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Human-Robot teaming Research Initiative for a Combat Aerial Network (HURRICANE)

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The "best of both worlds": an aerial manned-unmanned collaborative combat system and its force employment concept to maintain operational superiority

"The winner of the robotics revolution will not be who develops this technology first or even who has the best technology, but who figures out how to best use it."

Paul Scharre. *Robotics on the Battlefield: Part I: Range, Persistence and Daring*. Center for a New American Security, 2014.

In brief... Maintaining and increasing European operational superiority in future air battles will require not a total and rigid automation of systems, but a flexible automation combining the respective advantages of human and non-human assets.

The HURRICANE project outlines the opportunities and challenges that robotics and artificial intelligence technologies offer for future air combat by indicating how we can gain an advantage through human-machine teams. Its objective is to guide the development of coherent future technology and forces design, and to help define a suitable force employment concept.

Within the scope of network-centric warfare (NCW), the importance of informational superiority and the accelerating tempo of operations impose a revolution in the military use of artificial intelligence (AI) that is disrupting human-machine interactions on the battlefield.

The digitization of the battlefield has led to an "information deluge", resulting in a **cognitive overload of the crews**. Digital technologies and machine learning methods have become essential for analyzing huge amounts of data, consolidating information and usefully distributing situational awareness.

At the heart of **future military advantage** will therefore be the effective integration of humans, artificial intelligence (AI) and robotics into combat systems – human-machine teams – that best harness the capabilities of pilots and technologies to outperform our adversaries. Advantage will not automatically lie with the force with the newest or most expensive algorithm, but with **the most effective human-machine teams**.

Unlike humans, the **AI is not weakened by deconcentration, fatigue or stress**. The speed, the precision and the capacity of calculation, the reliability, the almost infinite memory and the indefatigability of the machine allow it to compensate for certain human limits. However, they are not as good at understanding complex unstructured data or performing non-deterministic analyzes (eg, predicting human behavior). Machines are poorly suited to exercise nuanced judgment on complex or ambiguous contexts which then moderate decisions. Also, because machines are programmed or trained using established data sets relevant to a task or problem, encountering a new problem or something very different from the established data sets tends to cause failure.

By contrast, **humans are better than machines at understanding context**, and they are likely to remain so for a long time. The human capacity to adapt to new situations is generally much greater, even if the answers are likely to be imperfect. Flexibility, creativity, strong capacities for abstraction and adaptation in the face of uncertainty and novelty, including from unstructured partial data, are faculties specific to human beings that the machine struggles to reproduce. This is partly because **humans use mental substitutions or approximations** from familiar skills or tasks to get approximate answers. Humans also have an intellectual agility that calls on emotional skills, such as empathy or intuition.

Even in the case of the most advanced technologies, man is still in the best position to set objectives and monitor the overall functioning of systems in order, if necessary, to be able to correct an automatic fault.

Combining strengths and weaknesses of man and machine in a collective intelligence

AI equals or exceeds human performance in a wide range of tasks, yet autonomous systems remain brittle and lack humans' flexibility outside their instructions. Therefeore, **human versus machine is a false choice.**

