Automated Launch, Landing and Refueling Technologies for Increased UGV-UAV Effectiveness

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Abstract – *This paper describes the latest efforts to develop an Automated UAV Mission System (AUMS) for small Vertical Takeoff and Landing (VTOL) unmanned air vehicles (UAVs). This system is intended to provide forward-refueling capabilities by utilizing a host unmanned ground vehicle (UGV) to serve as a launch/landing platform and service station. Teaming small UAVs with large UGVs can decrease risk to personnel and expand mission capabilities and effectiveness.*

There are several technical challenges that are being addressed by these development efforts. One of these is the development and integration of a precision landing system whose size allows it to be mounted on a small VTOL UAV while providing landing accuracy of 10 centimeters or less. Another challenge is the design of a UGV-transportable, expandable, self-centering landing pad which also contains hardware and safety devices for automatically refueling the UAV. A third challenge is to make the design of the AUMS flexible enough that it can accommodate different types of VTOL UAVs including the iSTAR and small helicopter UAVs.

In specific application areas like chemical/nuclear waste contamination, the UAV can continue to provide surveillance and visual data for longer periods of time while using the UGV refueling station instead of having to return to base for fueling and subsequent decontamination after only a short time. AUMS can also be used to provide routine security and monitoring and increased response times by providing a highly mobile UAV asset that can be quickly tasked to investigate a developing area of concern.

AUMS is funded by the Joint Robotics Program and is part of a Joint effort with the United States Air Force Research Laboratory and the Army Missile Research Development and Engineering Command. The Joint effort will develop and demonstrate UGV-UAV teaming concepts and work with the warfighter to ensure that future technical development is focused on the developing operational requirements.

I. INTRODUCTION

Small VTOL UAVs can be valuable tools for both the warfighter and the first responder to provide assessment of an operational situation. They can fly at a wide variety of altitudes, hover over specific areas for a steady view of an unfolding situation, and do not need a bulky launcher or a long runway.

The United States Army has characterized these UAVs as Class II (Fig. 1) in the Future Combat Systems (FCS) program. FCS is the Army's major effort to "fundamentally transform into a faster, more agile force with superior situational awareness and power projection capability." These UAVs will provide reconnaissance, security/early warning, target acquisition and designation to company commanders. They will be launched from vehicles and provide Line-of-Sight (LOS) enhanced digital imagery. The UAVs will be capable of teaming with selected ground and air platforms, and providing limited communications relay. The Class II UAV will be able to be carried by two soldiers. [1]

Fig. 1. FCS Class II UAVs

This type of UAV has several characteristics that can limit their adoption by a wide range of users. Their payload capacity is limited which results in an operational tradeoff between desired payload capabilities and mission duration. These UAVs may spend little time in their area of operation, returning frequently for refueling. This can reduce the effectiveness of the mission and place support personnel closer to hazardous conditions.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2006**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Automated Launch, Landing and Refueling Technologies for Increased UGV-UAV Effectiveness**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Space and Naval Warfare Systems Center, San Diego 5360 Hull Street San Diego, CA 92152**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

In order to increase the effectiveness and meet the requirements for future military operations, Space and Naval Warfare Systems Center San Diego (SSC San Diego) has developed the Autonomous UAV Mission System (AUMS). This system utilizes technologies developed at SSC San Diego and other research institutions to autonomously launch, land, and refuel Class II VTOL UAVs. AUMS is designed to be located on a movable platform such as a manned or unmanned ground vehicle (UGV) which can be transported closer to the area of operation. This reduces the reliance on and risk to support personnel while increasing the utility and impact.

This paper describes the latest achievements in the three phases of AUMS development and some of the military program and first responder situations that could benefit from this system.

II. AUMS

The AUMS technical development is divided into three major phases: Launch, Landing, and Refueling. Each phase utilizes a common set of technologies and builds on previous technical accomplishments.

