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A Plan for Fielding US Navy Air Domain Manned Unmanned Teaming Capabilities

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Outline

- Study Background and Question
- BLUF: Conclusion
- Review of Study Approach
- Findings
  - RFI reported TRLs
  - Non-traditional providers
  - Literature review and SME discussions
- The Plan to Field USN Air Domain MUM-T Capabilities
  - Fourteen recommendations under three lines of effort

Study Background and Study Question

- Study initiated by OPNAV N98 to inform POM programming
- Current N98 focus is the MQ-25 refueling tanker. What should come next?
- Final Products:
  - Controlled Unclassified Information (CUI) Distribution C report
  - Classified/proprietary information distribution F report annex
- Disclaimer: This CNA study made recommendations for *potential* investment by OPNAV N98—the Navy resource sponsor for air warfare. Any notice of intent to invest in MUM–T enabling technologies will come directly from the US government through established acquisition channels, and in accordance with the Federal Acquisition Regulations.

What investments should N98 advance to accelerate the fielding of US Navy air domain Manned Unmanned Teaming?

BLUF: Conclusion

Most of the enabling technologies for MUM-T are rapidly becoming available from US Navy, industry, and other service programs. An OPNAV N98 plan to deliver US Navy air domain MUM-T should execute three lines of effort:

- **LOE 1: Mature, marinize, and integrate the enabling technologies.**
- **LOE 2: Address critical (non–materiel) DOTmLPF-P* issues.**
- **LOE 3: Advocate for implementation of MUM–T-enabling efforts that fall under the roles and responsibilities of other organizations.**

* DOTmLPF-P: Doctrine, Organization, Training, materiel, Leadership & Education, Personnel, Facilities, and Policy

Review of Study Approach

- Cast a wide net for technologies *and CONOPS*
  - SME discussions
  - Literature review
- Develop a *Design Reference Mission*
  - Mission agnostic
- Develop supporting functional requirements
  - From requirements documents for semi-autonomous and autonomous air, land, surface, subsurface and space vehicles
- RFI to identify available/emergent enabling technologies
  - Government labs/programs, industry, and academia
  - Traditional and (very few) non-traditional providers
- Identify gaps between available and required technology
- Provide a plan to close the gaps and deliver USN MUM-T

The Design Reference Mission

- *One or more manned aircraft shall be able to operate with one or more unmanned aircraft without having to depend on, or communicate with, an air vehicle operator on the ground or on board ship (launch and recovery operations excepted)*
- *The unmanned aircraft shall have sufficient autonomy so that it's actions can be directed by the pilot of the manned aircraft without placing a cognitive (or physical) burden on the pilot that exceeds the burden created when a flight lead directs the actions of a human wingman (or RIO/NFO/GIB/WSO)**
- *Communication between the manned and unmanned aircraft shall be point-to-point LPI/LPD***

The "*Turing Test in the Air*"

*RIO: Radar Intercept Operator, NFO: Naval Flight Officer, GIB: "Guy in Back," WSO: Weapons Systems Operator

**LPI/LPD: Low Probability of Intercept, Low Probability of Detection

Origin of the 62 Functional Requirements

- **Consolidation of requirements from every physical domain**
  - Surface
    - (DARPA) ACTUV (*Sea Hunter*) Indicative Performance Specification
    - (DARPA) Unmanned Naval Vessel Study: Undersea Warfare Concept
  - Subsurface
    - (PMS 406 & 408) Functional Specification for the Medium Unmanned Undersea Vehicle (MUUV): Autonomy
  - Air/Space
    - (Army) A-Team Requirements Development Document for Artificial Intelligence Task Force
    - (USAF) Autonomous Horizons: System Autonomy in the Air Force: A Path to the Future Volume 1: Human-Autonomy Teaming
    - (NASA) Assurance Reasoning for Increasingly Autonomous Systems
  - Ground
    - (UN) Informal Working Group on Functional Requirements for Automated and Autonomous Vehicles

Seven Categories of Functional Requirements

- Category 1: Granting Conditional Operational Autonomy to Unmanned Teammates (7)
- Category 2: Developing Functional Autonomy to Reduce Cognitive Load of the Flight Lead (19)
- Category 3: Creating Ease of Directability to Reduce Cognitive Load of the Flight Lead (4)
- Category 4: Ensuring Independence of the MUM-T Formation (4)
- Category 5: Enabling Flexible and Dynamic Assembly of MUM-T Formations (11)
- Category 6: Making the Unmanned Teammates Predictable (13)
- Category 7: Increasing Observability of the Unmanned Teammates (4)

