Small Unmanned Aerial Systems Use for Agriculture

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Abstract: Small UAS platforms have the potential to transform agriculture in terms of increasing our ability to detect pests and disease early in the growth cycle. This study documents the procedures, operations and training of small UAS (sUAS) in agricultural domains and compares them to radio controlled model airplanes (RC). Both sUAS and RC fly at similar ranges, speeds and use similar operational and training procedures. This study uses only professional sUAS operators and manned aircraft pilots. The findings of this study suggest that sUAS operators should train using RC simulation software; two external operators should control the sUAS with one operator responsible for manual control and the other operator responsible for monitoring the automation. Additional operational and training recommendations are included throughout the study along with excerpts from the participants.

Keywords: Aircraft, pilots, operators, unmanned, robot.

I. Introduction

The accident rate of unmanned aerial systems (UAS) over all systems in operation is unacceptably high. In systems used by the U. S. Department of Defense, the accident rate exceeds 50% [1]. Many of the accidents are attributable to human performance problems of chronic or acute fatigue or a long flight time, poorly designed control stations, camera views that are likened to looking through a 'soda straw', lack of detect sense and avoid functions, lack of automation mode awareness, communication delays, transfer of control from one operator to another and the inconsistent mapping of vehicle controls [1]. In a report for the Federal Aviation Administration, Williams compared the accident data obtained for five different UAS systems in use by the U. S. Department of Defense: the Shadow, the Hunter, the Pioneer, the Predator and the Global Hawk. According to his report, each system's accidents were unique and attributable to unique causal conditions because of vastly different user interfaces and operation. Each system configuration leads to different types of human factors problems and safety concerns [2]. Williams concluded that an analysis of the user interfaces in the different systems and the procedures used for the operation of each system will yield information about what types of interfaces are best suited for which types of UAS [2]. This study takes Williams' suggested approach and compares the procedures and interfaces for two similarly sized remotely piloted vehicles- small UAS (sUAS) below 25lb. (11.34 kg.).

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This size of sUAS has significant potential to be used to improve the agricultural productivity of the field with a very low accident rate. The sUAS operators in this study estimated the overall accident rate to be one accident every two years. Accident rate statistics or substantial data on the accident rate is not yet available because very few of these systems are in current operation for agricultural research. However, the need for additional research on the implementation and development of sUAS for agricultural monitoring is great.

Agricultural research addresses applied biological problems, which threaten food production. In orange groves, there are problems of greening (disease), in turf management- nutrient management, nurseries- inventory and plant appearance. For each of these areas of concern, there have been traditional ways of addressing the problems, which are plagued by human error, wasted time, and an overall inefficiency. One of the methods to detect greening is to visually inspect each individual tree in a grove of thousands of similar looking trees In order to conduct this method; the grower sits on top of a platform lifted 20 ft. /6.1 m. above the tree canopy and he must visually inspect each tree from above. This traditional method is time consuming and prone to errors in human memory and perception. It is estimated that, with such method, the grower misses the initial signs of pests about 40-60% of the time. Growers also use manned planes to fly over the fields. With this method, the plane's cameras cannot capture small details in each tree, and misses the small trees that were planted to replace diseased trees. When the grower fails to detect the pests, they can rapidly spread from infected tree to a healthy tree destroying the entire grove.

A new way to address biological problems of the orange groves (other fields as well) is to use sUAS to take aerial photos and then identify the problems by analyzing the photos. This method, which is still in development, successfully captures nearly all-initial signs and has led to a significant improvement in plant health for the few research fields where it is in use. With sUAS, it is possible and inexpensive to locate plausible areas and to revisit them by flying just above the tree canopy with specialized sensors (250 ft. /76.2 m. above ground level). The Federal Aviation Administration (FAA) in the United States' regulations to further develop and conduct this type of research in order to test its efficacy are currently restrictive.

The purpose of this paper is to take Williams' suggested approach and examine the operation, training and procedures of the existing sUAS operators in order to suggest safe practices for further development of sUAS for agricultural research and implementation. sUAS are similar in operation, and platform size to radio controlled (RC) model airplanes used for fun. Many of the hobbyists who fly RC model airplanes are currently or have been pilots of manned planes. The local RC model airplane club officer estimates that up to 50% of his members have manned piloting expertise. The officer stated that "many of the older pilots start flying RC planes when they lose their medical certification to fly a manned plane".

