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# Extending the Reach of the Warfighter through Robotics: Autonomous Execution of a Tactical Resupply and Surveillance Mission

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## ABSTRACT

*Continued proliferation of terrorist activities throughout the globe, as well as other low to medium intensity conflicts, present unique challenges to the US Army, Marines, and Special Operating Forces, especially in times of reduced manpower and operating budgets. Soldiers are called upon to do increasingly complex, dangerous, and lengthy missions with reduced troop strength and in more remote and austere conditions often far from traditional means of ready resupply. The need for organic persistent surveillance of potentially hostile areas is also of significant value to improve situational awareness and preserve the tactical advantage. The high risk nature of these missions can be significantly mitigated and operational tempo (OPTEMPO) improved by using unmanned solutions. Previously proposed solutions attempting to make use of Unmanned Ground Vehicles (UGVs) or Unmanned Air Vehicles (UAVs) alone experienced multiple problems. One solution that addresses these issues is to team a relatively large and capable autonomous UGV with a similarly capable UAV, each with significant cargo capacity and Beyond Line of Sight (BLOS) communications capabilities, and the UGV also having good surveillance sensor capabilities. The Lockheed Martin Squad Mission Support System (SMSS™) UGV equipped with a Gyrocam Tactical Surveillance Sensor (TSS) was flown by sling load into the "hostile" area using a Lockheed Martin K-MAX® rotorcraft, and a tactical resupply and surveillance mission was conducted in autonomous and tele-operated modes. Both the SMSS and K-MAX were equipped with mobile Satellite Communications (SATCOM) systems as well as local LOS communications systems. A remote Operations Center was equipped with SATCOM base stations to control and monitor the UxV activities. The program demonstrated that teamed autonomous UAV and UGV systems, properly equipped, provide improved stand-off, rapid tactical resupply, increased force protection, and increased time on site without exposing Soldiers. The key technical objectives of the project were demonstrating the ability of an unmanned rotorcraft to fly, deliver, and autonomously release a large UGV, and demonstrating the ability of the UAV/UGV team to remotely execute an end-to-end mission with limited user intervention. The project demonstrated for the first time that any ground-based remote sensing or resupply mission can be performed by UGVs and UAVs at any distance from the operator.*

## INTRODUCTION

In late summer 2012, after a period of ongoing discussions about the potential utility of unmanned systems, TARDEC and Lockheed Martin reached an informal cooperative agreement to attempt to jointly demonstrate Beyond Line of Sight (BLOS) Command and Control (C2) of an Unmanned Ground Vehicle (UGV) from a Remote Operations Center (ROC) a significant distance from the Area of Operations (AO). The goal of the exercise was to demonstrate to the greater Department of Defense (DoD) that (a) while not perfect, UGV technology had reached a state of maturity that allowed UGVs to be tactically useful for a number of different missions, (b) C2 of a UGV could be successfully conducted from useful distances well beyond typical Line of Sight (LOS) ranges employed with most UGVs, and (c) C2 latency could be reduced to a sufficiently short time to make remote operations both reasonably effective and safe. The mission jointly chosen for demonstration was a Reconnaissance, Surveillance, and Target

Acquisition (RSTA) mission, and Camp Grayling, Michigan was chosen as the AO for the experiment. TARDEC's facility at Warren, Michigan, some 200 miles away from Camp Grayling, was chosen as the location for the ROC. Both TARDEC and Lockheed Martin wanted the demonstration performed expeditiously, so late November 2012 was set as the target date. The effort became known as the Camp Grayling Challenge (CGC).

Lockheed Martin based their solution on an SMSS UGV with Satellite Communications (SATCOM) On The Move (SOTM) and a mast-mounted Gyrocam Tactical Surveillance Sensor (TSS) 9M. The SMSS is a rugged, heavy-duty UGV about the size of a compact car. Its diesel powered, 6-wheel-drive, skid steer configuration makes it extremely terrain capable, able to carry large loads, and able to provide the electrical power necessary to support the Mission Equipment Packages (MEP). Further, the system's combination of autonomous and tele-operation capabilities made it ideal for the intended demonstration. The SMSS CGC configuration is shown in Figure 1.

**Figure 1**: SMSS at Camp Grayling with General Dynamics SATCOM Technologies (GDST) SOTM unit mounted near the front top of vehicle and mast-mounted Gyrocam 9M on the rear of vehicle.

