Requirements Driven UAV Development

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ABSTRACT

Over the past 5 years Advanced Ceramics Research (ACR) has established itself in the USA as a persistent producer of Tier II class UAVs with 2 gasoline systems in production and 1 electric sonobuoy launched system under development. The Tier II designation as defined by the U.S. Navy and Marine Corps typically refers to a short range tactical UAV with less than 12 hours flight duration and an operational altitude of around 15,000 feet. The U.S. Army has an equivalent Tier II designation that applies to the RQ-7 Shadow with a 12' wingspan. Our approach in manufacturing these small UAVs has been to automate their operation and to provide a robust system that can be used directly by the operator (war fighter or scientist) with the minimum of training. To achieve this goal, ACR has had to work closely with the end users to both define the requirements of operation and to continuously modify the capability. As a relatively new tool for science and in the battlefield, UAV requirements are continuously being redefined as operators realize the available capabilities and manufactures constantly upgrade existing systems.

This paper will start by briefly introducing the product UAVs - Silver Fox, Manta and Coyote – and will address the development of specific components – launch, ground station, recovery and water based operations – based on the lessons learned from operating with the user and tailoring the system to meet their requirements. The Silver Fox and Manta have recently been certified for military use. Two case studies will be discussed;

1. The integration of Silver Fox and Manta UAVs into NSCT1 littoral operations will be discussed with a focus on their operation from the Stiletto experimental hull vessel.
2. Selection of the Manta UAV by the Scripps Institute and operation in the Maldives to collect climate data in support of the International Atmospheric Brown Cloud project on Global Dimming.

Finally the lessons learned from past development efforts will be summarized and future efforts (such as additional sensor integration and testing) will be discussed to meet upcoming operator needs.

BIOGRAPHY

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.

Mr. Anthony Brescia, is an advanced technology program manager and a systems engineer acquisition professional at NAVAIR, Patuxent River, Maryland. He holds a Masters degree in National Security from the National War College and an Electrical Engineering Masters from Pennsylvania State University. He currently serves as a program manager for unmanned vehicle sensor payloads and airframes, anti-submarine warfare underwater systems, and liaison with Special Warfare groups and the Joint Improvised Explosive Device Defeat Organization (JIEDDO). He served as the Navy's Director of Science and Technology Resources, N911D, from 1999 to 2003.

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GLOSSARY

ACR - Advanced Ceramics Research
ASuW - Anti-Submarine Warfare
AUW - Anti-Surface Warfare
BDA - Battle Damage Assessment
C2 - Command and Control
CAS - Close Air Support
CDD - Capabilities Development Document
COA - Certificate of Authorization
CONOPS- Concept of Operations
CT - Contractor Testing
DoD - Department of Defence (US)
DT - Developmental Testing
EAC - Experimental Airworthiness Certification
E/DRAP- Engineering/Data Requirements Agreement Plan
EO - Electro-Optical
FAA - Federal Aviation Authority
GCS - Ground Control System
ICD - Initial Capabilities Document
iGCS - Integrated Ground Control System
IR - Infra Red
JCIDS - Joint Capabilities Integration and Development System
JIEEDO - Joint Improvised Explosive Device Defeat Organization
JTAC - Joint Terminal Air Controller
KPP - Key Performance Parameters
LCS - Littoral Combat Ship
MAC - Maldives Autonomous UAV Campaign
MCM - Marine Counter Measure
MMS - Marine Mammal Systems
NATO - North Atlantic Treaty Organization
NAVAIR- Naval Air Systems Command
NSCT - Naval Special Clearance Team
OPNAV - Operational Naval Aviation
OT - Operational Testing
PC - Portable Computer
PDA - Personal Digital Assistant
RDT&E - Research Development Technology and Engineering
RHIB - Rigid Hull Inflatable Boat
RVT - Remote Video Terminal
SATCOM- Satellite Communications
SEP - Systems Engineering Plan
TES - Test and Evaluation Strategy
UAS - Unmanned Air System
UAV - Unmanned Air Vehicle
UK - United Kingdom
UN - United Nations
USMC - United States Marine Corp
USV - Unmanned Surface Vehicle
UUV - Unmanned Underwater Vehicle

Requirements Driven UAV Development

INTRODUCTION

Over the past five years there has been a significant growth in the development of unmanned air vehicles (UAVs) driven in part by the need to gather additional data to support military activities as well as from earth scientists who are becoming increasingly aware of this potentially huge opportunity and cost benefit when applied to the collection of data. Depending on the type of data required and the desired mission and budget, there are several systems from which to select.