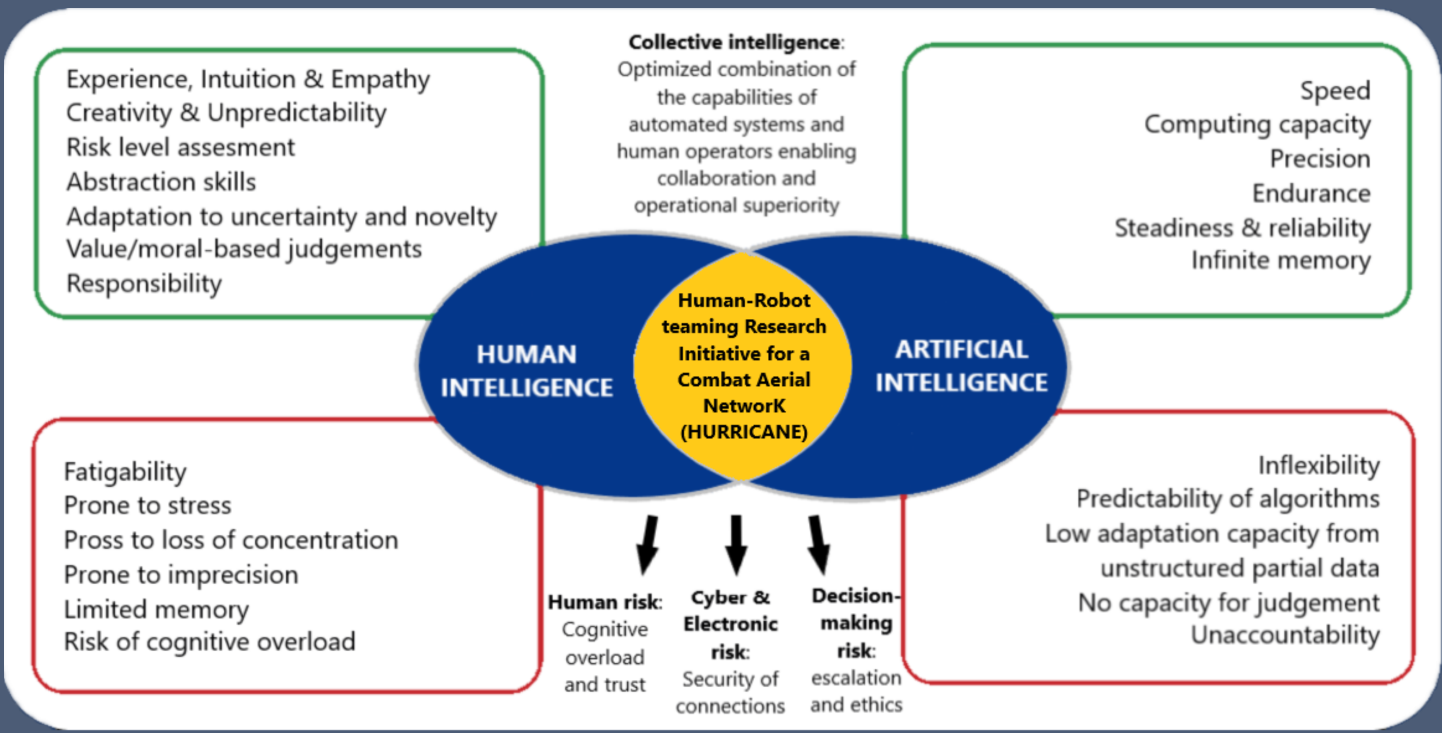


Diagram : Hein & Maquaire (2022)

It is rather a question of optimizing the use of autonomous technology while keeping human beings at the core of the weapon system, according to P. Scharre's **Centaur Warfighting model**. This hybrid approach benefits from the contributions of automation while maintaining the faculty of the human being to exploit them for the benefit of the mission. **Man-Machine Teaming (MMT) is thus more effective than human action alone or artificial intelligence alone, leveraging the advantages of each**.

If AI can compensate for the weaknesses of the human being, it especially has a strong potential in terms of increasing human performance. The air environment therefore needs an **anthropocentric, collaborative and augmentative AI**, capable of anticipating the intentions of its human partners, detecting deviations and acting in symbiosis with them within the framework a **collaborative aerial combat system and operational concept**.

1 Collaborative aerial combat as the key to achieve air dominance in the futur

The combination of manned aircraft and UAVs is one of the possible forms of hybridization for a collaborative air combat system gathering man and machine.

This **coupling can be done according to different models, ranging from a single "wingman" UAV to a multitude of UAVs evolving in a swarm** capable of coordinating and collaborating - the human being being always at the center of the device (human-centered design). Several concepts can be considered:

- "Wingmen" UAVs - HALE/MALE type or tactical UAVs - with a range of several hundred kilometers, capable of delivering mini-UAVs or loitering-munitions (like Russian dolls) in addition to conventional tactical weapons (bombs, missiles) ;
- Mini-drones delivered directly by the manned aircraft fighter or the unmanned aerial vehicles and having themselves a range of hundreds of kilometers in order to strike the enemy in depth and to saturate the enemy defense system.

