UAS Operations

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EXECUTIVE SUMMARY

The regulatory and policy landscape for civil UAS operations has changed rapidly over the past 5 years. The 29 August 2017 publication of the Rule for Non-Hobbyist Small Unmanned Aircraft Operations, Part 107 of the Federal Aviation Regulations, Title 14 of the Code of Federal Regulations, was the first rule resulting from the many congressional mandates of the FAA Modernization and Reform Act of 2012 (FMRA; now Public Law 112-095). The FMRA has arguably had more impact on the operations of UAS in the U.S. National Airspace System (NAS), than any other policy statement or event since the creation of the FAA Unmanned Aircraft Program Office in February 2006. FMRA "Section-333" empowered the FAA Administrator (through the Secretary of Transportation) to create a process that enables the Administrator to authorize civil UAS operations on a case-by-case basis. Prior to the FMRA, UAS policies were applied uniformly, regardless of the physical size or performance of the aircraft. Operations of large civilian UAS, such as the General Atomics Predator B and the Northrup Grumman Global Hawk, both military UAS repurposed for civilian agency applications, were subject to the same policies as small UAS (sUAS) weighing in at less than 55 lb (25 kg). Because large UAS are generally operated similarly to manned aircraft of comparable size, their operations are better understood by airspace managers and air traffic controllers, thus the integration of large UAS into the NAS and over international waters has generally been less disruptive than for sUAS that are more akin to "model aircraft" whose operations FAA agreed not to regulate according to the policy published in 1981 in Advisory Circular AC 91-57.[1]

Other outcomes from the 2012 FMRA include the creation of the mandated six FAA UAS test sites, and the creation of the FAA UAS Center of Excellence. To more directly address the immediate interests of the civil UAS industry, FAA also created the Focus Area Pathfinder Initiative with industry partners investigating three focus areas: 1) Visual line-of-sight operations over people, 2) Extended visual line-of-sight operations in rural areas, and 3) Beyond visual line-of-sight operations in rural areas. The industry partners include CNN, PrecisionHawk, BNSF, and recently Gryphon Services, LLC was added under a cooperative agreement.

The 2010 field campaign for the Second Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX2) and the 2013 Marginal Ice Zone Observations and Processes Experiment" (MIZOPEX) project are examples of science missions employing sUAS that pushed the boundaries of FAA policies and procedures for airspace access. The study of these two cases presents lessons that illustrate the need for regulators to adapt policies to accommodate users who satisfy all the regulatory requirements for authorized use of airspace, and the consequences when status-quo and a refusal to acknowledge the demonstrated ability for safe operations is the rule. The cases also illustrate the need for sUAS operators to acknowledge that the penultimate responsibility of airspace regulators and traffic controllers is to first ensure overall airspace safety.

Several opportunities and key challenges for current and future UAS operations are presented for discussion: 1) Increasing Autonomy: Operations without Continuous Human Oversight, 2) Operations

[1] AC 91-57 is now superseded by AC 91-57a, published 2 September 2015.

Over People and Beyond Visual Line-of-Sight, 3) Nighttime Operations, and 4) Urban/Suburban Operations, and 5) Multiple-UAS Operations.

SUMMARY OF PREVIOUS WORK

As part of the Department of Transportation, the FAA develops and administers airworthiness standards against which aircraft are certified for flight. The FAA also maintains and administers standards for pilot certification through licensure. Standards for the certification of aircraft and pilots, and regulations for the operation of aircraft in the National Airspace System (NAS) are codified in the Federal Aviation Regulations (FARs), Title 14 of the Code of Federal Regulations (CFR). Prior to the issuance of Part 107 in August 2016, there were no FAA regulations for the operations of UAS, nor for the certification/licensure of UAS pilots. Part 107 only addresses the operations of small UAS (sUAS) [those weighing less than 55 lb (25 kg)], at a maximum altitude over the ground, or over an obstacle, of 400 ft (122 m). The status of UAS operations in the NAS not covered by Part 107 remains unchanged since the policy changes resulting from congressional mandates in the FAA Modernization and Reform Act (FMRA) of 2012 (now Public Law 112-095). The following discussion first provides a background of some of the more important decisions leading up to the current state of UAS regulations and authorizations that enable UAS operations in the NAS. Since most developments of relevance for the NCAR UAS Workshop have been for sUAS operations, with the exception of a brief discussion of large UAS missions, the remainder of the discussion will focus on sUAS. Also, since the University of Colorado Boulder (CU) has had major influence on the regulatory policies related to sUAS operations, the sUAS discussion will be based significantly on CU experiences.