Having a wide selection of UAVs to choose from is good in that it provides a variety of choices however, there is often insufficient data on the capability, reliability, hidden costs and life cycle maintenance surrounding these systems, making the selection process difficult and potentially disappointing. One of the issues that can hinder the selection process can be a poor or incomplete understanding of the customer's requirements. Since UAVs are relatively new and first hand experience in their operation and capability is limited to relatively few, a lack of experience on the customer's side can lead to unrealistic requirements at an unrealistic cost. At the time this article was written (early in 2007) countries such as Australia, Canada, Ireland, and New Zealand were actively involved in assessing Tier II UAV systems for purchase to support selected military activities, while private and government organizations are doing likewise for a range of non-military activities such as pipeline and powerline monitoring, geophysical surveying, crop health assessment and mapping.

This commitment by governments, and by public and private sectors to invest in UAVs marks the next milestone in their transitioning from experimental exercises and curiosities to their acceptance as mainstream tools used in everyday operations. As with all new technologies, communication between the customer and the manufacturer is imperative in assuring the customer's needs are met and the overall success of the technology. It is still relatively early in the evolution of UAVs and it's projected that they will continue to evolve, incorporating smaller sensors with greater bandwidths, increased operational duration, better performance and power management through the use of energy scavenging devices, and that they'll be produced at a lower cost and with an overall improvement in their reliability. How their flight is legislated for safe operation with manned airplanes or for use over populated areas remains to be seen – but this will happen. For safe military operation it is required that these vehicles are certified through a rigorous evaluation of flight procedures (including pre and post flight operations) and training as is required for manned vehicles.

RECENT UAV DEVELOPMENTS

Silver Fox - The Silver Fox UAV was first designed and built in 2001 to meet a US Navy requirement to search for and monitor the movement of whales. The Silver Fox Block – B4, shown in Figure 1 has gone through several changes but has essentially remained the same size and shape with a 5 inch (0.127m) fuselage and a 94 inch (2.4m) wingspan

Figure 1. Silver Fox Block – B4 UAV

The initial success of the Silver Fox and the ease of launch and recovery gained support within the Navy with the goals of providing an organic intelligence capacity, in real-time, to small contingents of forward deployed military personnel. The design goals of the Silver Fox system were based on feedback from Navy operators who fielded 2003 versions of the UAV in Kuwait as shown in Figure 2.

Figure 2. Navy operators with early pneumatic launched versions of the Silver Fox UAV.

Initial efforts were focused at minimizing the system footprint and maximizing the portability of the system with an emphasis on simplifying the system operation and reducing the manpower requirements. Significant effort has gone into simplifying and automating much of the system and at assuring reliability in the system design. The original heavy, steel-framed pneumatic launcher has evolved through a light weight bungee catapult (powered by large elastic bands) and into a simple man-portable and rapidly deployable gas piston launcher, that can operate over a range of temperatures and environments. The desire for persistent, long range operation also resulted in the flight duration being extended to between 8 to 10 hours with a mission communications range of approximately 20 miles (36 km). The range is weather dependant and requires line of sight however, the system can be flown independently at any distance through a satellite link. Rapid deployment and turn around time was also a design factor which led to the belly landing and its use in hostile environments and the absence of finished surfaces. The desire for low life cycle costs led to the overall modularization of the system which has been designed as a series of interchangeable modules; this allows quick field maintenance without the need for extensive troubleshooting. Operators are trained to recognize, diagnose and replace key system components when needed, eliminating the need for regular depot level maintenance. As a result of these efforts, the Silver Fox system can be fully employed by a team of two (2) individuals, who if desired can fly multiple UAVs simultaneously.

Recent feedback from customers evaluating fielded systems has identified a desire for a gimbaled payload as well as for power generation and the need for an electric starter. Maritime operation at speed in heavy seas requires automatic engine start and launch and to fully benefit from the target tracking software that is presently available and significantly higher magnification imagery, a gimbaled optical train is now considered to be the minimum acceptance level for many applications. These design changes have been incorporated into the Block C design scheduled to be fielded in mid 2007.

