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Unmanned Aerial Vehicles

The Use of Small Unmanned Aircraft by the Washington State Department of Transportation

by

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16. ABSTRACT

Small, unmanned aerial vehicles (UAVs) are increasingly affordable, easy to transport and launch, and can be equipped with cameras that provide information usable for transportation agencies. The Washington State Department of Transportation conducted a series of UAV tests to evaluate their capabilities while also exploring institutional issues. These tests, while exploring the general capabilities of UAVs, focused on evaluating the use of a UAV as an avalanche control tool on mountain slopes above state highways. WSDOT's maintenance division has an active snow avalanche control program that is designed to reduce highway closure time and hazards to motorists, and the use of UAVs was seen as having some potential operational advantages. The UAVs also captured aerial images suitable for traffic surveillance and data collection. The evaluation found that the main limitation to UAV use is institutional, particularly the need to obtain approval to fly from the Federal Aviation Administration (FAA). This approval process will make UAV use a challenge, but these issues may change as the FAA considers new rules.

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Unmanned aerial vehicles (UAVs) have become an increasingly familiar technology and have become smaller, more capable, and less expensive because of both military investment in the UAV industry and improved technology. Current generation UAVs can be transported in small vehicles and launched from a road or a small truck but are still large enough to be equipped with cameras and sensors that can provide low-cost aerial information. These aircraft are capable of flying autonomously and completing preset flight plans.

This technology holds considerable promise for traffic and transportation organizations such as the Washington State Department of Transportation (WSDOT) because a UAV could be a beneficial, and perhaps cost effective, tool for a range of maintenance, engineering, planning, and operations functions. Potential uses of UAVs by transportation organizations include avalanche control, search and rescue, crash scene photography, land-use mapping, surveying, security inspections, hazardous material monitoring, construction data collection, aerial surveillance, and monitoring the condition and congestion of roadways.

Despite the promise of this technology, actual applications in the transportation world are limited. A major reason for this involves the barriers associated with institutional issues, particularly approval to fly by the Federal Aviation Administration (FAA). The FAA is responsible for the National Air Space (NAS) over the United States and is concerned about a UAV's ability to "see and avoid" manned aircraft. The FAA requires each UAV user to apply for a project-specific Certificate of Authorization (COA). The FAA realizes that there is considerable desire to use UAVs commercially, but it is still formulating policies. Industry forecasts indicate that, with the appropriate FAA regulations, the number and types of UAVs available could increase considerably (GAO 2008).

The University of Washington (UW) and WSDOT conducted a test of two types of UAVs to evaluate their technical capabilities while also exploring the institutional concerns associated with UAV use. The test was devised to help guide the development of WSDOT policies on longer-term use of UAVs.

This test, while exploring UAV capabilities in general, focused on evaluating the use of a UAV as an avalanche control tool on mountain slopes above state highways. WSDOT's maintenance division has an active snow avalanche control program that is designed to reduce highway closure time and hazards to motorists, and the use of UAVs was seen as having some potential operational advantages.

Overview of the UAV Industry

An unmanned aerial vehicle (UAV) is a blanket term for an aircraft that flies without a pilot. A wide range of UAVs can be either piloted remotely or flown autonomously, but all fly without direct human input. The FAA, recognizing that the technology requires ground control stations, refers to them as "UAS" or unmanned aircraft systems.

Growth in the UAV industry has been cyclical, but over the past five years the use and capabilities of UAVs have grown rapidly. This is due to increased military usage, as well as the availability of better sensors, lighter and stronger aircraft structures, more powerful and smaller computers, better aircraft-to-ground communications, and increasingly accurate global positioning systems (GPS).

According to the UAV Forum, which tracks UAV vendors and vehicles, approximately 80 U.S. companies, academic institutions, and government organizations are developing over 200 UAV designs that fly as production versions or prototypes (UAV Forum 2008). These companies range from a handful of multi-million dollar aerospace organizations (such as Boeing) with thousands of employees to a number of small operations with minimal revenues and a handful of employees. The larger companies tend to make expensive systems that are oriented toward the military. The other end of the spectrum includes smaller innovative, and often struggling, companies vying for the portion of the UAV market that includes lower cost systems with potential transportation applications.