The CGC successfully demonstrated all objectives, and this ground-breaking experiment laid the foundation for an ongoing TARDEC initiative, Extending the Reach of the Warfighter through Robotics (ERWR). To further extend the reach, a method of delivering the UGV to the AO, other than driving, which has both practical and tactical limitations, was needed. Using an Unmanned Aerial Vehicle (UAV) to deliver the UGV to a remote location was a natural extension of the technology and would provide yet another leap in capability for the warfighter. In 2013, TARDEC issued a competitive solicitation through the Robotics Technology Consortium (RTC), and Lockheed Martin competed and won one of two contracts. Lockheed Martin's proposed solution was to team a K-MAX unmanned rotorcraft (Figure 2) with the SMSS UGV to provide the necessary significant advancement in capability and reach. Like the SMSS, K-MAX has the capability of BLOS C2 and has both autonomous and tele-operation modes. A combined mission of tactical resupply and RSTA was chosen for the demonstration, and the AO would be Ft. Benning, Georgia.

**Figure 2:** The Lockheed Martin/Kaman Aerospace K-MAX unmanned rotorcraft.

## WEIGHT CONSIDERATIONS

One significant challenge was system weight. The K-MAX load carrying capability and the weight of the SMSS ERWR configuration had to be matched. Using autonomous robotic control of the K-MAX, and considering the probable high ambient temperature at Ft. Benning in August, resulted in the K-MAX maximum lift load threshold requirement of 4,500 lbs, including rigging, for this experiment. A margin of 200 lbs was established as a desired objective, so the weight of all carried equipment was to be approximately 4,300 lbs. A standard configuration SMSS equipped with mission essentials for the squad lighten the load mission, weighs approximately 4,300 lbs. However, adding the weight of the SOTM and masted Gyrocam mission equipment, plus supporting electronics and cabling, plus the sling rigging, generated a need to reduce the weight of the ERWR configuration by almost 900 lbs to meet the objective. The SMSS was put on a severe "diet" resulting in removal of all non-essential squad mission equipment, weight-reducing changes to internal subsystems, use of lightweight tires and wheels, and weight reductions in the rigging system. The end result was a total cargo weight for the K-

MAX of 4,350 lbs, which exceeded the threshold and nearly achieved the objective.

## RADIO FREQUENCY CONSIDERATIONS

Both the SMSS and the K-MAX were equipped with multiple radio systems. SMSS and K-MAX each have both LOS and BLOS radios. Additionally, the SMSS has an independent Emergency Stop (E-Stop) radio. Caution had to be exercised to ensure that the various radio systems did not interfere with each other, and all of the radio systems required both Federal Communications Commission (FCC) licensing or Special Temporary Authorizations (STA) as well as frequency authorization and coordination with the Ft. Benning range complex and Lawson Army Air Field (LAAF). Because the E-Stop is fail safe and shuts off the SMSS when communications to the E-Stop are lost, two E-Stop units were required for the SMSS; one in the cockpit of the K-MAX, and one with the safety chase crew on the ground. Because the SMSS systems were to be fully functional in flight, and because there could be no personnel around the K-MAX when it landed and released the SMSS autonomously, both E-Stops were needed to prevent loss of communications during various phases of operations. Further, both the SMSS and the K-MAX could potentially generate various forms of Electro-Magnetic Interference (EMI) from emanations of onboard systems, and in the case of the K-MAX, from the rotor blades. The SMSS SOTM unit was to be fully operational while in carriage under the K-MAX so that C2 of the SMSS was maintained throughout all aspects of the mission. This also allowed the Gyrocam sensor onboard the SMSS to be used to relay real-time video of the ground conditions to the ROC before the K-MAX landed the SMSS and released it. In a real operation in a hazardous or potentially hostile environment, this is a very desirable capability. Engineering review of all systems indicated that interferences would be expected to be minimal, if any, but the final proof would come from testing. As a part of the complete system integration testing, all radio systems were turned on simultaneously as they would be in the actual exercise, and a test lift and flight of the SMSS under the K-MAX was made. Testing indicated all systems were compatible, and EMI was not an issue, confirming the engineering review.

## SIMULTANEOUS REMOTE AND LOCAL OPERATIONS

The SMSS and the K-MAX have LOS radio systems as back-ups to the BLOS capability. For this exercise, the BLOS capability for both systems, and the LOS capability for the K-MAX were combined into a single ROC. AN SMSS operator and a K-MAX operator sat side by side to command the phases of the mission and monitor feedback. Both UxVs provided video feedback across their BLOS links that was available to the operators at their computers, and viewable on large screen monitors for the audience of observers for the experiment.