In this study, the qualitative methodologies recommended by Crandall, Klein and Hoffman [4] were used to elicit information in three areas: flight procedures, training procedures, and equipment. A hierarchical goal structure was chosen to outline the flight procedures for sUAS and RC models as each step in the process relied on the successful completion of the previous step [5]. The small number of participants available for the study required the use of methods that support small sample sizes and qualitative inquiry to document procedures and methods used by an emerging professional domain [6].

II. METHODOLOGY

A. Participants

Two operators of sUAS used for agricultural research (Operators) volunteered to participate in the flight observation and interview. The Operators were both certified to fly a sUAS by the Federal Aviation Administration. They had flown sUAS for more than 2 years as part of their research work in agriculture. Neither of the Operators had manned flight experience.

Four RC helicopter hobbyists (RC Pilots) volunteered to participate in the flight observation and interview. All four of the RC Pilots were also licensed pilots of manned aircraft who had 200 hours or more of manned aircraft piloting experience. Each of the RC Pilots had flown RC aircraft for more than 10 years as a recreational hobby. Two of the four RC Pilots were also RC aircraft instructors. One of the four RC Pilots was also a manned airplane flight instructor.

All procedures and materials had been reviewed and approved by the Institutional Review Board at the University of South Florida. All participants consented to have a flight observation recorded and to be interviewed about their training and flight experiences. All participants wished to remain anonymous.

B. Materials

The sUAS used by the sUAS operators was similar to an eight armed Multikopter [6]. The sUAS comes unassembled. The operator must purchase separately a multi-channel RC control box, any sensors needed, and a tablet or laptop computer to control the automation which allows the sUAS to travel to selected waypoints. In this case, the small UAS Operators used a customized multi-channel RC control box that they had modified in order to turn on and off the automation by a switch at the top of the box. The sensors and the automation were controlled by a tablet computer.

The RC Operators had small multi-copters which were comparable to the sUAS used in this study. The multi-copters used by the RC Operators are preassembled but the operator must provide any additional functionality. These multi-copters did not have automated waypoint navigation but they did have a "homing" automation function, when it is triggered, the multi-copter will be able to head back to the start point.

C. Materials.

We used handheld video cameras to record the flights and a handheld pocket audio recorder to record the interviews.

D. Procedure

Participants volunteered through word of mouth invitation or through an announcement posted on the RC model aircraft club website. The session for the sUAS Operators lasted one and a half hours. The sessions for the Pilots lasted less than one hour. The session consisted of an observation of flight and then an interview about the person's training, challenges, and experiences. In both types of sessions, the flight lasted less than 15 minutes under average flight conditions of a sunny day with light to no wind (under 5 miles per hour, mph or 8 kph).

III. RESULTS-SUAS

See Appendix A for a graphical description of the order of flight. The numbers 1000, 2000, 3000, refer to the headings in Appendix A. The narrative of the steps that the sUAS operators described during the flight observation is below.

A. Order of Flight Procedures

1) 1000 Authorization to Fly and Planning: The certificate of authorization (COA) to fly must be applied for and received from the U. S. Federal Aviation Administration (FAA) before any flight may take place in the national airspace; this includes the Class G airspace, 100 ft. (30.48 m. agl). The Operators of the UAS must have a Class B medical license, complete the necessary training, and have ownership level access to the sUAS. Currently, flights are only approved for daytime and observers must be present during the flight.

After the approval has been issued by the FAA, a considerable amount of preparation occurs before the flight of a sUAS. First, the flight plan is scheduled with the regional air traffic control center. The air traffic control center puts out a notice to airmen and notifies the local air traffic control center. Maps of the flight area must be loaded onto the system or special Bluetooth devices must be installed to load the maps into the sUAS when at the flight site.

Once the maps are loaded, one of the Operators selects the waypoints. This includes not only the GPS coordinates, but it also includes the time that the sUAS will hover over the waypoint. The hover time must incorporate time for the sensors to collect the required data. The time that it takes the sUAS to hover in order to collect the data is multiplied by the number of waypoints. This calculation is subtracted from the maximum flight time of 15-20 minutes. The calculations ensure that the lithium-ion battery will have enough power to safely launch and land the sUAS.