Manta – The Manta UAV was designed in 2002 with a view to providing a larger payload than the Silver Fox for a wider range of missions. While the wingspan is approximately the same as the Silver Fox the lifting area and fuselage region are significantly larger as shown in Figure 3 enabling it to carry a standard payload of 15 - 18lbs (6.81 - 8.17kg) compared with 5 - 8lbs (2.27 - 3.63kg) for the Silver Fox. The Manta gained early interest from the Navy Special Clearance Team (NSCT) for it's ability to

Figure 3. The Manta UAV Block B

carry a hyperspectral imaging unit and other advanced cameras. There was a similar desire for low life cycle costs, ease of operation, flight duration and long range operation and these requirements have been met using a similar approach to that used for Silver Fox, however, the forward deployed real time surveillance requirement has been lessened due to the uniqueness of the various payloads and the use in more specialized operations. Although the Manta presently requires a paved area for recovery, a catapult system was developed for maritime operations as shown in Figure 4 and an autonomous recovery capability is presently under development to meet future maritime needs.

Figure 4. Manta UAV being catapult launched from the Stiletto Experimental Hull Vessel.

The payload volume, easy access through a large top panel and engine placement behind the fuselage have made the Manta attractive for earth scientists as a means of collecting airborne data.

Multiple sensors can be flown simultaneously and on-board data processing and storage have resulted in a significant capability for data gathering.

Coyote – The Coyote was build for a specific design requirement that it could be stored and launched from a standard sonobuoy tube as shown in Figure 5.

Figure 5. Coyote UAV and sonobuoy packaging

The Coyote is designed to provide a standoff surveillance capability for aircraft. The defined mission would be preloaded into the flight control software prior to launch and the Coyote would gather surveillance data of the defined target area possibly obscured from view from the launch aircraft by a cloud layer. The Coyote will be launched from the P-3 Orion maritime-patrol aircraft and anti-submarine warfare (ASW) helicopters like the SH-60 using conventional sonobuoy launch techniques. A P-3 can carry 48 external and 36 internal sonobuoys plus an additional pressurized launcher that can be loaded inside the cabin[1]. As with sonobouys, the Coyote UAV will be expended at the end of its 90-minute flight time. At 12-14 lbs., the Coyote's weight is at the lighter end of the stores that can be expended by a P-3C. The UAV has a cruising airspeed of 50 knots and a dash airspeed of 75 knots, and it can operate at altitudes up to 25,000 ft. Due to the folding nature of the design and the high acceleration loads it has to survive, the Coyote design is an interesting combination of high performance (and yet expendable) materials.

Field trials have only recently started and the Coyote is presently only in its 2nd developmental design iteration. Once field testing is underway in a realistic use environment it is expected that additional design changes will be made.

Ground Control Station – The integrated ground control station (iGCS) is the link between the UAV and the operator allowing both Command and Control (C2) operations and payload reception and payload exploitation. Initially two separate operations with a PC based flight controller, directional antenna and a Remote Video Terminal (RVT) for data transfer, military requirements have driven the design to a single, self-powered iGCS containing two user interfaces as shown in Figure 6.

Figure 6. Military ground control station showing C2 flight control and data imagery screens. The miniaturized GCS is shown to scale (insert).

The iGCS facilitates operator to air vehicle interaction through iMission, ACR's vehicle control software suite. iMission is integrated into FalconView 3.3, a US standard mapping suite and supports the import and manipulation of many different map types. In addition to real-time system control, iMission can facilitate offline mission planning, terrain analysis and telemetry replay of previously executed missions. The iGCS incorporates dual touch screen displays, removable hard-drives and dual channel video receivers for selection of the "best" channels for data transfer. The iGCS also incorporates a short range antennae mast and a tracking antenna is used for more distant operations to approximately 20 miles (32km). As per military request the keyboard is fully waterproof for operation in a wide range of environments. The system is powered by either standard BA 5590U batteries or a NATO standard 28VDC slave cable.

For most operations this has proven adequate and can be stored, transported and set up rapidly when required. Selected mobile operators have however requested a much smaller GCS that can be worn on their person. A mini-iGCS was developed as shown in the insert in Figure 6 which allows C2 connectivity and access to the data stream that can be displayed through a range of interfaces such as a PC or Personal Digital Assistant (PDA). Additional RVTs are still useful for company commanders, or mounted personnel who are in the general vicinity of the UAV and desire a passive observation capability.

