



The Use of Unmanned Aerial Systems for Steep Terrain Investigations

Requested by

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The Caltrans Division of Research, Innovation and System Information (DRISI) receives and evaluates numerous research problem statements for funding every year. DRISI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.

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Executive Summary

Background

Small unmanned aerial systems (UASs) comprise an unmanned aircraft, flown autonomously using preprogrammed flight paths or by a pilot at a ground control station, and the support equipment necessary to operate the unmanned aircraft. A UAS outfitted with additional technology can be used to gather high-resolution aerial photography and other data needed by transportation agencies when gathering such data manually proves to be too challenging or too costly.

While a UAS can be used for multiple purposes within a transportation agency, the primary interest of Caltrans Division of Engineering, Geotechnical Services in this project is learning more about using a UAS to support geotechnical field investigations involving landslides, rockfall and other steep terrain.

To aid in this effort, CTC gathered information about:

- The current environment within Caltrans and other California state agencies with regard to the use of UASs and the legislative considerations affecting UAS deployment within the state.
- The role of the Federal Aviation Administration (FAA) in UAS regulation and testing, with a particular interest in state agency use of UAS.
- The application of UAS technology within state agencies and by other research teams for a range of uses that include but go beyond the steep terrain investigations of primary interest to Caltrans.
- Training resources, guidelines and specifications that prepare organizations to use UAS technology.

Summary of Findings

Several state DOTs are actively performing research into the use of UASs to facilitate operations. Little research has been performed by DOTs into the use of UASs for steep terrain investigations. The results of the previous state DOT research projects lay the groundwork for research into expanding the use of UASs for steep terrain investigations. The UAS technology is dynamic and advancing quickly; testing is just getting underway at FAA-sanctioned test sites across the country, and the FAA continues to review and promulgate guidelines and regulations that apply to UASs. Future Caltrans research will benefit from proof-of-concept testing and close monitoring of the evolving regulatory setting.

UAS Deployment in California

While Caltrans' interest in UASs is long-standing, there is little documented research on UAS development or use by Caltrans or other California state agencies. A Preliminary Investigation that dates back to 1999 examined the use of a UAS to conduct landslide investigations. This project was tabled in favor of a 2008 Caltrans research project that developed an aerial robot for use in bridge inspections that was never deployed. There has been no additional research conducted on UAS use or research within Caltrans or other California state agencies.

Bills in the California Assembly and Senate may affect Caltrans' deployment of UAS technology. Only the Assembly bill, AB-1327, is currently active. The bill as currently drafted permits Caltrans and other public agencies other than a law enforcement agency to use a UAS "to achieve the core mission of the agency provided that the purpose is unrelated to the gathering of criminal intelligence."

The FAA's Role in UAS Oversight

The 2012 FAA Modernization and Reform Act (the 2012 Act) included provisions that direct the FAA to develop a plan to enable UAS integration into the national airspace system (NAS) along with the necessary regulations. Most of the 2012 Act's requirements must be accomplished between May 2012 and December 2015. Among the requirements included in the 2012 Act are the establishment of a Center of Excellence (COE) and six test sites representing geographic and climate differences within the United States.

Center of Excellence

The FAA is preparing to launch the COE in 2015. Participating universities will execute five-year cooperative agreements and be required to match federal grants with funds from nonfederal sources. Initial COE research areas include air traffic control interoperability; airport ground operations; control and communication; human factors; and unmanned aircraft crew training and certification, including pilots.

Test Sites

Four of the six test sites required by the 2012 Act are operational:

- **North Dakota Department of Commerce.** A small UAS will be used to check soil quality and crop status in support of North Dakota State University/Extension Service precision agriculture research studies.
- **State of Nevada.** The test site team will make test flights at or below 3,000 feet, monitored by a visual observer and mission commander. Research will focus on UAS standards and operations as well as operator standards and certification requirements.
- **Texas A&M University—Corpus Christi.** A UAS that weighs approximately 85 pounds and has a wingspan of almost 13 feet will be deployed to aid in the preservation and restoration of the ocean and ocean wetlands along the Padre Island National Seashore.
- **University of Alaska.** A small UAS will be used for animal surveys at the Pan-Pacific UAS Test Range Complex in Fairbanks.

Two sites have yet to become operational:

- **New York's Griffiss International Airport.** This test site will examine sense-and-avoid capabilities for UASs and the complexities of integrating UASs into the congested northeast airspace.
- **Virginia Polytechnic Institute and State University.** This team plans to conduct UAS failure mode testing in two test site locations—Virginia and New Jersey.

Getting Approval for a Public Entity to Operate a UAS

Before operating a UAS, public agencies are required to get FAA approval through a Certificate of Waiver or Authorization (COA). COAs are usually issued for a period of up to two years and cover a specific location and operation.

Commercial Use of a UAS Over Land

While this Preliminary Investigation is focused on public agency use of UASs, we noted in June that the FAA authorized the first commercial UAS operation over land by giving approval to the energy company BP and UAS manufacturer AeroVironment to fly an AeroVironment Puma AE for aerial surveys in Alaska.

Recent Applications of UAS Technology

State Agency Investigations

To augment state-specific studies that examine the application of UASs to meet a range of needs, we found a recent conference paper that took a broader view by developing matrices that can be used by state departments of transportation (DOTs) to relate user requirements to technology and technical requirements, and define UAS design specifications to meet operational needs. State DOT research is summarized below.

Arkansas. Arkansas State Highway and Transportation Department opted against investigating UAS deployment to collect traffic data in a 2013 project, citing FAA restrictions and time constraints. Instead, researchers recommended a mobile, mast-mounted camera as a feasible option for remote observation.

Georgia. After extensive internal assessment, researchers developed five potential UASs to meet various needs within Georgia DOT. The proposed solutions, described in an April 2014 report, address a range of situations, including the need for survey and location data of survey quality, bridge or other structural inspections, and regional operations that separate the piloting tasks from the payload and data acquisition tasks.

Michigan. A project in process for Michigan DOT, expected to conclude in November 2014, is examining a range of UAS uses, including inspections of pump stations and roadway assets, traffic monitoring, evaluation of the structural integrity of bridge elements and the application of Light Detection and Ranging (LiDAR). Researchers will also study the UAS deployments by other state DOTs.

North Carolina. A March 2014 publication provides a governance plan for North Carolina state and local government entities' pursuit of UAS technology. Included are discussions of safety, data protection and privacy, benefits to the state, operational considerations, governance, and guidelines and limitations.

Ohio. A magazine article describes Ohio DOT's investigation of various UAS platforms, including the first UAS used in production by a state DOT to capture aerial imagery and surface models. The biggest challenge encountered by the agency was preparing for and obtaining approval for the flight, not the flight itself.

Utah. A May 2012 research report details the use of high-resolution aerial photography obtained from a UAS to aid in monitoring and documenting state roadway structures. Utah DOT has not pursued continued use of the technology employed in this project, electing instead to evaluate other aerial options such as LiDAR and multispectral camera images.

Washington. A 2008 study evaluated the use of a UAS as an avalanche control tool on mountain slopes above state highways. The UAS also captured aerial images suitable for traffic surveillance and data collection. While effective in supplementing Washington State DOT's routine avalanche control operations, researchers identified institutional barriers to UAS use. The agency has not undertaken further UAS research. Earlier this year, the state's governor instituted a moratorium on government agencies purchasing or using UAS-related technology for the next year.

West Virginia. Researchers developed a low-cost UAS to acquire high-resolution geotagged images for ground areas of interest, gaining valuable experience in how to instrument and calibrate an aerial platform for imaging purposes.

Landslide and Other Steep Terrain Investigations

We found little domestic research about the use of UASs for landslide or other steep terrain investigations. Exceptions are the 2008 Washington State DOT study noted above and a similar examination described in a June 2013 report about using a UAS to collect snowpack data to support snow applications in avalanche control operations and water resources analysis.

We did locate citations that illustrate UAS technology use to conduct landslide investigations abroad. A manufacturer in the Czech Republic used a UAS to obtain aerial photographs and aerial video of a landslide area; in Tasmania, researchers used a small UAS to collect aerial photography and then applied a structure from motion workflow to derive a 3-D model. Researchers conducting a landslide investigation in the southern French Alps gathered aerial images with a UAS and then applied open source tools to generate digital terrain models (DTMs). Another research group examining a landslide in southern France used a low-cost UAS solution with digital compact cameras to gather high-resolution images of the landslide. The project team generated digital surface models using a new approach that did not require ground control point information. Finally, a Spanish research project concluded that accurate measurements of a landslide can be taken using UAS technology.

Vegetation and Soil Investigations

Recent research conducted in New Mexico and on the Canadian prairies evaluated the use of UAS flights to make rangeland health determinations and the accuracy of a DTM developed from imagery acquired with a low-cost digital camera placed onboard a small UAS. In the Canadian project, researchers' results indicate that UAS-acquired imagery may provide a low-cost, fast and flexible alternative to airborne LiDAR for geomorphological mapping. In another application described in a 2013 journal article, the authors used a UAS to gather inexpensive aerial 3-D measurements of a forest canopy structure.

Disaster Response

A project in process, sponsored by U.S. DOT and expected to conclude in November 2014, is examining the use of UASs for disaster response and recovery. The University of Vermont Transportation Research Center, which is performing this research, has developed a list of lessons learned about purchasing and flying UASs in Vermont. A more localized examination of UAS use for disaster response is reflected in a report prepared for the Austin (Texas) Fire Department. The report's author recommends UAS use in disaster-ridden areas and offers suggestions for implementing a UAS pilot training program.

Bridge Inspections

Two projects in process and expected to conclude within the next 12 months are evaluating the use of UASs for bridge inspections. The first is a Florida DOT project; the second is sponsored by U.S. DOT's Research and Innovative Technology Administration.

Roadside and Roadway Inspections

Documents associated with a project in process conducted by Michigan Technological University outline the requirements for a remote sensing data collection system capable of collecting inventory and distress data for unpaved roads. A 2010 research report details three Texas field experiments of a small UAS used to collect condition data for roadside infrastructure. Researchers assessed conditions of the sample roadway sections by observing conditions on-site and by observing digital images acquired with a small UAS. In another roadway-specific project, a 2009 South Dakota report describes the use of UAS to collect road data and developed methods and systems to process UAS images.

UAS Conferences, Training Resources and Guidelines

As the development of UAS technology and application matures, and the regulatory environment stabilizes, it is likely that guidelines and training materials will become more plentiful. At the time of publication, such documentation is fairly limited in scope and volume.

Three upcoming conferences—in Ohio in August, Nevada in October and Virginia in November—provide an opportunity to learn from and share ideas with others interested in UAS technology. The FAA web site offers access to UAS-related training programs, test centers, handbooks and guides. A project in process, expected to conclude in July 2017, is considering how such training can be improved by assessing the availability, relevancy and deficiencies of existing training programs. The online knowledge base of an international association provides an example of publicly available web-based training tools.

Guidelines are available in a 2014 handbook that offers a comprehensive overview of UASs, from conception to operation. A report on the use of UASs in North Carolina, prepared for the state's Legislature, provides cost estimates for establishing a UAS program and a discussion of the policy implications. A Virginia report, again prepared for a state legislative committee, provides model protocols for the use of UASs by law enforcement agencies. (State legislation places a moratorium on the use of UASs by state and local law enforcement agencies in Virginia until July 1, 2015, except in defined emergency situations or in training exercises related to these situations.) Again with the focus on law enforcement use of UAS technology, guidelines developed by an international association of police chiefs provides recommendations for any law enforcement agency contemplating the use of unmanned aircraft.

Gaps in Findings

Application of UAS technology to conduct the type of steep terrain investigations of interest to Caltrans appears to be limited in the United States. While we identified a number of research efforts abroad that used a UAS to investigate landslides and other steep terrain, we found no recently published domestic research on the use of UASs for similar investigations. (Washington State DOT elected not to follow up on a 2008 investigation about using a UAS for avalanche control.) While state DOTs are investigating the possibilities for UAS deployment to address a range of agency needs, these efforts are relatively recent, with some still in process. As the FAA continues meeting the requirements of the 2012 Act, more UAS testing will be initiated and regulations will be finalized. As more of the current research projects wrap up, more guidance will be available to agencies such as Caltrans interested in applying UAS technology.

Next Steps

Caltrans might consider the following as it continues its evaluation of a UAS to support geotechnical field investigations:

- Continue to follow activity in the state Legislature with regard to state agency use of UASs.
- Monitor the FAA web site for the latest developments on UAS testing and regulatory issues.
- Contact the principal investigator working with Norwegian Public Roads Administration to test UASs for avalanche and landslide monitoring and other types of roadside environmental monitoring to learn more about this research effort.
- Examine the UAS research conducted abroad to investigate landslides to determine how it might inform Caltrans' efforts.
- Consult with the state DOTs that have completed investigations or continue to investigate UAS technology to learn more about:
 - The technical specifications of the five potential systems developed by researchers in a Georgia DOT project.
 - The relationship of UAS uses examined by the Michigan DOT project team to the use of a UAS for geotechnical investigations.
 - The multicopter UAS being tested by Ohio DOT in connection with asset condition assessments. Inquire also about the agency's experience with the operational issues associated with conducting in-house UAS test flights.
 - The experience gained by West Virginia DOT researchers in how to instrument and calibrate an aerial platform for imaging purposes.
- Consider how other UAS applications (vegetation and soil investigations, disaster response, bridge inspections, and roadside and roadway inspections) might inform Caltrans' use of a UAS for steep terrain investigations.
- Attend UAS conferences to be apprised of the latest developments on UAS technology, applications, and regulatory environment.
- Conduct proof-of-concept testing:
 - Apply matrices derived from previous research projects to define design specifications for a UAS that can fulfill their operational requirements.
 - Obtain one or several UAVs that meet the defined designed specifications.
 - Select possible test sites.
 - Obtain Certification of Authorization for UAV testing.
 - Perform field tests of UAVs at pre-approved sites.
 - Evaluate the results and produce a report on the findings.

