufacturing firm to develop a custom solution for control of the exoskeleton.

The extremely reduced available space led the engineering partner to specify COM Express. The engineering team ultimately designed the smallest available, full-feature Compact Type 6 Carrier Board at 95 millimeters square – identical in size to a Compact Type 6 COM Express module. The engineering team was able to incorporate the required I/O into the small footprint, including Gigabit Ethernet, USB 3.0, USB 2.0, GPIO, RS-232, and Mini DisplayPort.



The smallest available full-feature Compact Type 6 Carrier Board and COM module assembly used in robotic exoskeleton application. (Image: Sealevel Systems, Inc.)

By using COM architecture, engineers can provide application-specific solutions without the design, time, cost, and lifecycle management issues inherent to a more traditional design. Utilizing a COM Express architecture allows engineers and manufacturers to dedicate the bulk of development and design time to the carrier board, tailoring the I/O to meet the exact specifications for robotics and unmanned systems. Finally, the flexibility of the architecture allows the carrier board to be designed to the available mechanical dimensions – often reduced in unmanned systems – while eliminating failure points associated with high shock and vibe environments.

This article was written by Drew Thompson, Technical Writer, Sealevel Systems, Inc., (Liberty, SC). **For more information visit www.sealevel.com.**

RF-Cyber for Counter-UAS

Next Generation Air Defense in Sensitive Environments

It's become increasingly clear that the proliferation of drones across positive applications and use cases is driving modern civilization toward a new drone-driven society. However, enabling the emerging associated drone-powered economy will require a new generation of counter-drone or counter-unmanned aircraft systems (CUAS) to support the growth of safe and secure drone adoption. Innovative technology and solutions are imperative to defend against parallel rogue drone threats and highly advanced technologies are necessary to overcome rogue drone threats. This is because they can safely operate in even the most sensitive and crowded environments and airspace, as well as in a controlled manner that ultimately supports continuity.

With rapid growth comes a commensurate rise in dangerous drone incidents across various sectors, environments, and use cases. Threat types include attacks, collisions, smuggling, espionage, and various forms of harassment and nuisance while incidents have spanned near collisions at airports, smuggling across borders and into prisons, threats to VIPs, disruptions to events and sports at stadiums and arenas, incursions at critical infrastructure sites, criminal attacks, and invasions of privacy. Given this, counter-drone systems must be optimized for the wide range of environments and sectors in which these threats materialize.

Constant and Non-Stop Drone Incidents

Since the beginning of this year, there have already been numerous serious incidents at US stadiums, airports, and prisons. A drone intrusion at Luis Munoz Marin International Airport in Puerto Rico led to the diversion of an incoming flight to the Dominican Republic and caused cascading disruptions for more flights across the Caribbean. An unauthorized drone delayed the AFC Championship game between the Kansas City Chiefs and Baltimore Ravens at M&T Bank Stadium. Prisons in South Carolina, West Virginia, Georgia, and New York all suffered from various nefarious drone incidents. These are just a few of the many examples of dangerous drone incidents occurring across the country.

The hostile drone threat has migrated from the battlefield to the homeland. This is largely due to the weaponization of cheap and accessible "build or buy" drones, which have effectively become the new "flying improvised explosive devices (IEDs)." These devices have become a new weapon of choice for bad actors thanks to their accessibility and low cost. They can simply take the commercial drone right off the shelf or adapt it for disguise and hostile intents, or use Do-It-Yourself (DIY) drones built from off-the-shelf commercial components.

Traditional air defense technologies that are built for the battlefield have a role to play but often possess major shortcomings that can cause them to struggle in sensitive civilian environments. These drawbacks are seen across detection, identification, and mitigation.

On the detection side, radar may show false positives from other flying objects such as birds. Optical camera technologies used to identify threats fall short in urban environments with tall buildings and rural mountainous terrain when there is no clear line of sight. Acoustic sound-based detection is also challenged by increasingly quieter drones – especially in very noisy environments like airports or stadiums – and RF-based directional finders may not always be able to track the drones to a high degree of real-time accuracy.

On the mitigation side, the challenges posed by traditional technologies are even more severe. Jamming or spoofing communications between the hostile drone and the remote control may only have a temporary effect and even more problematic, has the potential to disrupt critical communications and operations in the affected area. Kinetic methods of shooting down the rogue drone by various means including nets, drone killing drones, rifles, lasers, or EMP/HPM can risk serious collateral damage. This could be from either the

(Image: Adobe Stock/Kletr)

The RF-Cyber takeover system supplied by D-Fend Solutions as pictured here can be set up in a wide range of locations for long-range directional CUAS operations. (Image: D-Fend Solutions)

The RF-Cyber takeover system deployed at a military base. (Image: D-Fend Solutions)

projectile itself or from falling debris after a hit, with the dangers varying depending on the employed technology.

A Next-Generation RF-Cyber Approach

Today's sensitive civilian environments require a next-generation approach to achieve more positive outcomes. This means fast and accurate detection without false positives and safe mitigation. This starts with a surgical takeover of the rogue drone and then guiding it to follow a safe route to land with continuity, meaning no communications or operational disruptions or stoppages, and no collateral damage.

RF-Cyber has emerged as a new generation technology that uses RF techniques to take control of threatening drone scenarios. This includes employing cyber techniques to detect and take control of the hostile drone and landing it safely in a pre-designated zone. This non-jamming, non-kinetic, no line of sight required approach executes the mitigation without any traditional air defense technology drawbacks.

RF-Cyber technology capabilities aimed at control and safety occur at all stages of the lifecycle of a rogue drone incident. The technology will first detect the unauthorized drone, activate an alert, and then start to locate and track the drone and its take-off and pilot position. The drone's key characteristics are identified. Finally, in either manual or autonomous mode, the system can either activate a "fend-off", causing the hostile drone to go to its fail-safe position of returning to its home, or hover in place. Or, alternatively, the system can take control and land the drone in a safe place.

Systems must determine whether detected drones are authorized and friendly, or unauthorized and hostile. This places more importance on detailed drone identification. The skies are becoming crowded with authorized drones that play a critical role in society and RF-Cyber C-UAS systems bring the advantage of distinguishing between authorized and unauthorized drones.

RF-Cyber technology can address a wide range of commercial and Do-It-Yourself drone threats of all levels. These threats can encompass commercial, long-range, high payload, advanced protocol drones, and simpler Wi-Fi-based drones. The primary focus of course is aimed at drones that can carry heavy payloads, travel long distances, and are easily accessible.

The latest versions of the new generation RF-Cyber technology also bring high operational flexibility and adaptability through multiple deployment configurations including permanent stationary fixtures for sites such as critical infrastructure or prisons, tactical configurations on tripods for on-the-move operations, mobile vehicular configurations to provide moving bubbles of protection on military or covert civilian vehicles, long-range directional configurations to protect environments like air corridors or borders, and even man portable backpack versions to protect areas reachable only by foot.