CERTIFICATION FOR MILITARY USE

System Acquisition - There is a well-defined and formalized process for transitioning concepts from research and development systems to operational use. There are a multitude of directives, regulations, policies, and procedures that govern program management, acquisition, and test and evaluation within the Department of Defense[2] (DoD). The Joint Capabilities Integration and Development System (JCIDS) outlines the capabilities based process[3]. We will briefly look at relationship between the Capabilities Development Document (CDD), Systems Engineering Plan (SEP), and the Test and Evaluation Strategy (TES) in the context of the acquisition and NAVAIR flight clearance process. The operation of the UAS in non-restricted airspace is another important issue but will not be discussed in this paper.

The CDD flows down from the Initial Capabilities Document (ICD) and describes the operational performance requirements. The CDD has measurable properties stating the required performance, operating environments, and interfaces which bound the problem space. Establishment of thresholds and objectives of the critical components is necessary for the program development process. A threshold value is the minimum acceptable value that is necessary to satisfy the mission need. An objective is a value beyond the threshold that would enhance the desired capability or mission performance. The variance between the two is the trade space available to the developer in meeting those expectations. To this end, key performance parameters (KPPs) need to be identified. Modeling and simulation of the proposed system with a notional CONOPS will aid the development of all future documents.

The Systems Engineering Plan (SEP) guides the program throughout the total development cycle as a living document. It is an event driven plan that addresses the questions who, what, where, why, and how in meeting the operational performance requirements. Using the ICD and CDD as the foundation, the Test and Evaluation Strategy (TES) is developed. The TES describes how the Contractor Testing (CT), Developmental Testing (DT), and Operational Testing (OT) each contribute to the measurement of overall system performance. Contractor Testing is done at the component to system level to determine suitability, performance and reliability. Developmental Testing is tightly controlled and executed through strictly defined procedures to characterize particular functional areas.

It assesses how well the system performance meets the threshold and objective values. Operational Testing is characterized by how well the system performs the conduct of the mission. The program manager is able to visualize program progress with the TES as the measurement tool.

Airworthiness Flight Certification - A flight clearance can be either Interim or Permanent. Interim flight clearances are typically found in the Research, Development, Test and Evaluation (RDT&E) community. They are governed by NAVAIR Instruction 13034.1C[4]. Permanent flight clearances are governed by OPNAV Instruction 3710.7T[5]. All aircraft and systems owned, leased, and operated by US Navy and US Marine Corps personnel must obtain an interim flight clearance before use. This applies to both manned and unmanned aircraft.

A cooperative agreement exists among the Services that permit the airworthiness certification of the system in one Service to be valid in another. The characteristic flight envelope is considered in the transfer acceptance process. At least part of the answer resides in the application and operating environment to which is being asked to perform.

Interim Flight Clearance Procedure:

1) Read NAVAIR Instruction 13034.1C
2) Determine a flight clearance strategy in coordination with NAVAIR Airworthiness Office
3) Schedule a planning meeting to educate Performance Monitors & determine data requirements
4) Construct an Engineering/Data Requirements Agreement Plan (E/DRAP)
5) Submit flight clearance request
6) Distribute and Conduct Systems Engineering testing and evaluation

Starting the Conversation - The Acquisition and Flight Clearance Process is straightforward. How well was the performance specifications in the contract translated from the CDD? Was the contract written with a full understanding of the flight clearance or operational employment context? What documentation and testing is required? In short, all interested parties need to meet and identify early on the needs of the end user. This gives everyone insight into the real needs of the customer; allows everyone to articulate their expectations; improves communication and reduces programmatic uncertainty. This, of course, is not without challenges.

During the initial flight clearance strategy meeting the program objective, air platform, flight envelope, what data are available, schedule, and what engineering disciplines need to be involved in establishing the testing regime will be discussed. The greater the fidelity the more refined the performance monitoring planning meeting will be. The main area that the flight clearance process is honing in on is airworthiness and safety of flight of the airframe and all associated hardware and software to operate it.

As mentioned earlier the available experience with unmanned air system capacity and capabilities is limited. The rapidly changing landscape of the mechanical, avionics, power plant, and electronic components comprising the system typically leads to a changing design. In the vetting of the operational performance parameters in terms of threshold and objective phrases like
“How about increasing the …”,
“It would be nice if the system could …”,
“If we add this, we could ...”, etc. will begin to permeate the Team’s vocabulary. This translates into what is called requirements creep. What warfighters need is a system that meets their needs and works reliability in combat.