2) 2000 Preflight Check: Once that all of these items are in place, the Operators must monitor the weather. A small sUAS must avoid wind which is greater than 5 mph/8 kph and rain. Experienced operators can fly in wind, but he does so at the risk of the loss of the sUAS. At the time of publication, the cost of a research grade sUAS is in excess of $20,000 in equipment costs alone. Safety and retaining the vehicle is a primary objective for the Operators. The sUAS, the Operators and observers travel to the planned site. Once there, they notify local air traffic control and then they may begin the flight.

3) 3000 Launch: The Operator takes the vehicle and places it in the launch position on the ground. One of the major tasks of the co-Operator is to observe the number of satellites available for operating the sUAS. At least six satellites are needed for sUAS to be able to fly. Once six satellites or more are detected on the tablet computer, the co-Operator notifies the Operator. The co-Operator verbally announces the status of the system as displayed on the tablet computer every 2 minutes. This information includes the battery life in percentage, and the feet above ground level (agl) of the sUAS, and the arrival of the sUAS at each of the Waypoints. The Operator positions herself/himself next to the sUAS with the RC control box and launches the sUAS when ready.

The Operator turns the sUAS on and keeps his/her thumbs on the two joysticks on the RC control box. First, the Operator pushes the throttle to full and the sUAS lifts. With both thumbs on the joysticks, the Operator maneuvers the sUAS so it is overhead and then presses a button on the RC control box to engage the automation.

4) 4000 Data Collection- Mid Flight: Once the automation is engaged, the sUAS flies to the first waypoint. The Operator keeps the RC control box in her/his hands and observes the motion of the sUAS. The Operator needs to fully concentrate on the task just in case unexpected events occur to the sUAS. The co-Operator maintains the automation and makes sure that it is fully engaged and operating as expected. The co-Operator announces at 2 minute intervals the battery life, number of satellites, altitude above ground level and waypoint status of the sUAS. Both of the Operators stated that if the sUAS had sensors on board then, the co-Operator would also monitor the data collection through the tablet computer. Observers watch the sUAS and perform the detect, sense, and avoid functions.

5) 5000 Landing: As the sUAS continues its flight to the last waypoint, the Operator returns to the launch area or the 'home' position that the sUAS will fly toward. Once the sUAS is at the home position, the sUAS hovers. The co-Operator disengages the automation and the Operator resumes manual control of the sUAS. The Operator begins to slow the sUAS down and lands. As the Operator concentrates on the manual landing, the co-Operator continues to announce the battery life, number of satellites, and altitude. As the Operator slowly lowers the sUAS back to the ground, the Operator does not communicate with the co-Operator. She/he concentrates on maintaining the hover and balancing the eight arms of the sUAS as it gently slows down. Lowers and lands. After the flight, we were told that the landing is the most difficult portion of the flight because of the downdraft of the rotor arms and the impact that a sudden wind can have on the stability of the sUAS. Sometimes the winds make it very difficult to land the sUAS and the Operator must keep the sUAS in flight until the winds die down and he/she is able to land. There have been times when operators have run out of battery life before they are able to land the sUAS. The balance of available power left in the battery and the time needed to land is a primary safety concern.

6) 6000 Post flight check: Once the sUAS has landed, the Operator begins the post flight check for damage to the vehicle or the components. Once all of the systems have been checked, the vehicle is packed for travel back to the research center. At the research center, the data is downloaded. The quality of the data is verified to determine if another flight is needed.

B. Safety and Accident Mitigation:

The particular sUAS that we viewed had eight rotors and traveled no farther than 250 ft. (76.2 m.) in a radius from "home" launch area. In cases where the operator would need to survey an area greater than the 500 ft. (152.4 m.) diameter, the operator would make a flight plan that would overlap and then the sensor analyst would 'stitch' the images or sensor data together according to the predefined plan. The Operators liked having the 250 ft. (76.2 m.) radius because that was the best balance between seeing the sUAS and collecting the data they needed. The Operators stated that they thought that this was an excellent safety feature that helped with possible loss of link challenges. In addition to the preset radius, the Operators had established standards of operation pertaining to speed, the actions and reporting duties of each of the operators, and the role of observers. These standards had helped to maintain an excellent safety record of only one system failure that resulted in a sUAS landing in the field. The system failure was due to a mechanical component that checked out before flight but failed during flight. The Operator was able to “catch” the sUAS by taking it out of automated mode and back to manual mode when the aberrant behavior was observed on the tablet computer by the co-Operator.

