AUTOMATION ENABLING MULTIPLE UAS AT THE SAME TIME (SAFELY AND LEGALLY)

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The ability to operate multiple Uncrewed Aircraft (UA) simultaneously offers significant commercial potential. However, manual control of such a fleet quickly becomes overwhelming and susceptible to human error. This paper provides an overview of the safety process used to identify and detail the automation needed for m:N Beyond-Visual-Line-of-Sight (BVLOS) operations, where "m" represents the number of human flight crew and "N" signifies the number of deployed UAs. The resulting framework enables safe and efficient control of multiple UAs by a limited crew in BVLOS operations.

INTRODUCTION

As part of a 2023 FAA UAS BAA project ***Standards for Piloting Multiple, Simultaneous UAS BVLOS***[‡], the team led by Anzen Unmanned (Au) developed the minimum criteria and open-source flight control software for a Remote Operator (RO) to operate multiple small uncrewed aircraft systems (UAS) simultaneously (also known as m:N, where "m" is the number of flight crew and "N" is the number of UAs in operation) operating Beyond Visual Line of Sight (BVLOS). The accomplishments in this project included defining, developing, and testing the:

- Minimum UA performance and behaviors for normal and off-nominal conditions, including the flight control modes and level of automation necessary to support Remote Operator (RO) responses
    - Included submitting the resulting ArduPilot and MAVLink software updates to the open-source repositories
- RO interfaces (e.g. display, alerts, controls) needed to maintain m:N situational awareness and enable timely, correct RO responses
- Minimum sUAS equipage needed to support the m:N safety case
- Operational pre-flight and flight procedures
- Location checklist that can be scaled nationwide
- Minimum RO qualifications and training
- Organizational practices, including safety management, quality management, configuration management, and training programs
- Safety case to obtain FAA waiver[§] under § 107.200 for §107.31 (BVLOS), 107.33b/c2 (VO), and §107.35 (m:N)

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[‡] Au-REP-0048 Anzen Unmanned Final Report for Piloting Multiple, Simultaneous UAS BVLOS
[§] FAA 107W-2023-01262 Asylon BVLOS m:N waiver

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Operating multiple UAS BVLOS simultaneously requires a level of automation that aligns with the scope, scale, and complexity of an operation. As the level of automation increases, the RO role shifts from an active hands-on pilot to a hands-off safety monitor.

Defining the level of automation is foundational to understanding the role of the human as a causal factor contributing to performance degradations and safety incidences. Based on the SAE International J3016 standard's Levels of Driving Automation*, UA automation levels were identified as part of this study to ensure human factors were captured within a defined automation context (Table 1).

Table 1 – Automation Levels

Level	Automation Name	Description
0	No automation	Human pilots do all the flight operations.
1	Crew Assistance	UAS is controlled by the crew, but some flight assist features may be included that can assist the RO with telemetry, speed, and altitude.
2	Crew Partial Automation	UAS has combined automated functions, but the crew must remain engaged with the flight tasks and always monitor the environment.
3	Conditional Flight Automation	An automated flight system on the UAS can perform all aspects of the flight tasks under some circumstances. Crew is still required to monitor the status of the UAS in operation. The RO is expected to be takeover-ready to always take control of the UAS with notice.
4	High Flight Automation	The UAS can perform all flight functions under certain conditions. The crew may have the option to control the vehicle.
5	Full Automation	The UAS can perform all flight functions under all conditions. The crew, as a safety monitor, never needs to be actively involved in flight tasks.

During off-nominal conditions, control of multiple UA at once by a single RO is extremely challenging without automation. A key part of the project was defining the minimum automation and technical requirements needed for scalable BVLOS m:N operation.

APPROACH

Most commercially available UAs are already produced with an autopilot for flight stability, control, and waypoint navigation. This allows the UA to follow pre-programmed paths without constant pilot input. Essentially, automation handles the routine aspects of UAS flight, leaving the pilot free to focus on strategic decisions and monitoring overall operations, while being able to immediately intervene in case of unexpected situations.

This project was designed to be at automation level 3 throughout human-in-the-loop operations, as the technology to enable this is readily available. Level 3 still requires that the crew monitor the status of the UAS in operation, and always be ready to take control of the UAS with notice.