Detailed Findings

UAS Deployment in California

Caltrans' Interest in UAS Technology

The Caltrans Office of Geotechnical Design has a long-standing interest in unmanned aerial systems (UASs). In 1999, at the urging of the Office of Geotechnical Design, Caltrans' New Technology & Research Program began a Preliminary Investigation of UAS technologies that could be used for site reconnaissance in landslide investigations, including visual assessment of hazards using photo and video techniques and map generation using photogrammetric methods. The Sikorsky Aircraft Corporation's Cypher unmanned aerial vehicle was identified as a possible solution. About the same time, Caltrans considered entering into a research contract to develop a UAS for bridge inspections. Caltrans decided to move forward with the bridge inspection research project (see Related Resource below) and tabled the Cypher solution.

At this time, there is no additional documented UAS use or research within Caltrans or other California state agencies.

Related Resource:

Caltrans Bridge Inspection Aerial Robot, Paul S. Moller, California Department of Transportation, October 2008.

<http://www.dot.ca.gov/newtech/researchreports/reports/2008/08-0182.pdf>

Researchers developed a 40-pound, twin-motor, single-duct, electric-powered Aerobot designed to carry video cameras up to 200 feet in elevation to enable close inspection of bridges and other elevated highway structures while the operating personnel remains safely on the ground. Control commands and sensor images are transmitted through a thin-wire and fiber-optic 200-foot cable. The device did not perform as expected in testing and has not been deployed.

State Legislative Activity

UAS-related bills in the California Legislature include:

- AB-1327, Unmanned aircraft systems.
- SB-15, Aviation, unmanned aircraft systems.

AB-1327, Unmanned aircraft systems. This is an active bill in floor process, amended on June 19, 2014, and re-referred to the Committee on Appropriations. Much of the bill relates to the use of a UAS by law enforcement and provides guidelines for images, footage, data or records that pertain to a pending criminal investigation. The bill also limits retention of data collected to one year, with exceptions for indefinite retention, including "[f]or purposes of monitoring material assets owned by the public agency." The following section of the bill may permit UAS use by Caltrans:

Section 2, Title 14, Section 14350, is added to Part 4 of the Penal Code:

(d) A public agency other than a law enforcement agency may use an unmanned aircraft system, or contract for the use of an unmanned aircraft system, to achieve the core mission of the agency provided that the purpose is unrelated to the gathering of criminal intelligence.

A May 12, 2014, bill analysis completed by the Senate Committee on Public Safety includes the discussion below of public agency use of drones (emphasis added). The June 19 amendment did not alter this language.

This bill would allow a public agency, other than a law enforcement agency, to use a drone or contract for the use of a drone to achieve the core mission of the agency provided that the purpose is unrelated to the gathering of criminal intelligence. *So under this exception the Department of Transportation could send a drone to inspect a bridge or the Resources Agency could send a drone to check levees or other similar things within a public entities scope.*

SB-15, Aviation, unmanned aircraft systems. The bill was amended in the Senate on May 24, 2013, and amended in the Assembly on August 6, 2013. On August 13, 2013, a second hearing was set; the motion to pass and re-refer the bill to the Committee on Appropriations failed passage in committee. On August 27, 2013, the bill was granted reconsideration.

This bill would define UASs for all purposes in California and require law enforcement to obtain a search warrant when using a UAS and to establish standards for use of a UAS. The bill addresses issues such as defining the invasion of privacy laws and that a UAS will not be equipped as a weapon. The following section may allow local public agencies to adopt provisions allowing UASs:

Section 5, Title 14, Section 14350 added to Part 4 of the Penal Code, UAS:
The acquisition of an unmanned aircraft system by a local public agency shall be subject to reasonable public notice by the applicable local public agency's legislative body. This section shall not preclude a city, county, or other local public agency from adopting additional provisions in regard to the use of unmanned aircraft systems.

Related Resources:

AB-1327, Unmanned Aircraft Systems, California State Assembly, 2013-2014 Regular Session.

http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB1327

This web site offers links to the text, votes, history, bill analysis and today's law as amended, and allows the user to compare versions of the bill.

SB-15, Aviation: Unmanned Aircraft Systems, California State Senate, 2013-2014 Regular Session.

http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140SB15

This web site offers links to the text, votes, history, bill analysis and today's law as amended, and allows the user to compare versions of the bill.

The Federal Aviation Administration's Role in UAS Oversight

Background

The 2012 Federal Aviation Administration (FAA) Modernization and Reform Act (the 2012 Act), which some refer to as the 2012 FAA reauthorization bill, included provisions that direct the FAA to develop a plan to enable UAS integration into the national airspace system (NAS) and the necessary regulations. Most of the 2012 Act's requirements must be accomplished between May 2012 and December 2015.

A November 2013 roadmap prepared by the FAA to address what is needed to permit UAS integration into the NAS identified policy, guidance and regulatory areas requiring research and development (pilot and crew, control station, data link and unmanned aircraft), and presents these issues driving the development of regulations:

- Developing minimum standards for sense-and-avoid (SAA), control and communications, and separation assurance to meet new or existing operational and regulatory requirements for specified airspace.
- Understanding the privacy, security and environmental implications of UAS operations and working with relevant departments and agencies to proactively coordinate and align these considerations with the UAS regulatory structure.
- Developing acceptable UAS design standards that consider the aircraft size, performance, mode of control, intended operational environment and mission criticality.

A February 2013 Government Accountability Office report describes FAA UAS oversight:

In 2012, the FAA established the Unmanned Aircraft Systems Integration Office to provide a one-stop portal for civil and public use UAS in U.S. airspace. This office is developing a comprehensive plan to integrate and establish operational and certification requirements for UAS. It will also oversee and coordinate UAS research and development.

UAS-Related Research

Center of Excellence

The FAA is preparing to launch a new UAS Center of Excellence (COE) in 2015 and is expected to support this effort over the next 10 years. A final solicitation is slated for publication in August, with the deadline for university teams to submit proposals in mid-September. Participating universities will execute five-year cooperative agreements and be required to match federal grants with funds from nonfederal sources.

Applicants selected will be required to perform research to aid in the integration of UAS into the NAS. Initial COE research areas of interest include:

- Air traffic control interoperability.
- Airport ground operations.
- Control and communications.
- Detect and avoid.
- Human factors.

- Spectrum management.
- Unmanned aircraft crew training and certification, including pilots.

Test Sites

In addition to requiring the FAA to establish a test site program that integrates UASs into the NAS, the 2012 Act also calls for “safe integration” of UASs by 2015. Six test sites were selected from submissions by 25 entities in 24 states. As of the date of publication, four of the six test sites are operational:

- **North Dakota Department of Commerce.** A Draganflyer X4-ES small UAS will be used at the Northern Plains Unmanned Aircraft Systems Test Site. The project team will employ UASs to check soil quality and the status of crops in support of North Dakota State University/Extension Service precision agriculture research studies.
- **State of Nevada.** Researchers will use an Insitu ScanEagle at the Desert Rock Airport, a private airport owned and operated by the Department of Energy. The ScanEagle will fly at or below 3,000 feet, monitored by a visual observer and mission commander. Research at this site will focus on UAS standards and operations as well as operator standards and certification requirements.

The UAS Program Management Office of the Nevada Institute for Autonomous Systems (NIAS), a state-sanctioned nonprofit organization, is managing the Nevada test site. NIAS services include:

- Assisting with the development of documents, checklists and programs required for FAA Special Airworthiness and/or Program Management Office certification.
- Evaluating and assisting with certification of UAS/remotely piloted aircraft crew members and visual observers.
- Evaluating UAS flight characteristics for the candidate UAS and ground control systems.
- Developing specific FAA Certificate of Waiver or Authorization (COA) locations and air space parameters for UAS operations that will be conducted in the NAS. The process begins with an application for a customer’s UAS at one of the NIAS-operated UAS test sites or the customer’s field of choice.
- **Texas A&M University–Corpus Christi.** The team will use an AAI RS-16 UAS that weighs approximately 85 pounds and has a wingspan of almost 13 feet. UAS projects at this site include preservation and restoration of the ocean and ocean wetlands along the Padre Island National Seashore, research related to tropical depressions and support to law enforcement in the Padre Island National Seashore.
- **University of Alaska.** The University of Alaska Fairbanks will use an Aeryon Scout small UAS for animal surveys at its Pan-Pacific UAS Test Range Complex in Fairbanks. Operations at this site will show how a UAS can accurately locate, identify and count large wild animals, such as caribou, reindeer, musk ox and bear, for survey operations requested by the state of Alaska.

Two sites have yet to become operational:

- **New York’s Griffiss International Airport.** The focus for this team’s research is SAA capabilities for UASs, and its sites will aid in researching the complexities of integrating UASs into the congested northeast airspace.

- **Virginia Polytechnic Institute and State University.** This team plans to conduct UAS failure mode testing in two test site range locations—Virginia and New Jersey—and identify and evaluate operational and technical risk areas.

Other points of interest related to the test sites:

- Each test site operator will manage the use and scheduling of the test site in a way that will give access to parties interested in using the site. The FAA's role is to ensure that each operator sets up a safe testing environment and to provide oversight that ensures each site operates under strict safety standards.
- Site operators and users will provide funding for their research activities.
- The test range program will be terminated by February 2017.

Getting Approval for a Public Entity to Operate a UAS

Public agencies obtain a COA to get FAA approval to operate a UAS. Applicants use an FAA online process to make the COA request.

A COA allows an operator to use a defined block of airspace and includes special provisions for the proposed operation. COAs are usually issued for a specific period—up to two years, in many cases—and cover a specific location and operation. Typically, requests for a COA will receive a response within 60 days of the completed application. Expedited procedures permit faster issuance of a one-time COA for time-sensitive emergency missions, such as disaster relief.

Among the services provided to customers of the FAA-sanctioned test site in Nevada is assistance with completing the COA application and subsequent FAA oversight after COA approval. The test site's management office also ensures that the customer's operations team is trained on the provisions and limitations of the COA as directed by the FAA.

Other test sites provide online information about their expected interactions with customers or users wishing to participate in testing at the sites, which may include assistance with obtaining a COA. An online flowchart illustrates the testing process at the North Dakota test site; the Alaska testing facility web site is under development and will eventually provide information for potential users and clients.

First Commercial Use of a UAS Over Land

FAA has certified only two UAS models—the ScanEagle and AeroVironment's Puma—for commercial use, and these UASs are only authorized to fly in the Arctic. In June 2014, FAA authorized the first commercial UAS operation over land. The energy company BP and UAS manufacturer AeroVironment received approval to fly an AeroVironment Puma AE for aerial surveys in Alaska. The Puma AE is a small, hand-launched UAS—about 4.5 feet long with a wingspan of 9 feet. Sensors on the Puma AE will gather data on pipelines, roads and equipment at BP's oilfield in Prudhoe Bay to help the company identify infrastructure maintenance needs.

Related Resources

General

General FAQs, Unmanned Aircraft (UAS), Federal Aviation Administration, July 15, 2014.

http://www.faa.gov/about/initiatives/uas/uas_faq/

This site, with questions and answers about the FAA's role in permitting UAS use by public entities and commercial enterprises, will be helpful to those new to the UAS topic.

Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap, First Edition, Federal Aviation Administration, 2013.

http://www.faa.gov/about/initiatives/uas/media/uas_roadmap_2013.pdf

From page 3 of the PDF:

This roadmap outlines the actions and considerations needed to enable UAS integration into the NAS. The roadmap also aligns proposed FAA actions with Congressional mandates from the *FAA Modernization and Reform Act of 2012*. This plan also provides goals, metrics, and target dates for the FAA and its government and industry partners to use in planning key activities for UAS integration.

Unmanned Aircraft Systems: Continued Coordination, Operational Data, and Performance Standards Needed to Guide Research and Development; Testimony Before the Subcommittee on Oversight, Committee on Science, Space, and Technology, House of Representatives, U.S. Government Accountability Office, February 15, 2013.

<http://www.gao.gov/assets/660/652223.pdf>

Testimony in this report is based on a 2012 Government Accountability Office report. *From page 2 of the 2013 report:*

... Congress established specific requirements and set deadlines for FAA in the 2012 FAA Modernization and Reform Act (the 2012 Act).

This testimony discusses 1) the roles and responsibilities of and coordination among federal agencies and other UAS stakeholders involved in integrating UAS, 2) FAA's progress in complying with the 2012 Act's UAS requirements, and 3) research and development efforts by FAA and other entities to address challenges for safely integrating UAS.

"FAA to Establish UAS Center of Excellence," press release, Federal Aviation Administration, May 27, 2014.