C. Training:

The sUAS Operators stated that first the Operator must be familiar with the sUAS. She/he must understand how the controls on the RC transmitter control box map onto the behavior of the sUAS. The second step in learning to fly a sUAS should be simulator training. The sUAS Operators focus on developing a few well targeted skills rather than learning to fly an RC aerial vehicle. In the simulator training, the sUAS Operators stated that: “they [new operators of sUAS] just need to be able to hover for about 2-3 minutes in one spot on the simulator. After this, an instructor can spend about three days with the operator to get them proficient”. When asked about flying an RC multi-copter before the sUAS, the Operator 1 stated: “flying an RC is much harder than flying one of these [sUAS], we tried that and kept crashing the RC multi-copter. Then, we tried to fly the sUAS and it was much easier. We have never crashed it.”

1) Who makes a good sUAS operator: Operator 1 answered the best he could, but as an emerging field at the time of this study’s publication, it was not possible to have definite answers. The Operator stated, “the other Operators we know of are other persons in this type of research. They are [starting] because of the research, not because they wanted to fly a sUAS. The current Operators are researchers who fly this because it is the best way to collect this kind of data. I don’t know who makes a good operator; I guess whoever has to do it.”

2) Rookie Mistakes: Operator 1 answered: “not using a simulator before you fly for the first time, you will crash if you don’t use a simulator first.” Operator 2 answered, “Battery life. If you have a heavy payload, the battery will last only 10 minutes.” Operator 2 also answered, “and not leaving enough time to land. If the battery life is only 10 minutes and the wind picks up during the flight, you need to have enough time to get to the home site and hover and land, if you do not estimate the time right the sUAS will run out of battery and fall. Then, you’ll be left trying to locate all of the pieces.”

3) UAS in Airspace: The Operator 1 answered: “We fly over fields when no one is around. Planes do not fly low enough for us to run into them. If a plane were to fly this low, it would be because the pilot needs to make an emergency landing. There is nothing we can do about that except get out of his way. The worst thing that can happen is that you lose the sUAS on top of one of the trees and have to go find it. I think it will be fine.”

IV. Results- RC

See Appendix B for a graphical description of the order of flight. The numbers 1000, 2000, 3000, refer to the headings in Appendix B.

A. Order of Flight Procedures

1) 1000 Certification and Air Traffic Control Notification: RC model airplanes are considered special use and hobby systems. They may fly in designated areas or large indoor areas such as a gymnasium. Operating a RC model airplane does not require special licensure or a certificate of authorization from the FAA. However, their activities are governed by the Academy of Model Aeronautics (AMA, www.modelaircraft.org) [7].

2) 2000 PreFlight: RC Pilots must monitor the weather and avoid flying in rain and winds which are greater than 25 mph/40.234 kph. The RC Pilots who were flying the multi-copters mentioned that they avoided flying if the wind reached speeds of 3-5 mph (~4-8 kph). At the time of publication, the current cost for an RC multi-copter is at $100 - $2000 depending on the size. Yet, because many RC pilots are also manned pilots, safety and retaining the vehicle is also a primary objective.

As with the sUAS, RC Pilots and their vehicle travel to the flight location. They begin their preparations with a checklist to ensure the proper operation of all systems: 1) the multi-copter, 2) the RC control box and 3) the battery and backup battery. Once all systems have been checked and are satisfactory, battery level and a battery backup is checked. Typically, at least one battery change is needed. The batteries are nickel cadmium, NiMH, or Lithium Polymer batteries. One of the Multi-Copters flown was the Syma X1 4 Channel 2.4G RC Quad Copter – BumbleBee.

3) 3000 Launch: The RC Pilot places the RC in the launch position on the ground and performs a visual scan for similar multi-copters nearby. If the same brand and type of multi-copter should launch near his multi-copter, the other person’s multi-copter may ‘bind’ to her/his controller. If this happens, he is controlling the other person’s multi-copter instead of his own. The RC Pilots self-regulate and when this happens (as it did during one of the flights), the RC Pilots land both multi-copters and move to separate areas of the field to fly.

Once the multi-copter is in the launch position, the RC Pilot must press a button on the multi-copter and on the RC control box for the multi-copter to ‘bind’ to his/her controller. This is a procedure similar to connecting a Bluetooth keyboard to a tablet computer or a wireless mouse to a computer. The two devices communicate and once the RC Pilot tries to control the multi-copter it becomes clear if the multi-copter ‘bound’ to the control box.