Certifications and Authorizations

Similar to manned aircraft, UAS are broadly categorized as: i) Civil UAS that are operated for commercial purposes, and ii) Public UAS that are operated by the U.S. or state governments, and their associated agencies [1]. In 2006, FAA stood-up the Unmanned Aircraft Program Office (UAPO) that began to administer applications for Certificates of Waiver or Authorization (COAs) through an online portal. Prior to the 2012 FMRA, civil UAS could only be operated in the NAS, outside of special-use airspace, with a Special Airworthiness Certificate in the Experimental Category. The COA enables a public entity to “self-certify” a UAS with the submission of an Airworthiness Statement prepared according to an accepted standard as described in Ref. [2]. In our experience, over the years the Airworthiness Statement for a custom-built sUAS has evolved from a 30-page document that states line-for-line compliance with the selected standard (e.g., CU has always employed the DoD standard MIL HNBK 516B), to now a one-page statement that attests that the public entity[2] has met the requirements of the standard. Therefore, for circumstances where Part 107 does not apply, the certification or authorization process, and access to the NAS, remains simpler for public UAS. A 2009 Memorandum of Agreement between FAA and the Department of Defense (DoD) streamlined FAA authorizations for DoD UAS flights in the NAS [3]. Because they are under the oversight of state governments, public (state) universities are allowed to operate public UAS with a COA; private universities cannot, unless they are contracted to work under a COA obtained for a public UAS.

Outside the U.S., most member states in the United Nations manage their airspace according to the accepted standards of the International Civil Aviation Organization (ICAO), where again there are no

[2] In this case, the University of Colorado Boulder, as certified by the Office of the Colorado State Attorney General.

specific ICAO UAS standards. As of this writing, several ICAO-member states have similar policies to the U.S., but generally pursue their own civil aviation interests with processes developed for allowing UAS in their specific airspaces.

The FAA may not regulate airspace in certain a “special use airspace” or a “special area of operation (SAO)” which includes active Prohibited, Restricted, or Warning areas [4]. When active, aircraft operations in a SAO might be conducted based on rules of administered by the airspace manager. Prior to the FMRA, the SAO was usually the easier of the two options for the operations of civil UAS in the national airspace system. In some of the early interactions of CU researchers with the UAPO, an often repeated line was: “if you want to fly these, do it in restricted airspace where we (FAA) have no jurisdiction.” The other option is the aforementioned Special Airworthiness Certificate, Experimental Class, which few have pursued because of the onerousness of the process. Ballinger and Bossert [12] present one of the few successes of, which we are aware, for a sUAS special airworthiness certification.

The “see-and-avoid rule” in the General Operating Rules of FAR Part 91 presents the greatest challenge for the operation of UAS in the NAS. Although there has been progress in the development of sense-and-avoid technologies that sometimes rely on non-vision-based sensing systems and automatic decision-making systems, no sense-and-avoid system is yet certified to satisfy the see-and-avoid rule. Murphy and Argrow [5] report on a workshop discussion about the requirement for a UAS to be capable of demonstrating “an equivalent level of safety” to the requirements of a licensed human pilot for the see-and-avoid rule. At that time the machine equivalent was referred to as “sense and avoid” to make it clear that a machine might satisfy the requirement with sensors distinctly different from the human eyeball. A subtle change in the argument was suggested to replace “equivalent level of safety” with “acceptable level of safety,” since the point is to develop a system that provides an acceptable (likely superior) level of safety as compared to a human pilot.

In lieu of a certified see/sense-and-avoid system, a UAS can only fly in the airspace regulated by the FAA with special provisions that compensate for the inability of the system to directly satisfy the Part 91 requirement from an airborne unmanned aircraft (UA). This might include a visual observer (VO) in a chase plane, or a ground-based VO who can provide the visual function required to satisfy the see-and-avoid rule. Until recently, VOs had to have a class-2 medical certification, which is a greater requirement than the class-3 medical requirement for conventional general aviation pilots in a manned aircraft, however it appears that the class-2 medical may not be required if FAA authorizes VO (and pilot) certification as part of the self-certification process by a public entity.

