Dr. Woolsey's research lab maintains formal safety/emergency guidelines (attached) for researchers engaged in UAV flight tests. Pilots and observers have been trained to identify and respond to emergency situations that may arise in the field. It is expected that the pilots and observers of the SPAARO UAV shall exhibit sound judgment to resolve any emergency safely and promptly.

Safety Procedures for UAV Experiments

Nonlinear Systems Laboratory

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1 Introduction

Flight testing an small unmanned air vehicles (UAVs) carries an inherent risk of damage to equipment or injury to personnel. Flight test personnel must understand these risks and follow appropriate procedures to minimize risk. This document outlines "best practices" for minimizing the danger to vehicle operators and spectators. Dangers and procedures are outlined in roughly the order of frequency or importance. Specific risks of injury and first aid procedures are given in Section 4. The guidelines provided here were developed for the specific UAV system described in [1]. These guidelines are appropriate, more generally, for fixed-wing UAVs with airframes based on conventional, radio-controlled (RC) designs. Special safety considerations may be necessary for rotary-wing aircraft or for unconventional aircraft.

Section 2 describes the airfield operational procedures followed by members of the Nonlinear Systems Laboratory when experimenting with small UAVs. These procedures may serve as a guide for other groups wishing to experiment with UAVs at Kentland Airfield. Section 3 describes specific risks of injury that can occur when working with small UAVs. Section 4 outlines treatment procedures in case of injury.

2 Airfield Protocol

This section describes the operational procedures followed by members of the Nonlinear Systems Laboratory when operating small UAVs at the Kentland Airfield. Access to the airfield is limited when experimental flights are taking place. Individuals permitted on the airfield include[1]

- **Test Site Director (TSD).** Currently, Dr. David Schmale, III (dschmale@vt.edu) and Dr. Craig Woolsey (cwoolsey@vt.edu) serve as Test Site Directors. Because the TSDs have ultimate responsibility for the safe conduct of flight tests at the Kentland Airfield, their approval is required prior to any flight test or series of flight tests. *The TSD has authority to cancel any flight activity due to safety concerns.* Any accident involving an injury to personnel or damage to a Kentland Farm facility or research project must be reported to a TSD by phone as soon as possible. Failure to comply will result in the loss of airfield use privileges.
- **Pilot in Command (PIC).** The Pilot in Command is the individual responsible for manual control of a UAV when the vehicle is operating in manual mode. The PIC is the pilot of record for any flight test, and has final authority to cancel any portion of the test, including transition to and from autonomous modes (as applicable). The PIC also has the authority to clear the airfield of personnel at any time. *A PIC may not be compelled to operate a vehicle in a manner which he or she believes is unsafe.* Attempts to encourage unsafe activity should be reported immediately to a TSD. Anyone wishing to serve as PIC must be approved in advance by a TSD.
- **Test Director.** The Test Director is responsible for coordinating the test to be performed and for coordinating a post-experiment report. Safe field management, including spectator control, is the responsibility of the Test Director.

[1] In some instances, an individual will serve multiple functions.

- **Ground Crew.** The Ground Crew includes individuals who support the experiment other than as UAV pilots. Activities of Ground Crew include telemetry data logging and processing, UAV maintenance and repair, documentation, and logistics. These individuals report to the Test Director.
- **Pilot in Training.** A Pilot in Training is an individual who is training to serve as PIC. This activity is to be overseen by an approved PIC.
- **Invited Guests.** Any of the preceding individuals may invite guests to attend the experiments, safety permitting. Spectators are restricted to an area designated for spectators, unless escorted by one of the authorized individuals mentioned above.

Individuals must avoid being on the airfield proper while air vehicles are in operation. Vehicle testing is to be be conducted in an area designated for such activity and the pilot must avoid overflying any personnel. Except in rare cases approved by the PIC or the Test Director, no individuals are permitted on the airfield during taxi, takeoff, or landing of an aircraft. In these exceptional cases, the individual must ensure that the PIC is aware of his or her activity and location.

3 Risks of Injury

Risks of injury associated with the airframe principally relate to the engine and propeller. Lacerations, burns, fuel exposure, and blunt force injury are the major concerns, each of which are discussed below. Treatments for these injuries are described in Section 4.