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* SAE J3016 Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles

A detailed safety analysis* was performed to identify the tasks requiring RO attention and/or intervention. These tasks were then evaluated to determine whether automation or other means could be used to minimize the RO's workload.

Figure 1 - Safety Risk Mitigations

Given the level of automation and assuming the maximum proportion of time where the RO must focus their attention and be ready to intervene, a task analysis was performed to determine the theoretical maximum number of partially automated UAs that each RO could safely operate BVLOS. The resulting number was verified and validated in both simulations and flight tests with multiple ROs of varying abilities.

MINIMUM BVLOS M:N AUTOMATION

During normal and contingency operations, the RO workload was designed to be low since the UA had the following features:

- Preplanned automated flight routes including take-off and landing (normal and emergency)
- Reliable, secure, real-time transmission of situational and safety data
- Lateral and vertical geofence at operating area perimeter
- Lateral exclusion (no-fly) zones around obstacles and other areas of concern in the operating area
- Deterministic activation of automated contingency actions, including:
    - On-UA lateral and vertical geofence preventing UA excursion from the defined operating area
    - On-UA exclusion zones preventing incursion into high-risk areas (e.g., unavailable Command and Control link (C2), assemblies of people, etc.)
    - On-UA exclusion zones around obstacles above the safe altitude floor (or lower near landing site) and critical infrastructure not involved in the operation
    - C2 anomalies trigger pre-defined Return to Safe Landing Zone (aka Return to Launch, RTL)
    - On-UA ADS-B detection of other aircraft and predictable autonomous avoidance maneuver

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* SAE 4761A Guidelines for Conducting the Safety Assessment Process on Civil Aircraft, Systems, and Equipment

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- GNSS/GPS anomalies result in landing using secondary/barometric altitude
- Low battery caution automatically triggers pre-defined Return to Safe Landing Zone
- Critical battery warning automatically triggers controlled landing

Automated Controlled Descent and Landings

Since abnormal/emergency landings may be needed away from the initial take-off point, it is important to limit the kinetic energy at low altitudes to less than the Association for the Advancement of Automotive Medicine Abbreviated Injury Scale[*] level 3 (AIS3) injury criteria. It is also important to ensure the UA can descend fast enough to avoid collisions with Intruding Aircraft. Figure 2 shows the automated vertical speed requirements during Detect and Avoid (DAA) descent and emergency landing that were implemented for this project.

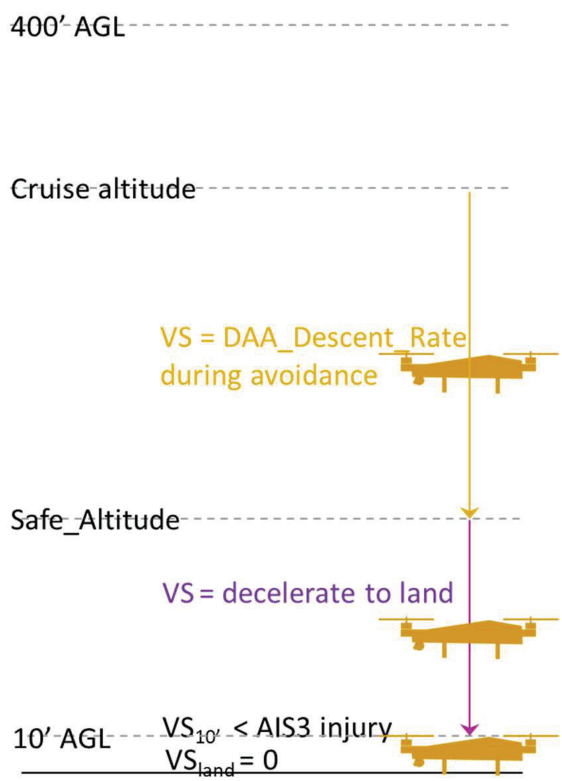

Figure 2 – Controlled Descent and Landings

The project's safe altitude for the operating area was chosen to be both below the typical flight altitude of manned/Intruding Aircraft (~50 AGL) and above the location's obstacles by ~30'.

Vertical descent speeds were automatically set as the situation demanded:

- If an intruding aircraft is detected while the UA is above the safe altitude, the UA performs a controlled descent to the safe altitude as a typical avoidance maneuver for small multicopters. The vertical speed is determined as a function of the maximum stable descent rate, height above safe altitude, and performance characteristics of the DAA

[*] Association for the Advancement of Automotive Medicine Abbreviated Injury Scale

system to ensure the UA remains well clear of the intruder (reference the timing analysis in ASTM F3442[*] appendix X2).

