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A Technical Roadmap for Autonomy for Marine Future Vertical Lift (FVL)

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A TECHNICAL ROADMAP FOR AUTONOMY FOR MARINE FUTURE VERTICAL LIFT (FVL)
EXECUTIVE SUMMARY

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Project Summary

The United States Marine Corps (USMC) is investing in aviation technologies through its Vertical Takeoff and Landing (VTOL) aircraft program that will enhance mission superiority and warfare dominance. One USMC program initiative is to launch unmanned aerial systems (UAS) from future human-piloted VTOL aircraft for collaborative hybrid (manned and unmanned) missions. This hybrid VTOL-UAS capability will support USMC intelligence, surveillance, and reconnaissance (ISR), electronic warfare (EW), communications relay, and kinetic strike air-to-ground missions.

This capstone project studied the complex human-machine interactions involved in the future hybrid VTOL-UAS capability through model-based systems engineering analysis, coactive design interdependence analysis, and modeling and simulation experimentation. The capstone focused on a strike coordination and reconnaissance (SCAR) mission involving a manned VTOL platform, a VTOL-launched UAS, and a ground control station (GCS). The project produced system requirements and architecture, a conceptual design, and experimental insights into the human-machine teaming aspects of future VTOL capability.

Key findings were that the UAS possesses a high level of digital automation organically and shared with its human partners, which also implies that the humans' planning and execution must be digitally captured. This ensures that the partners will observe, predict, and direct one another, building trust. The second finding was that the entire team requires a secure and redundant primary, alternate, contingency, and emergency (PACE) communications plan to support resilient mission planning, execution, and post-mission analysis. Lastly, the research demonstrated the efficacy of using networked simulators to explore, assess, and measure human machine teaming effectiveness.

The research recommends that the USMC adopt a strategy to procure high-level autonomous UAS, capable of natural language processing, mission assessment, and policy update protocols. Next, continue assessment of other USMC mission sets when employing VTOL and UAS, using the same techniques. Finally, pursue more distributed simulation for experiments and assessments.

Keywords: *future vertical lift; FVL; human machine teaming; HMT; interdependence analysis; IA; United States Marine Corps; USMC; primary, alternate, contingency, and emergency; PACE; digital planning; unmanned air systems; UAS; intelligence, surveillance, and reconnaissance; ISR; electronic warfare; EW; strike coordination and reconnaissance; SCAR; vertical takeoff and land; VTOL; observability, predictability, and directability; OPD; model-based systems engineering; MBSE*

Background

The USMC seeks to maintain mission superiority and warfare dominance. One pathway toward this goal is through technology advances and the ability to effectively provide innovations to warfighters. The USMC is studying the combination of two innovations (future VTOL helicopters and UAS with different capabilities) to significantly increase mission performance and capabilities. However, the collaboration of future human-piloted helicopters and UAS introduces new complexities for HMT. The USMC needs to better understand the complex HMT interactions among future piloted helicopters that launch and coordinate with future UAS for operational missions, such as the SCAR mission. The USMC needs to determine what mission planning factors must be considered and needs a set of human-machine functional requirements to support future USMC VTOL missions.

The objective of this research was to study HMT challenges and needs for future USMC VTOL-UAS hybrid operations. The research team addressed the following research questions as part of the project:

1. What capacities need to be analyzed between a VTOL, UAS, and GCS in accordance with the functional tasks required to conduct a SCAR mission?
2. How do the following interdependency factors of observability, predictability, and directability influence the HMT relationships between the VTOL, UAS, and GCS?
3. What are the decision-making abilities of an autonomous UAS and what decisions can it make on its own as part of the HMT system?
4. What are the HMT requirements in support of VTOL-UAS hybrid operations for a SCAR mission?

This four-phased research began with a needs analysis, which provided a foundation of understanding and background knowledge to support the analysis in later phases. The team researched key areas of the capstone project including interdependence analysis, HMT characteristics, USMC mission essential tasks, and capacity requirements. The team identified stakeholders and studied stakeholder needs and desires related to the project and mission.

During the Coactive Design Model phase, the team developed an operational view to display the mission scenario and hybrid operational concepts between a VTOL, UAS, and GCS for a SCAR mission. The team performed systems analysis and used the coactive design approach to develop functional tasks and HMT requirements in terms of observability, predictability, and directability (OPD) to display the interdependency relationships between the three systems. The team's interdependency analysis and MBSE artifacts were used to develop a roadmap to drive HMT system requirements using a specific SCAR mission scenario while receiving stakeholder feedback.

In the results generation phase, the team produced analysis results by utilizing the interdependency analysis table of HMT characteristics. The team assessed the results and finalized the project by reporting all results and recommendations obtained using the coactive design and MBSE approaches.

The final phase found the research team working with simulation experts to build an experiment that compared the efficacy of a VTOL platform and independent UAS operating separately versus a hybrid VTOL-UAS human machine team to complete the SCAR mission. This experiment included developing measures of performance and effectiveness for experiment comparison.

Findings and Conclusions

This research aimed to decompose and describe an HMT concept and framework between human operators and UAS' utilizing IA with the goal of constructing a USMC SCAR mission experiment. By combining Coactive Design with systems analysis and MBSE, the research team discovered multiple complex human-machine interdependencies that require significant cognizant input when a human operator is the primary performer. The research also discovered via the IA that the future HMT concept and operational complexity of partnering human operators with machine systems will require substantial analysis and experimentation in order to understand the strengths and vulnerabilities that exist within an HMT system.

