Precision Recovery Capability for Small UAS

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ABSTRACT

An Unmanned Aerial System (UAS) precision launch and recovery capability significantly improves the value of the platform for use in remote, hostile and undeveloped terrain as well as for offshore ship operations lacking improved landing surfaces for conventional landings. A net capture recovery system has been successfully developed by the U.S. Navy for the Silver Fox and Manta UASs.

This capability has been demonstrated for operation with a small net requiring an overall foot print of approximately 16 feet by 12 feet (4.8 meters x 3.7 meters). The capability has been demonstrated for both stationary and mobile ship based recoveries. The development efforts will be discussed with reference to specific missions and future U.S. Navy requirements.

BIOGRAPHY

Anthony Mulligan
Mr. Anthony Mulligan is a founder and CEO of Advanced Ceramics Research, Inc (ACR), which is a successful small business high technology defense contractor since 1989. He has served on the Defense Science Board, Manufacturing Technology Task Force, for the U.S. Department of Defense and also on the boards of Manufacturing Extension Partnership (MEP – a National Institute of Standards and Technology NIST), the Industrial Advisory Committee to the Aerospace and Mechanical Engineering Department of the University of Arizona and the College of Engineering and Mines. He holds a B.S. in Mechanical Engineering from the University of Arizona and he has 14 U.S. Patents.

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Andrew Osbrink is a program manager of UAV systems at ACR. He holds Bachelor of Science degrees in Aerospace Engineering and Mechanical Engineering from the University of Arizona. Andrew is currently managing the Coyote unmanned aircraft system (UAS) development program as well as a variety of other acquisition and engineering projects. Andrew's experience in the UAS field include managing a variety of programs, research engineering, performing missions as an operator for each of ACR's UAS programs, and the ACR technical lead for autopilot integration. He is the lead engineer working with NAVAIR to complete the certifications for all of ACR's UAS for deployment with the Navy. He has experience in aerodynamics, structural analysis, design of micro air vehicles, and aircraft stability and performance.

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Dr. Mark Patterson is a Materials Scientist by training and was educated in the UK and Canada (University of Exeter and Queens University respectively,) obtaining his PhD from the University of Cambridge in 1986. He is presently the Director of Research and Technology for Advanced Ceramics Research of Tucson, Arizona, USA where he oversees research efforts on the development of unmanned air vehicles and their associated sensors.

GLOSSARY

ACR	- Advanced Ceramics Research
AGL	- Above ground level
ANGLICO	- Air and Naval Gunfire Liaison Company (US Marine Corps)
COP	- Command Operation Post
DGPS	- Differential global positioning system
ETA	- Estimated time of arrival
EOD	-Explosive Ordnance Disposal
EODMU1	-Explosive Ordnance Disposal Mobile Unit One
GPS	- Global positioning system
IDF	- Indirect fire
INS	- Inertial navigation system
iGCS	- Integrated Ground Control System
JIEEDO	- Joint Improvised Explosive Device Defeat Organization
MCS	- Master control station
NAVAIR	- Naval Air Systems Command
NOAA	- National Oceanic and Atmospheric Administration
NSCT1	- Naval Special Clearance Team One
ONR	- Office of Naval Research
RC	- Remote control
RF	- Radio frequency
RHIB	- Rigid Hull Inflatable Boat
RIVRON	- Riverine Squadron
RPB	- Riverine Patrol Boat
RTK	- Real time kinematic
TF	- Task force
UAS	- Unmanned Air System
UAV	- Unmanned Air Vehicle
UN	- United Nations
US	- United States
3D	- Three dimensional

INTRODUCTION

The operation of the unmanned air vehicle (UAV) platform has been continuously developed to become better aligned to meet the user's requirements and to perform robustly in the defined environment. In the six years in which the Silver Fox UAV has been developed, there have been several focused improvements to the vehicles airframe, power supply, sensor suite and mode in which the vehicle is operated. The resulting vehicle is a reliable, man-portable platform that can provide time-critical information to an operator in a battlefield environment or survey regions of scientific interest.