To cover vast areas, RF-Cyber systems can come with their own command and control systems. This allows them to provide shared knowledge and show a single aggregated view across multiple sensors, in which mitigation could be executed by the optimally situated sensor and triggered by operations provided by the command-and-control center. Alternatively, RF-cyber systems can be integrated within a larger multiple-technology layered defense system.

Open Architecture for Multi-Layered Defense

To integrate in such a multi-layered defense and with such external control systems, and to complement other technologies, RF-Cyber systems should have open APIs to integrate with various governmental command and control systems and support the ability to partner and integrate with various defense systems to support defined operational requirements. With continuous software-driven system updates, RF-Cyber

RF-Cyber takeover identifies rogue drones in protected airspace and then neutralizes the threat by taking control over the drone and landing it safely in a predefined zone. (Image: D-Fend Solutions)

provides a rapid response to new threats and anticipates the unpredictable by proactively preparing for upcoming threats.

In summary, RF-Cyber CUAS is built on core concepts for continuity including the idea that the best way to control the drone threat is to take control of the drone itself. A safe landing or safe fending-off is the best possible outcome. This is achieved through a focus on the high risks, meaning the most dangerous drones, and confronting the constantly changing and increasingly complex drone threat by foreseeing the drone future and always staying a drone threat ahead.

Ultimately an RF-Cyber hostile drone takeover ensures continuity of communications, transportation, commerce, and everyday life.

This article was written by Jeffrey Starr, Chief Marketing Officer, D-Fend Solutions (McLean, VA). **For more information, visit www.d-fendsolutions.com.**

Counter Unmanned Aircraft System *Technology for Every Mission*

In the face of today's geopolitical conflicts, unmanned aerial systems (UAS) dominate modern warfare, with both Ukraine and Russia invoking drones in their ongoing battle, and more militaries developing UAS programs worldwide. While Counter Unmanned Aerial Systems (CUAS) are designed to respond — helping to detect, disrupt, disarm and defeat airborne vehicles — civil and military operations across the globe are hard-pressed to keep up with the demand.

Since 2012, SAIC has invested heavily in CUAS technologies, seeing the critical need for an integration team with efficient modernization capabilities and proven experience across Department of Defense's (DoD) programs. As a result, SAIC earned the position as a solutions provider for not only the DoD and its individual services but also other federal civilian agencies, including the Department of Homeland Security (DHS).

The SAIC Approach to CUAS Implementation

SAIC uses a combination of layered sensors, including radar, electro-optical and passive detection as well as effects provided by jammers, protocol override, and if needed, kinetics to defeat adversarial machinery. The team takes a system-of-systems (SoS) approach to ensure maximum mission effectiveness against a variety of threats, while focusing on a tailorable, scalable, and adaptable solution to meet the needs of its customers and their capabilities. This flexible approach allows SAIC to continuously integrate new technologies as they adapt, thereby outpacing the threat.

SAIC implements Artificial Intelligence (AI) and Machine Learning (ML) applications to allow defense operators to approach the mission at hand efficiently and effectively — in instances when a system's speed can have life or death consequences. It accomplishes this by approaching CUAS in five areas, providing end-to-end CUAS coverage. This approach supports efforts to detect, track, identify, mitigate and analyze/archive threats.

1. Detection: Having a clear understanding of the drones' location is essential, but many drones can be hiding in plain sight due to their small size. Radars are used to detect these hard-to-see threats, providing a 360-degree view of an area and helping to identify unmanned aircraft and then differentiating enemy UAS from commercial or personal aircraft.
2. Tracking: When monitoring adversarial drones, CUAS operators often develop fatigue as they sift through copious amounts of detected anomalies. Sensor data fusion and association of government-owned and developed algorithms are used to monitor unknown aircraft around the clock.
3. Identification: Electro-Optical and Infrared Sensors (EOIR) allow operators to identify a UAS system's capabil-

(Image: Adobe Stock/Hamara)

One of the first deployments of SAIC's Valkyrie CUAS technology was on the combat vehicles pictured here. (Image: SAIC)

SAIC's Valkyrie CUAS technology is shown here on three different military ground vehicles. (Image: SAIC)

ities using high-definition zooming, then enabling the opportunity of "hooking" targets by jamming specific drone frequencies.

4. Mitigation: Based on the details determined through detection and identification, SAIC's CUAS systems defeat, and diffuse drones based on its customer's jurisdiction and operational needs. CUAS technology enables teams to reduce UAS threats by overriding their systems to stop them, cause them to fall from the sky or return to sender. In situations where an override is not possible, CUAS systems can implement kinetic efforts to eliminate the threat altogether.
5. Analyzing and Archiving: Sensors fulfill evolving needs by providing time-phased deployment, meeting all threat levels through its user-friendly command and control system. Further, operators can log UAS encounters, analyze patterns of adversarial drone efforts and archive effective countermeasures in the event of another future attack.

Over the last 12 years, SAIC has played an integral role in various federal and defense departments' CUAS efforts, tailoring its solutions based on the mission at hand. The U.S. Air Force (USAF) recently implemented and deployed technology globally as a part of its CUAS efforts across multiple areas of operations. As a part of the technology's flexibility, these CUAS solutions are lightweight and are easily moved across theaters, allowing customers to set up effective countermeasures no matter where the mission takes them. In addition to SAIC's CUAS work with USAF, the team has also supported the Army and its Rapid Capabilities and Critical Technologies Office (RCCTO), integrating a prototype CUAS system using a High Energy Laser (HEL) system and supporting on related studies and analysis.

Thanks to SAIC's commitment to CUAS, it has become a trusted expert in the technology and the team's expertise is often requested during pilot programs and military exercises. In 2022, the company was invited to participate in a series of tests and evaluations within the Army's Joint Counter-Small Unmanned Aircraft Systems Office (JCO). Based on the outcomes of the event, the Army developed a formal memo of recommendation for SAIC's successful solutions for CUAS as a Service (CaaS).

Additionally, SAIC teams participated in other JCO events focused on Group 3 kinetic defeat, the classification from the DoD pertaining to large drones and operating at various altitudes and airspeeds. As a part of the exercise, SAIC was able to protect a defended area from threats ranging from Group 1 quadcopters to Group 3 drones, simulating the types of drone threats encountered in conflict zones today.

Addressing DoD's Current Threats with CUAS

Many agencies wishing to leverage CUAS systems still encounter hurdles in implementing the technology, including budget challenges, policy constraints and public misconceptions. Without a proper understanding of the technology, government leaders, especially military officials, are unable to obtain the proper funds to implement the tech. Additionally, leaders are hesitant to use CUAS systems due to policy constraints of what can and cannot be addressed in certain domains or contested environments. These challenges are worsened by the public's misconceptions of CUAS technology, which stem from a lack of knowledge of counter-drones and the human operators behind them. However, it's critical that CUAS advocates continue to press on as offensive drones are being manufactured by the thousands. Defense operators must have the technology in place to combat them if and when they're targeting the U.S. military.