3.1 Lacerations

Propellers on small UAVs typically operate between 1,000 and 20,000 RPM and have a mass of less than one-half pound. (For the Nonlinear Systems Laboratory's Sig Rascal 110's, the propeller weight is 0.24 lbs.) Most injuries involving propellers occur during startup, when operators must be in close proximity. When starting any small engine, the user should ensure that:

1. the vehicle is properly restrained.
2. operators/spectators are clear of moving parts, especially the propeller.
3. operators/spectators are clear of the propeller *arc*, a large (¿ 200 ft) circular disc, centered at the engine shaft, which is in the plane of the propeller's rotation. (While it is impractical to remain out of the propeller arc at all times, persons should avoid this region when possible, particularly during operation at high throttle or under high load.)
4. any operator involved in starting or restraining the engine has no loose clothing that could become entangled in the vehicle machinery.

During startup of a fixed-wing UAV engine, operators often reach around the propeller to stabilize the aircraft while applying the starter motor to the propeller such that an arm is both in the propeller arc and close to the propeller. Although discouraged, the practice is quite common. If the operator, being aware of the danger of injury, chooses to accept risk, the following procedures can help to mitigate that risk:

1. The airplane is otherwise restrained such that the action is unnecessary for the purpose of restraining the vehicle, and the action is used only to stabilize it while starting.
2. The propeller has been inspected and the tips identified with a high-visibility color such as orange or red.
3. The operator has covered the forearm with a material (leather is recommended) or jacket such that inadvertent contact with the propeller will not injure the arm. (Recall, however, that the operator should not wear *loose* clothing.)

4. All other body parts (particularly the head and face) are clear of the prop arc.

The propeller also represents the major danger to personnel while the UAV is in flight. Accordingly, no individual should touch a powered vehicle in flight.

3.2 Burns

During normal operation, engine components become quite hot and can easily burn the user on contact. While the diesel-fueled engines used on the Nonlinear Systems Laboratory's Sig Rascal 110 UAVs run significantly cooler than both gasoline and glow fuel engines, the potential for burns still exists. Care should be taken to avoid contact with the engine cylinder or crankcase both during and after operation. Compression adjustment while the engine is running is permitted, as long as a full-size hex key is used and the operator takes care to avoid the propeller.

3.3 Fuel Exposure

UAVs may use standard glow fuel or, in the case of the Nonlinear Systems Laboratory's Sig Rascal 110 UAVs, diesel fuel. Standard procedures for working with pertrochemicals apply, with the following additional concerns related to diesel fuel:

1. Model diesel fuel has a higher ether concentration than automotive fuel. As a result, vapor inhalation is a very significant concern. All fuel canisters should be tightly capped when not in use, and fueling of UAVs must be done in a well-ventilated area.
2. Diesel fuel should never be stored in an unlabeled container.
3. Glow fuel hardware will dissolve if exposed to model airplane diesel. All fuel tanks, valves, engines, and fuel hoses must be designed for diesel fuel use.

Individuals with sensitive skin may suffer chemical burns if fuel is allowed to remain in contact with skin. Any contact of petroleum products with skin should be avoided.

3.4 Blunt Force Injury

For the UAVs used by the Nonlinear Systems Lab, the engine has a mass of approximately 13% of the vehicle mass and can travel at speeds up to 30 m/s. This represents a potential for injury to persons who are unaware of the vehicle's trajectory. To minimize this danger:

1. Experimental procedures should be formulated in a way which eliminates or minimizes overflights of people.
2. A clearly-established flightline should be established forward of which all flight activity should take place.
3. Spectators and other persons not involved in the flight test should remain behind an established spectator line, aft of the flightline.
4. All operators and spectators should remain aware of the UAV's status and flight path.

4 Emergency Medical Procedures

Following are suggested first aid procedures for minor injuries. In the case of major injuries, professional medical attention should be sought immediately.

4.1 Lacerations

A laceration is any wound where the skin is broken. The following procedures are for all sizes of lacerations. If the wound is more then a half an inch long, is very deep, or is bleeding profusely, stitches might be required.

