Army Aviation Manned-Unmanned Teaming (MUM-T): Past, Present, and Future

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As the use of unmanned aircraft systems (UAS) in military operations has increased, so too have their capabilities. One recently developed capability is the ability to operate in conjunction with traditional manned aircraft through a process called manned-unmanned teaming (MUM-T), allowing manned aviators to benefit from the unique capabilities of UAS. This paper provides an introduction to the concept of MUM-T, describing the early stages of research and development, current MUM-T capabilities in fielded Army systems, and planned future development efforts to continue to advance the capability.

As unmanned aircraft systems (UAS) continue to increase in number and capability, the user community and technology developers have quickly recognized the tremendous combat multiplier they can provide across the full spectrum of armed conflict. While initially used as intelligence, surveillance, and reconnaissance (ISR) gathering assets, UAS now serve a variety of roles to include scout and attack. UAS also no longer operate in isolation, limited to sending information and receiving commands from a traditional ground control station (GCS). Instead, advanced data links now allow UAS to transmit sensor imagery directly to the aviation and ground warfighters who need it most through a process called manned-unmanned teaming (MUM-T). MUM-T is the cooperative employment of unmanned assets with traditional manned platforms, providing the unique capabilities of each system to be leveraged for the same mission. The primary benefit of this employment concept is to transmit live intelligence captured from the unmanned system to the manned asset, providing the manned operator with improved situational awareness without placing them at risk.

Although MUM-T can describe the coordination between any manned platform (land, air, or sea) and any unmanned platform (land, air, or sea), technologies specifically intended for manned and unmanned aviation platforms have received the greatest attention from the development and currently has the most advanced fielded capabilities. Therefore, this paper will focus exclusively on MUM-T research and technologies intended to support aviation assets. Specifically, the authors present a review of the initial series of MUM-T research programs and technology demonstrations, a description of the current state-of-the-art capabilities, and continuing research being conducted by the Army to further advance the concept.

Past: Previous MUM-T Research Programs

MUM I - IV

Preliminary investigations into the MUM-T concept began in 1997 with a series of four Concept Evaluation Programs titled MUM I, II, III, and IV, led by the Army's Air Mobility Battle Lab at Ft. Rucker, AL (Jones, 2001). These studies sought to evaluate the impact of MUM-T on the efficiency, effectiveness, survivability, and timeliness of the air weapons team, specifically while conducting tactical reconnaissance missions. The information collected through this series of studies established the foundation for all future MUM-T research and development.

The objective of these studies was to determine how many UAS could be controlled at once; the workload associated with controlling between one and four UAS at LOI 4 (see Table 1); appropriate tactics, techniques and procedures (TTPs); and the effectiveness of cognitive decisions aiding systems (CDAS) in reducing workload. The studies were conducted using two networked Comanche Portable Cockpits acting as a scout/attack weapons team, and a notional vertical lift UAS with hover and speed parity with Comanche.

The culminating study (MUM IV) showed that the maximum number of UAS that could be controlled while remaining an active shooter was marginally two. Managing three UAS took the manned aircraft out of the fight due to extremely high workload. Many different tactics were attempted including using the UAS as a wingman that clearly showed MUM-T to be a force multiplier. The CDAS was never fully implemented due to schedule and cost limitations. This resulted in very high workload managing even one UAS. The Comanche cockpit pilot vehicle interface was also not sufficiently optimized to support the necessary MUM-T tasks which again increased workload and negatively impacted crewmember situational awareness. Even with all of these negatives the knowledge gained from these experiments continues to shape the direction of MUM-T R&D efforts to this day.

Table 1.
Defined Levels of Interoperability (LOI).

LOI Level	Definition: Operator in the manned platform has the ability to…
1	Verbally communicate with UAS operator via radio
2	View UAS sensor imagery in real-time
3	Control UAS sensor payload orientation
4	Control UAS aircraft position via waypoint navigation
5	Assume complete control of UAS, including take-off and landing

Note. Higher levels include all lower level capabilities (e.g. LOI 4 provides control of aircraft position and sensor payload orientation, as well as real-time sensor imagery).