4) 4000 Data Collection- Mid Flight: The multi-copters do not have a navigation system but they will return to a ‘home’ position. The RC Pilot termed this as ‘gyro’ positioning which helps with stable flights and flight control. This explanation seemed to be a special use adapted by RC Pilots. After launch, the RC Pilot does not look at the control box; he/she looks at the multi-copter. As the multi-copter moves, she/he moves the left and right thumb joystick to adjust the multi-copters movements. At no point during each of the four flights did the RC Pilots look down at the control box. When asked about this unique skill, the RC Pilots termed it as 'muscle memory'. The RC Pilots stated that when you learn to make the multi-copter an extension of yourself, then you intuitively know which joystick to move in what way. RC control boxes use standardized modes to map the stick inputs to control surface effects. The predominant mode in the United States is Mode 2. With Mode 2, the right joystick is elevator (pitch) and aileron (roll) control; the left joystick is throttle and rudder (yaw) control. The RC control box is the only control point for the multi-copter. The RC Pilot intensely stares at the vehicle during flight control. Each of the RC Pilots stated that they needed complete concentration on controlling the multi-copter. After the flight, two of the RC Pilots described the experience of flying as a trancelike state where the rest of the world disappears while you concentrate on the control of the vehicle. The RC club officer stated that, "a highly skilled and experienced pilot can multi-task while performing simple maneuvers. Less skilled pilots get a kind of tunnel vision, and even expert pilots become aircraft-focused during extremely demanding maneuvers."

5) 5000 Landing: The RC multi-copter has about 5 minutes of battery life and can fly up to 40 m. (131.234 ft.) from the RC control box. As the battery life starts to wane or as the RC Pilot wishes to finish the flight, the RC Pilot will maneuver the vehicle back to where he/she is standing. First, the RC Pilot maintains a hover position and then slowly lowers the multi-copter to the ground or his outstretched hand. RC Pilot trainers state that landing is the most difficult part of the flight.

6) Special Considerations: The multi-copters that were flown had four rotors on the arms like the sUAS. A single RC Pilot maintained the flight and the detect, sense and avoid function, all of the RC Pilots watched the multi-copter while it was in the air and would warn if the multi-copter or another vehicle was going to hit something. The collaborative atmosphere of the community made the environment safe for novice flyers that were developing control skills. These cultural norms were present in both the indoor RC Pilots who were flying the small multi-copters as well as the other RC Pilots who were flying scale model planes.

The RC Pilots stated that the model planes and multi-copters crash regularly. In the case of the small multi-copters observed, their weight of 1.5 lbs./680.39 g. is very slight. Crashes did not result in harm to anything but the multi-copter itself. When a crash did occur, mechanical component failure was reported to account for about 1/3th of the crashes. The remaining crashes were due to the RC Pilot failing to notice the status of the system (battery was drained) or failure to control.

The RC Pilots reported that the club had not ever had a serious failure or crash. They do not recall that there was ever interference with a manned flight. However, the club members flew at the club's RC Plane Field which was 3 miles (4.83 km) from a regional airport and in Class G airspace. The RC club officer stated that the RC Pilots are "routinely instructed to "fly defensively" (maintain extreme separation) when full-scale manned aircraft are nearby. Sometimes small manned aircraft circle our field and waggle their wings at us as a greeting".

At the RC club field, RC Pilots stood in the spectator's area of the field until it was their turn to fly. When their turn approached, they picked up their model and set it down on the runway. Then, the RC Pilot walked over to a "v" shaped short fence. From this position behind the fence, the RC Pilot controlled his/her model aircraft. When the model aircraft landed, the RC Pilot picks up the vehicle and returns to the spectator area. Spectators are not allowed on the field or near the RC Pilot during his/her flight. When RC Pilots flew at the indoor field, RC Pilots stood at one side of the gymnasium only. One RC Pilot stated that he preferred the gymnasium, "When flying in the wind, it is more work than fun." They launched and landed near their standing position. Other RC Pilots avoided walking between a person's RC control box and model airplane when the model airplane was in flight. Spectators could stand with the RC Pilots or sit in the bleachers.