While UAVs can range from full-sized (and costly) aircraft to ones that weigh a few ounces, the unmanned aircraft of interest to WSDOT need to be large enough to carry cameras and other sensors that can be used for roadway monitoring and surveillance but also portable enough to be carried in WSDOT vehicles and launched on or alongside a road. The aircraft that generally fit this category are known as tactical or man-portable UAVs that weigh between 10 and 100 pounds. Tactical aircraft typically weigh between 50 to 100 pounds. Man-portable aircraft that are light enough to be carried by an individual and launched by hand-throwing or a sling-shot mechanism may have particular appeal to transportation agencies because of their ease of use. Another category of small, rotary wing (helicopter) UAVs that have vertical takeoff and landing capabilities are also seen as potentially valuable to WSDOT. Fixed and rotary wing UAVs have trade-offs, since fixed wing UAVs are simpler to fly, have been more thoroughly tested, and have better endurance but are also less mobile than rotary wing UAVs and are thus less capable camera platforms. Other categories of UAVs, such as the endurance aircraft that are capable of extended duration flight, typically 24 hours or greater, may also be useful in the transportation world for surveillance, but few transportation applications have been tested.

Previous Transportation Applications of UAVs

Unmanned aircraft usage in non-military applications is not uncommon. Federal agencies have used UAVs for a number of years for applications such as collecting scientific and weather data and assisting in border security (GAO 2008). Locally, for example, the U.S. Geological Survey used a small (22-pound) UAV to collect seismic data from the crater on Mount St Helens (Patterson et al. 2005, Advanced Ceramics Research 2004).

In terms of UAV use by transportation agencies, a 2005 survey of UAV use in transportation concluded, “It has been generally accepted that UAVs can be very useful and successful for traffic surveillance” (Puri 2005). In spite of the promise of UAVs, there have been few actual transportation applications. In part, this is because the technology has only recently matured to a level of feasibility attractive to transportation agencies but also because of institutional barriers.

A 2002 flight in Boston of a small UAV manufactured by the MLB Corporation and known as the BAT demonstrated the UAV's road following capability and produced real-time imagery of a commuter train and traffic by sending live videos to a computer on the ground (Research & Technology Transporter 2003).

In one of the more comprehensive studies involving UAVs, Ohio State University tested traffic surveillance by using the BAT in 2003. During a series of flights it found that the system could effectively collect a range of useful transportation data, including level of service, average annual daily traffic, intersection performance, local origin and destination, and parking lot utilization information (Coifman 2004, Cincinnati Enquirer 2003).

One study that highlighted the problems that transportation agencies might encounter in using UAVs was an effort by researchers at Western Michigan University, working with the Michigan Department of Transportation (MDOT), to integrate UAVs into traffic monitoring and emergency management. The MDOT purchased a BAT. However, after the purchase, MDOT was reluctant to allow the UAV to fly. According to one of the study authors, the difficulties related to liability and privacy concerns. The authors concluded that FAA regulations were a serious drawback but also found that, technically, UAVs could provide real-time traffic data to allow authorities to make quick decisions. (Ro et al. 2007, Ro 2007).

In 2005, the Florida DOT funded a research project to investigate the use of UAVs for traffic, incident, and emergency management and conducted several traffic data collection test flights. It determined that the use of UAVs was a "cost effective methodology to collect, analyze, and provide selected data for a variety of tasks and missions." However, it also concluded that the FAA COA requirement presented restrictions too severe to make UAVs an effective tool for traffic management, and the project was terminated (PB Farradine 2005).

Also in Florida, police in Palm Bay successfully tested an unmanned vehicle known as the cyber bug. This small aircraft weighs 10 pounds, costs about $30,000, and can be stored in a car trunk and launched by hand. The aircraft was tested for police surveillance and traffic management and was seen as a useful tool in areas where stationary traffic cameras have not been installed. However, the article made no mention of the need to obtain FAA approval (Urban Transportation Monitor 2007).

In Europe, the PEGAUS (Policy Support of European Governments by Acquisition of Information from Satellite and UAV-borne Sensor) project is developing high altitude, high endurance solar powered aircraft. The project involves a number of European companies, and the aircraft is anticipated to be useful for traffic monitoring and inspection of roadway conditions (Crawford 2005).

Test Flight Setup

This project was an effort to “get a foot in the door” so that WSDOT could become familiar with UAV technology and institutional issues. The test was applied to avalanche control because there was an obvious and immediate need for it, as well as support from WSDOT’s maintenance personnel.

