Final Report

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Georeferencing Capabilities and Operational Missions of the Nova 2 Small Unmanned Aircraft System

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Executive Summary:

Four Nova 2 small unmanned aircraft systems (sUAS) were delivered to the U.S. Army Corps of Engineers, Jacksonville District (USACE) in early 2009. The Nova 2 airframe increased the technical capability of the program, and brought us closer to realizing goals that we only dreamed of accomplishing. The Nova 2 was able to repeatedly deliver 45 minute sustained operational missions over Lake Okeechobee, while gathering high resolution imagery and data for post processing. Improvements in the georeferencing hardware and software also helped position the Nova 2 substantially above any of its competitors. The imaging platform was equipped with its own inertial measurement unit (IMU), increasing both the accuracy and precision of the imagery data collected. The Nova 2 proved to be a durable airframe for repeated takeoffs and landings, including several repeatable safe water landings.

During the spring and early summer 2009, the Nova 2 was able to conduct aerial imagery missions over 2,700 ha of invasive aquatic vegetation in Lake Okeechobee, as well as over several nesting wading bird colonies in Loxahatchee National Wildlife Refuge. These large imagery datasets have been archived, and will be used for time-elapsed comparisons with data scheduled to be collected in future years.

It became apparent in mid-2009 that the Nova 2 sUAS had several shortcomings that limited its continued use. Weaknesses in the water-proofing and aerospace design led to the decision of building an alternative airframe that incorporated the positive features of the Nova 2 with additional engineering to produce the Nova 2.1. During the fall of 2009, the majority of the

project's efforts were focused on the design and construction of the Nova 2.1 airframe. Templates and molds were fabricated to help in the production of Nova 2.1 aircraft in-house; improving the speed and efficiency of future airframe construction efforts.

The Nova 2.1 aircraft is considerably lighter, stronger, and more aerodynamic than its predecessor. These features allow the current aircraft to fly more efficiently, for longer duration, and at slower speeds. Redundant water proofing features and technical improvements promise to make the Nova 2.1 a workhorse for future operational missions.

Objectives:

1) *To further advance the Nova 2 sUAS platform through structural airframe changes, and potentially integrating new imaging sensors.*

   The Nova 2 sUAS platform was successfully used to collect imagery data over several areas of Lake Okeechobee that were treated with herbicide to eradicate invasive vegetation, and over nesting bird colonies in Loxahatchee National Wildlife Refuge. It became apparent with continued use that the Nova 2 airframe was too heavy for the wings and control surfaces it was provided with, and that it had several design flaws that allowed water to enter the fuselage. We had several crashes due to wing overloading, and electrical shorts due to water intrusion. The airframes were retrofitted with additional water-proofing measures, but we could not successfully remove enough weight from the avionics and payload to ensure reliable flight. The development of the Nova 2.1 was a result of the UF UAS Research Teams' suggestion to the USACE that continued use of the Nova 2 would result in failures over time.

   A critical problem that we solved was the merging of the optical payload integration team with the aircraft design and construction team. The Nova 2.1 fuselage and wings were designed around the optical payload and avionics. This helped advance the reliability of our airframes, and has left us room to add additional sensors in the future. The new wing design is much lighter, and more efficient through all phases of flight. The new fuselage was designed with redundant waterproofing techniques, and fewer places for water to potentially enter. The Nova 2.1 is much lighter, and therefore can fly longer, and at slower airspeeds than the Nova 2; a substantial advantage for aerial imagery.

   The Nova 2 optical payload was equipped with the Olympus E-420 digital SLR camera; the smallest and lightest digital SLR on the market at the time. Shortly after our development of the Nova 2.1, Olympus debuted its newest digital SLR, the E-P1. We obtained an E-P1, and our Geomatics team ground-tested its capability with the E-420. They were impressed with its smaller size, and lighter weight, however, its imagery was considerably worse than that of the E-420. The team decided to stick with the E-420 as our optical platform.

2) *To define the georeferencing capabilities of the Nova 2 sUAS, and report on specific aquatic invasive operational missions for the USACE at the Indian Prairie Canal area of Lake Okeechobee.*

The optical payload consisting of an Olympus 420E digital SLR camera with a 25 mm pancake lens, and XSens MTi-G GPS/INS, delivered images with 2.5 cm resolution and <0.5 m positional accuracy at 100 m altitude. These results were a substantial improvement from the 68 m positional accuracy that our team had with the previous payload and processing algorithm.

The invasive aquatic vegetation studies over the Indian Prairie area of Lake Okeechobee consisted of flying the Nova 2 UAS over areas of floating aquatic vegetation just prior to, and a short time after being sprayed with herbicides. Invasive vegetation species of interest included but were not limited to water lettuce (*Pistia stratiotes*) and water hyacinth (*Eichornia crassipes*). Aerial imagery of 2,700 ha of treated vegetation showed distinctive patterns where herbicide was effectively applied, as well as areas that were missed. Armed with these data, ground-based herbicide crews were able to go back and treat areas that were missed during the initial aerial treatments. It is anticipated that flights over the sprayed areas one year later may indicate that native vegetation will have replaced areas previously choked with invasive vegetation species.

3) *To further refine the georeferencing capabilities of the Nova 2 sUAS and its processing algorithm solutions. Additionally, we plan to report on individual sources of georeferencing error, and potential resolutions to these limitations.*

The direct georeferencing processing algorithm was able to process images with 2.5 cm resolution and <0.5 m positional accuracy at 100 m altitude. This was a huge gain in positional accuracy that can be attributed to the addition of a GPS/INS to the optical payload, and the refinement of the processing algorithm.

The sources of georeferencing error are primarily in the synchronization of the camera shutter with the GPS timing signal. There are also errors in the GPS/INS position and orientation parameters that contribute to the error as well. A set of collinearity equations was developed to help reduce the georeferencing errors and seam errors between images helping to make much more accurate mosaics. GPS provides both a position and velocity update which can be used to bound the growth of error in the INS solution. This is particularly effective due to the complimentary characteristics of the two systems: GPS error is dominated by short-term white noise whereas the INS error is dominated by long-term drift. On the other hand, GPS provides relatively low-frequency updates whereas INS is typically operated at 100 Hz or more. There are a variety of performance gains by integrating the two systems, but perhaps the most important is the ability to make the bias errors of the INS observable, allowing them to be compensated for.