Airborne Manned/Unmanned System Technology Demonstration

The first major follow-on to the preliminary MUM studies was the Airborne Manned/Unmanned System Technology Demonstration (AMUST-D) in 2002 (Colucci, 2004). This program sought to develop and demonstrate new technologies built specifically for interoperability with UAS from manned helicopters. The program consisted of two related efforts: the Warfighter's Associate, led by Boeing, which provided control of UAS from the co-pilot gunner (CPG) station of the Apache; and Mobile Commander Associate, led by Lockheed Martin, which provided UAS control from the Army Airborne Command and Control System (A2C2S) in the back of the Blackhawk. Both systems sought to transition CDAS functionality originally developed for the Rotorcraft Pilot's Associate (RPA, Miller & Hannen, 1999), which included advanced autonomous behaviors, data fusion techniques, and intelligent flight routing – all capabilities intended to free up operator cognitive resources, allowing them to focus their limited attention on the battle rather than aircraft management. The AMUST-D program also sought to overcome the interface shortcomings identified by the previous MUM studies. Although the Mobile Commander Associate system was never formally fielded, due to the A2C2S system never being integrated into the Blackhawk fielding plan, the Warfighter's Associate system continued development until eventually being an integral component in the Apache AH-64D Block III upgrade, as well as the AH-64E model.

Hunter Standoff Killer Team

The Warfighter's Associate and Mobile Commander Associate technologies from AMUST-D were further developed and tested through the Hunter Standoff Killer Team (HSKT) program in 2005, led by the Army's Aviation Applied Technology Directorate (AATD, Colucci, 2004). The HSKT program primarily focused on hardware integration (datalink, sensors, etc.) rather than the operator's control station. The improved hardware demonstrated for the first time that MUM-T could be beneficial beyond just tactical reconnaissance, but for weapons engagements as well. An improved sensor payload (including autotracking capabilities and a laser designator) on the Hunter UAS allowed it to designate a target to be engaged by an attack helicopter (cooperative engagement), increasing the standoff distance, and thus safety, of the manned platform.

Manned-Unmanned Systems Integration Capability

The Army's Program Executive Office for Aviation coordinated the Manned-Unmanned Systems Integration Capability (MUSIC) Exercise in 2011. This capstone event was the largest demonstration of MUM-T interoperability ever attempted (Shelton, 2011). It showcased new technologies that demonstrated the capability of providing interoperability between manned and unmanned assets at a higher technology readiness level (TRL) than ever before. These technologies, ranging from small soldier-portable systems such as the One System Remote Video

Terminal (OSRVT) to major upgrades to the Apache and Kiowa Warrior helicopter platforms, were the final proofs of the concept prior to the capabilities being fielded to live aircraft.

Present: Current MUM-T Capabilities

Although MUM-T capabilities currently exist in portable units like the OSRVT, which will soon be onboard Army utility and cargo aircraft, the most advanced MUM-T functionality currently fielded resides in the CPG station of the AH-64E model Apache helicopter. As such, this system will be the focus of discussion here.

Level of Interoperability

The AH-64E is the first fielded aircraft to provide manned platform crew members with LOI 3 and 4 capability, allowing them to not only view live imagery collected from the UAS sensor, but also take direct control of the sensor and even the UAS aircraft itself if desired. This capability greatly enhances the speed of MUM-T operations by avoiding the need for the traditional “talk on” process, wherein the manned aviator must verbally describe the desired target to the UAS operators in the ground control station. This can be a lengthy and complicated process, requiring a high degree of understanding of the local terrain from both parties. With LOI 3, the CPG can instead take control of the sensor himself and quickly orient it exactly where he wants. At LOI 4, this concept is extended to include the ability to control the position of the UAS aircraft itself, which is particularly useful if the CPG requires a view of a target from a specific vantage point, or needs to ensure that the UAS is in a safe position during a weapons engagement.

System Controls and Displays

One of the primary goals of the Warfighter’s Associate system, originally developed under the AMUST-D program, was to utilize existing controls and displays already onboard the aircraft for MUM-T operations. As the Warfighter’s Associate system gradually evolved into the AH-64D Block III upgrade, and subsequently the AH-64E model, this design philosophy maintained. In fact, the system allows the CPG to control not only his own aircraft’s sensor and weapons systems, but also take up to LOI 4 control of a single UAS, with only one additional switch: a mode selector which alternates the function of the existing Target Acquisition and Designation Sights (TADS) Electronic Display and Control (TEDAC) system between ownship equipment and UAS equipment (Figure 1). This interface design not only provides the most efficient use of size, weight, and power limitations (which are very restricted on attack helicopters), but also minimizes the training requirements and workload imposed on the operator through the use of a new interface. The CPG’s TEDAC system provide standard controls for UAS teleoperation, such as manipulating the pan/tilt/zoom of the sensor payload, alternating between a variety of UAS sensors, and activating the laser designator. In addition to these standard control methods, the system also provides two unique control methods that are significant workload reducers for MUM-T operations.

