Airworthiness and Protocol Development for Safe Night Flying Missions for Small Unmanned Aerial Systems (sUASs)

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***Abstract*— There are approximately twelve hours out of every day in which UAS are rarely utilized. Night time flights are a relatively untouched field of application for small UAS in part due to the risks associated. However, there is much to be gained through remote sensing at night in the realms of agriculture, environmental monitoring, species monitoring or surveillance. This paper introduces and steps through the design process for illumination systems on small UAVs for the purpose of safe night time remote sensing. Undoubtedly, there many risks to take into consideration to provide safe night flying, which the FAA has accounted for with restrictions due to safety concerns for public and property (including other aircrafts). Beyond the apparent riskiness, there are human factors that need be accounted for, such as pilot stress and situational awareness. This paper, for the first time, introduces the design, construction and human factors strategies associated with developing a mission operational protocol for night flying small UAVs based on our developments in additional airworthiness.**

I. INTRODUCTION

Unmanned aerial systems (UASs) have demonstrated a significant potential for a wide range of civilian applications. It is not unimaginable that there are applications for civilian UASs to operate during the night. However, current regulations and rules have limited their operation to within visible line of sight in order to maintain an adequate level of safety as defined by the US Federal Aviation Administration (FAA). The risks of night time operations are significantly greater and additional precautions are necessary. The purpose of this research is to develop a suitable lighting system for a small UAS (SUAS) and design appropriate protocols to ensure safety and airworthiness.

Many UAS developers have looked at the possibility of SUAS operations at night, for such missions as frost damage detection [1], surveillance, fire fighting [2] and wildlife counts. However, before such operations become regular events, further analysis of integrating SUASs into the national airspace must be accomplished. On the roadmap towards UAS integration, night operations was identified as a goal for small UASs, indicating a significant need [3]. However, very little has been discussed on how to provide an adequate level of safety at night. The Academy of Model Aeronautics has long supported RC night flying, and includes it within their Model Aircraft Safety Code [4]. However, within their requirements, they assert that hand-held illumination is insufficient and that an illumination system is required that provides 'the pilot with a clear view of the models attitude and orientation at all times' [4]. This information provides a start, but is insufficient from a regulations standpoint.

In order to develop a suitable night flying operation for SUASs, further research and development is necessary. The purpose of this paper is to introduce the design and development of a night flying SUAS, focusing on the development of a suitable aircraft lighting system and protocol adjustments. In Section II, an introduction to existing FAA regulations for night flying operations is presented. The proposed aircraft lighting system suitable for a UAS and the appropriate night flying operational adjustments are described in Section III. Section IV discusses best practices learned through the development of the night flying operations. Finally, concluding remarks are presented in Section V.

II. NIGHT FLYING OPERATIONS FOR MANNED AIRCRAFT - EXISTING REGULATIONS AND BEST PRACTICES

Existing regulations provide guidance towards the development of both a lighting system installation and protocols for night flying missions for SUASs. In this section, a brief overview of existing standards and regulations as enforced by the FAA for domestic aircraft within the US specific for night flying. In this section, regulations regarding aircraft lighting, pilot requirements and protocols are discussed in detail where they relate to UAS operations.

A. Aircraft Lighting

The regulations related to aircraft lighting systems can be found in 14 CFR Part 23 - AIRWORTHINESS STANDARDS: NORMAL, UTILITY, ACROBATIC, AND COMMUTER CATEGORY AIRPLANES, in Subpart F - EQUIPMENT [5]. The lighting of the aircraft has different design developments for internal lighting and external lighting. The regulations regarding the internal lighting system (§23.1322, §23.1381) are not applicable in a unmanned aircraft and will not be discussed. Instead, the focus of the section will be on the regulations regarding the external lighting of an aircraft (§23.1383 – §23.1401).

The configuration of positional lights are described in §23.1385 and are depicted in Fig. 1. Navigation lights are placed on wing tip and tail of the aircraft. The left wing

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light color is red, the right side is green and the tail light of the aircraft is white. These navigation lights are used by other air traffic to determine aircraft heading to identify potential threats. In a situation where a pilot sees a green position light on an aircraft to the pilot's 'red' side, it is an indicator of a potential collision. Conversely, green-to-green and red-to-red indicate low or no threat of collision. However, these position lights are not intended to be omni-directional as seen in Fig. 1. Regulation §23.1387 defines the directionality of the position lights. The lights on the wingtips are oriented forward and extend only 110° only slightly behind the aircraft. The tail light is designed to only be visible from behind the aircraft, covering a span of 140°.