The SMSS lightweight, wearable LOS and E-Stop systems remained with a safety chase crew on the ground. The chase crew maintained a watchful eye on the progress of the mission from a distance, and their purpose was only to provide safety or to assist the SMSS vehicle in the unlikely event it encountered an obstacle or issue t could not negotiate on its own. An interesting and useful aspect of having both simultaneous LOS and BLOS communications is that a commander on the ground, receiving the tactical resupply load and using the SMSS for RSTA, could also see the video feedback provided to the ROC. If necessary, C2 can be seamlessly transferred back and forth between the local ground commander and the ROC, giving the ground commander powerful tools for RSTA and defense at his disposal while allowing monitoring for situational awareness and possible sending of reinforcements from afar. The local communications to the SMSS support both C2 and voice communications in a common radio. Further, the feedback can be routed across the Internet to multiple simultaneous secure viewing locations, and ground personnel around the SMSS could use wireless devices to access the Internet through the SOTM as a gateway and WiFi hub.

## SLING RIGGING

The sling rigging was critical to the success of the program. The sling rigging must be safe and secure, but also lightweight. The rigging also needed to “self-stow” onto the SMSS when released. One of the goals of the program was to affect an autonomous release of the SMSS from the K-MAX; that is, no personnel were required on the ground to detach the SMSS and start the mission.

Lockheed Martin chose a purpose-built web style 4-point military sling, produced for another customer, but available as surplus. The sling was prof loaded to ensure integrity and safety. The sling connected to the four corner lift lugs on the SMSS by chains and clevis loops/pins, and the web straps converged to a common point above the SMSS for connection to the cargo hook from the K-MAX. A bridal of industrial strength “bungee cords” was engineered to pull the four legs of the sling webbing toward a central location on the SMSS when released. The bridal was designed to interface with the sling in such a way that the structural integrity of the sling was not compromised by the attachment points. Figure 3 shows testing of the bridal and sling design suspended from an overhead crane in the laboratory prior to system integration testing with the K-MAX.

The cargo line and hook from the K-MAX utilize a load cell to determine how much weight is on the line. When the SMSS was set on the ground, and significant fraction of the vehicle's weight came off the line, a signal from the load cell was used to automatically open the cargo hook, releasing the sling. Appropriate safety interlocks are used to prevent an accidental release from bouncing while in sling carriage.

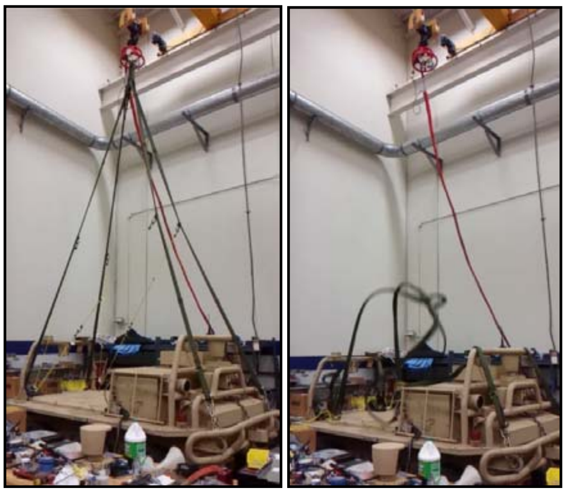

**Figure 3**: Self-stowing rigging testing in the laboratory.

## DEVELOPMENT TESTING AND ROUTE SELECTION

Besides laboratory and local Lockheed Martin robotics test center testing, there were two significant development test events. The first was a "terrain walk/drive" at Ft. Benning. And SMSS equipped with SOTM unit was brought o Ft. Benning, and the notional routes for the final mission demonstration were walked and driven by the customer representatives, Lockheed Martin engineers, and the Ft. Benning Maneuver Battle Laboratory project personnel. During this activity, the SOTM unit was used to monitor connectivity to the satellite, and the route was planned to reduce to an acceptable level communications drop outs caused by terrain and vegetation masking. Second, the route was refined to something that would be physically negotiable by the SMSS. Third, the Landing Zones (LZ) for the K-MAX for both initial rigging and take-off for the start of the mission as well as the LZ for delivery and release of the SMSS were defined in consideration of safe ingress and egress of a helicopter. Additionally, the flight path for the K-MAX was established to ensure it stayed in controlled airspace and over range areas which could be secured from personnel or vehicular access during the experiment for safety purposes. Safe areas for reviewers and for the ROC were also established.