Today, drones are a clear and present threat, both to service members on the battlefields and to civilians at home. Once the proper resources are secured to implement the tech, it will be essential for the DoD to collaborate with partners to integrate the systems into existing military operations. CUAS has not yet been deployed at the scale it needs to be, but industry partners can help equip service members with the CUAS know-how to improve cross-service understanding of the technology and its capabilities in protecting the nation and its allies.

When considering the various CUAS offerings available today, it's important to consider how most systems specialize in one aspect of a CUAS mission, such as detection or mitigation but rarely the entire mission. Instead, some of these capabilities are offered through various disparate subsystems that are tasked to work together. Customers must choose between separate limited systems or a tailorable, unique and interoperable solution.

By maintaining seamless collaboration between various elements of a CUAS, operators can in turn maintain command and control of CUAS operations across echelons, helping to improve efficiencies to employ these critical countermeasures. If a customer has different facets of CUAS technology with different vendors there is likely a disconnect between users that can decrease speed to accomplish critical tasks. SAIC's experts leverage AI/ML integrations to position CUAS as one commercially available command and control system where one operator can manage the mission at hand, while preparing for the threats of tomorrow.

Looking ahead to the future, the threat of adversarial drones will only increase. Drones don't necessarily recognize geographical borders or boundaries, and to protect service members and citizens from these impending challenges, the U.S. and its allies must look to CUAS technologies and scale effectively throughout their militaries and relevant civilian agencies.

This article was written by Greg Fortier, Senior Vice President, Aviation, Fires, Intel and C2, SAIC (Huntsville, AL). **For more information, visit www.saic.com/cuas.**

New Realistic Computer Model will Help Robots Collect Moon Dust

A new computer model mimics Moon dust so well that it could lead to smoother and safer Lunar robot teleoperations.

University of Bristol, Bristol, United Kingdom

A new computer model tool, developed by researchers at the University of Bristol and based at the Bristol Robotics Laboratory, could be used to train astronauts ahead of Lunar missions.

Working with their industry partner, Thales Alenia Space in the U.K., who has specific interest in creating working robotic systems for space applications, the team investigated a virtual version of regolith, another name for Moon dust.

Lunar regolith is of particular interest for the upcoming Lunar exploration missions planned over the next decade. From it, scientists can potentially extract valuable resources such as oxygen, rocket fuel or construction materials, to support a long-term presence on the Moon.

To collect regolith, remotely operated robots emerge as a practical choice due to their lower risks and costs compared to human spaceflight. However, operating robots over these large distances introduces large delays into the system, which make them more difficult to control.

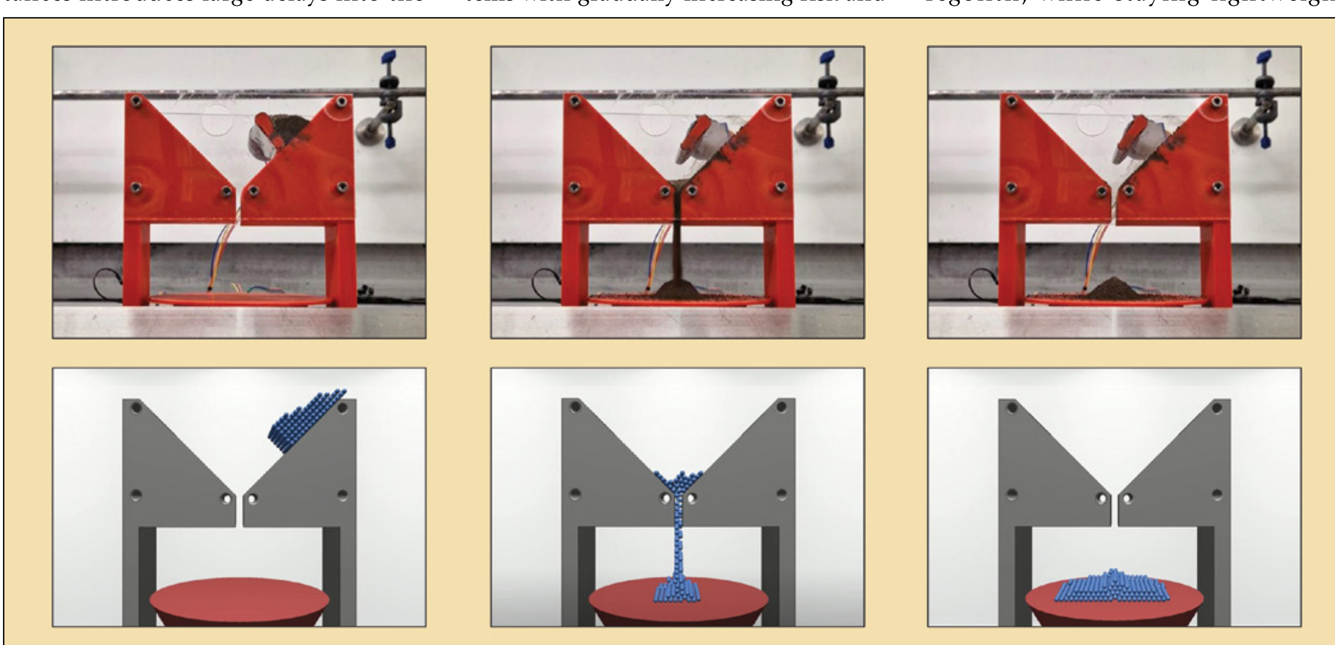
Now that the team know this simulation behaves similarly to reality, they can use it to mirror operating a robot on the Moon. This approach allows operators to control the robot without delays, providing a smoother and more efficient experience.

Lead Author Joe Louca, based in Bristol's School of Engineering Mathematics and Technology explained: "Think of it like a realistic video game set on the Moon – we want to make sure the virtual version of moon dust behaves just like the actual thing, so that if we are using it to control a robot on the Moon, then it will behave as we expect. This model is accurate, scalable, and lightweight, so can be used to support upcoming lunar exploration missions."

This study followed from previous work of the team, which found that expert robot operators want to train on their systems with gradually increasing risk and realism. That means starting in a simulation and building up to using physical mock-ups, before moving on to using the actual system. An accurate simulation model is crucial for training and developing the operator's trust in the system.

While some especially accurate models of Moon dust had previously been developed, these are so detailed that they require a lot of computational time, making them too slow to control a robot smoothly. Researchers from DLR (German Aerospace Center) tackled this challenge by developing a virtual model of regolith that considers its density, stickiness, and friction, as well as the Moon's reduced gravity. Their model is of interest for the space industry as it is light on computational resources, and, hence, can be run in real-time. However, it works best with small quantities of Moon dust.

The Bristol team's aims were to, firstly, extend the model so it can handle more regolith, while staying lightweight



Small Funnel Flow - The same experiments were set up in, both, simulation and reality to see if the virtual regolith behaved realistically. This test looked at how small (16 g) samples of material flowed through narrow funnels. (Image: Joe Louca) enough to run in real-time, and then to verify it experimentally.