Procedure

1. **Stop the bleeding.** The first step to treating a laceration is to stop the bleeding. Apply constant pressure to the wound using a clean cloth or bandage. If the bleeding does not stop and it is possible to do so, raise the body part above the level of the victim's heart. If bleeding continues seek medical assistance.
2. **Clean the wound.** To clean the wound, rinse it under cold water, however do not use soap directly on the wound. If there are debris in the wound, clean them out with a set of sterile tweezers.
3. **Bandage the wound.** Apply an antibiotic such as Neosporin and then dress the wound with a bandage. The bandage will keep the wound clean and prevent infection. Replace the bandage daily until the wound has healed enough to prevent infection. Once the wound has healed enough, remove the bandage and expose the wound to air which will speed the healing process.
4. **For deep wounds, stitches may be required.**

4.2 Burns

There are two kinds of burns that operators of UAVs should be aware of. Heat burns are caused by contact with a hot surface, such as the engine of a UAV. The second type of burn which may occur when operating a UAV is a chemical burn. This may occur if a victim comes in contact with a toxic chemical, such as the fuel used in most UAVs. If the toxic chemical comes in contact with the victim's eye, the eye should be thoroughly rinsed with water and medical attention should be sought.

There are 3 degrees of heat burns. *First degree burns* are the least severe, leaving a red spot on the victim's skin. *Second degree burns* resemble first degree burns, but the victim will also have blisters on their skin. *Third degree burns* are the most severe and the victim will have a deep wound with charred skin. Although there is little or no pain with a third degree burn, such wounds are quite severe and require careful attention.

The following procedures apply to chemical burns, first degree burns, and small (under 2 inch diameter) second degree burns. For a second degree heat burn that is larger then two inches or for a third degree heat burn, seek medical attention.

Procedure

1. **Remove source of burn.** If any of the victim's clothing is still smoldering or came in contact with the chemical, remove it.
2. **Cool the wound.** Cooling the burn will stop the burning process and remove chemicals left from contact. To cool the burn, run the affected area under cool water for fifteen minutes.
3. **Bandage the wound.** Bandaging the burnt area will keep the air off the burn and lessen the pain. When bandaging the burn wrap a sterile gauze strip *loosely* around the affected area. Do not use any cotton bandages, because these might stick and irritate the skin.

4.3 Vapor Exposure

When operating a UAV it is possible to inhale harmful vapors from the engine or engine fuel. Symptoms of light vapor inhalation are drowsiness and inability to think clearly. More serious exposure may lead to vomiting or unconsciousness. For serious vapor exposures, seek medical assistance immediately. Information about the fuel being used should be on hand to aid emergency crews.

The following procedures are appropriate for treating the symptoms of light vapor inhalation.

Procedure

1. **Remove the victim from the vapor source.** As quickly as possible, move the victim far away from the source of the vapors. Make sure the area is well ventilated so the victim can get fresh air.
2. **Aid breathing.** Keep the victim calm and have him or her lie down to reduce their breathing rate. Loosen tight clothing around the neck to aid breathing.
3. **If victim's condition does not improve, seek medical assistance.**

4.4 Blunt Force Injuries

When operating a UAV there is a remote chance of being struck by the engine of a moving aircraft. In blunt force injuries, the blood vessels under the skin are broken, resulting in a blue or black colored skin. If the skin is broken, follow the procedures for lacerations described in Section 4.1.

Procedure

1. **Elevate the injured area.** Elevating the injured area will reduce blood flow to the wound and reduce pain.
2. **Ice injured area.** Apply ice or a cold pack to the injured area for twenty to thirty minutes at a time for a few days afterwards. This will reduce swelling and pain.

Seek medical assistance if the pain is excessive or lasts for more then a few days.

Acknowledgements. These guidelines were prepared by Imraan Faruque and Robert Briggs for the benefit of the Nonlinear Systems Laboratory and other Virginia Tech UAV enthusiasts.

References

[1] L. Ma, V. Stepanyan, C. Cao, I. Faruque, C. Woolsey, and N. Hovakimyan. Flight test bed for visual tracking of small UAVs using a gimballed camera. In *AIAA Guidance, Navigation, and Control Conference*, 2006.