Chapter 18 – CONCLUSIONS

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This underlying report describes how HFM-170 successfully developed and demonstrated pertinent supervisory control human-system interface design practices and operator interface concepts for Uninhabited Vehicles (UVs) network-centric operations. In a series of 14 specific Technology Demonstrations (TDs) it was shown that the operator's role is becoming more supervisory of nature since future UVs will be increasingly automated (e.g., autonomous capabilities, multiple systems, systems of systems), on the other hand it was demonstrated that new sensor and control technologies enable operators to be closer in the loop in a telepresence situation. The applications addressed varied in degree of autonomy from manual robotic control to highly autonomous, swarming UVs. A variety of critical issues were addressed including multi-vehicle control, manned-unmanned teaming, human-automation interaction, telepresence interfaces, delegation interfaces, vehicle hand-offs, operator workload adaptive systems, variable levels of autonomy, authority sharing, situation awareness aids, cognitive workload assessment, swarming interfaces, and dynamic mission management. HFM-170 also concentrated on the identification and demonstration of successful supervisory control methodologies and interface design practices for enabling single operator control of multiple UVs.

Based on these TDs the following conclusions can be drawn:

- Live-demonstration of UV supervisory control methods and enabling technology as experienced within NATO HFM-170 is a complex undertaking which requires serious preparation. These TDs were well received by the entire Task Group. [ALL]
- These demonstrations, along with periodic meetings, provided a valuable forum to exchange technical information and discuss possible future collaborations in supervisory control research and development. [ALL]
- The developed 7 Dimension Framework model held the most promise for satisfying the ends of the Task Group. This model was largely descriptive, but it captured several dimensions relevant to the many alternate supervisory control systems, relationships and usages we were examining. While the specific dimensions examined need to be refined, and the scales for characterizing them might also be improved upon, this multi-dimensional description of alternate systems seemed to provide the right level and type of information for conveying how a set of supervisory control systems are similar and different from each other. [ALL]
- Hand-off demonstrations between two UV supervisory control crews, as well as between an external pilot (flying manual control) and a supervisory control station was successfully verified. [CAN-1]
- Self-organization and protection capabilities of multiple autonomous ground vehicles through Artificial Impedance Control for local autonomy including collision avoidance and trajectory generation showed

excellent results. Expanding this with formation control and flocking control through computer simulation showed promising results. [CAN-2]

- A technology demonstration called OmniSense showed the efficacy of a multi-modal display (i.e., the presentation of visual, auditory, and tactile information) for enhancing supervisory control of an automated UAV. The benefit of OmniSense is anticipated to be particularly evident in an increase in the detection of critical events, a reduction of response times to critical events, and increased situation awareness. This suggests that the OmniSense solution will be more effective than a visually-only GCS interface. [CAN-3]
- Swarm intelligence seems to be a promising approach for multiple UVs control in terms of algorithmic performance and robustness, as long as human factors and especially man-machine communication and interaction are properly adapted. [FRA-1]
- A program demonstrating new means of cooperation and interaction between Humans and Automates ("Authority Sharing") showed that it is possible to optimize the workload of existing UAV systems by allocating dynamically the operators' functions, allowing thus the integration of multiple UAVs and payloads without necessarily increasing the number of operators required to manage. The operators appreciated the human-machine interface, in particular the "draggable vector tool". Regarding the "authority sharing" engine, the overall performance does not change with or without the activation of the engine, but the test panel was too small to statistically confirm this data. [FRA-2]
- The demonstration of a generic approach in the development of a knowledge-based assistant system adapted to the domain of manned-unmanned-teaming focused on guidance of multiple UAVs from the commander's workplace in a helicopter cockpit aided by an assistant system. This approach was evaluated through experiments in the helicopter simulator. The introduction of the assistant system improved human factors related variables like situation awareness and workload, improved performance and safety, and was well accepted. It is also concludes that the next steps to further improve the assistant system performance and acceptance should be to refine the knowledge models for operator overtaxing estimation, current task recognition and cost prediction, and to refine the action and decision support for tasks. Finally, the cooperation and variable task assignment between commander and pilot flying have to be further investigated and regarded within the concept. [GER-1]
- An experimental research collaboration between the US Army Research Lab and NL TNO where robots were used for reconnaissance of a remote area revealed:

  1) No difference between the Mono-Headtracking condition and the Mono-Joystick condition in accuracy of target identification. However, more time was required for target identification when using joystick control.

  2) The Telepresence condition (that included 3D audio) increased the percentage of correctly identified targets by approximately 23% compared to the Mono-Headtracking condition (using a directional microphone). In addition, target identification took approximately 35% longer without having the 3D audio functionality available.