4) *To use computer-aided feature-recognition algorithms to assist in identification of specific targets within images. Development of sampling protocols is anticipated to reveal a measure of variance such that statistical inferences might be made on changes observed.*

   Feature-recognition algorithms were used to help construct larger scene mosaics out of the individual images captured with the UAS. These algorithms identify potential tie-points within adjacent images, and massage them into larger georeferenced products. Due to careful flight preparation on the ground before a mission is flown, flight paths are constructed to maximize image overlap in both the front-to-back, and side-to-side directions based on the direction and magnitude of the winds aloft at the time of the mission. This pre-flight planning helps the autopilot onboard the aircraft maintain altitude and orientation; consequently, image acquisition maximizes the likelihood of tie-point generation during post-processing.

   Based on flight experience, we ascertained the importance of flying the UAS mission transects directly into the prevailing wind over the target area. By flying into the wind, the aircraft is able to considerably slow its ground speed, producing much more forward overlap in the imagery, and improving tie-point generation opportunities. Due to our fixed image acquisition rate of approximately 2.5 seconds between image captures, the downwind legs of a mission usually end up with gaps between images, therefore these transects are routinely flown outside of the target area of interest.

   Future computer-aided feature-recognition algorithms will be used to analyze the georeferenced mosaic products based on adjacent pixel coloration statistics, and eventually texture analyses. These feature-recognition algorithms are still in development and refinement at this stage of our post-processing. We hope to be able to generate data that can then be used for statistical analyses of the target areas.

5) *To generate an operational flight planning manual for conducting Nova 2 sUAS missions over invasive vegetation infestations in Lake Okeechobee using the Procerus® Technologies autopilot system.*

System Operator's Manual

Nova 2 Unmanned Aircraft System

A joint collaboration between:

Unmanned Aircraft Systems Research Project

University of Florida

Gainesville, Florida

and

U.S. Army Corps of Engineers

Jacksonville District

Jacksonville, Florida

Version 1.2

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Abbreviations

AC	alternating current
AGL	above ground level
ATC	air traffic control
ATIS	automatic terminal information service
DC	direct current
DoD	Department of Defense
ESC	electronic speed control
EO	electro-optical
F	Fahrenheit
FAA	Federal Aviation Administration
ft	foot
GCS	ground control station
GHz	gigahertz
GPS	global positioning system
in	inch
kW	kilowatt
LED	light-emitting diode
LiPo	lithium-polymer
LOL	loss of link
LOS	line of sight
m	meter
mAh	milliampere-hour
min	minute
mm	millimeter
mph	miles per hour
mW	milliwatt
NAS	National airspace system
NOTAM	notice to airmen
NTSC	National Television System Committee
sec	second
SLR	single-lens reflex

sUAS	small unmanned aircraft system
TIR	thermal infrared
UA	unmanned aircraft
UAS	unmanned aircraft system
UF	University of Florida
US	United States
USACE	United States Army Corps of Engineers
V	volt
VHF	very high frequency

Introduction

The UF UAS research program has conducted investigational missions utilizing UA since 1998. In over a decade, the research program has executed hundreds of autonomous aircraft flights without a single incident resulting in property damage or personal injury. The perfect safety record of the UF UAS research program is due in part to careful attention to detail, and well-qualified operators.

The Nova 2 UAS was developed by UF scientists and engineers for the purpose of natural-resource monitoring and aerial surveys in support of ecological research. Major structural and electrical components, such as the airframe design, optical payload, and autopilot system, have a developmental pedigree spanning the last ten years.

The importance of safety throughout the history of the UF UAS research program cannot be overemphasized. Although the use of UAS offers many potential advantages—mission flexibility, portability, and overall cost savings—the greatest advantages offered to the field researcher are aerial surveys with improved accuracy and increased personal safety.

This manual details the Nova 2 UAS, its subsystems, as well as protocols for nominal operation and situational emergencies.

System Description

The Nova 2 is classified as a sUAS based on the aircraft weight and size, and is designed for operation in field sites lacking runways or large open spaces. The aircraft is hand-launched, operates autonomously to fly designated mission paths, and is recovered under non-autonomous, manual control. The system can be prepared for flight rapidly, and turnaround time between missions is short allowing many flights to occur in an operational day.

The Nova 2 UAS consists of an UA, a GCS, and the communication and support equipment required for its safe operation. All missions are conducted with a trained two-man crew consisting of an UA operator and a GCS operator. Training protocols for these crewmembers can be found in Appendix A.

Specifications

Feature		Specification
Length		1,650 mm
Wingspan		2,507 mm
Height		370 mm
Weight	w/batteries, no payload:	3,000 g
	nominal (w/ payload):	4,000 g
	maximum launch:	4,900 g
Speed	cruise:	15 m/s
	maximum (dash):	40 m/s
	stall:	10 m/s
Ceiling	nominal:	300-500 ft AGL
	operational maximum:	1,200 ft AGL
Range[1]	maximum, w/ batteries, no payload:	30 miles
	maximum, w/ payload:	15 miles
	operational maximum:	1 mile from GCS
Endurance[2]	no payload:	1.25 hr
	nominal (w/ payload):	1.0 hr
Link Range[3]	GCS—UA (uplink):	5 miles
	UA—GCS (downlink):	5 miles
Construction	fuselage:	carbon-fiber

	hatch:	fiberglass
	wings:	fiberglass over foam
	tail boom:	fiberglass over foam
Power	type:	electric
	source:	4,200 mAh LiPo batteries
Propulsion	motor:	1 kW brushless outrunner
	propeller:	10 in diameter, fiberglass
	position:	high-mount, pusher
Autopilot	manufacturer:	Procerus Technologies
	model:	Kestrel 2.2x
	GCS software:	Virtual Cockpit 2.4

Notes:

1. Specifications are theoretical one-way maximums assuming a mobile ground station is used. Operational protocols require that the UA operates within a one mile LOS of the UA and GCS operators. System failsafes in the autopilot software designate that the UA will not fly beyond the operational range.
2. Specifications are based on operation with lithium-polymer batteries having 4,200 mAh capacity.
3. Specifications are determined by the component manufacturer. No airborne testing has been conducted by UF to verify these figures.