This begins with the Contractor’s design and associated testing in accordance with the CDD. To obtain a flight clearance in a timely manner the system configuration has to be locked prior to the performance monitoring meeting. The engineering and data requirements documents will preclude significant deviation from the approved design. To reduce risk and increase the likelihood of program success, established key exit criteria will guide the test and evaluation efforts. A stable configuration will minimize rework and retesting by all parties involved and the process will flow smoothly.

The flight clearance process can be viewed as a combination of contractor, developmental and operational test rolled into one. The performance monitors are charged with evaluating the system to the levels specified in the CDD as they pertain to airworthiness and safety of flight. The approved system configuration and performance envelope will be defined in the interim flight clearance issued via naval message. If the system does not perform to those levels, a limitation is placed in the interim flight clearance regarding that parameter. Some Flight Clearance procedural pitfalls that occur are;

1) the system is not mature enough when entering the planning meeting and extensive rework and retesting is required;
2) the Airworthiness Office is not informed of the system until the last minute;
3) the Contractor deploys the system without the airworthiness certification; and
4) resources are unavailable to properly manage the testing phase.

There is both hope and despair in the whole process depending on your perspective and prior exposure to the process. The warfighter views the process with a persistent reputation that it does not do well in meeting their expectations in a timely manner. Although the acquisition and flight clearance processes have undergone restructuring and refinement the fundamental aspects of capabilities definition and associated performance testing remain rigid. A variety of factors about how well these are articulated and understood determine the delivery schedule of a capable system to the warfighter.

CASE STUDIES

UAVs for Maritime Surveillance (Howler). - The US Navy Special Clearance Team 1 (NSCT1) was established in October 2002 from what was previously the Very Shallow Water detachment. The team combines three communities: Naval Special Warfare; United States Marine Corp (USMC) Reconnaissance; and Explosive Ordnance Disposal. The team has four platoons: Marine Mammal Systems (MMS); Unmanned Underwater Systems Platoon, Unmanned Aerial Vehicles Platoon, and Dive Platoon. The team's role during wartime is to prepare near-shore areas covertly for amphibious assaults. This was most recently demonstrated during Operation Iraqi Freedom when they cleared the port of Umm Qasr to allow the landing of humanitarian aid[6].

The Navy is pursuing three distinct littoral warfare mission modules, mine countermeasures (MCM), anti-submarine warfare (ASuM) and anti-surface warfare (AUW). The first of these being addressed is the MCM in which assessments of the small warship prototypes will be made during a series of experiments utilizing collaboration with a variety of off-board unmanned systems. The first Littoral Combat Ship (LCS) will be ported in San Diego and future flights or generations of LCS will reflect the lessons learned from the early LCS operations and experiments with other advanced hull forms which will include the "X-Craft" and the "Stiletto" as shown in Figure 7.

Figure 7. The Stiletto experimental hull vessel – littoral platform for unmanned vehicles

The detection of mines is a relatively mature capability in deeper waters but in the surf zone and beach regions the capability for mine detection from small UAVs needs to be developed further to ensure a robust and reliable capability is available.

In April 2006 a military exercise called Howler was arranged to demonstrate the collaborative use of UUVs and UAVs from the Stiletto experimental hull for the purpose of littoral mine clearance. Earlier work with NSCT1 had transition the Silver Fox from a land based asset to one that could be launched from a 36 ft (11m) Rigid Hull Inflatable Boat (RHIB) as shown in Figure 8 that could also be recovered from a water landing. For the Howler exercise the RHIB is stored within the body of the Stiletto and launched from the aft facing entrance at water level.

Figure 8. Silver Fox UAV ready for launch at the front of a 36 ft (11m) RHIB operated by NSCT1

For the exercise it was required that we demonstrate the hyperspectral imaging capability, a sensor that was mounted on the Manta UAV and had not yet been transitioned to the Silver Fox. With over 200 spectral channels the hyperspectral imager was capable of surveying scanned regions of ground or water and establishing the position of anomalies such as sub surface mines. A Manta launcher was developed as shown in Figure 9 that allowed the Manta to be launched directly from the upper Stiletto deck. For the exercise the Manta was recovered on land but for future capability, ship recovery is desired and is presently under development.

Figure 9. The Manta UAV on the launcher on the upper Stiletto deck from where it is launched.

One of the objectives of the Howler exercise was to show the ability of UUVs and UAVs to work collaboratively. During the exercise the Manta was launched and completed a number of sweeps of the water with the hyperspectral system over the region of interest as shown georectified and superimposed over a land image in Figure 10. The surf zone is shown on the right of the image. These images successfully identified the position of submerged objects. The RHIB mounted Silver Fox was launched and performed routine surveillance, providing live EO and IR imagery.