  3) The Telepresence human-robot interface decreased identification/localization times for audio stimuli by approximately 42% as compared to currently commonly used interfaces. In addition, target identification performance increased by about 26% when using the Telepresence human-robot interface. [NL-1]

- A test of a new framework for managing UAV task and workload allocation between various operators in a mission scenario revealed improvements of optimal in-the-loop inclusion of operators

for the successful application of multi-UAV systems. Further testing, with simulated scenarios, will provide new insights over the real capabilities of the proposed framework. [PT-1]

- A demonstration/test where an operator had to mainly manually navigate one, two, or three partly autonomous UGVs to pre-designated inspection points in a simulated urban environment showed that the limited autonomous function was insufficient to significantly improve the operator to vehicle ratio. The operators were saturated even when only controlling two UGVs in a basic navigation task. More advanced autonomous functions or control station interfaces that reduce the attention demands are therefore necessary to improve the operator to vehicle ratio. [SWE-1]
- A demonstration/test revealed that partly autonomous UGV functions can improve the operator to vehicle ratio if there are weak dependencies between the task that an operator performs and the task that the partly autonomous function performs. However, these task dependencies also depend on the operators' task experience, as well as the formal task properties. The operators' control strategy showed that they were rather naïve towards the complexities of tactical reconnaissance tasks. More experienced operators may therefore find different task dependencies. [SWE-2]
- Demonstration and test of the Dynamic Airborne Mission Management (DAMM) program developed a set of principles, interfaces and interactions for the delivery of effects, enabled by advanced digital networking and mission enabling technologies, providing a distributed, collaborative and adaptive mission capability for stability and dominance in a dynamic environment. DAMM synthetic environment and flight trials provide evidence with high levels of proof for real benefits of a full suite of collaborative decision support tools across multiple tiers of the networked dynamic Command and Control (C2) architecture. This work has shown that as data rate, confidence and context increase/ improve, nodal (micro) and system (macro) C2 decision loop activity transposes from slow serial to concurrent-NRT speeds. Consequently, kill-chain timeline, fratricide and collateral incidents should reduce. [UK-1]
- The Multi-UAV Supervisory Control Interface Technology (MUSCIT) program demonstrated several advances in UAV control station interface technology that enables effective single-operator, multi-UAV performance for surveillance and re-routing tasks. Interface enhancements included a novel tactical situation (map) display, speech recognition, synthetic overlays, mission and sensor automation, integrated information displays tailored for supervisory control, and support tools for multi-sensor management tasks. The control station technology was demonstrated in a four-vehicle configuration made up of two actual UAVs in flight along with two simulated UAVs, all controlled by a single operator. The operator interface was iteratively developed using a spiral approach; combining simulation and flight testing to characterize operator and mission performance, empirically derive and refine technical requirements, and refine operator interface technology. Empirical results from simulation and flight evaluations reveal specific costs to operator performance, situation awareness, and workload as a result of increasing the number of UAVs a single operator is required to manage. [US-1]
- Delegation Control of multiple heterogeneous UVs by a single operator was successfully demonstrated. Navigation and payload control of four unmanned systems was monitored by a single operator in a collaborative urban mission scenario. Delegation Control employment strategy and interface design supported the build, initiation, modification and monitoring of simultaneous plays in progress. Use of voice recognition was considered an advantage to the operator during time critical mission phases. The operator's ability to bypass menus in favor of voice recognition control, significantly decreased reaction time to external mission events. Dynamic route re- planning was effectively accomplished while plays were in progress. In addition, play status was efficiently

depicted and real-time updates were accomplished when play modification and play terminations occurred. Automation transparency was increased through messages that described impacts of conflicting plays. Lastly, the Play Status window was considered a significant contribution to operator situation awareness for rapid awareness of asset allocation and play scheduling. [US-2]

- The results of two experiments using RoboLeader, using simulations to understand how to develop a synergistic relationship between human supervisors (having final decision authority) and intelligent agents (who supplies algorithmic solutions for many-to-one control problems) showed that operators were able to intervene more successfully with False Alarm Prone (FAP) error rates than with miss Prone (MP) error rates, contrary to previous findings in the literature. The apparent reason for this was that the more compact interface used in the current experiment allowed FAP verification to be accomplished more efficiently. In contrast, MP errors required operators to constantly scan the map reducing their target detection scores on the video displays. The final experiment showed the efficacy of RoboLeader in aiding the operator to conduct more complex missions which required four robots to entrap a moving target. [US-3]
- The results of usability studies to investigate alternate design configurations relative to optimum human performance and decision-making in USV supervisory control confirmed that the baseline concept design interface showing video graphics simulating forward/aft/starboard and port camera views for each USV would not safely support simultaneous operation of two USVs by a single operator. A design concept displaying an integrated “windshield” style display showed great promise but is not yet at a level that would support safe and reliable operation of multiple USVs simultaneously. The latter concept will be further tested. [US-4].

All TDs were very successful and well received by the Task Group members. It is therefore recommended to disseminate results and lessons learned associated with the technical demonstrations of HFM Technical Task Group HFM-170, Supervisory Control of Multiple Uninhabited Systems – Methodologies and Enabling Human-Robot Interface Technologies. The aim is to bring together representatives of the research and operational communities at invitation, to present technical demonstration results, and to review progress in this important area.