Airframe

The Nova 2 UA is constructed primarily of composites for high strength and low weight. Wings and tail surfaces are fiberglass-over-foam, while fuselage is constructed by hand lay-up techniques in fiberglass, carbon fiber, and aramid fiber. Carbon-fiber tubes comprise the tail boom, wing joining/reinforcing structure, and wing attachment points. Wings are attached by the use of 10 to 12 high-strength rubber bands. This method of attachment is very strong but also elastic, providing for some vibration-damping during flight as well as allowing for some “give” in the event of a hard landing or in case of a landing mishap such as cartwheeling. In the latter two cases the rubber bands stretch and may even break away, absorbing some impact energy and reducing the chance of damage to the wings, fuselage, or objects on the ground.

Propulsion is achieved with a 1 kW brushless outrunner-type electric motor spinning a 2-blade, 10 inch diameter propeller constructed of glass-reinforced nylon. Motor/propeller position is located above the fuselage, providing extra safety during range operations and launching as well as increasing control authority during periods of low airspeed/high throttle. Rechargeable LiPo battery packs which can be rapidly exchanged through the fuselage hatch provide a reliable power source. Battery packs containing LiPo require special handling and storage; refer to Appendix B for additional detail. A single battery pack provides power to all aircraft systems and payloads via a power-distribution board designed to ensure safe operation of the aircraft. In the event of low battery power, priority is given to the operation of the UA radio receiver and control surfaces, followed by the motor, and lastly to the sensor payload.

The Nova 2 UA was designed as a stable and efficient platform for low-speed aerial surveys. As a result, its design gives it flight characteristics similar to a radio-controlled trainer or sailplane. If a motor failure were to occur, the UA operator can easily perform a controlled landing to avoid creating a dangerous situation on the ground. In the event of a complete power failure, the inherent stability of the Nova 2 would result in a shallow glide to the ground at slow speed (i.e. less than 40 mph) rather than a steep dive. In this manner even a catastrophic power failure is very unlikely to result in damage to objects on the ground or the loss of the UA to damage.

Based on the need to operate in close proximity to bodies of water, the Nova 2 airframe was constructed to be water-resistant. The fuselage was constructed with multiple water-barrier features, and critical electronic components (e.g. autopilot unit, GPS, ESC, receiver) are further protected from moisture by airtight compartments. These construction features provide the ability for the Nova 2 UA to be operated in high humidity without damage, as well as the ability to be recovered on the surface of a lake, similar to a seaplane. However, it should be noted that the Nova 2 UA was not designed for routine amphibious operations. Amphibious recovery increases the risk of component damage, and precautions should be taken to minimize these risks prior to conducting operations in which a chance of amphibious recovery is predicted.

Avionics and Electronics

Non-autonomous flight control is achieved using a Spektrum DX7 spread spectrum radio and receiver combination (see Appendix C). Spektrum technology reduces potential glitches from radio interference by employing frequencies in the 2.4 GHz radio band, and using a unique coded identifier with over 4.2 billion possible combinations.

The Nova 2 uses a Procerus Technologies Kestrel autopilot system to enable autonomous operation. For comprehensive instructions on the features, operations, and technical specifications of the Kestrel autopilot system, refer to Appendix D and Appendix E. A user-defined flight path is loaded into the autopilot's memory prior to flight, and the Nova 2 UA will follow the flight path to a degree of precision greater than that at which a human pilot is capable. A flight path may be modified at any time during flight, and the GCS console may be used to immediately issue orders for the UA to: 1) return to a predetermined point or to the GCS location; 2) loiter around a given point at a specified altitude; or 3) automatically land. The auto-land option is least preferred because the UA operator is better able than the autopilot to select appropriate landing sites and to avoid obstacles on the ground that may cause damage to the aircraft. Failsafe features incorporated into the Kestrel autopilot software include LOL and low-battery emergency plans. Also, for added safety, the UA operator may override the autopilot at any time during flight.

Video and payload signal transmissions from the Nova 2 UA are facilitated by a 1000 mW Aerocom modem and a 1000 mW transmitter operating at a frequency of 2.4 GHz. The video transmitter carries a signal from the forward-looking camera as well as any imaging systems carried as payload.

The avionics and electronics of the Nova 2 UAS are not designed to be repaired or serviced by an end-user. For maintenance or repairs, the system should be returned to UF or Procerus Technologies.

Payload

A forward-looking, NTSC-resolution analog video camera with an approximate field-of-view of 60° allows real-time video transmission from the Nova 2 UA to the GCS. This video system increases situational awareness while the UA is in flight, and adds an additional method for crew members on the ground to scan the UA's flight path for potential obstacles. By virtue of the camera's resolution and the slow cruising speed of the Nova 2, large objects in the flight path of the UA can be seen with sufficient notice to reprogram the UA's flight path with the GCS to avoid them; however, a preferred course of action in the event an obstacle-in-view is for the UA operator to assume manual control or the aircraft, and maneuver the UA to avoid incursion.

A variety of lightweight payloads can be carried in the Nova 2 UA. Currently the airframe is configured to accept one EO and one TIR payload. The EO payload consists of a commercial, off-the-shelf Olympus E Volt 420 digital SLR camera (see Appendix F) with a Zuiko 25 mm f2.8 pancake-type lens and incorporated digital shutter-control device. The remote shutter-control device allows the digital camera to be actuated remotely or by a signal from the autopilot.

Available power for payloads is 5 V DC, distributed from the primary UA battery. Payloads powered by their own battery may be carried as well. A plethora of other payloads could potentially be carried, within the limitations of weight and size dictated by the Nova 2's capacity.