<http://www.faa.gov/news/updates/?newsId=77504>

This release announces a draft solicitation for a new FAA COE.

Draft Solicitation, Center of Excellence for Unmanned Aircraft Systems, Federal Aviation Administration, May 27, 2014.

http://www.faa.gov/about/office_org/headquarters_offices/ang/offices/management/coe/media/pdf/COE%20UAS%20Draft%20Solicitation%2005-27-14%20FINAL.pdf

This document provides background on the proposed COE and how eligible entities can apply "to perform research to assist the FAA and the UAS community to integrate unmanned aircraft into the NAS."

Certificates of Waiver or Authorization (COA), Federal Aviation Administration, April 23, 2014.

http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/systemops/aaim/organizations/uas/coa/

This web site provides a link to the COA online application system.

Busting Myths about the FAA and Unmanned Aircraft—Update, Federal Aviation Administration, March 7, 2014.

<http://www.faa.gov/news/updates/?newsId=76381>

In the course of busting myths, this web site identifies the UAS models currently certified for commercial use and the timing of regulations for small UASs.

“FAA Approves First Commercial UAS Flights Over Land: Surveys Will Check Pipelines, Infrastructure on Alaska North Slope,” press release, Federal Aviation Administration, June 10, 2014.

http://www.faa.gov/news/press_releases/news_story.cfm?newsId=16354

This release describes the first FAA-authorized commercial UAS operation over land to survey pipelines, roads and equipment at Prudhoe Bay in Alaska.

Test Sites

Fact Sheet—FAA UAS Test Site Program, Federal Aviation Administration, December 30, 2013.

http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=15575

This fact sheet provides background on the selection process and expected operation of the six UAS test sites.

“FAA Announces First UAS Test Site Operational: North Dakota Department of Commerce Ready to Start Testing,” press release, Federal Aviation Administration, April 21, 2014.

http://www.faa.gov/news/press_releases/news_story.cfm?newsId=16154

This release announces the first UAS test site to become operational, the type of UAS the test site will employ (Draganflyer X4-ES small UAS) and the testing focus (agriculture research).

Northern Plains UAS Test Site, North Dakota Department of Commerce, 2014.

<http://www.npuasts.com/>

This web site for the North Dakota test site, overseen by the Northern Plains Unmanned Systems Authority, provides a flowchart that illustrates the process for customers wishing to use the test site.

“FAA Announces Alaska UAS Test Site Begins Research Flights; University of Alaska Surveying Wildlife,” Press Release, Federal Aviation Administration, May 4, 2014.

http://www.faa.gov/news/press_releases/news_story.cfm?newsId=16194

This release announces the second UAS test site to become operational, the type of UAS the test site will employ (Aeryon Scout) and the testing focus (wildlife surveys).

Alaska Center for Unmanned Aircraft Systems Integration (ACUASI), University of Alaska, Fairbanks, 2014.

<http://acuasi.alaska.edu/>

From the web site: In 2013 ACUASI submitted its proposal to the FAA for one of the six test sites established by the 2012 FAA Modernization and Reform Act, and in December 2013 the

FAA announced that the University had been selected. The Pan Pacific UAS Test Range Complex reports to the ACUASI, but also includes principal partners in Oregon and Hawaii as well as 56 non-state partners located all over the US and internationally. Ranges are located in the three states as well as in Iceland, our key international partner.

The website, still under development, will provide information for potential users/clients.

“FAA Announces Nevada UAS Test Site Now Operational: Research to Examine UAS Integration with Air Traffic Control Procedures and NextGen,” press release, Federal Aviation Administration, June 9, 2014.

http://www.faa.gov/news/press_releases/news_story.cfm?newsId=16334

This release announces the third UAS test site to become operational, the type of UAS the test site will employ (Insitu ScanEagle) and the testing focus (UAS standards and operations).

Nevada Institute for Autonomous Systems, Program Management Office, Nevada Institute for Autonomous Systems, undated.

http://www.nias-uas.com/sites/default/files/NIAS_factSheet.pdf

This fact sheet describes the services available through the UAS test site in Nevada.

“FAA Announces Texas UAS Test Site Now Operational: Research to Include Wetlands Preservation, Storm Research, UAS Technologies and Standards,” press release, Federal Aviation Administration, June 20, 2014.

http://www.faa.gov/news/press_releases/news_story.cfm?newsId=16454

This release announces the fourth UAS test site to become operational, the type of UAS the test site will employ (AAAI RS-16) and the testing focus (preservation and restoration of the ocean and ocean wetlands).

Recent Applications of UAS Technology

We gathered recently published research and other publications to illustrate the varied uses of UAS technology. Each citation appears only once among the six topic areas below, though some citations are relevant to multiple topic areas.

- State agency investigations.
- Landslide and other steep terrain investigations.
- Vegetation and soil investigations.
- Disaster response.
- Bridge inspections.
- Roadside and roadway inspections.

State Agency Investigations

“A Comprehensive Matrix of Unmanned Aerial Systems Requirements for Potential Applications within a Department of Transportation,” Ebrahim P. Karan, Claus Christmann, Masoud Gheisari, Javier Irizarry, Eric N. Johnson, *Construction Research Congress*, 2014. Citation at <http://dx.doi.org/10.1061/9780784413517.099>

From the abstract: This study investigates various divisions and offices within a Department of Transportation to determine the operational requirements for UAS usage in specific divisions that have the potential to implement this technology to aid and supplement their daily operations. Through a series of interviews with subject matter experts at the management and operational levels, a matrix of user requirements for tasks that have the potential to use UAS was developed. This matrix is mapped to a UAS technical matrix that embeds the technological and technical requirements for development of a potential UAS. These matrices can be used by other DOTs for defining the design specifications for UAS that can fulfill their construction-related operational requirements.

Arkansas

Use of Unmanned Aerial Vehicle for AHTD Applications: “Studying Visual Aids to Assist in Corridor Analysis,” Tymli Frierson, Arkansas State Highway and Transportation Department, December 2013.

See [Appendix A](#).

Researchers examined data collection equipment that could be used to model real-time traffic movements and improve road design. While UAS were part of the initial examination, researchers concluded that while UAS has the potential to be effective for collecting traffic data, “with FAA restrictions and the time schedule for this particular project, UAVs were not applicable for AHTD at this time.” Instead, researchers recommended a mobile, mast-mounted camera as a feasible option for remote observation needs. Another alternative considered in the project—a tethered helium balloon camera—was not recommended for department use given the balloon’s instability, which led to poor overall image quality.

Georgia

Feasibility Study to Determine the Economic and Operational Benefits of Utilizing Unmanned Aerial Vehicles (UAVs), Javier Irizarry, Eric N. Johnson, Georgia Department of Transportation, April 2014.

<http://www.dot.ga.gov/doingbusiness/research/Documents/12-38.pdf>

To explore the feasibility of using UAS in Georgia DOT operations, researchers conducted interviews with staff in four Georgia DOT divisions. Results of those interviews led to the development of five potential systems, using three components to analyze each system: vehicle, control station and system. The five proposed systems:

- *Flying camera*. Used for any situation where a video or picture is all that is needed as a data input.
- *Flying total station*. Used anytime survey data or location data of survey quality is needed.
- *Perching camera*. Mainly to be used in two modes: as an ad hoc-deployed UAS for local, on-site inspection or measurement tasks, or as a deployed-on-demand system.
- *Medium altitude, long endurance (MALE)*. This system expands operations to a regional scale, allowing long operational usage throughout a county-sized area. The system separates the piloting tasks from the payload operation and data acquisition tasks, allowing for a high level of operator interaction.
- *Complex manipulation*. Used for bridge or other structural inspection activities. Most likely a custom-made, multirotor unit with eight or more rotors or an even more specialized “inverted” helicopter, where the main rotor sits below most of the airframe.

Researchers suggested a path forward, in cooperation with the FAA, to obtain a clearer idea of the economic and intangible benefits of the use of UASs for Georgia DOT operations:

- Analyze an inspection task at a construction job site to set the baseline for UAS operator system interface needs.
- Detail current practice and shadow personnel performing the task to estimate the time and cost of performance.
- Establish a potential UAS flight path through a job site.
- Use a staff-mounted sensor suite as a UAS mock-up or an off-the-shelf UAS to collect sensor data, including video along the established flight path, to develop a software replica of the site using the collected data.
- Use the developed system in a staged field test in an access-controlled construction site to validate the simulation results.

Michigan

“Evaluating the Use of Unmanned Aerial Vehicles (UAVs) for Transportation Purposes,”
Michigan Technological University, expected completion date: November 30, 2014.

http://www.michigan.gov/documents/mdot/2013_Annual_Report_452352_7.pdf (See page 91 of Michigan DOT’s *Fiscal Year 2013 Annual Report* for a summary of the project to date.)

Objectives of this project in process include:

- Develop, test, and demonstrate how UAS technology can help provide visual inspections from above for a variety of structures and locations of interest to Michigan DOT, such as pump stations, roadway assets and entrances to sewers and culverts.
- Provide a demonstration of how a rapidly deployable, relatively inexpensive UAS could be deployed to monitor traffic over an extended period without the need for new permanent infrastructure.
- Investigate nondestructive evaluation techniques using remote sensors on a UAS platform to evaluate the surface and structural integrity of bridge elements, including using thermal infrared and 3-D optical nondestructive methods.
- Demonstrate how a Light Detection and Ranging (LiDAR) sensor could be used to rapidly assess and inspect transportation infrastructure.
- Provide a review of the current state of the practice with a focus on practical UAS deployments by other transportation agencies including up-to-date academic research projects.
- Provide recommendations and an implementation plan on utilizing the UAS technology for Michigan DOT infrastructure inspections and asset management data collection.

Sponsor: Michigan Department of Transportation.

North Carolina

Unmanned Aircraft Use in North Carolina: Report to the Joint Legislative Oversight Committee on Information Technology, Joint Legislative Transportation Oversight Committee Fiscal Research Division, Chris Estes, State of North Carolina Office of Information Technology Services, March 2014.

https://www.scio.nc.gov/library/pdf/Unmanned_Aircraft_Report_March_2014.pdf

This publication provides a governance plan for the state’s pursuit of UAS technology for use by state and local government entities. The UAS Working Group identified potential uses for state government in the following areas: agriculture, precision surveying and mapping, wildlife monitoring, monitoring of vital state infrastructure, public affairs, cultural resources, traffic monitoring and control, migration monitoring and stewardship, and state and local emergency management.

Page 16 of the report (page 18 of the PDF) discusses the role of the Next Generation Air Transportation Center at North Carolina State University in the state’s UAS operations:

The [Next Generation Air Transport (NGAT)] will play a critical role in the state’s UAS operations. A Statement of Airworthiness (SOA) is a required element of the process when requesting a COA from the FAA. NGAT is available to all state agencies and local government entities to assist with obtaining a SOA. Additionally, the NGAT could assist

agencies in obtaining COAs and in collaborating with UAS vendors for system acquisition or leasing options.

North Carolina's Unmanned Aircraft Systems (UAS) Program, Kyle Snyder, NGAT Center Director, NC Aerospace Suppliers' Conference 2013.

<http://www.ncmbc.us/documents/NCASC2013NGATPublic.pdf>

The presentation describes the UAS used at the North Carolina UAS test site, the Hyde County test site's economic impact on the county and the state, and details of a planned test site.

Ohio

"The Ohio Department of Transportation and Unmanned Aircraft Systems," Fred Judson, *LiDAR Magazine*, Vol. 3, No. 5, September 2013.

http://www.lidarnews.com/PDF/LiDARMagazine_Judson-ODOTandUAS_Vol3No5.pdf

Ohio DOT is investigating UAS platforms for a variety of functions, including:

- A fixed-wing UAS for aerial photography in support of GIS, transportation asset management, construction project documentation and incident management.
- A multirotor UAS for asset condition assessments.
- A lighter-than-air UAS for incident management and traffic monitoring.

Ohio DOT has implemented the first UAS used in production by a state DOT for capture of aerial imagery and surface models. The UAS is a senseFly swingleT CAM (see <https://www.sensefly.com/drones/swingleT-cam.html>). The article describes the UAS platform in detail, the data collected and how results have been used. The agency notes that the biggest challenge associated with the use of a UAS is not the flying, but the work required to prepare to fly (COA application and coordinating with local air traffic control).

Utah

Evaluation and Development of Unmanned Aircraft (UAV) for UDOT Needs, Steven Barfuss, Austin Jensen, Shannon Clemens, Utah Department of Transportation, May 2012.

http://ntl.bts.gov/lib/45000/45600/45612/UT-12.08_UAV_report_July_2012.pdf

This research involved the use of high-resolution aerial photography obtained from a UAS to aid in monitoring and documenting state roadway structures and associated issues. Using georeferenced, UAS-obtained high-resolution aerial photographic imagery, the project documented the before, during and after stages of the Southern Parkway construction near the new Saint George International airport. Researchers also photographed and classified wetland plant species.

Follow-up contact: Tim Ularich, Utah DOT deputy maintenance engineer, indicates that Utah DOT has not continued its investigation of the technology developed in the May 2012 report. Instead, the agency is evaluating other aerial options, including LiDAR and multispectral camera images.

