USSOCOM S&T FUTURES

ARTIFICIAL INTELLIGENCE FOR MARITIME MANEUVER

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INTRODUCTION

THE USSOCOM S&T FUTURES INNOVATION PROCESS

USSOCOM S&T Futures serves as USSOCOM's high-risk, high-reward technology investigator and incubator, and is responsible for making sure Special Forces is ready for the future.

S&T Futures has developed and refined a unique process to engage technology pioneers and leaders.

The first stage in this process is a three-day Innovation Foundry event, where agile small businesses, entrepreneurs, academics, and researchers are gathered in a room along with subject matter experts and end-users from Special Forces and other defense organizations. Armed with a framework to develop concepts using a design thinking process, the participants ideate, explore, refine, and rank potential concepts.

The capability concepts are then taken to the second stage: a Rapid Capability Assessment event. Another group of experts from industry, academia, and defense develop solutions that include market research of potential technology partners, a subsystem-level architectural breakdown, and a technology development roadmap. The teams even generate initial Work Breakdown Structures and initial contract language to define the capabilities.

The concepts and capabilities created are captured in a Concept Book and an Operational Concept Video which are distributed to DoD Program Managers and SOF end users to spur their interest and to whet their appetite for new innovative capabilities.

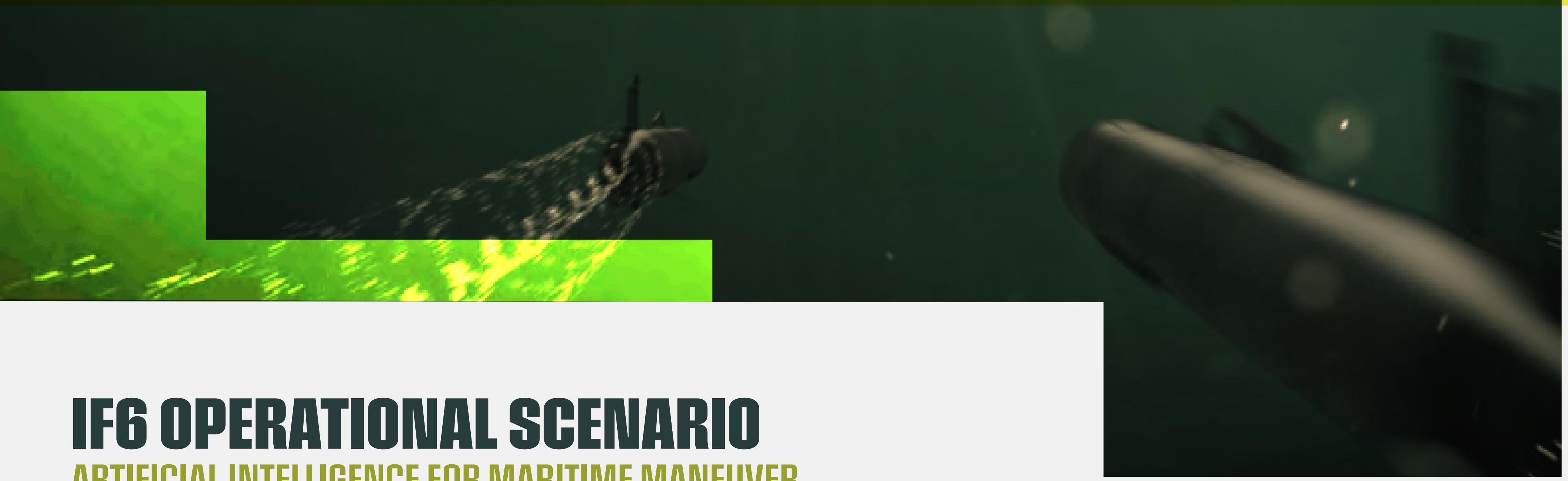
If the capabilities developed are wildly innovative and are in the early stages of development, we take them to the third stage of Project Wormhole: an Integrated Tech Sprint. This is a venue for timeboxed research, experiments and prototyping in sprints that last six weeks to four months, and create outputs such as proofs of concept, prototypes for developmental test, or demonstrations.

THE NSW VISION: AI FOR MARITIME MANEUVER

Emerging robotic technologies with high levels of autonomy and robust on platform processing capability will enable Naval Special Warfare (NSW) low-observable maritime forces to form enclaves of dispersed man-machine tactical maritime maneuver elements that can operate within the effects envelope of the enemy with relative impunity and great precision. Additionally, these man-machine enclaves can unite, drastically increasing mass, to conduct improvised, coordinated and precision maneuver, intelligence and scalable effects-based operations interoperable with and in support of the Joint Force.

Artificial Intelligence for Maritime Maneuver (AIMM) is the solution to maneuvering within contested, complex, and congested environments with existing SOF maritime capability and capacity. AIMM is the convergence of artificial intelligence, robotic autonomous systems and SOF operational concepts to create tactical maritime elements capable of early-entry “inside forces” that can operate within the effects envelope of the enemy's A2AD umbrella with relative impunity, either by operating from sanctuaries (e.g., undersea) or being protected by stealth.

To explore the potential of the AIMM vision, NSW and SOCOM S&T Futures conducted the Innovation Foundry 6 and Rapid Capability Assessment 6 events.



IF6 OPERATIONAL SCENARIO

ARTIFICIAL INTELLIGENCE FOR MARITIME MANEUVER, INTELLIGENCE, MISSION COMMAND AND EFFECTS

EVENT OVERVIEW:

The Innovation Foundry 6.0 (IF 6.0) event entitled “Artificial Intelligence for Maritime Maneuver, Intelligence, Mission Command and Effects” is a SOCOM S&T Futures-run design thinking event carried out in an unclassified setting in the Force Design timeframe (5-15 years in the future, centered around 2030).

APPROACH:

The goal is to envision how advancements in autonomy, machine learning, manned-unmanned teaming, emergent technologies, and unmanned systems might be employed by SOF to enhance the warfighting functions of maritime maneuver, intelligence, effects and mission command in the form of concepts designed to support potential future missions.

SPECIFIC COMPELLING CHALLENGES:

- Denied, degraded satellite communications (SATCOM)
- Denied, degraded precise navigation and timing (PNT), for example, GPS
- Transiting large areas of maritime geography with no SATCOM or GPS
- Limited capacity of manned SOF maritime mobility platforms
- As this is an unclassified, fictional setting the event will not focus on existing NSW maritime surface platform mobility capabilities.

ENVIRONMENTS:

- Complex Environment = a function of Weather, Natural and Manmade terrain without Dense Urban Clutter
- Contested Environment = a function of Cyberspace Electromagnetic Activities (CEMA), Threat Action, Stand Off and Adversary Speed

WARFIGHTING FUNCTIONS:

- Maneuver: The related tasks and systems that move and employ forces to achieve a position of relative advantage over the enemy and other threats.
- Intelligence: Provide the commander with intelligence to plan, prepare, execute, and assess operations.
- Mission Command: The related tasks and a mission command system that support the exercise of authority and direction by the commander.
- Effects: Effects that assist air, land, maritime, space, cyberspace, and special operations forces to move, maneuver and control territory, airspace, space, cyberspace, the electromagnetic spectrum, and key waters and to influence populations.

DEFINITIONS:

Artificial Intelligence: The capability of computer systems to perform tasks that normally require human intelligence such as perception, conversation, and decision-making. Advances in AI are making it possible to cede to machines many tasks long regarded as impossible.

Robotics: Interdisciplinary research area at the interface of computer science and engineering to design intelligent machines that can assist humans.

Automation: Rules based response. Little to no human operator involvement. System limited to specific designed actions. Typically well-defined tasks with predetermined responses.

Autonomy: Advancements in performance and functionalities under significant uncertainties in the environment with the ability to compensate for system failures without external intervention.

OPERATIONAL SCENARIO | AOR MAP

OPERATIONAL SCENARIO | ABSTRACT

Roughly $5 trillion USD in trade transits the contested waters of the East Marin (MAR-IN) Sea every year. With a capacity 6 times larger than the Suez Canal and 17 times the Panama Canal, these strategic waterways bring vital resources necessary to both fuel the growing economies of Marin, Napa (NA-PA), Sonoma, and Placer and to support a regional population expected to double by 2050. Trending upward with its surge in population and economic growth, analysts predict nearly 80% of the world's oil will trade along the East Marin Sea in the next two decades.

Historically, the UN Convention on Law of Sea recognized a 12-mile exclusive, sovereign, maritime claim. The signatories operated in loose partnerships inside a series of overlapping 200-mile Economic Exclusion Zones (EEZ).

These regional struggles for economic resources have resulted in an increase in naval activity and in land reclamation projects to achieve additional national territorial waters; the rights to surface and sub-surface resources therein, and an extension of EEZ's from mainland soils.

Although access to resources remain paramount and most nations have opted to pursue diplomatic solutions, recent tit-for-tat incidents have increased in frequency and intensity. In one such event in the spring of 2029, Marin lost a deep-sea exploration ship 100 nautical miles north of Bear Island, for which Marin holds Napa, Sonoma and Placer equally culpable.

In direct response, Marin did the following: assumed governorship of the island as compensation; claimed exclusive right to inspect all shipping; and mobilized their East Marin Seas Fleet. The last action led to the sinking of a Sonoman patrol boat by a land-based anti-ship missile from a battery located on Catalina in the Umbrella Isles.

The subsequent addition of a military fighter/attack aircraft squadron at Catalina enabled air-to-air, air-to-surface, and strategic bomber escort capabilities. Similar activities are underway in the Palo Archipelago, as Marin has built more than 25 square miles of artificial islands which directly affect the sovereignty of Cedro, Alto and Verde.

Each newly sovereign and EEZ-enhancing territory teems with anti-ship, anti-air, and fighter and attack aircraft capabilities. Furthermore, Marin boasts Atlantis as its southern most territory. This strategic, subsurface outpost is located roughly 750nm from the mainland and is currently beneath 65 feet of water.

Additionally, Marinese Navy and Marin's Coast Guard Corps (M-C-G-C) operate as both an overt protection arm, and as an enabler of the subtle intimidation force of "maritime militia" fishing vessels that have been emboldened to harass dialing rigs and sink civilian fishing craft.

America's priority in the East Marin Sea has always been to ensure the free passage for shipping, for all. In universally rejecting Marin's exclusive and expanding claims, the United States routinely conducts freedom of navigation operations, both unilaterally and multilaterally, with partner nations.

Focused attention on technological iteration and innovation, the Marin Navy and MCGC continue to close the maritime and littoral capabilities gap in contempt of the international community.

OPERATIONAL SCENARIO | INTELLIGENCE REPORT

Earlier this year Marin (MAR-IN) completed two reclamation projects in Slecarap (SEL-E-CARAP), subsequently establishing two new administrative districts, despite Manteivese sovereignty. Reclamation created the land mass necessary to advance Marin's EEZ (E-E-Z) expansion, thus enabling the increase in range of their information dominance strategy by several hundred nautical miles.

Reports of interdiction by official Marin naval forces, and informal maritime militia forces, increased fourfold culminating in the sinking of a Placer fishing vessel that refused to yield to Marinese (MAR-IN-EEZ) intimidation. Few Placer fishermen survived as distress calls went unheard; RF communications jamming was suspected.

This month, Marin renewed its efforts to increase their physical sphere of influence and information dominance capabilities within the South Marin Sea. Earlier this week, their government announced the construction of new research stations on the artificial islands of the disputed Atlantis reefs.

Per Marin standard procedure, construction projects began immediately following these announcements. The new research stations will serve as forward communications, intelligence, and logistical nodes, and as strike launch points.

During last night's strategic deterrence missions, U.S. high altitude aircraft overflew this area. Flight logs show conflicting location and navigation data when within 60nm of these outposts, as the redundant GPS and digital celestial navigation systems differed in readings. The mission aircraft also experienced degradation in their satellite communication's bands.

Additionally, human intelligence sources reported maritime engagement of friendly fishing fleets, including interdictions of commercial vessels roughly 55-70 feet long. Intelligence also estimates that Marin detection capabilities may be able to classify surface radar contacts longer than 50 feet at ranges of less than 12nm.

Recent imagery reveals the presence of stealthy Missile Boats and multiple types of surface and sub-surface warfare collection platforms, including rotary and fixed wing aircraft, surface and sub-surface platforms, and various sensor collection capabilities.

OPERATIONAL SCENARIO | OBJECTIVE

Your mission, code name "Fisherman's Shelter," is to conduct a special reconnaissance across the ever expanding Marin claim. This area spans the mainland to the Atlantis outpost. You must confirm or deny the presence of defense infrastructure, characterize the current status of suspected reclamation projects, all while generating maps, in real time, of the sub-surface terrain. You will have 72 hours to complete.

SPECIFIED TASKS

- Ascertain terrain characterization of new islands
- Develop sub surface mapping of potential future islands, and possible or likely supply routes
- Remain undetected

OPERATIONAL SCENARIO | CONSTRAINTS

- Denied, degraded SATCOM (SAT-COM)
- Denied, degraded GPS
- Radiofrequency jamming and Direction-finding
- Large areas of geography with no landmarks
- Limited Capacity of maritime mobility assets

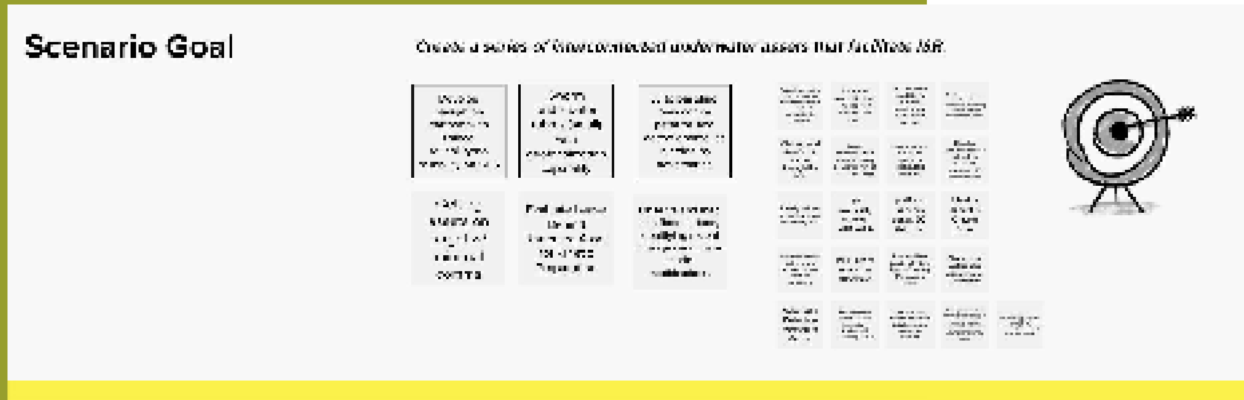
Marin seems intent on expanding its territorial claims into the East Marin Sea and beyond. This mission is delicate and politically sensitive. It is imperative the clandestine nature of this incursion be maintained, and it is paramount we develop the current intelligence picture. These components are equally necessary for the continuation of a free world and its free trade and transit.

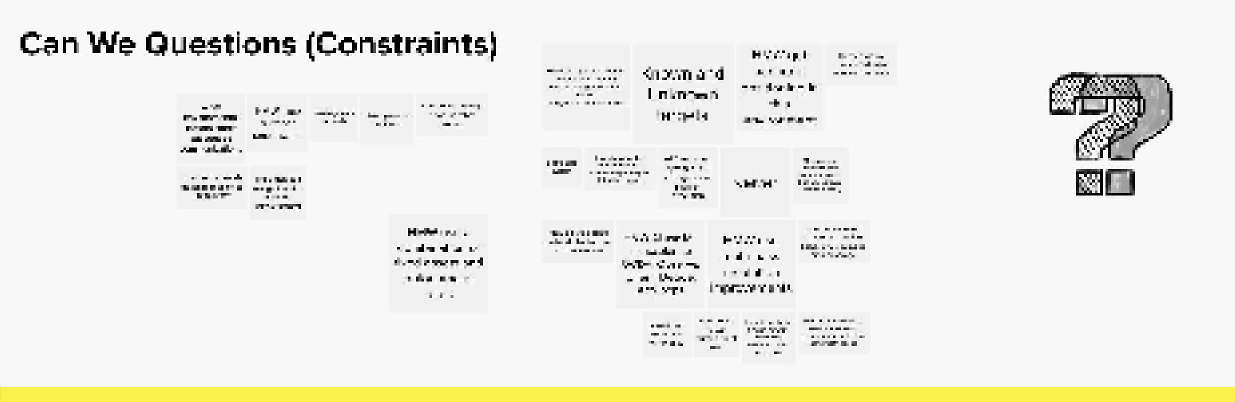
You are going up against an adversary that has studied our playbook for decades and observed how we operate in real world scenarios over the past century- taking very good notes. They are smart, capable, and technologically savvy.

We need new plays and a whole new game plan for this one.

Good luck.

Hemingway sends...





IF6 CAPABILITY CONCEPTS

Special Operations Command (SOCOM) hosted their 6th Innovation Foundry (IF6) online in a virtual workshop event. IF6 brought together Special Operations Warfighters and non-traditional technologists to explore future Special Operations scenarios over a three-day period.

A diverse set of participants was gathered and assembled into seven teams of 6-10 people. The teams used design thinking exercises to ideate, explore, refine, and rank potential concepts. On the final day, each team selected one concept to pitch to SOCOM leadership and other military VIPs.

UNDERSTAND THE MISSION

Together, the participants watched an overview video for the context of the scenario. Then Operation “Fisherman’s Shelter” was presented as the Special Reconnaissance mission, This provided context on the operational environment, and detailed critical constraints such as denied, degraded SATCOM (SAT-COM) and GPS, large areas of geography with no landmarks, and limited capacity of maritime mobility assets.

Each team of participants were to envision how advancements in autonomy, machine learning, manned-unmanned taming, emergent technologies, and unmanned systems might be employed by SOF to enhance the warfighting functions of maritime maneuver, intelligence, effects and mission command in the form

of concepts designed to support potential future missions.

OPERATION FISHERMAN’S SHELTER

Each team was challenged to conduct a special reconnaissance across the ever expanding Marin claim. This area spans the mainland to the Atlantis outpost. You must confirm or deny the presence of defense infrastructure, characterize the current status of suspected reclamation projects, all while generating maps, in real time, of the sub-surface terrain. Specified tasks included ascertain terrain characterization of new islands, develop subsurface mapping of potential future islands, and possible or likely supply routes, and to remain undetected.

ESTABLISH GOAL

Participants, without conversation, each described

the goal in their own words. After sharing with the group, each table voted to align on the task at hand.

IDENTIFY CHALLENGES

Participants were assigned to one of seven teams that included both technology experts and special warfighters. Each team began by discussing the objective and then identified key challenges and risks in the form of Critical Questions.

ASK THE EXPERTS

Technologists interviewed the warfighters while taking “How might we” (HMW) notes to learn from the warfighters’ perspective.

GROUP 1: DEEP HIVE

A mobile hive of **small auto**nomous UUVs *to* explore the area of interest

KEY ELEMENTS

- Data collectors use unique biomimicked pathing
- Data runners move information
- Data aggregators perform data processing and data exfiltration.

GROUP 2: SPY TRASH

Exploit ocean refuse by adding intelligence with low C2 overhead

KEY ELEMENTS

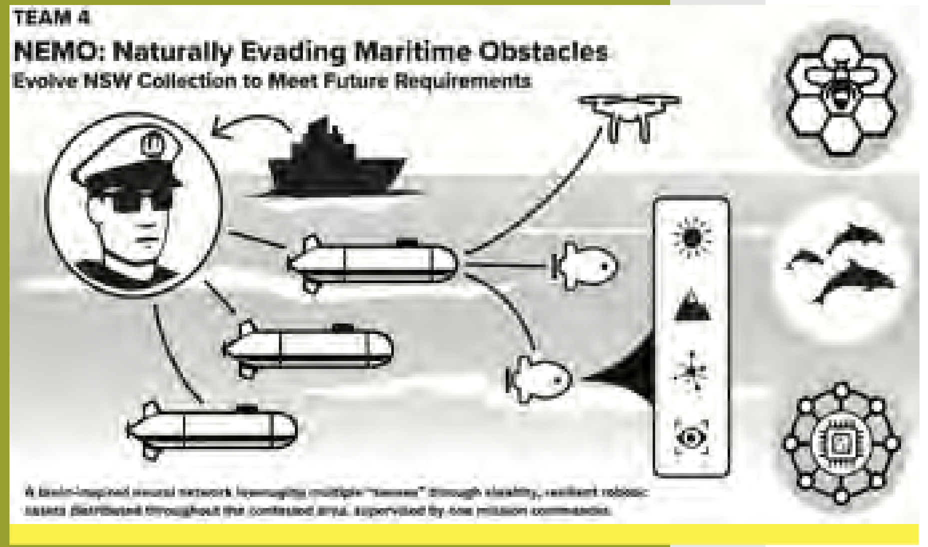
- High resolution EO/IR
- Acoustic transducers
- Smart navigation
- ML to learn environment

GROUP 3: AI TO REVOLUTIONIZE MISSION REHEARSAL

Provide mission rehearsal (simulation) capabilities for human-machine integration that can drive RDT&E and mission planning

KEY ELEMENTS

- AI, ML
- Computation
- Open-source tools



GROUP 4: NEMO: NATURALLY EVADING MARITIME OBSTACLES

Develop bio-inspired, platform-agnostic AI to create a school of smart, autonomous robots using both existing and new assets

KEY ELEMENTS

- A brain-inspired neural network leveraging multiple “senses” through stealthy, resilient robotic assets distributed throughout the contested area, supervised by one mission commander.

GROUP 5: SUBSEA CENTAUR CYBORGS

A highly intelligent subsea ISR system unreliant on satellites or radio

KEY ELEMENTS

- Multimodal, uses proven tech from other industries
- Clandestine, communicates through “whale songs”
- Advanced mission and payload autonomy
- Magnetic velocity navigation
- Celestial-based geolocation
- Graceful failure modes for PNT, ML, and data processing

GROUP 6: SCALING SOF CAPACITY IN A CONTESTED MARITIME ENVIRONMENT

AI equipped robotic autonomous systems

KEY ELEMENTS

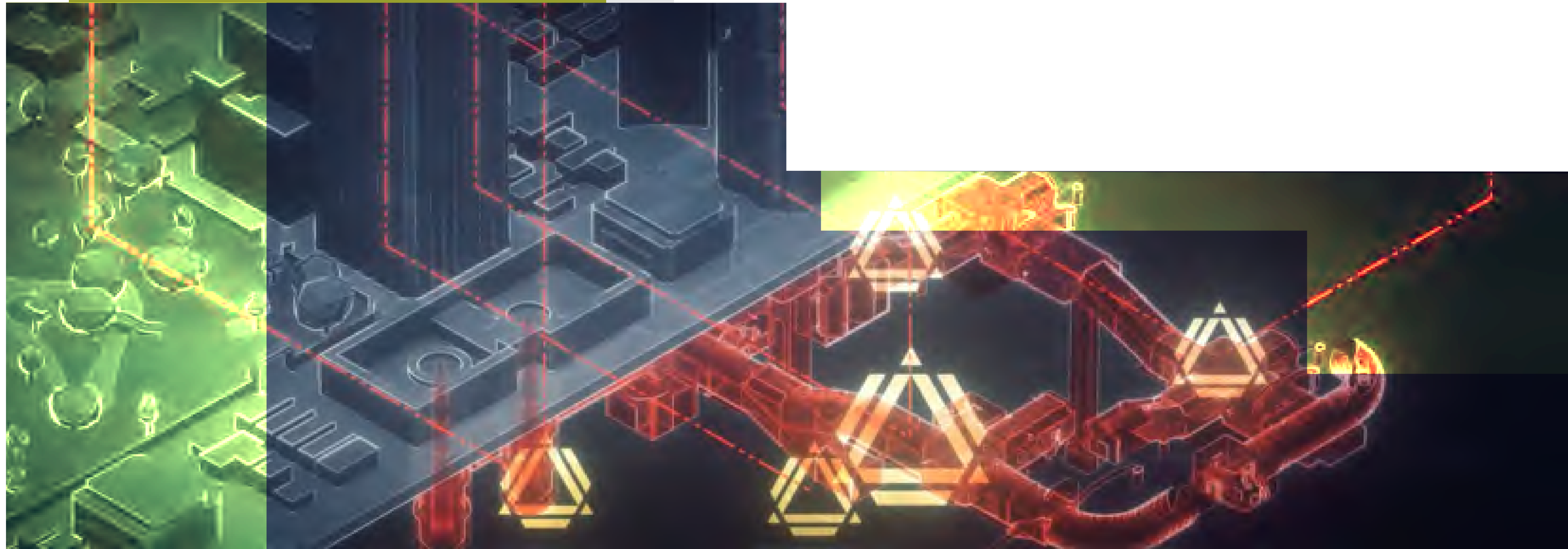
- Maneuver
- Intelligence
- C2 (machine-machine teaming, human out of the loop)
- Swarming – make current inventory smart (force multiplier)
- AI portability – free up exquisite assets

GROUP 7: JARV-AI

Employ individual and unit-level AI/ML-enabled man-machine teams to manage mission complexity and enhance decision making

KEY ELEMENTS

- Quantum gyroscope PNT solutions
- Biological storage for low SWAP
- Increases in battery energy density
- High-fidelity world simulations
- Edge compute
- Passive communication via laser-induced retroreflection
- Advanced wearables



IF6: SUMMARY OF CONCEPTS

Aspect	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Denied communications					Comms through “whale songs”		Laser-induced retroreflection
Denied PNT	Relative sensors				Magnetic, celestial	Magnetic anomaly navigation	Quantum gyroscope PNT solutions
Stealth – RF signatures	Low / no emissions	Acoustic transducers	Modeling and simulation		None		
Stealth – other signatures (acoustic etc.)	Biomimicked pathing				Comms through “whale songs”		
Stealth – form factor		Hide as ocean refuse	Modeling and simulation				
Stealth - deniability							
Infiltration of vessels / assets		Use shipping lanes – drop off fishing vessels					
New assets	Small autonomous UUVs	Assets hidden as trash		Bio-inspired small autonomous robots		Intelligent unmanned systems (UAVs / UUVs)	
Exfiltration of vessels / assets		No retrieval; physical assets will degrade					
Coverage of AOI							
Power	Hibernate / charge using ocean currents				Nano-diamond power		Increases in battery energy density
Propulsion		Ocean currents, some steering					
Sensors				Platform supporting existing and new assets			
Data integrity	Multiple passes						
Data storage					When required		Biological storage for low SWAP
Data communication	Collectors to runners to aggregators				When required		
Data processing / analysis	At the edge				Edge or Server as required		Edge compute
Integration of other data sources							
Command and Control			Tools for human commander / operators	Bio-inspired neural network for C2	Orchestrated AI/ML	Decentralized collaborative C2	
Mission Planning			Mission Rehearsal and simulation				AI designs the optimal man-machine team for the mission
Training			Mission Rehearsal and simulation				High-fidelity world simulations

RCA 6: READ-AHEAD DOCUMENT

ARTIFICIAL INTELLIGENCE FOR SPECIAL OPERATIONS: AN INTRODUCTION

THE DOD AI STRATEGY

The Department of Defense (DoD) Artificial Intelligence (AI) Strategy[1] recognizes that AI is poised to change the character of the future battlefield and as a result the pace of future threats, and seeks to harness the potential of AI to transform all functions of DoD.