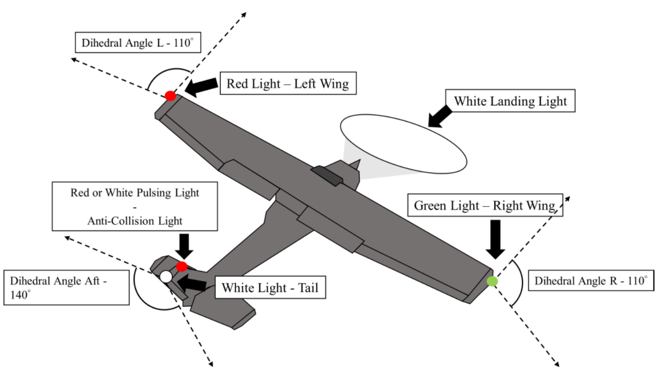

Fig. 1: Diagram of existing Aircraft Light Regulations §23.1383, §23.1385, §23.1387 and §23.1401.

Additionally, aircraft are required to install anti-collision lights as defined by §23.1401. Anti-collision lights, located either on the wing or fuselage, are used to improve the aircraft's visibility with bright flashes of light. The color of the light is white or red and it pulses between 40 and 100 cycles per minute. Within §23.1401, the minimum intensity and viewing angles are also defined. Additionally, taxi or landing lights are commonly used to increase visibility for the pilot to see the runway, though they are only minimally defined by §23.1383. Regardless if its day or night, the landing lights are on when approaching landing.

Regulations §23.1389 – §23.1395 relate to the required minimum light intensities across the range of visibility for each light. Regulation §23.1397 defines the color of each light according to the CIE colorspace coordinates, while §23.1399 defines the minimum requirements for anchor or riding lights if installed on an aircraft.

An additional regulation can be found in §91.209 that asserts that no person may (a)(1) operate an aircraft unless it has lighting position lights; and (b) operate an aircraft without a lighted anticollision light system, unless the pilot determines that it would be in the interest of safety to turn the lights off [6].

B. Night Flying Protocols and Pilot Requirements

Aircraft operations at night differs significantly than daylight operations and there exists significant safety challenges. The addition of aircraft lighting enables aircraft visibility, but introduces additional operational requirements and pilot training.

In order to adjust to operating in dark environments, pilots are taught to wait at least 30 minutes in the dark environment before beginning operations [7]. Once in the air at night, different scanning techniques are often recommended. Whereas during daylight, pilots focus their scanning, at night, pilots are taught to utilize their peripheral vision more as their peripheral vision is more sensitive in low-light situations.

Due to the additional training, pilots are required to fulfill additional currency as defined by 14 CFR 61 [8]. The night flying currency includes three takeoffs and three landings to a full stop. The night currency is to be completed during the period of one hour after sunset to one hour before sunrise.

During night operations, pilots are required to have three hours of night training. This also includes flight over 100 nautical miles and at least 10 takeoffs and landing to a full stop [8].

III. Night Flying Operations for Unmanned Aircraft

While there are many parallels between operations of unmanned and manned aircraft, there are plenty of differences between night flying operations that have not been aggressively addressed in literature. Since the pilot of an unmanned aircraft system is no longer inside the aircraft, many regulations and best practices commonly discussed for night flying protocols, such as cockpit instrumentation visibility and pilot scanning are not applicable. In a SUAS mission, the main operator is considered the pilot in command (PIC) and is often supplemented with visual observers (VOs) to provide the PIC with additional situational awareness. Using the previously described existing regulations related to aircraft lighting and night flying operations as a guideline, both a SUAS lighting system and night flying protocols is developed. In this section, first an overview of the various issues regarding visibility and observability for night time operations of UASs are introduced, followed by a description of a proposed lighting system and additional night flying protocols.

A. Night Flying Hazard Analysis

In order to enable night flying operations, a new system and operational requirements are necessary to be added to achieve an adequate level of safety. In this section, a hazard assessment analysis is presented in the following table to enumerate a wide variety of potential hazards associated with night time operations, along with potential solutions. While a handful of the hazards presented pose a minimal or acceptable level of risk, it is clear that there are many hazards that can be mitigated through the use of a properly designed lighting system and additional requirements for night time operation planning and management.

