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DEFTECH SCAN

MAY 2020

HUMAN-MACHINE
Interface & Interaction

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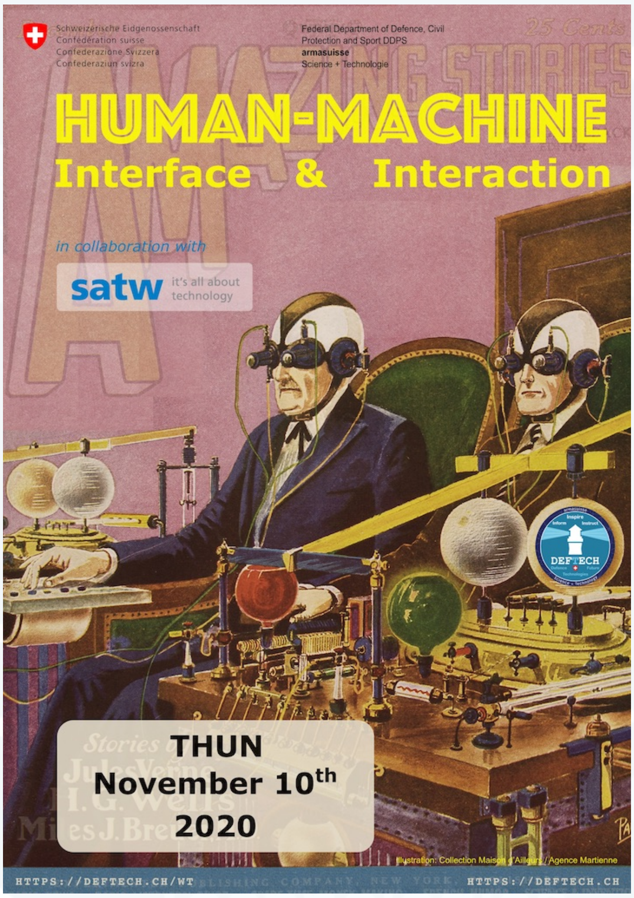
Dear Reader,

Given the circumstances, we hope that this edition finds you in good health!

You will notice that this version does not have the standard structure of the previous DEFTECH SCAN reports. It focuses on the topic of "Human Machine Interface - HMI" only, and provide an overview of the different military activities worldwide, even if you will notice that the majority of the examples are USA based. This report can be considered as a "mind opener" for the workshop of November 10th 2020.



For that occasion, we will try a format promoting more discussions and interactions around HMI rather the presentations about that theme. This DEFTECH Scan is the first step towards bringing more understanding about ongoing activities in that domain.

We wish you a very nice reading,

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Introduction and Summary

This third DEFTECH SCAN of 2020 focuses entirely on developments in a single—and increasingly pressing—category of technology and capability: Human – Machine Interactions (HMI).

HMI is an increasingly important topic of interest for defence and security communities, as autonomous "machines"—be they robots or artificial intelligence (AI) software—are more prominently integrated into forces structures, future procurement plans, and operational concepts. And while investment in several areas of HMI—for example, brain-machine interfaces—is particularly high in the United States and other large militaries, interest in and implications of HMI technology development are shared by large and small militaries throughout the world. Indeed, this report includes reporting on and analysis of companies and developments in the United States, but also the United Kingdom (UK), France, Singapore, Australia, Russia, Japan, Ukraine, Canada, China, and Israel.

HMI is also an expansive and nuanced topic area, and the acronym is also occasionally used to describe solely the *interfaces* that connect humans and machines and enable their operational partnership. This report takes a broader perspective, examining five sometimes overlapping research and development priorities and associated military tasks related to the efficient and effective teaming of humans and machines in military and security settings.

1) Building Two-Way Understanding and Trust
2) Manned-Unmanned Teaming
3) Intuitive Interface Development
4) Brain-Machine Interface
5) Decision-Support

Below are several critical themes that emerged across the five category areas:

Artificial Intelligence, Autonomy, and the Fourth Industrial Revolution: Advancement in several dual use Fourth Industrial Revolution (4IR) technologies is making more advanced and ambitious human-machine interaction capabilities possible. At the top of the list of enabling technologies is artificial intelligence, which plays a multifaceted role in facilitating increased efficiency in HMI, whether it is manned-unmanned teaming, decision-support tools, or even brain-machine hybrid intelligence. Indeed, according to Lt. General Liu Guozhi, Director of the People's Liberation Army's (PLA) Central Military Commission Science and Technology Commission, "the combination of AI and human intelligence can achieve the optimum, and human-machine hybrid intelligence will be the highest form of future intelligence."[1]

Smart sensors, virtual and augmented reality, bio- and neuro-technologies are other critical technologies that in conjunction with one another and with AI are providing "new possibles" in the area of HMI. The pace of the advancement of technologies and innovation in how they are used is also driving demand across militaries in HMI solutions that can be easily upgraded and that use open or modular systems. This is

Trust, Understanding, and Two-Way Learning: Increasing interaction between humans and autonomous machines and AI software holds great promise for both large and small militaries, but achieving this promise requires improvement in trust and understanding between humans and these autonomous agents. Militaries are investing in new ways for humans and machines to learn more about how the other makes decisions in different contexts in order to ensure that machines are able to make

[1] Elsa Kania, "Minds at War: China's Pursuit of Military Advantage Through Cognitive Science and Biotechnology", *PRISM, Vol. 8, Issue 3,* National Defense University Press, https://ndupress.ndu.edu/Journals/PRISM/PRISM-8-3/

usable recommendations and take ethical and appropriate action and that humans have trust in those decisions.

Evolving Concepts of Operations: Emerging military operational concepts and doctrine such as multi-domain operations and mosaic warfare stress the need for more unmanned systems across all military domains. In these visions of future combat and force structure, large formations of manned platforms are replaced in part with pods of manned and unmanned platforms operating together with the manned platform frequently operating as "a C2ISR platform for a group of standoff missiles and sensor-and EW-equipped" UAVs.[2] Development of HMI technologies and novel interfaces that enable improved communication and collaboration between manned and frequently autonomous unmanned platforms and systems is essential to effective implementation of these concepts. In addition, as these technologies become deployable, they are enabling small and large militaries to conceive of and test new tactics and means of "operationalizing autonomy."

Situational Awareness, Cognitive Burden, and Mission Effectiveness in the Modern Operating Environment: The increasing speed with which events on the modern battlefield and in the broader operating environment are taking place in the era of "intelligentized" and autonomous ware is placing a premium on "speed, efficiency, and flexibility" in decision-making in order to keep pace.[3] New modes of communications between humans and machines are designed to meet this challenge while also enhancing situational awareness, reducing the cognitive burden of operators, and, ultimately, ensuring mission effectiveness.