Figure 1. TEDAC system from the Apache helicopter, used to control both helicopter and UAS sensors.

The first unique mode is the *sensor guide mode*, which is sometimes informally referred to as LOI 3.5, because it provides the operator with complete control over the sensor (LOI 3) with partial authority over the vehicle's flight path. However, rather than explicitly commanding a specific loiter point or route for the UAS to follow, the aircraft will autonomously generate its own flight path to provide the optimal viewing angle of the ground region currently in view of the sensor (typically a 45° downward angle). This method of control allows the operator to only focus his attention on the task that is important to him, viewing a particular region of the ground, without the additional workload associated with managing the aircraft itself.

Another method used to reduce workload is the *sensor slave* functionality. This function allows the operator to instantly orient the UAS sensor to image the same geographic position on the ground that is currently viewed by the Apache's own sensor (or vice versa, slaving the Apache sensor to the UAS sensor position). This technique simplifies the common task of coordinating target locations between the manned and unmanned systems, allowing all team members to more quickly and accurately establish a common operator picture.

Future: Ongoing MUM-T Research Efforts

Development of Tactics, Techniques, and Procedures (TTPs)

The most pressing current need for MUM-T development is the formalization of doctrine. Despite the capability being fielded for several years, technological development has outpaced the tactical development to the extent that formalized doctrine prescribing proper tactics, techniques, and procedures (TTPs) to be used for MUM-T missions has yet to be established. This is an uncommon circumstance for the Army, as new technological capabilities are typically developed to overcome an established capability gap, allowing for the TTPs associated with the technology to be well understood prior to fielding. MUM-T has evolved in a unique fashion, wherein the capability was recognized to provide a benefit to the warfighter, but wasn't developed as a deliberate solution to a specific problem. As a result, the capability has been fielded without explicit instruction regarding its associated TTPs, leaving the decision of how to tactically implement the capability to the warfighter.

Although this approach to implementation is uncommon, it seems to have yielded positive results. The users, unconstrained by official doctrine, have been free to test the capability across a variety of situations to establish how it can be used most effectively. The results of these fielded trials are being fed up the chain to user representatives at the Training and Doctrine Command (TRADOC) Capability Management (TCM) offices to be incorporated into the formalized MUM-T doctrine currently under development, an effort led by the TCM for Reconnaissance and Attack as well as the TCM for UAS (POC: CPT Tom Kavanaugh, Thomas.P.Kavanaugh2.mil@mail.mil, 334-255-2108).

MUM-T 2030

As users are working to establish the ideal implementation of current MUM-T capabilities, they are also identifying limitations of the current systems that can be overcome through continued technological development. As with the TTP development, these requests for system modifications are also consolidated by the TCM offices. Of course, the users' desired capabilities will always exceed what can feasibly be delivered due to constrained budgets, time, and technological capabilities. Therefore, the challenge lies in the need to identify from the list of user requests those which are anticipated to provide the greatest benefit. Leading this effort is the TRADOC Analysis Center (TRAC), which is currently conducting complex cost-benefit analyses on a wide variety of desirable MUM-T capabilities that could conceivably be fielded by 2030 (POC: Iris Chavez, Iris.L.Chavez2.civ@mail.mil). Insight into the feasibility, impact, and anticipated cost of development is provided by the research and development community (primarily from the Aviation and Missile Research, Development, and Engineering Center, or AMRDEC) as well as the Program Management offices for UAS, Apache, and Sensors-Aerial Intelligence. The final report from this analysis, expected to release in the middle of 2016, will establish the framework for the research, development, and integration of new MUM-T capabilities targeted for 2030.

Supervisory Controller for Optimal Role Allocation for Cueing of Human Operators (SCORCH)

Although the specific technological improvements expected to have the greatest impact have yet to be established by the TRAC MUM-T 2030 study, the science and technology (S&T) community has already initiated efforts toward developing improved MUM-T capabilities. One such effort currently in progress is the SCORCH program, a collaborative effort between researchers from the AMRDEC Aeroflightdynamics Directorate (AFDD), United Technologies Research Center (UTRC), and the University of California, Santa Barbara (POC: Amit Surana, SuranaA@utrc.utc.com). The SCORCH program will develop and evaluate cognitive decision aiding tools and sensor tasking automation that will enable aviators to effectively command teams of up to three advanced UAS simultaneously up to LOI 4 in support of a variety of missions and roles. The research is focused on three areas identified through prior research efforts as critical for a single operator to manage multiple UAS in support of a common mission: the *pilot-vehicle interface*, a *sensor management aide*, and *attention allocation aide*.