B. Safety and Accident Mitigation

The sUAS operators implemented the following procedures for safe operation: A) know the vehicle and what it is likely to do when the automation fails. B) set boundaries of height above ground level, distance from home/launch point and speed so you can estimate the location of the vehicle and recover the vehicle in case of a malfunction. C) be sure that each component operates in the way that it should before flight. D) follow the recommended procedures. E) always have two operators: one to fly the vehicle manually and the other to fly the automation and monitor the system status. Verbally announce system status at regular intervals to reduce workload and increase situation awareness. F) follow a checklist. G) estimate the time you will need to takeoff, land, navigate to each waypoint and hover for data collection, then add in 20% for changes in the weather.

The RC Pilots implemented similar procedures of A) know the vehicle and what it is likely to do. B) check and re-check the operability of all systems with particular attention paid to the condition and characteristics of the battery packs. C) use other operators to help with detect sense and avoid.

The RC Pilots did not develop their procedures alone. All of the RC Pilots interviewed were members of the AMA and adhered to the AMA safety code [7]. The safety code includes key statements designed to protect the public and prevent collision with manned aircraft.

RC Pilots who do not conform to the code are subject to losing their RC Pilot's license, are unable to use facilities and fields to fly their RC airplanes, and are unable to compete in RC model airplane events.

C. Training

When asked about the differences and similarities between the manned airplanes and RC airplanes, the RC Pilots stated that, "manned airplanes and piloting [them] is much easier than operating an RC airplane". One of the main differences they stated is the control reversal problem. The control reversal problem occurs when the airplane flies toward you instead of away from you. This can happen during landing or avoidance of an object. The multi-copters will self-orient for a landing, but learning to compensate for the control reversal problem still exists. The RC Pilots also stated that "Landing is the hardest. Launching is optional but landing is mandatory."

1. Training procedure and simulators: RC Pilot 3 stated that he believed detect, sense and avoid to be the biggest problem. He stated that "the stabilized aircraft such as the gyro stabilized multi-copters are difficult to crash. People now use [computer] simulators. Most of the learning is muscle memory and orientation to the opposites of your right and the plane's left". He stated that "the younger a person is, the faster they learn this stuff, a young person can learn it in one hour. An older person will take weeks or even months to develop the hand eye coordination and spatial ability".

RC Pilot 4 stated that: "my Dad sat me down and showed me how to do it. I learned through trial and error. There isn't any indication if a person is going to 'get it' or if they are not. It can take them minutes or hours to develop the 'muscle memory' to control the RC without watching the control box constantly. Some people were born as birds and learn how to control planes very quickly. My child learned very fast, he soloed after only 6 hours of instruction. I am also a manned airplane pilot instructor at a general aviation school. I have been for 20 years. It is easier to teach manned pilots to fly a plane than it is to teach people to control an RC plane. When you are flying an RC, you are flying by the 'seat of your pants'. You do not know what is going to happen next. Plus, when the plane comes toward you to land, everything is reversed. If RC pilots understand the Bernoulli Effect, then they have it. I don't believe in simulators- you just have to go fly. The sUAS is not a big issue, it is all global positioning system (GPS) guided stuff and it's pretty reliable. We will fly the RC planes in anything but rain and lightning or winds over 30 mph/48.28 kph. The plane doesn't know that it's windy. Only the RC Pilot knows."

Another RC Pilot stated "when you use the simulator, you should have a thing to learn, a specific maneuver. Spend thirty minutes learning that maneuver and then do it in real life with the vehicle. Then, go back to the simulator and learn something else. The rookie mistakes are too many to list, you just have to do it to learn it."

2) Who makes a good operator: One RC Operator stated that "a manned pilot makes the worst RC Pilot because he/she has to unlearn everything they think they know about flying. An RC plane or multi-copter flies differently from a manned plane. The difference between manned flight and RC flight is that manned pilots feel the plane move and RC Pilots use only visual cues while watching the plane. The visual cues tell you what to do next to control the plane. It is difficult for manned pilots to understand and make the change. The RC fixed wing airplanes do not fly the same as the multi-copters. It is much easier to fly the multi-copters. When the multi-copters experience loss of signal, they come to the launch spot or wherever you designated as home."

V. Recommendations

Given the outcomes of the study, we offer following recommendations for the safe operations of sUAS for monitoring agricultural fields.

First, use a standard operating procedure that includes a checklist to ensure that all mechanical systems are functioning and all operators are aware of their roles and tasks before, during, and after flight.