The second major test activity was the system integration testing conducted by Lockheed Martin at the Kaman Aerospace's facility. In this test, all aspects of the actual mission were exercised. These included rigging, lift, carriage, flight dynamics and aerodynamic response of the SMSS, landing, automated release, Gyrocam function, joint ground station function (SMSS and K-MAX), checks for radio frequency (RF) interference, and carriage of an SMSS emergency stop radio (E-Stop) in the K-MAX cockpit. All test objectives were successfully achieved, clearing the way for the full capability demonstration at Ft. Benning. Photos of events during integration testing are shown in Figures 4, 5, 6, and 7.

**Figure 4**: K-MAX starting lift with SMSS in sling rigging.

**Figure 5**: SMSS fully slung in lift by K-MAX.

**Figure 6**:  SMSS in flight under K-MAX at 50 kts showing stable aerodynamics.

**Figure 7**:  Close-up of SMSS in flight showing rigging system.

## FINAL DEMOSNTRATION SCENARIO

The final demonstration scenario at Ft. Benning, including both the K_MAX flight route and the SMSS ground route, is shown in Figure 8.

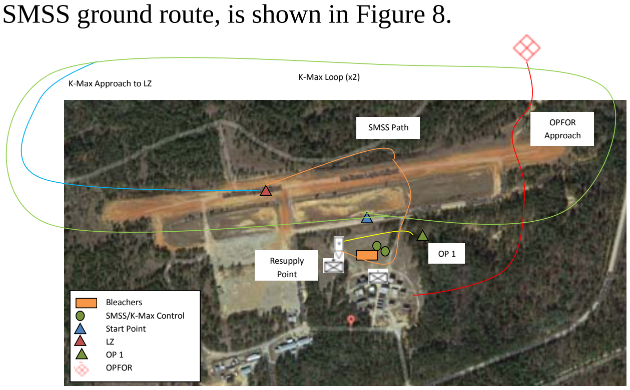


**Figure 8**:  Mission routes at Ft. Benning.

The mission scenario proceeded as follows.  A K-Max helicopter received its mission from the command center.  It launches with an SMSS in sling load and moves to LZ Fire to drop off the unmanned ground vehicle.  The K-Max made two loops to simulate travel time to the LZ.  While en-route, the Gyrocam sensor on the SMSS was activated, allowing operators to observe the conditions on the ground prior to landing.  The SMSS continued the mission by moving autonomously to the resupply point that was secured by a squad of Soldiers.  The SMSS was remotely released from the K-MAX, and received an autonomous mission using selected waypoints from the operators.  The SMSS then maneuvered autonomously across the terrain, and proceeded to the resupply point.  Upon arrival, one team moved forward and off-loaded the SMSS.  The squad leader let the control team know that the mission was complete.  The squad continued its tasks.  The SMSS was re-tasked to complete a reconnaissance mission in support of the Company defense.  The SMSS received a new mission from the operator, and travelled to OP 1.  The SMSS conducted surveillance of an area from OP 1.  The control team observed information and alerted the commander of the unit defending the village.  The commander, through future capabilities may be able to tap directly into sensor feeds from the SMSS.  The commander confirmed the threat and conducted a call for fire, using coordinates provided by the Gyrocam, that destroyed the enemy.

## SUMMARY

The program demonstrated that teamed autonomous UAV and UGV systems, properly equipped, provide improved stand-off, rapid tactical resupply, increased force protection, and increased time on site without exposing Soldiers. The key technical objectives of the project were demonstrating the ability of an unmanned rotorcraft to fly, deliver, and autonomously release a large UGV, and demonstrating the ability of the UAV/UGV team to remotely execute an end-to-end mission with limited user intervention.  The project demonstrated for the first time that any ground-based remote sensing or resupply mission, and perhaps other missions requiring manipulation of the environment, can be performed by UGVs and UAVs at any distance from the operator.  The benefit to the warfighter includes significantly reducing the risk and exposure of Soldiers; extending onsite dwell time, range of operations, and capabilities; and reducing reporting times and improving situational awareness at the site.  The outcome has proven the Department of Defense (DoD) has the ability to extend the Warfighter's reach to execute missions such as tactical resupply; Chemical, Biological, Radiological, and Nuclear (CBRN) sensing/monitoring; and Reconnaissance, Surveillance and Target Acquisition (RSTA) missions by using a combination of BLOS and local remote control and autonomous capabilities. The project has enabled the requirements community to inform the requirements for UGVs and UAVs to be implemented in the future, and the project reduced the development risk for any fieldable UGV or UAV to be used in the resupply or RSTA missions.