> "Emphasizing that the women and men of the U.S. armed forces remain our enduring source of strength, we will use AI-enabled information, tools, and systems to empower, not replace, those we serve."
>
> DoD AI Strategy

The Strategy seeks to identify appropriate use cases for AI across DoD, rapidly pilot solutions, and scale successes across the enterprise. Specifically, the Strategy directs that we will use AI in a human-centered manner to support and protect U.S. service members and civilians around the world; protect our country and safeguard our citizens; create an efficient and streamlined organization; and become a pioneer in scaling AI across a global enterprise. To support the Strategy, DoD has established the Joint Artificial Intelligence Center (JAIC).

ON PROGRAM MANAGEMENT

When it comes to investing in new strategic capabilities, DoD organizations often seek to establish a program of record. The advantages are that it centralizes the distribution of funds and the management of capability.

A program of record approach makes sense for capabilities that are distinct and lack clear synergies – tanks, planes, submarines, etc. However, when a capability or technology is synergistic to every platform, it is better to integrate the capability into existing programs rather than to create new ones, as called out in the recently published House Armed Services Committee 'Future of Defense Task Force Report 2020' findings.[2]

> "AI is the new electricity."
>
> Andrew Ng, Chief AI Scientist at Baidu

AI is such a technology that will underlie just about every platform and program in the future. Andrew Ng of Baidu calls it "the new electricity"[3]; JAIC Chief Technology Officer Nand Mulchandani emphasizes that AI is a very large technology and industry. "It's not a single, monolithic technology," he said. "It's a collection of algorithms, technologies, etc., all cobbled together to call AI."[4]

The DoD does not have a program of record for electricity; instead, every program assumes there will be electrical components and ensures funding exists for those components. Similarly, AI is a capability and technology that can positively impact every DoD program that touches a platform.

There are some AI capabilities where centralization of program management makes sense, such as what the JAIC is doing with computer vision algorithms, but AI will likely fare far better when the programs themselves implement AI in their program plans.

ON REQUIREMENTS AND FUNDING

In DoD, the funding that matters is tied to specific and detailed requirements. As the Future of Defense Task Force 2020 Report notes, this is "designed to minimize risk and ensure competition and fairness; however, this often leads... to legacy platforms rather than the emerging technology-based systems necessary to operate in future conflicts".

This emphasis on requirements has hindered the Department's ability to quickly operationalize AI capabilities, where there are few programs that have contemplated these requirements.

DoD requirements writers have difficulty capturing AI requirements, and what is technically possible is moving faster than the Joint Capabilities Integration and Development System (JCIDS) process can keep pace with. This has been widely acknowledged.

Disparate requirements generation, funding allocation, and development tempo result in asynchronous investment strategies, reduced speed of development and acquisition, and operational capability gaps. So how do program managers get funding for AI if funding is tied to requirements, and requirements are hard to capture?

What is needed is a framework that supports the development of both AI concepts as well as AI metric based requirements. Importantly, this AI framework needs to be traceable from National and higher headquarters (HHQ) strategy to more directly connect investments with key priorities.

The Special Operations Command (SOCOM) S&T Futures Rapid Capability Assessment 6.0 (AI for Maritime Maneuver, Intelligence, Mission Command and Effects), henceforth referred to in this paper as RCA 6.0, gives us an opportunity to develop this framework.

THE CURRENT STATE OF AI IN SOCOM

Special Operations Command (SOCOM) has been a thought leader in seeking to integrate AI technologies into its programs. The *SOF Enterprise Capabilities and Programming Guidance 2023-2027* SOF modernization focus areas noted, "Advances in AI, ML, com-

1 United States Department of Defense. Summary of the 2018 Department of Defense Artificial Intelligence Strategy: Harnessing AI to advance our security and prosperity. 2018. At https://media.defense.gov/2019/Feb/12/2002088963/-1/-1/1/SUMMARY-OF-DOD-AI-STRATEGY.PDF

2 House Armed Services Committee. Future of Defense Task Force Report 2020. U.S. House of Representatives, 2020. At https://armedservices.house.gov/_cache/files/2/6/26129500-d208-47ba-a9f7-25a8f82828b0/424EB2008281A3C79BA8C7EA71890AE9.future-of-defense-task-force-report.pdf

3 Ng, Andrew. "Artificial Intelligence is the New Electricity". Talk at the Stanford Graduate School of Business, 02 Feb 2017. At https://www.youtube.com/watch?v=21EiKfQYZXc

4 Cronk, Terri Moon. "Defense official calls artificial intelligence the new oil". DoD News, 19 Oct 2020. U.S. Department of Defense. At https://www.defense.gov/Explore/News/Article/Article/2386956/defense-official-calls-artificial-intelligence-the-new-oil/

puting power, ubiquitous availability of data, robotics/autonomous systems will change the way we fight future conflicts…".

SOCOM is pursuing a wide range of applications for AI, including ISR, mobility, precision fires and effects, operator interfaces, and data and networks. These initial pilot projects are likely to yield benefits to specific SOF functions and have the potential to transform the capabilities of individual SOF teams. However, as the Secretary of Defense remarked, "Unlike advanced munitions or next-generation platforms, artificial intelligence is in a league of its own, with the potential to transform nearly every aspect of the battlefield, from the back office to the front lines" .

Therefore, SOCOM should strive to design and correlate an AI framework to map new operational concepts to programs of record. An agreed upon framework will ensure a common understanding of what SOF is attempting to develop and in what order. As AI implementation grows within SOCOM, this common AI framework will allow these initial efforts to be scaled across the enterprise.

We thus require a commitment to the development and fielding of artificial intelligence technologies with investment and dedicated resources prioritized across an agreed upon framework. **That is, should we invest in algorithm evolvement, software engineering, hardware engineering, scalable simulation and data systems, or scalable verification and validation systems.**

To link AI effectively and rapidly to critical DON missions, manning and organizational requirements, and policy considerations, Navy Chief AI Officer Brett Vaughan has described the need for a tactical/operational framework for military applications of AI technologies across the enterprise, in the categories of Warfighting, Corporate and Personnel.

While commercial AI technologies are most readily transferrable to the corporate and personnel categories, warfighting has proven more difficult as DoD requirements constructs transfer poorly to commercial constructs. SOCOM S&T Futures has outlined the AI framework needed as shown in Figure 1, with an emphasis on Warfighting. To operationalize AI for the battlefield an AI framework utilizing the seven warfighting functions of maneuver, intelligence, mission command, effects, logistics & maintenance, protection and information will need to be used.

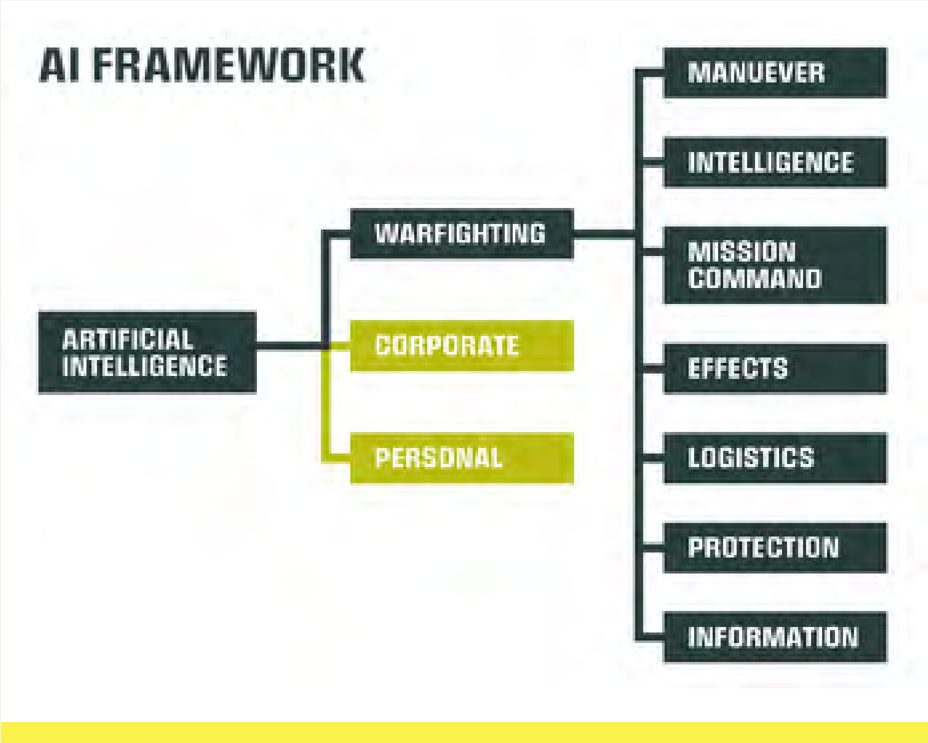


Figure 1. The SOCOM AI Framework needs to support SOCOM's Warfighting Functions.

> "AI refers to machines that can... make their own decisions when faced with new situations, in the same way humans can."

WHAT IS AI?

To begin building this common AI framework, we first need to develop a common language to describe the multitude of AI technologies and projects. Let us begin at the beginning: what is AI?

In the broadest sense, AI refers to machines that can learn, reason, and act for themselves. They make their own decisions when faced with new situations, in the same way humans can.

Due to the tremendous commercial growth in technology capability over the last few decades, AI capability has increased significantly, and appears poised to grow even further. Some of the most commonly used terms in AI are described below.

Machine Learning: In contrast to knowledge (automatic) systems where the rules are programmed by humans, in machine learning, the software is trained to build its own rules, learning from data provided by programmers, and from desired end states. In some implementations, machine learning happens only during software development, while in others, the software continues to learn from new data after implementation. Within machine learning, some specific terms are described below.

Supervised Learning requires software to learn about patterns using explicit human input. Humans provide labeled and categorized data to train the software. This technique is useful in applications such as image recognition.

Unsupervised Learning provides data for training without explicit human-created labels. The software organizes the data into multiple clusters. Since no human preprocessing is required, very large amounts of data can be used in training. The software-created clusters may not make obvious sense to humans! This technique is useful in applications such as anomaly detection in signal processing.

Reinforcement Learning is a technique where goals are provided to the software and rewards are provided for reaching these goals. During the learning process, the machine attempts multiple actions and takes many different paths (usually in the order of millions) in order to develop optimal ways to solve the problem. This technique is useful in applications such as game playing (chess, Go, etc.), autonomous vehicle navigation and mobility, etc.

Deep Learning is a specific technique that is used in machine learning. It uses technologies called **Artificial Neural Networks** (or sometimes just Neural Networks), which, loosely modeled on biological neural networks, take in information and process it through multiple layers of nodes. Each node and each layer processes the information in some way and prepares it for the next layer. Data from an input layer is processed through one or more hidden inner layers until an output layer is reached. Image processing applications often use deep learning techniques, and use mathematical operations called convolutions in the hidden layers, leading to the term **Convolutional Neural Networks**.

Robotics and Autonomy: Autonomous vehicles and robots are capable of independent actions that may range from remote human operation to full autonomy. These systems will use the techniques described above to implement specific functions for autonomous operation. For example, they will sense the environment and terrain to identify obstacles and determine their path.

Swarm Algorithms: When multiple autonomous systems work together, there needs to be communication and control of the entire system of systems. So-called swarm control algorithms allow robots to share the load of executing mission requirements, rebalance the load if one or more robots is damaged, and allows human command and control by one mission commander or a small team.

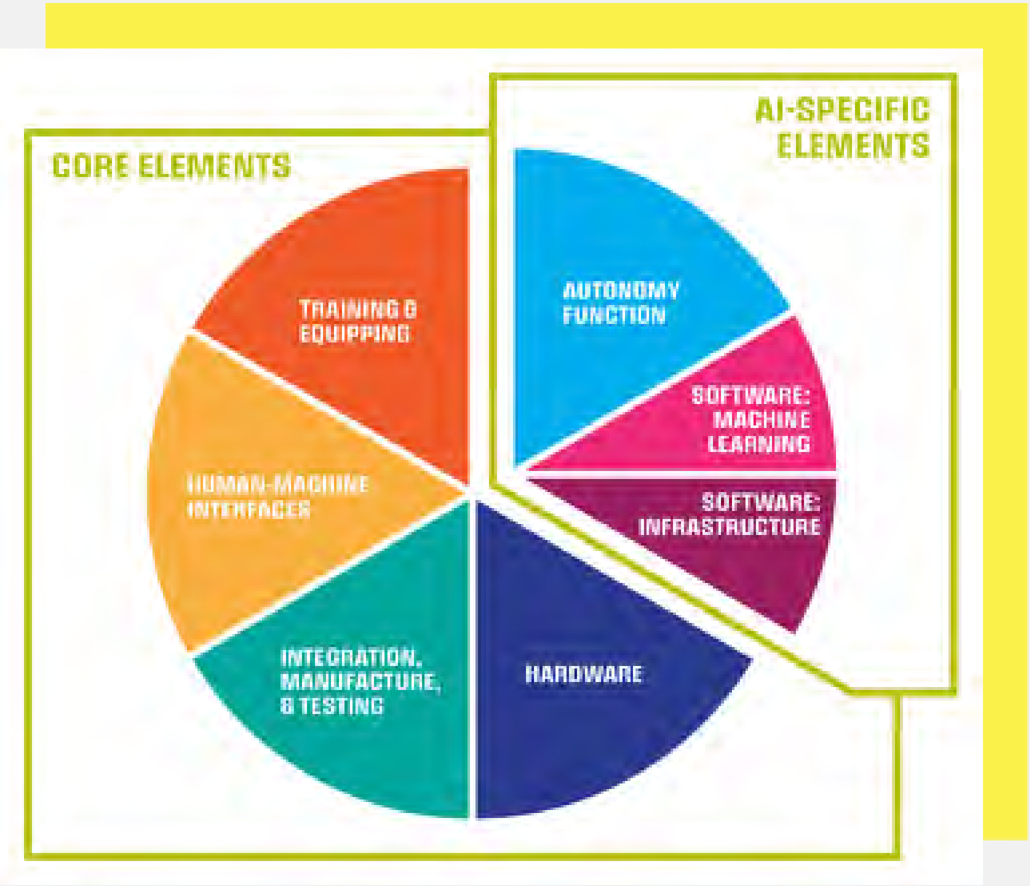
THE AI DEVELOPMENT, IMPLEMENTATION, AND USAGE ECOSYSTEM

To implement AI technologies, a number of elements are needed.

- At the base, we need the **hardware** – for example, a vehicle, a sensor, or a system.
- As with most technologies today, the **software** is by far the most complex part of the solution. With AI, there are two significant aspects of software: domain knowledge, usually involving **machine learning**, and a supporting **infrastructure**.
- The technology solution needs to be **integrated, manufactured, and tested** before implementation, and this engineering function is best handled by industry.
- For implementation, a robust set of **human-machine interfaces** are required – these would include command and control solutions, data visualization and analysis systems, and specialized user interface hardware and software elements.
- Another critical aspect of the solution is **training and equipping** – the system should provide for the development of tactics, techniques, and procedures, and provide live, virtual, and constructive simulations for operator training and mission planning.

All these elements will need to interoperate with and support the SOF warfighting function, as shown in Figure 2.

Figure 2. AI development areas showing different segments of the AI ecosystem.

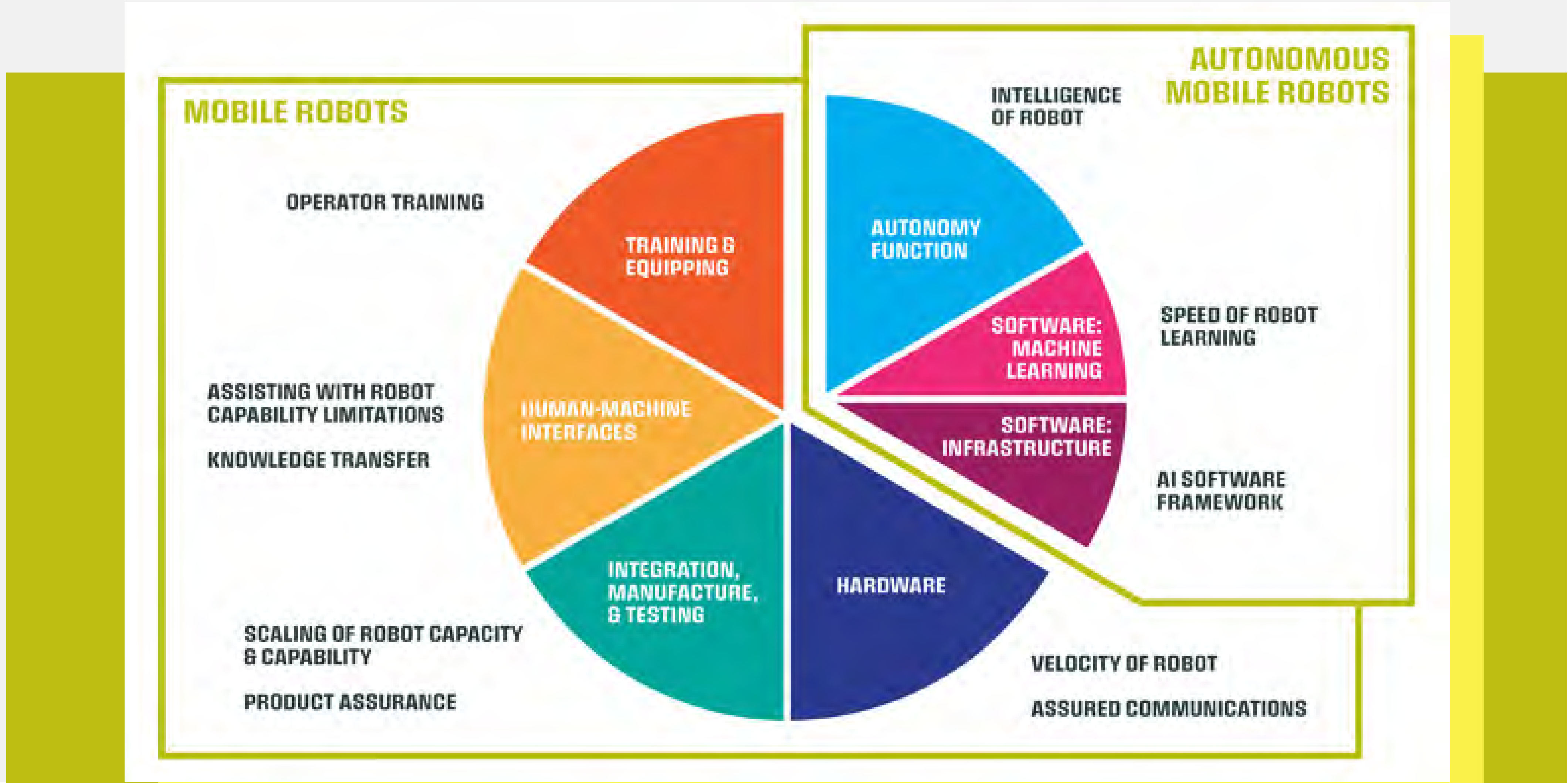


An example will serve to illustrate how the different elements of the AI ecosystem serve to build the warfighting capability. Consider the implementation of Autonomous Mobile Robots. There are numerous considerations that go into the design and implementation of robot technologies. These include the performance of the robot platform, scalability and product assurance, human interfaces, knowledge transfer, training, software infrastructure, machine learning to provide the robots with domain knowledge, and autonomy functions. Figure 3 Illustrates how these elements come together in this hypothetical example.

The number of subsystems that comprise AI for warfighting functions is expansive. Even narrowly focused efforts should be informed by the capability and trajectory of many human, technical and operational factors. SOCOM PEO/PMs can evaluate the ability of companies to complete AI systems by assessing technical capabilities in the related sub-system fields, outlined below, which will be required to ensure successful outcomes.

At the same time, these elements are largely developed inde-

Figure 3. How the different AI development areas provide capabilities for a specific use case - Autonomous Mobile Robots.

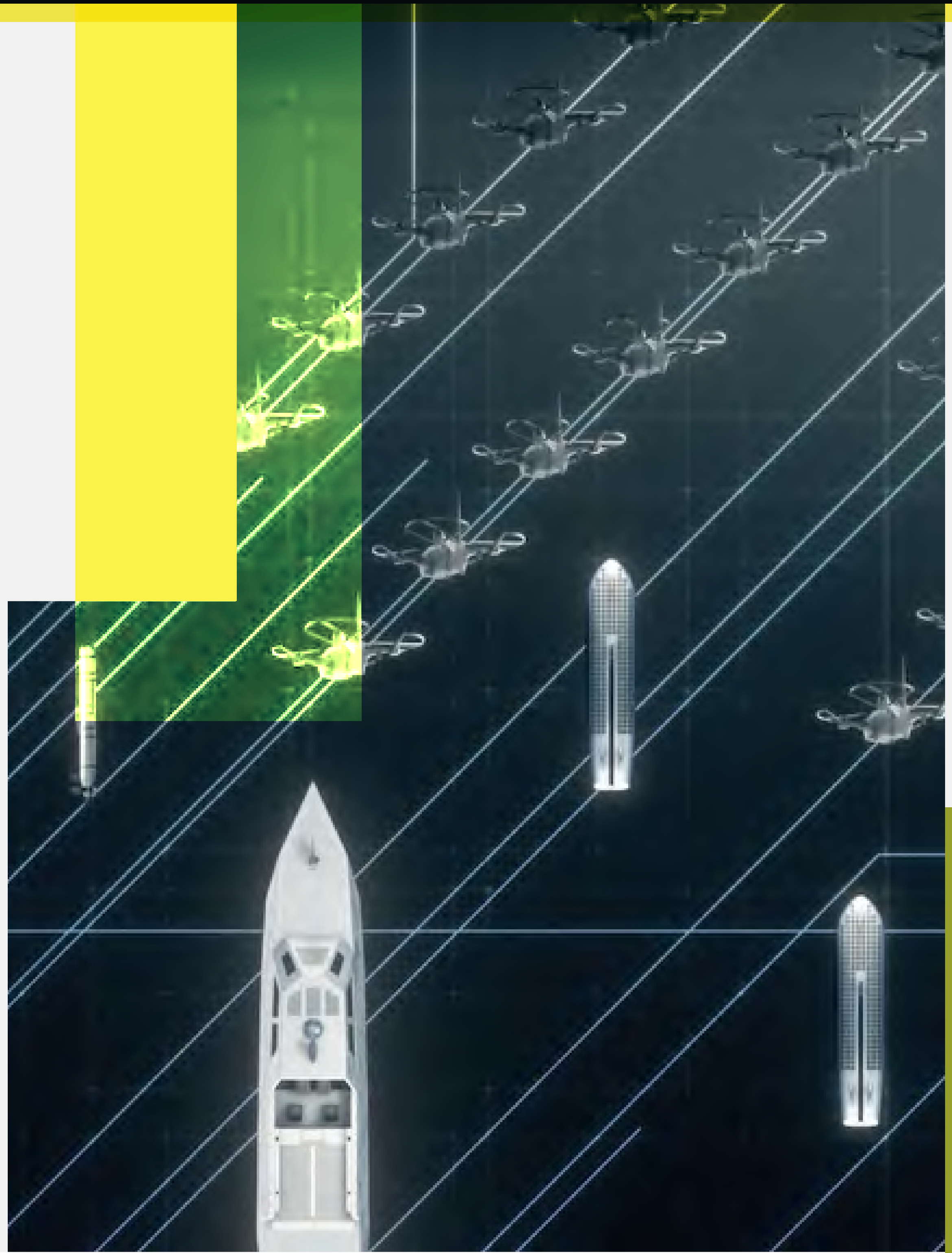


pendently of each other. Advances in computer hardware, for example, are constantly being made by computer and microprocessor manufacturers. Industrial needs may drive the development of controllers. The consumer market spurs advances in user interface technologies.

Some aspects of the ecosystem are much more specific to the needs of government, DoD, or SOCOM in particular. Mission command requirements require development of specific data visualization and communications solutions. Sensors and autonomous vehicles need to adhere to strict and often extreme specifications. Training and simulation needs are paramount.

The AI ecosystem is a dynamic one, with development cycles in industry being extremely rapid. While academic and government researchers and laboratories continue to do pioneering work in various aspects of AI, reducing those research advances into practice is being done at a furious pace by industry. Industry has thus established a significant advantage in the development of integrated AI solutions, and SOCOOM must look to industry to obtain solutions for its warfighting AI needs.

Establishing a common language for discussion of AI technologies, and developing a common AI framework for SOCOM, will allow innovative technologies to be deployed quickly, safely, and effectively in support of Special Forces missions.



AUTONOMY

What	Why
Preception – The robot's ability to observe and generate data about the environment around it. **Cognition** –The thinking component of the robot. It is where the data the robot collects is processed, interpreted, and used to draw conclusions and make decisions. **Action** – The action component of a robotic system that employs the decisions made in cognition in order to enable the robot to engage in an environment.	Allows machines to see, reason, interact with the world and collaborate with people to achieve tasks.