Ground Control Station

The Nova 2 GCS consists of a wireless video receiver, an autopilot communications module, and a laptop computer for operating the Kestrel Virtual Cockpit software. An independent auxiliary computer monitor is used for simultaneous viewing of video imagery from the UA while running the Virtual Cockpit software.

Antennas for the GCS are mounted on a camera tripod in a vertical orientation. When the GCS is located on a vehicle or a boat, the antenna and connecting cable are positioned in such a way as not to interfere with operation of the vehicle or with movement of personnel.

A reliable power system is essential for the safe and dependable operation of the Nova 2 UAS. A system of batteries and inverters are employed to deliver 120 V AC for the operation of the GCS while in the field.

Additional Equipment

Additional required equipment for operation include: two-way radios for crew communication, a VHF radio for communication with ATC, a weather radio, an additional 12 V DC automotive or marine battery for charging the LiPo aircraft batteries, repair tools and materials, and spare aircraft parts. Charging of LiPo batteries is achieved with a Tejera Micro Electronics Xtrema-model battery charger (Appendix G).

Personnel involved in Nova 2 operations are in communication prior to, during, and after missions. Although communication products and procedures are outside the scope of this manual, appropriate two-way communications devices are considered indispensible items in the inventory of a Nova 2 operations team. A VHF radio is essential as a means of contacting local ATC, or the pilots of any manned aircraft that should happen to enter the area of local operations. Likewise, a means to monitor both local weather conditions and weather forecasts via radio or Internet broadcasts is available at the site of ground operations.

Operating Protocols

This section provides details on operational protocols to be used when planning and conducting missions with the Nova 2 UAS.

One week prior to operation:

During the operation planning phase, ensure that the area of operation is clearly defined. The area of operation should envelop the flight path over which the Nova 2 UA will fly as well as sufficient additional area for turns and maneuvers, plus an additional safety margin as a buffer. The appropriate aviation sectional map should be consulted to determine the locations of any airports in the vicinity. Although not required when operating in Class G airspace (up to 1,200 ft AGL), longstanding UF UAS research program policy has included contacting nearby airports to inform them of an intention to operate the UAS in the vicinity of their facility.

A mission log sheet should be created as part of the planning process. Information that should be on the log sheet includes the following:

- Nearby airport locations and contact information (telephone and radio)
- Personnel assigned to the mission (name, contact information, etc.)
- Equipment needed for the mission (include the identification numbers or codes of airframes, computers, batteries, etc.)
- Details of the mission parameters (launch/recovery location, launch/recovery time, expected number of flights, etc.)
- Payload to be carried
- Last inspection date of airframe and equipment

24-48 hours prior to operation

During this phase of mission planning, all UAS equipment should be checked for operation/functionality/reliability and loaded for transport to operation site. All batteries should be charged to capacity, and properly stored for transport. A detailed analysis of the local weather forecast for the operational area should be monitored. NOTAM's in the operational area should be evaluated. Flight plans should be finalized, and uploaded to the autopilot prior to the mission.

Immediately prior to operation

Upon arrival to the operation area, all system components should be checked for damage as they are unloaded, and any damage should be repaired and noted on the mission log. Flight batteries to be used during the operational day should be topped off to maximum capacity, and communications equipment (i.e. two-way radios, VHF radio, and weather radio) should be checked for functionality. Waypoints and flight path should be uploaded to the GCS, and failsafe options of the autopilot software should be entered. Once the waypoints and flight plan are loaded into the GCS, another member of the flight crew should examine the entries and failsafes for errors. Local ATIS and NOTAM's (if applicable) should be scanned and noted on the mission log sheet. Nearby airports in the area should be contacted, and notified about the operational mission. Local weather conditions and a local forecast should be reexamined.

If the following weather conditions are observed, or are forecast during the operation timeframe, the mission should be postponed:

- Lightning in the vicinity (within 7 miles of the GCS or area of operation)

- Flight-level winds exceeding 25 mph, or ground-level winds exceeding 20 mph
- Rainfall (within 3 miles of the GCS or area of operation)
- Cloud cover below 1,200 feet AGL
- Visibility below 1 mile
- Temperature below 32° F

Pre-flight and pre-launch checklists as detailed in Appendix E should be followed, with minor alterations as noted:

- The radio transmitter for the Nova 2 is a Spektrum DX7 rather than the pad illustrated in Appendix E
- The nominal airplane battery voltage should be 18.0 V

Launch and mission operation

If the Nova 2 UA is launched from a moving platform, the speed of the platform should be sufficient to create an apparent wind of 15 mph over the UA wings. After the UA is launched, the UA operator will guide the aircraft to an altitude of at least 300 ft, and a location within glide range of a suitable recovery site should malfunctions occur during handoff to the autopilot control. Once this altitude and location are reached, the GCS operator will initiate the autopilot. If no problems are detected with the handoff, the UA will begin to fly its preprogrammed flight plan.

During the time that the UA is on course, the GCS operator will monitor the UA position by using the Virtual Cockpit software and the video telemetry transmitted by the UA to the GCS. If simple payload sensor operations are required to be initiated by the UA operator or the GCS operator, they can be performed at this time.

During the flight, the UA operator is responsible for maintaining visual contact with the aircraft and for scanning the airspace around the UA for the presence of any manned aircraft or potentially hazardous conditions. At no time should the UA be flown on or near major highways or heavily traveled secondary roads. Should any crewmember detect conditions requiring emergency action, the UA operator will acquire manual control of the aircraft and take appropriate action (see **Emergency Procedures**). For example, if a manned aircraft enters the operational area and appears to on a collision course with the UA, the UA operator will take command of the UA, decrease its altitude to 200-300 ft AGL, and adopt a heading that directs the UA away from the path of the manned aircraft. The GCS operator will immediately assume the responsibility of using the VHF radio to make contact with the manned aircraft and local ATC.