The pilot-vehicle interface developed for the SCORCH program is representative of cockpit designs expected to be fielded in near-future Army helicopters. The interface follows guidance set forth in Army UAS Roadmap documents (Department of Defense, 2013) and also takes inspiration from modern commercial aviation cockpit design as well as previous experimental interfaces. Significant departures from current cockpit design include the use of multiple large (15”diagonal) high resolution full color displays with touchscreen capability, and a variation on the current Apache TEDAC hand controller which features its own full color touchscreen display and modified button configuration similar to that found on modern video game controllers (Figure 2). The use of touchscreens throughout is expected to reduce workload associated with initiating system functions, which, through traditional cockpit design, can require the operator to navigate through multiple levels of bezel button pages. Using touchscreens to initiate system functions, the interface can be designed to dynamically adapt to the current mission phase and provide the operator with convenient access to the functions most relevant to their current goals (Sarter, 2007). Of course, touchscreens interfaces have limitations as well, most notably a lack of tactile feedback which requires the operator to focus their visual attention to the interface when executing a function. For this reason it is important that the most frequently used functions continue to utilize traditional physical buttons and switches.

Figure 2. Pilot-vehicle interface developed for the SCORCH program.

The sensor management aide is the first of two independent autonomous support systems developed for evaluation in the SCORCH program. The sensor management aide aims to offload operator workload for lower level sensor control tasks, freeing mental resources to focus on higher level information processing and decision making. The system will consist of various intelligent search algorithms that can manage multiple UAS sensors to collectively search ground regions with optimal efficiency. These autonomous behaviors will free the operator from traditional sensor operations, allowing them to focus instead on processing the imagery collected by the sensors. Further, a robust automatic target recognition system allows the aide to further off-load the operator through assistance with the visual search task, leaving the operator free to focus on top-level mission management and decision making tasks.

The final SCORCH system component is the attention allocation aide, an adaptive CDAS with the goal of improving the operator’s visual search behavior. Development of this system will begin by establishing an algorithmic model of optimal human effectiveness when conducting a visual search with UAS sensors. This model will run in the background as operators conduct their MUM-T missions. Meanwhile, their visual attention will be monitored in real-time through an eyetracker system (a series of cameras that provide continuous measurement of the location of the user's visual focus). Continual comparison of the user's visual search behavior to the known optimal model will allow the system to make real-time recommendations to improve the efficiency of the operator's visual search. Through this method, the human operator and autonomous system can collaboratively conduct the visual search, with both human and system performing functions for which they are respectively best suited.

Synergistic Unmanned-Manned Intelligent Teaming (SUMIT)

The lessons learned from the SCORCH program will feed into the similar, but larger scale, SUMIT program (POC: Ray Higgins, Raymond.T.Higgins.civ@mail.mil). This effort, led by AATD in collaboration with AFDD, NASA Langley, and various industry and academic partners, will investigate a wide variety of pilot-vehicle interface and CDAS concepts to determine the systems best suited to support MUM-T operations on the Army's next-generation helicopters (Future Vertical Lift, or FVL). In addition to the best-performing system components from the SCORCH program, other industry- and government-developed technologies will be included in the evaluations. These technologies are expected to include voice-control systems, head/eye-tracking, head-up and head-mounted displays, touchscreen displays, and a suite of advanced autonomous support behaviors and CDAS capabilities. These technologies will be systematically evaluated to identify the most beneficial systems, which will be demonstrated in a planned live flight test at the conclusion of the program (expected roughly 2020).

Conclusion

As a result of the efforts of the research and development community, current MUM-T capabilities are already providing manned aviators with a diverse benefits, leading to improved situational awareness, survivability, and lethality. The lessons learned from the current fielded systems, as well as continued research and development, will provide future warfighters with even greater capabilities to better confront future threats. However, current systems have reached a level of complexity and sophistication such that continued advancement is only possible through the coordinated efforts of a diverse collection of research and development professionals working together toward a unified goal.

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