SOFTWARE AND INFRASTRUCTURE

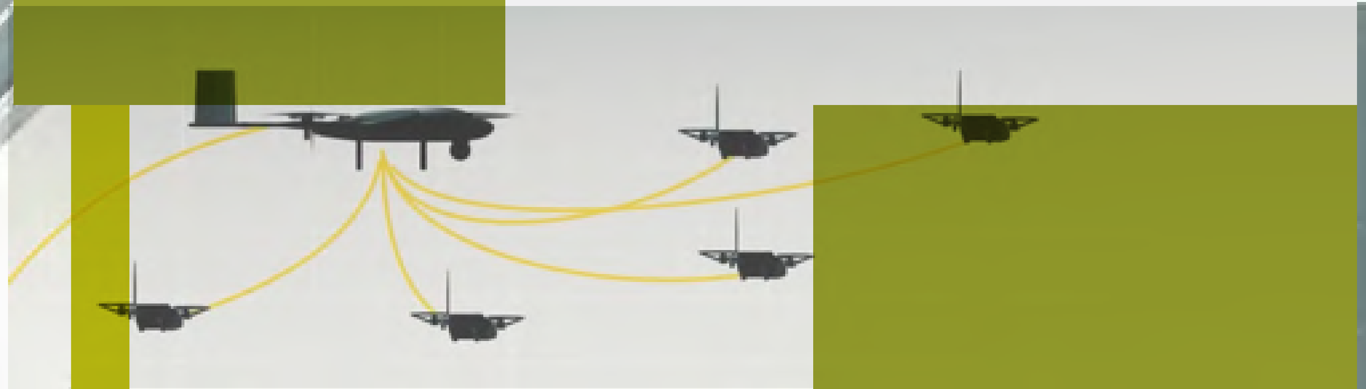
What	Why
Computing software – technologies and systems for edge computing, middleware, and cloud computing **Communications software** **Simulation and machine learning** – to train AI software on data relevant to the mission **Data management** – data capture, encryption, storage, security, processing, analysis, transmission, etc.	The glue that binds together all AI, autonomy, and human-machine interface components. The foundation of rapid development, test, verification and deployment.

HARDWARE

What	Why
Computing & Memory – Enabling AI to think, remember, and comprehend. **Sensing** – Enabling AI to see, hear, and perceive the surrounding environment. **Vehicles** – Enabling AI to move around its environment to explore, gather information and provide effects. **communications** – Enabling AI to interact with other robots and people; facilitating information sharing. **Interfaces** – Allowing people to provide direction and receive useful information in an intuitive way.	Enables AI to go places, inform, deliver effects, and coordinate with people. SOCOM will need to specify the parameters for computing hardware, vehicle performance, stealth, and command and control, etc. By having a clear language and framework to describe these parameters, the ecosystem can respond quickly and effectively to SOCOM's needs.

INTEGRATION, MANUFACTURE, AND TESTING

What	Why
These are traditional aspects of system integration; with AI technologies, the challenges include the rapid pace of technology development, the difficulty of testing in uncertain environments, etc. **Systems Engineering** – with autonomous systems and machine learning, this requires new and robust methods to be developed and implemented **Systems Integration** – the rapid pace of technology change will make systems integration a more complex task in the future **Manufacturing** – hardware manufacturing may lend itself to traditional approaches, albeit at a more rapid pace; however, software, especially AI software, will require adoption of very rapid cycles of changes, upgrades, and reactions to new developments **Validation & Verification** – large amounts of data will be required, as will well-developed simulation environments **Supply Chain** – the global nature of technology, both hardware and software, will pose challenges in ensuring a viable and secure supply chain	Pulls together all components to yield mission capability and then checks to see if results meets mission needs. The more opaque nature of validation and verification, combined with the expected rapid pace of technology evolution and implementation, means that SOCOM needs to develop adaptive, innovative procedures to ensure successful integration and testing of AI technologies.



HUMAN-MACHINE INTERFACES

What	Why
Manual control interfaces – traditional interfaces for equipment and vehicles **Blue Force Tracking solutions** (e.g. ATAK) **Data visualization systems** – to effectively process enormous amounts of data in real time and to make effective decisions in collaboration with humans and AI systems **UI systems** – Innovations in UI technologies include Head-Up Displays, gesture control systems, eye tracking systems, speech interfaces, immersive technologies (e.g. Virtual Reality), etc. and there are likely to be many more in the future	Allows a single operator, based on preference, to manage 'n' number of autonomous platforms/ systems. Humans are central to SOCOM as well as the larger DoD organization, and human-machine interfaces, always critical, take on much bigger importance when it comes to AI technologies. SOCOM will need a robust AI framework that gives SOF operators and analysts the confidence that they have the correct, timely information to make the right decision

TRAINING AND EQUIPPING

What	Why
TTP Development is needed for all new solutions that are deployed **Sustainment** Training is required in one or more of: **Live Environments,** **Virtual Environments** **Constructive Environments**	Training and simulation are critical to SOF operations, and new forms of training are required to keep pace with AI technologies and to use them effectively in missions

THE AI NEEDS OF SOF WARFIGHTING FUNCTIONS

As we have seen, a large ecosystem is required to support AI technologies for SOCOM deployment. Any solution that is deployed begins with mission needs that serve to support one or more of the SOF Warfighting Functions (WfFs).

In early AI projects at SOCOM, the entire cycle of technologies and steps in the ecosystem has sometimes been performed by one vendor – from hardware to software to implementation to training and user interfaces. Such an approach is difficult to scale, difficult to adopt across groups, difficult to integrate with other technologies, and is dependent on one vendor or a few vendors.

If we look at the ecosystem as a set of capabilities that can be provided by a large number of organizations, we can then focus on defining the SOF need precisely, and allowing systems integrators to select the optimal technologies in hardware, software, and user interfaces to implement the solution. Such an implementation will be easier to scale and adapt to new technologies and new mission needs. Some potential applications are listed[1].

In this section, some initial AI needs are presented for each SOF warfighting function. It is intended to spark discussion and yield a more accurate and detailed list of needs for SOF to carry out each WfF.

1 A more detailed look at AI applications across the seven Joint Functions is presented in:
Ray et al. Harnessing artificial intelligence and autonomous systems across the seven Joint Functions. Joint Force Quarterly 96, 1st Quarter 2020. At https://ndupress.ndu.edu/Portals/68/Documents/jfq/jfq-96/jfq-96.pdf

MANEUVER

AI NEEDS	POSSIBLE APPLICATIONS
State Estimation Mapping Scene Understanding Task Planning Motion Planning Controls	Autonomous vehicles and robots can operate in dangerous environments, can accept high levels of damage or loss, can undertake prolonged missions, and can take advantage of swarm algorithms for mass control.

INTELLIGENCE

AI NEEDS	POSSIBLE APPLICATIONS
Plan & Direct Sense (Collect) Identify (Detect, Classify, Identify) Attribute (Fuse, Produce) Share	Processing and exploitation of data INT processing Detection and identification of objects, threats, and anomalies **Trust is an important requirement in this function**

MISSION COMMAND

AI NEEDS	POSSIBLE APPLICATIONS
Assured Communications Human on the Loop Critical Assess / Decide Dynamic Mission Planning Dynamic Re-Tasking	Relevant, accurate, timely information presented in a visually compelling way AI provides a dynamic and comprehensive COP with additional information for different interest groups Automated AI analysis of large, complex data sets Recommended COAs **Trust is an important requirement in this function**

EFFECTS

AI NEEDS	POSSIBLE APPLICATIONS
Cooperative Sensing Scene Context Understanding Collaborative Search Distributed and Synchronized Effects	Obstacle avoidance Stealth measures Sensor activation and data capture It will be very important to have clear protocols in place to define when AI technologies can make decisions

LOGISTICS

AI NEEDS	POSSIBLE APPLICATIONS
	Maintenance and diagnostics of equipment Supply chain using autonomous vehicles

PROTECTION

AI NEEDS	POSSIBLE APPLICATIONS
	Robots and autonomous vehicles in dangerous environments Threat analysis in dynamic situations and in real time

INFORMATION

AI NEEDS	POSSIBLE APPLICATIONS
	Data management Data analysis (sensor data, threats, etc.) Cyber security

INTEGRATING SOF FUNCTIONS INTO AN AI DEVELOPMENT FRAMEWORK

By treating SOF WfFs as the critical need that drives acquisition and deployment decisions, we can leverage the larger ecosystem to support a strong SOCOM AI capability. Developments in each of the sectors can be utilized and adapted as needed to support the WfF. To do this effectively, we need a common SOCOM AI development framework. At the same time, DoD should work to adapt its requirement process to be less rigid and sequential and more iterative, which is how software-driven emerging technologies such as artificial intelligence (AI) and autonomous vehicles are developed. Figure 4 shows how Autonomy for the Maneuver WfF function might fit into the AI framework.

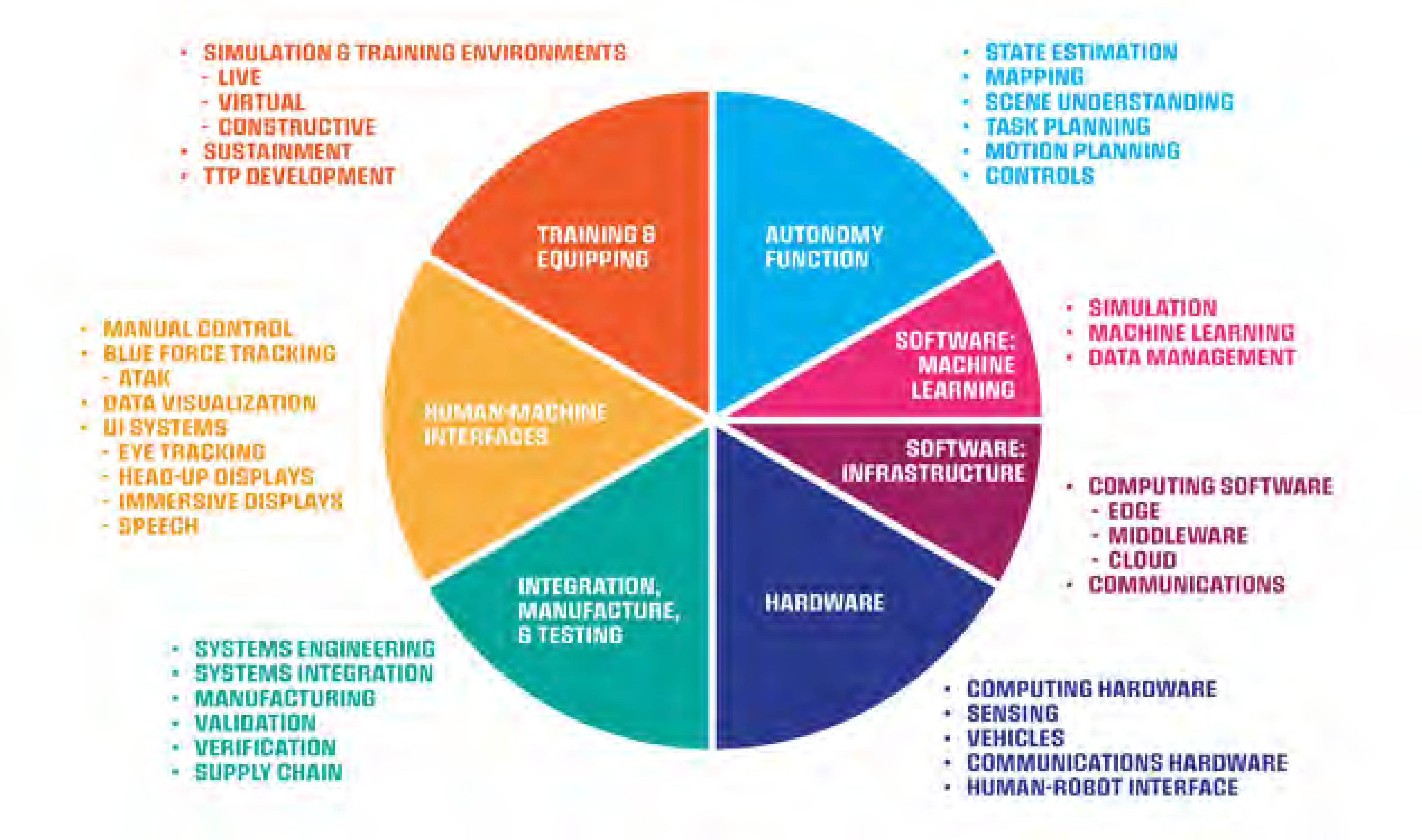


Figure 4. *A detailed view of the AI development framework, showing how a SOF warfighting function (Maneuver in this case) would fit in to the ecosystem.*

THE FUTURE: ESTABLISHING MARITIME AUTONOMY USING AI IN SOF MISSIONS

A specific example may serve to showcase the possibilities of AI technologies in SOF missions, as well as the challenges. The Future Operating Environment (FOE) will be a complex one with extensive use of technology by allies and adversaries, and is increasingly likely to be in urban and built-up areas, or in maritime environments, with complex terrain and signal challenges. In such environments, it would be advantageous to have a large number of distributed sensors in the operating environment.

Small unmanned surface and undersea systems (USV/UUVs) would be able to meet this need in a dynamic way. They could be deployed in swarms at sea, delivering synchronized lethal and non-lethal effects from near and far, from every axis, and in every domain. They could carry payloads of sensors, communications equipment, weapons, or equipment for maritime forces. They could provide intelligence, surveillance, and reconnaissance (ISR) capabilities, and provide support for multiple SOF WfFs including maneuver, intelligence, mission command, effects, logistics, and protection. And they could transform mission operations due to their ability to be deployed at scale to go effortlessly above and over obstacles, negotiate challenging environmental conditions, etc. Most importantly, the swarm of unmanned systems could autonomously (under the control of a single operator) detect, classify, and track objects of interest.

The maritime autonomy scenario allows us to consider the benefits and challenges of AI-assisted missions. It also allows us to explore the initial elements of a framework for how AI technologies would be deployed and how they would interact with human operators.

The AI-assisted mission would have to contend with a number of classes of complexity, which are described below.

MISSION COMPLEXITY

The challenges around mission complexity include **mission type, threat level,** and **threat action,** and can range from very low for a routine surveillance mission in a permissive area to extremely high for a complex effect in a high-threat environment of a near-peer adversary. Some of these challenges are knowable ahead of the mission, while others are dynamic and can change during the course of the mission.

ENVIRONMENTAL COMPLEXITY

The FOE is expected to be challenging, with environmental complexity that includes meteorological and oceanographic **(METOC)** conditions, **terrain**, and the **electromagnetic spectrum**. While environmental complexity can range from low, under clear skies, available maps, calm seas, 5G communications, and GPS; all the way to extremely complex under sleet, high seas with no maps, and under denied communications. Some of these challenges, such as bathymetry, are knowable ahead of the mission, some others, such as weather, are predictable with available data, and still others, such as electromagnetic spectrum availability, may change dynamically during the course of the mission.

HUMAN INTERACTION COMPLEXITY

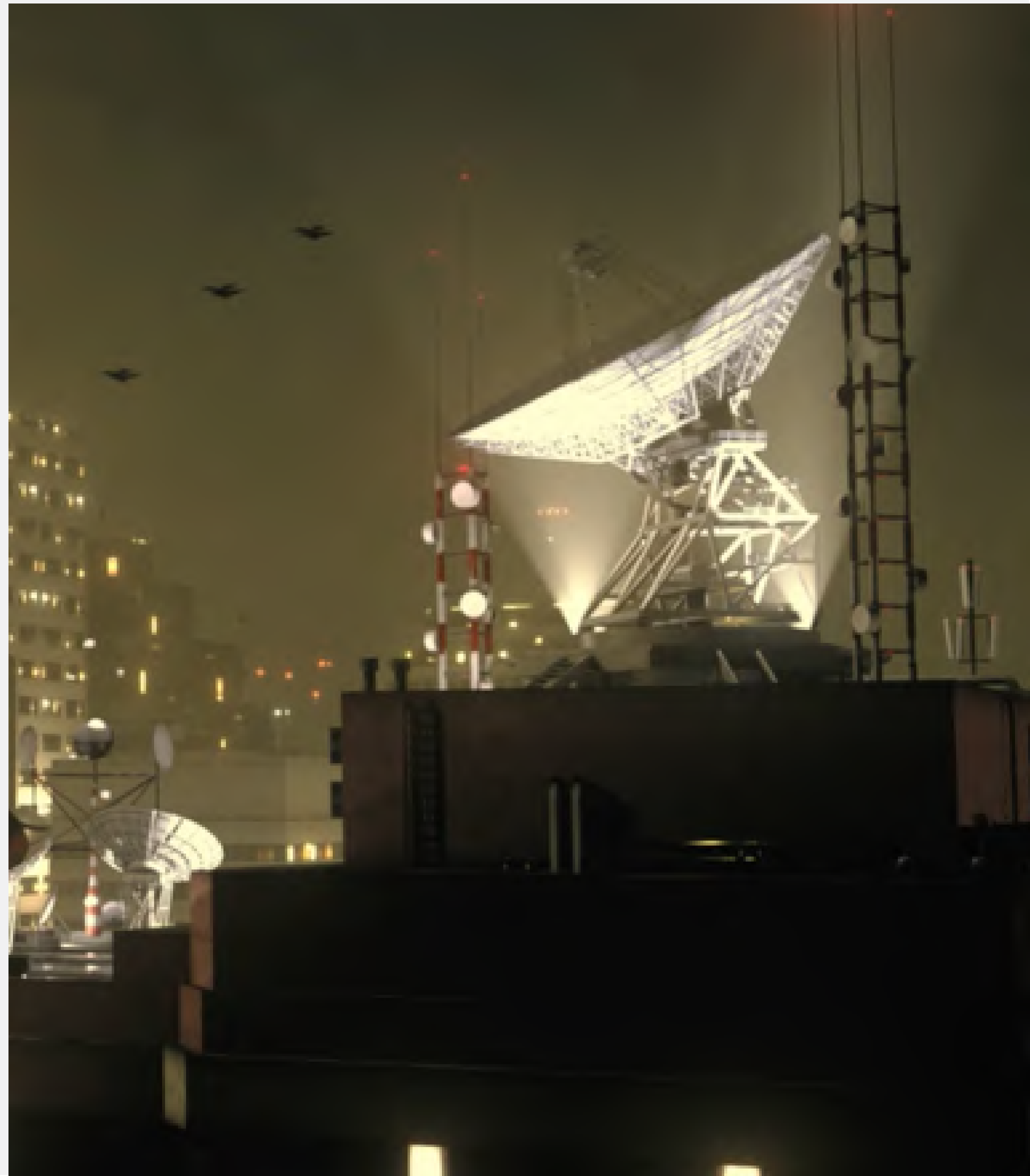
This is a measure of the number of individual **human interactions required** to control the autonomous technologies that participate in the mission. It can be zero for a fully autonomous mission where robots perform their tasks without requiring human assistance, and any interaction is purely a pull by the human to analyze the data obtained real-time during the mission. Higher numbers indicate increasing levels of human control of autonomous systems, with a corresponding reduction in the efficiency of the mission, as humans are distracted from their primary roles and autonomous systems are slowed in their tasks while waiting for human input as well as a greater need for assured communications.

The level of human interaction required is a metric for the level of trust that can be placed in the AI system such as an autonomous system. If an AI system has been tested and proven to require zero interaction, it has a high level of trust; conversely, when many human interactions are required, there is a lower level of trust.

Trust levels can change over time. When human teams are formed (for example, when a SOF team is assigned to work with a foreign partner on a mission), interpersonal trust often starts out low, and there are initially many interactions between the members as they verify each other's work. Over time, trust increases, as the members of the team grow to understand the capabilities of the others in the team. A similar dynamic may be expected when humans partner with AI systems on collaborative missions. Initial missions are likely to have lower levels of trust and thus higher levels of human interactions. As the human operators become more familiar with the capabilities of the AI system, interaction levels should fall as trust in the system increases.

MISSION DYNAMICS

Mission planning and simulation can identify the optimal autonomous platforms and payloads for the mission and environment. With AI technologies, it will be possible for the autonomous systems to react in real time to changes in the mission complexity or environmental complexity, and to unexpected findings during the course of the mission. Thus, when a robot encounters an unexpected strong current, it might be possible to warn other vehicles in the swarm to avoid the area or to change depth. If PNT is lost, a graceful degradation plan might be followed, with the vehicles in the swarm cooperating to share local positioning information. When unexpected obstacles or threats are encountered, human operators may be alerted to intervene.



FRAMING REQUIREMENTS FOR AI SYSTEMS

A multidimensional matrix of maritime autonomy challenge areas could be constructed, and used to develop strategies and technologies that support all possible state combinations. Mission planners would be aware of specific challenges that could cause delays or changes to the mission, and could take appropriate measures to counter them if they are encountered. Figure 5 shows different types of complexity along three axes, to provide a simple view of how various challenge areas can interact with each other over the course of a mission.

In reality, this would be a multidimensional problem. In the example shown in Figure 5, there are three types of environmental complexities (METOC, terrain, and electromagnetic spectrum); three types of mission complexities (mission type, threat level, and threat action); and the number of human interactions per mission, which is a metric for the trust level in the AI solution.

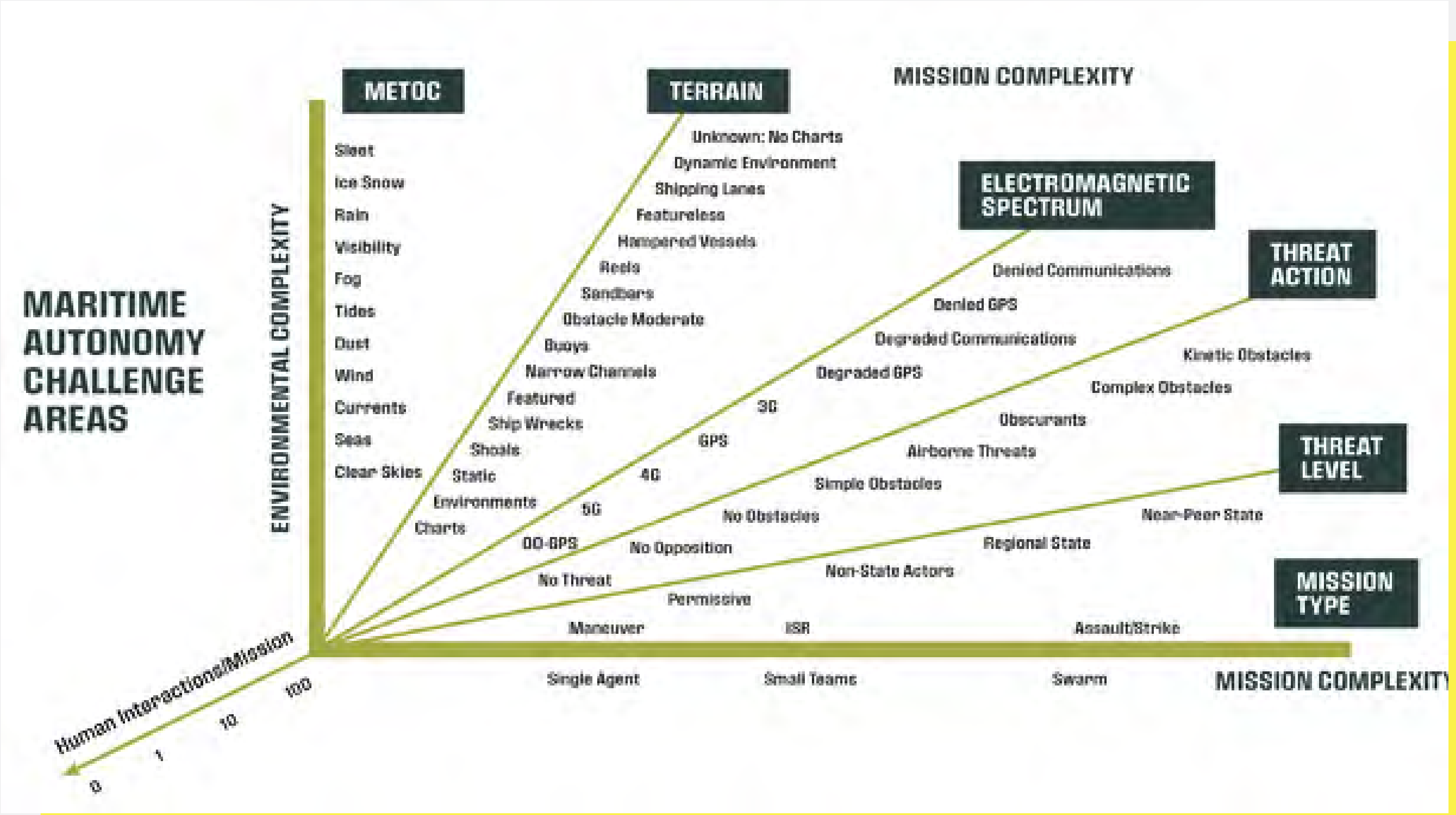


Figure 5. The challenges of maritime autonomy are represented by the interactions between mission complexity, environmental complexity, and human interaction complexity.

In a hypothetical mission, the challenges may be as follows:

- METOC: predictable using weather reports with the potential for some unexpected events
- Terrain: generally known but there may be some cases where the terrain is unknown and uncharted
- Electromagnetic spectrum: dynamic, with varying levels of communication and PNT availability
- Mission type: known, but may be subject to change based on events
- Threat level: known
- Threat action: dynamic, with varying threats at different stages of the mission possible

While the AI system will process these as a multidimensional matrix, for this paper let us consider a series of two-dimensional tables to illustrate how requirements may be specified. The goal is to specify the requirements for human interactions per mission.

Mission Type: ISR
Threat Level: Regional State
Terrain: Shipping Lanes

EM \ METOC	Sleet	Ice	Snow	Rain	Visibility	Fog	Tides	Currents	Clear skies
Denied Comms	0	0	0	0	0	0	0	0	0
Denied GPS	20	20	10	10	10	10	10	10	0
Degraded Comms	20	20	10	10	10	10	5	5	0
Degraded GPS	10	10	10	10	10	10	5	5	0
3G	3	3	2	2	1	1	0	0	0
GPS	3	3	2	2	1	1	0	0	0
4G	2	1	1	0	1	1	0	0	0
5G	2	1	1	0	1	1	0	0	0
D-GPS	2	1	1	0	1	1	0	0	0

EM \ Threat Action	Kinetic	Complex	Obscu-rants	Airborne	Simple	No ob-stacles	No op-position
Denied Comms	0	0	0	0	0	0	0
Denied GPS	20	20	10	10	5	0	0
Degraded Comms	10	10	10	10	5	0	0
Degraded GPS	20	20	10	10	5	0	0
3G	20	20	2	2	1	0	0
GPS	10	10	2	2	1	0	0
4G	10	10	1	1	1	0	0
5G	10	10	1	1	1	0	0
D-GPS	10	10	1	1	1	0	0

Threat Action \ METOC	Sleet	Ice	Snow	Rain	Visibility	Fog	Tides	Currents	Clear skies
Kinetic	50	50	20	20	20	20	10	10	10
Complex	20	20	20	10	10	10	10	10	5
Obscurants	20	20	10	10	10	10	5	5	2
Airborne	20	20	10	10	10	10	5	5	0
Simple	10	10	5	5	1	1	0	0	0
No obstacles	3	3	2	2	1	1	0	0	0
No opposition	2	1	1	1	1	1	0	0	0

The requirements may be specified at the level of detail that is appropriate for the program. Firm requirements as well as stretch goals may be specified; or vendor responses may be evaluated on their proposed human interaction levels.