The final waypoint, or rally point, should be designated to be within 100-200 ft of the GCS location at an altitude of 200-400 ft AGL. Once the UA as completed the entire flight path, the UA should be directed to fly to this location (automatically, or by the GCS operator if necessary) for handover to manual flight control by the UA operator. The GCS operator will then assist the UA operator in determining that the area chosen for recovery is safe, and cleared for landing, at which time the UA operator will land the aircraft.

Post-mission

Following each flight, detailed information should be noted on the mission log. All equipment used during the mission should be inspected and returned to its appropriate storage locations. The exterior and interior of the Nova 2 UA should be inspected for any damage, and any water or debris should be removed. If the UA was recovered on water or in a humid environment, the rear pitot tube assembly plug should be removed, and a crewmember should gently blow into the pitot tube (at the nose of the UA) while holding the UA at an upright and slightly nose-high attitude. This procedure will allow any water in the pitot tube assembly to be cleared, and will prevent the movement of water into the sensitive autopilot components. After the pitot tube is cleared, compressed air should be used to blow any residual water from the electric motor, and a corrosion-inhibiting lubricant (such as WD-40) should be liberally sprayed into the motor. The rechargeable LiPo battery pack should be removed following each flight.

Emergency Procedures

The following events or conditions require immediate action as stated to correct or prevent a dangerous situation:

Loss of communication

In the event of a communication loss between the UA and GCS, the GCS operator will attempt to restore communication with the UA. Normally, a loss of communication triggers a preprogrammed response of the autopilot to level the UA, and then to return it to the predetermined rally point. If operations are taking place in sufficient proximity to an airport in which the uncommunicative UA could potentially fly into its airspace, the GCS operator will contact the airport and inform the local tower of the UA’s last known position, speed, direction, and condition. If communication is restored, the GCS operator will command the UA to return to the rally point at which time the UA operator will assume manual control and land the aircraft.

Loss of battery power

Should battery power become critically low, the GCS operator will issue a "return home" command to the UA, along with gradually decreasing altitude commands as the UA approaches the GCS. Once the UA is easily visible to the UA operator, he or she will assume manual command of the aircraft and attempt to recover it safely.

Communications interference

In the event of interference to communication that causes intermittent or undesired UA operation, the autopilot's failsafe behavior will initiate maneuvers to regain contact with the GCS. If no contact is regained after 20 sec, the UA will initiate an automatic landing procedure.

Manned aircraft in vicinity

If the crew observes a manned aircraft entering the operational area and appears to be on a collision course with the UA, the GCS operator will attempt to contact the manned aircraft via the VHF radio. Additionally, the GCS operator will contact local ATC. Meanwhile, the UA operator will take manual control of the UA and change its course and altitude to avoid the manned aircraft.

Severe weather

Should the weather conditions rapidly deteriorate below the threshold for Nova 2 operations, the crew will attempt to command the UA to return to the GCS for recovery. If conditions prevent safe return of the UA to the rally point (e.g., extremely high winds, waterspout), the GCS operator will initiate an automatic landing procedure. Upon landing, the GCS operator will note the last known position of the UA based on GPS telemetry, and recover the aircraft.

Maintenance/Inspection

After each flight, the condition of the airframe and external components (control surfaces, motor, propeller, etc.) is noted, and any damage is logged and repaired if possible. Any worn or loose parts are noted in the system log and replaced.

Beyond routine inspections that should be conducted before each flight, an additional maintenance and service schedule for the Nova 2 UA is recommended:

Every 10 hours of flight time (service to be completed by field operators):

- Motor mount screws tightened
- Waterproof seals inspected
- Internal components and connections inspected
- Wing mounting rods inspected
- Tail-mounting hardware tightened
- Propeller removed and inspected for proper balance

Every 100 hours of flight time (service to be completed by UF engineers):

- Motor replaced
- Propeller replaced

- Waterproof seals replaced
- Servos removed, tested, and replaced if necessary
- Connectors from the ESC to battery replaced
- Any structural damage repaired

Appendices

Appendix A: UAS Training Manual (UF UAS Research Program)

Appendix B: Lithium Polymer Battery Usage (Procerus Technologies)

(http://www.procerusuav.com/Downloads/Manuals/LithiumPolymerUsage.pdf)

Appendix C: Spektrum User Guide (Spektrum Technologies)

(http://www.spektrumrc.com/ProdInfo/Files/SPM2710_DX7_Manual.pdf)

Appendix D: Kestrel User Guide (Procerus Technologies)

(http://www.procerusuav.com/Downloads/Manuals/Kestrel_User_Guide.pdf)

Appendix E: UAV Flight Guide (Procerus Technologies)

(http://www.procerusuav.com/Downloads/Manuals/UAV_Flight_Guide.pdf)

Appendix F: Olympus E-Volt 420 User Guide (Olympus)

(http://www.olympusamerica.com/files/E-420_Instruction_Manual_EN.pdf)

Appendix G: Xtrema Manual (Tejera Microsystems Engineering)

(http://www.tmenet.com/pdf/Xtrema%20Manual%201-3-0.pdf)

Appendix A

UAS Operator Training Manual

University of Florida Unmanned Aircraft Systems Program

Gainesville, Florida

Version 1.1

October 2008

Background and Purpose

The rapidly-expanding demand for UAS for non-military roles has led to intense demand for the integration of UAS into the National Airspace System (NAS). The FAA currently provides avenues for legal UAS operation in the NAS; however, a standardized procedure for the rating and qualification of UAS operators (analogous to that for manned aircraft) does not yet exist. The development of standard UAS operator qualifications would enhance the safety of UAS operations, and would improve the confidence of non-UAS stakeholders in the ability of UAS to be safely integrate into the NAS.

The USGS Florida Cooperative Fish and Wildlife Research Unit and University of Florida have conducted investigational missions utilizing UA since 1998. In over a decade, the research program has executed hundreds of autonomous aircraft flights without a since incident resulting in property damage or personal injury. The perfect safety record of the UF UAS research program is due in part to careful attention to detail, and well-qualified operators.