The night flying hazard assessment is broken down into three phases of night flying operations: Pre-Flight Preconditions, Launch & Recovery Operations, and Standard Mission Operations.

The common themes of potential hazards led to the development of a set of goals that a safe night flying operation must achieve. A night flying operation must

TABLE I: Pre-Flight Preconditions

Potential Hazard	Resolutions
The pilot is not sufficiently trained.	Require sufficient proficiency in night flying prior to UAS operation.
The ground crew is not sufficiently trained.	Require sufficient proficiency in night flying prior to UAS operation.
The ground crew is unable to view ground equipment.	Provide additional illumination.
The ground control station operator is unable to view control station.	Provide additional illumination.
The additional illumination from the ground crew is distracting to the PIC or visual observer(s).	PIC and/or visual observer(s) must be distanced from illuminated ground crew operation.
The PIC and/or ground crew are distracted and forget critical safety checks due to fatigue or prolonged exposure.	Limit exposure and operation to prevent excessive operations.
The UAS lighting system is inoperable.	Add UAS lighting subsystem checks to pre-flight checks.
The aircraft, after returning from a mission, has suffered damage that requires repair before the next flight.	Increase the rigor of flight status inspection for night operations.

TABLE II: Launch & Recovery Operations

Potential Hazard	Hazard Severity	Probability	Resolutions
The PIC encounters flight control issues due to environmental disturbances.	Minor	Probable	Acceptable risk, exists in current operations.
The PIC is unable to see aircraft performance issues.	Major	Probable	Supply specific illumination for launch phase.
The PIC is unable to see aircraft disengage from launch mechanism.	Major	Frequent	Supply visible indicator for successful release.
Aircraft launch is too shallow.	Minor	Probable	Acceptable risk, exists in current operations.
The PIC is unable to determine aircraft altitude as it descends.	Major	Probable	Ensure lighting system is sufficient. Ground control station to announce aircraft altitudes.
The PIC does not have sufficient distance for a safe landing.	Minor	Remote	PIC and visual observers to inspect recovery location prior to twilight.
The aircraft collides with ground crew on approach.	Hazardous	Remote	Require sufficient proficiency. Improve flight planning.
The PIC is unable to determine aircraft heading upon approach.	Minor	Probable	Utilize strip lighting on wings that improve heading orientation observability.

- Define the visibility range of the lighting system for manual flight, guided or autonomous flight and observability.
- Implement a lighting system that enables the PIC to determine aircraft attitude.
- Implement communication protocols for multiple VOs.
- Develop additional protocols for ensuring proper lighting system functionality.
- Develop additional protocols to minimize the risk of collisions (intruding air traffic and obstacles).

In the following subsections, a detailed description of the UAS lighting system and procedural updates is presented.

B. SUAS Lighting System

The SUAS is to be outfitted with a lighting system that ensures visibility to the PIC and visual observers, and is sufficient to determine aircraft orientation and position. Following the convention of §23.1385, the UAS lighting consists of wingtip lights, wing-strip lights, tail lights and launch mechanism lights (Fig 2).

1) Wingtip Lights: Wingtip lights as previously described are used for position and right-of-way determination in general aviation. While the proposed wingtip lights have a similar design, they have additional uses specific for UAS use. With the PIC on the ground, the ability of the PIC to fly safely is dependent on the PIC's situational awareness of the aircraft. At night, the normal visual cues of aircraft attitude (roll, pitch and yaw) and position (lat, long and altitude) are not visible without illumination. The wingtip lighting is a simple mechanism for determining which wing is facing the PIC, from which to infer flight direction and aircraft roll. At close range, it can be used for full pose estimation, however at long distances is only useful for roll and heading estimation by the PIC. In contrast to §23.1387 requirements, nearly omni-directional lighting is preferred. The pilot must be able to estimate aircraft orientation from any orientation in order to maintain an adequate level of safety. In the proponents system, the lighting used on each wing provided visibility up to 170 degrees. The use of red and green on the left and right wing respectively, conforms to existing FAA regulations, and while not as bright as required by §23.1389, provides sufficient visibility of aircraft roll and heading.