RFI findings: reported TRLs*

- Functional requirements that need:
  - Mature technologies ready for integration (15 of 62)
    - average TRL > 6
    - at least one TRL > 8
    - more than seven responses
  - S&T investment for technology maturation (7 of 62)
    - no TRL > 6
    - average TRL < 4
  - Technology vendor base expansion (10 of 62)
    - fewer than 7 responses
    - only 1 response with TRL>6
  - R&D investment for technology (32 of 62**)

* TRLs are self-assessed by each organization/company. Analysis only includes reported TRLs

** Two requirements required both maturation and vendor base expansion

Identifying non-traditional providers

- Our RFI was limited to USG labs and known DOD contractors
  - FOUO nature of the functional requirements
  - Prohibition on foreign contact
- RFI responses highlighted immature and missing technology from these "traditional providers"
- N98 asked us to identify non-traditional providers to help close remaining enabling technology gaps
- We used the following open information sources:
  - Academic Journal Articles
  - Conference Abstracts / Proceedings
  - Technology Challenges
  - Patents

Enabling technologies with very limited availability from traditional providers

- Capability Gaps:
  - Machine planning for unexpected actions, upcoming tasks, and critical/emergency situations
  - Incorporation of operator state in teaming behavior
  - Connectivity Plans
- Enabling Technologies:
  - Decision aids and algorithms
  - Physiological monitoring
  - Smart communications
  - Modeling and simulations of MUM-T scenarios

Findings from literature search and SME discussions

- MUM-T and HMI design approaches
- Trust in autonomous systems
- Lessons from history
  - Automation in the cockpit
  - Human teammates
- Machine learning opportunities/challenges
- Interoperability/composability

MUM-T and HMI Design Approaches

- Many MUM-T design approaches are “unsophisticated”
  - Simple functional task allocations based on whether the human or the machine is best suited to execute
- Emerging approaches like Coactive Design illuminate additional opportunities:
  - Human only – no machine support required
  - Machine only – no human support required
  - Human lead with machine support
  - Machine lead with human support
- Illuminates “digitization opportunities”

Trust in Autonomous Systems

- It can be argued that lack of trust in autonomous systems is a direct result of a lack of:
  - Predictability
  - Observability
  - Directability
  - Explainability
- The lead/follow approach of Coactive Design helps to identify ways to engineer these attributes into the human-machine system
- Paradigm shift:
  - Old: design the aircraft and train the pilot
  - New: Design both together *and train both together*
- Training together increases predictability and thus, trust

Lessons from history

- Automation in the cockpit
  - MUM-T is "just" automation in another cockpit
  - Automation does not (necessarily) reduce the cognitive burden on the pilot
- Human teammates
  - Historically, flight lead/wingman relationships treat the wingman like a predictable automaton
  - Extensive team training negates the need for observability – the flight lead knows the wingman without even looking
  - The wingman is a directable extension of the flight lead's intentions

We've been down this road before: the issues we face with MUM-T are not all that unfamiliar.

Machine learning opportunities/challenges

- The unmanned aircraft in a MUM-T formation can be engineered to be learning systems that leverage machine learning:
  - **Supervised learning** requires lots of training data – need to think about how you will collect, retain, and use it
  - **Reinforcement learning** requires current knowledge of the environment and a policy that directs actions to maximize a reward – requires the system interact with the environment numerous times to learn through trial and error
- Increased learning leads to increased unpredictability
  - How do you put the human in/on the loop to mitigate unpredictable behavior?
  - How do you train the learning system and then “turn of” the learning before you use it in an operational environment?
  - Training vs. combat time scales

Interoperability/composability

- How effective is a team if you cannot "pull a teammate off of the bench" based on the nature of the opposing team?
- How do you avoid the operationally and technologically brittle solutions that result from "vendor lock"?
- How do you reduce the barrier to entry for small and/or "nontraditional providers"?
- How do you build a MUM-T solution in the air domain that can (eventually) extend to cross-domain MUM-T?
- ***How do you preserve design flexibility that confounds enemy attempts to build reliable training data sets?***

The answer to all five of these questions is architecture and interface standards.