The **"companion" unmanned aerial vehicles would surround, protect, and assist the manned aircraft in engaging in combat**, while providing uncertainty about the actual position of the human combatants within the whole man-machine device. **MMT directly contributes to pilot protection by prioritizing exposure of unmanned aircraft** in a mission where the risk of casualties appears high like contested Anti-Access/Area-Denial (A2/AD) environments for example.

In the case of a positive detection of a threat initiating an alert, the operator would regain control of the remotely operated UAV in order to specify the intelligence and, possibly, engage the target. The pilot's "job" could thus evolve from the function of commanding an aircraft to that of mission leader at the head of a hybrid device. It is thus **a question of moving from a vision of AI as a tool to an approach of AI as a team member, in an anthropocentric and collaborative logic.**

As semi-autonomous effectors and remote sensors that can provide fire support, Intelligence, Surveillance, Target Acquisition, & Reconnaissance (ISTAR), jamming or deception/decoy capabilities to manned platforms, UAVs allow us to rethink aerial maneuver in order to optimize effects, or even create new ones, with the **aim of paralyzing the adversary in depth through saturation and complexity**.

This **collaborative air combat would be particularly effective for SEAD missions** and could be decisive in the initial phase of the engagement to quickly achieve air superiority. Such a hybrid system would allow a true "air occupation" of the contact zone by hundreds of UAVs/munitions and dozens of manned penetrating platforms with fast and precise munitions**. Thanks to the capabilities of decoying, jamming, cyber-electronic intrusion, confusing and dispersing the efforts of the adversary anti-aircraft defence and targeting system**, forcing the adversary radars to silence or to "shoot and scoot" modes of action, which would no longer allow a complete coverage of the zone. It would authorize an effort to destroy telecommunications, airfield capabilities, etc. To the lightning strike of hypersonic weapons and to the informational paralysis resulting from electronic attack by the more sophisticated manned and unmanned platforms, will be added the deepening of the **effects of saturation by low-cost autonomous systems such as loitering-munitions/suicide-drones**.

Moreover, when faced with an evenly matched adversary in a **high-intensity conflict**, obtaining a favourable balance of power in the critical phases of the maneuver requires an increase in the mass involved in the action. **MMT offers an alternative to enlargement in a context of constrained defense budgets**. Such force employment concept could be integrated in the FCAS development and requires **interoperability with existing platforms such as theEurofighter-Typhoon or Eurodrone**.

2 A human-centered design : Unmanned Aerial Vehicules as a force multiplier

The design of future forces must find the optimal combination of manned and unmanned platforms, and balance the use of human and machine cognition for various tasks. Optimizing the use of human mental and physical capabilities within such a force will become a key factor in thwarting adversary maneuvers and ideas.

Connected collective air combat with the tandem of manned aircraft(s) and UAVs leads to **augmenting the function of pilot with that of leader of a delegated sensor/effector device**. The **manned fighter aircraft would most certainly be used as the "quarterback" of this network of autonomous systems by concentrating the C2 capability in the hands of the human pilot.**

We propose here a **hierarchical coordination of a "kill web" multiplying the combinatorial options between these sensors, C2 sub-nodes and effectors**. It would be a control delegated to the UAV (examples: Eurodrone, Predator, Kratos Valkyrie) becoming in a way the command post of the sub-network of mini-UAVs or of the loitering-munitions capable of evolving in swarm, relaying and translating the orders of the manned aircraft fighter, **coordinating the network through a tactical combat cloud**.

This **C2 design would obviously go towards a logic of decentralization for the purposes of tactical flexibility, seizing opportunities and resilience,** especially considering cyber-electronic threats likely to isolate pilots from the inhabited platform and the need for reducing the cognitive load of the human operator. However, everything would really depend on the level of decision-making autonomy of the systems, on the level of situational awareness, but also on the multiple political constraints that can be envisaged. Let us note in passing that the **decentralization of C2 requires the maintenance of manned platforms**. The exclusive use of drone systems would result in a transfer of situational awareness and would therefore not contribute anything to the current situation. In our opinion, **the final decision to engage a target must remain in human hands**.