As this example illustrates, Program Managers could develop key performance parameters tied to a quantifiable metric such as number of interactions or assists required of the human operator by the robot. At the same time, the DOD should work to adapt its requirement process to be less rigid and sequential and more iterative, which is how software-driven emerging technologies such as artificial intelligence (AI) and autonomous vehicles are developed.

SOCOM already has a common vision and a common doctrine. We now need a common language to describe AI needs, technologies, policies, and implementations. Developing this common language to describe mission requirements and challenges will allow us to build an AI framework for SOCOM that will support current and future AI tools and technologies that are shareable, scalable, and interoperable across the SOF enterprise.

RCA 6 CAPABILITY ASSESSMENTS

INTRODUCTION

The RCA 6 teams used the early SOFIA framework and associated vocabulary to understand the AI ecosystem, identify existing technologies, determine technology gaps, and come up with high-level concepts for solutions. The teams further developed the beginnings of Work Breakdown Structures (WBS) and specific contract language that would be appropriate for certain key AI functions in their solutions.

One of the goals of the RCA 6.0 event was to obtain feedback on the SOFIA framework and to evaluate how well it performed in a rapid response environment under near-real-world challenges.

This document provides an overview of the challenges provided to each team, how they employed the early SOFIA framework, and the solutions they identified.

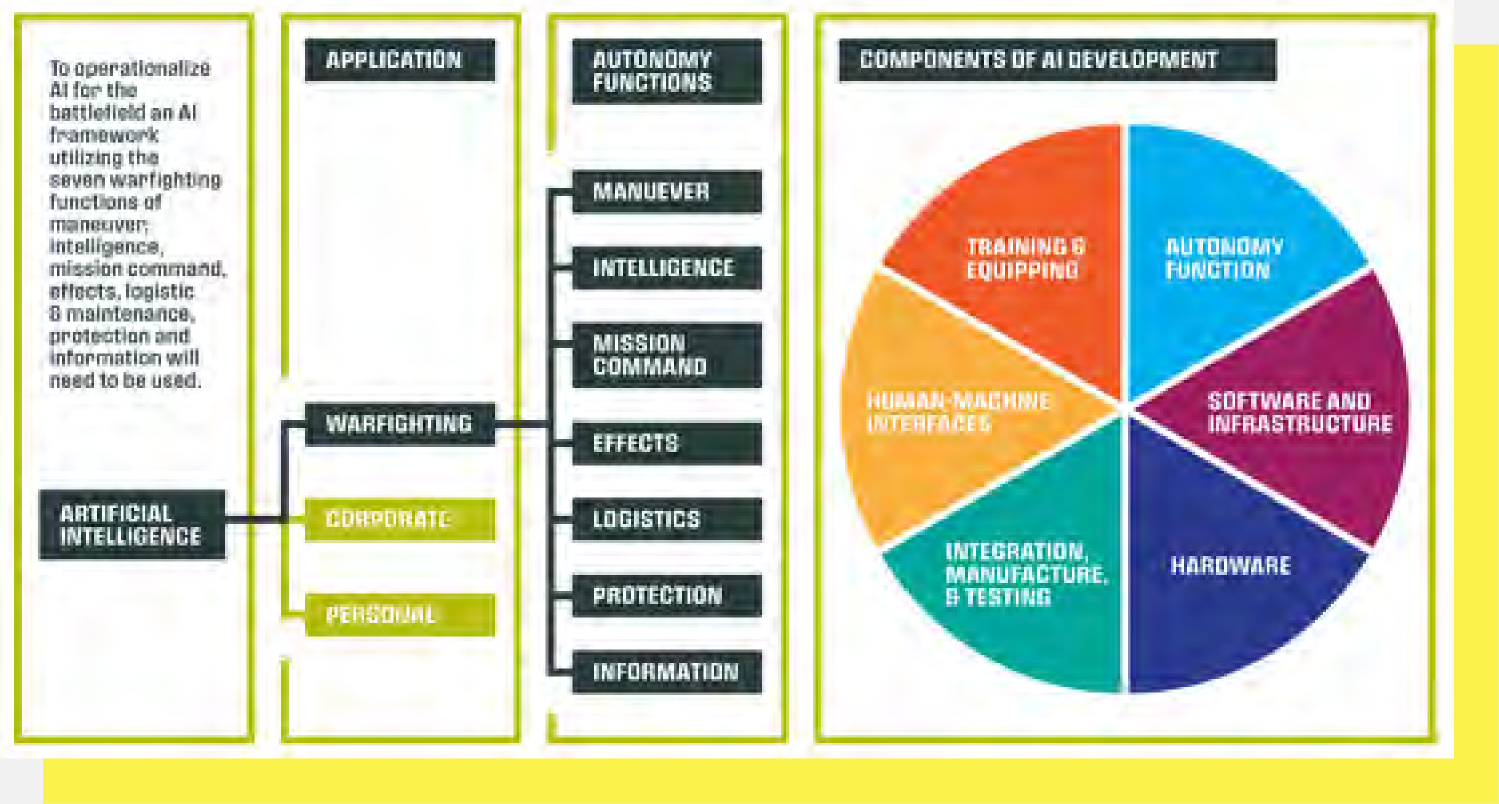


Figure 6. High-level SOFIA elements include Application, Autonomy Function, and Components.

AI FRAMEWORK AND AUTONOMY MEASURES

The teams were presented with the early SOFIA framework, as well as two models of complexity for autonomy: a simple model based on SAE International's "levels of autonomy" model for commercial autonomous vehicles[2], and a multidimensional complexity model developed by NSW/N9 for SOF missions.

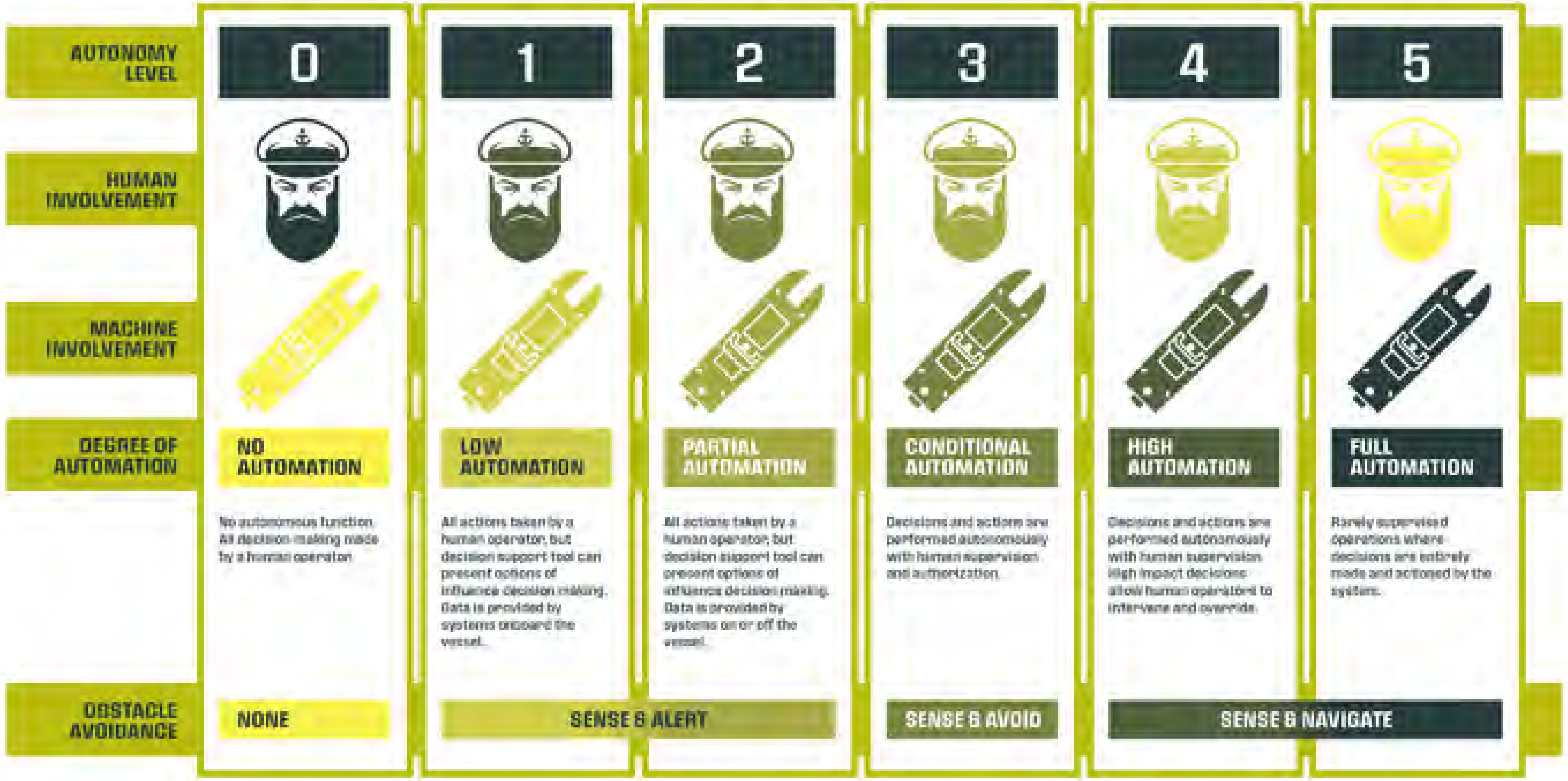


Figure 7. Six Levels of Maritime Autonomy.

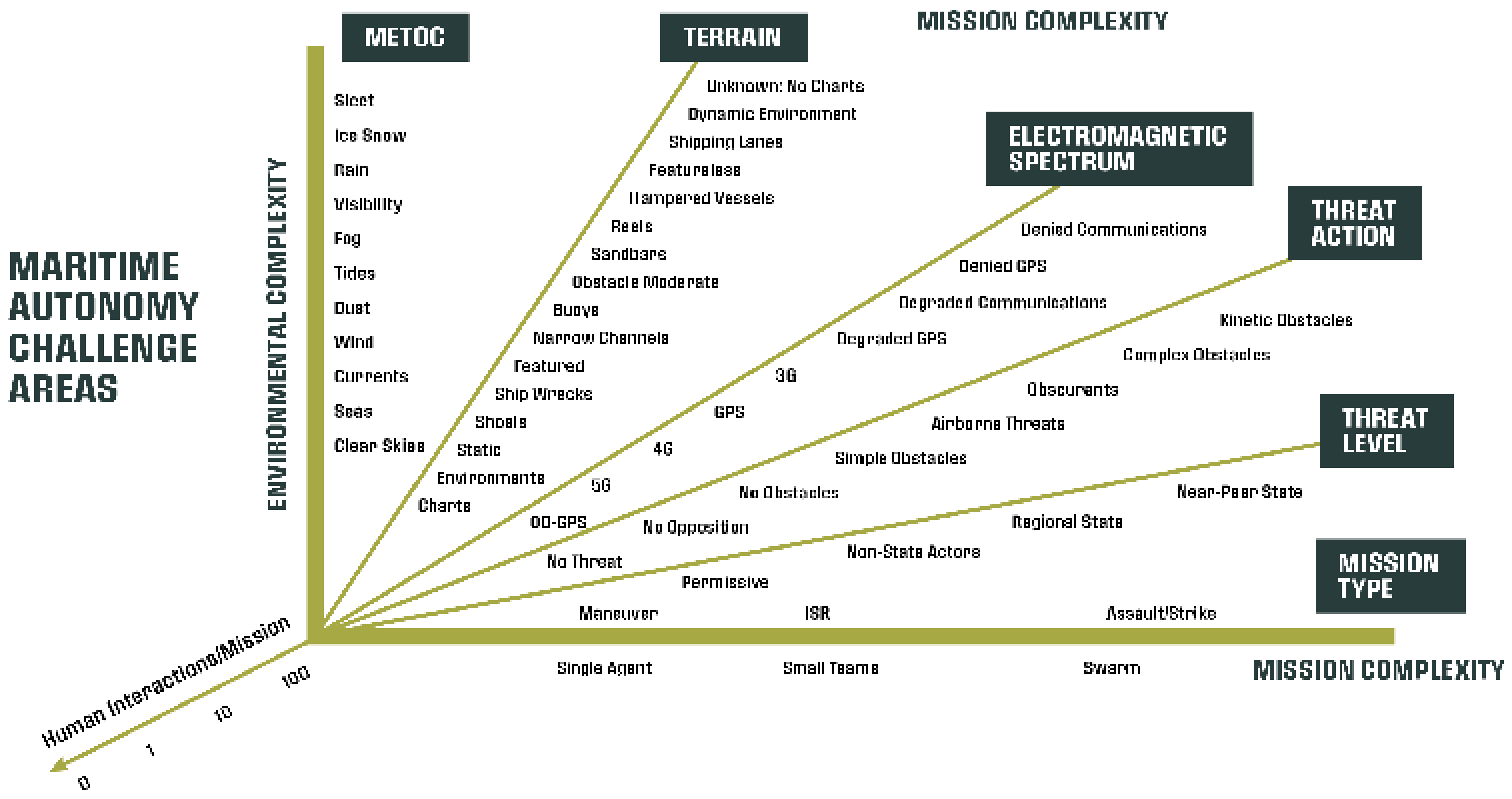


Figure 8. The NSW/N9 multidimensional mission complexity model represents the interactions between mission complexity, environmental complexity, and human interaction complexity.

2 SAE International. SAE J3016 Levels of Driving Automation. At https://www.sae.org/binaries/content/gallery/cm/articles/press-releases/2018/12/j3016-levels-of-automation-image.png

CHALLENGE 1: AI-ENHANCED NAVIGATION

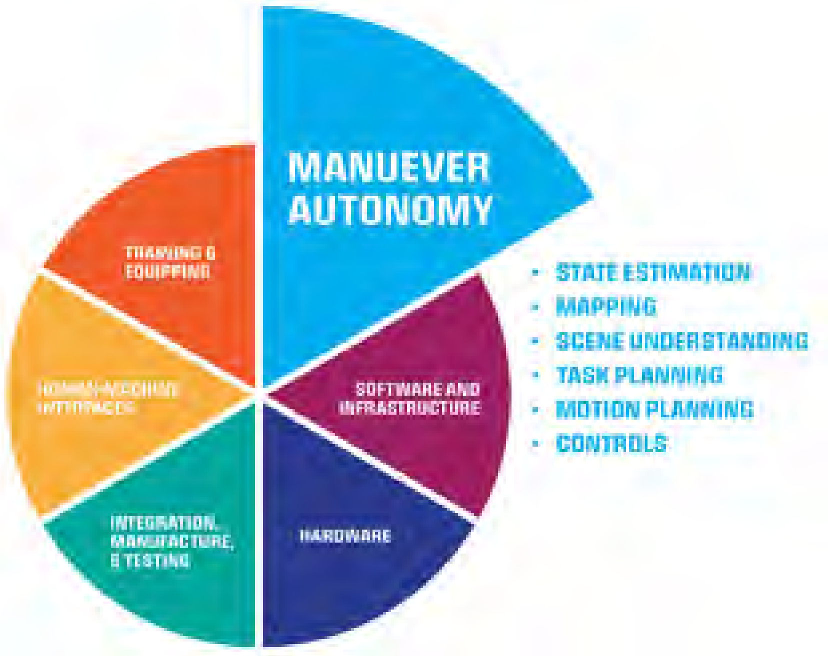
AI FRAMEWORK FOCUS AREA: Maritime Maneuver for Manned Surface Maritime Vessel

CHALLENGE DESCRIPTION: Deliberate, intentional jamming is occurring with increasing regularity. This can disable tracking, spoof data causing failure of mission. This is particularly worrisome given operating in environments without distinctive landmarks or other observable obstacles. How do we find alternatives to navigation, or reinforce the capabilities we currently have?

PROBLEM STATEMENT: How can AI and Autonomy enhance navigation in GPS-denied featureless environments (with no distinct geographical landmarks)?

Extended Problem Statement: How do we make the current Combatant Craft Medium (CCM) driverless?

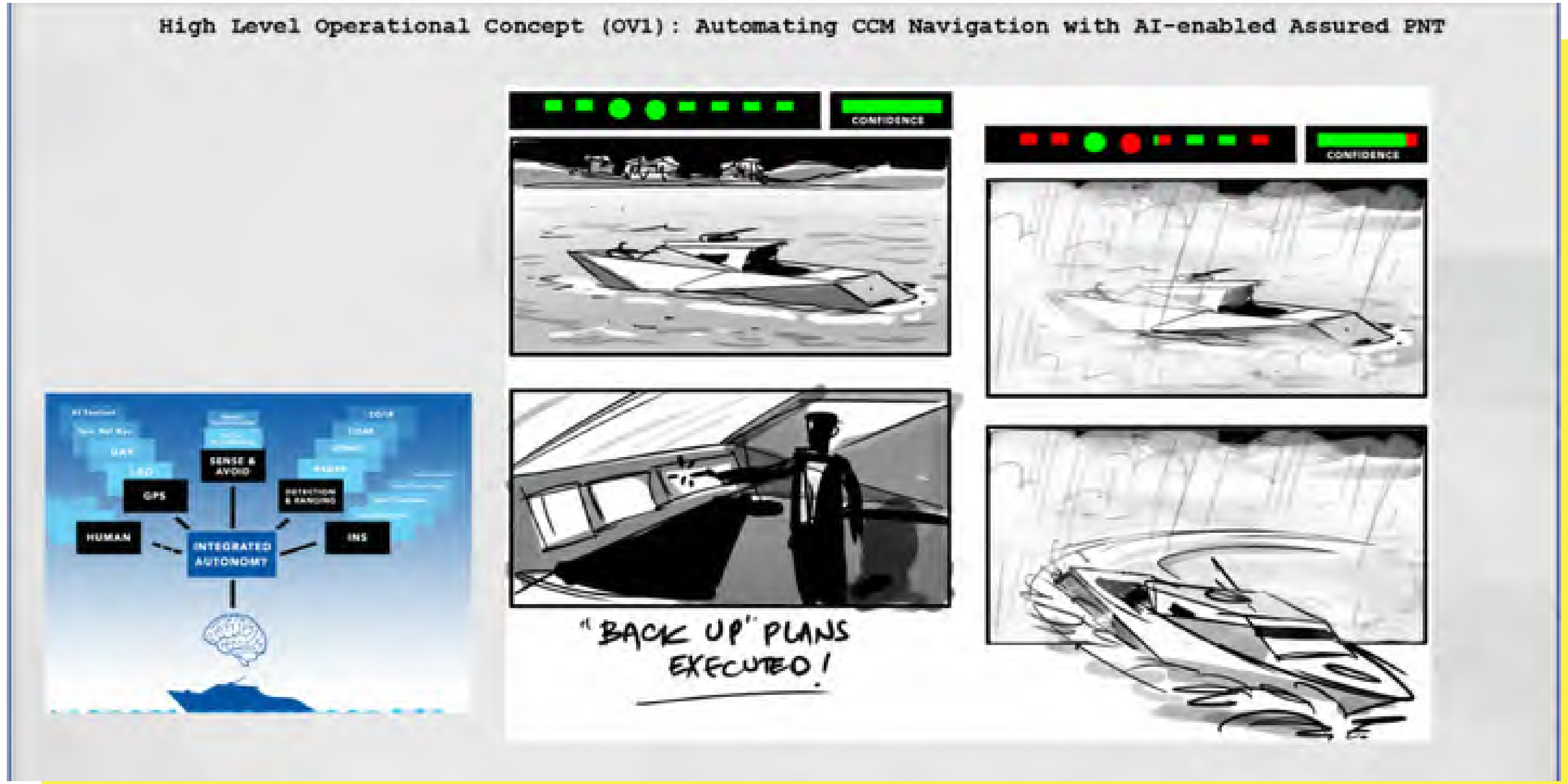
SOFIA CAPABILITIES FOR MANEUVER AUTONOMY



TECHNOLOGY GAPS FOR AI-ENHANCED NAVIGATION

- Holistic Data Solution (edge, local, cloud, UI)
- Machine Learning (human training & labeling effort)
- Vehicle Control Computer
- Mission Autonomy Computer
- Payload Autonomy Computer
- Up to date high resolution maps (terrestrial and subsea)

HIGH-LEVEL OPERATIONAL CONCEPT FOR AI-ENHANCED NAVIGATION



SOLUTION DESCRIPTION FOR AI-ENHANCED NAVIGATION

All autonomous vehicle (AV) systems aim to imitate human drivers. The method that the commercial AV industry has centralized on to solve this involves logging the actions of human drivers over millions of miles and then training AIs to replicate that human behavior. SOCOM must do the same thing to enable autonomous maritime navigation. Every day that we do not log the sensor data and human behavior of CCM drivers is a lost day of opportunity cost that delays SOCOM's AI aspirations. Moving beyond that, we propose a framework to automate a CCM to achieve both GPS-denied navigation (how to get from A to B) and collision avoidance/ maneuver.

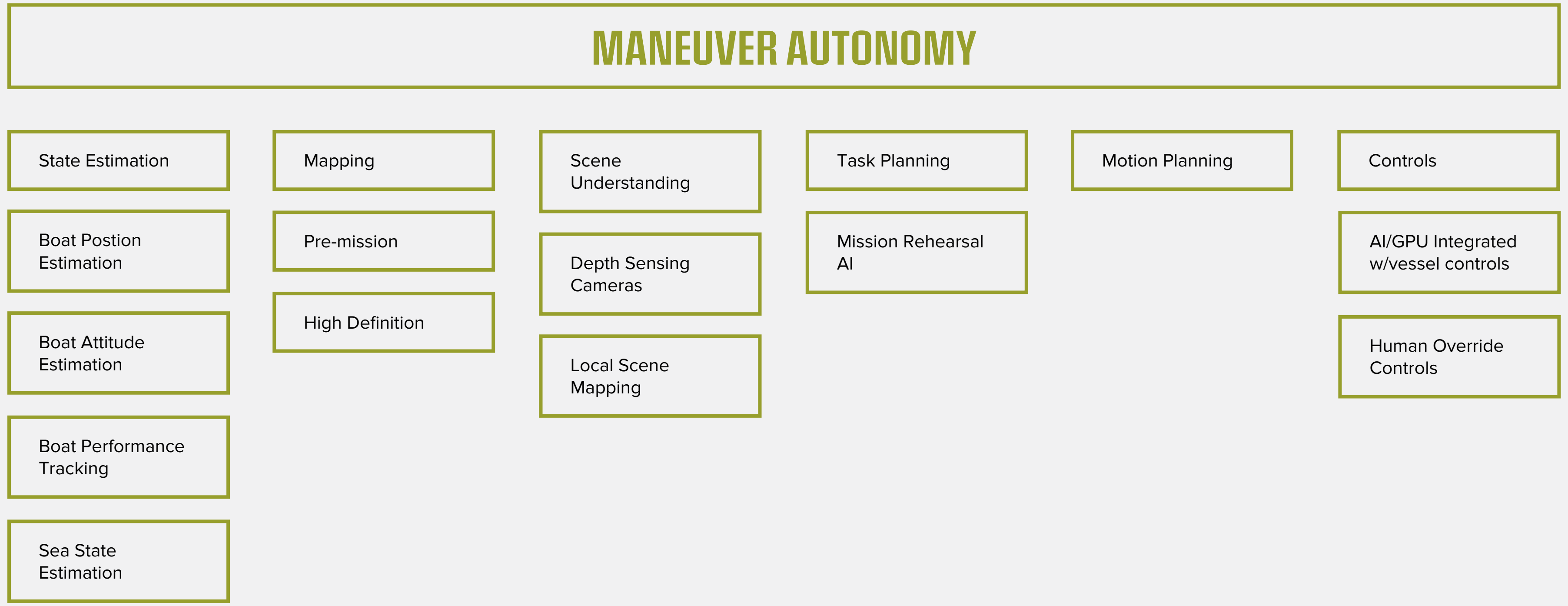
Implement Immediately:

1. Sensor Integration – Identify the sensor suite (e.g., radar, EO/ IR, RF) needed for autonomous navigation and integrate them onto manned boats immediately
2. Edge Data Logging – Log and store every bit of data and human action (e.g., steering, throttle) on the boat
3. Centralized Data Repo – Store all data from all boats in an enterprise/cloud-based architecture
4. Develop Annotation Framework – create and deploy a method to label all the data (e.g., identify objects in sensor data, why people took actions) so it can be used to train future AI/ML algos
5. Create Training Dataset – label the data from the boats on an on-going basis to continually increase size of training corpus

Future:

1. Train AI – Use the labeled data to train an AI to navigate autonomously. This training will be done in the cloud and will result in an AI model (it requires significant compute horsepower). This should include both the GPS-denied PNT (how to get from point A to B) and local sense and avoid (collision avoidance). In time, it could be naturally extended to more advanced behaviors such as targeting, evasion, etc.
2. Containerize the AI – package the AI model developed in the last step so that it can run in arbitrary compute footprints (Kubernetes, Docker, etc.) so that it can run on a variety of edge devices.
3. Identify Edge Compute Requirements – determine how much compute power will be required to execute the autonomous AI on the boat
4. Integrate Edge Compute – Install the additional compute required for autonomous navigation on the boat and perform HW/SW integration necessary to enable the AI to control the boat
5. OT&E – Install the AI on the boat and begin test & eval. Continue to store/log all data and interactions for future AI training
6. Feedback Loop – continually retrain AI to improve the AI's decision making

INITIAL WORK BREAKDOWN STRUCTURE FOR AI-ENHANCED NAVIGATION



EXAMPLE CONTRACT LANGUAGE FOR AI-ENHANCED NAVIGATION

VISION SYSTEMS

2-sentence description:

Fully spherical real-time vision systems around the vehicle which the AI can use in order to have full spatial awareness and scene understanding for collision and obstacle avoidance. Multi-Sensor Array around the Unmanned Craft and Robotic Vision Systems.

2-paragraph description:

Integrated robotic vision in all directions around the vehicle Is critical to reach the full capability of an unmanned craft to perform maneuvers and navigate itself in dynamic environments.

Each direction should have a compilation of optical, IR, and 3D depth sensors in order to rely on the best modality for the environment. The system also could serve a dual purpose of remote Teleoperation if satellite communication is available.

ADVANCED MAPPING

2-sentence description:

We need good maps of the entire marine environment in potential operating environments. By using AI-enabled data mining, crowd sourcing, and organic autonomous data collection, we can begin to build these today.