Joe Louca added: "Our primary focus throughout this project was on enhancing the user experience for operators of these systems – how could we make their job easier?

"We began with the original virtual regolith model developed by DLR, and modified it to make it more scalable. Then, we conducted a series of experiments – half in a simulated environment, half in the real world – to measure whether the virtual moon dust behaved the same as its real-world counterpart."

As this model of regolith is promising for being accurate, scalable and lightweight enough to be used in real-time, the team will next investigate whether it can be used when operating robots to collect regolith.

This work was performed by Joe Louca for the University of Bristol. For more information, download the Technical Support Package (free white paper) at mobilityengineeringtech.com/tsp under the Sensors category.

AI Co-Pilot Enhances Human Precision for Safer Aviation

Designed to ensure safer skies, "Air-Guardian" blends human intuition with machine precision, creating a more symbiotic relationship between pilot and aircraft.

Massachusetts Institute of Technology, Cambridge, Massachusetts

Imagine you're in an airplane with two pilots, one human and one computer. Both have their "hands" on the controllers, but they're always looking out for different things. If they're both paying attention to the same thing, the human gets to steer. But if the human gets distracted or misses something, the computer quickly takes over.

Meet the Air-Guardian, a system developed by researchers at the MIT Computer Science and Artificial Intelligence Laboratory (CSAIL). As modern pilots grapple with an onslaught of informa-

With Air-Guardian, a computer program can track where a human pilot is looking (using eye-tracking technology), so it can better understand what the pilot is focusing on. This helps the computer make better decisions that are in line with what the pilot is doing or intending to do. (Image: MIT CSAIL Midjourney AI Image Generator)

tion from multiple monitors, especially during critical moments, Air-Guardian acts as a proactive copilot; a partnership between human and machine, rooted in understanding attention.

But how does it determine attention, exactly? For humans, it uses eye-tracking, and for the neural system, it relies on something called "saliency maps," which pinpoint where attention is directed. The maps serve as visual guides highlighting key regions within an image, aiding in grasping and deciphering the behavior of intricate algorithms. Air-Guardian identifies early signs of potential risks through these attention markers, instead of only intervening during safety breaches like traditional autopilot systems.

The broader implications of this system reach beyond aviation. Similar cooperative control mechanisms could one day be used in cars, drones, and a wider spectrum of robotics.

"An exciting feature of our method is its differentiability," says MIT CSAIL postdoc Lianhao Yin, Lead Author on a new paper about Air-Guardian. "Our cooperative layer and the entire end-to-end process can be trained. We specifically chose the causal continuous-depth neural network model because of its dynamic features in mapping attention. Another unique aspect is adaptability. The Air-Guardian system isn't rigid; it can be adjusted based on the situation's demands, ensuring a balanced partnership between human and machine."

In field tests, both the pilot and the system made decisions based on the same raw images when navigating to the target waypoint. Air-Guardian's success was gauged based on the cumulative rewards earned during flight and shorter path to the waypoint. The guardian reduced the risk level of flights and increased the success rate of navigating to target points.

"This system represents the innovative approach of human-centric AI-enabled aviation," adds Ramin Hasani, MIT CSAIL Research Affiliate and Inventor of liquid neural networks. "Our use of liquid neural networks provides a dynamic, adaptive approach, ensuring that the AI doesn't merely replace human judgment but complements it, leading to enhanced safety and collaboration in the skies."

The true strength of Air-Guardian is its foundational technology. Using an optimization-based cooperative layer using visual attention from humans and machine, and liquid closed-form continuous-time neural networks (CfC) known for its prowess in deciphering cause-and-effect relationships, it analyzes incoming images for vital information. Complementing this is the VisualBackProp algorithm, which identifies the system's focal points within an image, ensuring clear understanding of its attention maps.

For future mass adoption, there's a need to refine the human-machine interface. Feedback suggests an indicator, like a bar, might be more intuitive to signify when the guardian system takes control.

Air-Guardian heralds a new age of safer skies, offering a reliable safety net for those moments when human attention wavers.

"The Air-Guardian system highlights the synergy between human expertise and machine learning, furthering the objective of using machine learning to augment pilots in challenging scenarios and reduce operational errors," says Daniela Rus, the Andrew (1956) and Erna Viterbi Professor of Electrical Engineering and Computer Science at MIT, director of CSAIL, and senior author on the paper.

"One of the most interesting outcomes of using a visual attention metric in this work is the potential for allowing earlier interventions and greater interpretability by human pilots," says Stephanie Gil, Assistant Professor of Computer Science at Harvard University, who was not involved in the work. "This showcases a great example of how AI can be used to work with a human, lowering the barrier for achieving trust by using natural communication mechanisms between the human and the AI system."

This work was performed by Lianhao Yin for the MIT Computer Science and Artificial Intelligence Laboratory (CSAIL). The research was partially funded by the U.S. Air Force (USAF) Research Laboratory, the USAF Artificial Intelligence Accelerator, Boeing Co., and the Office of Naval Research. The findings don't necessarily reflect the views of the U.S. government or the USAF. For more information, download the Technical Support Package (free white paper) at mobilityengineeringtech.com/tsp under the Sensors category.

One Person Can Supervise a Swarm of 100 Unmanned Autonomous Vehicles

An open research question has been whether a single human can supervise a true heterogeneous swarm of robots completing tasks in real-world environments. A general concern is whether or not the human's workload will be taxed to the breaking point.

Oregon State University,
Corvallis, Oregon

Research involving Oregon State University has shown that a "swarm" of more than 100 autonomous ground and aerial robots can be supervised by one person without subjecting the individual to an undue workload.

The findings represent a big step toward efficiently and economically using swarms in a range of roles from wildland firefighting to package delivery to disaster response in urban environments.

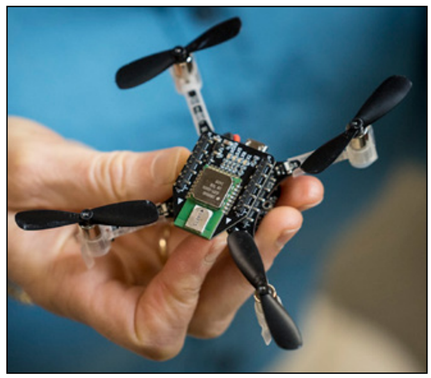
"We don't see a lot of delivery drones yet in the United States, but there are companies that have been deploying them in other countries," said Julie A. Adams of the OSU College of Engineering. "It makes business sense to deploy delivery drones at a scale, but it will require a single person be responsible for very large numbers of these drones. I'm not saying our work is a final solution that shows everything is OK, but it is the first step toward getting additional data that would facilitate that kind of a system."

The results, published in Field Robotics, stem from the Defense Advanced Research Project Agency' program known as OFFSET, short for Offensive Swarm-Enabled Tactics. Adams was part of a group that received an OFFSET grant in 2017.