HURRICANE's force design : a kill web of UAVs led by the human pilot

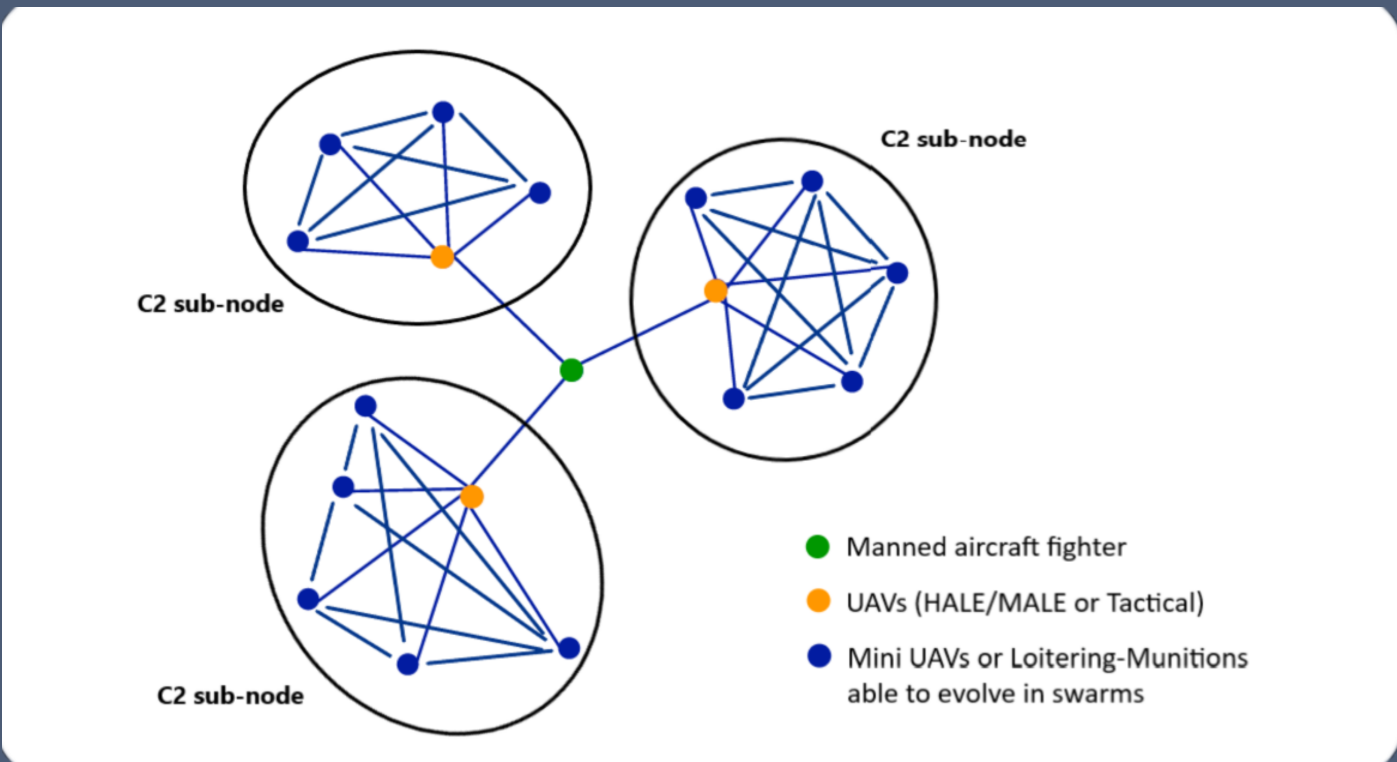


Diagram : Hein & Maquaire (2022)

Exemple of a combat UAV (Kratos XQ-58A), head of the C2 sub-node, carrying mini-drones (ALTIUS-600). Credits : USAF

Current and future platforms integrated into man-machines teams will be incrementally equipped with more sophisticated technologies enabling combat clouds, such as high-speed directional connections, on-board computing capabilities, semi-automated processing of the masses of available data and analysis tools based on artificial intelligence techniques. In theory, **they should provide the pilot with the situational awareness and automated management tools necessary for these new functions**.