This training document serves multiple purposes. First, it expands upon, and formalizes training procedures used at the University of Florida. Secondly, the training program provides a means for other potential UAS operators, such as the US Army Corps of Engineers—with whose collaboration this document is written and with whom the University now works on a variety of UAS projects—to achieve UA operator rating. Finally, this document is a contribution to the growing civilian UAS community. It is hoped that it will serve as a resource for other agencies and organizations who wish to develop their own UAS programs.

Introduction

The intent of the training protocol described in this document is to produce skilled operators of small unmanned aircraft systems (sUAS) operated under restrictions of weather, proximity, and altitude such as those described in a 2007 Memorandum of Agreement for between DoD and FAA concerning UAS. The University of Florida's UAS program has operated with the vision of sUAS operating in remote areas, at low levels, within reasonable proximity of the ground-based operator to ensure reliable communication. Inspired by that vision and the current operational restrictions of DoD sUAS in the NAS, this training protocol should be considered applicable within the following guidelines:

1. The unmanned aircraft (UA) component of the UAS should weigh no more than 20 pounds fully loaded for a mission.
2. The UA should be operated within Class G airspace, below 1,200 feet (365 meters) above ground level (AGL).
3. The UAS should be operated during daylight hours, when the cloud ceiling exceeds the maximum altitude of the planned mission, and visibility is at least one mile.
4. The UA is operated within one mile line-of-sight of the ground control station (GCS). Note that the GCS may be located on a mobile platform, such as a boat, which allows the takeoff and landing points of the UA to be located more than one mile apart.
5. The UAS mission operation area is either uninhabited by people, or is inhabited so sparsely that the likelihood of a crash resulting in damage to people or property is nearly nonexistent.

The above restrictions are not exhaustive; others will be covered elsewhere in this training manual. The limitations set forth above, however, paint a picture of UAS operations that take place in relatively small areas and far away from populated areas. Small UAS operations have the same high requirements for safety as those of larger UAS; however, the training requirements are different. This training protocol provides a method for achieving safe operation of sUAS.

Crewmember Roles

Safe operation of any UAS mission requires a two-person team: a GCS operator and a UA operator. The primary roles of each of these positions are described as follows:

GCS Operator:

The GCS operator prepares the aircraft's flight path and failsafes prior to launch and monitors the progress and condition of the aircraft during flight. Perhaps the most important responsibility of the GCS operator is constant and efficient communication with the UA operator, who may need to be warned of a hazardous condition or request assistance with little notice.

Generally, it is the GCS operator who formalizes a conceptual mission path into a flight plan using the Virtual Cockpit software. He or she is responsible for discussing the primary flight path and any contingency routes with the crew prior to launch. The GCS operator is also equipped to contact local ATC or other aircraft with a VHF radio should these communications become necessary.

The GCS operator checks the UA prior to launch to ensure that all systems are nominal.

UA Operator:

Analogous to the pilot of a manned aircraft, the UA operator is ultimately responsible for the safe conduct of the mission, and must be sufficiently familiar with the UAS to ensure its safe operation.

Prior to the mission, the UA operator is responsible for loading the payloads and batteries into the aircraft, and reviews the mission plan, including any alternate flight paths as well as logistics that may affect all flight operations. The purposes of such reviews include, but are not limited to, the following: checking that the that the flight plan remains within safe and permitted altitudes; checking that all turns incorporate sufficient radii; line-of-sight distances are maintained; ensuring that the flight parameters fall within regulatory guidelines; and confirming that contingency flight and logistics plans are sufficient to allow for the safe continuation of the mission or recovery of the aircraft should they be implemented.

The UA operator reviews weather forecasts for the mission area to ensure that conditions are favorable during the mission. Additionally, the UA operator is responsible for identifying the locations of the nearest airports (with respect to the area of operation) from which manned aircraft flights may originate. The UA operator makes the determination of whether to contact airports near the operational area to request that a Notice to Airmen (NOTAM) be posted.

From launch to landing, the UA operator remains in visual contact with the aircraft at all times. During manual operation, the UA operator controls the aircraft via radio-control.

Manual operation is typically used for takeoff climb and landing procedures. While the UA is operating under autonomous operation, the UA operator has the ability at any time to regain manual control. After landing and between missions, the UA operator inspects the aircraft for damage and is responsible for ensuring that any needed maintenance or repairs are performed.

Rating Qualifications

The requirements for ratings at each level are as follows:

R/C Operator:

- Complete Training Phases 1 and 2
- Pass knowledge and skills exams
- Maintain training and mission log books, verified by instructor

GCS Operator:

- Complete Training Phases 1 through 4
- Pass knowledge and skills exams
- Maintain training and mission log books, verified by instructor

UA Operator:

- Complete Training Phases 1 through 5
- Pass knowledge and skills exams
- Maintain training and mission log books, verified by instructor

UA Operator/Instructor:

- Complete Training Phases 1 through 5
- Pass knowledge and skills exams
- Maintain training and mission log books, verified by instructor
- Receive approval as an instructor from an existing UA operator/instructor

Note: A trainee who does not complete the required training program within six months of beginning the training process is considered to have interrupted training. In such cases, the trainee must resume training at the last level completed. Rating may still be attained at any level for which the trainee has completed the required phases after the initial six months; further training activities will count toward attainment of the next level, and so on. Upon resumption of training, the trainee must complete the remaining phases within three months.

Training Phase 1: Computer Simulation Training

Objectives:

All members of a UAS operations group must be familiar with the basic operations and characteristics of small aircraft under remote control. Use of simulation software provides a time-efficient, cost-effective way to build these skills.

To successfully complete this phase of training, the trainee will demonstrate to a qualified UA operator/instructor:

- Understanding of the basic components and subsystems of a radio-controlled aircraft, including control surfaces and radio system.
- Knowledge of factors affecting flight of manned and unmanned aircraft.
- Understanding of the regulatory environment in which UAS operate, and procedures required for legal operation, including airspace restrictions and proximity regulations.
- The ability to operate a simulated model radio-control aircraft under various environmental conditions including wind and limited visibility, and to safely recover the aircraft in a designated area.