During the course of the four-year project, researchers deployed swarms of up to 250 autonomous vehicles – multi-rotor aerial drones, and ground rovers – able to gather information in "concrete canyon" urban surroundings where line-of-sight, satellite-based communication is impaired by buildings. The information the swarms collect during their missions at military urban training sites have the potential to help keep U.S. troops and civilians safer.

Adams was a co-principal investigator on one of two swarm system integrator teams that developed the system infrastructure and integrated the work of other teams focused on swarm tactics, swarm autonomy, human-swarm teaming, physical experimentation and virtual environments.

"The project required taking off-the-shelf technologies and building the autonomy needed for them to be deployed by a single human called the swarm commander," said Adams. "That work also required developing not just the needed systems and the software, but also the user interface for that swarm commander to allow a single human to deploy these ground and aerial systems."



A drone in the hand of one of the OSU researchers involved in the testing for this research. (Image: Karl Maasdam)

Collaborators with Smart Information Flow Technologies developed a virtual reality interface called I3 that lets the commander control the swarm with high-level directions.

"The commanders weren't physically driving each individual vehicle, because if you're deploying that many vehicles, they can't – a single human can't do that," Adams said. "The idea is that the swarm commander can select a play to be executed and can make minor adjustments to it, like a quarterback would in the NFL. The objective data from the trained swarm commanders demonstrated that a single human can deploy these systems in built environments, which has very broad implications beyond this project."

Testing took place at multiple Department of Defense Combined Armed Collective Training Facilities. Each multi-day field exercise introduced additional vehicles, and every 10 minutes swarm commanders provided information about their workload and how stressed or fatigued they were.

During the final field exercise, featuring more than 100 vehicles, the commanders' workload levels were also assessed through physiological sensors that fed information into an algorithm that estimates someone's sensory channel workload levels and their overall workload.

"The swarm commanders' workload estimate did cross the overload threshold frequently, but just for a few minutes at a time, and the commander was able to successfully complete the missions, often under challenging temperature and wind conditions," Adams said.

This work was performed by Julie Adams, Joshua Hamell and Phillip Walker for the Collaborative Robotics and Intelligent Systems Institute, Oregon State University. For more information, download the Technical Support Package (free white paper) at mobilityengineeringtech.com/tsp under the Electronics category.

New Cyber Algorithm Shuts Down Malicious Robotic Attacks

Safe and secure operations of robotic systems are of paramount importance. Aiming for achieving the trusted operation of a military robotic vehicle under contested environments, we introduce a new cyber-physical system based on the concepts of deep learning convolutional neural networks (CNNs).

University of South Australia, Adelaide, Australia

Australian researchers have designed an algorithm that can intercept a man-in-the-middle (MitM) cyberattack on an unmanned military robot and shut it down in seconds.

In an experiment using deep learning neural networks to simulate the behavior of the human brain, artificial intelligence experts from Charles Sturt University and the University of South Australia

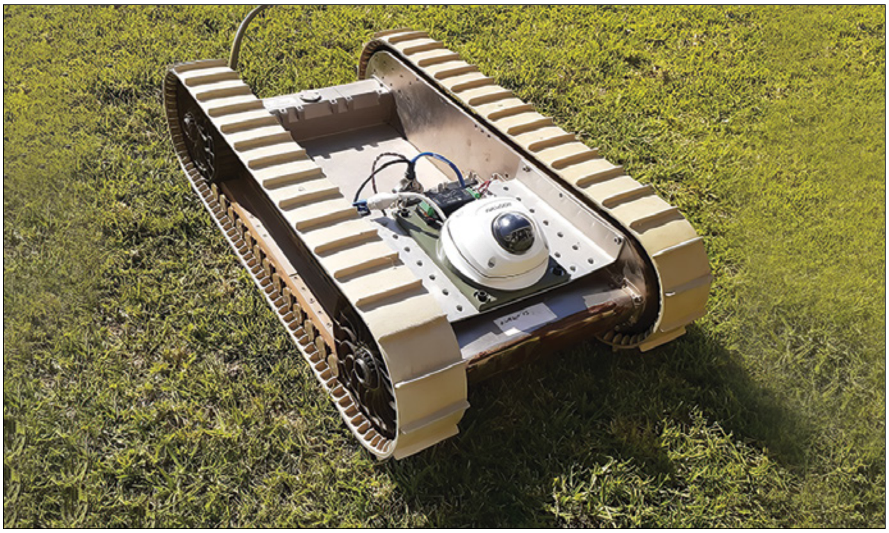


Image: The GVR-BOt used in the experiment by UniSA and Charles Sturt AI researchers. (Image: UniSA.)

(UniSA) trained the robot's operating system to learn the signature of a MitM eavesdropping cyberattack. This is where attackers interrupt an existing conversation or data transfer.

The algorithm, tested in real time on a replica of a U.S. Army combat ground vehicle, was 99 percent successful in preventing a malicious attack. False positive rates of less than 2 percent validated the system, demonstrating its effectiveness.

The results have been published in IEEE Transactions on Dependable and Secure Computing.

UniSA autonomous systems researcher, Professor Anthony Finn, says the proposed algorithm performs better than other recognition techniques used around the world to detect cyberattacks.

Professor Finn and Dr. Fendy Santoso from Charles Sturt Artificial Intelligence and Cyber Futures Institute collaborated with the U.S. Army Futures Command to replicate a man-in-the-middle cyberattack on a GVT-BOT ground vehicle and trained its operating system to recognize an attack.

"The robot operating system (ROS) is extremely susceptible to data breaches and electronic hijacking because it is so highly networked," Prof Finn says.

"The advent of Industry 4, marked by the evolution in robotics, automation, and the Internet of Things, has demanded that robots work collaboratively, where sensors, actuators and controllers need to communicate and exchange information with one another via cloud services.

"The downside of this is that it makes them highly vulnerable to cyberattacks.

"The good news, however, is that the speed of computing doubles every couple of years, and it is now possible to develop and implement sophisticated AI algorithms to guard systems against digital attacks."

Dr. Santoso says despite its tremendous benefits and widespread usage, the robot operating system largely ignores security issues in its coding scheme due to encrypted network traffic data and limited integrity-checking capability.

"Owing to the benefits of deep learning, our intrusion detection framework is robust and highly accurate," Dr. Santoso says. "The system can handle large datasets suitable to safeguard large-scale and real-time data-driven systems such as ROS."

Professor Finn and Dr. Santoso plan to test their intrusion detection algorithm on different robotic platforms, such as drones, whose dynamics are faster and more complex compared to a ground robot.

This work was performed by Anthony Finn and Fendy Santoso for the Defence and Systems Institute (DASI), University of South Australia. For more information, download the Technical Support Package (free white paper) at mobilityengineeringtech.com/tsp under the Sensors category.

Grip Tab Active Controllers

AeroVironment
Arlington, VA
703-418-2828
www.avinc.com

Advanced Technology International has issued a $2.67 million contract to AeroVironment for the production of its Tomahawk Grip Tab Active (Grip TA) controllers, that will be managed by the U.S. Marine Corps Warfighting Lab (MCWL). This contract supports the Marine Corps' Force Design 2030 and other Department of Defense (DoD) initiatives of enhancing lethality and mission success across the warfighting functions.