On the assigned aircraft, the human pilot would trigger an application that would retrieve and then automatically update the intelligence elements of the UAV's integrated into the team, which would be integrated into its navigation and attack system that would provide tactical action mode options based on its approach course. Once in the area, **data from all of the MMT's sensors would provide it with complementary perceptions from its sensors, allowing the pilot to share a better view of the tactical situation**.

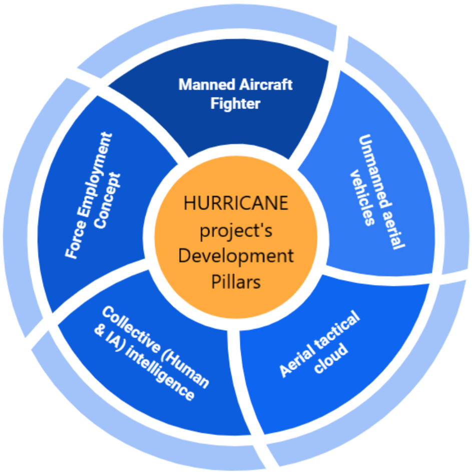
For example, a kinetic strike delivered by the manned aircraft fighter could be done on the basis of integrated data from other UAVs' sensors. **The gain in efficiency is not only in terms of the speed of execution of the OODA loop, but also better exploitation of intelligence, more detailed shared awarenes** e of the operational capabilities of the units involved in a given situation in real tim, and the **capacity for collaborative combat will increase the precision of the effects sought**.

The shared situational awareness enabled by the cloud will be **a factor in increasing or reinforcing informational superiority over the adversary**, and the consequent decision and operational superiority postulated by Network-Centric Warfare. Furthermore, its interconnections, as well as the shared situational awareness they generate, potentially enable the full transition from connected to a really collaborative warfighting

The limits of human mental capacity imply the need to dynamically vary the level of active control that operators must exercise over remote automated systems. Dynamically managing levels of remote automated systems' automation balances human-assessed risks with the benefits of machine capability (mass, speed, accuracy) in changing contexts. As a safeguard, automated alerts and warnings must be in place to get the human's attention early enough to orient, act, and decide, if necessary. This frees up humans to focus on important tasks or those that are not well suited to machine execution alone, including ambiguous or context-dependent tasks.

The main challenge of MMT is not so much the availability of sensors and information as it is the ability to exploit them wisely in a timely manner. Collaborative air combat means that the capabilities of different manned and unmanned platforms are implemented as a single system to improve the detection of adversary systems and generate the desired effect more quickly and efficiently, both in action and in reaction.

3 Developpment process and policy implications



The interdependencies between technologies, tactics and strategy are likely to be complex. Our understanding must be improved through **research and experimentation transversally** (doctrine,, equipment, personnel, infrastructure, logistics, training, organization, human & financial resources management) for each of the **five development pillars**. This **development process involves a multitude of different actors on a European scale**: industrialists, engineers and civilian experts, members of European and military institutions. Military access to the best technologies will become a challenge, but the benefits of such a project would be dual.

Civilian commercial investment in AI and robotics technologies and the recruitment of subject matter experts exceeds that of any state. The best systems are already, and remain, in the civilian sector. Therefore, there is a need **to develop public-private partnerships linking the civilian and military sectors**. The HURRICANE research team should also include academic researchers because **force design and concepts of operation must also take into account legal, ethical, and societal factors of employment**.

To exploit AI and robotics developments as they emerge, we will need to adopt **a strategy of iterative experimentation, prototyping, concept and technology development, and organizational improvement** to optimize our ability to create effective human-machine teams. **Training and experimentation with end-users (i.e. pilots) will be essential** for operators to understand the critical strengths, weaknesses, and limitations of these AI systems, particularly on human behaviors within the man-machine team in combat situations.

The pilot's "job" could thus evolve from the function of commanding an aircraft to that of mission leader at the head of a hybrid man-machine device. Moving from a vision of AI as a tool to an approach of AI as ateam member implies a doctrinal development and an evolution of the pilots' training. If this collaborative combat system comes into being, it will be of cardinal importance to develop (education) and maintain (training) the skills of personnel to assume these decentralized C2 authorities with the delegation to UAVs.