AUMS was designed around the Allied Aerospace iSTAR platform (Fig. 2). The iSTAR is a FCS Class II vehicle and has a Lift Augmented Ducted Fan (LADF) design that can be used for vertical takeoff and landing as well as high-speed horizontal flight. Payloads may be carried in the nose, duct, or tail section of the iSTAR. [2]

Future AUMS development will utilize other FCS Class II VTOL UAVs. SSC San Diego is using an autonomous helicopter (Fig. 3), developed by Rotomotion, LLC. as a technology development surrogate for the iSTAR platform by incorporating landing gear similar to the one found on the iSTAR platform. This landing gear is also equipped with the AUMS refueling coupler for testing and demonstration purposes. The helicopter is used to test cameras and other payloads as well as AUMS command and control software. [3]

Fig. 2. Allied Aerospace 29 inch iSTAR UAV

Fig. 3. Rotomotion Helicopter

III. LAUNCH

Initial development of the AUMS project began at SSC San Diego with the fabrication of a basic fiberglass prototype launch fixture. This was mounted on a Mobile Detection Assessment Response System (MDARS) UGV and tested with the iSTAR. MDARS provides intruder detection and assessment, barrier (lock status) assessment, and inventory accountability at military depots. After initial testing, it was determined that a latch to hold down the middle of the iSTAR until launch would greatly improve the ability to safely operate from the UGV. The first latch was a simple hook controlled by a solenoid. [4]

In 2003, a second AUMS prototype was developed and demonstrated with the iSTAR. This prototype incorporated a self-centering mechanical device (Fig. 4) that coupled with the UAV for refueling and launching capabilities. After the UAV lands, a linear actuator raises the coupling system until the coupler, integrated on the UAV, and the center mechanism mate. This activity is assisted by the passive centering cone, which is free to slide up to an inch in any direction in the horizontal plane.

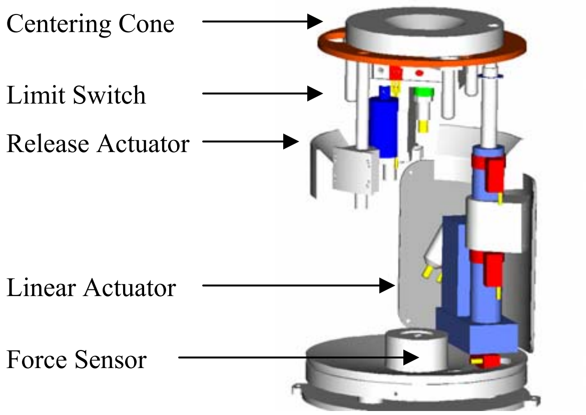

Fig. 4: Refueling/Release Center Mechanism

After a successful coupling, the actuator is lowered to apply tension to the UAV, seating the UAV firmly on the landing pad. Tension forces are calibrated by the force sensor and redundantly confirm a positive coupling. The procedure for launching the UAV is to allow the UAV to go to full thrust while it is still latched. The thrust is measured using a force sensor that is coupled to the capture/release mechanism.

The reason for restraining the UAV in this fashion is twofold: the UAV quickly gains altitude and gets away from the area containing antennas and sensors, and the UAV avoids the regime of near-neutral buoyancy that occurs when it is loaded with fuel and has a low thrust-to-weight ratio. When the UAV reaches its maximum thrust a release solenoid activates the outer collar of the fuel coupler and releases the UAV. The design of the system accommodates any radial orientation of the UAV. The UAV can be rotated in any direction in the vertical axis and the center mechanism will still function as designed.

The second prototype also utilized moveable arms that could be configured like a launch tube or expanded to form a landing funnel. The arms were found to interfere with the UAV's ability to land safely.

After additional testing, a third prototype, vented for increased airflow and without arms, was developed in 2004 (Fig. 4). This was used for testing and development of the refueling system.

Fig. 5. Third prototype of AUMS.

Finally, a fourth prototype was developed in late 2005 to enable the landing UAV to self-center around the refueling system hookup. The launch technology remained the same as in the previous prototype.

IV. LANDING

The landing development process has two major subcomponents. The first is the precision landing capability of the UAV. The second is the automated capturing and centering mechanism that moves the UAV to the proper position for refueling and relaunch.