In late 2012, Utah DOT had mobile, road-based LiDAR performed on the entire UDOT highway system (no local roads). The agency is now evaluating how to cost-effectively maintain that feature inventory and is considering flying the areas of known change as a possible solution. Mr.

Ularich recommends the use of LiDAR for geotechnical needs as “an easy ‘change detection’ method for analyzing slopes.”

Washington

Washington State DOT elected to not pursue further research on the use of a UAS as an avalanche control tool after publication of the 2008 research study described below. In April 2014, the state’s governor vetoed a UAS-related bill passed by the Legislature and instituted a moratorium on government agencies purchasing or using UAS-related technology for the next year.

The Use of Small Unmanned Aircraft by the Washington State Department of Transportation, Edward D. McCormack, Washington State Department of Transportation, June 2008.

<http://www.wsdot.wa.gov/research/reports/fullreports/703.1.pdf>

In addition to exploring the general capabilities of UAS in a series of tests, researchers evaluated the use of a UAS as an avalanche control tool on mountain slopes above state highways. The UAS also captured aerial images suitable for traffic surveillance and data collection. A UAS is seen as particularly applicable to avalanche control operations given the unpopulated flight area, which simplifies obtaining approval to fly the UAS, and researchers found that the data collected by the UAS was effective in supplementing the agency’s routine avalanche control operations. However, researchers did identify institutional barriers to UAS use, specifically the need to obtain approval to fly from the FAA.

Related Resource:

“Exploring Transportation Applications of Small Unmanned Aircraft,” Edward McCormack, *ITE Journal*, Vol. 79, Issue 12, pages 32–36, December 2009.

<http://www.ite.org/membersonly/itejournal/pdf/2009/JB09LA32.pdf>

This article provides a concise discussion of researchers’ efforts to test a UAS for use by Washington State DOT for avalanche control operations. The author notes that “[a]s a result of reliability concerns and because of FAA authorization rules, routine operation of a UAV will continue to be a challenge for state DOTs. These issues may change with new technology and FAA rules.” Challenges identified in the Washington State DOT testing and in other early state DOT UAS projects described in the article may be addressed by the FAA efforts now underway.

“Task Force Meets to Discuss Regulations for Drone Use in Washington,” *The Oregonian (Oregon Live)*, June 30, 2014.

http://www.oregonlive.com/pacific-northwest-news/index.ssf/2014/06/task_force_meets_to_discuss_re.html

This article describes the potential issues raised in the first meeting of a task force convened at the request of Washington’s Gov. Inslee. In April, the governor vetoed a drone—or UAS—bill passed by the Legislature and instituted a moratorium on state government agencies purchasing or using UAS-related technology for the next year.

West Virginia

Evaluation of Remote Sensing Aerial Systems in Existing Transportation Practices, Yu Gu, U.S. Department of Transportation Research and Innovative Technology Administration, Division of Highways, West Virginia Department of Transportation Highway, October 2009.

<http://www.mautc.psu.edu/docs/WVU-2008-01.pdf>

Researchers instrumented the remotely controlled aircraft used in this project with a GPS receiver, a flight data recorder, downlink telemetry hardware, a digital still camera and a shutter-triggering device to conduct a proof-of-concept demonstration of aerial data acquisition. During the flight, a ground pilot uses one of the remote-control channels to remotely trigger the camera. Researchers found the developed UAS to be a low-cost aerial platform to acquire high-resolution geotagged images for ground areas of interest, and garnered valuable experience in how to instrument and calibrate an aerial platform for imaging purposes.

Landslide and Other Steep Terrain Investigations

We found little domestic research with regard to the use of UASs for landslide or other steep terrain investigations. Exceptions are the 2008 research study conducted by Washington State DOT on the use of a UAS in avalanche control (see page 20) and a similar examination of the use of a UAS described in the June 2013 report cited below. The other citations listed here describe European uses of a UAS for investigating landslide areas.

“UAV Mapping of the Landslide on the Highway Under Construction for Geological Survey in Czech Republic,” Jakub Karas, *GISCafe*, May 27, 2014.

<http://www10.giscafe.com/blogs/uav/2014/05/27/uav-mapping-of-the-landslide-on-the-highway-under-construction-for-geological-survey-in-czech-republic/>

Note: There appears to be issues with the translation for this article.

UPVISION, the largest UAS company in the Czech Republic, mapped a landslide using an unmanned aerial vehicle. In addition to obtaining classic aerial photographs and aerial video of the landslide, which provided a comprehensive overview of the current situation, the UAS mapped the area near the landslide, including the adjacent quarry.

“Mapping Landslide Displacements Using Structure from Motion (SfM) and Image Correlation of Multi-Temporal UAV Photography,” Arko Lucieer, Steven M. de Jong, Darren Turner, *Progress in Physical Geography*, Vol. 38, No. 1, pages 97–116, February 2014.

Citation at <http://ppg.sagepub.com/content/38/1/97.abstract>

In this article, researchers present a flexible, cost-effective and accurate method to monitor landslides using a small UAS to collect aerial photography. Researchers’ activities include the use of a structure from motion workflow to derive a 3-D model of a landslide in southeast Tasmania from multiview UAS photography. Results indicate that UAS-based imagery in combination with 3-D scene reconstruction and image correlation algorithms provide flexible and effective tools to map and monitor landslide dynamics.

Snow Depths from the Heights: Developing a Mission-Specific Civilian Unmanned Aircraft System for Sensing the Mountain Snowpack, Jessica Lundquist, Edward McCormack, Francesca White, Kris Gauksheim, Juris Vagners, Joint Center for Aerospace Technology Innovation, June 30, 2013.

See [Appendix B](#).

This project explored the use of UASs for the collection of snowpack data to support snow applications for avalanche control operations and water resources analysis. Researchers note that “[t]he instruments most suited for mounting on a UAS, such as the Flexrotor, are visible and IR [infrared] wavelength cameras. These instruments are lightweight, robust, and can map snow at less than a 1-m spatial resolution (depending on height flown and specific camera resolution).”

Follow-up contact: Edward McCormack, one of the investigators for the June 2013 report on collecting snowpack data, is working with Norwegian Public Roads Administration to test UASs for avalanche and landslide monitoring and other types of roadside environmental monitoring. The research team has just completed testing UASs in the mountain environment and is hoping to evaluate the use of UASs to investigate landslides, avalanches and other natural hazards above roads in Norway. Published documents related to this research are not yet available.

“Open Source Image-Processing Tools for Low-Cost UAV-Based Landslide Investigations,” U. Niethammer, S. Rothmund, U. Schwaderer, J. Zeman, M. Joswig, *Conference on Unmanned Aerial Vehicle in Geomatics*, 2011.

http://www.geometh.ethz.ch/uav_g/proceedings/niethammer

This conference paper described a low-cost UAS and image processing chain based on open source tools for generating orthomosaics and DTMs. *From the paper’s conclusion:*

Even photogrammetric processing of hundreds of UAV-based images acquired with uncalibrated cameras was managed by applying open source software tools. The used algorithms can easily handle unordered image collections and have provided digital surface models of landslides without any ground control point information. ... Overall, it can be concluded that a complete remote sensing working cycle with no commercial hardware or software is now possible. However, many of these software-tools are only supplied in a very sparse command-line beta version. The user also has to prepare and convert input data between many different data formats.

“Surveying a Landslide in a Road Embankment Using Unmanned Aerial Vehicle Photogrammetry,” F. Carvajal, F. Agüera, M. Pérez, *Conference on Unmanned Aerial Vehicle in Geomatics*, 2011.

http://www.geometh.ethz.ch/uav_g/proceedings/carvajal_neu

Note: There appears to be issues with the translation for this article.

Researchers sought to develop an accurate and low-cost method to characterize landslides based on the size of a road. A photogrammetric project was carried out from a set of images taken from a Microdrones md4-200 with an on-board calibrated camera. Test results, with planimetric and altimetric errors of 0.049 meters and 0.108 meters, respectively, indicate that accurate measurements of the landslide can be taken using this UAS technology.

“UAV-Based Remote Sensing of Landslides,” U. Niethammer, S. Rothmund, M. R. James, J. Travelletti, M. Joswig, *ISPRS Technical Commission V Symposium*, 2010.
<http://www.isprs.org/proceedings/xxxviii/part5/papers/102.pdf>

Researchers used a low-cost remote sensing approach that employs a UAS and digital compact cameras to gather high-resolution images of landslides. Manual-controlled, quad-rotor helicopters proved to be well-suited for landslide monitoring in difficult alpine terrain. Airborne photographs of the Super-Sauze landslide in southern France were combined with an orthomosaic by applying plane image rectification methods. Digital surface models were generated using a new feature-based surface reconstruction approach that does not require any ground control point information.

Vegetation and Soil Investigations

“Utilization of Unmanned Aerial Vehicles for Rangeland Resources Monitoring in a Changing Regulatory Environment,” A. Rango, E.R. Vivoni, D.M. Browning, C. Anderson, A.S. Laliberte, *American Geophysical Union*, Fall Meeting, 2013.

Citation at <http://adsabs.harvard.edu/abs/2013AGUFM.B34A..02R>

The authors of this meeting paper are part of a group conducting UAS flights within the Jornada Experimental Range in southern New Mexico. Most of the UAS flights have taken place over rangelands or watersheds in the western United States to make rangeland health determinations, including classification of vegetation cover and type, measuring gaps between vegetation patches, identifying locations of potentially erosive soil, deriving digital elevation models and monitoring plant phenology.

The group has developed an air- and ground-vehicle approach for long-distance, continuous pilot transport that always maintains line-of-sight requirements. This allows flying several target areas on a single mission and increasing the number of images acquired using the UAS.

“High Spatial Resolution Three-Dimensional Mapping of Vegetation Spectral Dynamics Using Computer Vision,” Jonathan P. Dandois, Erle C. Ellis, *Remote Sensing of Environment*, Vol. 136, pages 259–276, September 2013.

Citation at <http://www.sciencedirect.com/science/article/pii/S0034425713001326>

This article describes a new aerial remote sensing system that permits routine and inexpensive aerial 3-D measurements of canopy structure and spectral attributes, with properties similar to those of LiDAR but with RGB (red-green-blue) spectral attributes for each point, enabling high-frequency observations within a single growing season. Aerial photographs are acquired using off-the-shelf digital cameras mounted on an inexpensive (less than \$4,000), lightweight (less than 2 kg), hobbyist-grade UAS.

“Geomorphological Mapping with a Small Unmanned Aircraft System (sUAS): Feature Detection and Accuracy Assessment of a Photogrammetrically-Derived Digital Terrain Model,” Chris H. Hugenholtz, Ken Whitehead, Owen W. Brown, Thomas E. Barchyn, Brian J. Moorman, Adam LeClair, Kevin Riddell, Tayler Hamilton, *Geomorphology*, Vol. 194, pages 16–24, July 15, 2013.

Citation at <http://www.sciencedirect.com/science/article/pii/S0169555X13001736>

From the abstract: Here we present results from a field experiment designed to evaluate the accuracy of a photogrammetrically-derived digital terrain model (DTM) developed from imagery acquired with a low-cost digital camera onboard [a small UAS (sUAS)]. We also show the utility of the high-resolution (0.1 m) sUAS imagery for resolving small-scale biogeomorphic features. The experiment was conducted in an area with active and stabilized aeolian landforms in the

southern Canadian Prairies. Images were acquired with a Hawkeye RQ-84Z Areohawk fixed-wing sUAS. ... Overall, our results suggest that sUAS-acquired imagery may provide a low-cost, rapid, and flexible alternative to airborne LiDAR for geomorphological mapping.

Disaster Response

Rapid Exploitation of Commercial Remotely Sensed Imagery for Disaster Response and Recovery, U.S. Department of Transportation, expected completion date: November 30, 2014. Abstract at <http://trid.trb.org/view/2012/P/1263872>

This project in process, sponsored by the U.S. DOT Research and Innovative Technology Administration, has two objectives:

- To develop, calibrate and deploy a decision support system capable of identifying road and bridge damage from high-resolution commercial satellite images.
- To estimate the amount and type of fill material required for repairs using digital surface models derived from a lightweight UAS programmed to fly over damage road segments.

Related Resource:

“Flying UAVs in Vermont: Lessons Learned,” Transportation Research Center, University of Vermont, undated.

<http://www.uvm.edu/~transctr/research/documents/Lessons%20Learned%20on%20Flying%20UAVs%20in%20Vermont.pdf>

From the document: This is the first university research project in the State of Vermont which will use Unmanned Aerial Vehicles (UAVs). To assist in future UAV projects, we have compiled a list of lessons learned about purchasing and flying UAVs in Vermont. This list will be updated as the project progresses.

The Practicality of Utilizing Unmanned Aerial Vehicles for Damage Assessments, Richard L. Davis, Austin (TX) Fire Department, undated.

<http://www.usfa.fema.gov/pdf/efop/efo48084.pdf>

This report's author recommends use of a UAS in disaster-ridden areas and offers suggestions for implementing a UAS pilot training program. The report includes an extensive reference list and appendices related to UAS use.

Bridge Inspections

The two projects below are in process and expected to conclude within the next 12 months. See page 8 of this Preliminary Investigation for another bridge-related UAS application described in the Caltrans research study, *Caltrans Bridge Inspection Aerial Robot*.