Large UAS Operations

The resources required to operate large UAS has limited their operations primarily to government agencies, particularly NASA, NOAA, and DHS. Programs of note include a series of NASA programs employing Altus, Altair, and Ikhana (various versions General Atomics Predator-series UAS repurposed for civilian applications) for a series of fire-mapping missions over the western U.S., that started about 2001 [6]. The more recent NOAA “Sensing Hazards with Operational Unmanned Technology (SHOUT) Program is focused on sensing high impact weather-related hazards. In a partnership with NASA, the SHOUT Program has completed several long-endurance, oceanic targeted-observation missions with the Global Hawk UAS [7].

FAA Modernization and Reform Act (FMRA) of 2012 and Section 333 Exemptions

With the passage of the FAA Modernization and Reform Act (FMRA) of 2012 (now Public Law 112-095) [8], the U.S. Congress directed FAA to accelerate its efforts to safely integrate UAS into the National Airspace System. One of the most impactful provisions of the FMRA is *Section 333 Special Rules for Certain Unmanned Aircraft Systems*, that states: "*—If the Secretary determines under this section that certain unmanned aircraft systems may operate safely in the national airspace system, the Secretary shall establish requirements for the safe operation of such aircraft systems in the national airspace system.*" Between the publication of the FMRA in February 2012 and the publication of Part 107 in August 2016, thousands of civil UAS operators gained limited access to the NAS with FAA authorization through FMRA Sect. 333.

With pace of sUAS operations, both authorized and not, the FAA Administrator issued an "Interpretation of the Special Rule for Model Aircraft" [9] to provide an updated interpretation of the 1981 Advisory Circular AC 91-57 that first defined "model aircraft," recognized that they present a potential hazard to manned aircraft operations, and then provided operations guidelines to mitigate the safety risks.

Part 107 Rule for Operations of Small UAS

On 29 August 2017, 14 CFR Part 107 Rule for Operations of Small UAS became active. Although the requirement for UAS registration was the first significant policy change to broadly affect sUAS operations since the COA-online process was established in 2006, as previously mentioned, Part 107 is the first regulation for the operation of a UAS of any size. An immediate consequence of Part 107 was to eliminate the need for most FMRA Section-333 exemptions for sUAS operations below 400 ft (122 m). Part 107 also established clear requirements for a Remote Pilot Certificate and re-affirmed the statutory requirement that all sUAS greater than 0.55 lb (0.25 kg) must be registered. Additional constraints include a requirement for daytime, visual line-of-sight (VLOS) operations only, and a prohibition of flying sUAS over people. However, Part 107 waivers can be sought for any of the prescribed constraints. As of this writing, a number of waivers have been granted that include BVLOS and nighttime operations.

FAA UAS Test Sites, Center of Excellence, and Pathfinder Program

In December 2013, FAA awarded permission to six university-agency consortia to create UAS test sites at locations around the country, as mandated by Congress in the FMRA.[3] This was followed in 2015 with the award of the FAA UAS Center of Excellence (COE) to a university-led team. In addition to the UAS test sites and the UAS COE, FAA also created the "Focus Area Pathfinder Program" [10] with three industry partners to investigate: 1) Visual line-of-sight operations over people (CNN); 2) Extended visual line-of-sight operations in rural areas (PrecisionHawk); and 3) Beyond visual line-of-sight operations in rural/isolated areas (BNSF). These are applications that currently require an exemption or waiver. Since the release of Part 107 it is clear that BVLOS, flying over people, and nighttime flying are primary areas of FAA research focus by the COE, test sites, and Pathfinders. The creation of the test sites and COE appear to enable FAA to be more responsive to the need to conduct research for equipment and operations standards and policies.

[3]For reasons that remain unclear to us, the UAS test site that had been operated by New Mexico State University was not originally counted as a seventh site in addition to the six sites designated in 2016.

Pushing the Limits: Two Case Studies

As mentioned previously, the only UAS-specific regulation is FAR Part 107, which applies to UAS weighing less than 55 lb (25 kg) operated below 400-ft (122-m) altitude. Other UAS operations are enabled through a FMRA Section-333 exemption, a COA, or a Memorandum of Agreement. The following two cases are presented to illustrate the types of interactions that have occurred over the past 10 years, where public sUAS operators have attempted to conduct first-of-their-kind operations that required FAA regulators to assess current sUAS policies and how they addressed the proposed operations.