2) Underwing Lights: Ideally wingtip lights would be sufficient for PIC and VOs, however, in practice they were insufficient on their own. Factors such as wing dihedral and narrow viewing angles at large roll angles necessitated the use of additional lighting. Underwing lighting was proposed to improved orientation estimation, especially at close distances. Two options were proposed: lighting strip parallel

TABLE III: Standard Mission Operation

Potential Hazard	Hazard Severity	Probability	Resolutions
The PIC lost visual sight of aircraft due to distance.	Major	Probable	Ensure aircraft lighting system provides sufficient visibility. Establish clear visibility limits and improve mission planning.
The PIC lost visual sight of aircraft due to obstruction.	Major	Probable	Improve flight planning operations. Require PIC and visual observers to inspect for potential obstructions prior to twilight. Utilize secondary visual observers.
The PIC lost visual sight of aircraft due to UAS lighting system failure.	Major	Remote	Add UAS lighting subsystem checks to pre-flight checks.
The PIC is unable to determine aircraft orientation due to lack of training.	Major	Probable	Require sufficient training on determining orientation from lighting system. Ensure adequate visibility.
The PIC is unable to determine aircraft orientation due to distance.	Minor	Probable	Require sufficient training on determining orientation from lighting system. Ensure adequate visibility.
The PIC is unable to determine aircraft orientation due to changes in visibility or external factors.	Minor	Remote	Utilize secondary visual observers. Ground Control provide supplementary information.
Aircraft flight performance has changed.	Minor	Remote	Analyze the lighting system integration to minimize changes to flight envelope.
The aircraft is heading to an obstruction.	Major	Remote	Require PIC and visual observers to inspect for obstructions prior to twilight. Improve flight operation planning.
The aircraft is heading to an object in air (air traffic).	Hazardous	Remote	Utilize a second visual observer for intruding air traffic monitoring. Provide sufficient operation maneuverability for evasive actions.
The aircraft collides with power lines, trees or vegetation.	Hazardous	Remote	Require PIC and visual observers to inspect for obstructions prior to twilight. Improve flight operation planning. Provide sufficient operation maneuverability for evasive actions.
The PIC and primary observer lose communication.	Major	Remote	Require PIC and primary visual observers to be co-located.
The PIC and secondary observer lose communication.	Minor	Probable	Utilize secondary means of communication. Acceptable risk.

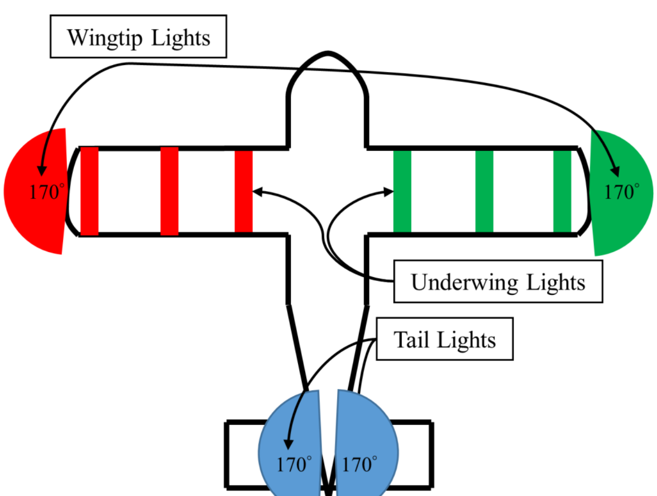

Fig. 2: Wingtip Lights, Underwing Lights and Tail Lights for UAS

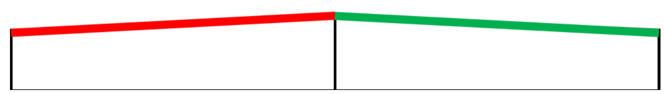

Fig. 3: Underwing lights parallel with leading edge of wing

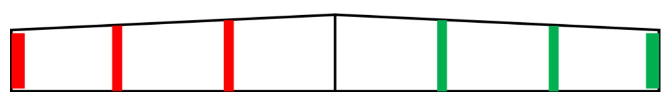

Fig. 4: Underwing lights perpendicular with leading edge of wing

to the leading edge of the wing (Fig 3) and lighting strips perpendicular to the leading edge of the wing (Fig 4). While underwing lights parallel to the leading edge of the wing initially seemed effective, it was found that the arranging the lights perpendicular to the leading edge of the wing proved more effective. In this perpendicular orientation, the heading or yaw estimation was greatly improved, especially when directly facing the aircraft. As seen in Figs. 5-**??** , the heading angle of the aircraft can be judged by the angle of the lights, whereas when parallel with the wing, the PIC or VO must estimate the relative length and infer heading angle from that. In aircraft where recessing the lights within the wing is unfeasible, the use of strips of lighting additionally reduces the loss of airflow compared to arranging strips parallel with the leading edge of the wing.