Proof of Concept for Using Unmanned Aerial Vehicles for High Mast Pole and Bridge Inspections, Florida Department of Transportation, expected completion date: June 30, 2015.

Abstract at <http://trid.trb.org/view/2013/P/1250474>

From the abstract: The inspection of structures such as bridges and high mast lighting poles (HML) depends heavily on visual assessments from experienced field inspectors. The object of this project is to lay the foundation to fully develop a system that can assist structural inspectors during the inspection process consisting of a Micro-Copter hosting a camera or small mobile device and a ground viewing station that will show near-real time images being captured by the camera. Sponsor: Florida Department of Transportation.

Develop a UAV Platform for Automated Bridge Inspection, Mid-America Transportation Center, expected completion date: December 31, 2014.

Abstract at <http://trid.trb.org/view/2013/P/1256989>

From the abstract: This project seeks to develop an automated bridge inspection technology that can make the inspection process safer, more efficient and convenient. The focus of this research is to study the technical foundation of an Unmanned Aerial Vehicle (UAV) system capable of remotely inspecting bridges with sensors without interfering with the road operation. The applicability of this technique will be validated by a prototype UAV system with field testing. Sponsor: Research and Innovative Technology Administration.

Roadside and Roadway Inspections

Characterization of Unpaved Road Conditions Through the Use of Remote Sensing, Michigan Technological University, U.S. Department of Transportation, undated.

<http://geodjango.mtri.org/unpaved/>

The goals of this project in process are to develop a sensor for, and demonstrate the utility of, remote sensing platforms for unpaved road assessment. The platform could be a typical manned fixed-wing aircraft, a UAS or both.

Related Resources:

Characterization of Unpaved Road Conditions Through the Use of Remote Sensing—Deliverable 1-A: Requirements for Remote Sensing Assessments of Unpaved Road Conditions, Colin Brooks, Tim Colling, Chris Roussi, Michigan Technological University, October 31, 2011.

http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del1-A_RequirementsDocument_MichiganTechUnpavedRoadsr1.pdf

This document outlines the requirements of a remote sensing data collection system capable of collecting inventory and distress data for unpaved roads. Among the platforms to be evaluated: a manned, fixed-wing aircraft and a variety of UAS platforms including fixed-wing, helicopter, and aerostatic (e.g., blimp) unmanned vehicles. Page 13 of the report provides details on the requirements for the remote sensing system.

Characterization of Unpaved Road Condition Through the Use of Remote Sensing Project—Deliverable 7-B: Performance Evaluation of Recommended Remote Sensing Systems in Unpaved Road Type Condition Characterization, Colin Brooks, Chris Roussi, Tim Colling, Melanie K. Watkins, Ben Hart, David Dean, Joe Garbarino, Richard Dobson, Brian White, Michigan Technological University, November 26, 2013.

http://geodjango.mtri.org/unpaved/media/doc/deliverable_Deliverable_7_B_PerformanceEvaluation_Final_2013-11-27_updated_1.pdf

Page 1 of the report (page 7 of the PDF) describes results of project testing;

The UAV-based system more than met the requirements to collect the type of overlapping imagery data needed to collect 1% crown measurement variations using readily available commercial hardware costing \$9,000. However, even flying at the lowest safe elevation (about 500' or 150m), using the same single camera from the UAV-based system in a manned fixed wing aircraft could not meet resolution requirements due [to] a lack of needed angular diversity. Without sufficient angular diversity, creating the needed 1" / 2.5cm resolution data is not possible with a 36 mp camera flying above 400' (120m). In the future, as technologies advance, a manned

fixed-wing aircraft-based data collection system could eventually match the current capabilities of our UAV-based system.

Use of Micro Unmanned Aerial Vehicles for Roadside Condition Assessment, William Scott Hart, Nasir G. Gharaibeh, Southwest Region University Transportation Center, Texas Transportation Institute, December 2010.

<http://d2dtl5nnlpfr0r.cloudfront.net/swutc.tamu.edu/publications/technicalreports/476660-00019-1.pdf>

From the abstract: Micro unmanned aerial vehicles (MUAUVs) that are equipped with digital imaging systems and global positioning systems provide a potential opportunity for improving the effectiveness and safety of roadside condition and inventory surveys. This study provides an assessment of the effectiveness of MUAUVs as a tool for collecting condition data for roadside infrastructure assets using three field experiments. The field experiments entail performing a level of service condition assessment on roadway sample units on IH-20 near Tyler, Texas; IH-35 near Dallas, Texas; and local streets at the Riverside Campus of Texas A&M University. The conditions of these sample units were assessed twice: on-site (i.e., ground truth) and by observing digital images (still and video) collected via a MUAUV. The results of this study will help transportation agencies decide if MUAUV technology can be adopted for inventory and condition surveys of roadside assets and maintenance activities.

Analysis of Unmanned Aerial Vehicles Concept of Operations in ITS Applications, Demoz Gebre-Egziabher, Zhiqiang Xing, Department of Aerospace Engineering and Mechanics University of Minnesota, March 2011.

<http://www.cts.umn.edu/Publications/ResearchReports/pdfdownload.pl?id=1512>

From the abstract: The work described in this report is about developing a framework for the design of concept of operations (CONOP), which use small uninhabited aerial systems (SUAS) to support of intelligent transportation system (ITS) application of highway and transportation infrastructure monitoring. In these envisioned applications, these vehicles will be used for tasks such as remote collection of traffic data or inspection of roads and bridges. As such, a risk that has to be managed for these applications is that of vehicle-infrastructure collision. Various solutions to ensure safe separation between the unmanned aerial vehicle (UAV) and the object being inspected have been proposed. However, most, if not all, of these solutions rely on a multi-sensor approach, which combines digital maps of the infrastructure being inspected with an integrated GPS/Inertial navigator. ... The method outlined shows, in part, how these vehicle/infrastructure collision risks can be estimated or conservatively bounded.

Monitoring the Condition of Unpaved Roads with Remote Sensing and Other Technology, Chunsun Zhang, South Dakota State University, 2009 (approximate).

<http://ntl.bts.gov/lib/42000/42300/42378/FinalReport.pdf>

Researchers explored the use of a UAS to collect road data, developed methods and systems to process UAS images, and identified and quantified unpaved road surface condition parameters. The UAS tested is a low-cost model helicopter equipped with GPS and a digital camera. The flight uses an autonomous flight control system engaged by a ground control system. Researchers developed a set of image processing algorithms for camera calibration, sensor orientation, digital 3-D road surface model and orthoimage generation, and measurement for road surface distress. The developed system is faster, safer and more consistent than manual surveys.

UAS Conferences, Training Resources and Guidelines

UAS technology is advancing quickly. UAS testing is just getting underway at FAA-sanctioned test sites across the country, and the FAA continues to review and promulgate guidelines and regulations that apply to the use of UASs. As UAS development and application matures and the regulatory environment stabilizes, it is likely that guidelines and training materials will become more plentiful. At the time of publication, such documentation is fairly limited in scope and volume.

Below is a sampling of the materials available to provide background and guidance to an agency considering the use of a UAS. Citations in other sections of this Preliminary Investigation, particularly those appearing in **State Agency Investigations**, also offer guidelines and specifications.

Conferences

“California’s Unmanned Aircraft Systems Summit Explores Potential Industry Growth,” Michele Nash-Hoff, *San Diego Newsroom*, June 17, 2014.

<http://sandiegonewsroom.com/business-finance/1102-california-s-unmanned-aircraft-systems-summit-explores-potential-industry-growth>

This article provides highlights of the California UAS Summit held June 10 in San Diego.

UAS Aviation: A Partnership for the Future! *Third Annual Ohio UAS Conference*, Dayton Convention Center, Dayton, Ohio, August 26–28, 2014.

http://www.starwin-ind.com/index.php?option=com_content&view=article&id=84:ohio-uas-conference-2014&catid=19:press-releases&Itemid=104

From the web site: [T]his year’s event will be a forum to establish UAS community partnerships between representatives from government, industry and academia. We will examine requirements for access into the National Airspace System (NAS), review technologies associated with enabling UAS applications and discuss recent developments within the research and academic community. See <http://ohiouasconference.com/pages/register.html> for online registration.

UAS Mapping 2014 Reno: American Society for Photogrammetry and Remote Sensing (ASPRS) UAS Technical Demonstration and Symposium, Eldorado Resort Casino and Reno Stead Airport, Reno, Nevada, October 21–22, 2014.

<http://uasreno.org/>

From the web site: The purpose of the event is to assemble academia, UAS developers, survey and mapping companies, government agencies, and UAS enthusiasts, to share information, showcase new technologies and demonstrate UAS systems in action (in flight)...The mission of the event is to advance knowledge and improve the understanding of UAS technologies and their safe and efficient introduction into our national airspace, government programs and business. See <http://uasreno.org/conference-registration/> for registration information.

Unmanned Systems Program Review 2014, Association for Unmanned Vehicle Systems International, The Ritz-Carlton, Tysons Corner, McLean, Virginia, November 4-6, 2014.

<http://www.auvsi.org/events/1/eventdescription/?CalendarEventKey=2e6876be-e8e9-43cd-81f5-93ef616a973b>

The agenda for this conference is not yet available. The agenda and a description of the topics of discussion from last year’s conference are available at

<http://www.auvsi.org/ProgramReview2013/Program/Air>.

Training Resources

Training Resources & Guides, Federal Aviation Administration, March 27, 2013.

http://www.faa.gov/training_testing/training/

This web site provides links to training programs, test centers, handbooks and guides.

Knowledge at AUVSI, Association for Unmanned Vehicle Systems International, 2013.

<http://www.auvsi.org/knowledgeatauvsi/home>

This web site is the knowledge base of Association for Unmanned Vehicle Systems International and includes links to research and training tools.

Technology and Workforce Development for Remote Sensing of the Transportation Infrastructure, Mountain-Plains Consortium, expected completion date: July 31, 2017.

Project description at <http://www.mountain-plains.org/research/projects/downloads/2014-mpc-460.pdf>

From the project description: The primary goal of this study is to assess and develop means of optimizing hyperspectral remote sensing for use with lightweight (less than 50 pounds) unmanned aircraft systems (UAS) and to provide the relevant training necessary for future practitioners to construct and deploy full solutions. A secondary objective will be to investigate the use of ground or vehicle based hyperspectral systems.

Guidelines

Handbook of Unmanned Aerial Vehicles, Kimon P. Valavanis, George J. Vachtsevanos, editors, Springer Reference, 2014.

<http://www.springer.com/engineering/robotics/book/978-90-481-9706-4>

From the product description: The Handbook offers a unique and comprehensive treatise of everything one needs to know about unmanned aircrafts, from conception to operation, from technologies to business activities, users, OEMs, reference sources, conferences, publications, professional societies, etc. It should serve as a Thesaurus, an indispensable part of the library for everyone involved in this area.

Unmanned Aircraft Use in North Carolina; Report to the Joint Legislative Oversight Committee on Information Technology, Joint Legislative Transportation Oversight Committee, Fiscal Research Division, Chris Estes, State of North Carolina Office of Information Technology Services, March 2014.

https://www.scio.nc.gov/library/pdf/Unmanned_Aircraft_Report_March_2014.pdf

The following sections of this report will be of particular interest to agencies seeking guidelines for their own UAS programs:

- Page 19 of the report (page 21 of the PDF) provides a cost estimate for establishing a UAS program, including costs for governance board support, centralized data storage and maintenance, and operations.
- Page 21 of the report (page 23 of the PDF) offers recommendations for further legislation and a discussion of policy implications.

Protocols for the Use of Unmanned Aircraft Systems (UAS) by Law-Enforcement Agencies, House Document No. 12, Virginia Department of Criminal Justice Services, October 7, 2013.

<http://www.dcjs.virginia.gov/cple/documents/UAS%20Protocols%20GA.pdf>

State legislation places a moratorium on the use of UASs by state and local law enforcement agencies in Virginia until July 1, 2015, except in defined emergency situations or in training exercises related to these situations. This legislation also required the development of model protocols for the use of unmanned aircraft systems by law enforcement agencies; this document satisfies that requirement. Among the topics addressed in the document are agency model policy and operational procedures, including community engagement, system requirements, operational procedures, legal considerations and agency/operator certifications.

Recommended Guidelines for the Use of Unmanned Aircraft, Aviation Committee, International Association of Chiefs of Police, August 2012.

http://www.theiacp.org/portals/0/pdfs/iacp_uaguidelines.pdf

This document provides recommendations for any law enforcement agency contemplating the use of unmanned aircraft, addressing such topics as community engagement, system requirements, operational procedures and image retention.

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Transportation Research Committee

Final Report

TRC 1104

USE OF UNMANNED AERIAL VEHICLES
FOR AHTD APPLICATIONS

“Studying Visual Aids to Assist in Corridor Analysis”



Final Report

**TRC 1104
Use of Unmanned Aerial Vehicles for AHTD Applications
“Studying Visual Aids to Assist in Corridor Analysis”**

By

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Conducted in Cooperation with the U.S. Department of Transportation Federal Highway
Administration

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The contents of this report reflect the views of the author, who are responsible for the facts and accuracy or the information presented herein. The contents do not necessarily reflect the official views or policies of the Arkansas State Highway and Transportation Department or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. The U.S. Government assumes no liability for the contents or use thereof.