Case 1: Nomadic UAS Operations

In 2010, the University of Colorado Boulder introduced "nomadic deployments" of a sUAS during the field campaign for the "2nd Verification of the Origin of Rotation in Tornadoes Experiment (VORTEX2)". Stachura et al. [2], describe the interactions with the FAA Unmanned Aircraft Program Office (UAPO) that led to the creation of 59 COAs covering about 24,000 mi^2 (62,000 km^2) of northeast Colorado, northwest Kansas, southwest Nebraska, and southeast Wyoming. Each of the COAs was nominally a box, 20-mi (32 km) on each side, with a 1,000-ft (305-m) AGL ceiling. Four of the COAs had 400-ft (122-m) ceilings because of the proximity of the airspace to approaches to airports; those COAs proved to not be useful. To satisfy the Part-91 see-and-avoid requirement, and the requirement for a fixed ground control station (GCS), a concept of operations (CONOPs) was developed where the UA (the Tempest UAS) was launched at the GCS site, then commanded to automatically track a 2.4-GHz WiFi radio node carried in a ground "tracker vehicle." Inside the tracker vehicle was a driver, a meteorologist, a VO, and a remote UAS operator with limited control of the UA through the WiFi link. The Pilot in Command (PIC) and the UAS operator maintained long-range command and control from the stationary GCS through a 900-MHz GCS-UA link, and VHF radios were used to maintain voice communications between the PIC and the occupants of the tracker vehicle.

At the start of the field campaign, FAA required that COAs be activated with Notices to Airmen (NOTAMs) 72-48 hours in advance of UA launch. Within 2 weeks, this requirement was reduced to up to 4 COAs activated with NOTAMs 2 hours in advance of UA launch. After a review of the CONOPs and procedures with the Denver Area Route Traffic Control Center (ARTCC) at the conclusion of the VORTEX2 field campaign, FAA reduced the COA NOTAM lead time to 1 hour. Since 2010, the original 59 COAs shown in Fig. 1 for Tempest UAS operations have been consolidated into 5 COAs for the operation of the Tempest/TTwistor UAS covering more than 380,000 mi^2 (with 40,000 mi^2 two pending COAs) over seven states of the Great Plains, with a ceiling of 2,500 ft (760 m), and provisions for the simultaneous operation of multiple-UAS. The updated CONOPs eliminates the fixed GCS in favor of a fully mobile GCS carried inside the tracker vehicle with the PIC, a VO, a meteorologist, and a driver. This CONOPs was successfully demonstrated in June and October 2016 with several flights in Colorado, Kansas, Nebraska, and Oklahoma. Multiple-UAS operations will begin in spring 2017.

Lessons learned in working with the FAA during VORTEX2 include:

1. Prior to submitting a COA application, contact the appropriate liason at the FAA UAS Integration Office [UASIO; formerly the UAS Program Office (UAPO)] to discuss your intentions and inform the UASIO that you will discuss the operations with the affected ARTCCs to discuss potential air traffic control concerns.
2. During the COA online submission, prepare maps to identify special-use airspace (restricted areas, military operations areas (MOAs), warning areas) and prepare text that states how your

activities will be conducted (e.g., "UAS activities will avoid restricted airspace R-XXXX). Once the COA is submitted, be prepared to discuss a plan for how the special airspace managers will be notified prior to operations in their area, and how you will coordinate with airspace managers if the special-use area is active during flights.

3. If relatively small changes are made to the UAS or the CONOPs, submit a "Pen & Ink" request that explains the changes. If properly done, the COA will be updated with the requested changes within a few days, without need for a COA re-submission.