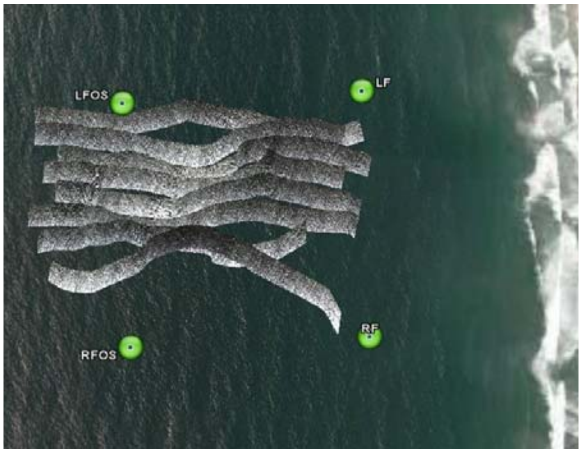

Figure 10. Sweeps of images from the hyperspectral sensor georectified onto an image of the littoral zone and an expected mine field.

The Howler exercise demonstrated the detection of underwater objects from an autonomous UAV platform and also showed the benefits of providing situational awareness to the mission control center through live video. This information was successfully fed into a common operating interface based on the Stiletto where in the future it will be meshed with UUV data to achieve a complete assessment of the region above and below the water.

Maldives Autonomous UAV Campaign (MAC). - In March 2006 a UAV campaign was launched from the Maldives by Dr V. Ramanathan from the Scripps Institute of Oceanography in San Diego, California, to study how human beings are polluting the atmosphere and their impact on climate, including global warming[7]. Interactions between particles in pollution, clouds and reflected solar radiation are one of the fundamental challenges in the global warming problem, and during the four week campaign in the Maldives, UAVs were used for the first time to collect atmospheric data in a synchronized manner at different altitudes, above, below and within the clouds. The science missions logged over 120 flight hours that included 55 takeoffs and 18 science missions and collected data on pollution and dust transported from S. Asia, Arabian and SW Asian deserts and their impacts on global dimming at the sea surface, the energy absorbed in the atmosphere and cloud properties. Direct measurements were made on the role of black carbon in the solar heating of the atmosphere.

The MAC campaign was the culmination of over 12 months of discussions, designs and testing a variety of small, lightweight, atmospheric sensors on UAVs and required significant modifications over the baseline UAV initially selected. There were a number of reasons why the Manta UAV was selected for these experiments. It has a large payload volume (0.45 ft^3, (0.013m^3)) that is readily accessible and can accommodate a number of sensors. The Manta is a pusher design with the prop behind the fuselage, which for atmospheric science means that the scientist can sample “clean” air directly ahead of the UAV during flight. The Manta also utilizes the iMission software which allows the controlled synchronous flight of multiple UAVs, a key requirement for the success of the MAC campaign.

The goal of the MAC campaign was to gather information on the pollution in the atmosphere, its effect on the formation of clouds and the reflectance of the sun’s radiation above and below the clouds. The clouds are constantly changing and it was important that the data collected from the different UAVs was synchronized.

The campaign successfully demonstrated that three fully instrumented UAVs could be stacked over each other (at altitudes ranging from 1,500 ft for the bottom UAV to 12,000 ft for the top UAV) maintaining less than 65 ft (20 m) horizontally separation within 20 secs. (and usually less than 5 secs.) of each other maintaining level flights with a pitch less than 2 degrees. The data that was collected gave a clear indication that new insights into aerosol-cloud-radiation interactions could be achieved with these 3-UAV stacked flights[8],[9],[10].

Approximately 8 different sensors were flown in the stacked formation to collect the required data. The top and bottom UAVs had similar payloads but the middle UAV required a different payload as this UAV collected data from within the cloud. Figure 11 shows the in-cloud UAV equipped with the cloud droplet sensor mounted on top of the payload in "clean" air with the below and above cloud UAVs in the background. Several modifications were made to the sensor placement and the fuselage as the sensors were test flown and the data was collected.

Figure 11. The in-cloud Manta UAV showing the cloud droplet probe on top (front) and above and below-cloud UAVs (behind), prior to take off.