Early versions of the Silver Fox unmanned air systems (UAS) that were operated in Operation Iraqi Freedom (OIF) used a pneumatic launcher that weighed 350 pounds (158.8 Kg), required additional electrical power, required 1-15 minutes to arm, and was not man portable. Use of rubber bungee chords was tried but suffered from life cycle issues and variability due to the environment in which they were operated. The present launcher is man portable, weighs less than 70 pounds (31.8 Kg), can mount on its own case or on any standard 50 caliber gun mount, it takes only minutes to set up, is manually charged, and exhibits very little environmental variability in its operation. The total time for launching the UAV is now between 5 and 10 minutes depending on the level of training. In addition, storage and transportation of the device takes place in standardized containers identical to those already used for the UAVs as shown in Figure 1. This metered change in the product marks a typical evolution for most emerging technologies and has taken place (and continues to do so) for all aspects of the vehicle where deficiencies are identified.

Figure 1. Silver Fox UAS consisting of three UAVs, launcher, ground control station (iGCS) – package fits in standard HUMVEE.

Recovery of aircraft in general has always been an area where there's considerable risk. With unmanned vehicles knowledge of the exact position of the UAV, the position of the ground and the rate at which their separation distance is changing is important. The first generation Silver Fox UAVs operated with landing wheels in 2002, but small changes in the ground conditions or the approach caused the vehicle to bounce and resulted in poor control. The belly landing approach that was adopted as the preferred recovery method led to a highly reliable recovery method that did not necessitate the need for a finished surface, such as a road, on which to recover the vehicle. The catapult launch and belly skid landing has therefore allowed the UAV to be operated successfully over a wider range of natural environments desired by the end user.

More recently marinization of the UAV has been investigated to facilitate operation from ships. While this has been successful, it does introduce new issues with retrieval of the UAV from the water from boats with high side boards or in dark night time conditions. Also, in higher sea states it can be extremely challenging to even locate the UAV let alone recover the UAV out of the water from the vessel. Much of the operational uses now being discussed by both scientists and the military desire the UAV to be ship launched to explore estuaries, inland coastal regions, ice flows or even open waters. Also of interest is the ability to recover the UAV onto the ship so that the wet water landing and recovery can be eliminated. A program from the Office of Naval Research (ONR) in Arlington Virginia has supported this "precision recovery" development effort that autonomously recovers the UAV platform into a small net, which can be vessel, land, or vehicle mounted. This precision recovery technique has been successfully demonstrated for the Silver Fox UAV over a complete range of platforms and is now under development for the larger, Manta and smaller, Coyote UAV platforms. This precision recovery approach essentially reduces the recovery footprint from a hundred feet in the landing direction to a small 16 feet wide by 12 feet high (4.8 meters x 3.7 meters) net.

THE DEVELOPMENT APPROACH

Vision Based Recovery – The precision landing capability has been funded through ONR and was first investigated in Upolu Point Hawaii, in April 2005. At that time, stationary net captures were successfully carried out in remote control (RC) mode in which the pilot steered the UAV into the centre of a tethered net approximately 15 feet square (1.35 square meters). The same net was also elevated to an altitude of approximately 30 feet (9.1 meters) above ground level (AGL) through the use of a light weight parasail as shown in Figure 2 although no UAV recoveries were carried out with this configuration.

Figure 2. Recover net elevated above the ground by twin parasails – Hawaii, April 2005

A number of approaches were investigated for the autonomous recovery. A comparison between vision assisted approaches was conducted.

In the first, a ground based vision system monitored the approach path and any deviation that occurred from the desired final approach path. The deviation was measured and transmitted through the ground control station to the UAV to perform the final approach path correction. This approach offered certain advantages but relied on good visibility between the ground and the approaching UAV as well as a robust communications link to allow for the transfer of time-critical corrections.

Another system looked at a forward based vision system on the UAV that monitored the UAV's final approach and compared with a "desired" orientation of the net to allow for the deviation to be monitored. This approach was manageable but required an additional forward looking vision system and an on-board processor to compute the necessary changes to the final approach.