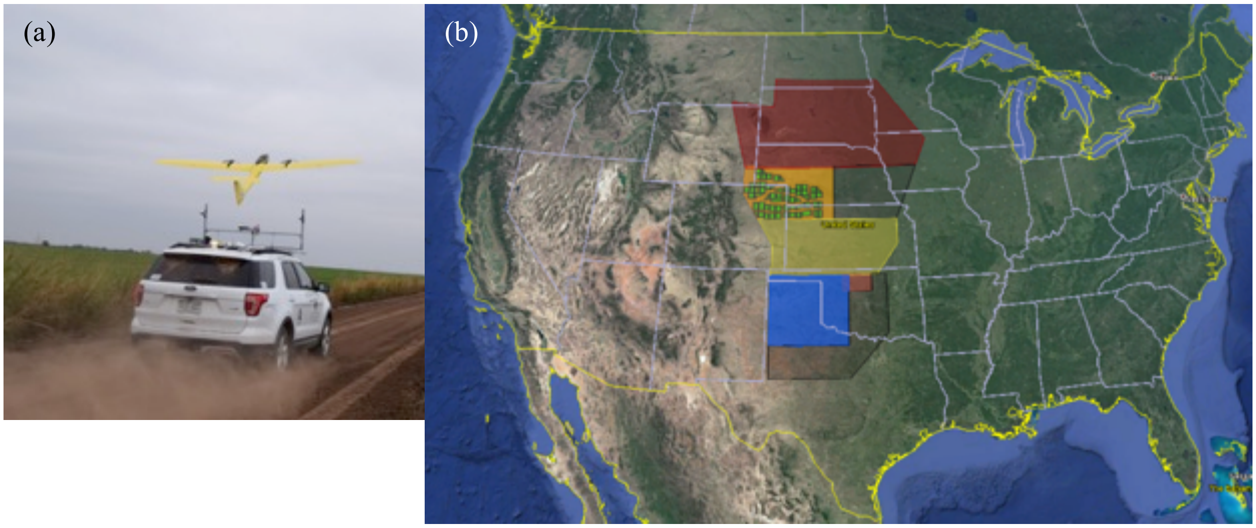

Figure 1 (a) Roof launch of a TTwistor UA in northern Oklahoma in 2016; (b) original 59 Tempest COA areas during the 2010 VORTEX2 field campaign compared to current Tempest/TTwistor COA areas, the two transparent polygons are pending COA areas.

Case 2: MIZOPEX and Fully Autonomous UAS Flights—Almost

Maslanik [11] reports on the "Marginal Ice Zone Observations and Processes Experiment" (MIZOPEX) missions that were conducted July-August 2013 from the Oliktok Long Range Radar Station at Oliktok Point, Alaska, about 30 miles (48 km) west of Prudhoe Bay Alaska. Flights begin in Restricted Area R-2204, a restricted flight area of 4 miles (6.4 km) in diameter centered at Oliktok Point and assigned to the Office of Science in the U.S. Department of Energy for atmospheric research purposes. MIZOPEX mission flight paths extended northward through an Altitude Reservation (ALTRV) corridor to international airspace. The MIZOPEX campaign established several important new "firsts" including the first flights of scientific payloads using unmanned aerial system from northern Alaska into international airspace and over international waters.

Over the four weeks, MIZOPEX missions included flights of the ScanEagle and DataHawk instrumented unmanned aerial systems. The ScanEagle was operated by a team from the University of Alaska Fairbanks. DataHawks were operated by a team from the University of Colorado Boulder that included the MIZOPEX Principal Investigator, Professor Jim Maslanik. The following excerpt from the final report [11] recounts the actions of FAA that prevented one of the primary mission deployment objectives:

> *"Our attempts at obtaining a COA for BLOS operation of the small CU DataHawk UAS, or alternatively, an exemption under Part 101 rules (i.e., treatment as equivalent in risk to a small*

balloon payload), were not approved by FAA. The COA was rejected based on the fact that our plans involved operating the aircraft beyond communications range (i.e., in "intentional lost-comm mode"). The reasons for rejecting the Part 101 exemption have not been given formally to CU. Informally, it was suggested that an insufficient safety case was made. A standard within-line-of-sight COA had been granted earlier for DataHawk, but was not needed because we were able to operate within R-2204."