Voice and gesture control of robots, for instance, reduce communications latency and ensure that operators do not have to put their heads down or focus on displays. Digital cockpits allow pilots to configure the cockpit to their comfort level and mission and to control multiple displays simultenously with their eyes or the movement of their head. Brain-machine interfaces could enable control of drone swarms or other machines through human brainwaves.

[2] Bryan Clark, Dan Patt, Harrison Scramm, "Mosaic Warfare: Exploiting Artificial Intelligence and Autonomous Systems to Implement Decision-Centric Operations", Center for Strategic and Budgetary Assessments, 2020, https://csbaonline.org/research/publications/mosaic-warfare-exploiting-artificial-intelligence-and-autonomous-systems-to-implement-decision-centric-operations

[3] Elsa Kania, "Minds at War: China's Pursuit of Military Advantage Through Cognitive Science and Biotechnology", *PRISM, Vol. 8, Issue 3,* National Defense University Press, https://ndupress.ndu.edu/Journals/PRISM/PRISM-8-3/

Building Two-Way Understanding and Trust

Key Insights:

- Among the biggest challenges constraining interaction between humans and AI for all militaries seeking to integrate AI and autonomous systems is a lack of trust in and understanding of AI produced outputs. This lack of trust stems first from the frequently black-box nature of AI. It also stems from the inability of current AI to develop Theories of the Mind that incorporate elements of social behavior and intelligence that are central to interactions between humans.
- Ensuring trust as well as a common understanding and shared perception of the environment in which human-machine partners are operating is crucial to developing reliable and replicable teams and flexible and effective decision-making in complex, contested, and crowded contexts
- Developing this trust and understanding requires not only humans learning more about their AI partners, but also two-way learning that enables AI to learn more about how humans think, interact, communicate, and behave, especially in stressful environments
- Efforts to incorporate AI into HMI in modern strategic, operational, and tactical environments can be complicated by the need for both small and large militaries to operate with allies and partners. HMI solutions must take into account this need and, in the best case scenario, involve proactive collaboration with partners to ensure common protocols, standards, and approaches to interacting with autonomous systems and AI and ensuring a common coalition situational awareness

Human-Agent Knowledge Fusion: HMI solutions are focused on improving efficiency and coordination between humans and both physical machines and software. Critical to the success of more efficient engagement with the latter is improving trust and understanding between humans and AI as well as the ability of AI to more precisely model their human partners. According to the US Defense Advanced Research Projects Agency (DARPA) , "Current AI agents are able to respond to commands and follow through on instructions that are within their training, but are unable to understand intentions, expectations, emotions, and other aspects of social intelligence that are inherent to their human counterparts."[4]

Closing this two-way gap in trust and understanding is a growing focus area for militaries around the world. While the examples cited in this report are largely from a large and well-funded military, these research areas are significant for all militaries as AI is incorporated in a growing range of missions and tasks, including intelligence processing, decision-making support, human performance enhancement, autonomous systems, cognitive sensing and communications, information and cyber operations and beyond.[5]

The inability of artificial intelligence (AI) to represent and model human partners is the single biggest challenge to human-machine teaming today."—DARPA, "Using AI to Build Better Human-Machine Teams", March 21, 2019

For example, on April 20, the United States Army released a pre-solicitation notice for a Human-Agent Teaming Research and Engineering Services contract to design ways to facilitate "the exchange of information between the soldier, system, and environments."[6] The effort seeks to improve the ability of AI to

[4] "Using AI to Build Better Human-Machine Teams", DARPA, March 21, 2019,

[5] Tate Nurkin and Stephen Rodriguez, "A Candle in the Dark: US National Security Strategy for AI", Atlantic Council, December 10, 2019

[6] Aaron Boyd, "Army Wants to Study How Humans Team With AI-And Vice Versa", *NextGov*, April 21, 2020,

“collaboratively make decisions and solve problems as part of teams, maximizing the strengths and minimizing the weaknesses of individual team members-human or autonomous.”[7]

The project’s deliverables will intersect with other categories of applications of HMI covered in this report, including manned-machine teaming and brain-machine interfaces. For example, the Army seeks to integrate this research with its Next Generation Combat Vehicle Program (an autonomous vehicle program) and “iterate on existing methods and develop new ways of mapping soldiers’ brain functions, psychology and behavior when interacting with AI teammates.”[8]

Unsurprisingly, the area of machine-human two – way trust and understanding is also a concern for DARPA. In March 2019, the organization established the Artificial Social Intelligence for Successful Teams (ASIST) to advance understanding between AI and humans. ASIST aims to create AI agents that demonstrate a machine Theory of the Mind (ToM) that can observe and understand their environment and human partners, “developing useful context aware actions, and executing those actions at appropriate times.”[9]

In the first phase of ASIST, DARPA is conducting experiments with single human-machine interactions to understand how well the AI can determine human objectives and situational awareness and, based on this understanding, predict human teammate actions. Over time, the program will investigate teaming between multiple human team-members and AI agents in order to test the AI’s capacity to develop and understand a broad cognitive model of team objectives and behaviours and its ability to recommend situationally relevant actions.[10]

Another Layer of Trust: Allies and Partners: Small and medium-sized militaries are also increasingly working with larger militaries around the world to resolve another layer of complexity around human – machine understanding and trust; namely, how to establish common standards and technologies to facilitate human interaction with AI among allies and / or coalition partners.

As an article appearing in the Spring 2020 volume of the Texas National Security Review of Texas A&M University noted, “The data- and resource-intensive nature of AI development creates barriers to burden-sharing and interoperability that can hamper multinational operations. By accelerating the speed of combat and providing adversaries with a tool to heighten mistrust between allies, AI can also strain the complex processes that allies and security partners use to make decisions.”[11]

Reporting from February 27 detailed joint research by the United States-United Kingdom Distributed Analytics and Information Science International Technology Alliance on designed to improve common situational awareness and improve coalition decision-making, especially in the contested, complex, and fast-moving operating environments in which coalition partners frequently operate. The alliance brings together the United States Army Research Lab (ARL) and researchers from UK academic institutions.[12]

There are two main components to this research. The first is known as coalition situational understanding (CSU), which applies explainable artificial intelligence to complex coalition tasks.