Position Based Recovery – GPS - The NAVSTAR Global Positioning System (GPS) is a space-based radio positioning system which provides suitably equipped users with highly accurate position, velocity, and time data. When fully operational, this service will be provided globally, continuously, and under all weather conditions to user at or near the surface of the earth. GPS receivers operate passively, thus allowing an unlimited number of simultaneous users.

GPS system comprises of three major segments, Space, Control, and User. The space segment of the GPS system consists of a constellation of GPS satellites in semi-synchronous orbits around the earth. Each satellite broadcasts radio-frequency (RF) ranging codes and a navigation data message. The GPS control segment consists of a Master Control Station (MCS) and a number of monitoring stations located around the world. The MCS is responsible for tracking, monitoring, and managing the satellite constellation. Additionally, the MCS is responsible for the updating the navigational data, and messages to the satellites. The user segment of the GPS system consists of a variety of radio navigational receivers, specifically design to receive, decode, and process the GPS ranging codes and navigational data messages.

The ranging codes broadcasted by the satellites enable a GPS receiver to measure the transit time of the signals and thereby determine the range between a satellite and the user. The navigational data enables a receiver to calculate the position of each satellite at the time of transmission of the signal. Four satellites are normally required to be simultaneously in view of the receiver for a three-dimensional (3-D) position to be obtained. The accuracy of the position obtain from the navigational data is a 16 meter (52.5 feet) spherical shell, where the user can be anywhere within. The need to improve the accuracy of the 3-D position obtained from the navigational data was a goal achieved from the user using Differential Global Positioning System (DGPS).

Position Based Recovery –DGPS - The concept of DGPS is to operate a GPS receiver in a known location that has been previously surveyed. This receiver must track all satellites in view in order to compute their differential pseudo range corrections. These corrections are generated by comparison of the measurements taken by the receiver with those based on the true receiver position. The receiver is part of the reference station located in an area where higher accuracy is required. It is important to perform integrity management to ensure that the transmitted output data corrections are valid. The resultant valid corrections for each satellite in view are formatted in a standardized protocol and modulated onto the broadcast radio signal. DGPS derives its potential from the fact that the measurement errors are highly correlated between users located in a local area. The pseudo range corrections are received by the user receiver and incorporated into the navigational solution to correct the observed satellite pseudo range measurements, there by improving the position accuracy. Differential GPS primary goal is to determine and then correct errors that are biases in the GPS system. A differential operation of the GPS system offers an accuracy of 5 – 20 meters (16.4 – 65.6 feet) for dynamic navigation applications, and better than 3 meters (9.8 feet) for stationary applications using code-phase measurements.

There are several options for implementing DGPS, depending on the type of information transmitted. The normal implementation method is to transmit the pseudo range corrections of each satellite in view. In this case, the user needs to simply difference the received measurement corrections with the independent pseudo range measurements. The alternative is to transmit position corrections, such as latitude, longitude, and altitude, and apply them to the user navigational solution in the same frame. Though this approach looks easier to implement than the previous method, the problem is that the position solution errors are dependent on which satellites are used. Since, in general, the reference station receiver has knowledge of which satellites might be in use by the user receiver, it must compute and transmit position corrections for all possible combinations of satellites. Another option for implementing a DGPS is called the translator method. This method, the user does not track the GPS signal to compute a navigational solution, but simply translates it to a communication frequency which is retransmitted to the ground. A GPS receiver on the ground receives this translated frequency and computes a GPS solution for the particular user. A separate conventional reference station provides the differential corrections to be applied to the previous solution. A method for used for mobile systems, is called the kinematic phase differential GPS. This method uses a dynamic phase tracking which will establish a relative phase position of the GPS carrier including the integer ambiguity. Absolute carrier lock must be maintained during the receiver movement. This is a mobile version of the geodetic survey technique using the phase observable of the GPS.

Depending on the type of data link used, DPGS can also be implemented in different ways. In the uplink option, the differential corrections are sent from the reference station to the user as previously described. A downlink option is also possible and in this case the differential solution is only calculated on the ground. This is the surveillance case for test range applications for precise vehicle surveillance. Another possibility is the use so-called pseudolites where a GPS signal and code generator broadcast the differential corrections over the signal and therefore, separate data link system is not required. However, the reference station becomes complex and the transmission must be over GPS signal frequencies.