WSDOT estimates that a 2-hour avalanche closure can cost the state economy over a million dollars. Current WSDOT efforts involve the use of surplus military equipment to shoot explosives into areas that are in range of the roadside and the dispatching of skiers with handheld charges, plus the occasional use of helicopters to drop explosive charges into inaccessible areas. The project test flights explored whether, in the longer term, UAVs may provide a less expensive and safer option for triggering avalanches than shooting explosives from howitzers or dropping explosives from manned aircraft, and also explored the UAV’s ability as a tool to provide enhanced information about the terrain and conditions in the area.

Because the FAA application process is aircraft specific, the first step required finding a suitable UAV. A review of others' studies of UAVs, as well as discussion with WSDOT staff, suggested the following parameters:

- The tests should use smaller tactical or man-portable UAVs that could be operated on or near a state highway.
- To avoid training costs, the actual flights would be completed under contract with the aircraft owners but following WSDOT test requirements.
- The test would use a system (aircraft as well as the ground control station) that would potentially be affordable to a state DOT. For this effort it was decided the UAV systems should cost no more than $500,000. In addition, the UAV should be operable and maintainable by WSDOT maintenance personnel with appropriate training.
- Both a fixed wing and rotary wing system would be considered.

Given that certification and other institutional issues could be a major roadblock, this test also focused on reducing potential FAA concerns. The researchers decided to complete the test in a rural, lightly populated area with minimal air traffic. The application process and test were closely coordinated with WSDOT's aviation division. This ensured that proper air traffic pre-flight notification was completed and that project staff were conversant with the specialized aviation and air traffic control terminology necessary for the application process.

The First Test

Application Process

The regional FAA office was contacted to initiate the COA process. Because the UAVs would be used in conjunction with avalanche control operations, the selected test area was centered on State Route 20 in the Cascade Mountains of north-central Washington State (approximately between mileposts 160 and 168). The UAV operating test area was a square roughly 9 miles by 9 miles, with steep terrain. The test area focused on a narrow valley with SR 20 on the north side and with 3000-ft walls and a 30-degree slope on either side.

The aircraft selected for the first test was the MLB BAT. This is the same aircraft type that was used for the tests in Ohio and Boston mentioned above. This 25-pound UAV had a 72-inch wingspan and carried both a pan-tilt video camera and a digital camera (Figure 1). (Technical specifications for this aircraft are in Appendix 1.) The aircraft could be disassembled and placed in a car trunk. The aircraft could be launched from a vehicle (Figure 2) and landed on a 100-ft stretch of roadway. The ground station consisted of a portable computer and a video screen that was temporarily located in the back compartment of a van (Figure 3), plus an external antenna on a tri-pod.

Approximately six months after submission of an application, the FAA awarded a one-year COA to WSDOT to fly the BAT. The COA stipulated a number of procedures for using observers and communications protocols, and the COA required that the aircraft remain in contact with observers at all times.

Figure 1: MLB BAT

Figure 2: BAT Catapult Launch

Figure 3: BAT Control System

MLB BAT Test

The MLB Company was contracted for the flights, and the test of the UAV occurred in April 2006 along a snowy, avalanche-prone section of SR 20 that had been closed for the winter. WSDOT maintenance staff were in the midst of a month-long effort to reopen the road and were conducting avalanche control operations by using a 105-mm military howitzer. The test flight was designed to evaluate the ability of the UAV to use an on-board video camera to

- view a roadway
- operate off a highway
- survey the surrounding terrain.

In terms of avalanche control, of interest was the ability of the UAV and camera to identify avalanche trigger zones, verify that the targets for the howitzer were free of skiers and other hazards, and generally evaluate snow pack conditions.

The flying conditions during the test were difficult, with visibility ranging from poor (clouds and snow) to a 1500-foot ceiling, with temperatures around 35 degrees F. At times, wind speeds above the surrounding peaks were 30 mph.

The BAT was launched by a catapult system on top of a van, and the first flight attempt resulted in a failed launch. This was attributed to pilot error, the thinner air in the high altitude, and downwind conditions resulting in low airspeed. The launch catapult rubber may have also have been weaker because of the cold.

The second launch attempt was successful. The MLB operator climbed the plane to 600 feet and turned on the autopilot to circle a pre-set GPS waypoint at 1000 feet above the roadway. The plane was then commanded to climb to 2500 feet above the road to obtain flying space away from ridges. Video of various snow gullies and the roadway were taken, but in some cases clouds obstructed the view, so the aircraft was brought down to 1000 feet above the ground. The plane then shot some videos of avalanche-prone snow chutes.