2-paragraph description:

Given the complex nature of near peer EEZ subsea data availability, alternative data collection methods must be employed to increase knowledge of the battlespace in advance of operations.

By combining AI-enabled collection of third-party organic data sets with fully autonomous organic data collection, SOCOM can build comprehensive and accurate seafloor and sea-surface maps to aid in navigation and mission planning. (these data sets may include RF, bathymetry, imagery, etc.)

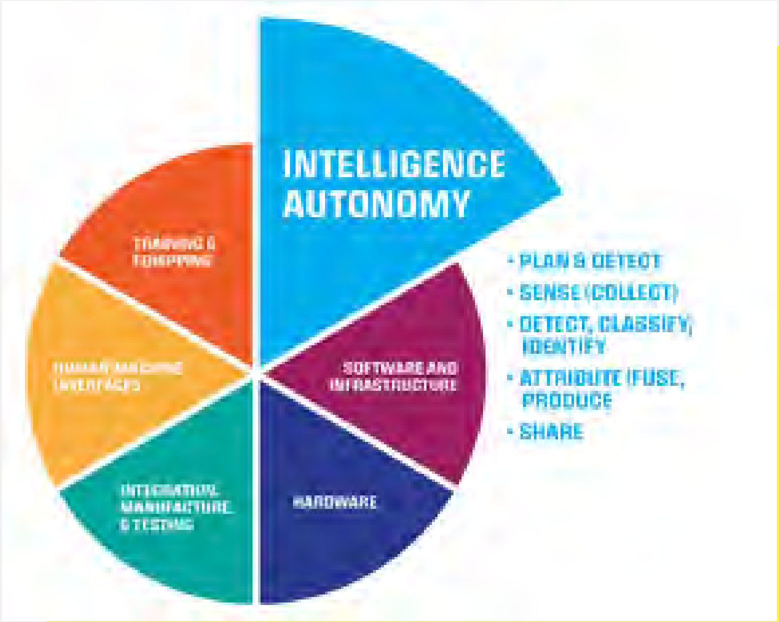
CHALLENGE 2: AI-ENHANCED ISR (INTELLIGENCE, SURVEILLANCE AND RECONNAISSANCE)

AI FRAMEWORK FOCUS AREA: Intelligence for Manned Surface Maritime Vessel

CHALLENGE DESCRIPTION: Increase and enhance SOF's ability to manage and understand threats in the Maritime environment. Process multiple data inputs, and support rapid on-the-move ability to detect, classify, and identify tactically relevant commodities of interest for optimized decision making.

PROBLEM STATEMENT: In (DIL) Degraded, Intermittent, and Low Bandwidth areas, how can AI enable the operator to better manage and understand unknown obstacles (threats/non threat) in the environment?

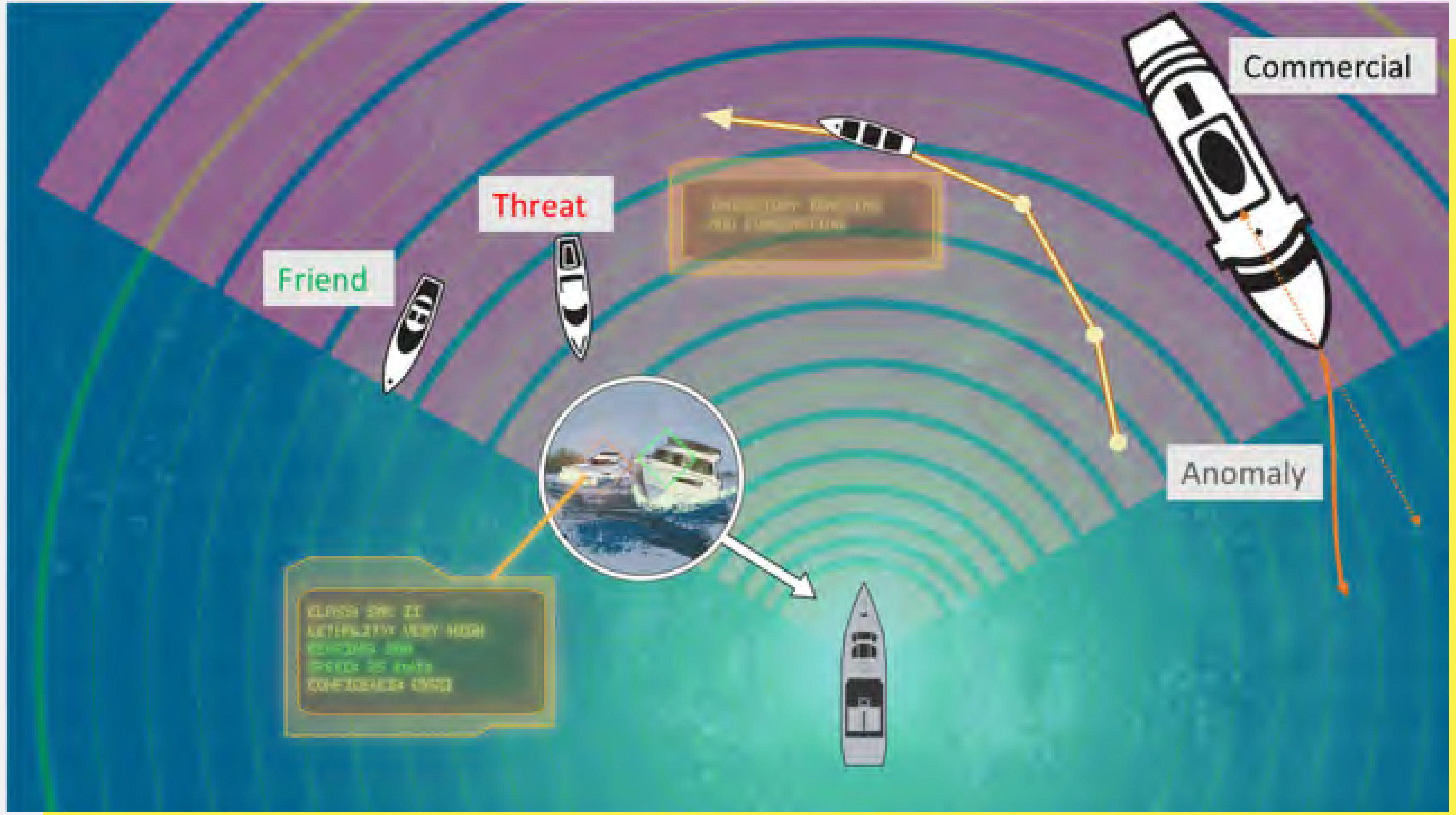
SOFIA CAPABILITIES FOR INTELLIGENCE AUTONOMY



TECHNOLOGY GAPS FOR AI-ENHANCED ISR

- Maritime simulation
- Maritime vessel models
- Covert communications
- Localized / mesh networks

HIGH-LEVEL OPERATIONAL CONCEPT FOR AI-ENHANCED ISR



SOLUTION DESCRIPTION FOR AI-ENHANCED ISR

CHALLENGES:

Nascent stages of AI Intelligence Autonomy for Maritime ISR

- Limited operational data for model training
- Preload navigation charts, weather, background scenery
- Environmental noise and uncertainty
- Evolving situations: What is the AI looking for?
- Prefusion of data informs which sensors to use

Edge Processing Limited

- Limited/no bandwidth/backhaul - must do all processing on board
- Object detection difficult w/ all cameras
- Need image stabilization
- Storage / compute needs

Maritime Intelligence Autonomy more challenging than Air/ Ground environment

- Pattern-of-Life important for intelligence
- EO/IR cameras are 2D only
- Sea state and other environmentals (rain, sleet, etc.)
- Obscured craft

NEEDS:

Datasets for modeling maritime vessels + behaviors

- Radar signature
- Images
- Behavior patterns
- Performance envelopes
- Taxonomy

Models of potential anomalies – weapons systems, radars, AIS, etc.

Synthetic testing environments

Better / redundant EO/IR cameras

Integrate radar + auto-swiveling camera for auto scan & detection

Autonomous systems use AI and ML techniques

- Data gathering
- Compute Power
- Edge Processing

Sensor fusion from multiple vessels and platforms (marsupial or otherwise)

Explainability of AI

- Threat level explained – vessel type, bearing, speed, etc.

TECHNOLOGIES - 1-3 YEARS

State Estimation: detect, identify, and characterize

- Equip crafts with ruggedized compute/GPU capabilities
- Upgrade sensor suite with computer-controlled EO/IR Cameras
  - Z-axis movement preferred
- Access robust craft models (ie sailbot vs...) for detection
  - IR camera shows IR sensor of sailboat under power vs sailing
- Provide separate huan touchpoints for Detect, Identify, Recognize
  - Human provides corrections for AI
  - Areas of interest (focus of attention)
- Develop maritime-optimized HMI hardware
  - Easy to interact with regardless of sea state, spray, temperature, etc.
  - Vulnerabilitiy adaptive - tailor information based on balance of multiple factors
  - Limit “alerting fatique”
- Establish Modeling/Simulation + synthetic training environments

TECHNOLOGIES - 4-6 YEARS

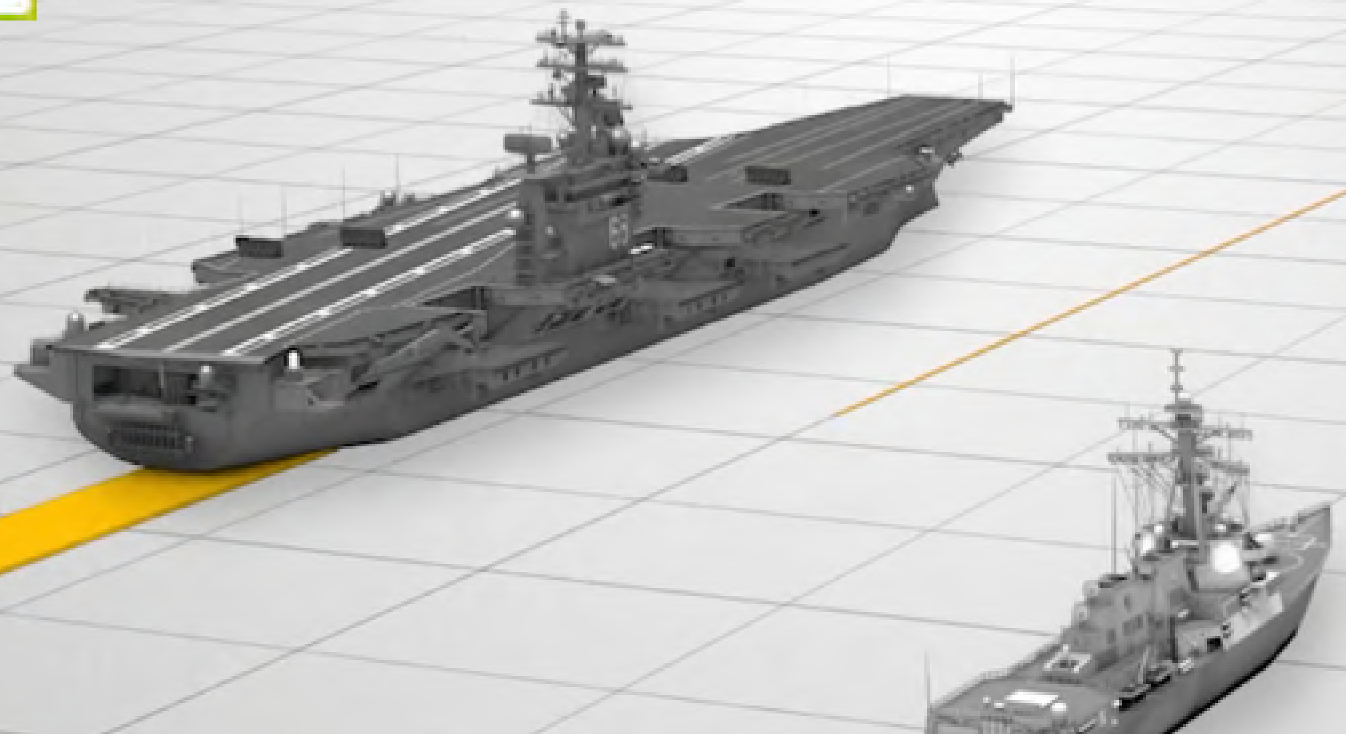
State Understanding: patter of life generation and anomaly detection

- Upgrade craft with multiple redundant cameras for safety-of-navigationn + ISR
  - Also gives opportunities for greater field of view
- Fuse data across modalities and views:
  - radar + AIS
  - multiple angles to provide higher fidelity to classification
  - Attribute AIS data to vessels classified using EO/IR camera
- Detect anomalous behavior/threats
  - Use Rules-of-the-Road datasets (COLREG)
  - What do anomalies look like?
- Maintain and track “watchlisted” craft:
  - Collect list of known target vessels
  - Prioritize “known bad” for TTL
  - Assess other vessels in the area
- Refine algorithms based on user feedback
  - “Not a hotdog” algorithm
- Establish Advanced modeling/sim environment

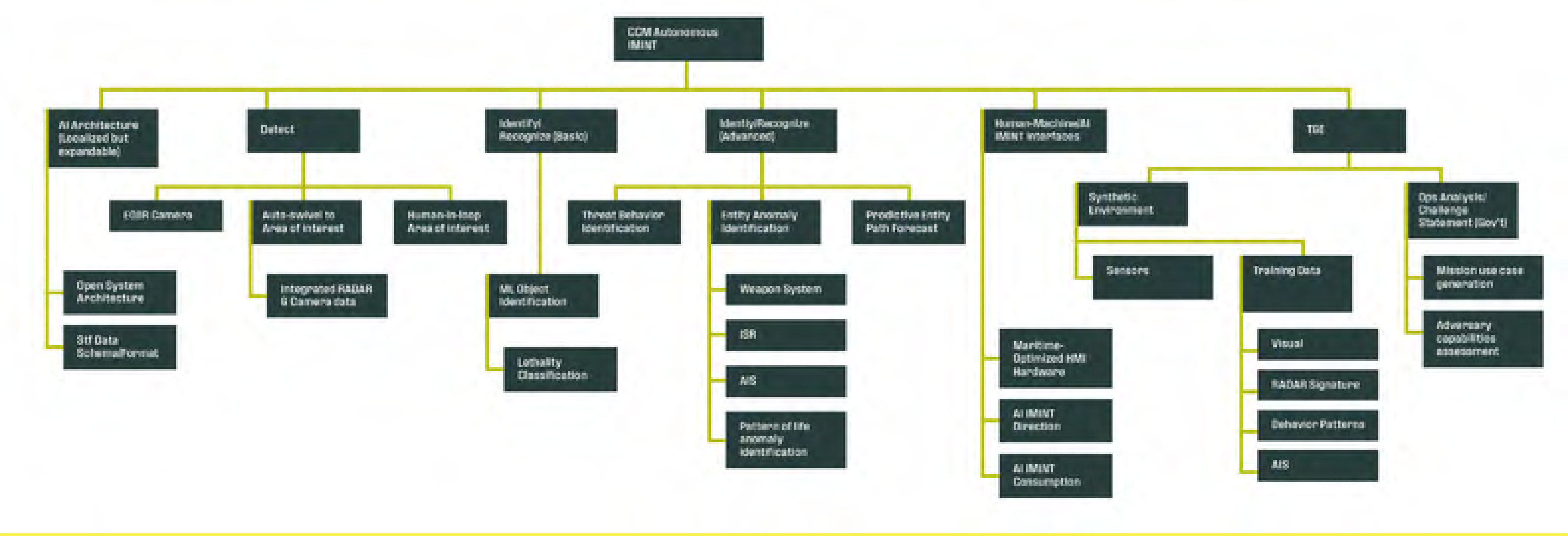
TECHNOLOGIES - 7-10 YEARS

Motion Planning: anticipatory and pro-active engagment

- Proactive ISR collection + evalution
- Recommended changes to ISR + FP posture based on other sensors (radio, GPS, etc)
- Automatic emissions control
- Masking communications inside other locatized frequency bands
- Signature masking/re-signaturing
- Masking radar cross-section heat signature, RF-signature



INITIAL WORK BREAKDOWN STRUCTURE FOR AI-ENHANCED ISR



EXAMPLE CONTRACT LANGUAGE FOR AI-ENHANCED ISR

IDENTIFY / RECOGNIZE (BASIC)

2-sentence description:

Identify / Recognize (Basic) is the concept of AI-assisted identification, recognition, and classification of potential targets and threats. This added autonomy reduces burden from the operator of the CCM in high contact areas and assists in prioritization of threats.

2-paragraph description:

AI assisted threat identification and classification is required to reduce the cognitive load on the operator and free time for higher level strategic decision making. The EO/IR camera feeds combined with the RADAR input provide the machine learning detection and classification models the required data to assess confidence levels in threat identification.

Objects are autonomously detected and classified for lethality and threat and presented to the operator as a data overlay allowing easy prioritization.

ML OBJECT IDENTIFICATION

2-sentence description:

Machine Learning identification of maritime objects from an EO/IR vessel-mounted camera is essentially existing technology. The maritime environment and lack of consistent, annotated learning data are two challenges to creating a successful ML detection system.

2-paragraph description:

There are several existing COTS ML models for image detection and classification such as Google's Inception, Faster R-CNN, Mask R-CNN, and Single Shot Multibox detector. These models each have tradeoffs in terms of training speed, required training datasets, run-time detection speed, processing power, accuracy, agility, etc.. This task includes research and prototyping to determine selection of the most appropriate model(s) given the actual operational characteristics of the CCM and equipped sensors.

CHALLENGE 3: AI-ENHANCED C3 (COMMAND, CONTROL, COMMUNICATIONS)

AI FRAMEWORK FOCUS AREA: Mission Command for Manned Surface Maritime Vessel

CHALLENGE DESCRIPTION: Operating within Weapons Engagement Zone (WEZ) support SOF and Navy ability to deliver synchronized lethal and non-lethal effects from near-and-far, every axis and every domain. AI-Enhanced C3 develops the assured networks required to support manned, unmanned teaming by SOF and Navy Distributed Maritime Operations.

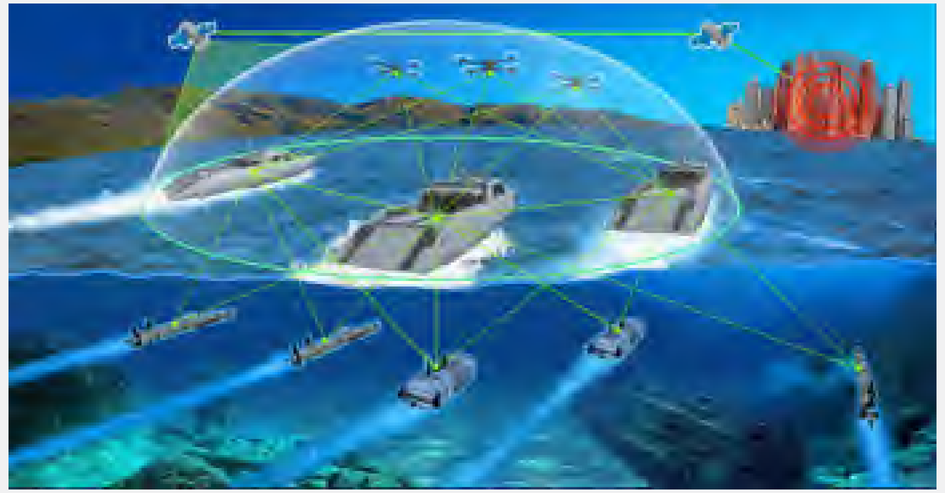
PROBLEM STATEMENT: Where Communications are Degraded, Intermittent, or Low Bandwidth (DIL), how can AI enable assured communications to better manage multiple SOF platforms in a high threat environment?

SOFIA CAPABILITIES FOR MISSION COMMAND AUTONOMY

TECHNOLOGY GAPS FOR AI-ENHANCED C3

- **Automatic link budget management**
- **Real-time signal environment sensing and prediction**
- **Continuous AI-based jamming defense optimization**

HIGH-LEVEL OPERATIONAL CONCEPT FOR AI-ENHANCED C3



SOLUTION DESCRIPTION FOR AI-ENHANCED C3

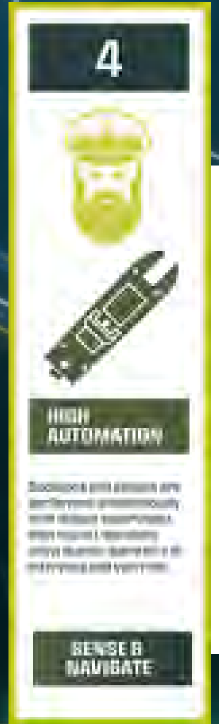
CCM manned-unmanned team approaches target area with established satellite communications between CCM and command element. Via datalink, CCM operators assign UUV tasks to be autonomously performed.

Adversary attempts to degrade CCM team's communications. AI software embedded in CCM communication equipment senses and predicts the EM environment and optimizes transmissions to ensure voice and datalinks are maintained.

Command element and CCM team achieve assured communications for situational awareness, mission tracking, and ensuring commander's intent is met.

TECHNOLOGIES - 1-3 YEARS

- Software defined radio
- Low-SWaP hardware for edge computing/hosting of AI/ML algorithms
- Miniaturized, lightweight Active Electronically Steered Arrayed (AESA)
- Actively steered Light Directing Arrays (LDA)
- Enhanced data transfer rate bus (e.g. MIL-STD-1533/1760) >1Gbs
- High fidelity digital terrain model
- Resilient, precise PNT: Chip Scale Atomic Clock (pico sec realm), weapons-grade IMUs
- Multi-freq Laser (>10 color)
- Intelligent power and thermal management
- Predictive analysis of the EM spectrum and physical environment for optimizing comms



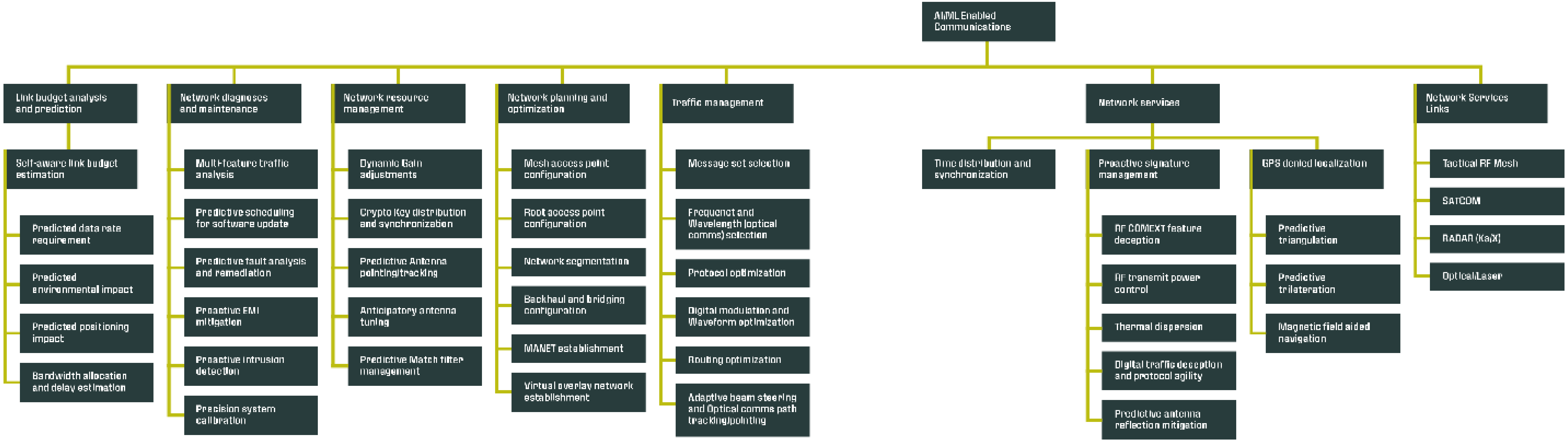
TECHNOLOGIES - 4-6 YEARS

- Cooperative multi-input, multi-output (MIMO) allowing for superior transmission, reduced power, antijam, and orderrs of magnitude higher data rates.
- Ultra-wideband photonic synthesizer (>10 GHz IBW)
- High fidelity synthetic training data generator
- Live, Virtual, Constructive Modeling & Simulation environment for AI/ML synthetic entities
- AI-designed wave forms and protocols implemented in real-time
- Hive model where all comm nodes track eachothers' state, form optimal networks on the fly, and cooperatively manage security and processing
- Ability to share learned behavior and strategies amongst comm nodes
- AI-enabled advanced encryption

TECHNOLOGIES - 7+ YEARS

- Dynamic QR-Code data transfer
- AI based EP/EA where AI responds to situation creatively reusing, creating, combing effects as needs arise
- Rapid detect, intercept, demodulate, and decode signals for SIGNIT or EP/EA
- Leverage nodes side backhaul/secondary channel as a computer bus virtualizing many processors that can work on problems using distributed AI
- Manage nodes as elements of a phased array, combining effects for enhanced RX/TX and EA
- Incorporation of aperatures of opportunity

INITIAL WORK BREAKDOWN STRUCTURE FOR AI-ENHANCED C3



EXAMPLE CONTRACT LANGUAGE FOR AI-ENHANCED C3

FREQUENCY HOPPING

2-sentence description:

Machine learning algorithms can be designed to create new and more complex frequency hopping patterns for AI-based anti-jamming. AI can optimize existing patterns based on known enemy jamming capabilities and consider whether data or voice transmissions are more appropriate (LPI/LPD/LPC).

2-paragraph description:

Frequency hopping spread spectrum (FHSS) rapidly changes a carrier frequency among spectral sub-bands in a predetermined order within a larger frequency band. Traditionally, FHSS signals have been resistant to deliberate enemy jamming as the enemy must know the frequency hopping pattern to direct energy to sub-bands at the appropriate time. Advances in AI, however, make it increasingly likely that peer and near-peer competitors will attempt to decipher the frequency-hopping patterns of legacy FHSS key generating systems such as KY-57 by collecting and analyzing secured transmissions.

Through machine learning algorithms, DoD can create more complex and precise patterns that optimize spectrum use and minimize narrowband interference, while making it more difficult for enemy algorithms to rapidly decipher a generated pattern. Onboard computing systems running AI algorithms may also be used to detect and analyze enemy jamming during a mission and autonomously switch frequency hopping patterns, with the new pattern shared between transmitter and receiver in the form of a hash function or other cipher method. In this way, an operator can be assured of unjammed communications while not relying on cumbersome crypto keying or system reprogramming mid-mission.