Increasing understanding between these human and autonomous agent partners will be critical, placing a premium on the second area of interest: human–agent knowledge fusion, or HAKF. According to Pham, “HAKF supports explainability and tellability naturally as conversational processes between human and

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[7] Aaron Boyd, “Army Wants to Study How Humans Team With AI-And Vice Versa”, *NextGov*, April 21, 2020,
[8] Aaron Boyd, “Army Wants to Study How Humans Team With AI-And Vice Versa”, *NextGov*, April 21, 2020,
[9] “Using AI to Build Better Human-Machine Teams”, DARPA, March 21, 2019,
[10] “Using AI to Build Better Human-Machine Teams”, DARPA, March 21, 2019,
[11] Erik Lin-Greenberg, “Allies and Artificial Intelligence: Obstacles to Operations and Decision-Making”, Texas National Security Review, Vol 3, Iss 2, Spring 2020, March 5, 2020
[1212] “Army researchers enhance AI critical to Soldier-machine teamwork”, U.S. Army CCDC Army Research Laboratory Public Affairs, February 27, 2020,

machine agents. This enables AI agents to provide explanations of results arising from complex machine learning tasks and to receive knowledge that modifies their models or knowledge basis."[13]

Collaborating on and building trust in AI is a part of other defence and security–related partnerships around the world. For example, in June of 2019, the United States and Singapore held an engagement "that represented the first step by both countries to officially operationalize a defense partnership in the area of artificial intelligence."[14] The U.S. DoD's Joint Artificial Intelligence Center (JAIC) and Singapore's Defense Science and Technology Agency (DSTA) held a multi-day exchange to promote collaboration on the use of AI. The exercise had a particularly strong focus on humanitarian assistance and disaster relief operations, though there are indications that the defense – related collaboration runs deeper than that one mission set. A June 27, 2019 statement about the exercise noted that it represented a "first step."[15]

Manned-Machine Teaming

- The need to integrate unmanned systems into militaries around the world are placing a premium on technologies and operational concepts that enable human control of suites of unmanned systems that are capable of operating either independently or in conjunction with manned platforms.
- The delivery of the first Loyal Wingman drone to the Royal Australian Air Force in May marked a significant milestone in the development of manned-machine teaming technologies and concepts. Variations of the Loyal Wingman concept are being trialed or investigated in militaries throughout the world and go beyond merely teaming fighter jets with unmanned systems. Other applications include pairing helicopters with UAVs, manned ground vehicles with unmanned ground vehicles, and, potentially manned platforms with unmanned platforms across multiple domains.
- These human-machine teaming concepts and technologies provide several advantages to small and large militaries throughout the world, including serving as a force multiplying capability, offering operational flexibility, increasing situational awareness of both manned and unmanned platforms, and potentially relieving operator cognitive burden.

Advances in Loyal Wingmen and Manned-Unmanned Teaming: On May 5, Boeing Australia delivered the first unmanned Loyal Wingman aircraft to the Royal Australian Airforce (RAAF). Boeing described the event as "a historic milestone for the company and the Commonwealth."[16] Boeing anticipates mass production of the aircraft by the middle of the 2020s.[17]

The aircraft is the first of three prototypes to be delivered as part of the Airpower Teaming System (ATS) program, which is designed to leverage AI to extend the capabilities of manned and unmanned platforms through teaming multiple loyal wingman aircraft with a single manned aircraft. The Loyal Wingman UAV is 38 feet long and has a 2,000 nautical mile range with a nose that can be removed to fit various

[13] "Army researchers enhance AI critical to Soldier-machine teamwork", U.S. Army CCDC Army Research Laboratory Public Affairs, February 27, 2020,
[14] Prashanth Parameswaran, "Whats in the New US-Singapore Artificial Intelligence Defense Partnership?", *The Diplomat*, July 1, 2019, https://thediplomat.com/2019/07/whats-in-the-new-us-singapore-artificial-intelligence-defense-partnership/
[15] Prashanth Parameswaran, "Whats in the New US-Singapore Artificial Intelligence Defense Partnership?", *The Diplomat*, July 1, 2019, https://thediplomat.com/2019/07/whats-in-the-new-us-singapore-artificial-intelligence-defense-partnership/
[16] "Boeing Rolls Out First Loyal Wingman Unmanned Aircraft", Boeing MediaRoom, May 5, 2020,
[17] Jamie Freed, "Boeing could produce Loyal Wingman fighter-like drone by middle of decade: executive", *Reuters*, May 4, 2020,

payloads.[18] Together, this suite of manned and unmanned aircraft constitute a flexible capability that is increasingly shaping the future of airpower and broader military capabilities development.

The Australian program is the most advanced and most high-profile of an array of programs militaries of different sizes are pursuing on similar capabilities. In the United States, Kratos' Valkyrie aircraft is being

Figure 1: The Boeing Australia prototype Loyal Wingman drone (source: Boeing)

developed with a similar objective of offering a low-cost force multiplier capability that teams with manned aircraft. Also, of note in February 2020, Boeing and the U.S. Navy demonstrated the ability to control unmanned two E/A-18G Growler electronic warfare aircraft with a third manned fighter acting as mission control for the unmanned aircraft.[19]

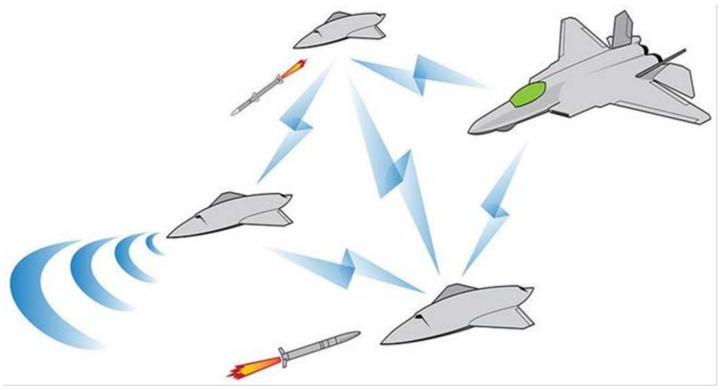

Figure 2: A diagram of the Combat Support Unmanned Aircraft concept, source: Japan Ministry of Defense

Several other countries are also pursuing this capability.