The next task was to fly the plane at 1500 feet above and along the highway. While flying above the road, the plane encountered strong turbulence, and the operator decided to land it before the weather got worse. The aircraft was manually landed on the closed highway after 22 minutes.

The resulting videos provided a clear view of the roadway, and individual vehicles could easily be identified. Post flight interviews with the WSDOT avalanche control staff indicated that they thought the concept had potential. They reviewed the aerial video and determined that the views captured by the camera also had value and that such video would be worth further exploration.

The test also highlighted some issues that may affect a transportation agency's use of a fixed wing aircraft. The aircraft required a 100-foot-long flat stretch of roadway. This need for a miniature airstrip could limit the use of these aircraft in urban areas. The aircraft also has operational limitations related to difficult terrain and weather. The aircraft owner was understandably reluctant to push the aircraft to some areas in which WSDOT was interested.

The Second Test

Given the difficulties with terrain and weather encountered in the first test, a more mobile, vertical takeoff and landing UAV was selected for the second test. The aircraft selected was the R-Max made by Yamaha. This rotary wing (helicopter) aircraft weighed 150 pounds and had a rotor span of 10 feet (Figure 4). (Technical Specifications are in Appendix 1.) The aircraft was developed in Japan and is used for crop spraying in Asia, but a few are in the United States for research purposes.

Application Process

The FAA's COA process had changed from the first test and now required an on-line application. The process was new, initially complex, and required some detailed information about the aircraft as well as an airworthiness certification. As a public agency, WSDOT had an advantage in that it could certify the airworthiness of each UAV in the test. This certification was mainly based on the fact that the aircraft would be operated over an unpopulated area.

Figure 4: R-Max

Yamaha R-Max Test

After a number of delays in obtaining the COA (because of startup difficulties with the FAA's on-line process), the second test occurred in September 2007. The R-Max contracted for this project was owned and operated by Georgia Technical University and was equipped with pan-tilt cameras. The ground station for this aircraft was considerably larger and more complex than that for the BAT (Figure 5). The station was set up in the back of a specially equipped van that doubled as a transporter for the aircraft. The van was equipped with spare parts, generators, portable computers with several aircraft controls screens, and a number of external antennae on tri-pods.

The weather was warm, with light winds and good visibility. During this two-day test, nine flights, varying from two to forty minutes long, were completed. The aircraft was operated off a pull-out on the side SR 20, and WSDOT personnel provided traffic control while the R-Max was landing and taking off.

Figure 5: R-Max Control System

The aircraft and the on-board sensor demonstrated the ability to follow a road with predetermined waypoints. This exercise was designed to simulate a survey before the start of snow clearing operations on the road, but it was also a successful test of the UAV's ability to fly along a road center-line to record traffic or conditions. The ability of the aircraft to hover provided a stable platform on which camera use was effective.

Other test flights demonstrated the ability of the UAV to accurately drop packages at pre-determined GPS locations and heights. Such missions could be used to drop explosive charges at predetermined avalanche trigger zones.

This test also demonstrated the R-Max's ability to survey terrain alongside a roadway. This capability could easily be used for construction site surveys, security checks, and numerous other transportation tasks that require an aerial view.

A test of the aircraft video camera's ability to locate people was conducted by sending a person into the rocky and partially tree-covered slope alongside the highway. The UAV operator was given the general area of the "missing" person, and the R-Max was flown in a search pattern to locate the person. The test showed that it was extremely difficult to identify a person with video cameras because of the contrasting colors, patterns, and relatively rugged terrain. However, an infrared camera with the capability to detect heat radiation may have greater potential because this technology can identify people, which are warmer that the surrounding area. Infrared capability is especially effective in snow-covered terrain because of the greater temperature contrast. Use of this type of camera in a UAV may allow avalanche personnel to explore an area before it is shelled to determine whether any people are in the area. A number of vendors have developed infrared systems suitable for use in UAVs (UAV Forum 2008).

Several issues arose that affected the R-Max flights. The day was warm, and the resulting thinner air, combined with the altitude, degraded the ability of the R-Max, which was heavier than the production model because of the number of research sensors installed, to operate in the afternoon. In addition, the GPS system devices that the aircraft used to navigate demonstrated some inaccuracy, possibly because of signal bounce (possible multiplexing). In addition, as a safety precaution, the flight crew restricted the flight range of the aircraft to no more than a mile from the ground control station, limiting the potential effectiveness of the aircraft.