ONE-WAY COMMUNICATIONS

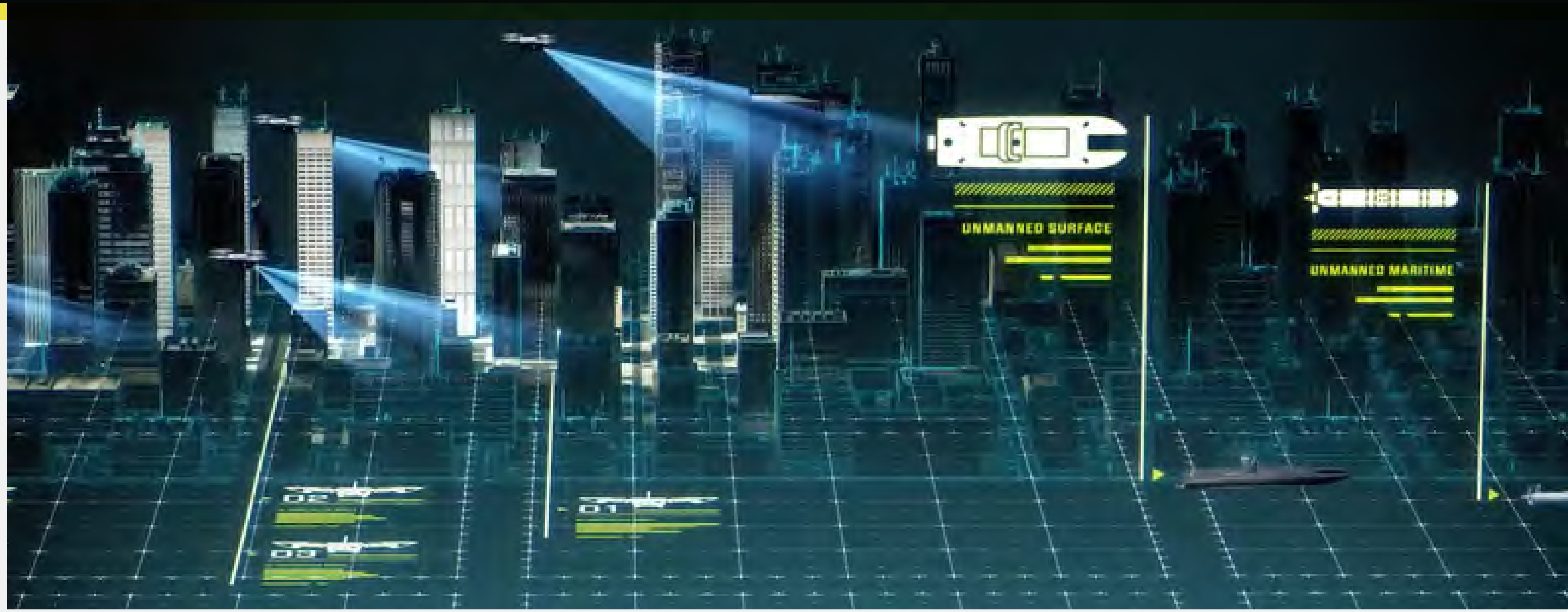
2-sentence description:

To reduce the risk of detection, communications and datalink systems can enter into receive-only communications (i.e., HQ to operator or operator to HQ). Communications traffic can be queued for transmission at optimal times using AI-based sensing and prediction of the RF environment.

2-paragraph description:

Continuous transmission between command elements and forward operators greatly increases the potential for enemy detection. By minimizing communications to essential information at the appropriate time and on the appropriate channel, risk to operator and risk to mission can both be reduced while maintaining situational awareness.

Communications systems employing AI to sense and predict the RF environment can optimize the time and frequency that critical information is transmitted between commanders and operators, and vice versa, to minimize detection or jamming and ensure successful transmission. Essential data will be automatically queued within the system and prioritized based on data type (i.e., unit location, mission checkpoints, etc.) for transmission. Operators will be able to override queuing and intentional delays if urgent communications are necessary, but AI will reduce the burden on the operator to prioritize and plan transmissions and provide an additional level of communications security during the mission.



CHALLENGE 4: AI-ASSURED ACCESS

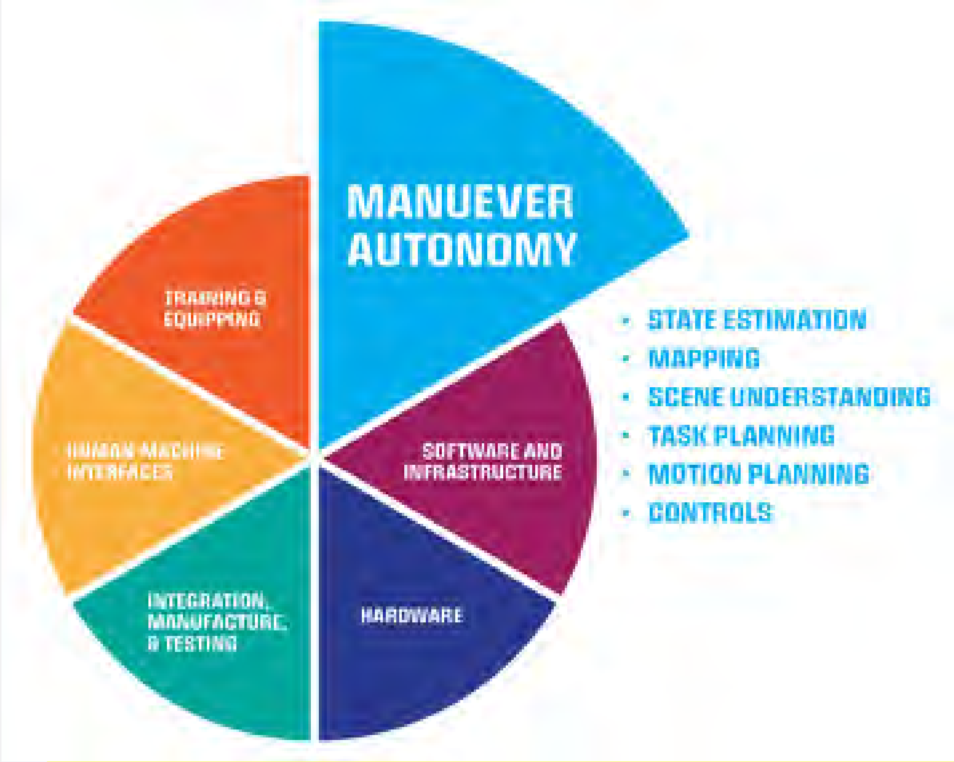
AI FRAMEWORK FOCUS AREA :Maritime Maneuver and Intelligence for Unmanned Undersea Vessel (UUV)

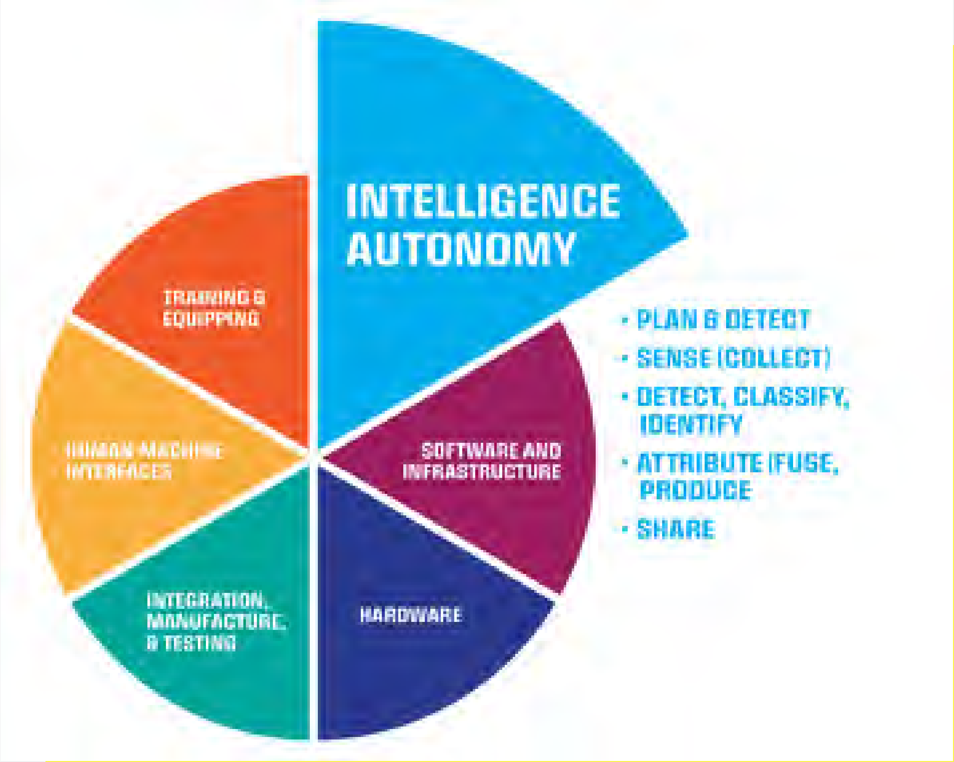
CHALLENGE DESCRIPTION: Focus on disruptive technologies aimed at improving capabilities against near peer in denied environments, including manned/unmanned solutions, advanced materials and payload expansion.

PROBLEM STATEMENT: How can AI enable SOF unmanned undersea maritime platforms (UUV) operating in disconnected, intermittent and low bandwidth (DIL) communication and GPS environments?

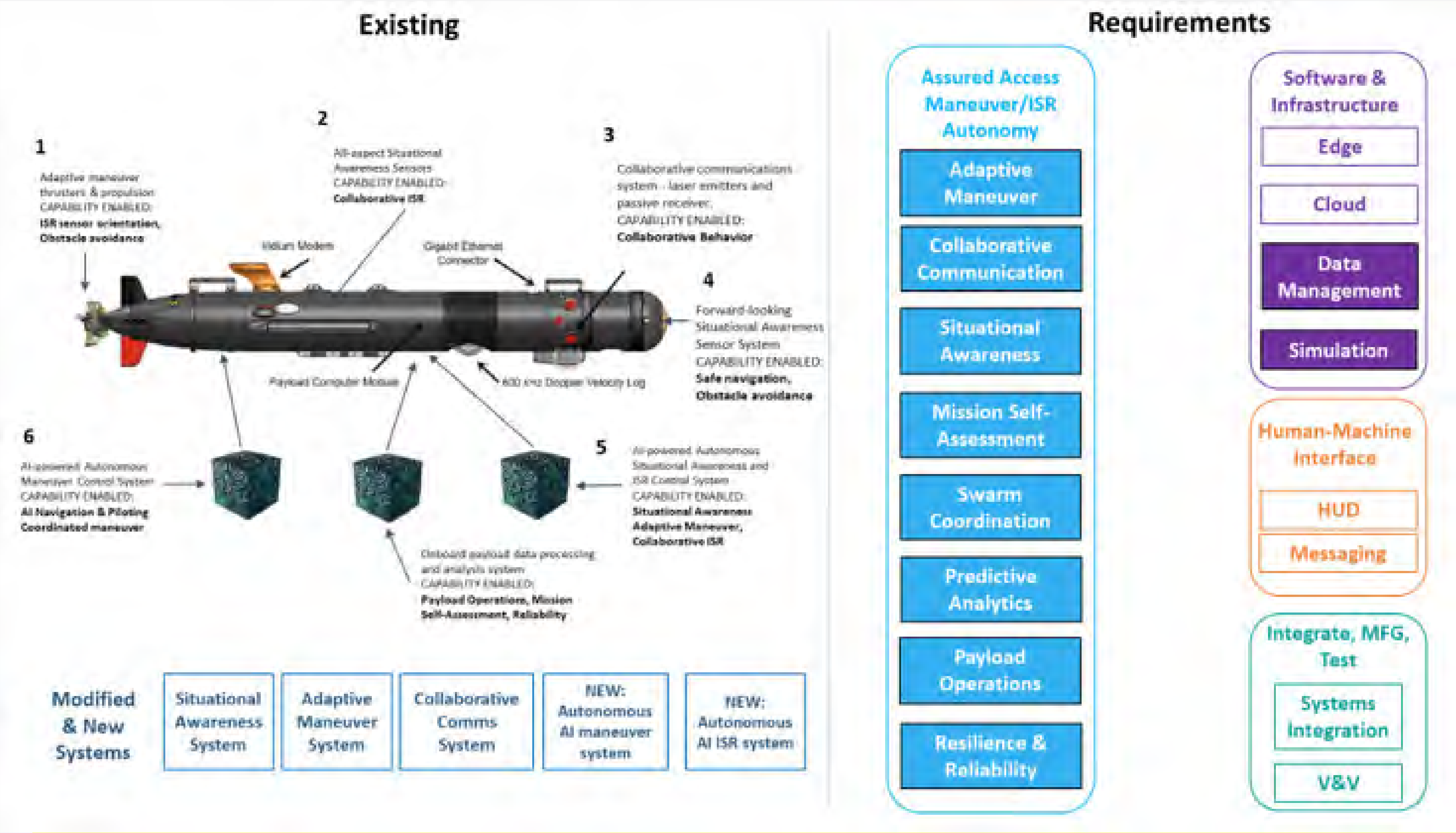
Definition of Assured Access: The ability to project military force into an operational area with sufficient freedom of action to accomplish the mission as well as the unhindered use of the global commons and select sovereign territory, waters, airspace, and cyberspace.

SOFIA CAPABILITIES FOR MANEUVER AND INTELLIGENCE AUTONOMY

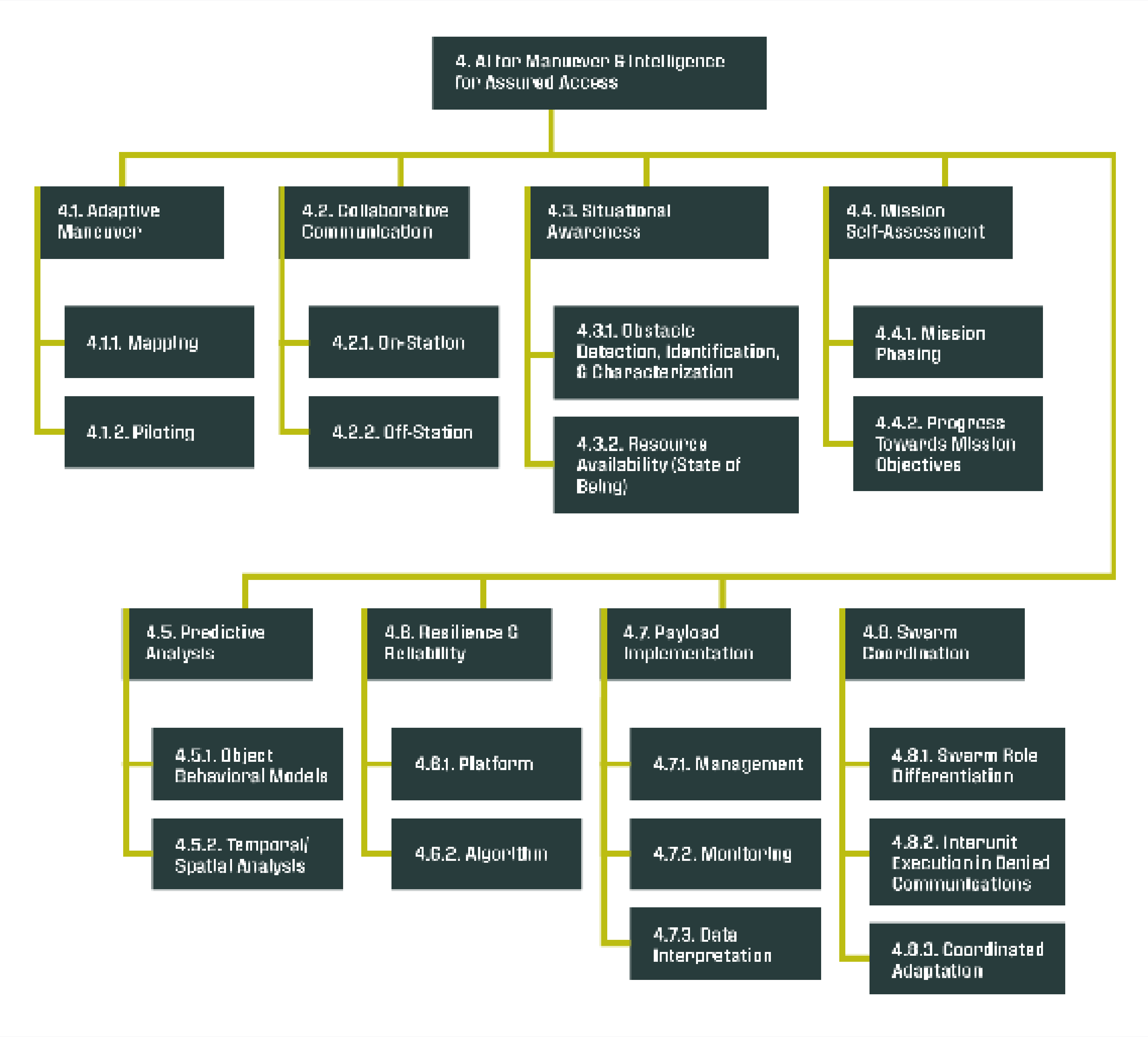




HIGH-LEVEL OPERATIONAL CONCEPT FOR AI-ASSURED ACCESS

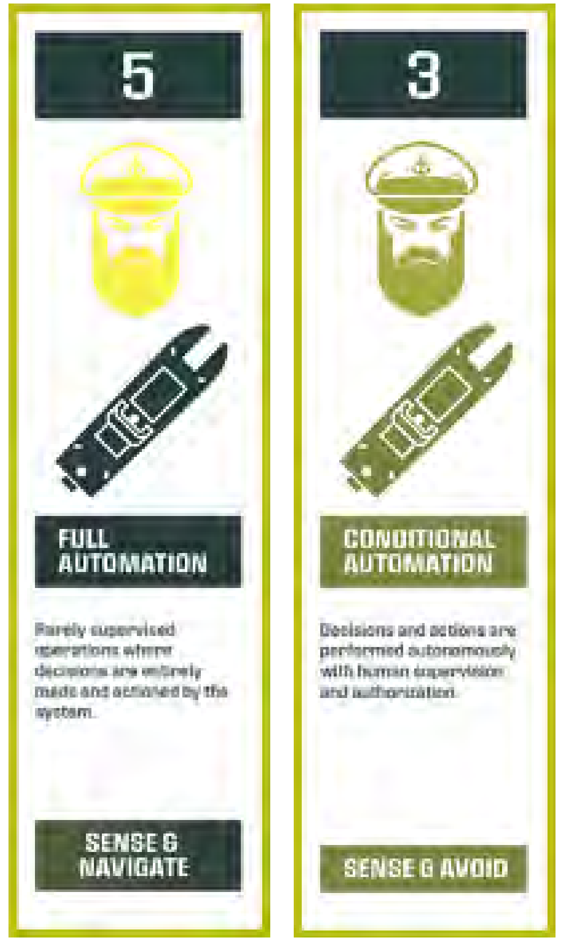


INITIAL WORK BREAKDOWN STRUCTURE FOR AI-ASSURED ACCESS



EXAMPLE CONTRACT LANGUAGE FOR AI-ASSURED ACCESS

ADAPTIVE MANUEVER



Simulation

Technical Evaluation

3-year resource plan (stretch goal)

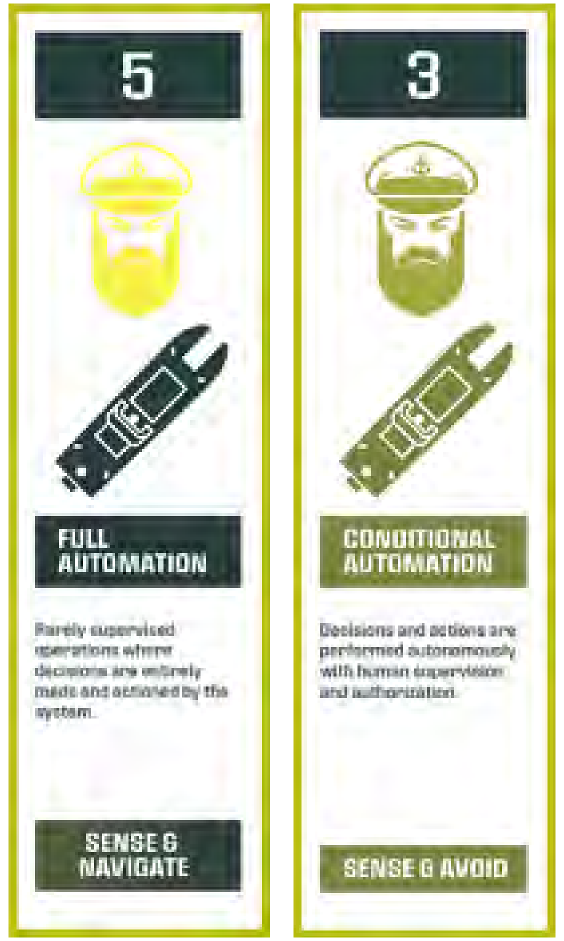
The AI-enhanced navigation system shall plan, command, and monitor transits to and from operational area, and all movements within the operational area, in various sea states and comms environments.

The AI-enhanced piloting system shall plan and execute control sequences to achieve navigation system commands, and automatically avoid obstacles and hazards detected by the situational awareness system.

AI-powered navigation system tracks UUV position and velocity and **locates and tracks all team members and other actors** detected by the situational awareness system, using the **continually updated environmental map** maintained by the situational awareness system. Navigation system **automatically plans UUV maneuvers** based on mission waypoints, current resources, expected recourse use, and state of the UUV (internal awarness system), and known hazards, obstacles, currents, and sea state.

Piloting system uses AI-enhanced active feedback monitoring and control algorithms to **plan and adaptively execute control sequences in a range of sea states.** Piloting system receives direct input to situational awareness system to override navigation commands and plan and execute additional commands to **avoid collisions and then recover to planned course.** Piloting system has access to the main propulsion system and to auxillary **all-aspect maneuver thrusters** with an adaptive control system able to operate in different sea states and environmental conditions.

SITUATIONAL AWARNESS



Simulation

Technical Evaluation

3-year resource plan (stretch goal)

The external sensor system shall detect, identify, characterize, track, and monitor environmental hazards and objects of interest, including red and blue actos and UUV team members, and inform maneuver and intelligence AI decision systems.

The internal sensor system shall monitor and log all internal resources and usage rates: fuel, power, state of health of instruments, and logs resource utilization throughout the mission for after-mission review, knowledge transfer across the fleet, and AI-driven optimization via simulation.

At launch SA system will automatically receive an initial data package from host platform containing

1. known **sea floor and coastal topography.**

2. **coastal land use and land cover and patterns of activity** at high and low tide based on latest (<week) imagery as reference data for on-board navigation and intelligence collection systems, and

3. **known environmental hazards or objects** (e.g. reefs, sand bars, fishing grounds, shipping lanes, pipelines, off-shore installations). SA system updates, expands, and records this environmental and situational data with observations collected by onboard sensors, including: **forward-looking sonar and optical sensors for obstacle avoidance** and object detection, side and ventral/dorsal sensors for **all-aspect observation**, physical measurement systems (e.g. accelerometers, pressure monitors, electromagnetic sensors, acoustic microphones) for **measuring and minitoring environmental state.**

All UUV key resources and **internal systems are instrumented, monitored, and logged continuously** to enable on-mission self-assessment by the onboard manuever and intelligence AI decision system. SA data collected throughout the mission will capture system performance and enables **smart maintenance, validation of UUV simulations, and future UUV-to UUV learning** and mission optimization aross the fleet of UUVs in training and simulation.

COLLABORATIVE COMMUNICATION

Simulation

Technical Evaluation

3-year resource plan (stretch goal)

The AI shall control and manage commuication data flow and priorization, as well as monitor the contested environment for reestablished connectivity.

In EMS-denied environments, the AI shall manage intra-swarm Knowledge Transfer (IKT) and coordinate high-priority debriefs mid-mission.

Like a human operator, the AI will need to prioritize information based on data collected and **commuicate highest priority data first.** Moderate priority and low priority data may not need to be transmitted at all and can be saved on-board for post-mission collection and debrief. When in an EMS-denied environment, the system shall **periodically attempt to re-establish connectivity with command** (may be more relevant to USVs than UUVs).

When units within a swarm cannot transmit communications between each other, alternatives must be sought. Based on location of other swarm units, the AI shall **determine how and when to communicate what to which unit**, based on the mission objectives. In instances of very high priority data achieved while mission objectives are incomplete, the **AI may assign a single unit to break away from the swarm to leave EMS-denied area to communicate data to command.**

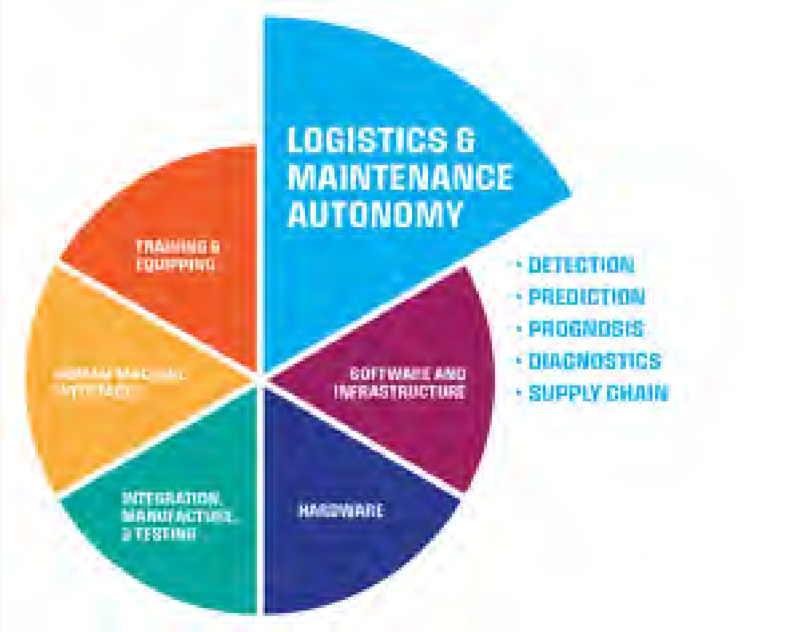
CHALLENGE 5: AI-ENHANCED LOGISTICS AND MAINTENANCE

AI FRAMEWORK FOCUS AREA: Logistics and Maintenance for Manned Maritime Vessel

CHALLENGE DESCRIPTION: DAU teaches us that sustainment accounts for 80% of program cost. Consequently, this represents an area where we can achieve a significant ROI.