As highlighted in an Atlantic Council report on Japan-US defence collaboration released in April[20], Japan's Acquisition, Technology, and Logistics Agency (ATLA) has had interest in the loyal wingman concept since 2016. ATLA's "Combat Support Unmanned Aircraft." involves UAVs operating in conjunction with a manned aircraft—in Japan's case, likely the under-development F-3. In drawings included with ATLA's description of the program, three unmanned systems are flying in formation with the F-3, each carrying out a different mission: one is a sensor platform, the second is firing an air-to-air missile, and the third is drawing enemy fire away from the

[18] Jamie Freed, "Boeing could produce Loyal Wingman fighter-like drone by middle of decade: executive", *Reuters*, May 4, 2020,

[19] David B. Larter, "US Navy and Boeing use manned jet to control drone Growlers", *C4ISRNET*, February 4, 2020,

[20] Tate Nurkin and Ryo Hinata-Yamaguchi, "Emerging Technologies and the Future of US-Japan Defense Collaboration", April 2020,

manned aircraft.[21]. As with the Boeing / RAAF prototype, the unmanned systems will be able to carry out a range of missions beyond those in the picture.

In the summer of 2019, the UK's Rapid Capabilities Office (RCO) and Defence Science and Technology Laboratory announced the awarding of preliminary design contracts for a Royal Air Force program known as the Lightweight Affordable Novel Combat Aircraft concept. Phase one of the project is assessing the "key risks and cost-capability trade-offs for an operational Loyal Wingman concept" with the ambition of initial flight trials of demonstrator air vehicles by 2022.[22]

Russia is also testing a similar concept. On September 27, 2019, the Russian Ministry of Defence announced it had conducted a test flight that teamed a S-70 Okhotnik UAV and a Su-57 combat aircraft. The Okhotnik UAV served as a "sensor amplifier" for the Su-57, flying ahead of the manned aircraft and using its onboard sensors to feed information back to the pilot.[23]

Figure 3: An image of a Russian Su-57 teaming with an Okhotnik UAV in September 2019, source: Russian Ministry of Defence

This area of manned-unmanned teaming is not solely fixated on partnering fixed wing fighter jets and unmanned systems. Last month, Italian defence contractor Leonardo began a series of flight trials in the United Kingdom in which a UAV is controlled by the crew of Lynx Wildcat helicopter. The UAV will be piloted by the observer / gunner in the helicopter's left-hand seat while data from the UAV's electro-optical payload will be fed into the helicopter's standard displays—as if the payload on the UAV was actually on the helicopter. According to Leonardo, "the big idea is to test the cognitive burden and the pilot and then trying to reduce that."[24]

European Man-Machine Teaming Studies: On September 30, 2019, the French Direction Generale de L'Armament (DGA), the French Procurement Agency, commissioned 19 new man machine teaming project studies designed to develop artificial intelligence and human-machine interface (HMI) technologies for future combat aircraft.[25]

The program was originally launched in March 2018 and is being led by Dassault Aviation in conjunction with Thales[26]. Research studies to date are focused on six research areas: 1) virtual assistant and intelligence cockpit; 2) interfaces; 3) mission management; 4) intelligence sensors; 5) sensor services; and 6) robotic support and maintenance. The 19 studies commissioned in September are in addition to 19 projects commissioned in 2018.[27]

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[21] "Unmanned Wingman for Japan's Piloted Force Planned for 2030s," *Aviation Week*, September 23, 2016, https://aviationweek.com/defense-space/unmanned-wingmen-japans-piloted-force-planned-2030s.
[22]
[23] Gareth Jennings, "Russia flies MUM-T trial with Okhotnik UAV and Su-57 fighter", *Janes,* September 27, 2019,
[24] Dominic Perry, "Leonardo to test manned-unmanned teaming with Wildcat helicopter", *FlightGlobal*, February 25, 2020
[25] Nicolas Fiorenza, "DGA commissions man machine teaming studies", *Jane's Defence Weekly,* November 22, 2019
[26] "Launch of the Man Machine Teaming advanced study programme", Dassault Aviation, March 16, 2018
[27] Nicolas Fiorenza, "DGA commissions man machine teaming studies", *Jane's Defence Weekly,* November 22, 2019

Also in September 2019, the UK Defence and Security Accelerator (DASA) announced it awarded funding to six companies for the development of concepts for semi-autonomous unmanned reconnaissance systems to work in collaboration with manned forces for the British Army. The six awards were to Leonardo, General Dynamics (UK), QinetQ, Horiba-Mira, SCISYS, and Tekever, each of which would work on three separate areas related to man-machine teaming:[28]

- Leonardo and General Dynamics (UK) would focus on integrating the control station for UAVs into these platforms
- QinetQ and Horiba-MIRA will focus on how high levels of automation will reduce the cognitive burden for vehicle commanders and helicopter crews
- Consortiums of small and medium-sized enterprises led by SCISYS and Tekever will explore the benefits of open architectures and operating UAVs beyond visual range

French – UK Off-Board Maritime Mine Counter Measures Program: Human-machine teaming is not limited to variations of the autonomous loyal wingman concept. There are also efforts to increase operational flexibility and reduce danger to manned platforms through the incorporation of new technologies and operational concepts that offer autonomous operation of unmanned systems, remote-control of unmanned systems, or manned operations to achieve a specific mission.

In late 2019, a Thales-led industry team announced it was embarking on full-scale demonstrations of a French / UK (FR/UK) Maritime Mine Countermeasures (MMCM) program based on Operational Scenarios and Task Vignettes (OSTVs). The ambition is to deliver two MMCM operational demonstrator systems in 2020 capable of detecting, localizing, classifying, identifying, and disposing of maritime mines..[29]

The system of systems concept revolves around a manned command vessel, an unmanned or optionally manned surface vehicle, three unmanned underwater vehicles, towed synthetic array aperture sonar module (TSAM), and a multi-shot mine neutralization system.

The system relies on a portable operations centre for mission management and efficient HMI. Each POC includes three triple-screen operator consoles, plus a large screen display for the mission supervisor. "The supervisor is responsible for overseeing the tactical situation and making decisions. You then have positions for the USV pilot, the TSAM pilot and the sonar analyst"[30], according to Antoine Caput, Thales' MMCM program director. The system is capable of operating in autonomous mode absent human intervention; remote operation in which the operator can manage speed and heading and pass simple commands; and in a fully manned mode.