Transportation Agency Applications

Both aircraft systems showed considerable potential for aerial roadway surveillance and avalanche control. They were able to obtain clear and usable videos of the roadway at a height that allowed for efficient viewing of roadway conditions and traffic. At times, however, the mountainous terrain provided operational challenges related to both altitude and weather (hot and cold).

If transportation agencies are to routinely use UAVs, a number of specific issues will have to be addressed. In 2003, the U.S. Department of Transportation's Volpe Center sponsored a conference to develop a roadmap for deploying "Unmanned Aerial Vehicles in Transportation" (Brecher 2003). The resulting document acknowledged that there is a great deal of interest in expanding and demonstrating the use of UAVs. However, the document, also noted a number of barriers, most of which are institutional. The effort forged a plan to address these barriers to deploying UAVs for transportation applications.

Operating Costs

UAVs are often described as performing work that is too “dull, dirty or dangerous” for a human. However, as UAV technology has become more effective and less costly, they have become candidates for new applications that do not necessarily replace manned flight. For example, a UAV might be considered a replacement for fixed roadside cameras.

The cost of using a UAV is one area in which there is considerable confusion and inaccuracy, as many of the UAVs in use today are research platforms or in development. However, the costs associated with the UAVs chosen for this test do give some idea. If WSDOT used an aircraft such as the MLB BAT operationally, the agency would need to purchase an aircraft, computer equipment, software, ground control equipment, and a launching catapult. The MLB is one of the less expensive UAVs in production, and this system would be around $52,000. If the use of the aircraft was part of critical operations, WSDOT would need to consider a backup aircraft, and each additional aircraft would cost approximately $30,000. Other costs to WSDOT would include the process of training personnel as aircraft operators (one is required for a flight). According to the MLB Company, training a proficient operator requires about a week of training time and 20 hours of flight time with multiple landings; this runs around $15,000. There would also be some maintenance costs, which the MLB Company estimates to be around $500 every 200 hours (Morris 2007).

According to the Georgia Tech team, the cost of the Yamaha R-Max is “around” $270,000, but importing such an aircraft from Japan into this country is currently difficult because of export restrictions. This cost includes a full ground control system. The operating cost of this aircraft would be higher than that of the fixed wing BAT, since the rotary aircraft must be operated by a minimum of two people (Johnson 2007). Other costs, such as training, maintenance, and aircraft transport, would also be higher than those for a small fixed wing UAV such as the BAT.

For a cost comparison, renting a smaller manned helicopter (a Bell Ranger 207) costs the WSDOT $800 an hour, with added costs for some flights, such as renting a fuel truck. As an example, a one-day rental of this helicopter by WSDOT at the same day and location as the R-Max UAV test to replace a nearby hilltop weather station cost $2,900.

Contracting a fixed wing aircraft is less expensive than for a rotary wing aircraft. A small fixed wing aircraft (a Cessna 172) and pilot can be hired by WSDOT for about $160 an hour.

A critical and uncertain cost factor is the potential of losing or destroying a UAV aircraft; the cost of flying a UAV may also need to include the expected loss. While the technology is maturing, UAVs are not as reliable as manned aircraft. Although reliability figures for civilian UAVs are hard to find, the military's UAV accident rates are still an order of magnitude greater than the accident rate for Air Force manned aircraft (U.S. Air Force 2005). The reliability issue is directly tied to costs because repairing and replacing a damaged or destroyed UAV could have a significant impact on a UAV program. The manufacturer could include redundant systems in UAVs to help prevent accidents and increase their reliability, but these actions would also raise costs.

Liability is also linked to reliability because aircraft failure could damage property or injure people on the ground. Liability concerns could also be tied to the possibility of a collision between a UAV and other aircraft (Brecher 2003). However, WSDOT frequently operates potentially dangerous equipment (such as the military tanks and howitzers used for avalanche control) and has mechanisms to deal with liability. In addition, the UAVs used for these tests had some fail safes; for example, the BAT has a lost–link safety feature that allows it to autonomously return to a landing site if there is a communications failure, and the R-Max can be manually overridden by a safety pilot. The BAT also is lighter weight, thus reducing its potential to cause accidents. Small UAVs may also carry parachutes in case of engine failure. Another consideration mentioned by the Volpe study is that UAVs might have lower liability risks than any manned helicopters or aircraft used by a DOT because no pilot and passengers would be hurt in a crash landing. In addition, the UAVs used in this project, and for avalanche control in general, would operate over unpopulated areas, which might also reduce liability concerns.