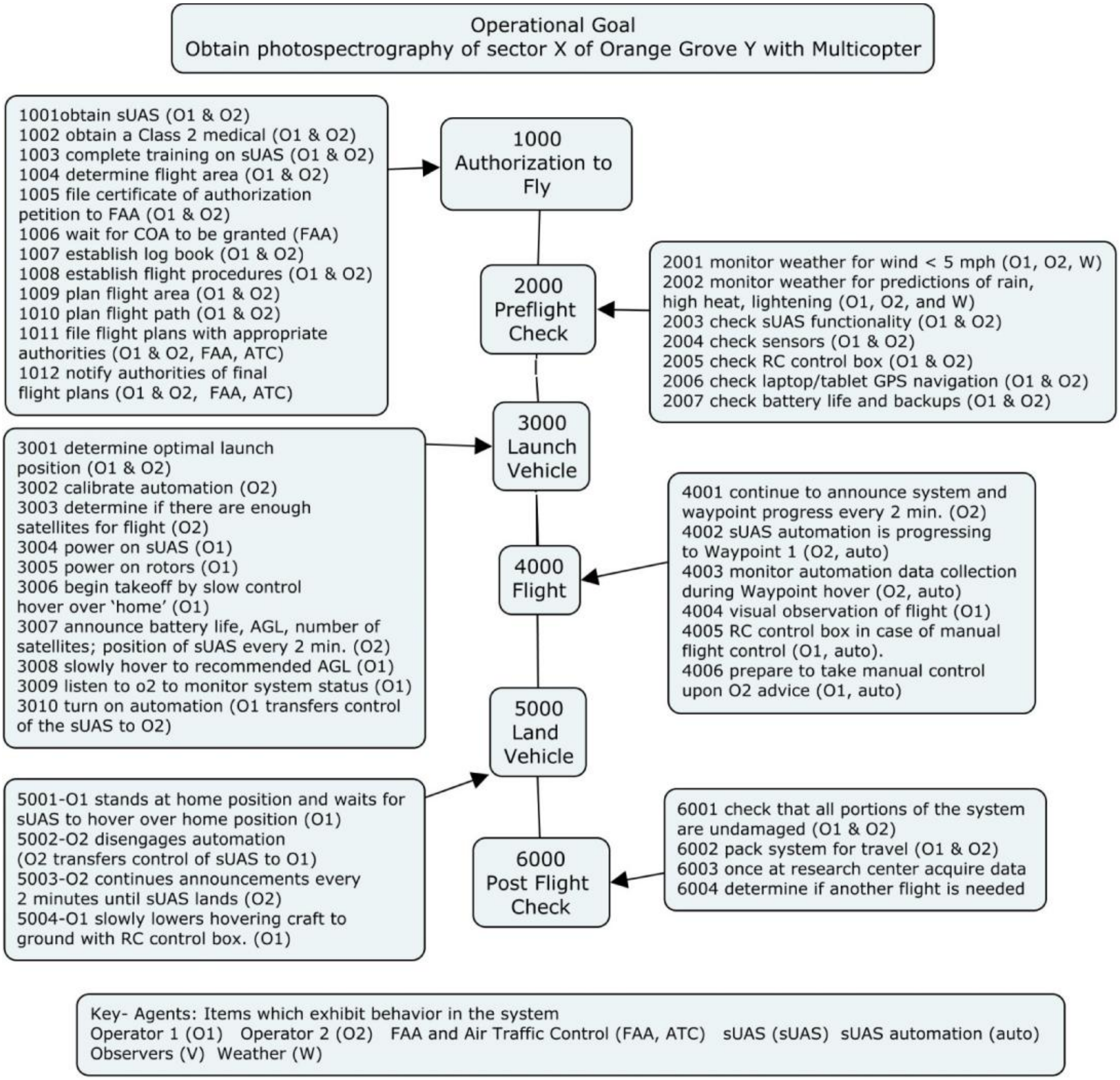
Second, ensure that the operator(s) has sufficient knowledge of how the automation works and how the mechanics of the sUAS works. This knowledge will allow them to overcome any aberrant behavior of the sUAS and compensate for a sudden loss of automation.

Third, use a computer flight simulator for training. RealFlight (www.RealFlight.com) and Phoenix (http://www.phoenix-sim.com/) are two simulators recommended by the RC community. AeroSim is recommended by the sUAS operators (www.AeroSim.com). Specific training procedures that mimic the real-world operations help new operators get used to and then become proficient in controlling the sUAS.