[28] "UK DASA awards funding to companies for Manned-Unmanned Teaming", September 4, 2020
[29] Richard Scott, "Into the minefield" MMCM swis ahead for autonomous mine countermeasures, *Janes Navy International,* November 22, 2019
[30] Richard Scott, "Into the minefield" MMCM swis ahead for autonomous mine countermeasures, *Janes Navy International,* November 22, 2019

Figure 4: The Thales systems of systems concept for the MMCM solution (left, source: Thales UK) and the inside of the portable operations center (right, source: Shaun Roster photography / Thales, from Janes)

The United States Navy tested a similar concept in September 2019, successfully demonstrating single-sortie mine-hunting in which an autonomous boat is able to sweep for mines, detect a mine-like object, classify it, and then deploy another system to destroy the mine.[31]

Intuitive Interface Development

- The ability of small and large militaries to achieve sought after efficient HMI frequently rests on the development of interfaces that reduce the friction and latency of communication between humans and machines and are intuitive for humans to use.
- There is a growing focus on interfaces that do not require human operators to put their head's down or to take their attention away from the rapidly unfolding tactical or operational environment in which they are in. In addition, interest is growing in (and technology is developing to support) interfaces that allow for gesture or voice control of machines and the use of virtual and augmented reality to enable interaction between humans and machines in a range of settings
- The development of new interfaces and the ability to "operationalize autonomy" is driving innovation in the area of operational concepts and tactics for militaries of all sizes throughout the world.

The Virtual Cockpit: A video posted to the UK government's Forces TV YouTube channel on February 13 offered insight into the radical redesign being considered for the UK's Tempest fighter jet, which is currently under development and expected to be ready in the early to mid-2030.

The cockpit is a clean, software reconfigurable wearable cockpit design that lacks physical displays or controls other than a joystick. The core element of this cockpit is the Striker II display helmet that enables pilots to view and manipulate different displays through an intuitive virtual interface.

[31] Larter, David, "US Navy Makes Major Breakthrough in Autonomous Weapons", *Defense News,* 10 September 2019, https://www.defensenews.com/digital-show-dailies/dsei/2019/09/10/the-us-navy-just-had-a-major-breakthrough-with-autonomous-weapons/

One important function built into the system is "eye tracking", which BAE systems engineer Chris Hepburn noted allows the pilot to "have one set of controls and operate multiple displays" rather than have multiple interfaces per display.[32]

The virtual and reconfigurable design not only offers ease of use, but also enables easy upgrades. According to Suzy Broadbent, the Human Factors Lead for Research and Technology at BAE Systems, the program will "stop the cockpit from getting too cluttered. [The program] is trying to keep it as clean and easy to upgrade as possible."

Figure 5: A screenshot of a mock-up of the Tempest cockpit design and Striker II helmet (source: Forces TV)

Virtual Training Interfaces: During the I/ITSEC exhibition in Tampa, FL in early December 2019, Canadian training and simulation company CAE unveiled its "Trax Academy" program. The program is advertised as a student-centric and self-paced training continuum that helps get pilots through training faster.[33] The system includes several novel task-specific human machine interfaces.

Trax Academy offers a three-phase training continuum—from Learn to Practice to Perform—each of which involves different interfaces. The Learn phase leverages a mobile application that can be accessed from a tablet or laptop to deliver training courseware. The Practice phase revolves around a virtual reality trainer and a virtual assistant that provides on-going and immediate correction as part of an immersive modules that create familiarity with cockpit and training procedures. This virtual trainer also includes physical controls, such as a joystick, throttle, and rudder with force feedback, and haptics for dashboard instrumentation physical feedback.

[32] "Cockpit of the Future", Forces TV YouTube channel, February 13, 2020, https://www.youtube.com/watch?v=HDCdBEd_qAE
[33] CAEvidogallery, I/ITSEC 2019-Launch of CAE Trax Academy, YouTube, December 3, 2019, https://www.youtube.com/watch?v=gsbM3yJw52s

The final stage—Perform—places the trainee in a high-fidelity training device and, over time, a live aircraft.[34]

The company's promotional videos and marketing materials distributed at the UMEX conference[35] held in Abu Dhabi in February 2020 stress how the ease of use of the various interfaces speed up the pilot training process.

Figure 6: An overview of the stages of Trax Academy and the primary HMI tool associated with each. (Source: CAE Trax Academy video on YouTube)

Operationalizing Autonomy with Two Clicks: In July 2019, DARPA's Squad X Experimentation initiative conducted tests in collaboration wi0th the United States . Marines in Twentynine Palms, California. The exercises tested two complementary HMI-enabling systems that allow infantry squads to collaborate with AI and autonomous systems to make better decisions in complex, time-critical combat situations. A key objective of the program is to "operationalize autonomy."[36]

One of the tested systems was Lockheed Martin's Augmented Spectral Situational Awareness and Unaided Localization for Transformative Squads (ASSAULT) system. The system includes a vest fitted with sensors and a distributed common world model that sends tracking information to their unmanned ground vehicle partners. The UGVs then carry out several roles to support the dismounted marines and soldiers, including providing reconnaissance of areas ahead of the unit as well as flank security and surveying the perimeter. UGV inputs are sent directly to squad members' handheld Android Tactical Assault Kits (ATAKs). According to DARPA, "within a few screen taps, squad members accessed options to act on the systems' findings or adjust the search areas."[37]

The second system tested was CACI's BITS Electronic Attack Module (BEAM) Squad System (BSS), which comprises of a network of warfighter and unmanned nodes. The June 2019 experiment included a Super Node, described as a sensor-laden optionally manned, lightweight tactical all-terrain vehicle, that communicated with backpack nodes and an airborne BEAM on a Puma unmanned aerial system. The BSS provides situational awareness, detects electronic emissions and attack, and collaborates to geolocate

[34] CAEvideogallery, CAE Trax Academy, YouTube, February 13, 2020, https://www.youtube.com/watch?v=jHLACQ815LI
[35] The Author attended the UMEX event and collected promotional material on Trax Academy
[36] "With Squad X, Dismounted Units Partner with AI to Dominate Battlespace", DARPA.Mil, July 12, 2019, https://www.darpa.mil/news-events/2019-07-12
[37] "With Squad X, Dismounted Units Partner with AI to Dominate Battlespace", DARPA.Mil, July 12, 2019, https://www.darpa.mil/news-events/2019-07-12

signals of interest. AI synthesizes the information and provides optimized information to the squad members via the handheld ATAK.[38]

The HMI tools are critical to the success of these systems and DARPA has set as a goal designing a user interface "so intuitive that training takes an hour or less and any available action is accessible in two screen taps."[39]

From Technologies to Tactics and Operational Concepts: One of the key objectives of the Squad X program is not only to develop new HMI technologies, but also to build novel tactics that are now made possible by more efficient partnership between humans and machines. Lt. Col Phil Root, the Squad X program manager, noted that the program was about both "developing hardware and tactics that allow us to operate seamlessly within a close combat ground environment."[40]

Figure 7: The HMI components of Lockheed Martin's ASSAULT system designed to support DARPA's Squad X prorgam (source: https://www.youtube.com/watch?v=DgM7hbCNM

Similarly, the Israeli Defence Force (IDF) is increasingly incorporating a range of new autonomous unmanned ground vehicles into its operations with a particular emphasis on rethinking tactics and operational concepts. Sahar Gal, the CEO of Israeli company General Robotics, which provides the DOGO UGV to the IDF, highlighted the need for tactical innovation to accompany technical innovation: "We need to adjust the concepts of operation of the special forces. They have their normal procedures, such as how to break into aroom, or how they send in canines, and now we're saying to them, 'there's another, better way."[41]

Gesture and Voice Control: In October 2019, Ukrainian company Infocom unveiled its new Scorpion combat UGV. The tracked UGV is designed for combat operations and offers various levels of autonomy, including "follow me", waypoint navigation, and return home. Notably, the Scorpion can reportedly by remotely operated and controlled by "voice, gestu[42]res, smart glasses, smart phone, tablet, or PC."