3) Tail Light: The use of the tail light on a SUAS is used both as a beacon and as an indicator of aircraft pitch. While a pulsing light on the tail is common for general aviation, it was found to be ineffective and potentially distracting for the PIC. As the PIC or VO must maintain constant visual with

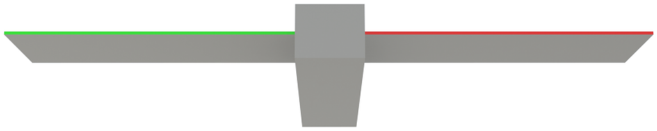

Fig. 5: Perspective view of underwing lights parallel with leading edge of wing.

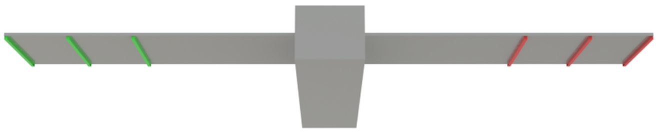

Fig. 6: Perspective view of underwing lights perpendicular with leading edge of wing.

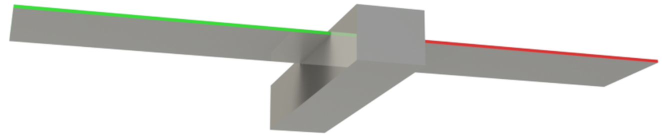

Fig. 7: Perspective view of underwing lights parallel with leading edge of wing with aircraft at 20° yaw.

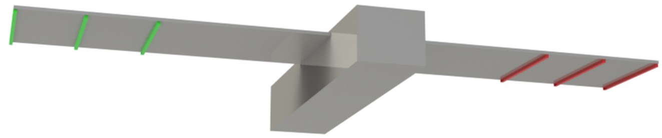

Fig. 8: Perspective view of underwing lights perpendicular with leading edge of wing with aircraft at 20° yaw

the SUAS at all times, the need to be attention grabbing was not a priority over aircraft attitude estimation. The PIC or VO would use the general relationship between the wingtip lights and the tail light to infer aircraft pitch. To prevent obscuring the tail light with the red or green light of the wings, white was chosen as the light color. At close distances, the light from the tail provided illumination of the UAS registration number on the tail of the aircraft.

4) Launch and Recovery Lighting Systems: The launch and recovery of the SUAS is often the most sensitive and challenging aspect of UAS operation. As such, extra precautions were developed to provide a sufficient level of situational awareness during these key phases. In the case of a catapult, slingshot or other assisted launch system, indicator lights are valuable to alert the PIC and VOs of successful actions or the need for corrective actions. In the proponent's system, a slingshot or bungee system is used to propel the aircraft with sufficient airspeed for lift. Two critical conditions exist for this setup: the successful release of the bungee cord and the aircraft has cleared the launch zone at an appropriate velocity. Due to the need for the PIC and VOs to have adapted to the darkness, all phases of the UAS mission must occur at the same illumination. This eliminates the ability to use a brightly lit runway for the visualization of these two critical conditions. Instead, two indicator LEDs are used: on the bungee cord and at the clearance point. The PIC is able to use the bungee indicator LED to judge if the bungee cord has released from the aircraft. The clearance point marker provides the PIC a reference point at which the PIC may judge the airspeed of the aircraft (Fig)

Recovery operations also may require modifications. In general aviation, landing lights are common to illuminate the terrain or runway during approach, however, these are most effective to the pilot within the aircraft. The same lights are of limited value to a PIC or VO outside of the aircraft. The major challenge of the recovery operation is in the accurate determination of aircraft altitude on approach and heading angle. In practice, PICs found the addition of bright landing lights to be a distraction. Instead, the use of mild lights at an evenly space interval was found more conducive for a safe landing. These mild lights provided the necessary reference point for the PIC to judge aircraft altitude, and the use of underwing lights provided the necessary information to infer aircraft heading.

C. Night Flying Operations

Supplemental operations are necessary for safe night flying in addition to the implementation of a UAS lighting system. In this section, additional operations for site inspection and training requirements are discussed to minimize risk.

1) Site Inspection: Site inspections are common for UAS operations, however, the added difficulty of night operations necessitates several additional requirements and processes. The UAS lighting system previously described addresses the visibility issues of night operations, however, it does not adequately addresses the potential of air safety threats such as visual obstructions and potential collisions.