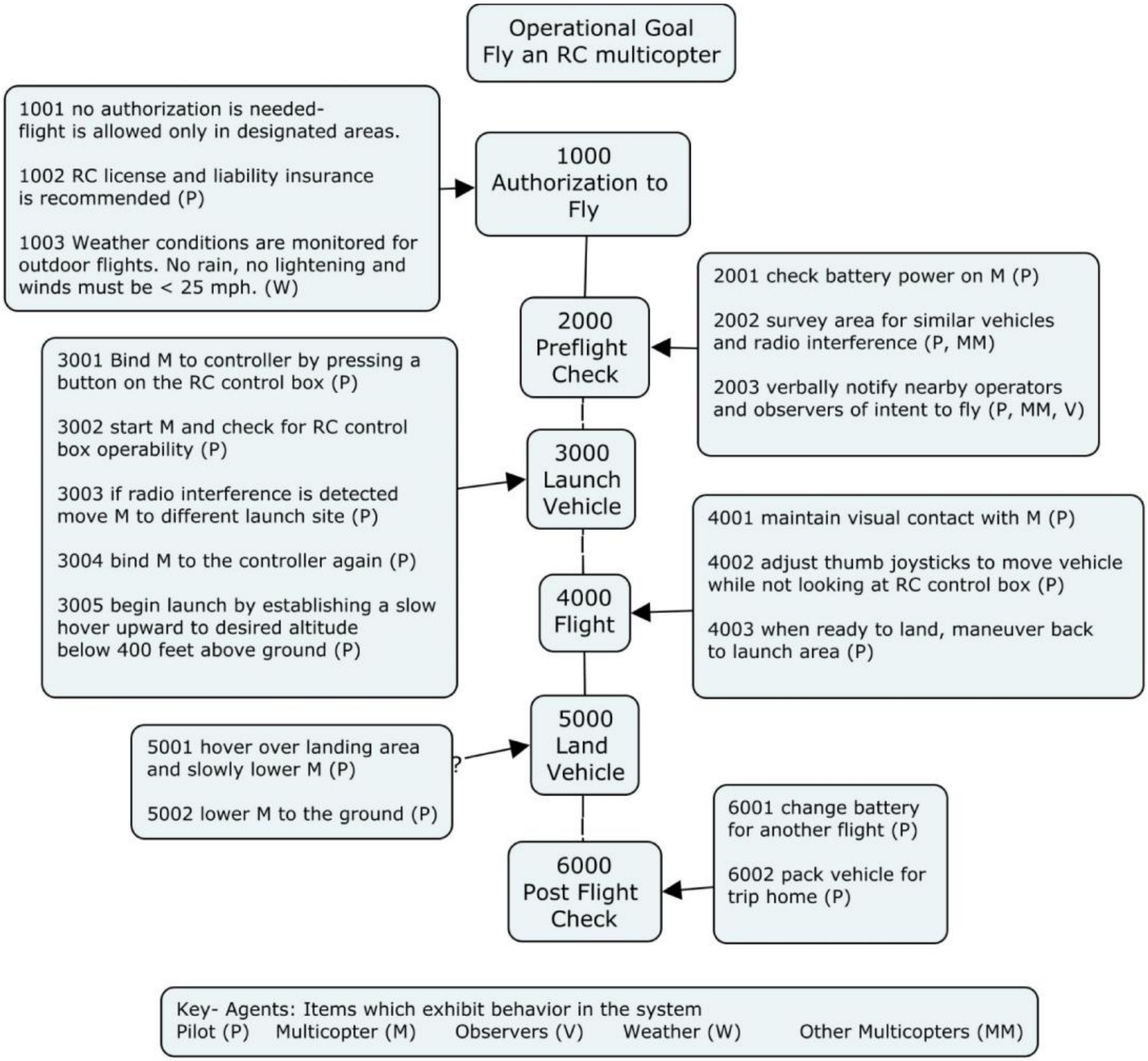
The last, weather, speed, and distance parameters are strongly recommended. Current limits in the U.S. state that sUAS flights must be below altitudes of 1000 feet agl (304.8 meters), tracking the sUAS can be difficult beyond 500 feet agl (152.4 meters). The sUAS operators interviewed used a maximum of 300 feet agl (91.44 meters) limit and found this to be the maximum distance at which they could view the sUAS at all times. Limits on agl, speed, and the distance from launch location can be set and should be standard.

VI. APPENDICES

1. Appendix A- Procedure for Operating a sUAS.



2. Appendix B-Procedure for Operating an RC plane.



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