The plan to deliver USN air domain MUM-T

- **LOE 1: Mature, marinize, and integrate the DRM enabling technologies.**
- LOE 2: Address critical (non–materiel) DOTmLPF-P issues.
- LOE 3: Advocate for implementation of MUM–T-enabling efforts that fall under the roles and responsibilities of other organizations

Prioritize investments in DRM enabling technologies not mature enough for integration

- DRM execution requires *all* of the enabling technologies
  - Only 15 of 32 functional requirements are supported by enabling technologies that are fully mature and ready for integration
- S&T focus from ONR and/or DARPA required to advance technologies with low TRL or with limited vendor base
  - 15 additional functional requirements fall into this category
  - These organizations are not directly resourced by OPNAV
- Advancing more mature technologies that are not ready for integration falls in the purview of R&D done by PEOs
  - The majority of functional requirements—32 of 62—fall into this category
  - These organizations are directly resourced by OPNAV

Marinize DRM enabling technologies

- Why
  - We are recommending integration of technology not originally made with maritime environment employment as a requirement
    - Carrier/big deck/helo flight deck launch and recovery
    - Flight deck EM Interference
    - Below decks stowage
    - Salt air corrosion
- How
  - We make no specific recommendation since these issues are not unique to the aircraft used in MUM-T applications
  - Simply need to recognize that additional marinization investments will be required before adopting non-DON aircraft

Integrate (and adapt) DRM enabling technologies

- Why
  - 2018 NDS: Rapid integration confers an advantage
  - ML components of MUM-T: Integrate software *changes*, not software *upgrades*
  - Correct allocation of tasks to human or machine (or both) to optimize contribution of each
- How
  - Adopt the *Coactive Design* methodology to simultaneously integrate technologies from stove-piped providers and the human teammate
    - Integrate to build a team, not a system

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Reconcile USAF/USA/DON autonomy standards

- Why
  - Retain composability of MUM-T formations
  - Avoid vendor lock, and thus, brittle and expensive systems
  - Lower barrier to entry from non-traditional providers
  - Enable cross-domain MUM-T
  - Facilitate counter-ML design (hardware and software)
- How
  - Coordinate with PMS 406 to build ICDs for MUM-T UAS that are compatible with The UMAA ICDs for USVs and UUVs
  - Maximize use of existing, industry-compliant USAF and Army autonomy standards for US Navy autonomous aircraft
  - Require flag-level approval of waivers for non-compliant and/or proprietary technology components
    - In the age of AI, inflexible aircraft will be shot out of the sky

Train the MUM-T formation as a team

- Why
  - Training together creates predictability, and thus, trust
  - Massive expansion of the TTP solution space
- How
  - Move from virtual to actual:
    - Digital twins ***(MBSE)*** of the machine and the pilot in a simulator
    - Allow the machine to explore TTPs on its own
    - Bring human back into the loop for validation/rejection
    - Train together in the actual physical environment
  - Accommodate the time-scale-induced increasing risk:
    - Long term TTP development at NAWDC: human in loop
    - Near-real-time TTP development on board ship: human on the loop
    - Real-time TTP development in the air: human out of the loop

Collect and retain ML data

- Why
  - ML provides opportunities to improve effectiveness of the MUM-T, but requires massive amounts of training data
  - The unpredictability (to the enemy) of an ML-enabled MUM-T formation confounds and complicates their acquisition plans and operational planning
- How
  - Instrument the pilot, the manned aircraft, and the unmanned aircraft
  - Record every action, every sensor input
  - Make data *collection and retention* a JCIDS KSA
  - Retain data at NAWDC for tactics development
  - Retain data at NAVAIR for acquisition development

Mandate digitization of data

- Why
  - Analog data cannot be consumed by the machine teammate
  - ***Humans end up doing things machines are better suited for***
- How
  - Use coactive design to identify “analog-data-induced sub-optimization” of the human teammate
  - Make data *digitization* a JCIDS KSA

Tell a compelling and provable story to Congress

- Why
  - The surface and subsurface communities had their budgets marked because they failed to articulate the value of UxS
  - DON air domain MUM-T could suffer the same fate
- How
  - Draft a narrative describing the benefits of MUM-T:
    - In GPC scenarios against peer ad near-peer nations
    - Differentiating it from “unteamed” UAS capability
    - As the key to victory at sea
  - Provide the narrative to CHINFO, CNO, and SECNAV for public, industry, and Congressional engagements
  - Validate the narrative with experiments, war games, and studies
  - Feed these analytic results back into the POM