In economic terms, the different characteristics of the HURRICANE project suggest **needs between quality, quantity and resilience**. Indeed, the remote end effectors should at the same time: **be available in large numbers** to guarantee these saturation effects, which implies low unit costs and consumable drones; **have sufficiently sophisticated AI algorithms** to guarantee the required decision-making autonomy and limit their communications with manned aircraft fighters.

We could thus envisage a mix of more sophisticated recoverable UAVs with precision ammunition and used to station swarms of mini-drones or loitering munitions, capable of carrying out decoy, jamming or attack missions. The man-machine team's force design would thus follow a **high-low mix** logic where the cost and the level of sophistication decreases progressively: a very high-tech stealthy and penetrating manned platform at several tens of millions of euros per unit, recoverable wingmen-drones sufficiently sophisticated to be able to deal with the diversity of combat and reconnaissance missions while being able to evolve autonomously in the adversary's operational depth (e.g. Kratos Valkyrie or Dynetics Gremlins), and finally a multitude of low cost attritable UAVs capable of evolving in swarms and guaranteeing saturation effects.

4 Man-Machine Teaming brings new risks

A human pilot responsible for several air systems is at risk of cognitive overload in combat. Artificial intelligence is fully required, in order to relieve the pilots of the simplest tasks, to assist in decision making, or not to lose the drones in case of data link failure. **MMT requires not a total and rigid automation of systems, but a flexible automation combining the respective advantages of human and non-human assets to develop decision-making agility**, i.e. to have the ability to dynamically change automated decision levels according to lines of operations, missions, the environment, and the operational situation.

The increasing capabilities of robotic and AI systems will be limited not only by what can be done, but also by what actors trust their machines to do. **The effectiveness of the MMT can also be impaired by the user's lack of confidence in the machine**, which may not be used to its full potential. Trust and reliability are therefore key issues that drive the level of confidence, and hence the degree of automation we place in remote automated systems. The fundamental factors affecting our trust in systems are the following: mechanical understanding, predictability, familiarity, context.

In addition, **one of the primary risk is increased exposure to the cyber-electronic threat**. MMT may also become inoperable under conditions of degraded or denied communications between the manned platform and non-human assets. Indeed, the possibility of flying a drone alone, without a manned aircraft, comes up against the fragility of the satellite data link in the case of contested spaces, which can be hacked or jammed. **The drone would then become uncontrollable**. By remaining integrated into the team led by the piloted aircraft, the drone can benefit from a local cyber-electronic network, which is also susceptible to threats.

The multiplication of interconnections increases the potential for electronic intrusions into the combat cloud and increases **the risks of systemic effects of these intrusions**. Moreover, by enslaving a large portion of airpower's competitive advantage to this deep and wide networking, the cloud also multiplies the criticality of this vulnerability. In other words, **with an insufficiently insecure tactical cloud in the face of a (near)peer-adversary, the risk of systemic airpower paralysis potentially emerges**.

In addition, one way of getting around the difficulty of the long-distance data link is to envisage a totally autonomous drone, therefore not dependent on this data link. However, two questions arise in this case: **an ethical/legal question and the question of tactical efficiency**. Some think that AI would be unable to be more efficient than humans in an environment highly contested by sophisticated denial of access systems, or more generally in situations where there are many choices and decisions to be made.

There is **a risk of dilution of human responsibilities, moral distancing, and unintended escalation** that must remain at the heart of the military command's concerns and ethical reflections on the human-being's place in the decision-making loop. The argument is that man is in the global loop: **a machine can be autonomous, but it cannot invent a mission for itself or modify it without asking a human being for authorization**. Therefore, **the human being must retain the responsibility of command and be able to respect international humanitarian law**.

As future technologies emerge, particularly for systems supporting targeting and fires, we must consider the ethical and legal implications. Automated and remote armed systems must not only be reliable and secure, but also operate in a manner that is perceived as such by users and observers. Those who develop such systems must ensure that they are capable of complying with international law. Similarly, legislative measures to encourage the adoption of technology in society must be closely examined to ensure that, in an increasingly connected world, lines of accountability are maintained.