RECOVERY CONFIGURATIONS

Stationary Ground Net Recovery – The simplest configuration is the recovery of the UAV on land into a stationary net. In this method the final approach is configured to deliver the UAV into the center (or other predefined region) of the net while erected directly in the final approach path of the vehicle as shown in Figure 3.

Ten live approaches and recoveries were attempted. Of these, ten resulted in successful captures from a navigation and guidance standpoint, but twice, the net failed to adequately contain the aircraft and it sustained minor damage. Both times, the tail surfaces were damaged, but were quickly replaced and the Silver Fox

UAV was readied for another flight within a few minutes. The navigation and control errors on final approach are graphed in Figures 4 and 5 for the cross track and altitude variance respectively. The plots show that the measured error in aircraft guidance is generally kept to less than about 1 meter (3.3 feet) during the last 30 seconds until capture.

Figure 3. Recovery net, fixed to the ground for autonomous captures. Tucson, June 2007

The standard deviations of the navigation error, as measured by the GPS/inertial navigation system (INS) are shown in Figures 4 and 5. These numbers are useful in evaluating the accuracy of future tests and/or changes to the approach method.

Moving Ground Net Recovery - The test apparatus consisted of a version of the land-based net recovery device mounted to a trailer pulled by a truck. Additionally, the GCS base station GPS antenna is mounted on the moving platform containing the net. The updated navigation algorithm monitors the speed and direction of the net and sends updates to the aircraft, along with moving baseline real-time kinematic (RTK) DGPS corrections. The aircraft uses this information to update its position estimate and flight plan to intersect the net. When the aircraft impacts the net, it triggers the release of the bottom corners, which are pulled upwards and basket the aircraft, preventing it from falling away from the net. Extensive testing has resulted in the aircraft accurately impacting the net on all occasions. The development of the lower net release was implemented as a direct result of observations carried out on the early captures when the chance for the UAV to fall out of the net if not contained properly was initially observed. This testing also revealed some flaws in this capture mechanism that needed to be resolved before the at-sea testing was undertaken. The errors in cross track and altitude from the predicted final flight path were plotted against distance to time of impact. It can clearly be seen from the graphs in Figures 4 and 5 that while the altitude deviation is extremely small that the cross-track can be quite large initially due to cross winds etc.,

Net Capture on Water - The capture of a UAV in a dynamic environment, such as water, will envision minimizing errors associate with position. The dynamic environment of water allows the ground station to move in 3-D. This movement is associated with the water moving up and down associated with waves, and rotation associated with water currents. The use of Differential GPS in a dynamic environment will allow errors associated with position to reduced, allowing the UAVs to accurately know its position. This will aid the UAV to in landing and avoiding obstructions. The landing of the UAV can be accomplished through the use of a net, which is fixed mounted on a ship. This net on the ship, however, will be moving due to forces out side its control, which could cause the UAV problems if DGPS is not used.

Further water recovery testing is to be carried out in Spring/Summer 2008 with the National Oceanic and Atmospheric Agency (NOAA) to demonstrate that ship launch and recovery can be utilized for open sea monitoring and surveillance in support of a scientific exercise. We have shown that the UAV is capable of hitting a moving target, when the object is moving straight or zigzagging. This was accomplished by relaying the position of the target to the UAV using DGPS. Additionally, the UAV was able to hit the net at an angle because the vehicle caring the net move off in a different direction than the UAV was heading. However, was not a problem the UAV because, it was being supplied with position data for the net. Additionally, once the UAV hit the net, the bottom of the net would release from its mounts to enclose the UAV protecting and securing it.

All the testing was conducted fully autonomously. The testing also successfully demonstrated autonomously commanded go-arounds which were triggered by the autopilot when it determined that its position error was out of the bounds set by the configuration parameters.