- In the case of an abnormal/emergency landing, the UA decelerates to minimize the severity of injuries in case there are people underneath. The rate of deceleration must be enough that the UA's kinetic energy is below the AIS3 injury criteria at no less than 10' AGL.

On-site Ground Control Station Automation

The base station provides the on-site GCS infrastructure needed for remote operations. Key safety features include:

- Means for automated safe and accurate takeoff and landings
- Sensors for automated built-in tests and preflight checks (e.g. weather, cameras)
- Secure, reliable communications infrastructure with minimal data latencies to the Remote Operations Center and UA
- DAA Surveillance Sensor, where needed/approved for BVLOS operations

Human/Machine Interface

Since Part 107 UASs typically lack the integrity and availability assurance needed for more complex operations, the RO must be ready to provide situational awareness and some mitigation measures. A detailed safety analysis was performed of the m:N BVLOS operations. Most of the hazards and corresponding safety measures identified are in accordance with BVLOS operations. The primary concern introduced by m:N operation was reducing the risk of hazards resulting from error or inaction by an RO whose attention is divided between multiple UAs. Based on the safety analysis, automated visual and aural alerts were implemented for actions requiring the RO's attention.

Remote Operations Center (ROC)

The ROC houses the equipment needed for the RO and support personnel (e.g., dispatch, supervisor) to monitor and control the UAs. The safety analysis requirements for the ROC include:

- Secure, reliable infrastructure to minimize common failure modes for multiple flight operations (e.g., internet, servers, computers, displays, speakers, controls, failover mechanisms, etc.)
- Automated Task Management software that can manage pre-programmed tasks for each UAS to minimize the pilot's workload.
- Automated, real-time monitoring of the UAS and operational area with caution alerts (visual and aural) for safety issues needing pilot attention/intervention.
- Display of safety related parameters to ensure situational awareness for all UAS
- ROC Supervisor monitoring one or more RO's performance and providing back-up for events (e.g. RO health issue, extended ATC coordination).
- Supervisor control station to monitor multiple ROs' operations and assume control
- Ability to easily coordinate transfer of UA control to/from the supervisor for personal reasons and handling of events.

[*] Standard Specification for Detect and Avoid System Performance Requirements

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ADDITIONAL AUTOMATION TO INCREASE MAXIMUM UA

Level 3 automation was chosen for this project as it is within the scope of many commercially available UAS. To achieve a higher number of simultaneous UAs, higher-level automation should be implemented including:

- Traffic Management system to strategically and tactically deconflict at least UAS and potentially crewed aircraft in the operating area
- Advanced preflight checks
- On-UA DAA system for non-cooperative (e.g. non-ADS-B) detection of other aircraft and birds and then automatic avoidance maneuvers
- On-UA identification and avoidance of people/wildlife on ground
- On-UA obstacle identification and avoidance for areas where current obstacles may be unknown or not precisely mapped
- Higher systems/software/hardware maturity levels for safety and security mitigations such as geofences, exclusion zones, parachute deployment, C2 monitoring
- Redundancy and partitioning of safety mitigations to minimize common mode events

With increased automation, it is expected that the task analysis, simulation, and flight test will confirm that a single RO can safely and effectively operate even more UAs.

CONCLUSION/SUMMARY

Multiple UAs flying simultaneously with a single operator is safe and practical with today's technology. The key is to perform a detailed safety analysis to identify the tasks requiring RO involvement, and then a task analysis to determine the safe number of UAs for a given level of automation.

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- Asylon Incorporated for developing the reliable BVLOS m:N DroneCore system, building an impressive ROC simulator, providing most of the ROs, and willingly sharing their lessons learned with the industry.
- New York UAS Test Site operator NUAIR for sharing their expertise, providing ROs with varying levels of experience, giving honest RO feedback during the simulator testing, and hosting the flight test program.
- Purdue University for providing academic rigor during the simulator and flight testing, and much of the analysis for the Human Factors report.
- Anzen Unmanned team who continues to assist the industry with system and safety engineering solutions resulting in precedent setting regulatory approvals for advanced operations.

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