This research validates the credibility and applicability of combining the systems engineering framework and Coactive Design process together to decompose and visualize high-level system requirements while also establishing the key interdependencies. This combination enabled HMT interdependencies with direct traceability to high-level system requirements.

This analysis provided the foundation to understand and analyze the primary performer and supporting team member in the execution of a SCAR mission. The IA demonstrates the detailed analysis required in order to understand the complexity of human-machine teams and underpins the criticality of relevant and realistic assumptions within the IA table. Over 86 specific subfunctions were analyzed.

One key takeaway is the assumption that machine systems will possess Level 4 automation, meaning the UAS operates at high automation. This assumption was critical to ensure the HMT concept was adequate to support HMT trust, VTOL cognitive overload concerns, and real-time critical mission decision-making processes.

The research conducted in this capstone provides insights into the development and future application of HMT systems in operational environments. The USMC should continue to invest in the research and development of HMT concepts and continue to refine and construct the HMT relationships in order to understand the complexities of interdependence between humans and machines. For human-machine teaming, the USMC should continue to use the systems engineering framework in conjunction with Coactive Design and IA. This combined approach to system decomposition ensures the appropriate traceability can be achieved within the systems engineering framework and established architecture while also utilizing the benefits of IA to depict human-machine interdependencies. The continued investment in AI and designing AI into future HMT systems will be vital to achieve HMT effectiveness. A deeper understanding of AI and its applicability to future systems should follow the systems engineering approach to enable the visualization of future HMT system concepts.

Two specific recommendations emerge. First, the UAS and the humans must capture their mission planning, execution, and post mission debrief digitally. It is the only common way humans and machines can communicate. An important corollary is that resilient, robust, reliable, and redundant communications channels between the human machine teams are a must.

The final recommendation is that the use of distributed simulation will play a pivotal role in helping the USMC and their partners learn early, fail fast, and accelerate the capabilities of the VTOL family of systems. The sponsor confirmed his continued interest in this approach.

Recommendations for Further Research

The USMC is exploring the use of human-machine teaming to control unmanned aerial systems (UAS) in forward deployed environments across a wide array of mission sets. For USMC hybrid warfare applications to achieve mission superiority and warfare dominance, the USMC needs to understand the human-machine interactions between a vertical takeoff and land (VTOL) crew and UAS to gain battlespace situational awareness. This research involves a USMC strike and coordination reconnaissance (SCAR) mission in a maritime environment.

The study reviewed the VTOL program, autonomy and automation. It used the coactive design model to explore human-machine teaming interactions and determine interdependencies between the human performer and machine team member using the interdependence analysis (IA) framework based on three factors: observability, predictability, and directability.

Systems analysis supported this method by decomposing the high-level functions of a SCAR mission into hierarchal tasks and subtasks. According to Johnson (2014), the coactive design method exposes interdependencies and uses the IA framework as a design tool. The IA framework captured the interaction between primary and supporting team members to generate HMT requirements by analyzing 17 primary tasks, 33 hierarchical subtasks, and 85 required capacities necessary to conduct a SCAR mission.

Research revealed the need for a robust digital mission planning system that facilitates machine learning, increases in processing power and storage of information on the UAS, and a validated primary, alternate, contingency, and emergency (PACE) communication plan.

To properly assess the HMT requirements, the research team built an exploratory experiment at the Naval Postgraduate School (NPS) Modeling, Virtual Environments, and Simulation (MOVES) laboratory. Measurements were developed to determine HMT effectiveness.

This research provides clear evidence of the complexity of HMT interactions to execute VTOL-UAS hybrid operations during a SCAR mission. The research identifies the need for sophisticated levels of autonomy and technology readiness not currently available. Researchers recommend the USMC continue to study human-machine teaming, with an emphasis on achieving strong automation.

Future work should focus on the initial experimentation of HMT concepts as they apply to current doctrine and multi-domain operations. The use of the NPS MOVES laboratory presents the opportunity to simulate the HMT concept across the domains of air, land, and sea. This opportunity could provide the USMC with relevant and realistic feedback to support the continued refinement of HMT interdependencies and application of systems engineering across future human-machine systems.

More research into the use of digital mission planning systems is needed. This mission planning provides the capability to leverage simulation environments to understand the intricacies of HMT interdependencies while maintaining a cost-effective approach that defines the HMT concept of the future.

As DoD priorities change, the IA studied in this research report must be expanded to encompass multiple future system platforms across the multi-domain environments. The systems engineering process and Coactive Design analysis provide the framework to expound on the HMT concept and move beyond the SCAR mission scenario. Foundational frameworks must be developed that enable the application of HMT across all operations while supporting requirements development.

References

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Acronyms

EW	electronic warfare
FVL	future vertical lift
HMT	human machine teaming
ISR	intelligence, surveillance, and reconnaissance
IA	interdependence analysis
MBSE	model-based systems engineering
NPS	Naval Postgraduate School
OPD	observability, predictability, and directability
PACE	primary, alternate, contingency, and emergency
SCAR	strike coordination and reconnaissance
USMC	United States Marine Corps
UAS	unmanned air systems
VTOL	vertical takeoff and land