The development of new HMI technologies and techniques to control unmanned systems has gained momentum over the last two years as both small and large militaries seek to minimize complexity, latency,

[38] "With Squad X, Dismounted Units Partner with AI to Dominate Battlespace", DARPA.Mil, July 12, 2019, https://www.darpa.mil/news-events/2019-07-12
[39] "With Squad X, Dismounted Units Partner with AI to Dominate Battlespace", DARPA.Mil, July 12, 2019, https://www.darpa.mil/news-events/2019-07-12
[40] "With Squad X, Dismounted Units Partner with AI to Dominate Battlespace", DARPA.Mil, July 12, 2019, https://www.darpa.mil/news-events/2019-07-12
[41] Melanie Roverie, "Unmanned edge: Integrating robotic systems into the IDF", *Jane's Defence Weekly*, November 21, 2019
[42] Melanie Rovery, "Arms and Security 2019: Infocom displays new Scorpion combat UGV", Janes Defence Weekly, October 11, 2019, https://janes.ihs.com/Janes/Display/FG_2413556-JDW

“heads down” control mechanisms, and the resulting reduction in situational awareness in fast-moving tactical environments associated with remote operations.

For example, U.S.-based Charles River Analytics has developed a range of solutions that enable natural, head’s up direction of robots, including the Supervisory HMI Enabling Practical Autonomous Robot Direction (SHEPARD and “Follow-Me” interface. SHEPARD’s hands-free HMI includes a context-sensitive control module based on a model of operator intent. According to the company’s website, “by fusing context cues with inputs provided from multiple control modalities (e.g., voice, gesture), the system infers a model of operator intent that can be used to resolve ambiguous commands and provide situation-appropriate feedback. It uses smart devices, such as a smart watch, for easy communication with robots.”[43]

Brain-Machine Interfaces

Key Insights:

- The accelerated pace of military and security operations and need for nearly instantaneous decision-making by defence communities throughout the world is driving interest in a different sort of advanced interface between humans and machines. Brain-machine interfaces seek to enable humans to control machines with their minds.
- Research is moving quickly in this area as several large militaries have established programs to collaborate not only with the traditional defence industry, but primarily academia to develop new ways of harnessing human thoughts and the human brain to facilitate HMI. There is also significant overlap between the development of these technologies by militaries and the medical industry
- .There are significant overlaps between defence and security community research on brain – machine interfaces and research being conducted in the medical field. The capability to, for example, translate brainwaves into physical actions are relevant across both disciplines.

The People’s Liberation Army’s (PLA) Pursuit of Cognitive Dominance: HMI is a critical part of an emerging competition between militaries of all sizes in the “cognitive domain” largely to ensure that operators are able to keep up with the increasing pace of military operations. As a result, militaries are investing in the development not only of human-machine hybrid intelligence but also the capacity to manipulate brain waves to achieve military objectives.

Elsa Kania, an expert on China’s military-technological development, noted in a February article published in the U.S. National Defense University’s *PRISM* publication that China in particular has embraced the need for “mental / cognitive dominance” and “intelligence dominance.” Achieving this dominance requires a “competition for cognitive speed and quality advantage” and ultimately implies command and control to be managed through “brain-machine fusion.”[44] Moreover, Kania’s review of People’s

> *“Combining the high functioning of the machine with the high intelligence of human beings to achieve high performance of equipment systems, this is an important domain of application in intelligent science.” – Hu Dewen, head of the PLA’s National University of Defense Technology, Cognitive Science Research Team*

[43] “SHEPHARD uses smart devices—like a watch—to make communication with military robots easy”, Charles River Analytics, https://www.cra.com/work/case-studies/shepard

[44] Elsa Kania, “Minds at War: China’s Pursuit Of Military Advantage Through Cognitive Science and Biotechnology—Analysis”, Eurasia Review, February 23, 2020, https://www.eurasiareview.com/23022020-minds-at-war-chinas-pursuit-of-military-advantage-through-cognitive-science-and-biotechnology-analysis/

Liberation Army writing shows an interest in "mental confrontation" involving "attack, defense, and enhancement of the brain" to include "brain control weaponry."[45]

Brain-machine interfaces are critical to achieving this component of the "intelligentization"[46] of warfare. According to Kania, there are several notable on-going programs in this area, including, but certainly not limited to:[47]

- The PLA's National University of Defense Technology (NDUT) Cognitive Science Basic Research Team has been engaged in research on brain-machine interfaces "for more than 20 years" and has produced technologies that allow individuals to "operate a robot, drive a vehicle, or even operate a computer, enabled by the processing of EEG signals."
- The Academy of Military Medical Sciences (AMMS) has also conducted extensive research on brain machine interface. Wang Changyong, Deputy Director of the Institute of Military Cognition and Brain Science at AMMS has pursued both EEGs placed on the scalp and implants in the cranial nerves of macaques, which "are believed to be an apt model to simulate human cognition, concentrating on neural information acquisition. It has also teamed with commercial enterprise specialising in the development of EEG products in support a range of dual-use applications including attention and memory training
- The Chinese government has also begun to hold a national competition on brain-computer interfaces, which is co-sponsored by the PLA NUDT
- Tianjin University and China Electronics Corporation are jointly developing a brain-computer interface (BCI) chip known as "Brain Talker" that decodes brainwave information.

BMI and Medical Research

Research in BMI is not limited to defence and security communities. Academia and applied research are also engaged in BMI research largely in support of the medical community to support recovery of stroke and paralysis patients as well as individuals who have lost their ability to speak.