The sequence of shots shown in Figure 6 highlights the typical landing impact and manner in which the net folds around the UAV. In the case of the Silver Fox UAV the propeller is stopped by the net and actually “hooks” into the net keeping it attached. No damage was observed on either the UAV or the net for these autonomous net capture tests. Also, Figures 4 and 5 show just how accurate the DGPS is at delivering the UAV to the precise location in the net. In elevation this corresponded to significantly less than a meter and in cross track this was ±1 meter (3.3 feet).

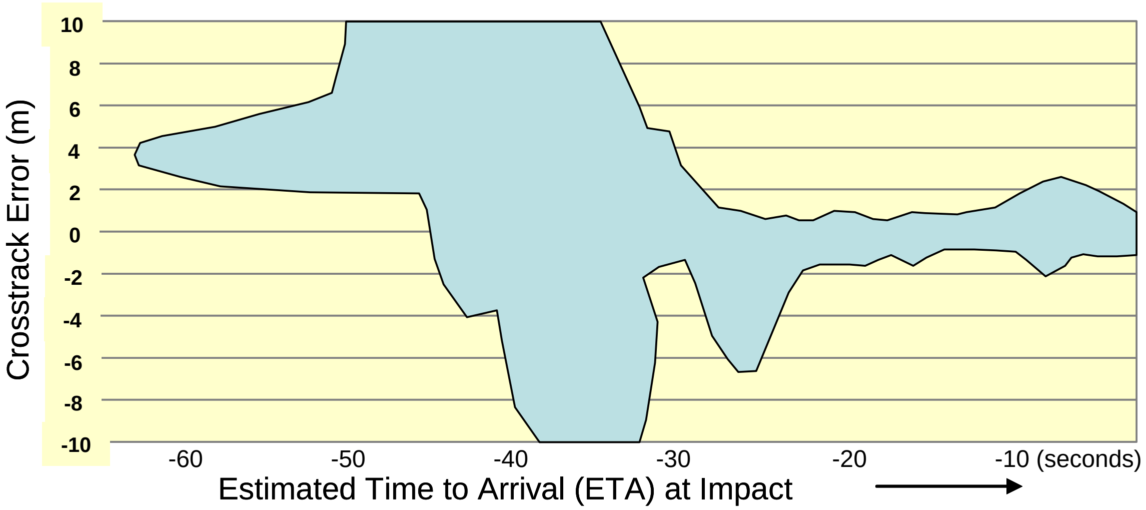

Figure 4. Measured cross track error cloud over 10 sequential ground based net recoveries. The graph shows that of those flights that were recovered in the net they were within ± 1m

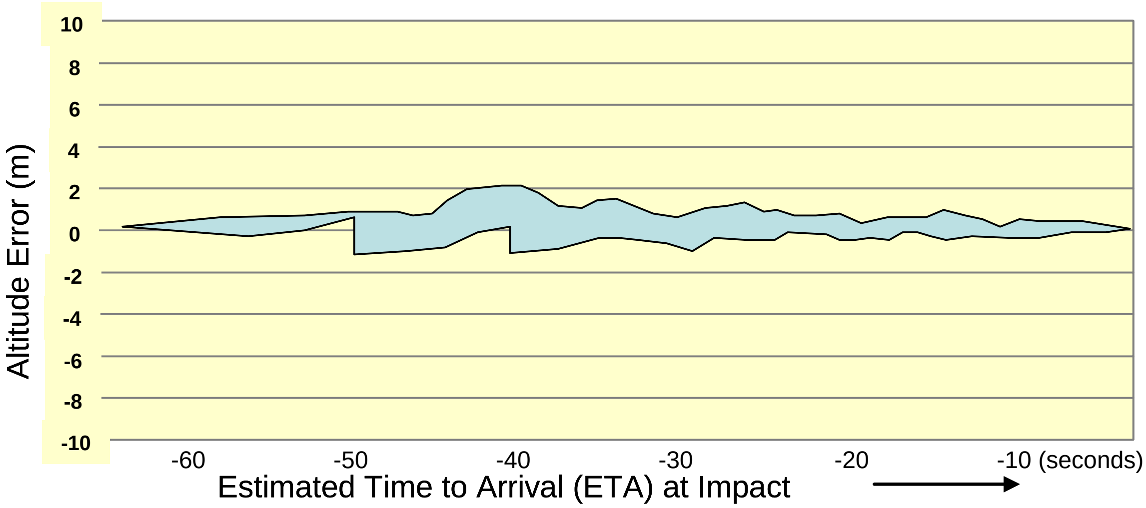

Figure 5. Measured altitude error cloud over the same 10 sequential ground based net recoveries. The graph shows very good correlation between the predicted and actual altitude over the entire final approach.