Equipment:

Computer-based simulation software such as Realflight® G4 (Great Planes Manufacturing Co., Inc.) is used in this training phase, along with compatible computer equipment and training logs. Books on the mechanics of aircraft flight, documents concerning UAS operations and regulations, and other materials may be used to supplement learning at the instructor's discretion.

Training progression:

Under supervision of an UAS Operator/Instructor, the trainee learns and practices the following maneuvers:

- Taxiing
- Takeoff
- Turns
- Square "box" patterns
- Figure-eight patterns
- Coordinated turns
- Touch-and-go maneuvers
- Landing
- Stall initiation and recovery
- Cross-control stall landing procedures

- Inverted flight
- Dead-stick (i.e. motor failure) landing

Each of these maneuvers is accomplished during simulated calm wind conditions, as well as with simulated winds of five, 10, and 15 mph. Wind direction is set parallel to the runway and flight path, as well as perpendicular to and diagonal to the runway to allow the trainee to experience the effects of wind on flight.

As the trainee's skills progresses, the Edit Airframe option of Realflight is used to decrease the throw (i.e., maximum deflection) of all control surfaces on the aircraft. Doing so gives the trainee experience in operating a less-maneuverable aircraft.

Flight Time Requirements:

The trainee must log a minimum of 50 simulator flights, each lasting at least three minutes. A total of at least 180 minutes of flight time must be logged by the student at this phase of training. Although there is no limit to the amount of time a trainee may spend using the simulator, no more than 10 flights during a single day may be counted toward the minimum requirements.

Examination and Skills Evaluation:

After fulfilling the flight time requirements, the trainee will complete a written examination to consist of approximately 25 questions. The trainee must achieve a score of at least 80% correct to pass. Successful trainees also will complete two skill evaluation simulator flights to demonstrate a sufficient level of skill for progression to the next phase of training. During these flights, the trainee will be instructed to perform maneuvers from the list above, during both calm and simulated wind conditions. The instructor will evaluate the trainee's performance on a scale of 1 (inability to perform maneuver) to 4 (excellent). The trainee must complete the skills evaluation with an 80% score to move to the next training phase.

Should a trainee fail the written exam or skills evaluation, he or she may repeat either one up to two times, but he or she must wait at least three days before repeating an exam or evaluation. Records of the trainee's score will be recorded on the trainee's training log.

Training Phase 2: Radio-Controlled Aircraft Training

Objectives:

After completing computer simulation training, the progression to a radio-control model aircraft allows trainees to learn the nuances of operating under relatively controlled conditions. To successfully complete this phase of training, the trainee will demonstrate to a qualified UA operator/instructor:

- Familiarity with the construction, maintenance, and repair of radio-controlled model aircraft.
- Familiarity with radio-control transmitter operation, including frequency control and other pre-flight checks and safeguards.
- Knowledge of safe procedures for charging batteries for aircraft flight and radio systems.
- The ability to operate a radio-control aircraft under various environmental conditions including wind and limited visibility, and to safely recover the aircraft in a designated area.
- Knowledge of accepted practices for the operation of model remote-controlled aircraft according to Academy of Model Aeronautics (AMA) guidelines.
- Use of instruments to monitor environmental conditions.
- Ability to a compass and binoculars to locate distant targets such as manned aircraft or other hazards to flight, and to quickly communicate their bearing and course to others.

Equipment:

A remote-controlled trainer aircraft, such as a Hobbico Nexstar is used in this training phase, along with its Futaba radio system. A suitable battery charger and flight batteries are also required.

Training progression:

Under supervision of an UAS Operator/Instructor, the trainee learns and practices the following maneuvers:

- Taxiing
- Takeoff
- Turns
- Square “box” patterns
- Figure-eight patterns
- Coordinated turns
- Touch-and-go maneuvers

- Landing
- Stall initiation and recovery
- Cross-control stall landing procedures
- Inverted flight
- Dead-stick (i.e. motor failure) landing
- Hand launching techniques
- Skid landing techniques

These maneuvers are identical to the ones learned during the computer simulation phase of instruction. Each of these maneuvers is practiced during calm wind conditions, as well as with moderate winds later in training. All training flights are conducted in a suitably large area such as an AMA-sanctioned flying field, airfield, etc. to be agreed upon by instructor and trainee.

The instructor and trainee usually begin this phase of training with a buddy-box setup. Depending on the trainee's level of skill and comfort, the instructor determines when the trainee is ready for solo flight. It is expected that the computer simulation phase of training will have provided trainees with sufficient experience to permit solo flight within approximately ten flights; however, no limits are defined.

Upon becoming proficient with the remote-controlled aircraft, the trainee will reduce the control surface throws. This training will help improve the trainee's ability to anticipate the aircraft's behavior.

Flight Time Requirements:

The trainee will complete a minimum of five instructor-assisted flights covering the maneuvers described above. The trainee must then log a minimum of 25 flights, each lasting at least five minutes. At least five of these flights must take place during windy (at least 7mph) conditions; also, five of the required flights must include cross-wind landings (i.e. wind is perpendicular to runway). A total of at least 180 minutes of flight time must be logged by the student at this phase of training. Although there is no limit to the amount of time a trainee may spend flying the remote-controlled model, no more than 5 flights during a single day may be counted toward the minimum flight requirements.

Flight Recording and Evaluation:

Subsequent to the instructor-assisted flights, the trainee will use a video camera to record, at a minimum, the final approach and landing for each flight not witnessed by the instructor to be counted toward the flight time requirements. The recordings will be sent to the instructor for evaluation and documentation; the instructor will communicate with the trainee concerning technique and make suggestions for future flights. This requirement and the limitation on number of flights per day will ensure that the student can receive periodic feedback from the instructor, who need not be present during all of the trainee's solo flights.

Examination and Skills Evaluation:

After fulfilling the flight time requirements, the trainee will complete a written examination to consist of approximately 25 questions. The trainee must achieve a score of at least 80% correct to pass. Successful trainees also will complete a skills evaluation consisting of ground skills, pre-flight check, and two evaluation flights. During these flights, the trainee will be instructed to perform maneuvers from the list above, during both calm and moderate wind conditions. The instructor will evaluate the trainee's performance on a scale of 1 (inability to perform maneuver) to 4 (excellent). The trainee must complete the skills evaluation with an 80% score to move to the next training phase.