Under the contract, AeroVironment will deliver prototype controllers and supporting test kits, allowing evaluation of the technology's capabilities for future operations. The company's RAID System provides a large screen and ensures current and future cyber, safety, and fire control requirements are met. The controllers will be part of the larger Kinesis Ecosystem that already includes 20+ robotic systems, various input devices, and numerous AI-enhanced capabilities. This ecosystem uniquely enables multi-domain, many-to-many UxV operation through a single user interface, all while reducing the physical and cognitive burdens placed on the operator.

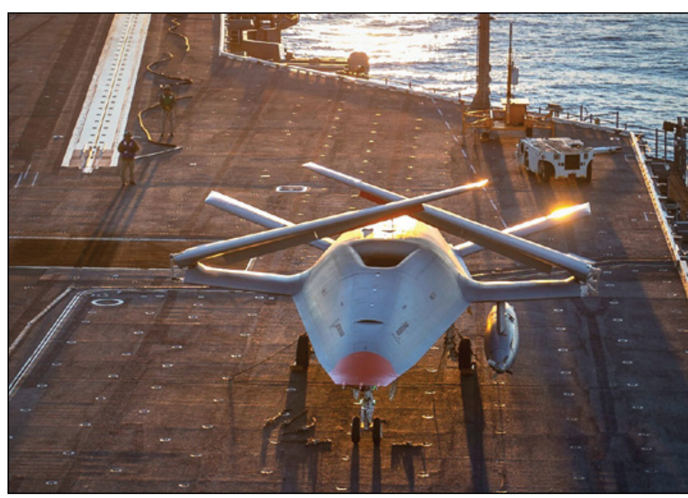
"AeroVironment is excited to deliver these systems to the DoD," said Scott Bowman, Tomahawk Robotics Product Line Manager at AeroVironment. "The tablet-based Grip Tab Active Controller will provide a larger viewing area and dedicated safety functions to operate large vehicles and weapon systems, all while maintaining the low-profile, ruggedized design our customers have come to expect from the Tomahawk product line. This controller will improve operator efficiency and unlock new use cases such as fire control and sensor-to-shooter."

This contract extends the ongoing work between the Tomahawk Robotics product line and the DoD to provide a common controller for DoD's tactical robotic systems.

www.avinc.com

MQ-25 Vehicle Management Computer Upgrade

BAE Systems
Endicott, NY
603-288-4082
www.baesystems.com/US



BAE Systems has been selected by Boeing to upgrade the vehicle management system computer (VMSC) for the U.S. Navy's MQ-25 autonomous unmanned aerial refueling system. The technology refresh will increase computing power and address obsolescence issues, providing the unmanned aerial tanker with an integrated solution that improves aircraft performance and allows for future capability growth.

The MQ-25 is the Navy's carrier-based unmanned aircraft that is tasked with performing aerial refueling missions that were previously managed by F/A-18 aircraft. The next generation vehicle management computer controls all flight surfaces and performs overall vehicle management duties for the MQ-25.

The new vehicle management computer is enabled by quad-core processors to increase computing power while optimizing the size, weight, and power footprint on the MQ-25. The multicore processor selected for the MQ-25 VMSC has also recently completed qualification on another U.S. military platform thereby reducing cost, schedule, and integration risk for this program.

BAE's new computer will replace multiple other onboard computers while providing growth capability to support future missions of the MQ-25, such as intelligence, surveillance and reconnaissance (ISR), and lays the foundation for all future carrier-based unmanned systems by enabling the manned-unmanned teaming (MUM-T) operational concept.

www.baesystems.com/US

New Satellite Connectivity for Air Force Research Aircraft

Intelsat
McLean, VA
240-308-1881
www.intelsat.com

Intelsat will supply new satellite connectivity terminals on several different U.S. Air Force Research Laboratory (AFRL) aircraft, according to a Feb. 14 announcement by the satellite network operator.

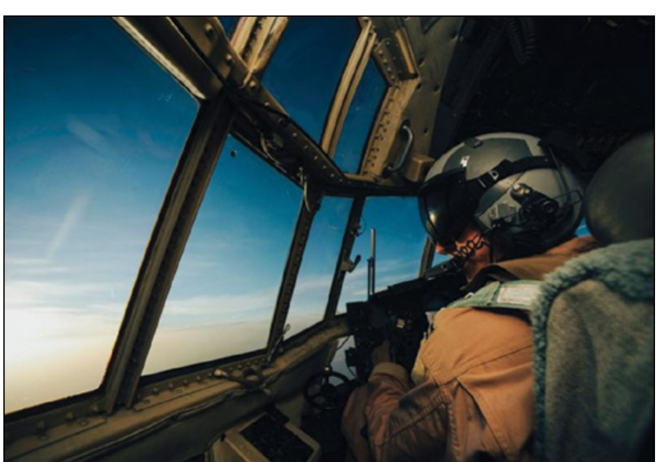
The new terminals being developed by Intelsat are the result of a one-year $9 million contract issued by AFRL under the Defense Experimentation Using Commercial Space Internet (DEUCSI) program. The DEUCSI program is intended to establish communications with military platforms via multiple commercial space internet (CSI) constellations in Geosynchronous Orbit (GEO), Medium Earth Orbit (MEO), and Low Earth Orbit (LEO) utilizing a common user terminal with the ability to alternate between space broadband providers.

Intelsat is one of the latest satellite connectivity service providers to be selected to supply aircraft terminals for the program. In September 2023, AFRL issued a multi-year contract to SES Space & Defense.

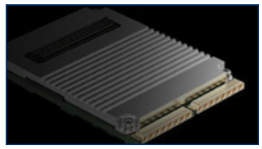
Intelsat's Resilient multi-Orbit Airborne Module (Intelsat ROAM) platform will be used for this mission. Intelsat ROAM will be integrated on aircraft selected by AFRL, utilizing different bands and constellations in multiple orbits to enable mission success and ease of use for operators without major hardware configuration changes.