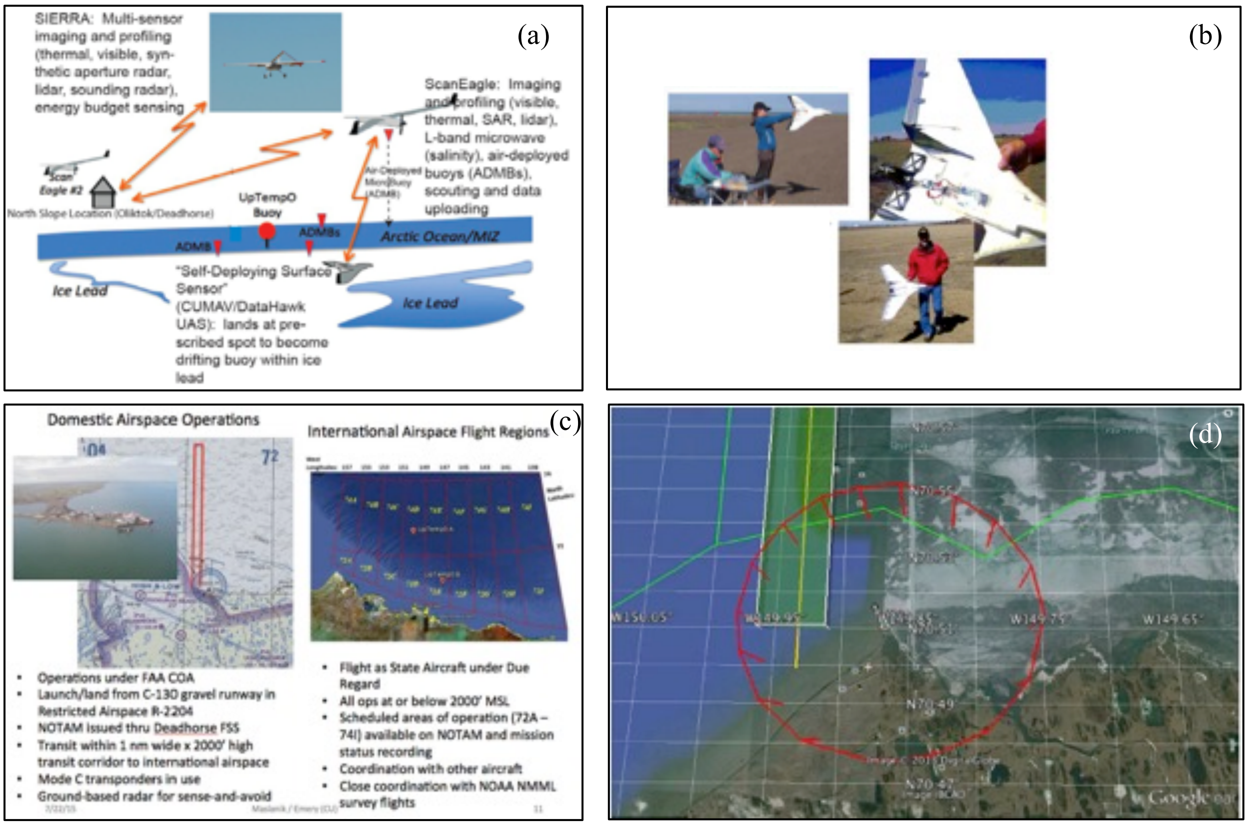

Figure 2 (a) MIZOPEX concept of operations; (b) Datahawk UAS; (c) planned airspace over domestic and international waters; (d) zoomed view of restricted airspace at Oliktok Point and corridor to international waters.

As shown in Figure 2, the plan for MIZOPEX was to fly the Scan Eagles over the marginal ice zone, to locate open-water leads. The 1.5-lb (0.68-kg), foam airframe, Datahawk UAS, would then fly through the ALTRV corridor at an altitude not to exceed 50 ft (15 m) above the water, to land in the open water at the designated locations. The Datahawks were equipped with an instrumented tether to be suspended from the foam airframe to become a micro-buoy reporting data to the ScanEagles during periodic overflights. Because the ScanEagles were equipped with satellite radio link, they were allowed to fly beyond visual line-of-sight (BVSOL). Since there was no expectation of recovery, the Datahawks were not equipped with a long-range or satellite link, so once the communications range was exceeded, FAA considered the UAS would operate in an unacceptable "fully autonomous" mode. Given that the airframe is made of foam and small metallic parts, similar to one of the larger radiosondes (e.g., a Vaisala RS-41

Ozonesonde[4]) that are routinely launched by balloon under FAR Part 101, a request was made to operate the Datahawk as a "guided radiosonde" under Part 101. As alluded to in Ref. 11, the Part 101 exemption request was rejected. One of the authors received the rejection correspondence the: "it is not a balloon."

