Objective

The purpose of this document is to lay out appropriate procedures for the safe launch and recovery of aircraft when many aircraft are simultaneously in the air. Obviously as the number of aircraft increases and if the aircraft are being launched, controlled and recovered by multiple, disparate teams, the procedures will need to adjust to mitigate additional risks that arise. Further, some procedures described in this document may be thought of as “best practices,” whereas other procedures must be treated as firm regulations. These will be denoted in the text as “BP” and “REG.” NPS and the ARSENL team have previous and growing experience with larger numbers of aircraft. The current revision of the document will be based on the current level of experience, and is anticipated to evolve over time as the group gains additional experience.

Other groups at NPS have flown multiple aircraft simultaneously for many years, but the number of aircraft remained low enough that one or two GCS operators and a single safety pilot were sufficient to maintain safe operations. This document is not intended to cover those operations, but rather to address the issues that arise when the number of aircraft becomes sufficiently high such that pilot handling with a single individual is infeasible.

Background

Failsafes

There are a number of key features (or requirements) that will be necessary for this type of operation. First and foremost, the aircraft will rely heavily on dependable, proven failsafe behaviors which are completely autonomous, that is, known and thoroughly tested behaviors that the aircraft will perform if, e.g., the link goes dead, GPS signal is lost, or another type of disability is experienced. Such failsafes are considered a requirement for swarm operations of 10 or more aircraft. This has been a cornerstone of the ARSENL swarm development, with all failsafes being checked during every functional control flight (FCF), as dictated by ARSENL’s flight software checkout SOPs.
Higher Risk of Loss

The nature of swarm UAV research and experimentation necessarily puts aircraft at risk of damage. As autonomous aerial combat is one of the key emerging technologies being developed in the program, such possible damage or loss is completely acceptable for the program, and thus the flight hardware utilized is necessarily low-cost and expendable. Specifically addressed in this document and mitigated through the outlined procedures is the potential risk to personnel and property on the ground. Injuries and property damage (other than the airframes) is not considered acceptable. The risk injury or property damage caused by damaged airframes during combat is mitigated by physically separating the combat airspace from personnel and property. A few flight operations -- launch and recover -- necessarily require direct human interaction; the operating procedures detailed in the sections below are designed to ensure safe operations for personnel involved in such flight operations activities.

Swarm UAS Launch and Recovery Operations

Launch

Launch procedures are unique in that they are the single point during an operation where hands-on human interaction is required. A human will need to handle each aircraft, place it on the launcher, and perhaps be present during the launch. The human exposure is limited to a small number of trained individuals servicing one or more launchers. All other personnel are to be physically separated from the vicinity of the launch. The basic steps to prepare for a launch are given below:

- Trained GCS Operator(s) and Flight Technician(s) conduct preflight checklists, which include:
  - Confirmation of active geo-fence boundary in GCS software by Pilot and Mission Commander
  - Confirmation of valid mission flight plans in GCS software by Pilot and Mission Commander
- Minimized number of Flight Technician(s) and Pilot coordinate launch of each UAV using predefined hand signals and verbal call-and-response cues
- Catapult launchers are designed to provide reliable and repeatable takeoffs of the UAVs, including easy repositioning to take off in correct wind direction
- Final pre-takeoff checks are conducted to ensure motor is armed\(^1\) only immediately prior to launch
- Remaining personnel, including Mission Commander, GCS Operators, and any observers, remain safe distance from launch locations, possibly inside covered structures for additional safety

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\(^1\) The motor must be “armed” for the motor to run. In the unarmed state, the motor cannot be commanded accidentally or otherwise to rotate the propeller.
• After automated or guided takeoffs, Pilot maintains safety readiness while observing for nominal controlled ascents to staging areas (e.g., loiter points)
• Time of launch is recorded for additional awareness of elapsed UAV mission time (and endurance)

Due to the difficulty of a safety pilot taking control of one of many aircraft for hands-on-control, it is anticipated that launch is the only time during a mission where a safety pilot may possibly interact directly with an aircraft. To mitigate any risk from this, the area of operations or arena will be physically separated from the launch area, with a geo-fence around the arena that will enforce failsafes if the arena boundaries are breached. After the launch, the aircraft will head for the arena, and once inside the fence will be enforced until landing, and the safety pilot will likely not be involved in that aircraft again.

At all times, the launchers will face open space, never directing aircraft towards personnel or property. If the launcher heading must be changed to account for shifting winds, care is taken that the new launcher heading remains away from personnel or property. The aircraft are quite tolerant of cross-wind and even light tail-wind launches, which will aid in mitigating this risk. Accepted procedures utilize a launch window that is 90 degrees wide (45 degrees to either side of the launch heading) and reaching out a minimum of 200m in the direction of the launch (see Fig. 1) which must be kept clear of unprotected personnel and any property that could be damaged by this class of aircraft. Additionally, once the motor is armed, all unprotected personnel must be kept clear of the propeller line and all points forward of the propeller line for a minimum distance of 10m until the aircraft is clear of the launch area.

If multiple launch teams are utilized, a method to ensure secure and unambiguous communications between the GCS operator and the launch team is required. This may include verbal signals, hand signals, or electronic communications of some type, but the launch team must have direct communications with the GCS operator before releasing an aircraft.

Recovery
Recovery operations of large numbers of aircraft are designed to ensure safety to personnel and property. Designated landing points or landing zones are specifically defined at safe distances from all personnel locations. These landing locations and approach directions are coordinated between GCS operator and recovery team members for shared awareness and redundancy. The basic steps to prepare for the recovery of one or more aircraft are given below:

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Note that the arena boundaries are designed to be contained well-within any and all restricted airspace boundaries. These boundaries specifically designate the airspace for the present flight operations.
• Rally and landing points for autonomous landings are specified by GCS Operators and confirmed by Pilot and Mission Commander prior to commencing landing sequences
  o Landing direction confirmed (or possibly repositioned, if necessary) to accommodate favorable wind conditions
  o Landing points are confirmed to be a safe distance from personnel, and non-essential personnel are advised to retreat to enclosed or sheltered structures
  o Final approach is confirmed clear of obstructions or personnel and/or permission to land is requested from range or Air Boss
• GCS Operators coordinate with recovery team personnel on mode transition to autonomous landing mode
• UAVs are safely recovered by Flight Technician(s) after visual or telemetry confirmation of landing, and if conducting multiple (nearly) simultaneous landings, retrieval occurs after the multiple UAVs have collectively landed.
  o Upon recovery, motor switch and/or battery power is disengaged
  o Flight Technicians maintain situational awareness at all times if airspace is still hot with other swarm elements, though landing areas are separated from overhead flight operations.
• Post-flight procedures include:
  o Recorded time of landing for assessment of nominal flight endurance
  o Safe battery handling procedures are also used (e.g., recording expended battery voltages, check for possible damage, wait until cool before charging)
  o Automated transfer and/or annotation of flight log and telemetry data log files for post-mission analysis

ARSENL has conducted extensive validation and demonstration of autonomous landing capabilities, and is additionally included in functional control flights for continued safe operations. Due to the difficulty of a safety pilot taking control of one of many aircraft for hands-on-control, safety of landing operations is maintained by careful procedural execution and validated automated failsafes or emergency actions, to include automatic disarming of motors upon detection of touchdown or the ability to execute go-arounds, with return to the flight pattern for any unexpected behaviors during final approach.