"Intelsat's offering is unique because we have a virtualized network. This allows for quick integration, increased resiliency and protection which is essential in contested operations," said Intelsat's President of Government Solutions David Broadbent. "This virtual network can be changed on the fly and works with new equipment as well as legacy systems allowing the user to make critical changes based on mission needs."

www.intelsat.com



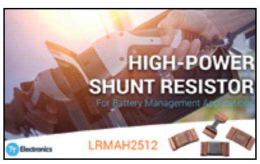
Direct RF System on Module



Mercury Systems (Andover, MA) has introduced a Direct RF system-on-module (SOM) that uses Intel Agilex FPGAs to detect and process adversary emissions from a wide portion of the electromagnetic spectrum. Direct RF components and modules directly digitize radio frequency signals at the antenna signal frequency, eliminating the analog signal down conversion stages required by legacy hardware. This approach requires extremely fast converters, high bandwidth digital data links, and powerful real-time digital signal processing. The playing card-sized DRF2580 SOM brings new capability to the Mercury Processing Platform, giving customers the ability to design aerospace and defense systems that digitize a large swath of the RF spectrum at the edge. The DRF2580 is a four-channel SOM based on the Intel Agilex 9 SoC FPGA AGRW014 that converts between analog and digital signals at 64 Gigasamples per second.

www.mrcy.com

Shunt Resistors



TT Electronics (Woking, U.K.) has introduced the LRMAH2512 surface-mount technology (SMT) shunt resistors. Designed to seamlessly complement the existing LRMAP3920 and LRMAP5930, this compact resistor boasts a robust 6 watt rating, making it the perfect solution for precision current measurements in motor control, power supply, and battery management applications. Building on TT's expertise in current sense resistors engineered to meet demanding accuracy targets, this new innovation offers values down to 200μΩ at 1 percent tolerance with TCRs down to 50ppm/°C.

www.ttelectronics.com

1U and 2U Rackmount Servers

General Micro Systems (Rancho Cucamonga, CA) launched its ultra-rugged, naval-focused 1U and 2U "Shorty 4" servers. At only 16-inches deep, the servers flexibly mount in table-top, equipment tray, sideways or vertical orientations, or can be rack mounted in space-constrained naval applications where full-sized server racks are too enormous to be practical. The leading-edge Shorty 4 servers come equipped with Intel's 4th generation Scalable Xeon® CPUs, PCIe Gen5, and DDR5 ECC memory, and are available in 1U and 2U versions. Both servers use GMS' "egg crate" honeycomb-like design, which mechanically divides the server into rigid quadrants to resist flex to dramatically enhance the unit's shock and vibration performance.

www.gms4sbc.com

Flight Certifiable Mission Computer

The FORCE2C mission computer from AMETEK Abaco Systems (Huntsville, AL) has passed its final hardware and software SOI reviews and has been officially approved by the Federal Aviation Administration (FAA). Along with the mission computer, all artifacts for certification are now available and comply with the airborne certification guidelines of DO-254 and DO-178C for fixed and rotary wing aircraft (crewed and uncrewed) and are also approved for ground-based applications. At the heart of the FORCE2C is the QorIQ-based SBC314C single board computer (SBC). Based on the Power Architecture T2081, with manufacturer's availability out to 2035, the SBC features four processing cores within the power envelope of previous dual core boards and 8 GB DDR3 SDRAM memory.

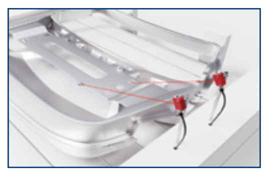
www.abaco.com

Thin Walled Tubing

Sigma-Netics (Morristown, NJ) announces the addition of precision, thin-walled metal tubes to its product offering for use in sensor systems, biomedical components, defense applications and other industrial and precision uses. These deep-drawn tubes are available as completely open or as closed at one end, and they come in various metal materials, including stainless steel, Monel, beryllium-copper, brass and bronze alloys. Using advanced tooling and manufacturing techniques, we can offer precision tolerances as low as 0.004 inch (in.) on the tube diameters, as well as tighter tolerances ranging from 0.00015 to 0.0005 in. on the wall thickness.

www.sigmanetics.com

Compact Diffuse Sensor



With the new ODT3CL1-2M laser diffuse sensor, the Sensor People from Leuze Electronic, Inc. (Duluth, GA) are extending the operating range of their 3C series distance sensors. Thanks to innovative time-of-flight (TOF) technology, the switching and measuring sensor with background suppression works with an operating range of up to two meters. This makes the ODT3CL1-2M suitable for all applications in intralogistics where long distances need to be bridged: e.g. in automated guided vehicles for monitoring the position of goods, for controlling robot grippers or in quality control. Reliable use is guaranteed even under harsh conditions. This is because the sensor satisfies the high requirements of degree of protection IP69K.

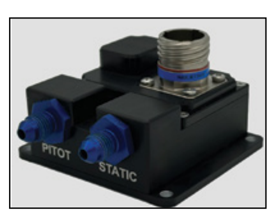
www.leuze.com

TrueView 3D Imaging Systems

GeoCue (Denver, CO) has set the stage for a groundbreaking year with the introduction of three new TrueView LiDAR Systems and an innovative FLEX pricing plan. This strategic move not only solidifies GeoCue's position as a market leader but also addresses the increasing demand for comprehensive drone mapping hardware. The newly launched TrueView 3D Imaging systems include the TrueView 540, the TrueView 545, and the TrueView 585, each catering to distinct market needs. To complement these additions, GeoCue is also introducing the innovative FLEX pricing options on flagship models TrueView 515 and 535 payloads.

www.geocue.com

NanoADC™ Air Data Computer



Genesys Aerosystems, a Moog company, (Mineral Wells, TX) announced that it has completed TSOA certification of its new NanoADC™ Air Data Computer (ADC) designed specifically for unmanned and optionally piloted aircraft. The new ADC was developed for applications where small size and light weight are critical, without sacrificing robustness, reliability, or certification requirements. Approximately the size of a deck of cards, the Genesys NanoADC (plus the MIL-SPEC connectors) weighs just 304 grams (0.67lb). Developed for its first certified application, the Genesys NanoADC is used in the new 200Kg (440lb) class Leonardo Rotary Unmanned Aerial Systems (RUAS).

www.genesys-aerosystems.com

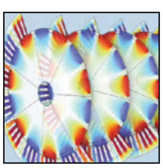
Optical Gas Imaging Camera Module

Teledyne FLIR (Goleta, CA) announced the Neutrino LC OGI optical gas imaging camera module, a made-in-the-USA, ITAR-free, mid-wave infrared (MWIR) imager for products designed to detect, measure, and visualize harmful gas emissions. The Neutrino LC OGI provides best-in-class performance within a small, lightweight, and low-power module for integration into unmanned aerial vehicles, small gimbals, handheld devices, and fixed-mounted gas leak detection systems. The Neutrino LC OGI offers multiple modes: a 640x512 VGA resolution mode with up to eight times digital zoom to maximize scene awareness; or it can operate in bin mode, which can improve sensitivity to an industry-leading <20 millikelvins (mK) to create a crisper, higher-contrast image for pinpointing leaks.

www.flir.com

Product Spotlight

MULTIPHYSICS MODELING AND SIMULATION APPLICATIONS



COMSOL Multiphysics® is a software environment for creating physics-based models and standalone simulation apps. Add-on products provide specialized functionality for electromagnetics, structural, acoustics, fluid flow, heat transfer, and chemical simulations. Interfacing products offer a unified workflow with all major technical computing and CAD tools. COMSOL Compiler™ and COMSOL Server™ are used for deploying simulation applications to colleagues and customers. https://www.comsol.com/products

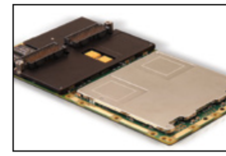
COMSOL, Inc.