Should a trainee fail the written exam or skills evaluation, he or she may repeat either one up to two times, but he or she must wait at least three days before repeating an exam or evaluation. Records of the trainee's score will be recorded on the trainee's training log. In the event of a crash during training, the trainee will write an incident report describing the conditions under which the crash occurred and factors contributing to the crash. The instructor, if present during the crash, will complete a summary report as well. A crash will increase the trainee's number of required solo flights by five. A second crash during this phase of instruction will require the trainee to complete a simulator re-test and instructor-assisted evaluation flight before the trainee is allowed to resume remote-controlled flights.

Training Phase 3: UAV Trainer Aircraft Training

Objectives:

This phase of training will introduce the trainee to the performance characteristics of the UA under manual control, providing sufficient confidence and familiarization that subsequent training with a mission-capable UAS can be accomplished with low risk of damage to the UAS, persons, or property. To successfully complete this phase of training, the trainee will demonstrate to a qualified UA operator/instructor the ability to perform launches, flights, and landings of a radio-controlled airframe identical in performance to the UAS.

Equipment:

A radio-control UAV airframe equipped with its associated radio and electrical equipment. No autonomous control devices or payload in this phase of training.

Training progression:

Under supervision of an UAS Operator/Instructor, the trainee learns and practices the following maneuvers:

- Ground takeoffs
- Hand launches
- Constant-altitude maneuvers
- Rapid ascent takeoffs
- Rapid descents to landing
- Stall initiations and recoveries
- Cross-control stall landing procedures
- Inverted flight
- Dead stick landings

Each of these maneuvers is practiced during calm wind conditions, as well as with moderate winds later in training. The instructor and trainee usually begin this phase of training with a buddy-box setup. Depending on the trainee's level of skill and comfort, the instructor determines when the trainee is ready for solo flight.

Flight Time Requirements:

The trainee will complete a minimum of three instructor-assisted flights covering the maneuvers described above. The trainee must then log a minimum of 10 flights, each lasting at least 5 minutes. At least five of these flights must take place during windy (at least 7mph) conditions; also, five of the required flights must include cross-wind landings (i.e. wind is perpendicular to runway). In addition, three long flights of at least 30 minutes each are required. These long flights must occur on separate days. A total of at least 180 minutes of flight time must be logged by the student at this phase of training. As before, no more than 5 flights during a single day may be counted toward the minimum flight time requirements.

Flight Recording and Evaluation:

Subsequent to the instructor-assisted flights, the trainee will use a video camera to record, at a minimum, the final approach and landing for each flight not witnessed by the instructor to be counted toward the flight time requirements. The recordings will be sent to the instructor for evaluation and documentation; the instructor will communicate with the trainee concerning technique and make suggestions for future flights. This requirement and the limitation on number of flights per day will ensure that the student can receive periodic feedback from the instructor, who need not be present during all of the trainee's solo flights.

Skills Evaluation:

During a series of four examination flights, the instructor will evaluate the trainee's performance on takeoffs, maneuvers, controls, and landings. The instructor will evaluate the trainee's performance on a scale of 1 (inability to perform) to 4 (excellent). The trainee must complete the skills evaluation with an 80% score to move to the next training phase.

Training Phase 4: Ground Control Station Training

Objectives:

The ground control station contains all the equipment needed to operate the UAS from the ground. Each member of the UAS crew must have some degree of familiarity with the GCS components to ensure a safe and successful mission. To successfully complete this phase of training, the trainee will demonstrate to a qualified UA operator/instructor:

- Ability to identify each component of the GCS.
- Describe the function of each component of the GCS.
- Familiarity with the assembly of the GCS hardware and communication devices.
- Familiarity with flight planning and ability to create and upload plans.
- Ability to troubleshoot problems.

Equipment:

The GCS unit for each UAS may vary from model to model, but in most cases consists of the following components:

- Power supply equipment (12V automotive/marine battery or generator).
- A notebook computer equipped with autopilot software, GoogleEarth software, Microsoft Office or OpenOffice software.
- A Commbox unit.
- Video receiver.
- Control transmitter.
- Antennas and cables.
- Protective case.

Training progression:

Under supervision of an instructor, the trainee will learn the components, functions, and connections of the GCS. In addition, the instructor will introduce the trainee to the procedures for creating and saving flight plans and related map files. The trainee will learn safety and failsafe procedures of the autopilot software, as well as the recommended procedures for creating flight paths of mobile-GCS missions and contingency paths for varying weather conditions.

The determination of possible local air traffic patterns and areas to be avoided during operations will be covered, as well as procedures for contacting local airports for routine communication and emergencies will be covered.

Evaluation:

The trainee will complete a skills evaluation consisting GCS assembly for a mission, inspection of the GCS for functionality, loading primary and contingency flight plans, and disassembling the GCS for storage or transport. In addition, the trainee will prepare a portfolio of flight plans for three different missions based on criteria designated by the instructor. The portfolio will be evaluated on its appropriateness for the mission objectives, conformation to established regulations, and safety.

Training Phase 5: UAS Training

Objectives:

This phase of training introduces the trainee to a mission-capable UAS. Upon completion, the trainee will be rated for UAS operational missions.

Equipment:

A fully-operational UAS, including an autonomous control device, and payload.

Training progression

Under supervision of an UAS Operator/Instructor, the trainee learns and practices the following techniques:

- Pre-flight checks
- Manual/autonomous flight transitions
- UAS troubleshooting and maintenance
- Post-flight checks

Flight Time Requirements

To complete this phase of training, the trainee must plan and execute five UAS missions with the oversight of an instructor. Each mission must last a minimum of 10 minutes.

Skills Evaluation:

During a series of three examination flights, the instructor will evaluate the trainee's performance on completing an operational mission. The instructor will evaluate the trainee's performance on a scale of 1 (inability to perform) to 4 (excellent). The trainee must complete the evaluations with an 80% score to complete training.