IV.A. Precision Landing

The ability to autonomously and precisely land a VTOL UAV on a UGV-mounted landing pad requires very accurate positioning technology. The actual landing area will vary depending on the size of the UGV, but the landing pad for the MDARS UGV can be no longer than 48 inches without interfering with communications and GPS antennas.

The UAV needs to be capable of very precise, three-dimensional navigation in order to ensure accurate repeatable landings with extremely low position error relative to the fixture. Furthermore, this highly accurate relative position must be updated at very fast rates to account for UAV dynamics as well as environmental factors affecting the UAV approach and landing. [5]

Various technologies have been examined by SSC San Diego for use in developing this capability. These technologies include a highly accurate, relative positioning GPS technology using low-cost receivers from Geodetics, Inc; a vision-based positioning system that relies on infrared (IR) beacons arranged in an asymmetrical pattern on the UGV from Carnegie Mellon University; and a small, lightweight, vision-based target tracking and landing algorithm from University of Southern California. [6, 7, 8, 9]

SSC San Diego has also looked at government-developed systems including the Joint Precision Landing System (JPALS). The goal of this Joint system is to create the military equivalent of the Local Area Augmentation System (LAAS) currently used for civilian aircraft. JPALS utilizes differential GPS and ship-based GPS signals to provide highly accurate aircraft landing capabilities. This system is currently larger and more expensive than what is needed for AUMS. It also requires a GPS correction signal which may not be available in a dynamically changing ground based environment. [10]

There are several challenges associated with integrating a precision landing capability with AUMS. The first major challenge is the lack of commercial-off-the-shelf solutions that meet the weight and size requirements. The second major challenge is that the solutions or technologies that could be utilized require significant investments of time and resources to mature them into easily reproducible, modular deliverables that are easy to integrate onto the UAV. The third challenge is that while there are a variety of UAVs and missions that could utilize AUMS, there are also a wide variety of potential landing requirements. This makes it difficult to determine the level of precision that is necessary. SSC San Diego will continue to work with technology developers and users to identify and test various technology approaches that can be combined with project resources to achieve a practical solution.

IV.B. Capture

Even with precision landing technology, the UAV may not be close enough to the refueling nozzle after landing. There needs to be a mechanism to position the UAV over the refueling nozzle.

The current design (Fig. 6) utilizes four levers that actuate independently to move the UAV into the proper position. These levers have sensors to provide feedback on the movement of the UAV and to ensure correct positioning. In the extended position they are located below the landing area, which will ensure that they do not interfere during the landing process.

This design was completed in November 2005 and will be tested over the next several months to determine whether further modifications need to be made.

Fig. 6. AUMS with UAV-centering levers.

V. REFUELING

Automated refueling allows the base of operations to be moved into a hostile or contaminated environment while reducing impact on human personnel. The primary obstacle to the realization of an automated refueling system is the assurance of operational safety and consistency. The AUMS design addresses the detection of fuel leaks and false latches and the prevention of fires. AUMS also provides automatic fire extinguishing capabilities, and forces the system to default into a safe, de-energized state should any of these problems arise.

AUMS utilizes a fault tolerant system of sensors that return latch and refueling status messages to the command and control software. This system detects and reacts to UAV coupling and positioning errors that could result in an unsafe environment for refueling.

Currently there are no turnkey solutions for automated refueling of small UAVs. SSC San Diego engineers examined commercial-off-the-shelf (COTS) products such as intrinsically safe zener barriers used to electrically separate fuel components from electronics. When intrinsically safe components that met overall AUMS requirements were not available, additional hardware was put in place to detect any potentially dangerous situations.

Failsafe modes were designed by allowing these independent, often redundant sensor arrays to individually put the system into a safe state. To further this effect, all flow control solenoids were chosen to have a normally closed state of operation such that in the case of complete power failure, the fuel lines would become sealed.