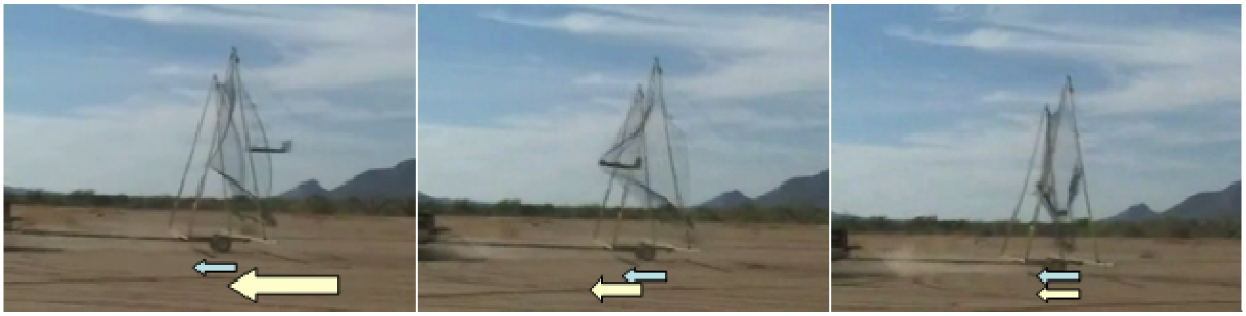

Figure 6. Sequence of photographs showing the capture of a Silver Fox UAV into a moving net travelling in the same direction. The arrows indicate the relative speed of the net and UAV.

LESSONS AND FUTURE PLATFORMS

In comparison, earlier efforts in 2004 investigated the manual delivery of the Silver Fox UAV into a net mounted over the port side of the Lockheed Martin's Sea Slice vessel as shown in Figure 7.

Figure 7. Initial manual net capture tests on the Lockheed Martin Sea Slice vessel in 2004.

While these recovery tests were successful in achieving the desired goals, significant turbulence was encountered due to the boat's superstructure particularly over the stern of the vessel. In these tests as a safety measure a second net was arranged under the capture net in a horizontal manner so as to catch the UAV if it fell out of the primary net. The rigid posts of this test also posed a significant safety issue to the UAV if the approach deviated far from the centre of the net. In this work we learned much about the importance of choosing the right net material and matching it with the loading encountered by capture. Too heavy or stiff a net results in damage to aircraft components. This approach also included a capture hook that was deployed from the bottom of the UAV with the intention of catching a wire just in front of the net. The wire would capture the UAV and the nets both behind and in front were to act as a capture mechanism if the UAV were to miss the wire. This technique is proprietary to Lockheed Martin who operated the advanced recovery testing.

A significant amount of experience was gained from performing these early manual recoveries and future efforts have been to launch and recovery small UAVs from a wide range of platforms. In February of 2005 tests were performed n the US Coast Guard vessel the USS Assateauge to demonstrate that there were several suitable operation positions and that the UAV and associated flight control system did not interfere with, or was interfered by the on-board radar and communications. The Silver Fox UAV was mounted from the bridge as shown in Figure 8 as well as from any of the 50 caliber gun mountings around the vessel.

Figure 8. Silver Fox mounted on the US Coast Guard Vessel USS Assateauge in Hawaii 2006.