Early flights with the initial motor exhibited extreme vibration and so a two cylinder opposing piston motor was installed which reduced the vibration considerably. The pyrenometers that measured total radiation (one looking upwards and the other downward looking) were mounted through the fuselage[11]. Thermal changes to these sensors measured in early test flights resulted in a design change that forced air to flow both over and under the sensor thereby keeping the thermal gradient across the sensor to a minimum and improving the sensor fidelity. Difficulty in estimating the position of the middle UAV with respect to the cloud, particularly when flying out of visible range, prompted the installation of a small video camera as shown in Figure 12 together with multiple aerosol measuring probe inlet tubes.

Figure 12. Payload for the in-cloud UAV showing the cloud droplet probe and total water probe on top of the payload with the transmitting antenna, video camera and three aerosol sampling probes at the front of the payload.

This approach for data gathering from UAVs is relatively new and the performance information that was gathered each time a sensor was integrated and test flown was large. Many of the system improvements described herein were made only weeks before the UAVs were shipped to the Maldives and if that deadline had not been present, further improvements would have been made, to "perfect" the system.

The MAC campaign signified the first successful step in transitioning Dr V. Ramanathan's dream and vision into a reality. Through a continued collaboration between the scientists and producers of UAVs and the initial success of the MAC campaign it is possible in the future that hundreds of light weight UAVs will be documenting how human beings are polluting the planet and hopefully provide an early warning system for potential environmental disasters in the future.

LESSONS LEARNED

It is clear that UAVs offer a powerful technical capability for data collection and that the limitations of this capability are as yet undefined. The technology is particularly suited for repetitious surveillance, routine or targeted data gathering, as well as for its ability to collect data in hostile and dangerous environments without risk to human life. There is also a significant overall cost benefit in the use of UAVs. Both government and scientific customers have embraced this technology but sometimes underestimate the development required to establish a UAV based data gathering capability that meets their specific needs. Issues with electro-magnetic interference, georectification of data, environmental concerns and the sheer volume of data that can be collected, but not accessed in real time with conventional wireless modem links are but a few of the issues that need consideration.

Our approach has been to train the customer as an operator wherever possible so that they have complete control over mission planning, execution and data gathering. This is preferred when dealing with military customers but often not practical for individual scientific endeavours. It is expected however that this will change as the UAV systems become even more user friendly and automated. There are a number of generic steps that should be given consideration in providing a UAV based capability to a customer;
Communication with the customer during the planning and development period is extremely important to define expectations and collaborate in sensor integration, which is often an iterative process. This helps narrow the gap between what the customer imagines the final outcome to be and what is actually delivered.

Demonstrate the UAV capability with the customer in as realistic a flight environment as possible. Often these first flight tests are an enlightening experience for the customer, and illustrate what the expected data stream might be as well as providing a better understanding of other issues such as environmental impact, safety, identifying problems and possible limitations in the scope of the effort. Again, these first exercises often result in changes in both the design and customer expectations with a possible replanning of the desired mission.

It is important to balance the development with the schedule. Improvements should be made only in the development phase and at some point prior to the final acceptance flight by the customers, the final version of the design should be frozen. This is important to let the operator build some level of experience in how the final configuration performs and to limit the number of “unknowns” that can be designed into the UAV at the last minute. For military flights this is not an issue since the vehicles require certification, in-part to limit this type of problem.

Application for Naval Certification for UAVs is a thorough and time consuming process and is not always conducive with the typical spiral development efforts that are usually ongoing. For each change made to the UAV, additional testing and evaluation needs to be performed together with an updated application containing a complete and up to date documentation which details the changes as well as updated Technical Manuals and Operator Checklists. Every time a change is made, the flight certification process starts over. NAVAIR must ensure that any changes to the aircraft, do not affect other operational components that have previously been tested. Certification is often delayed due to these continuous improvements. Early submittal is recommended, but the final design and documentation must be complete in each case.