The software was also designed to default to safe values. The sensors of the system are queried before any action with potential hazards is allowed to occur. The approach taken for the software design was to write modular functions and to exercise strict control over which functions could cause the hardware to be activated.

In order to demonstrate a complete UGV-UAV solution for refueling, the AUMS is designed to operate without knowledge of the current fuel level of the incoming UAV. Many, if not all, small UAVs do not have fuel gauges, operating instead based upon a set value of average flight time. As a result, the first refueling step is to de-fuel the UAV before refueling. This not only allows precise calculation of fuel needed to fill the UAV, more importantly it allows for partial refueling to reduce fuel weight and therefore increase payload capacity. By incorporating a bidirectional pump, fuel is drained completely from the UAV and then filled to a desired level by passing the pump through a flow meter integrated with the electronics system.

The refueling system including the electronics, fuel container, pump and filter are housed in a large Pelican case. The Pelican case is attached to a payload mounting frame used for multiple payloads that are carried by the MDARS platform (Figs. 7 and 8). On the rear of the MDARS platform is a frame with keyholes. All compatible payloads have brackets with circular keys attached. When mounted, the payloads are constrained from motion in all directions. Support legs can be attached to the braces for stand-alone applications. The Pelican case and connectors are weather-proof up to a light rain and blowing dust.

Fig. 7. AUMS on MDARS with iSTAR

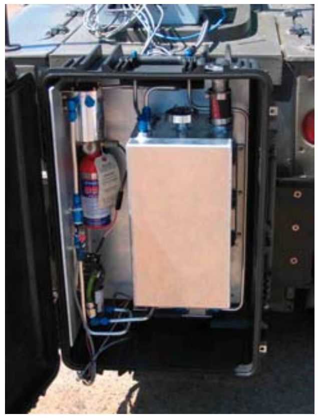

Fig. 8. AUMS Refueling Case

The electronics in the system can be divided into sensors and actuators on the UAV and on the refueling system. When the UAV has landed on the fixture the two systems are connected via a fuel safe coupler that is used for securing the UAV and in the fuel line.

On the UAV, sensors are used for overflow detection at the vent on the fuel tank and a flow rate sensor. Most UAVs being used today do not have a fuel level sensor and the iSTAR and Rotomotion are no exceptions, however there are future plans to integrate a fuel level sensor into the Rotomotion. A flow rate sensor, reversible pump, capacitive fuel level sensor, and an optical overflow sensor in the Pelican case were added to the AUMS refueling system.

In the event of a fire, there are fire suppression systems in the Pelican case and on the UAV landing platform. The case and platform are lined with a tube filled with pressurized fire retardant. In the event of a fire, this tube will melt where the fire is occurring and locally distribute a fire retardant. Upon depressurization of the tube, a normally closed switch on the extinguisher will open, signaling the micro controller to enter a safe state.

To increase the safety of the system, all the components that cause fuel to flow and all the components that cause the UAV to be released were chosen and integrated so that their non-energized default state is closed. This was done to prevent a loss of power, a computer glitch or some unforeseen condition from creating a situation that could harm people or equipment. Normally non-energized components also save power since they spend more time at rest than otherwise. In addition to power savings and a safe default state, this design reduces the possibility of fire due to the elimination of the large quantity of heat radiating through the system that can be generated by a solenoid that has been left energized for an extended amount of time.

Inside the Pelican case there is a false bottom with a slope towards one corner. The optical overflow sensor is mounted in that corner so that if there is a fuel leak inside the case it will change the amount of light reflecting in the optical capsule and send a detection signal back to the micro controller as quickly as possible. However, the most likely place for fuel to leak is at the boundary where the couplers on the refueling system and the UAV mate. The overflow sensor would not detect a fuel leak in this part of the system so the flow rate sensors on the AUMS and the UAV are constantly compared to one another to determine if a leak has occurred at this boundary.

The refueling system prototype was completed in August 2005 by SSC San Diego engineers and Office of Naval Research interns from University of California, San Diego.