While MIZOPEX was successful by many measures, the investigators failed to receive FAA authorization to fly one of the most low-risk, high-return missions probably ever proposed. In the final report, Maslanik lists recommendations and lessons learned for "campaigns that have challenging and/or unique UAS aspects." A few of these include:

1. As early as possible, designate a single field campaign point of contact (POC) to oversee interactions with FAA.
2. Request that, if possible, FAA provide a complementary single POC to help assure that consistent information and interpretations are being passed to the campaign's POC. This would be warranted for campaigns with special complications, such as those contained within MIZOPEX.
3. Provision of exemptions for very low-risk UASs such as DataHawk under Part 101 (i.e., treating the aircraft as posing risk comparable to a weather balloon) would open up considerable capabilities for sensing using UASs. An alternative would be to allow such aircraft to operate under a COA in fully autonomous mode outside communications range (i.e., in a planned lost-link mode.)

DISCUSSION TOPICS: OPPORTUNITIES AND KEY CHALLENGES FOR CURRENT AND FUTURE UAS OPERATIONS

1. *Increasing Autonomy: Operations without Continuous Human Oversight*.

   In 2014, the National Research Council's report autonomy research for civil aviation [13] reviewed the state of increasingly autonomous (IA) for civil aviation, and discussed the "benefits in terms of safety, reliability, affordability, and/or previously unattainable mission capabilities." One of the challenges is encapsulated in the statement: *"... Develop the system architectures and technologies that would enable increasingly sophisticated IA systems and unmanned aircraft to operate for extended periods of time without real-time human cognizance and control.*" Although this is expressed in the context of "civil aviation," it is reasonable to extend this to all "civilian aviation," therefore including the operation of public aircraft that share the airspace. The now overused expression of UAS being appropriate for missions that are "dull, dirty, or dangerous" is appropriate when describing many missions of interest to the science community, where endurance and persistence in potentially hostile environments are exactly the capabilities enabled by increasingly autonomous UAS.

2. *Operations Over People and Beyond Visual Line-of-Sight*

   Following the publication of FAR Part 107, the sUAS community immediately turned attention on the constraints of VLOS operations. Having to keep the UA in sight with unaided vision severely limits some of the applications of most interest. This is being particularly driven by large commercial interests such as Amazon and Google who have been competing to develop "drone" package delivery services, that necessarily require BVLOS operations. In addition to the UAS test sites and the UAS COE, FAA also created the "Focus Area Pathfinder Program" with three industry partners to investigate: 1) Visual line-of-sight operations over people (CNN); 2) Extended visual line-of-sight

[4] http://www.vaisala.com/en/products/soundingsystemsandradiosondes/radiosondes/Pages/default.aspx

operations in rural areas (PrecisionHawk); and 3) Beyond visual line-of-sight operations in rural/isolated areas (BNSF). While the commercial interests are obvious, eliminating the barriers to these categories of operations would enable a broad range of science applications.

3. *Nighttime Operations*

   FAR Part 107 and most COAs restrict sUAS operations to daylight hours, in part to satisfy the VLOS requirement. This constraint is a major impediment to many science and emergency/disaster response applications. There are many opportunities for low-risk deployment of sUAS for nighttime operations. An example is monitoring the nighttime behavior of an active wildland fire. While there are examples of nighttime sUAS operations under an emergency COA [14], the perceived risk of night operations appears to often be artificially inflated compared to daylight operations, thus is an area for sUAS operators should lobby to increase research opportunities and airspace access.

4. *Urban/Suburban Operations*

   This topic might be considered an extension of the Pathfinder topics described in (2), however, suburban/urban environment includes more challenges than the rural or semi-rural applications described earlier. One of the prevailing issues is increased hardware/software reliability. Standards for sUAS construction and operations are currently in development. Since there are yet no requirements to construct sUAS according to any published standard, reliance on components repurposed from the hobby industry will continue. In addition to the obvious challenges of obstacle avoidance and possible geo-fencing, hardware/software reliability present significant challenges.

5. *Multiple-UAS Operations*

   The idea of deploying swarms of sUAS was prominent 10-15 years ago, to the point that "swarm" became a buzzword with an accompanying loss of precision in its meaning. The clamor over swarm deployments waned with concerted efforts of FAA to enforce requirements for COAs and special airworthiness certificates for operations outside special-use airspace. Regardless, science applications for the simultaneous deployment of multiple UAS abound. In 2011, CU received FAA authorization to conduct multi-UA operations with a pen & ink change to an existing COA. To ensure UA separation to prevent mid-air collisions, one requirement is that each UAS have a dedicated GCS, PIC, and VO. CU has operated safely with these constraints, however the burden of replication of equipment and personnel severely constrains applications. Easing or eliminating the replication requirements will expand opportunities for novel missions.

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