The demonstration of a successful UAV capability is usually the result of a long relationship where the UAV sensor integration has been through several iterations and the initial requirements modified in some way to incorporate what has practically been demonstrated. It is often better to be somewhat conservative in delivering a proven capability and where possible to perform simple tasks rather than complicate the mission unnecessarily. Accidents usually happen due to the use of unproven equipment or through a series of unique events, or environmental conditions not previously encountered. In the Maldives the original objective was to fly offshore 100 miles (160 km) in an air mass that was unaffected by any nearby land mass. The UAVs were equipped with satellite links but they had not been tested at this distance. As events unfolded and the initial experimental data collected was analyzed, it was discovered that the data 5 miles (8 km) offshore was very good and contained all the necessary elements with little influence from the island of Hanimaadhoo. It was quickly determined that the importance of successfully collecting multiple, synchronized data sets far outweighed the risk of demonstrating data collection in an even more remote location. Additionally, the required flight duration was originally estimated at 6 to 8 hours which was possible from the Manta UAV. However, with a full payload of sensors and significant changes to the fuselage with protruding sensors which increased the drag significantly, the 6 to 8 hour flight duration remained unproven. In practice, it was found there was a natural window of between 3 and 4 hours where we had flight clearance between the morning and afternoon commercial flights on and off the island. Again, a more conservative decision to fly for only 4 hours was wisely made after discussions with all relevant parties to assess the risks.

The Howler exercise was in many ways more of an incremental demonstration in linking several aspects of UAV operations that had been previously proven, together in a single exercise. Due to the certification process and operating practices under which the military are bound this exercise successfully demonstrated the operation of multiple UAV types from a single seaborne operating station (Stiletto) and provided an environment where separate missions were carried out simultaneously. It also provided a forum where autonomous UUVs, USVs and UAVs of this type, successfully performed collaboratively for the first time. As with all missions, planning and practice is beneficial and helps provide an established and reliable capability.

CONCLUDING REMARKS

Around the world there is a growing interest in the use of UAVs of all types. The Silver Fox, Manta and Coyote systems offer relatively high performance versions of Tier II UAVs for which customers can be trained to operate independently if required. Although rapidly becoming more capable and autonomous, differences often exist between the customers requirements and current UAV capabilities. In providing the customer with a product that meets their requirements it is important to enter into discussions and collaborative testing to ensure expectations are met and to plan for the required authority to fly.

In the US, certification of the aircraft is a process that should be applied for early, once the final design of the aircraft is complete. This process is a necessary evil that will allow, in the future, approval of certificates of authorization (COA) from the Federal Aviation Authority (FAA). These COA allow the owner of the certified UAV to fly in designated locations throughout the USA. Other countries have their own flight authorizing agencies which must be involved. Currently, there are two distinct methods to apply for certification.

The first method involves submitting paperwork through the FAA about the aircraft in question. After a thorough review of the paperwork by an FAA inspector, a team of experts will schedule a short demonstration of the aircraft with the manufacturer. At this demonstration, the flight crew will be asked to perform specific maneuvers in order to verify the accuracy of the submitted paperwork. Following this, the FAA will grant experimental airworthiness certification (EAC) for that specific aircraft. Keep in mind that currently, certification in this manner only applies to the aircraft serial number that was flown for the demonstration.

The second method involves the certification branch of the Military. Each different service requires different items for airworthiness certification. For the Silver Fox, the US Navy began certification through their Air Systems Branch, NAVAIR. NAVAIR certification follows much the same route as the FAA certification, with two major benefits: the aircraft are proven within the military, the entire platform is granted certification versus a single airframe.

There is a growing interest in the use of UAVs for the gathering of scientific data, particularly in light of the newly found United Nations (UN) report on Global Warming. The development of UAVs for military use will also continue to grow. In conclusion, I'd like to finish with a quote from a UAV Mission Commander operating in Afghanistan, which summarizes the impact of Tier II type UAVs in theatre.

"Mid-endurance UAV assets have been a key to providing real time intelligence to the tactical ground based commanders in Afghanistan. Deployed before Coalition Forces arrive they provide pattern of life analysis and situational awareness to our forces. The UAV has the ability to cover a widely dispersed area that greatly narrow the time the enemy would be able to prepare strikes against Coalition Forces.

The UAV platform has proven to be critical in filling a significant void of intelligence in around a key volatile area in southern Afghanistan. This area is a main sanctuary for Taliban, and the UAV has been successful in providing tactical commanders an invaluable tool to find, fix and destroy enemy forces. The tactical commanders have real time video provided to them and have the ability to direct the UAV assets via SATCOM. In turn the UAV operator is able to provide real time movement of enemy forces. The UAV operators working with the JTAC (Joint Terminal Air Controller) are able to identify and tactically destroy enemy forces using CAS (Close Air Support) assets. The UAV has also proven to provide instant BDA (Battle Damage Assessment) as *well. This BDA assessment is critical in follow-on tactical decisions by the ground based commander.*

Clearly we have been instrumental reducing friendly casualties, and destroying enemy assets".

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