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CHAPTER 1

INTRODUCTION

As part of its mission to develop, operate and maintain a safe and efficient transportation system, the Arkansas State Highway and Transportation (AHTD) monitors, inspects and surveys its highways, bridges and facilities. Outside of surveying, this is done in many other ways, such as the Automated Road Analyzer (ARAN) vehicle, traffic counters, bridge sensors, cameras and field or site inspections. However, there is a need to view areas from a bird's eye view in a flexible, safe and cost-effective manner. This ability could be beneficial to the Environmental Division, the Arkansas Highway Police, the Maintenance Division, the Transportation Planning and Policy Division, the System Information and Research Division, the Public Information Division, the Right of Way Division and AHTD District Personnel. By recording High Definition (HD) video from varying altitudes, AHTD staff can collect real-time movement of traffic while in the field. This ensures proper data collection before returning to the office.

Previously, aerial imagery consisted of fly over photos limited to a specific time or telescopic mounted cameras with limited viewing angles, both of which are cost prohibitive. With advancement in technology, AHTD is now able to examine other equipment that provide an economical and feasible solution with the versatility needed to adapt to different data collection situations. The availability of High Definition video, High Definition pictures, low light visibility and thermal imagery at a fraction of the cost of alternative solutions warrant an investigation into the possible uses of other video

equipment for recording turning conflicts, number of vehicles, headways, queues and vehicle classification. This research was done to examine data collection equipment that will not only be useful to to correctly model real-time traffic movements, but also to better design roads in the state of Arkansas in a cost effective way.

CHAPTER 2

LITERATURE REVIEW

A review of literature was conducted to identify research concerning other ways to collect traffic data from a bird's eye view. Details of literature that were of assistance in regards to equipment that could be used for this research project are provided below.

EQUIPMENT

Unmanned Aerial Vehicle

The Unmanned Aerial Vehicle (UAV), also known as the drone, is an aircraft that is operated without a human being on board (Figure 1). It is controlled by a pilot operating a remote control on the ground or autonomously by computers in a vehicle. The UAV is said to be a flexible and a cost-effective approach to collecting real-time data from a bird's eye view over intersections or other large areas. UAVs have become more popular over the last couple of years in transportation planning, engineering and operation, and several options and designs have entered the market. UAVs are able to carry cameras or video cameras, and their use in data collection can be expected to improve traffic management. However, there are restrictions when using the UAVs that limit the use of operating a UAV to collect traffic data. The main restriction is that of the Federal Aviation Administration (FAA), which limits the use and research of UAV applications. The FAA Modernization and Reform Act of 2012 was introduced in on February 11, 2011 and signed by the President of the United States on February 14,

2012. It includes important provisions on the integration of unmanned aircraft systems (UAS) into the national airspace system.



Figure 1. Unmanned Aerial Vehicle (Source: DraganFly)

A few states have studied the UAV for traffic data collection, including static remote sensing images and real time traffic information. Studies also include UAVs route planning and strategies of path-planning for a UAV to track a ground vehicle (PB Farradyne 2005).

Recently, newer applications are being studied, and the government is also looking into the feasibility of UAVs for transportation. The Utah Department of

Transportation (UDOT) used UAVs to monitor and document State Roadway structures by taking advantage of high-resolution aerial photography (Steve Barfuss et. al 2012).

UAVs have potential to become a great application for collecting traffic data. However, with FAA restrictions and the time schedule for this particular project, UAVs were not applicable for AHTD at this time.

Lighter-Than-Air-Surveillance

Aerial Products, a company specializing in aerial photography and surveillance equipment, has a Lighter-Than-Air-Surveillance (LTAS) series that employ a unique combination of Commercial Off The Shelf (COTS) and military technologies with ground breaking operational methods. Below are two examples of LTAS systems suitable for this project.

LTAS Mast Surveillance

According to Aerial Products, using a mast or pole is one of the most cost-effective means for elevating a camera to record a video or photograph from a bird's eye view. Models range from 20 feet to 100 feet high with head-load ratings from 15 to 120 pounds. The overall operation of this equipment is simple, allowing anyone to use it with some simple training. Setting up the equipment takes up very little room, leading to more available setup locations. Packages can be engineered for specific mission-sets, such as mobile border patrol, perimeter security, crowd management, emergency incident responses situational awareness, communications relay, check points, etc. Mounting options include vehicle 2" hitch, command vehicle integrated, field-stand, or

trailer tilt-over. The mast extension options are either belt or pneumatic. Organizations such as US Border Patrol, US Army or US Marines use belts masts because of its advantage of low maintenance in high-dust environments. Pneumatic mast models are used by highway departments for traffic monitoring, forestry services, first responders and police. Pneumatic models are lighter weight and are typically used when heights exceed 50 feet.



Figure 2. LTAS Mast Surveillance

LTAS Aerostat Surveillance

According to Aerial products, LTAS Aerostat Surveillance provides solutions for persistent airborne surveillance without the failure rate of typical UAVs. They are flexible and operate up to 2,000 feet. The LTAS 75 -100 systems can be used for the following:

- municipal deployments
- crowd management
- incident response
- other heightened security situations where aerial surveillance provides situational awareness, a force multiplier, command and control and evidential video and
- traffic monitoring.

The LTAS 75-100 series includes a range from highly tactical to completely self-controlled. The highly tactical system consists of using a hitch mount winch (Figure 3) that launches the balloon (Figure 4).

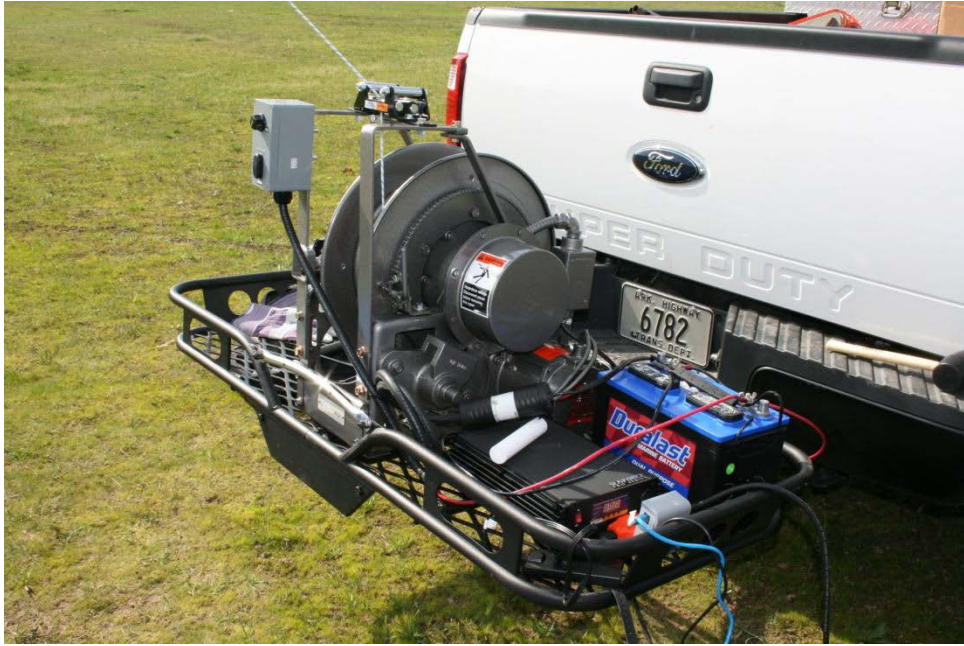


Figure 3. 12 volt DC electric winch



Figure 4. LTAS Aerostat Surveillance Launched

The pictured system is the LTAS 75, which is a low-cost system that operates up to 450 feet. Standard features include:

- Portable, electric 24 volt DC winch system, variable speed
- Vehicle receiver hitch mount for winch, batteries, inverter package
- Power and data tether
- Payload and laptop power inverter with separate battery
- Vehicle 7-pin harness charging system
- 1-ply Kingfisher aerostat, model K14U-SC balloon
- FAA approved automatic GPS deflation device
- Laptop controller with Hall-effect joystick
- 24 hour DVR (software, pre-loaded on laptop)
- Single-sensor, gyro-stabilized UAV camera gimbal
- 2-days factory training (1 day classroom, 1 day field)
- Aerostat inflation system
- Spares kit; aerostat patches, fly-lines, payload lines

Standard features for the LTAS 100 System includes:

- Expanded launcher for (4) additional Helium tanks
- Additional single-sensor camera gimbal; Daylight EO or Thermal LWIR
- Dual-sensor camera gimbal; EO+LWIR
- Extended operating altitude; + tether and larger Kingfisher aerostat
- Simultaneous video downlink to mobile viewing station

CHAPTER 3

WORK PLAN

The primary objective of this research project was to find a way of monitoring traffic in a flexible, safe and cost effective manner. This was done by testing the above literature to see which of the two LTAS systems will produce the same type of information as does the UAV for AHTD applications. Though the project initially focused on a UAV, other equipment was researched due to restrictions on the UAVs, such as minimal loft time, multiple batteries needed, payload limitations, FAA requirements and retrieving a Certificates of Authorization, which is an authorization issued by the Air Traffic Organization to a public operator for a specific Unmanned Aircraft activity.

Locations were evaluated. Video footage of traffic flow was collected and collated using VisSim software. The value of the data obtained was determined following the collection of data. A demonstration of the UAVs practices for a police department was shown, and a demonstration of the LTAS equipment was shown by a sales representative, Kevin Hess.

After reviewing the literature, it was decided that the 2 systems that would be used for this research project were the mobile mast camera system and the tethered helium balloon system.

CHAPTER 4

DATA COLLECTION

The most critical step in an analysis process is data collection. One must know what, where, when and how long to collect. You must also know how to manage the data. Data collection for this project varied depending on the needs of the study for which the data was being collected for at each location. The purpose of the field data collection was to see if the equipment used was feasible enough to provide AHTD with clear visible footage to reduce data for simulation modeling and any other needs.

A pilot test was done at the AHTD Central Office to determine time and manpower requirements to set up equipment and the amount of space needed for data collecting.

The first step in obtaining data was to locate an area that would be suitable for collecting data at the study site. This was done by finding possible locations surrounding the test site on Google maps and examining these locations in the field prior to setting up equipment. Though both pieces of equipment were used for the same purpose, the setup was different for each. Below, both setup processes are briefly described.

EQUIPMENT SETUP

Tethered Helium Balloon Camera

Prior to launching, helium needs to be purchased. Based on the pilot test, a minimum of 4 people are needed to set up the tethered helium balloon. If the day is

windy, more people will be needed, which is why calm days are strongly recommended. It takes approximately 30-45 minutes to set up. The launch site would have to be large and obstruction free and due to FAA regulations, the tethered balloon cannot be launched within 5 miles of an airport.



Figure 5. Tethered Helium Balloon Setup

Mobile Mast Mounted Camera

Based on the pilot test, a minimum of 2 people are needed to set up the mobile mast mounted camera. It takes approximately 15-20 minutes to set up. Setting up this equipment takes very little room, which leads to more available setup locations at each project site. However, making sure to account for space needed to place the guy wires and making sure there are no power lines nearby are not within falling distance of the pole are essential.



Figure 6. Setting Up Pole for Placement



Figure 7. Mounting the camera to the pole



Figure 8. Securing the Mast

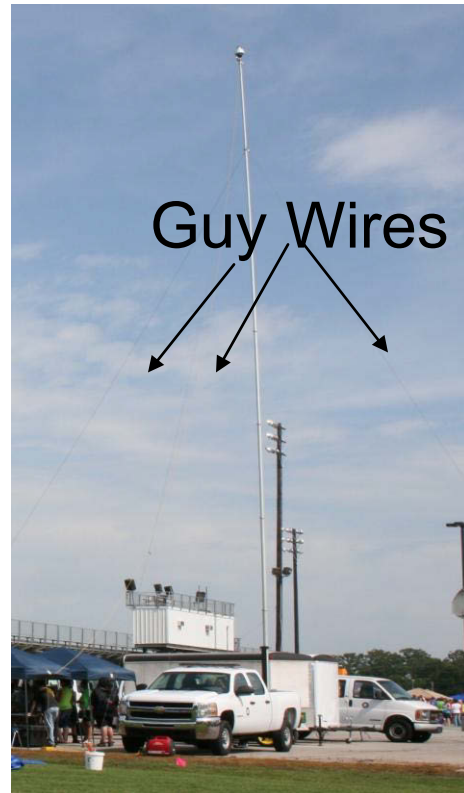


Figure 9. Pole Extended with Guy Wires

FIELD DATA COLLECTION

All data collected were of current studies throughout the highway department. Figure 5 shows a map of where the equipment was deployed. Due to issues with launching the tethered helium balloon, data collected using this equipment was limited.