The Stiletto is an advanced experimental M hull vessel developed by Office of Force Transformation and used by Navy Special Clearance Team One (NSCT1) for littoral mine clearance experiments. It has been designed as a mobile maritime platform for a range of autonomous vehicles and has been configured to allow UAVs to be launched from its upper deck as shown in Figure 9. In April 2006 the Stiletto Vessel was equipped with Manta and Silver Fox UAVs and took part in a military evolution called Howler Experiment to demonstrate the collaboration of autonomous vehicles and the detection of sub surface objects from an autonomous UAV platform. NSCT1 also operated Silver Fox from an 11 meter RHIB and recovered from water as shown in Figure 10. They also launched the Manta UAV from the upper deck of the Stiletto to perform hyperspectral imaging as shown in Figure 11.

Figure 9. The US Navy's experimental hull littoral combat vessel "Stiletto" used as a platform for autonomous vehicles.

Figure 10. NSCT1 Sailor recovers Silver Fox UAV from water during Howler Experiment.

The Manta UAV shown in Figure 11 was launched from the Stiletto to perform a series of flights over a known region of water containing sub surface and bottom mines. The hyperspectral imager was used to provide georectified images that penetrate the water and observed these targets together with regions showing kelp beds and the sandy bottom.

Figure 11. Manta UAV with hyperspectral imager being launched during the Howler Exercise at sea from the deck of the Stiletto

Navy Special Clearance Team One (NSCT1) first operated the Silver Fox UAV in a maritime environment and requested in 2005 that the UAV could be launched from the rigid hull inflatable boat (RHIB) boats while they were in motion. This was achieved from the 11m and 8m RHIB boats as shown in Figure 12.

During this same timeframe the Silver Fox UAV marinization experiments were conducted for recovery from the water. While water tight sealing of components proved relatively straightforward, delayed response saltwater corrosion of certain metallic components prove to be much more difficult to overcome. In addition, in higher sea states and in night operations recovery can be extremely challenging even though the adverse weather does not interfere with the UAV's operation. The autonomous net-capture capability therefore became an important factor for the continued use of UAVs from maritime vessels both small and large as it avoided the need for a water landing and allows for more straight forward opportunity for the vehicles to be certified for operation with the US military.

Figure 12. Silver Fox UAV mounted and launched from an 8m RHIB operated by NSCT1

Since 2007 the newly "stood up" Riverines Squadron have been operating Silver Fox in Iraq. Riverine Squadron 1 (RIVRON1) completed their deployment operating from the Haditha dam in 2007 and Riverine Squadron 2 (RIVRON2) has replaced them and is currently deployed there, figures 13 and 14. Although presently recovered on land, the net capture will allow considerably more freedom of operation from the boat platforms presently used.

05/31/2007

Figure 13. RIVRON1 using Silver Fox UAV on Riverine Patrol Boat – Haditha, Iraq 2007

Figure 14. Silver Fox UAV ready for launch off of RIVRON1 Riverine Patrol Boat – Haditha, Iraq 2007

Riverine Squadron 3 (RIVRON3) is under going Silver Fox training and will replace RIVRON2 in 2008. It is hoped that they will possibly get to do limited in theatre trials of the new Precision Net Recovery during their deployment. They are also training to operate Silver Fox on land based vehicles and may use fixed ground based Precision Net Recovery as well. Figure 15 below shows RIVRON3 training on multiple HUMVEE vehicles.

Figure 15. RIVRON3 training on multiple HUMVEE based Silver Fox UAS operations.

In addition to use of Precision Net Recovery for maritime operations we anticipate that this capability will be of benefit for Navy Explosive Ordnance Disposal (EOD) applications. Navy EODMU1 recently completed a successful JRAC funded user evaluation for Silver Fox UAV and the Honeywell GMAV VTOL UAV in Baghdad, Iraq. In this user evaluation, Navy EODMU1 personnel successfully flew Silver Fox UAV in day and night missions in the urban environment of southern Baghdad. As the bulk of all their missions were outside the “wire” off a base they were always encountering the requirement to land in new locations within the urban zone. Figure 16 shows the operational area of a typical forward operating base location. The capability to quickly install a small light weight net for precision recovery on a roof top in this environment would greatly simplify recovery operations.