Visual obstructions are a common issue in all UAS operations, however, the magnitude of difficulty is increased during night operations. Whereas during day operations, a visual obstruction is immediately apparent, at night with limited visibility, the complete loss of visual on the aircraft is sudden, without warning and introduces ambiguity where the PIC or VO must guess whether the loss of visual is an obstruction or an aircraft failure. To mitigate this potential hazard, a site inspection is recommended during daylight hours to allow the PIC and VO an opportunity to scout. UAS flight plans can be adjusted or alternatively, potential obstructions can be marked with low-intensity illumination. Potential collision hazards can be marked in a similar fashion during a daylight site inspection.

2) Additional Training Requirements: Aircraft orientation is more difficult to determine when the number of visible cues are reduced. In the proposed system, the PIC or VO must be able to infer aircraft orientation solely on the installed lights. At short distances, this is relatively easy as the individual lights are sufficiently spaced to be visible. However, as the distance increases, it becomes more and more difficult to discern the colors and shapes. In practice, for an 8 ft wingspan aircraft, full pose estimation was rendered impossible at distances greater than 1000 ft, however, roll and heading estimation was possible to 2.0 NM.

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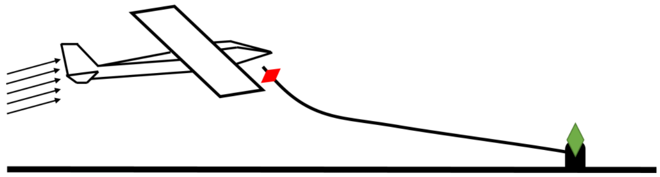

Fig. 9: Underwing lights perpendicular with leading edge of wing

In order to sufficiently train the PIC and VOs for night operations, an aircraft orientation training and testing system was developed. This training system uses a model aircraft outfitted with the UAS lighting system and the trainee practices inferring the correct orientation from a distance greater than 700 ft. This training is described as follows. The testing team is composed of a crew of two: the test evaluator and an aircraft manipulator. The aircraft manipulator will be set up at a predefined location, greater than 700 ft from the test evaluator and testee. When the test begins the aircraft manipulator will activate the UAS lighting system with the aircraft in a predefined orientation, such as level with right wing facing testee. The aircraft manipulator will rotate the aircraft slowly in a predefined pattern mimicking the motions of an aircraft in flight. At predefined test points, the aircraft manipulator will signal to the test evaluator to question the testee on the aircraft's orientation. This process is repeated for a minimum of 15 evaluations. The test evaluator will score the testee on the accuracy of their responses in coordination with the aircraft manipulator. A score is considered passing with an accuracy rate over 70%.

As night flying poses an additional challenge, an additional concurrency requirement is added. PICs and VOs must complete 3 night launch and recovery operations within the past 90 days to maintain their concurrency. It is recommended that VOs be able to substitute a successful aircraft orientation test in lieu of a night flying mission.

3) Night Flying Protocols: Additional adjustments to UAS protocols are required for night flying missions. These adjustments are small, but critical adjustments to maintain an equivalent level of safety as daylight flights.

The use of a secondary, distant VO provides a secondary viewing point for obstacles and to monitor for intruding air traffic. This is particularly important as inferring position becomes more difficult at night with the reduction in visible cues.

To ensure the PIC and VOs have adapted their visibility to the dark, it is required that both PICs and VOs to be in place at least 30 minutes prior to UAS operations. This provides sufficient time for the PICs and VOs to adapt to the dark such that they are able to see effectively during the night.

Additional pre-flight checks to ensure that the UAS lighting system is operational and that VOs are in place prior to UAS operations.

During long operations, the PIC and VOs may begin to lose orientation as fatigue sets in. It is required that the Ground Control Station Operator or operator with access to the UAS telemetry repeat heading, altitude, general location and aircraft attitude every minute. This provides the PIC and VO with a known aircraft status for them to infer future aircraft orientation and position.

During night operations, it can be easier to overlook aircraft damage in the dark. An additional round of aircraft inspection is required immediately after a flight in addition to the pre-flight aircraft inspection.

The human factors of night operations also require addressing. During night operations, operator fatigue and prolonged exposure at night can contribute to operator complacency and potential unsafe acts. Operational requirements to mitigate these effects include reducing operation time compared to daylight flights and utilizing a rotating ground crew for inspections and critical flight elements.