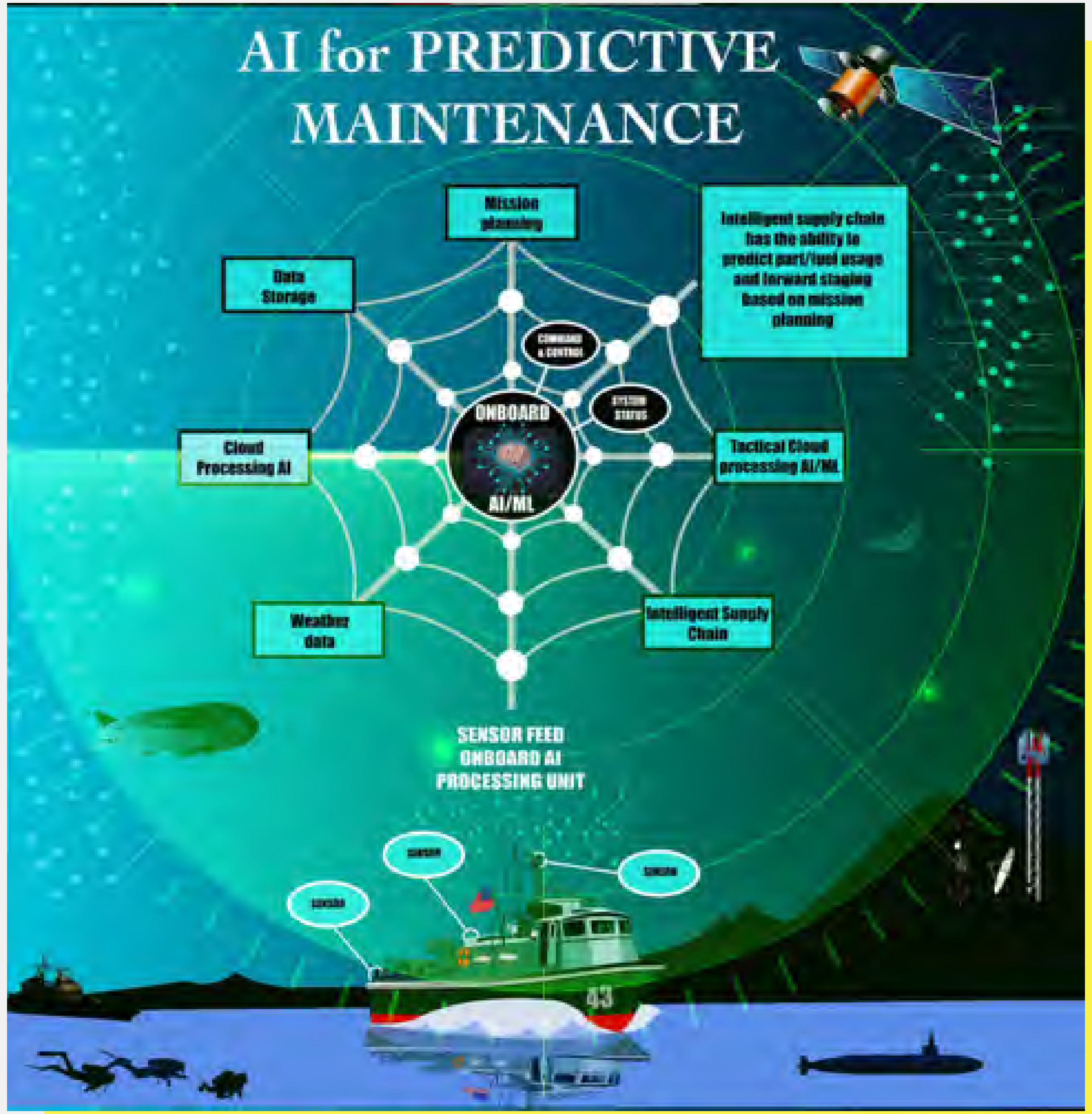
PROBLEM STATEMENT: How can AI and machine learning create a predictive maintenance system integrated with the supply chain to increase maritime platform asset reliability and availability by preventing equipment failures and assimilating maintenance into the platforms operational schedule with all supplies on-hand?

SOFIA CAPABILITIES FOR LOGISTICS AND MAINTENANCE AUTONOMY



TECHNOLOGY GAPS FOR AI-ENHANCED LOGISTICS AND MAINTENANCE

- Data Collection
- Lack of Government owned standard API
- No observability to internal variables of subsystems
- Built in obsolescence
- Imperfect, multi-modal, missing input data
- Training represents the bulk of the data that can be collected while operations is the highest priority. Developing systems on training data is insufficient for operating environments
- Industry dominated by few machine learning frameworks such as Tensor Flow
- Frameworks restrict hardware solutions
- Conventional AI model solutions are brittle and don't adjust to changing environments

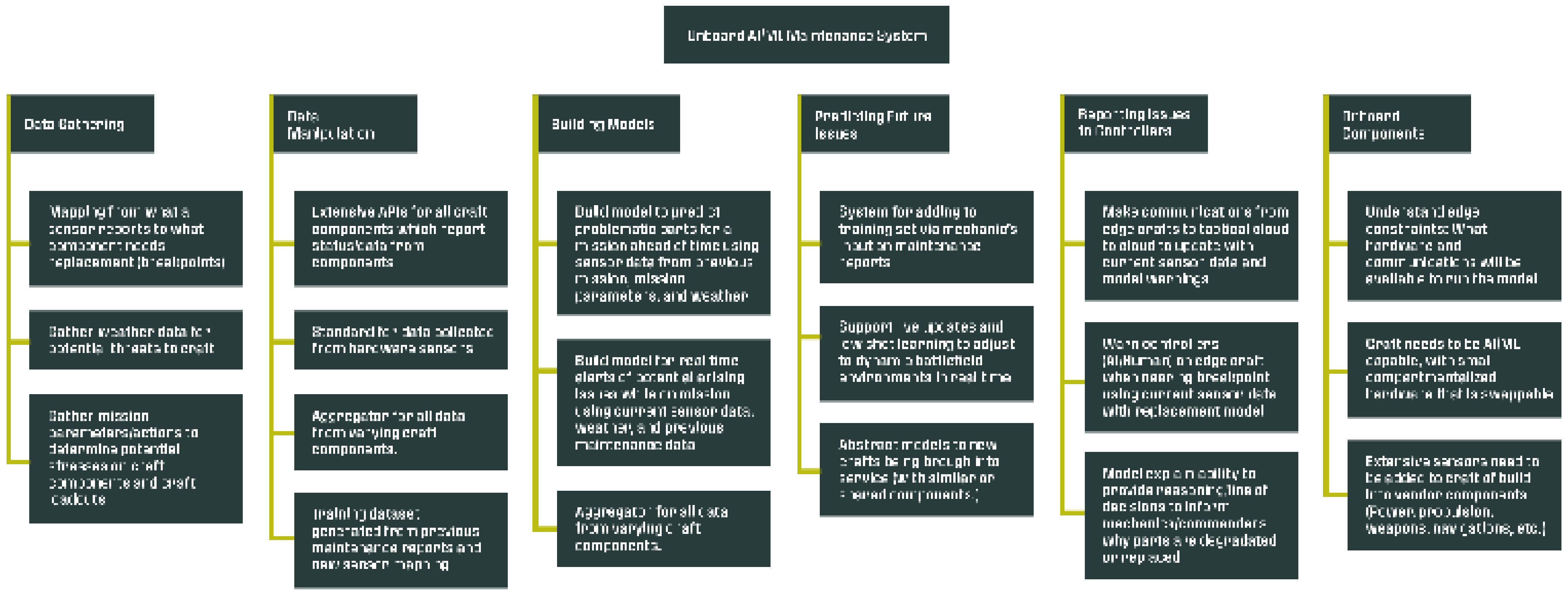


High-Level Operational Concept for AI-Enhanced Logistics and Maintenance

SOLUTION DESCRIPTION FOR AI-ENHANCED LOGISTICS AND MAINTENANCE

- Multi-tiered processing environment
- Onboard AI Maintenance System shall be able to consume data via standardized API feed for processing of each available shipboard system.
- The onboard AI Maintenance System shall be able to generate predictions of maintenance needs for parts, consumables, and other logistically related items.
- The onboard AI Maintenance System shall have the ability to communicate with an intelligent supply that incorporates demand forecasting.
- The cloud-based AI Maintenance System shall be able to provide long term analytics.
- Each onboard AI Maintenance System shall provide input to the cloud-based AI Maintenance System.
- Onboard AI Maintenance System shall provide a human interface such as a dashboard for feedback, explanations, and Prognosis of Operational Impact to the command structure.
- The onboard AI Maintenance System shall have the ability to update models with the changing state of various inputs such as sensor data.
- Onboard AI Maintenance System needs to be able to a changing environment, such as sensor degradation, or adversarial attack without loss of accuracy.
- Onboard AI Maintenance System needs to be SWaP capable to enable use across all SOCOM mobile platforms.

INITIAL WORK BREAKDOWN STRUCTURE FOR AI-ENHANCED LOGISTICS AND MAINTENANCE



EXAMPLE CONTRACT LANGUAGE FOR AI-ENHANCED LOGISTICS AND MAINTENANCE

AI-ENHANCED LOGISTICS

2-sentence description:

Maritime maintenance is faced with high degrees of difficulty regarding the state of data and the ability to turn this data into meaningful information on a timely basis to integrate into the supply chain and provide operational impact. Existing silos of data collection, interfaces and propriety models create risk in developing a cognitive capability that can provide understanding from multiple system that feed the overall maintenance status for a platform.

2-paragraph description:

Our concept address the edge ,fleet level and logistics and supply chain with a cognitive solution. Maintenance issues not only effect the performance of a platform but also effect the operational capabilities that platform performs in a mission. Our AI/ML concept –aligns the data collection and inference at the edge that includes learning and diagnostics that support enhanced maintenance and operational readiness.

Maintenance AI/ML will require a large amount of data that will come from multi-dimensional data source and non-homogenous data sets. The process of learning and inference will be a challenge for SOCOM so a solution will need to be able to "learn" from a smaller data set to provide the necessary capabilities.

EXPLAINABLE RESULTS

2-sentence description:

Most current AI models are black boxes and decisions, and predictions are not explainable. Explainable outputs are needed to build trust and competency assessment of the AI system and provide real time input to C2 of the platform.

2-paragraph description:

Current Human Machine Interfaces in tactical environments is very brittle and limited. Providing a robust interface from the prognostic maintenance system into the C2 of the platform is essential for mission success. The AI model used for the maintenance system must provide explanations for the predictions of failures, or identification of anomalies. It needs to provide detailed reports on the sources of projected faults and failures so that real time actions and decisions can be taken or made regarding the mission.

Having explainable outputs from the AI model that provide a detailed drill down into potential failures, or rational for remaining useful life changes will enable the building of trust in the AI system during training, better competency assessment by platform commanders and specialists and enable high comfort decision making during tactical operations.

AIMM VIDEO

AIMM VIDEO SCRIPT

Total running time: 5:12

CH ONE: OPENING (TEXT OVER BLACK)

The 2018 National Defense Strategy states that the U.S. military will face increased global disorder, characterized by decline in the long-standing rules-based international order—creating a security environment more complex and volatile than any experienced in recent memory. The reemergence of long-term strategic competition, rapid dispersion of technologies, and new concepts of warfare and competition that spans the entire spectrum of conflict requires a Joint Force to meet the challenges of this reality.

:32 secs

(START VIDEO)

CH TWO: SITUATION - ANTI-ACCESS/AREA-DENIAL

Adversary's anti-access/area denial (A2/AD) capabilities ON SCREEN WORDS: (space, cyber and electronic warfare capabilities; ballistic missile, targeting and tracking systems, naval and aviation forces) aim to create a broad area maritime surveillance capability, targeting system and comms contested environment that in time of conflict would render the existing Navy's large ship architecture increasingly vulnerable.

Recognizing the increasingly complex security environment detailed in the National Defense Strategy, Naval Special Warfare's Ai for Maritime Maneuver concept was designed to tip the balance of power in multi-domain A2/AD competition space to our advantage – today and into the future.

:40 secs

CH THREE: INSERTION/EXFILTRATION

[Theme: GAIN and MAINTAIN ACCESS via low observable CCM and deception decoys]

NSW's Artificial Intelligence for Maritime Maneuver concept is designed to gain and maintain access into an adversary's competition space while also reducing access challenges for the Joint Force.

Hallmarks of the AIMM concept: seasoned NSW operators, stealth, deception, mass, and precision are intended to penetrate the adversary's defenses and complicate enemy kill chain's, and ensure own force survivability.

Future success will increasingly go to the actor who can best gather data, process it into actionable information, and team with partners both human and machine in real-time.

:45 secs

CH FOUR: ACTIONS AT THE OBJECTIVE

[Theme: EXTEND ACCESS via AI for CCM's and AI for Autonomous Robotics (UAV, USV, UUV]

Naval Special Warfare utilizing its existing maritime mobility with targeted investments to incorporate AI and autonomy into its inventory of unmanned systems will extend its access, mass and effects from the maritime domain, through the littoral commons and inland to directly enable effects-based operations… on-scene but un-seen.

AIMM with cutting-edge usage of on-board compute, data, artificial intelligence, and machine learning allows for AI enabled autonomy in small UxS to then be deployed within range of adversary targets, enabling AI autonomous systems to detect, classify and identify aim points to provide precise targeting to fires platforms enabling a clear Decision Advantage.

Critical to the success of these missions is the ability of these highly autonomous platforms to utilize alternative PNT and maintain Communications in highly contested environments while ensuring Mission Command from NSW's maritime platform to UxS and from NSW's maritime platform to the Joint Force.

Given their stealth and autonomy, Ai enabled robotic systems are uniquely positioned to excel in their ability to GAIN, MAINTAIN, and EXTEND access into highly contested environments.

1:28 secs

CH FIVE: STRIKE COORDINATION & RECONNAISSANCE

An "above, on and under" Sea Strike Portfolio of access, mass and precision could provide the Joint Force with options to create new and more complex dilemmas for defending adversaries. AiMM expands the Maritime Strike Warfare's ability to achieve kinetic effects on a broader variety of targets that might have otherwise been inaccessible.

Automated target detection, tracking, cross-cueing, and command and control will further expand the ways in which drones can enable strikes—not to mention the speed and efficiency with which they support the kill-chain.

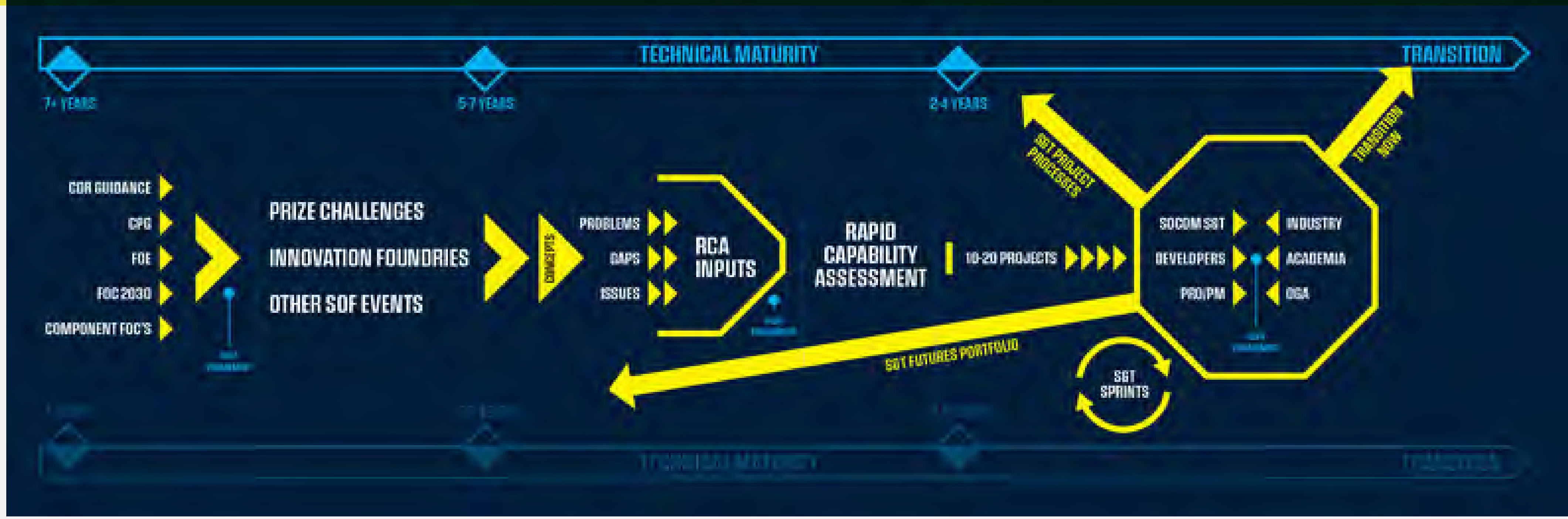
:42 secs

CH SIX: CONCLUSION

AIMM promises to "shrink the competition bubble" in highly contested A2/AD environments by inserting low observable manned/unmanned Ai enabled robotics elements to deliver kinetic and non-kinetic effects that will GAIN, MAINTAIN and EXTEND access, including unprecedented access to SubT and mobile launch sites ultimately removing cover and concealment of our opponents while providing aim points to the Navy's larger Carrier Strike Group.

Artificial Intelligence for Maritime Maneuver leverages existing investments in the NSW's maritime platform inventory while simultaneously investing in Ai enabled unmanned UxS systems that will provide a collection of unique, scalable capabilities that will enable the Joint Force to compete and win in complex, contested and denied environments across the competition continuum. This is what the nation expects from Special Operations.

1:05 secs

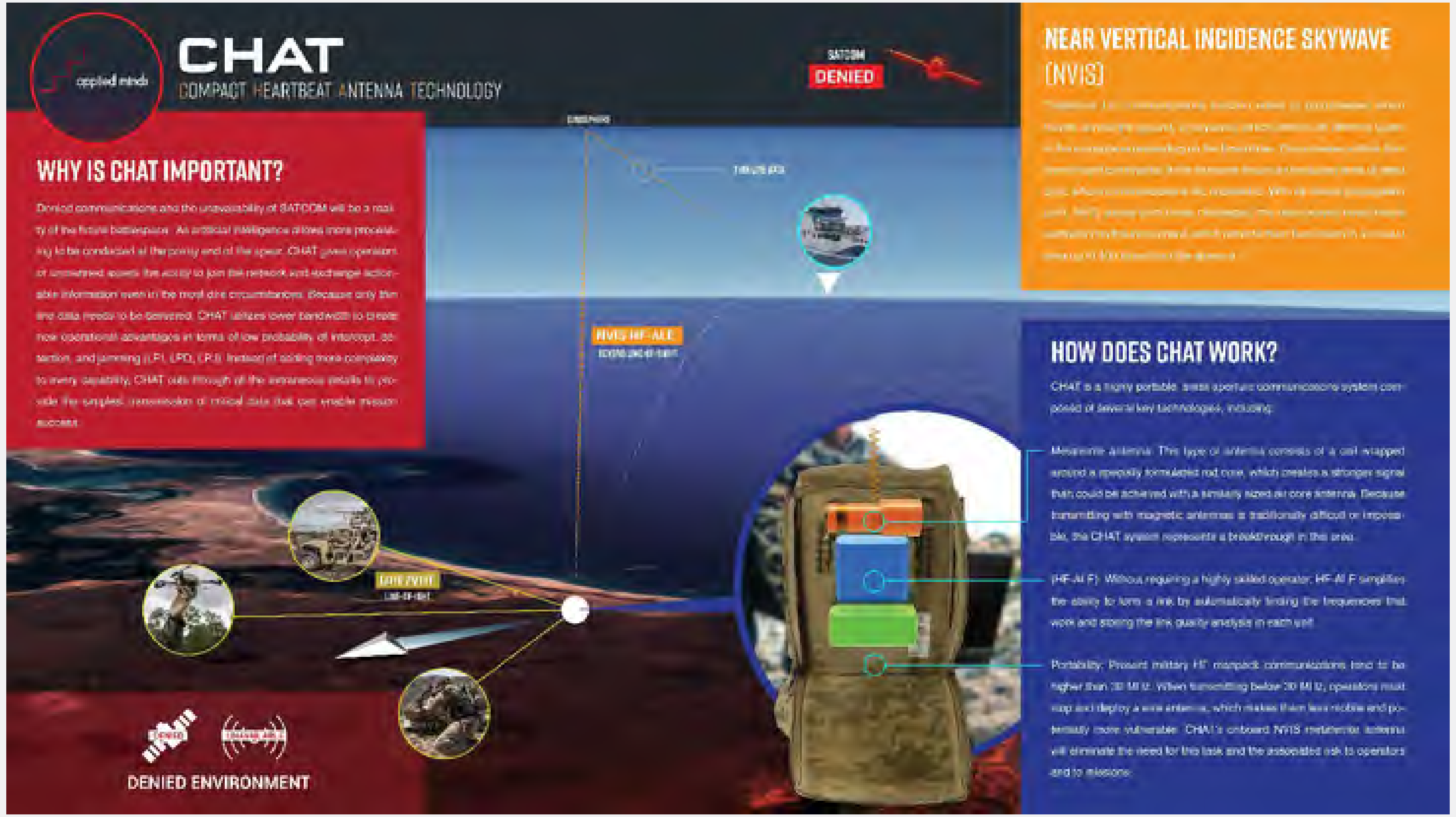


AMI TECH SPRINT PROPOSAL
CHAT COMPACT HEARTBEAT ANTENNA TECHNOLOGY

AI FOR MARITIME MANEUVER

PROPOSED PROJECT: CHAT PHASE 2, $282K

Develop the key technologies to enable an operational Compact Heartbeat Antenna Technology (CHAT) system as demonstrated during the July, 2020 Tech Sprint in Tampa, FL. Automated self-tuning agile HF antenna system and the "Imperative to Communicate": The heart of the CHAT system is an innovative relatively small HF antenna based on meta material ferrite, and advanced conductive element control. This system requires intelligence and tuning for reliable operation, simple for a trained RF engineer but impractical for field use. The goal of this effort will be to develop an automated system that performs this function by creating a "black box" unit that simply operates without operator intervention. The system will be developed to be expandable and able to integrate future multiple core systems as well as future additional communications modes with intelligent path management and an imperative to communicate.



Objective System: The ultimate system that these technologies enable is envisioned to be an integrated system approximately 6”x3”x3” weighing approximately 2-4 lbs and powered by a small commercial lithium ion battery. This system would incorporate an antenna suite and intelligent tuning designed to be driven by a standard GOTS transceiver (radio). The system would ship with a COTS radio for testing purposes. This system will be stylized for functionality.

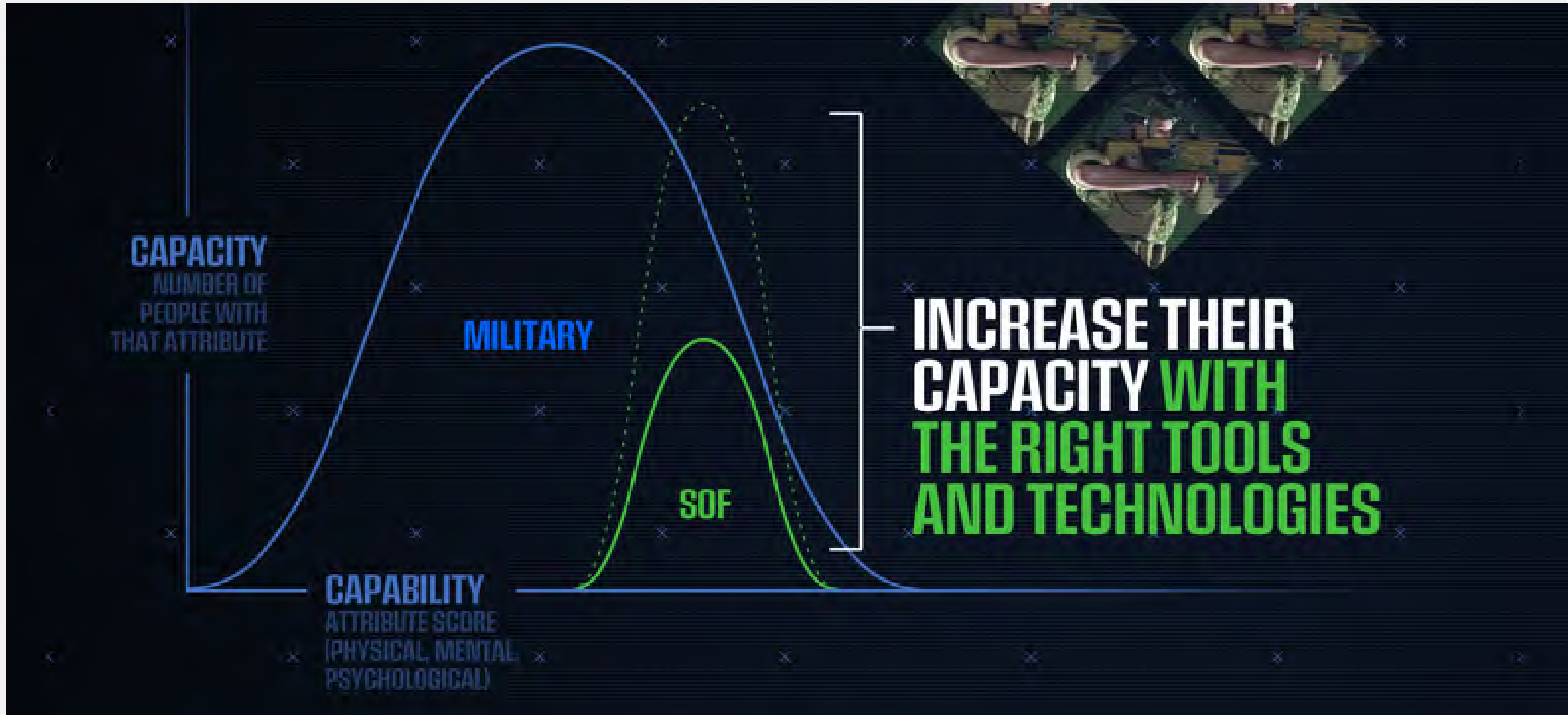
Demo System: This demo will incorporate the objective system elements in tabletop form and a COTS radio to drive it. The demo system will be autonomous like the objective system.