Figure 16. Navy EODMU1 Silver Fox UAS at a Forward operating Base in Southern Baghdad, Iraq.

In addition to U.S. Navy forces, Precision Net Recovery of Silver Fox UAV should also benefit the 31st Marine Expeditionary Unit (31MEU). 31MEU operates in the littorals and on shore. Recently the 31 MEU successfully completed Silver Fox UAV training exercises in the harsh jungle environment of the Philippines. Precision Net Recovery would allow them to perform missions directly from their ship in many cases without the need of going ashore to operate. Precision Net Recovery would also enhance their operations in more difficult locations without open fields. Figure 17 below is from 31 MEU Silver Fox UAV flight operations in the Philippines in 2007.

Figure 17. 31 MEU operating Silver Fox in Philippines, 2007.

The ability to launch and recovery UAVs autonomously has proven to be a key capability for many of the maritime applications. User feedback has indicated that the operator can in many situations have very little time to pay attention to the net recovery and that the ability to recover autonomously is a requirement to free up the operator for other important tasks. The DGPS system has proven essential in order to accomplish the precision required to successfully land into a net 12 feet by 16 feet (3.7 meters x 4.8 meters) in size and although larger nets could be used, maintaining a small footprint is also a user requirement.

CONCLUDING REMARKS

There is a growing interest in the use of UAVs in support of military troops, for the routine gathering of information from maritime environments, in both coastlines and from open water, and for the gathering of scientific data, particularly in light of the newly found United Nations (UN) report on Global Warming. While the small Tier II size UAVs developed by Advanced Ceramics Research (primarily the Silver Fox, Manta and Coyote) have been specifically tailored to meet the needs of the end user, the ability to finally provide an autonomous precision launch and recovery capability will greatly enhance the capability of these vehicles and further widen their acceptance.

Early test flights under manual recovery mode performed in 2004 demonstrated the use of a wire and hook mechanism to capture the Silver Fox UAV and identified a series of issues that needed to be addressed if an autonomous capability was to be developed. Although a number of autonomous recovery methods were investigated using vision systems, the differential GPS system that was finally decided upon offer a high accurate and reproducible recovery capability. Interrogation of the predicted and actual final flight path in real time allows the recovering UAV to operate within a predetermined glide path with known errors. If the vehicle extends outside the "safe" recovery profile the flight recovery is aborted and the UAV circles around for another try. The DGPS is able to deliver the UAV to the precise location in the net. In elevation this corresponded to significantly less than a meter and in cross track this was ±1 meter (3.3 feet). This capability now offers the operator the ability to completely remove themselves from the recovery operation as this will be totally autonomous and will allow the operator to concentrate on other, often more pressing activities.

To date this capability has been demonstrated for stationary and moving net platforms with an exceptionally high degree of success. Following the successful completion of seaborne trials with NOAA in April this year the net recovery capability will be extended to provide precision recovery for a wide range of maritime users.

In conclusion we would like to provide the reader with a couple of the after action reports from Iraq stating the benefit and capability of the Silver Fox UAV used in maritime missions. These operations will be significantly more capable in the future with precision net recovery capability and will allow the operators to better concentrate on other activities in what can be a confusing, and dangerous environment.

"[the Silver Fox UAV] can provide all the necessary support with zero operational impact on the riverine unit. In short, the UAV provides us an unmatched combat capability that allows riverine forces to execute missions over the horizon while providing a real time picture of the battlefield [1]. "

"I am the Battalion Air Officer for Task Force Highlander and it has been my pleasure to deal with the Marines and Sailors from RIVRON 1 and Fifth ANGLICO. We have had over ……… of fight time with the Silver Fox UAS. Silver Fox has flown in support of Rivron 1 and TF Highlander completing a variety of missions. The missions range from river reconnaissance to counter IDF. COP Rawah has had a history of IDF around the beginning of every month since the Task Force arrived at COP Rawah. Silver Fox added a great capability to stop the IDF on COP Rawah and the surrounding areas. The capabilities of Silver Fox are a great addition to Task Force Highlander's limited UAS capabilities[2]."

REFERENCES

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