For example, In October 2019 researchers from Russian corporation Neurobotics and the Moscow Institute of Physics and Technology (MIPT) demonstrated a way to visualize a person's brain activity as actual images mimicking what they observe in real time. The technology was designed to enable new post-stroke rehabilitation devices controlled by brain signals, according to a press-release on the MIPT website.

Similarly, in April 2019, a team at the University of California San Francisco (UCSF) published a paper in *Nature* magazine showing that it had used a two-step process to decode human thoughts using an array of electrodes surgically placed onto the brain that controls movement, and a computer simulation of a vocal tract to reproduce the sounds of speech. The capability is still being improved but could be useful for people who have lost the ability to speak or struggle with disorders such as ALS that cause loss of control of muscles.

Direct Neural Enhancements and the N3 Program: In November 2019, the US Army's Combat Capabilities Development Command released a report authored by a study group from the DoD Biotechnologies for Health and Human Performance Council (BHPC) entitled "Cyber-Soldier 2050-

[45] Elsa Kania, "Minds at War: China's Pursuit Of Military Advantage Through Cognitive Science and Biotechnology—Analysis", Eurasia Review, February 23, 2020, https://www.eurasiareview.com/23022020-minds-at-war-chinas-pursuit-of-military-advantage-through-cognitive-science-and-biotechnology-analysis/

[46] "Intelligentization" is a term frequently used in Chinese military writings to describe the increasing incorporation of autonomy, robotics, and artificial intelligence on the battlefield. It is frequently viewed in comparison with the "informatization" of warfare in which the pace and scale of the communication of information has increased through the use of advanced information technologies.

[47] Elsa Kania, "Minds at War: China's Pursuit Of Military Advantage Through Cognitive Science and Biotechnology—Analysis", Eurasia Review, February 23, 2020, https://www.eurasiareview.com/23022020-minds-at-war-chinas-pursuit-of-military-advantage-through-cognitive-science-and-biotechnology-analysis/

Human -Machine Fusion and the Implications for the Future of the DoD." This report was previously featured in an the January 2020 DEFTECH SCAN report.

A key component of the report was its focus on the impact of "direct neural enhancement of the human brain for two-way data transfer."[48] According to the report, the development of this area of technology "would create a revolutionary advancement in the future of military capabilities" by facilitating "read/write capability between humans and machines and between humans through brain-to-brain interactions." The resulting capacity for direct communication with autonomous unmanned systems would speed up command and control, greatly enhancing situational awareness and improving "target acquisition and engagement and accelerate defensive and offensive systems."[49]

These BMI technologies are already moving from the hypothetical to the realisable. The US DoD—among others—is actively partnering with commercial industry and academia to explore the intersection between artificial intelligence and human intelligence and its many applications. In June 2019, DARPA's Next- Generation Nonsurgical Neurotechnology (N3) program awarded six contracts to academic and applied research institutes to support the program's objective to "develop high-performance, bi-directional brain-machine interfaces for able-bodied service members."[50] These interfaces will be applied to the development of several military and security applications including "control of unmanned aerial vehicles and active cyber defense systems or teaming with computer systems to successfully multitask during complex military missions."[51]

A key component of the program is to achieve these effects through technologies that do not require implants and that would be man-portable. Moreover, the new technologies will have to exceed the capabilities of existing non-invasive neuro-technologies such as EEGs and transcranial direct current stimulation, which, according to DARPA "do not offer the precision, signal resolution, and portability required for advanced applications by people working in real-world settings."[52] N3 is instead funding research in magnetism, light beams, and acoustic waves. The awards provide funding to a diverse range of N3-related technologies:, including:[53]

- A team at Rice University is using genetic engineering, infrared laser beams, and nanomagnets for a bidirectional system
- Carnegie Mellon's team is using ultrasound waves to pinpoint light interaction in targeted brain regions, which can they be measured through a wearable hat
- Johns Hopkins University is measuring light path changes in the brain to correlate them with the regional brain activity to "read" wetware commands
- A team with Teledyne Scientific and Imaging is using tiny light-powered "magnometers" to detect small, localized magnetic fields that neurons generate when they fire, and match these signals to brain output

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48 U.S. Army, Biotechnologies for Health and Human Performance Council Study Group, "Cyber Soldier 2050: Human / Machine Fusion and the Implications for the Future of the DoD", *November 2019, https://community.apan.org/wg/tradoc-g2/mad-scientist/m/articles-of-interest/300458*

49 U.S. Army, Biotechnologies for Health and Human Performance Council Study Group, "Cyber Soldier 2050: Human / Machine Fusion and the Implications for the Future of the DoD", *November 2019, https://community.apan.org/wg/tradoc-g2/mad-scientist/m/articles-of-interest/300458*

50 Dr. Al Emondi, "Next-Generation Nonsurgical Neurotechnology", DARPA.mil, https://www.darpa.mil/program/next-generation-nonsurgical-neurotechnology

51 Dr. Al Emondi, "Next-Generation Nonsurgical Neurotechnology", DARPA.mil, https://www.darpa.mil/program/next-generation-nonsurgical-neurotechnology

52 Dr. Al Emondi, "Next-Generation Nonsurgical Neurotechnology", DARPA.mil, https://www.darpa.mil/program/next-generation-nonsurgical-neurotechnology

53 Shelly Fan, "DARPA's New Project Is Investing Millions in Brain-Machine Interface Tech", Singularity Hub, June 5, 2019, https://singularityhub.com/2019/06/05/darpas-new-project-is-investing-millions-in-brain-machine-interface-tech/

- Battelle's team is using magnetic nanoparticles wrapped in a piezoelectric shell, which can convert electrical signals from neurons into magnetic ones and vice-versa

Decision-Support

- Among the most prominent objectives of effective HMI for all militaries is to relieve the cognitive burden and enhance situational awareness of military personnel
- AI is particularly important in the development of solutions to help process the abundance of information, sometimes conflicting, to which military and security personnel have access and to help relieve humans of what can be intensive and time-consuming tasks
- A range of solutions exist to enable this decision-support, many of which are applicable to militaries of all sizes. For example, the use of chatbots and virtual assistants to help operators in the field develop a more complete understanding of their environment or help avoid collisions in crowded environments have broad applicability for defence and security communities throughout the world

Chatbots on the Battlefield: In August 2019, the UK Ministry of Defence' Defence Science and Technology Lab (Dstl) awarded a two-year contract to data company Envitia to develop a chatbot to support operators in accessing and filtering a potential abundance of information available to MoD personnel.; that is, finding the right data at the right time.[54]

Chatbots are not necessarily new to defence and security communities and have previously been used largely in information domain-related operations such as cyber-attack and defence, disinformation campaigns, counter-radicalization and engaging extremist groups, and recruiting.