Security

The Volpe report noted that UAVs could potentially be used for nefarious purposes, such as spying or delivering explosives or biological, chemical, or nuclear materials. However, the UAV that the transportation community might use would have a minimal payload, such as a camera, and this could help reduce security concerns. The FAA requirement for advance notification of flight would also help address security concerns.

Privacy and Civil Rights Issues

One concern mentioned in the Volpe report is that a UAV using a video camera for monitoring traffic could arouse concern about privacy violations and unauthorized surveillance, and the use of UAVs to monitor transportation infrastructure and operation would have to work within the legal framework. However, WSDOT already operates cameras and has mechanisms to deal with privacy concerns.

Institutional Issues

The major barrier for transportation agencies flying UAVs is related to the ability of a UAV to “see and avoid” other aircraft. This concern is the main reason that the FAA requires UAV flights to obtain a Certificate of Authorization. The COA process is the source of some confusion because model aircraft, which in some cases are similar in size and capabilities to UAVs, can operate without any certification up to 400 feet above ground. This suggests that transportation use of UAV as a model aircraft may provide some capability without requiring a certification process. However, this approach would need to be carefully considered; several police agencies (the Palm Beach and Los Angeles sheriff's departments) flying small UAVs without a COA have been challenged by the FAA and restricted from flying (Aero News 2007, Space Daily News 2006).

The FAA recognizes the increasing interest in civilian UAV use. The number of applications to obtain permission to fly has been steadily increasing. The FAA has an Unmanned Aircraft Program Office with responsibility for developing a regulatory framework for UAVs. In the spring of 2007, the FAA hired a consulting company to help develop a five-year "roadmap" for integrating UAVs into the National Air Space. It is expected that a ruling will be made in 2009. The FAA has also shown some indication that it may make the certification process simpler for aircraft under 50 pounds (GAO 2008). WSDOT professionals can follow the progress of this program through the FAA Web site (www.faa.gov). Concurrently, improved technology—such as detect, see, and avoid systems or transponders—may enhance a UAV's ability to safely fly in the NAS.

Conclusions

Unmanned aircraft systems have become more affordable (starting at $50,000), and their functionality has increased so that a transportation agency could operate them without major organizational additions. These unmanned aircraft systems are technically able to complete a range of surveillance and monitoring tasks that are potentially useful to transportation organizations. Work by several research groups, as well for this project, indicates that they can perform effective aerial surveillance of the road and are able to do so while operating autonomously.

Because of institutional considerations, there are some notable limitations to flying a UAV. These are principally linked to the need to obtain FAA authorization to fly in order to comply with strict "see and avoid" rules. Fortunately, both technical and organizational solutions are being considered. Other concerns include liability and privacy, but WSDOT has dealt with these issues in numerous other formats. For example, WSDOT had to address privacy concerns before installing traffic cameras.

Another potential limitation for transportation agencies is uncertainty about the reliability of UAVs related to the costs of equipment replacement and the consequences of a crash. These problems may be reduced in the future, as UAVs become less expensive, more expendable, or more reliable. However, the tests completed as part of this project highlighted the reluctance of the aircraft owners to risk their UAVs. The reliability of the aircraft was a concern and may make their use difficult in extreme conditions.

As a result of replacement concerns and because of FAA procedures, routine operation of a UAV will continue to be a challenge for WSDOT. However, these issues may change with new technology and NAS rules.

Nevertheless, this project found that UAVs also hold considerable promise for WSDOT's avalanche control operations. Not only is the ability to obtain FAA approval to fly for avalanche control less complicated because of the unpopulated flight area, but also the ability of the UAV to effectively supplement routine avalanche control operation was shown to be effective. WSDOT's avalanche control staff hopes to expand the use and testing of UAVs.

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Appendix 1: Aircraft Technical Specifications

R-Max
Weight: 205 pounds
Payload: 65 pounds
Main Rotor Diameter: 12 feet
Tail Rotor Diameter: 21 inches
Overall Length: 11.9 feet
Flight duration: One hour
Flight Speed: 10 to 12 mile/hour
Engine: Water-cooled, 2-stroke, horizontally opposed 2-cylinder (246 cc)

MLB Bat
Weight: 24 pounds (maximum)
Payload: 5 pounds
Wingspan: 80 inches
Flight duration: 5.0 hours (nominal); 8 hours (maximum)
Flight speed: 40 to 60 mile/hour
Altitude (maximum operating): 10,000 feet
Engine: 1.25 cubic inch (26cc) 2-stroke
Range: 10-mile radius (telemetry limited); 180-mile fuel range