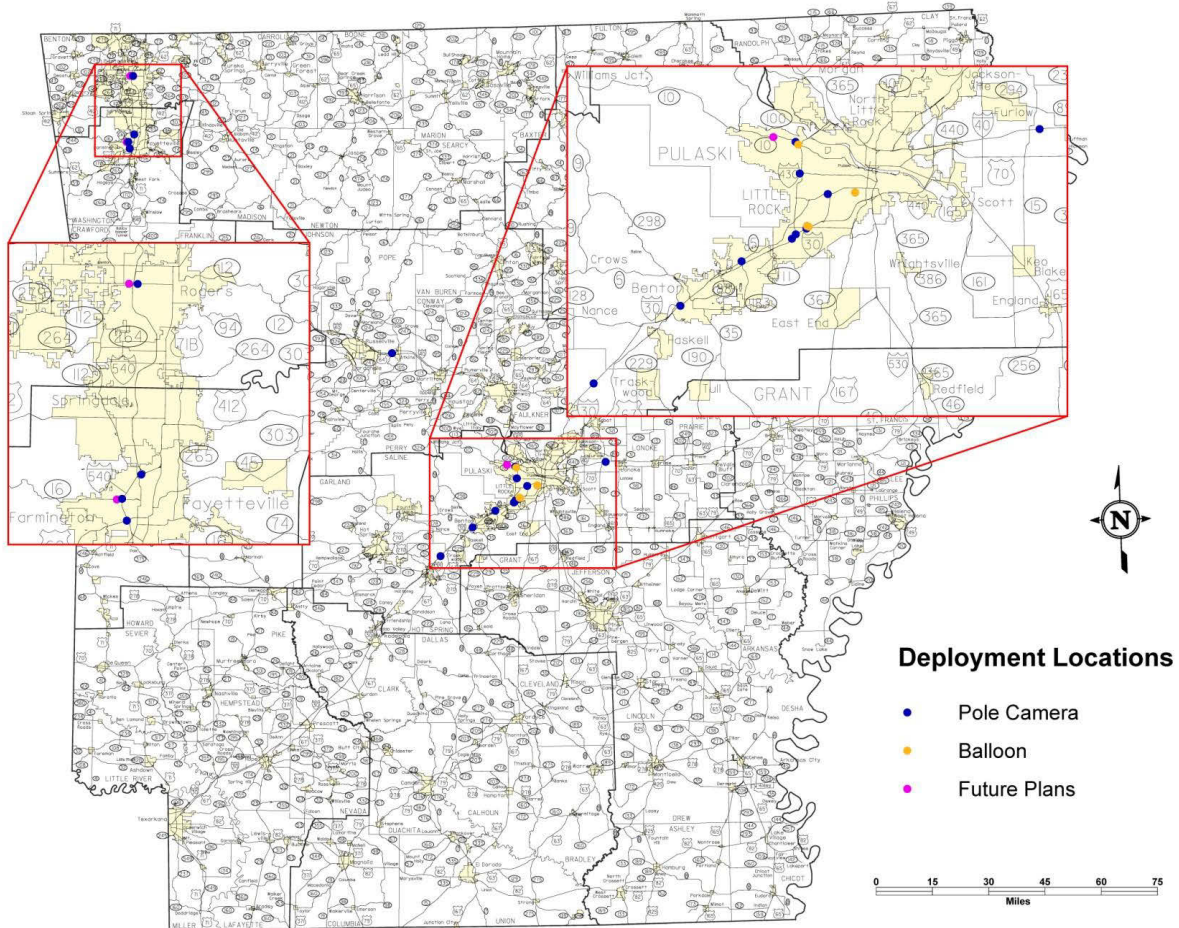


Figure 10. Deployment Locations for Equipment Use

Table 1 shows a summary of each study. As shown in the table, the equipment that was used was the mast mounted camera. However, please note that the helium balloon was launched several times to see if it was applicable for the study. Due to

limited space, wind and other problems, the balloon was not feasible at most locations that were chosen to collect data. See Appendix A for detailed information on each study.

Table 1. Studies Using Mast Mounted Camera

STUDY	LOCATION	REQUESTED BY	DATE	EQUIPMENT USED	REASON
Highway 5 Widening Study	Intersection of Highway 183 (Reynolds Rd.) and Highway 5 in Bryant, AR	Planning and Research Division, Statewide Planning Section	3/9-10/2011	Mast Mounted Camera	Monitor traffic signal & queuing at intersection; determine if NB traffic in the outside lane is blocking inside lane
I-540/Highway 112/Highway 71B Interchange Justification Report	I-540/Highway 112/Highway 71B Interchange near I-540 Exit 66 in Fayetteville, AR	Planning and Research Division, Statewide Planning Section	3/15/2011	Mast Mounted Camera	Determining number of people weaving on I-540 SB between Hwy 71B entrance ramp & the Hwy 112 exit ramp; operational analysis for the reconfiguration and improvement of I-540 and the interchange area
Hwy 10 Corridor Study	Intersection of Highway 10 and Rodney Parham Rd. in Little Rock, AR	Planning and Research Division, Statewide Planning Section	3/23/2011	Mast Mounted Camera	View traffic movements; needed to see vehicles movements from I-430 SB to Hwy 10 WB to left on Rodney Parham Rd.
I-30/I-430 Interchange Study	I-30/I-430 Interchange in Little Rock, AR	Planning and Research Division, Statewide Planning Section	5/3-4/2011; 5/26/2011; 3/13/2012	Mast Mounted Camera	Model the traffic patterns; used camera footage in place of attempting volume count data collection on the multi-lane freeway; needed to see the origins and destinations within the weave on I-30 WB between I-430 SB and Otter Creek off-ramp
Interstate Platooning Study	I-40 near Lonoke, AR, I-40 near Atkins, AR and I-30 near Malvern, AR	Planning and Research Division, Policy Analysis Section	3/25/2011; 5/23/2011; 6/14/2011	Mast Mounted Camera	View platooning characteristics on rural freeways with high truck percentages; counted lane density for 1/4 mile distance
I-630/Shackleford Intersection	Intersection of Shackleford and Financial Center Parkway/I-630 in Little Rock, AR	Maintenance Division	8/8/2011	Mast Mounted Camera	Corridor view of the I-630 approach
Study of Adding a New Access Point at an Intersection	Intersection of Highway 5 (Col. Glenn) and Highway 70B (University Ave.) in Little Rock, AR	Planning and Research Division, Statewide Planning Section	10/4/2011	Mast Mounted Camera	Used video as a calibration tool in the composition of a microsimulation model to study the effects of a new access point on an adjacent signal
Highway 71B Interchange Improvements	Intersection on the East side of I-540 Exit 85 near Rogers, AR	Planning and Research Division, Statewide Planning Section	10/6-7/2011	Mast Mounted Camera	Used to accurately model the traffic patterns occurring in this interchange area
I-540/Highway 16/Highway 112 Spur Interchange Improvements	Intersections on either side of I-540 Exit 62 in Fayetteville, AR	Planning and Research Division, Statewide Planning Section	4/10-11/2011	Mast Mounted Camera	Used to accurately model the traffic patterns occurring in this interchange area
I-540/Highway 62 Interchange Improvements	Intersections on either side of I-540 Exit 64 in Fayetteville, AR	Planning and Research Division, Statewide Planning Section	4/10-11/2011	Mast Mounted Camera	Used to accurately model the traffic patterns occurring in this interchange area

ADJUSTMENTS TO EQUIPMENT

The research team attempted to use image stabilizing software to improve the quality of the videos for the tethered helium balloon, but the results were not good. Some of the videos would not load in the software due to their size, and those that would process did not turn out well. The software worked by matching pixels between frames. This process was to keep parts of the image that did not move in the same relative location (frame-to-frame). However, with as much movement as was observed, the software deleted too much footage, leaving very little stabilized video.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

MOBILE MAST MOUNTED CAMERA

The mobile mast mounted camera appears to be feasible for highway department planning studies and remote observation needs. At a raised height of 58-ft, the mobile mast mounted camera gives a bird's eye view of the area, allowing the user to observe much more than what is possible from the ground. The overall operation of this equipment is simple, allowing anyone to use it with some basic training.

Advantages

- Setting up the equipment takes up very little room, leading to more available setup locations at each project site. The only limiting factors for setup location sizing are the guy-wire anchoring locations, the need to avoid power lines within falling distance of the pole and the overall height itself. If these can be accounted for, and the view from the location is acceptable, the site can be used.
- Several other aspects of this equipment made it easy to use. The articulating hitch-mount utilized for the duration of this project appeared to be acceptable for all operations. This standardized mounting hardware meant that any truck with a 2-inch hitch receiver could be used to deploy the camera.

- Once trained, the computer software was easy to use and did not require constant supervision during filming. The mast system itself was very low-maintenance. It just needed to be lubricated every so often to make sure everything moved smoothly.
- Setup can be done with a small group. Most experiences during this project included a setup team of 3-4 people and an observation and take-down team of two. This many people are recommended because some of the equipment is heavy and it all goes quicker with everyone working together. Although, if needed, this can all be set up by a single person. The research team only tried this once and would not recommend it unless absolutely necessary.

Disadvantages

Even as good as this equipment was, there were still some disadvantages.

- One disadvantage was making sure to have everything before heading out for a job. A checklist of 10 items was made to ensure nothing required for operation was left behind, but with that much equipment, mistakes did happen and important items were forgotten.
- The extended height of 58-ft is another disadvantage. This height just isn't high enough for some applications. This problem was observed at several of the test sites where easy setup locations would have to be passed up because the camera could not get high enough to avoid

obstacles or see over a slight hill. Having a mast 10-20 feet taller may allow for better views.

- Other major disadvantages have to do with the weather. This equipment was made for use in dry weather and thus the camera head and other important connections are not waterproof. This means that any operation in precipitation must be avoided. The fact that this is a 58-ft lightning rod must also be taken into account when deciding when and where to deploy. Even storms in the distance may mean that the mast shouldn't be raised. Wind can also cause problems if it is strong enough to move the camera. A moving camera leads to shaky video that is difficult to watch.

Recommendations

Though the equipment is feasible, it is recommended that a few changes be made to the equipment.

- While the hitch-mount worked very well, some other mounting ideas were discussed. One such idea was to permanently mount the mobile mast onto a trailer with a tilting mechanism to raise it into place. All of the other equipment required for operation could be mounted on the trailer as well, removing the guesswork of gathering everything each time the equipment is deployed.
- Though the computer software is easy to use, the computer operator should "break" the video every hour to keep the file sizes at a more-manageable level.

TETHERED HELIUM BALLOON CAMERA

The tethered helium balloon camera is not viewed as a feasible option for Departmental use. While a view from 500-ft high could be very beneficial to planning studies, the balloon was too unstable and that led to poor overall image quality. Every slight shift in wind would require an adjustment of the camera, leading to a constant need for the user's attention. This constant attention to detail would become tiresome very quickly and would require a minimum of two people on the observation team so that they could switch intermittently.

Advantages

- Other than a view from 500-ft above, no other advantages were determined.

Disadvantages

Image quality was definitely a drawback for this system. However, it wasn't the only drawback.

- The helium required to launch the balloon, just once, cost \$200-\$300, and since helium supplies are getting low, the cost of helium will only be going up. An attempt was made by the research team to save some of the helium between launches. A polyurethane bladder, made up of the same material as the balloon, was purchased and placed in an enclosed trailer.

All interior surfaces of the trailer were covered in carpet to keep from puncturing the bladder. By pumping helium out of the balloon and into the bladder at the end of the day, the helium could be stored and re-used for subsequent launches (Figure 11). However, attempting to save the helium would also require another vehicle to haul the trailer.



Figure 11. Transferring Helium from Balloon to Bladder



Figure 12. Helium stored in bladder

- Setting up and launching the balloon required a minimum of 4 people and would require more on a windy day. Though, due to the instability in the video, calm days were strongly recommended for launch. The launch site would have to be large and obstruction free and due to FAA regulations, the tethered balloon cannot be launched within 5 miles of an airport. That last point alone greatly reduces the usefulness of the balloon since most studies where this would be needed are in metropolitan areas near airports.
- The system is also not weatherproof. The box containing the camera is not sealed and the cable tethered could act like a lightning rod. Water would not directly damage the balloon, but not allowing it to dry completely before storage could lead to mildew or rot. appearing.

Recommendations

Though it has been concluded that this equipment is not feasible, other options are available to make it feasible, but not economically feasible. In order for the Department to use it, a gyro-stabilized camera to steady the images could be purchased and tested. The money for this type of equipment was not in the project budget.

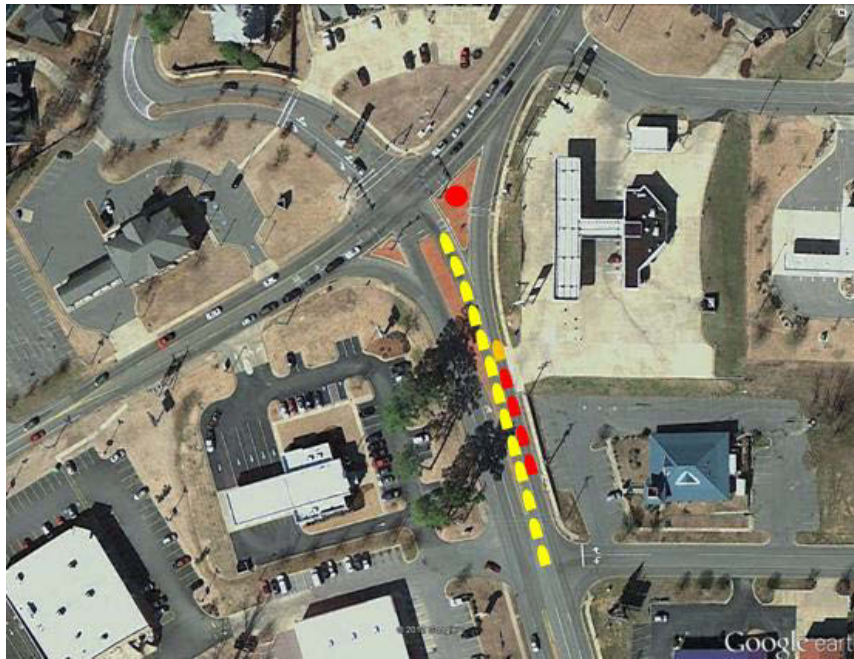
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APPENDIX A

STUDY SITES

Highway 5 Widening Study/Highway 183



- Location: Intersection of Highway 183 (Reynolds Rd.) and Highway 5 in Bryant
- Date: March 9-10, 2011
- Requested by: Statewide Planning
- How Mast Camera was Utilized:
 - Determine how the traffic signal operated and how much queuing occurred at the intersection.
 - Determine if northbound traffic in the outside lane was blocking the inside lane.