Expand nontraditional provider participation

- Why
  - MUM-T-enabling technology currently under development by providers with no history as DOD contractors
  - Increase competition to lower costs
  - Complicate enemy acquisition decisions and operational planning by presenting a larger set of capabilities and platforms that must be countered
- How
  - Adopt interface standards (as previously noted)
  - Leverage nontraditional acquisition authorities
    - USAF Autonomy Research Collaboration Network (ARCnet)
    - Defense Innovation Unit Commercial Solutions Opening (CSO)
  - Caution: Avoid the known pitfalls of rapid acquisition

Move from control to direction

- Why
  - Controlling, instead of directing the unmanned aircraft:
    - Requires communications that create vulnerabilities
    - Creates a cognitive burden on an already preoccupied pilot
- How
  - Develop autonomous functionalities so that the unmanned aircraft is directable
  - Leadership messaging of this intention
    - *Turing Test in the Air*
    - *A human brain is the CCS of the future*
  - Orderly evolution of OPNAV N98 requirements officer and PMA 281 responsibilities from Common Control System to "Common Direction System"
    - (eventually) rescind and replace CCS mandate and KPP

The plan to deliver USN air domain MUM-T

- LOE 1: Mature, marinize, and integrate the DRM enabling technologies.
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Advocate for LPI/LPD as a critical enabler

- Why
  - Breaking the vulnerable communications link between the UAS and its shipboard or ground-based control station is the primary operational advantage of the DRM
- How
  - OPNAV N2/N6 is the resource sponsor for LPI/LPD communications
  - Develop and present US Navy air domain MUM-T LPI/LPD communication requirements to N2/N6
    - Compliance with standards
    - Passage of the *Turing Test in the Air*
    - Digital data capture and storage KSAs

Advocate for *CNO Unmanned Systems Campaign Plan* actions

- Why
  - Many of the contemplated action items enable MUM-T
  - Focuses N98 resources on air-specific, and mission-specific MUM-T requirements, not MUM-T enterprise infrastructure
  - High probability that this CNO-directed effort will produce
  - Lead action officer in in N9I
- How
  - Participate in N9I's meeting, workshops, and data calls
  - Encourage (air) SYSCOM, TYCOM, DASN, Fleet participation
  - Advocate for:
    - standards development and adherence
    - MUM-T TEVV policy and capability (with N94)
    - LOAC policy and law clarifications
    - UxS acquisition community reorganization analysis

Advocate for ONR *Intelligent Automated Systems S&T Strategy* actions

- Why
  - Contemplated action items enable MUM-T
  - Focuses N98 resources on air-specific, and mission-specific MUM-T S&T requirements
  - High probability that this RDT&E leadership chartered effort will produce
- How
  - Participate in ONR's meeting, workshops, and data calls
    - Encourage air- SYSCOM, TYCOM, and fleet participation
  - Advocate for inclusion of Directability, rather than control, as an IAS design principle
  - Advocate for AI workforce development
  - Advocate for S&T investments for the very immature (and limited availability) DRM enabling technologies

Advocate for clear and definitive policies and procedures for autonomous systems TEV&V

- Why
  - *"How much time will it take to build a MUM-T capability that meets the requirements of the Design Reference Mission?"*
  - Despite an eight year old policy, DOD has not yet provided quantifiable measures and standards to define successful attainment of TRL 8 (or 9) for autonomous systems
  - Subjective policy terminology is unenforceable/unattainable
    - "sufficiently" robust to minimize failures
    - "appropriate" levels of human judgement
- How
  - Make known the inability to attain TRL 8+ for autonomous systems absent the mandated T&E and V&V procedures
  - Describe the safety of operations implications of fielding autonomous systems that can only reach TRL 7

Questions and Discussion

"Man merges with machine; he doesn't simply use it. You don't climb into an aircraft and sit down. You strap the machine to your butt, become one with it. Hydraulic fluid your blood; titanium, steel, and aluminum, your bones; electrical currents your nerves; the instruments, an extension of your senses; fuel, the food; engine, the power; the control surfaces, the muscle. You are the heart, yours is the will, you're the reasoning power. You are something more than earthbound man. You are augmented and expanded by the miracle of the machine. You are tied to it physically and you are part of it emotionally."

Brig Gen Robin Olds, USAF
Triple Ace (WW II and Vietnam)