IV. Best Practices

The current lighting system is a conglomerate of design, trial and error, testing and eventually a validated product. While night flying is allowed and performed regularly by AMA licensed persons for pleasure at AMA fields, the scale and scope of many UAS operations require a different approach. It was noticed during development that the brightly lit aircraft regularly flown by AMA licensed persons were ineffective at long distances. The shear number of lights blend together at long distances, creating an indiscernible bright spot that disorients the PIC. While the aircraft was plainly visible, the level of situational awareness was a significant safety risk, unsuitable for UAS operations.

It was determined that rather than adding a fully illuminated aircraft, that optimally placed lights would prove to be a more efficient and safer solution. Initial developments utilized the regulations found in 14 CFR 23 to mimic the utility found in full-size aircraft. However, the drastic reduction in lighting also led to a different set of issues. The purpose of the lights found in 14 CFR 23 ultimately held a different purpose than the proposed operations. In a UAS operation, constant visual observation of the aircraft is required, but this also includes the ability of the PIC to retain a sufficient level of situational awareness to pilot the aircraft when necessary. This revelation caused a shift in approach and design to focus on the PIC's ability to maintain correct orientation during flight, while maintaining the ability for air traffic to visually observe the UAS from an adequate distance. Visibility of at least two of the three colors (red, green and white) on the aircraft was necessary at all times, and thus the need for nearly omni-directional lighting was realized.

Initial testing of illumination system was performed on a half-sized foam aircraft, where orientation tests were performed on the ground with the pilot observing orientation and assistant manipulating aircraft attitude at a series of set distances. The illumination system was then adjusted and retested until justifiable confidence in the system was achieved. The aircraft was then flown at night by licensed AMA persons to reassure the concluded system, as well as assess the effectiveness of the system and make necessary changes. Some conclusions drawn from this testing are:

1) **PIC Experience:**

TABLE IV: Relevant Federal Aviation Regulations

Statute	Description	Notes
§23.1322	Cockpit Warning Lights	Not Applicable on aircraft for UAS operations
§23.1381	Instrument Lights	Not Applicable on aircraft for UAS operations
§23.1383	Taxi and Landing Lights	Could be considered applicable for UAS operations, but was found that landing lights were distracting to PIC, and thus a safety risk. Recommendation is to grant exemption for UAS operations at night.
§23.1385	Position Light System Installation	Applicable for UAS Operations.
§23.1387	Position Light System Dihedral Angles	Insufficient for UAS operations. Recommendation is to expand dihedral angles R and L to 170°, and tail light should be visible 360°.
§23.1389	Position Light Distribution and Intensities	Difficult to meet intensity requirements on small UASs. Recommendation is to grant exemption and adopt a scale appropriate intensity requirement.
§23.1391	Minimum Intensities in the Horizontal Plane of Position Lights	Difficult to meet intensity requirements on small UASs. Recommendation is to grant exemption and adopt a scale appropriate intensity requirement.
§23.1393	Minimum Intensities in Any Vertical Plane of Position Lights	Difficult to meet intensity requirements on small UASs. Recommendation is to grant exemption and adopt a scale appropriate intensity requirement.
§23.1395	Maximum Intensities in Overlapping Beams of Position Lights	Overlapping beams of position lights is necessary for orientation estimation by the PIC. Recommend exemption for UAS operations.
§23.1397	Color Specifications	Applicable for UAS Operations.
§23.1399	Riding Light	Not evaluated in this study
§23.1401	Anticollision Light System	Anti-collision light proved distracting and detracted from the conspicuity of the position lights for PIC and presented a safety risk. Exemption not necessary due to §91.209(b)
§61.57(b)	Recent Flight Experience	Applicable for UAS Operations.
§61.109(a)(2)	Aeronautical Experience	Applicable for UAS Operations, but recommend scale appropriate.
§91.209	Aircraft Lights	Applicable for UAS operations. §91.209(b) provides exemption for lack of anti-collision light as its installation would pose a safety risk.

a) Too much ambient light results in disorientation;
b) Too much light on the aircraft is too distracting;
c) The pilot needs a VO that can assist in radio communications between the pilot and the GCS, transportation of the pilot if need be and illumination of landing strip;
d) Red light must be used by anyone in close proximity to the PIC prior to and during operation.