VI. COMMAND AND CONTROL

AUMS utilizes the Multi-Robot Operator Control Unit (MOCU) software developed by SSC San Diego. This software provides the user the ability to control multiple unmanned systems at the same time. MOCU provides the operator the ability to send the UAV on waypoints and to receive back video and position information. MOCU also monitors the landing/refueling mechanism and gives the operator the ability to control the refueling process. [11]

MOCU is compliant with the Joint Architecture for Unmanned Systems (JAUS), which is a protocol that defines the interaction between different unmanned systems. JAUS enables the UGV and UAV to be controlled by MOCU at the same time, increasing the ability of these platforms to perform a collaborative mission. JAUS-compliant platforms from other organizations can also be controlled by MOCU, increasing its usefulness in developing unmanned collaborative behaviors. [12]

A MOCU experiment was conducted in December 2005 with an unmanned surface vehicle, an unmanned ground vehicle, and an unmanned air vehicle all controlled at the same time.

VII. COLLABORATIVE ENGAGEMENT

SSC San Diego is a member of the Collaborative Engagement Experiment (CEE) sponsored by the Office of the Secretary of Defense's Joint Robotics Program. CEE is a Joint effort, started in early 2005, to develop and demonstrate collaborative engagement systems. CEE members also include Air Force Research Laboratory (AFRL) at Tyndall Air Force Base, Army Missile Research Development and Engineering Command (AMRDEC) at Redstone Arsenal, and Soldier Battle Lab (SBL) at Fort Benning.

CEE is designed to provide the framework for developing and demonstrating collaborative behaviors for unmanned systems. CEE members meet regularly to discuss emerging issues including definitions of collaborative behaviors and barriers to implementation.

SSC San Diego supports the Joint effort by working with the other services to accomplish Joint goals including definition of operational need, development and integration of technology solutions, live and simulated experimentation, user involvement, and Joint technical solutions.

A Joint experiment to demonstrate target acquistion, tracking, and elimination by unmanned ground and aerial vehicles is planned for July of 2006, contigent on funding.

VIII. APPLICATIONS

The operational use of AUMS is indicated in several current programs including FCS and the Family of Integrated Rapid Response Equipment (FIRRE) program.

FIRRE is an advanced technology demonstration program intended to develop a family of affordable, scalable, modular, and logistically supportable unmanned systems to meet urgent operational force protection needs and requirements worldwide. The near-term goal is to provide the best available unmanned ground systems to the war fighter in Iraq and Afghanistan. The overarching long-term goal is to develop a fully-integrated, layered force protection system of systems for our forward deployed forces that is networked with the future force C4ISR systems architecture. The intent of the FIRRE program is to reduce manpower requirements, enhance force protection capabilities, and reduce casualties through the use of unmanned systems. FIRRE could utilize AUMS as one of several unmanned systems that would create a portable in-theater security system. [13]

AUMS is also indicated for first responder situations. It can be used for responding to a potential chemical or biological attack by providing eyes on the situation without exposing personnel to contamination. The automated refueling capability allows it to stay on station continuously without need for human intervention and possible contamination. A VTOL UAV can provide capabilities that a fixed wing UAV cannot. These include the ability to take off without a runway, the ability to hover over an area and provide continuous video of a specific location, the ability to change altitudes quickly to get different perspectives of the situation, and the ability to operate in between obstacles to provide a close-in view of the area.

IX. CONCLUSIONS

Class II VTOL UAVs provide value to the warfighter and first responder. Their operational flexibility and ability to hover make them a great tool for assessment and decision-making. However, their limited payload capabilities and flight durations reduces their effectiveness. AUMS is a system designed to increase the effectiveness of VTOL UAVs by mounting them on unmanned ground vehicles and automating the launch, landing and refueling process.

SSC San Diego has developed several prototype systems and conducted tests and experiments with VTOL UAV platforms. Future plans include analysis, development and integration of automated landing technologies, further integration of command and control capabilities using JAUS and MOCU interfaces, and participation in Joint UGV-UAV experiments.

ACKNOWLEDGMENTS

This work was supported by the Office of the Secretary of Defense under the direction of the Joint Robotics Program.

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