The chatbot is designed to replace current cumbersome and iterative means of finding relevant information. According to Envitia CEO Nabil Lodey, "Currently the user needs to access document stores, such as disparate SharePoint sites or secure file shares to find the information. This is both time consuming and not necessarily easy to navigate."[55]

The machine-learning enabled chatbot will initially use a text-only interface, though upgrades to voice-activated interfaces could follow. Even with the text interface, the chatbot will be able to "have a conversation with the user to discover exactly what is needed", including asking the user for more context in order to effectively filter out irrelevant material and "then provide the vital information that is needed for mission success."[56]

Military requirements create constraints and specific requirements for chatbot development that are not present in the commercial sector. Notably, it will have to work over the limited bandwidth provided by a secure tactical radio connection rather than over 4G or wi-fi. In addition, the MoD's chatbot will only access data on the MoD's satellite network or stored locally rather than accessing publicly available information on the internet.[57]

NAVSEA Operator Decision Aid: The US Navy's Naval Sea Systems Command (NAVSEA) is currently investigating the development of a decision-support aid that would leverage rules-based artificial intelligence technologies originally developed for the Sea Hunter unmanned surface vessel programme.

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54 "Frontline Tech: Could Chatbots Be the Answer to Battlefield Quetsions?", *Forces.Net,* September 26, 2019, https://www.forces.net/news/frontline-tech-could-chatbots-be-answer-battlefield-questions
55 "Frontline Tech: Could Chatbots Be the Answer to Battlefield Quetsions?", *Forces.Net,* September 26, 2019, https://www.forces.net/news/frontline-tech-could-chatbots-be-answer-battlefield-questions
56 "Frontline Tech: Could Chatbots Be the Answer to Battlefield Quetsions?", *Forces.Net,* September 26, 2019, https://www.forces.net/news/frontline-tech-could-chatbots-be-answer-battlefield-questions
57"Frontline Tech: Could Chatbots Be the Answer to Battlefield Quetsions?", *Forces.Net,* September 26, 2019, https://www.forces.net/news/frontline-tech-could-chatbots-be-answer-battlefield-questions

The program is explicitly designed to reduce the incidence of surface ship accidents, a problem which has affected the U.S. Navy's operations, especially in the Indo-Pacific, over the last three years.

In December of 2018, Sea Hunter became the first autonomous ship to complete a round-trip trip transit from California to Hawaii without a crew member on-board. NAVSEA's Operator Decision Aid (ODA) program seeks to modify the autonomy-enabling AI behind Sea Hunter and apply it to manned platforms.

Ann Lowe, a Senior Associate with Herren Associates, an engineering and analytics company supporting the project, noted that the key challenge was "how can we unlock the goodness from Sea Hunter and pair it with humans?" One option, according to Lowe was "something where 'Alexa' provides recommended manoeuvres, or maybe sounds the collision alarm. Or even, in extremis, takes the con."

In addition to a focus on AI software, the program has two additional research thrusts: hardware and a graphical user interface (GUI), both of which are critical to transitioning Sea Hunter's AI to a manned platform. Indeed, Lowe stressed that "the GUI is really important. [The sailors} have got tons of information and data coming into that ship. If it's overwhelming, or not user friendly, they're not going to use it . .. . the GUI will provide an intuitive maritime situational awareness tool that includes a manoeuvring recommendation." The hardware as currently envisioned will consist of a 24-inch touchscreen display plus two Peli ruggedized carry cases and a heat exchange.

Fifth Generation Cockpit: Decision-support applications are also being developed as part of a radical rethink not only of the design of future cockpits (as highlighted above), but also of the role of pilots—enabling the transition from an individual whose primary function is to fly an aircraft to one whose primary function is to manage a mission.

New human-machine interfaces and manned-machine teaming technologies are increasingly viewed as crucial to reducing the cognitive burden on pilots who are now being asked to control a growing number of separate avionics systems and process and act on large amounts of data. Technologies that can perform certain pilot tasks and search, sort, and synthesize this data across several systems will enhance situational awareness, safety, and mission effectiveness and allow humans in the cockpit to focus on other, higher-value tasks.

This vision of the future pilot is at the core of the on-going Airbus autonomous taxi, take-off-and-landing (ATTOL) project, which crossed an important milestone in December 2019 when a modified A350-1000 performed eight automated / autopilot take-offs using an image-recognition system. Landing trials followed in January 2020.[58]

Improving autopilot capabilities to take on more flying functions is crucial to advancing what Airbus calls the "fifth generation flight deck." It will allow the AI to take on more tasks including "coping with wind gusts" and being engaged throughout a given flight. The A350 includes advanced autopilot technology that remains engaged even though flight-envelope protection becomes active. In addition, the speed brakes automatically extend after the aircraft surpasses 5 kt above maximum operating speed.[59]

The US Army—among many others—is also investigating new technologies and concepts related to "manage aircraft crew member cognitive workload."[60] On April 20, the Army Contracting Command at

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[58] Thierry Dubois, "Airbus Advances Autonomy Project As Part of Future-Cockpit Concept", *Aviation Week,* February 21, 2020, https://aviationweek.com/aerospace/program-management/airbus-advances-autonomy-project-part-future-cockpit-concept

[59] Thierry Dubois, "Airbus Advances Autonomy Project As Part of Future-Cockpit Concept", *Aviation Week,* February 21, 2020, https://aviationweek.com/aerospace/program-management/airbus-advances-autonomy-project-part-future-cockpit-concept

[60] John Keller, "Army asks industry for open-systems avionics technologies for future attack and reconnaissance helicopters", *Military Aerospace,* April 20, 2020, https://www.militaryaerospace.com/computers/article/14174361/opensystems-avionics-helicopters

Fort Eustis, VA issued a request for information (RFI) for open -systems avionics technologies as part of the Revolutionary Technology and Strategies for the Holistic Situational Awareness Decision Making (HSA-DM) program. Technologies developed from this program will be integrated into the first two programs associated with the Army's Future Vertical Lift effort—the Future Attack Reconnaissance Aircraft (FARA) and Future Long-Range Assault Aircraft (FLRAA) programs. Technical priorities include: information management, data and sensor fusion, autonomous decision aiding and information distillation, and human-machine interfaces. The program is expected to run from 2021 to 2026.[61]

[61] John Keller, "Army asks industry for open-systems avionics technologies for future attack and reconnaissance helicopters", *Military Aerospace,* April 20, 2020, https://www.militaryaerospace.com/computers/article/14174361/opensystems-avionics-helicopters

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