2) **VO Experience:**

a) Similar to PIC, too much light on the aircraft is too distracting;
b) Ensure all necessary pre-flight preparations;
c) Ensure crew readiness prior to launch;
d) Difficult to confirm cord was detached from hook when using the catapult launcher;
e) VO needs to follow proper radio communication protocol, including repeating every message for clarification;
f) Constant scan for air traffic is needed to help PIC.

The most obvious difficulty that the PIC must deal with is the visibility of the aircraft at a distance. It is known that visibility is defined through the case of a black object viewed against a white background. The visual contrast is then defined as the relative distance between the light intensity of the background and the object. This value decreases exponentially with the distance from the object, in ideal conditions. This degradation is further amplified in foggy, misty and hazy environments. While manned helicopter pilots may utilize night-vision goggles for night operations, according to the FAA [9], "To ensure that the operator has the best view of the aircraft, the statutory requirement would preclude the use of vision-enhancing devices, such as binoculars, night vision goggles, powered vision magnifying devices, and goggles designed to provide a first-person view from the model." Therefore, certain limits on visibility conditions that are more rigorous than current FAA manned aircraft visibility must be set in order to safely operate UAS at night.

As previously described, the current night flying operations require some level of adherence to existing FAA regulations. A summary of existing relevant regulations and their applicability to UAS operations is presented in Tab IV.

While many regulations are applicable for UAS operations, several are recommended to require amending. Minimum intensities as required may be significantly excessive depending on the size of the UAS and the scope of the operation. The lighting system intensity is recommended to be sufficient for the maximum proposed distance rather than regulated to a specific intensity level.

The use of anticollision lights is recommended to be relieved for UAS. In the proponents development and testing, the pulsing light proved to be a distraction and detracted from the conspicuity of the position lights. While a pulsing light greatly improves detectability, especially in the peripheral of a pilot's vision, it is unnecessary for a UAS PIC who is required to maintain constant visual contact. When the PIC focused on the bright flashes of the anti-collision light, the PICs eyes attempted to adapt to the elevated brightness and diminished the PICs ability to discern the other dimmer position lights.

V. Conclusion

The development of night-time UAS operations is a natural progression as the use of UAS expands throughout the civilian and commercial realm. Remote sensing by means of UAS at night can contribute a currently unimaginable amount to the fields of agriculture, environmental monitoring, species monitoring or surveillance. The design process for illumination systems on UAVs for the purpose of night time remote sensing was discussed an experimental analysis is provided. While this paper provides evidence that night-flying UAS for data collection and repeatable missions are feasible and safe, these are merely the first steps towards the development and analysis of UAS night operations. Further case studies in real world applications need to be investigated in order to justify the usefulness of UAS it night time operations. Future work will focus directly on optimization of lighting systems and human factors.

References

[1] S. Herwitz, K. Allmendinger, R. Slye, S. Dunagan, B. Lobitz, L. Johnson, and J. Brass, "Nighttime uav vineyard mission: Challenges of see-and-avoid in the nas," in *Proc. AIAA 3rd Unmanned... Unlimited Conference, Workshop and Exhibit*, pp. 20–23, 2004.

[2] M. R. Roberts, "5 drone technologies for firefighting." [ONLINE] `http://www.firechief.com/2014/03/20/5-drone-technologies-firefighting/`, 2014.

[3] Federal Aviation Administration, *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspac System (NAS) Roadmap*. 2013.

[4] Academy of Model Aeronautics, *Academy of Model Aeronautics National Model Aircraft Safety Code*. 2015.

[5] 14 CFR 23, *AIRWORTHINESS STANDARDS: NORMAL, UTILITY, ACROBATIC, AND COMMUTER CATEGORY AIRPLANES*. Code of Federal Regulations, 2015.

[6] 14 CFR 91, *GENERAL OPERATING AND FLIGHT RULES*. Code of Federal Regulations, 2015.

[7] Federal Aviation Administration, *FAA-H-8083-3A, Airplane Flying Handbook*. U.S. Department of Transportation, Federal Aviation Administration, Airman Testing Standards Branch, AFS-60, 2004.

[8] 14 CFR 61, *CERTIFICATION: PILOTS, FLIGHT INSTRUCTORS, AND GROUND INSTRUCTORS*. Code of Federal Regulations, 2015.

[9] Federal Aviation Administration, "Interpretation of the Special Rule for Model Aircraft," *[Docket No. FAA-2014-0396]*, 2014.

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