SILVER FILLED EPOXY CURES AT 80°C

Master Bond EP4S-80 is a one part, silver filled epoxy for bonding, sealing and coating. It is low in viscosity and flows smoothly and easily. EP4S-80 has superb dimensional stability, low shrinkage upon curing, and contains no solvents or diluents. It bonds well to a wide variety of substrates such as metals, ceramics, composites and many plastics. https://www.masterbond.com/tds/ep4s-80

Master Bond

MPSoC XMC Module



Curtiss-Wright's Defense Solutions (Ashburn, VA) has expanded its family of Enhanced TrustedCOTS™ plug-in modules with the introduction of the XMC-529 AMD Ultrascale+™ MPSoC XMC Mezzanine Card. The XMC-529 speeds the integration of advanced system IP into VPX, ATX, and legacy VMEbus systems. The module can also be used to increase a system's overall compute power by providing FPGA co-processing to the baseboard. Enhanced TrustedCOTS XMC (VITA 42/61) cards eliminate the need for costly and time-consuming customization of the target hardware. The XMC-528/529 modules enable system integrators to quickly add IP to fielded systems without a complete redesign.

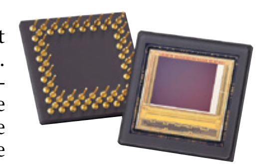
www.curtisswrightds.com

Signal Source Analyzer

Keysight Technologies, Inc. (Santa Rosa, CA) expands its SSA-X Signal Source Analyzer portfolio with three new higher frequency models – 26.5 GHz, 44 GHz, and 54 GHz – giving radio frequency (RF) engineers integrated, one-box phase noise and signal source analysis solutions for advanced wireless communications, radar, and high-speed digital applications. The new higher frequency models of the Keysight SSA-X Signal Source Analyzer series address these challenges in these advanced applications with an all-in-one platform that includes a very clean signal enabled through a direct digital synthesis (DDS) source and proprietary cross-correlation channels.

www.keysight.com

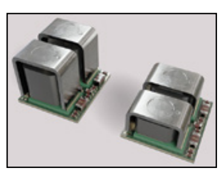
OnyxMax CMOS Image Sensor



Teledyne e2v (Grenoble, France) OnyxMax™, launched the next generation of its popular Onyx 1.3M low light CMOS image sensor. This new sensor has been designed for extremely low light conditions, down to 1 mLux. The combination of sensitivity and image resolution increases its range, allowing even small objects to be detected in harsh conditions. This makes OnyxMax ideal for a wide range of applications including science, defense, traffic cameras, broadcast, surveillance, border control and astronomy. OnyxMax features 1.3 Megapixels (1,280 × 1,024) and is available in monochrome, as standard, and with CFA arrangements available on request.

imaging.teledyne-e2v.com

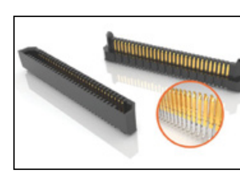
High Density Power Modules



Infineon Technologies AG (Munich, Germany) launched its TDM2254xD series dual-phase power modules that enable best-in-class power density, quality and total cost of ownership (TCO) for AI data centers. The TDM2254xD series products blend innovation in robust OptiMOS TM MOSFET technology with novel packaging and proprietary magnetic structure to deliver industry-leading electrical and thermal performance with robust mechanical design. This lets data centers operate at higher efficiency to meet the high power demands of AI GPU (Graphic Processor Unit) platforms while also significantly reducing TCO.

www.infineon.com

Slim Body Edge Rate® Connectors



Samtec (New Albany, IN) has expanded its successful line of Edge Rate® board-to-board connectors to include a higher density mated set that is half the width of previous designs and offers a lower-profile 5 mm mated height. ERF6 & ERM6 Series Edge Rate® connectors support 56 Gbps PAM4 high-speed, rugged mezzanine applications for industrial, embedded vision, instrumentation and monitoring, drones, and robotics. ERF6 & ERM6 have two rows of pins while maintaining an extremely narrow body width of 2.5 mm. Body length is 11 mm to 42.8 mm with a 0.635 mm centerline.

www.samtec.com

High-Power Multi-Chip Module

SemiNex (Danvers, MA) has introduced the High-Power Multi-Chip Module (MCM). This XCM laser module is a cutting-edge MCM with an impressive 50W high power package at 1470nm that is built for unmatched performance. With a peak power of 72.8W and the ability to achieve 55W @12A, it performs best in high power applications. The XCM's optical output power of 50W and electrical power capacity of 220W make it a powerhouse in precision control. Operating at a drive current of 10A and a drive voltage of 22V, it delivers exceptional efficiency.

www.seminex.com

Upcoming...

Webinars

The Moon and Beyond from a Thermal Perspective

Wednesday, April 17, 2024 at 2:00 pm U.S. EDT

Countries worldwide are actively engaged in advancing lunar exploration initiatives, channeling substantial resources into the development of rovers, terrain vehicles, and space stations. However, the pursuit of these endeavors is accompanied by significant technical hurdles, with thermal control systems emerging as a focal point in the overarching system architecture discussions. This 60-minute Webinar will embark on an expedition into the realm of mission-critical thermal management strategies.

Speakers:

Bryan Muzyka
Vice President – Sales and Marketing,
Advanced Cooling Technologies

Jimmy Hughes
Lead Engineer – Orbital Systems,
Advanced Cooling Technologies

Please visit www.techbriefs.com/webinar439

Webinars on Demand!

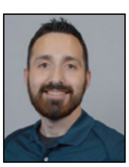
Integrating Additive Manufacturing Into Aerospace Production

Additive manufacturing offers cutting-edge applications for the aerospace industry. The latest manufacturing innovations utilized by the industry re-risk projects, accelerate program timelines, and save iteration costs, bridging the gap between prototype to production. This 30-minute Webinar will explore the journey from design concept through full-rate production, showcasing the latest additive manufacturing technologies and how they are applied in “real world” aerospace examples.

HAWK RIDGE SYSTEMS

PTI TECH | Molding the Future™

Speakers:



Jesse Haworth
3D Printing Application Engineer,
Hawk Ridge Systems

Neal Goldenberg
President,
PTI Tech

Please visit www.techbriefs.com/webinar435

Choosing a Silicone for Operation in Harsh Thermal Environments

avantor™ | NuSil™

In extreme environments, materials tend to break down from long-term heat exposure or become brittle when exposed to extremely low temperatures. For satellites and other space applications, there is risk of silicone contamination from thermal cycling where volatile compounds evaporate when heated under low pressure then condense onto cooler surfaces. This 30-minute Webinar demonstrates how to select the best silicone for operating in extreme temperatures based on their intended function.

Speaker:

Michelle Velderrain
Senior Applications Engineer,
NuSil Technology LLC, part of Avantor

Please visit www.techbriefs.com/webinar406

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April 2024, Volume 9, Number 2

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