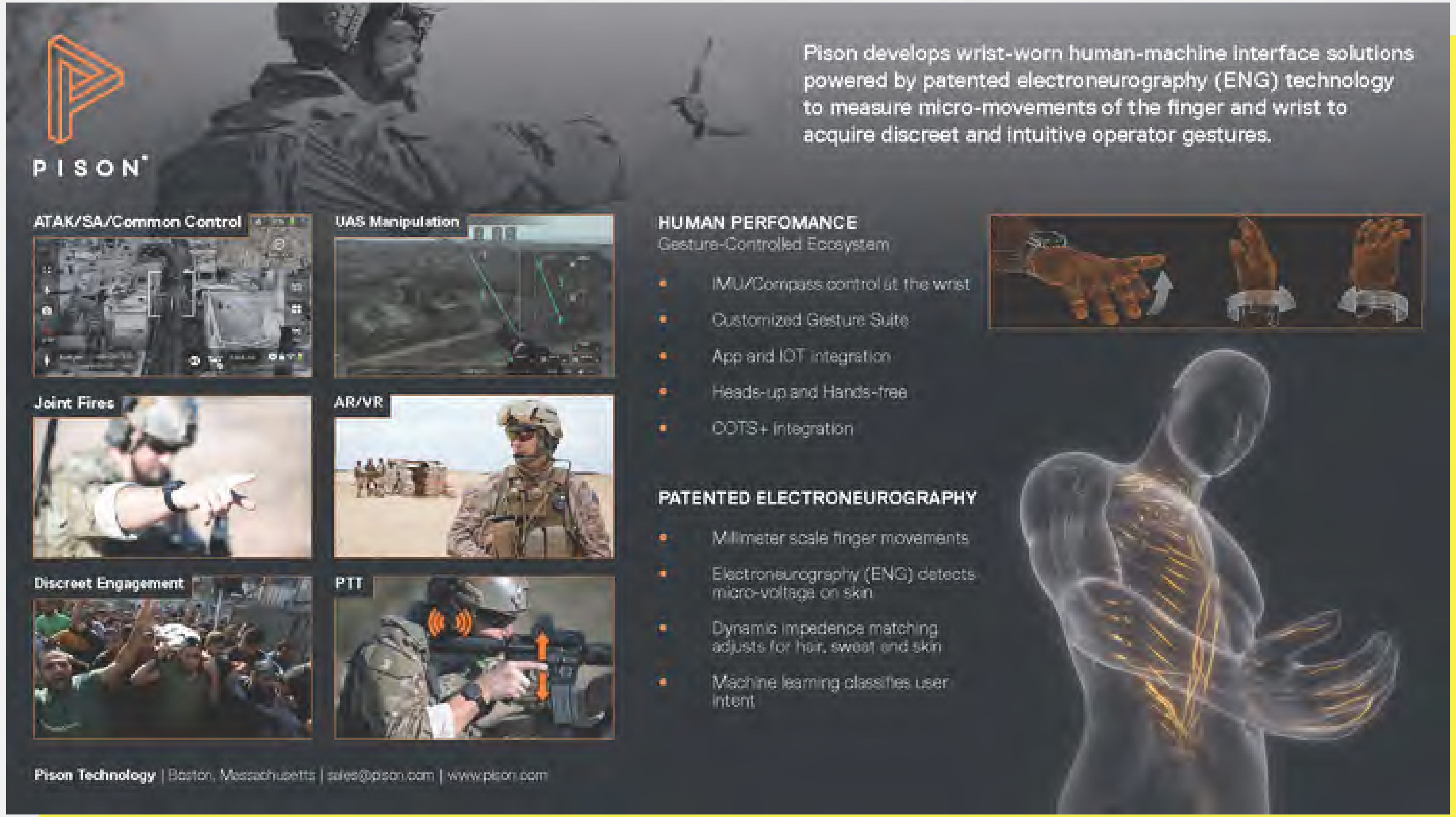
AMI TECH SPRINT PROPOSAL CHAT COMPACT HEARTBEAT ANTENNA TECHNOLOGY

AI FOR MARITIME MANEUVER

Testing: The system will be field-tested on public wild-lands in the greater Los Angeles area, then packaged into a demonstration for the SOCOM Tech Sprint in March, 2021 at which Applied Minds will be available to familiarize operators with the systems feature and capabilities.

A stretch goal will be to provide a version ruggedized for an operator to experiment with but this is likely to be fully achieved in Phase 3.





SOCOM TECH SPRINT:SEQUENTIAL GPS

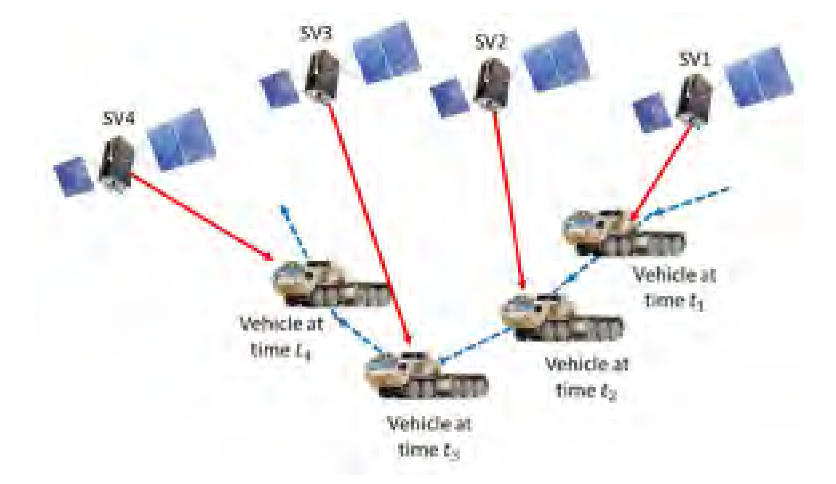
BACKGROUND AND PROBLEM STATEMENT

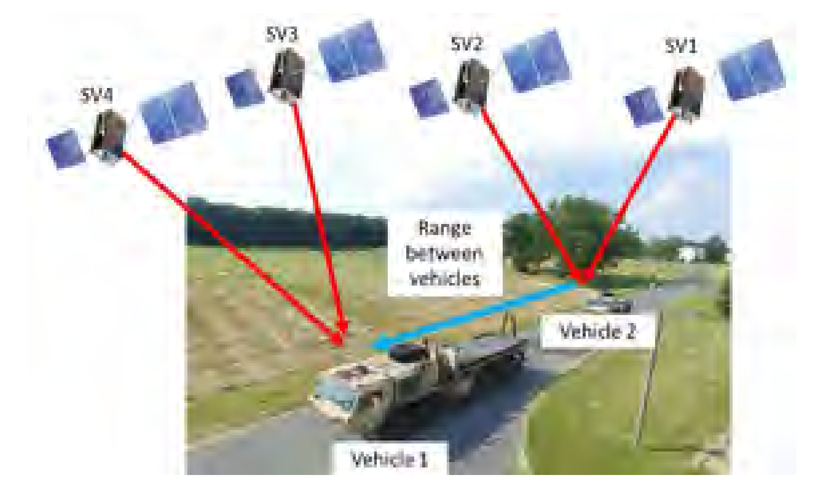
Global Navigation Satellite System (GNSS) require a minimum of four satellite measurements to compute a position (x, y, z) and the time bias of the receiver relative to the satellite clocks.

The time bias of the receiver must be solved for because the receiver clock drifts and is not synchronized to a stable time source.

For a standard standalone GPS receiver, if the receiver does not have a minimum of 4 satellite measurements at the time of measurement (also called the epoch), the user will have NO positioning information. RR seeks to improve upon this.

ALTERNATE GPS SOLUTION METHODS





Sequential GPS

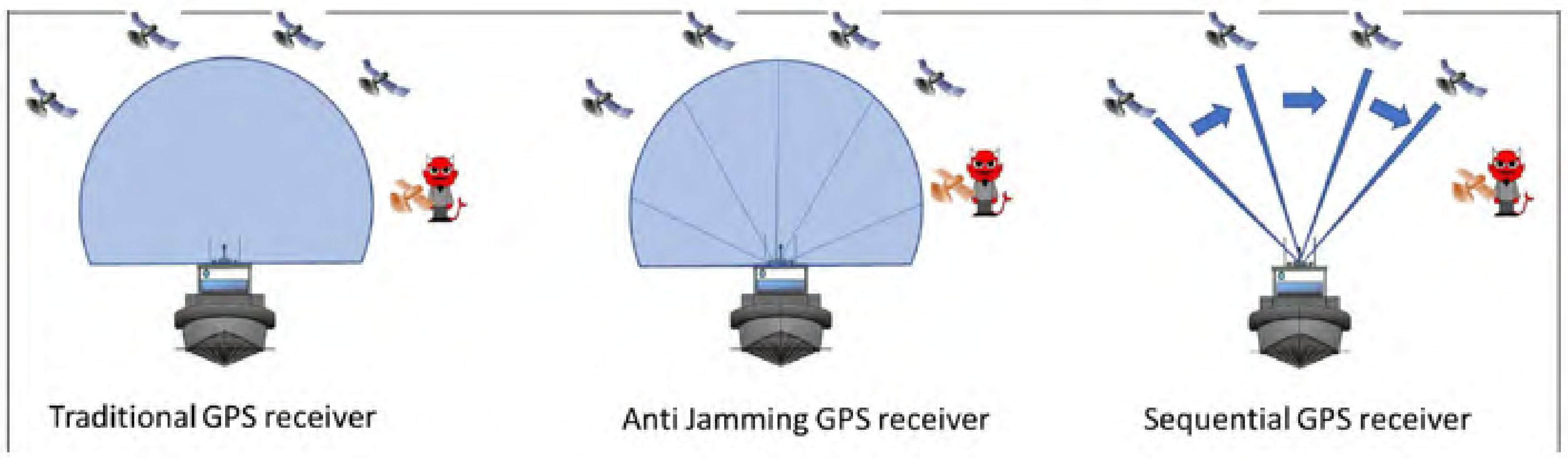
- Use GPS pseudorangesand relative vehicle motion (RR-N-140) at different moments in time to compute a GPS position solution.
- The CSAC eliminates the need to solve for the receiver clock bias at every epoch.

Collaborative Sequential GPS

- Takes the idea of sequential GPS and extends it to multiple vehicles.
- With a range measurement and a data link, the GPS measurements from multiple vehicles can be fused together to provide all vehicles with GPS positioning in more challenging scenarios.

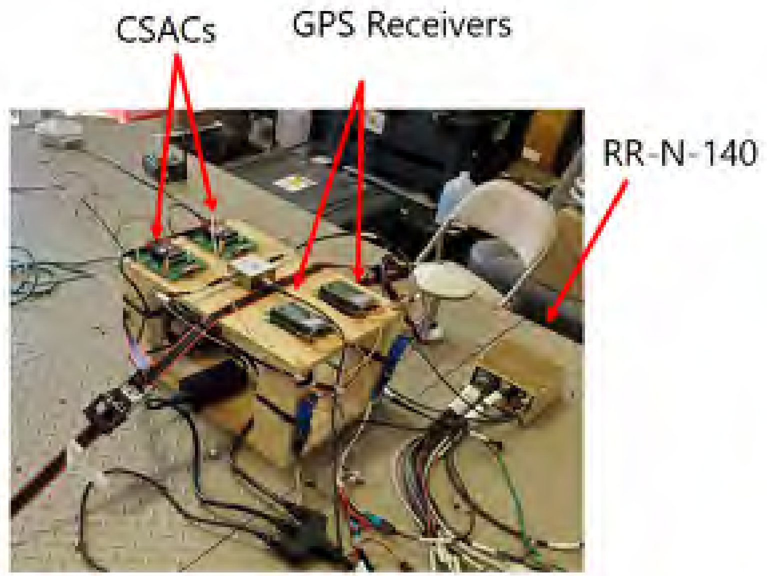
DATA COLLECTION EQUIPMENT

Using RR-N-140 navigation unit, SA.31m Miniature atomic clock, and Novatel OEM628 GPS receiver.



Performed data collection with the SMET vehicle (pictured below) at the RR COMSAT facility. We simulate directional antennas with omnidirectional antennas.

Note the assembled equipment can be used as a prototype.



BENEFITS

- Clear line of site can be one satellite at a time.
- Directional antennas can be used to acquire single satellite, making jamming significantly more difficult
- Number of required satellites reduced to three, two, or even one.
- GPS/GLONASS/Galileo can be mixed and matched
- Significantly more robust to spoofing
- Directional antenna can reduce jamming
- Could reduce SWAP and cost of antenna
- Easier to synchronize sensor data from multiple systems

DIRECTIONAL ANTENNA PROTOTYPE 1

The prototype antenna design shown below is constructed from a 10.0” diameter cardboard shipping tube, lined with aluminum foil, and a TaoglasGPS antenna mounted to the bottom. This assembly will be mounted to the pan/tilt head, the PelcoPT1250P, which will point the antenna at each relevant satellite.

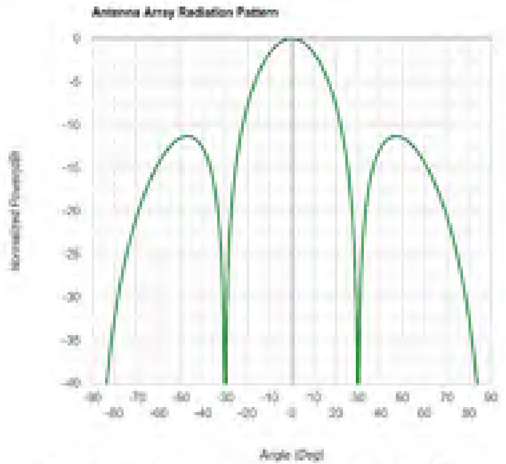
DIRECTIONAL ANTENNA PROTOTYPE 2

To increase gain in a narrow beam width, one approach is to combine a large number of antennas in a square grid pattern (half of the L1 wavelength for the edges on the square). See beamwidth figure.

Combine 16 L1 passive antennas using the combiner below. A final design would be a phased array (i.e., electronically scanned array).

PD2116 - 16 Way RF Power Splitter, Combiner, Divider


L1P antenna



Beamwidth vs gain on 16 L1P antennas in grid configuration

TECH SPRINT

Deliverables:

- Report (4/26): Narrow beam antenna selection
- Report (4/26): Steering mechanism selection prototype
- Demonstration (4/26): GPS acquisition for fixed GPS receiver, combining pseudorangesfrom different moments of time
- Demonstration (4/26): WarLoc and UWB anchor node integration

Tasks

- Overall prototype integration with single receiver using CSAC and directional antenna (mechanically steered with pan/tilt head)
- Signal to noise rejection study to model anti-jamming/spoofing rejection
- Preliminary feasibility study for miniaturization/volume production

PROGRAMMATICS

Cost: $198,000
Period of Performance: February 12, 2021 –April 26, 2021

Milestone Description	Deadline	Invoice
1. Tech Sprint Project Plan with Cost Estimate	02/03/2021	N/A
2. Initial Tech Report	02/03/2021	N/A
3. Tech Sprint Decision Review	02/05/2021	N/A
4. Kick-off	02/12/2021	$99,000.00
5. Mid Sprint Review	03/29/2021	N/A
6. Prototype/Demonstration	04/26/2021	N/A
7. Final Report	04/26/2021	$99,000.00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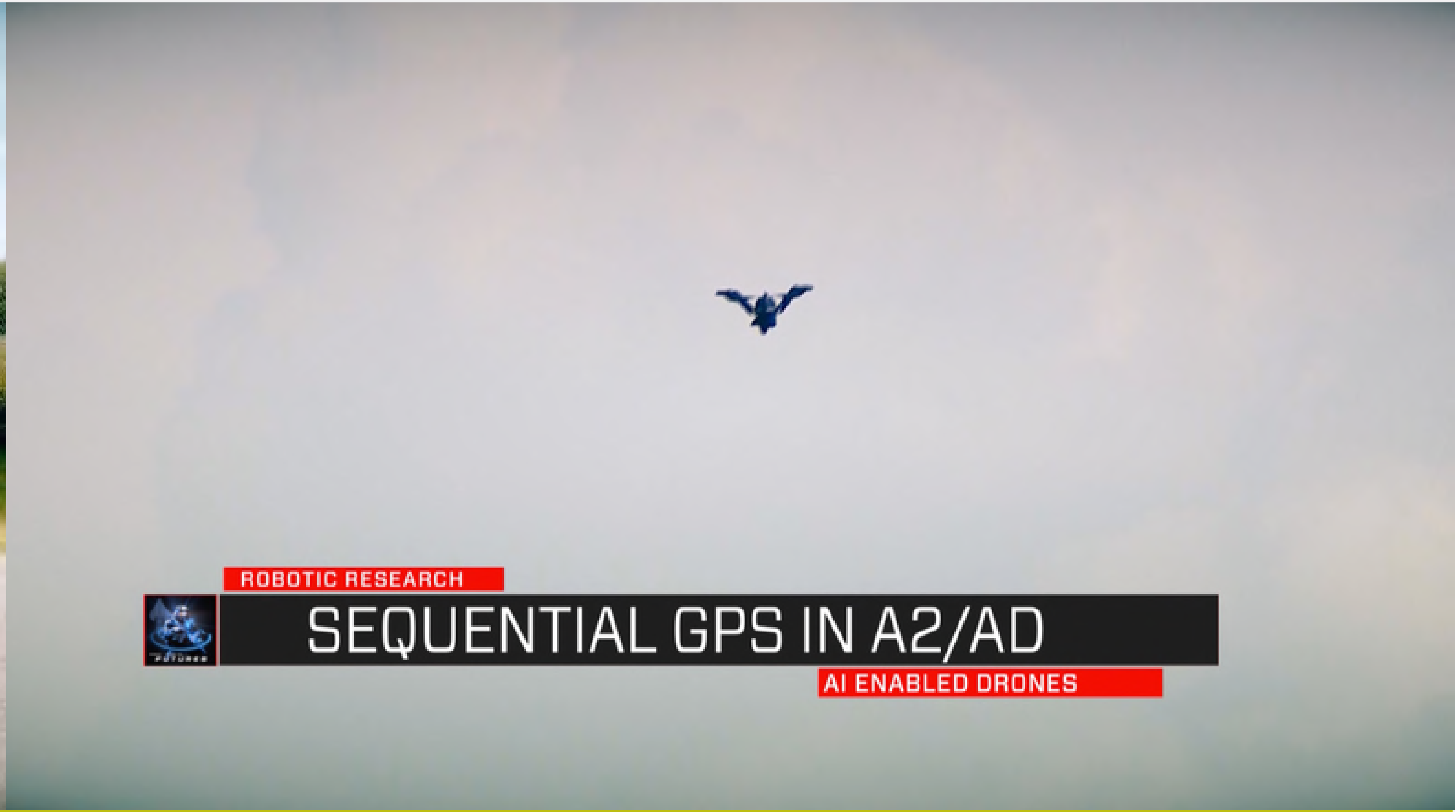
2021 TECH SPRINT


APPLIED MINDS
HF COMMS, TEXT AND IMAGERY
IN DENIED ENVIRONMENTS


ROBOTIC RESEARCH
SEQUENTIAL GPS IN A2/AD
AI ENABLED DRONES


ROBOTIC RESEARCH
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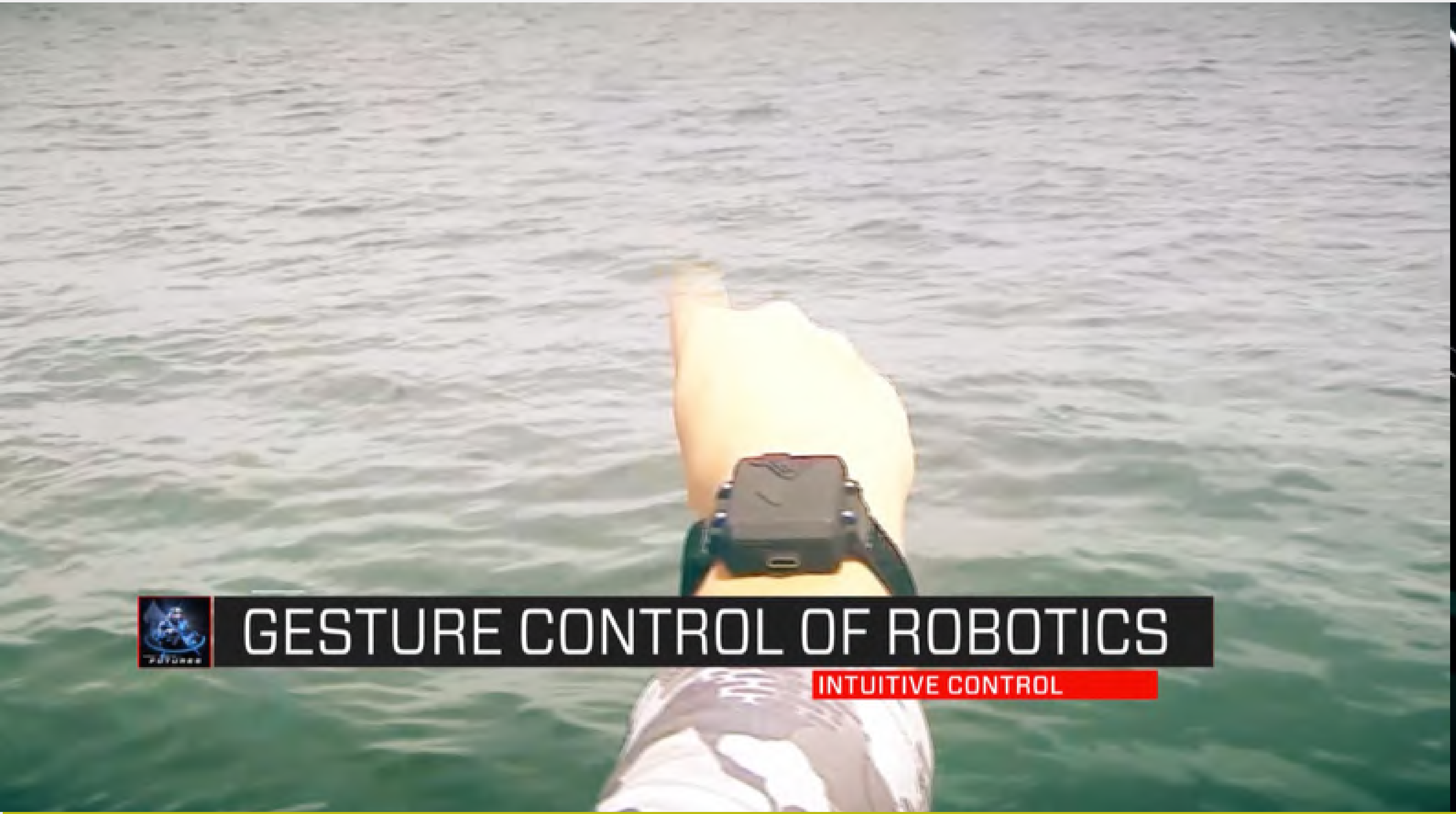
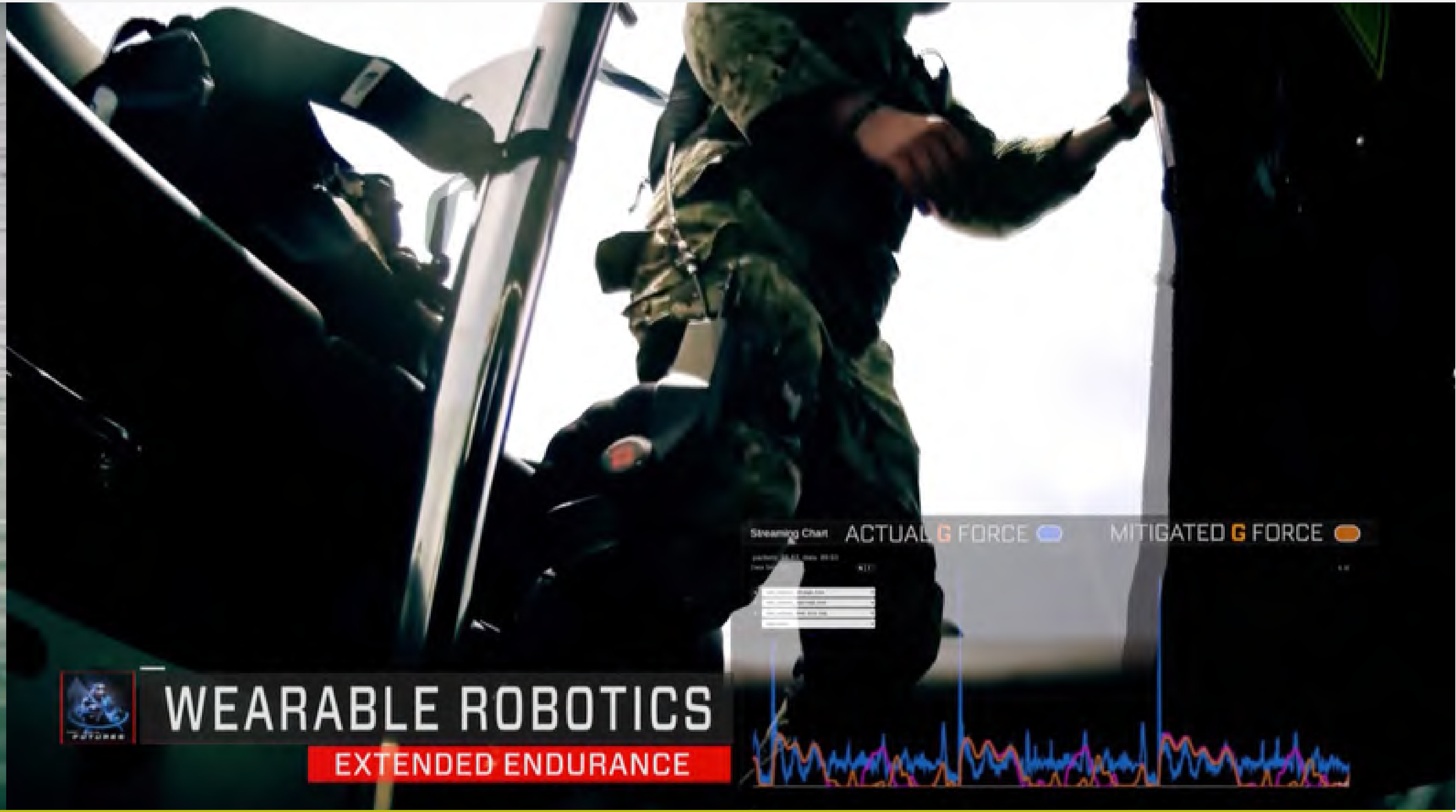

GESTURE CONTROL OF ROBOTICS
INTUITIVE CONTROL


ACTUAL G FORCE
MITIGATED G FORCE
WEARABLE ROBOTICS
EXTENDED ENDURANCE