I-540/Highway 112/Highway 71B Interchange Justification Report



- Location: I-540/Highway 112/Highway 71B Interchange near I-540 Exit 66
- Date: March 15, 2011
- Requested by: Statewide Planning
- How Mast Camera was Utilized:
 - Determine how many people were weaving on I-540 southbound between Highway 71B entrance ramp, and the Highway 112 exit ramp.
 - Do an operational analysis for the reconfiguration and improvement of I-540 and the interchange area.

Highway 10 Corridor Study



- Location:
- Date: March 23, 2011
- Requested by: Statewide Planning
- How Mast Camera was Utilized:
 - The camera elevation gave us perspective to view traffic movements that would not be picked up on a typical volume count and that would have been very difficult to observe at ground-level.
 - View vehicles going from I-430 SB to Highway 10 WB and then wanting to turn left on Rodney Parham.

I-30/I-430 Interchange Study



- Location: I-30/I-430 Interchange in Little Rock
- Date: May 3-4, 2011; May 26, 2011; March 13, 2012
- Requested by: Statewide Planning
- How Mast Camera was Utilized:
 - Accurately model the traffic patterns occurring in this interchange area.
 - The camera footage was used in place of attempting volume count data collection on the multi-lane freeway.

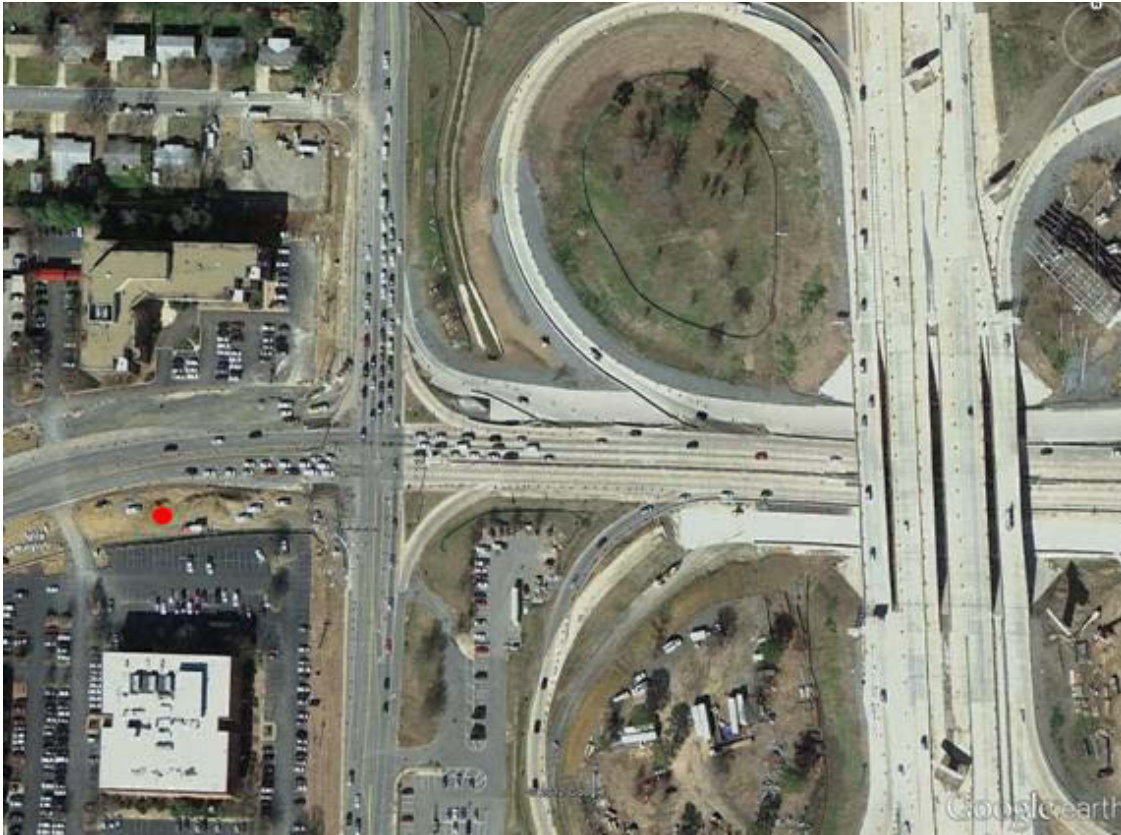
- Specifically, the origins and destinations within the weave on I-30 WB between I-430 SB and the Otter Creek off-ramp needed to be viewed.

Interstate Platooning Study



- Location: I-40 near Lonoke, I-40 near Atkins and I-30 near Malvern
- Date: March 25, 2011; May 23, 2011; June 14, 2011
- Requested by: Policy Analysis
- How Mast Camera was Utilized:
 - View the platooning characteristics on rural freeways with high truck percentages.
 - When determining Level of Service (LOS) with Highway Capacity Manual (HCM), everything looked fine, but that is not how it seems to drivers.
 - Lane density was counted for $\frac{1}{4}$ mile distance at any given time.

I-630/Shackleford Intersection



- Location: Intersection of Shackleford and Financial Center Parkway/I-630 in Little Rock
- Date: August 8, 2011
- Requested by: Maintenance Division
- How Mast Camera was Utilized:
 - During the start of lane exchanges on I-630 that lead into the signal at Shackleford & Financial Center.
 - Extremely long queues on I-630 and as with most signals in Little Rock, this signal is connected by radio to a centralized traffic controller server.

- The server synchronizes the traffic signals along the corridor to maximize LOS.
- The lane changes had upset the previous coordination plans for the corridor, especially at this intersection.
- The mast camera provided a corridor view of the I-630 approach to this signal.
- This allowed for better development of the coordination plans for this signal and in-turn the Chenal corridor.
- When we are working on coordination plans it is always better to have video.
 - It allows for direct observation of queues, gaps, offset issues, arrival times, and demand.
 - We can also generate quick counts from video.
 - Having video throughout the day allows for the creation of properly sized coordination plans and when they should be implemented.
 - It can also show that at particular times the signals should not be coordinated at all and instead be run in Free mode.

Study of Adding a New Access Point at an Intersection



- Location: Intersection of Highway 5 (Col. Glenn) and Highway 70B (University Ave.) in Little Rock
- Date: October 4, 2011
- Requested by: Statewide Planning
- How Mast Camera was Utilized:
 - Video was used as a calibration tool in the composition of a microsimulation model to study the effects of a new access point on an adjacent signal.
 - In particular, the camera was used to monitor lane selection and queue lengths.

Highway 71B Interchange Improvements



- Location: Intersection on the East side of I-540 Exit 85
- Date: October 6-7, 2011
- Requested by: Statewide Planning
- How Mast Camera was Utilized:
 - The camera was used to accurately model the traffic patterns occurring in this interchange area.
 - Due to heavy congestion in the area, video of the intersections close to the interchange is good supplemental data for helping determine demand at the intersections instead of just turning movement counts and volume counts.

I-540/Hwy 16/Hwy 112 Spur Interchange Improvements



- Location: Intersections on either side of I-540 Exit 62
- Date: April 10-11, 2011
- Requested by: Statewide Planning
- How Mast Camera was Utilized:
 - The camera was used to accurately model the traffic patterns occurring in this interchange area.
 - Due to heavy congestion in the area, video of the intersections close to the interchange is good supplemental data for helping

determine demand at the intersections instead of just turning movement counts and volume counts.

I-540/Hwy 62 Interchange Improvements



- Location: Intersections on either side of I-540 Exit 64
- Date: April 10-11, 2011
- Requested by: Statewide Planning
- How Mast Camera was Utilized:
 - Used to accurately model the traffic patterns occurring in this interchange area.

- The camera elevation gave us perspective to view traffic movements that would not be picked up on a typical turning movement count or volume count.
- Specifically, needed to see how many vehicles were coming southbound on Shiloh Drive, turning left onto Highway 62/180, and then turning left again onto Futrall Drive.

**SNOW DEPTHS FROM THE HEIGHTS: DEVELOPING A MISSION-
SPECIFIC CIVILIAN UNMANNED AIRCRAFT SYSTEM FOR
SENSING THE MOUNTAIN SNOWPACK**

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INTRODUCTION

Unmanned aircraft systems (UASs) are a relatively new technology that has resulted from improved global positioning systems (GPS), better software, smaller computers and sensors, and material advances such as carbon fiber airframes. UASs have become smaller, more capable, and less expensive mainly because of military investment in the UAS industry. Current generation UASs 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 that can provide high quality aerial information and can carry significant payloads such as sensors or charges for bombing avalanches. In addition, these aircraft are capable of flying without direct human input, autonomously completing preset flight plans. These capabilities have generated considerable interest in civilian applications of UAS, including for environmental sensing needs. This Joint Center for Aerospace Technology Innovation (JCATI)-funded project explored the use of UASs for the collection of snowpack data to support snow applications for avalanche control operations and water resources analysis.

Snow Applications—What Is Needed

For water resource applications, managers need to quantify how much snow is in the mountains. At a point on the ground, this is typically achieved by weighing the snow. Aerially, this can be accomplished by mapping snow depth (with LiDAR or with visual references) and by assuming spatially uniform snow density (Sturm et al. 2010), or by measuring some property that is attenuated by the water content within the snow (through gamma radiation or microwave). Snow quantity can also be estimated by modeling snow accumulation and melt, but errors in and calibration of the model are fundamental weaknesses. Therefore, observations that can be used to improve snow modeling, even if they are not direct measurements of snow water equivalent, are also valuable. These include snow state measurements (such as snow surface temperature or albedo) that can be used for spatial model validation and calibration, and energy balance measurements (such as atmospheric temperature, humidity, wind, incoming longwave and shortwave radiation) that can be used to improve the estimates of when, where, and how fast snow melts.

For avalanche operations, managers need to know where and when snow is likely to slide. This requires detailed knowledge of not only where and how much snow has accumulated in the area but also of the structure of the snowpack, including thermal and granular gradients or buried hoar frost. Table 1 details major uses of snow information for various applications.

**Table 1: Current and Future Needs of Snow Information
(reprinted from Foster et al. 1984).**

TABLE 1. Major Uses of Snowpack Information

Application	Depth	Snow Water Equivalent	Snow-Covered Area	Density	Stratigraphy	Albedo	Liquid Water Content	Temperature Distribution	Snow/Soil Boundary Condition
Water supply forecasting									
Agriculture									
Irrigated land	C	C	C	C			F		
Nonirrigated land	C	C	C	C	C			C	C
Range management	C	C	C						C
Forest management	C	C	C						
Hydropower		C	C			F	F		C
Flood control/warning	C	C	C			F	F	C	C
Municipal and industrial uses	C	C	C						C
Navigation	C	C	C						
Global crop assessment	C	C	C						C
Snow hazard analysis									
Avalanche prediction	C	C	C	C	C	F	F	C	
Transportation/snow removal	C	C	C				F		
Snow loading analysis	C	C	C						
Weather modification	C	C	C						
Military application	C	C	C	C	C	C	C	C	C
Multiuse land planning									
Fish and wildlife management	C	C	C	C					
Winter recreation	C	C	C	C					
Land use zoning	C	C	C	C					
Snow/climate interaction	C	F	C	C		C		C	

Data are from NASA [1982]. C indicates currently required information, and F is anticipated need for future.

Current State of Operations

Avalanche Operations

A number of western states, including Washington state, have important travel corridors that cross mountainous terrain and over high-altitude passes. In the winter, keeping these roads open for safe and reliable winter travel requires that state DOTs operate avalanche control programs to both monitor snow conditions and trigger controlled avalanches before enough snow accumulates to create large and destructive snow slides. These avalanche control operations, while necessary to keep roads open, are costly, potentially dangerous, technically complicated, and time consuming.

Current avalanche control efforts involve a range of methods to trigger avalanches. DOTs may use surplus military tanks and howitzers that shoot explosives into avalanche prone areas, skiers or snowmobilers with handheld explosive charges, and, occasionally, airplanes or helicopters that drop charges. Each of these methods, while effective, is costly and can be dangerous if not used carefully. As a result, many mountain roads have to be closed for lengthy periods until avalanche control operations have been completed. These unpredictable closures can have notable negative economic impacts for both people and freight mobility.

This Joint Center for Aerospace Technology Innovation program application, in part, explored the use of small unmanned aircraft as an additional tool for DOT avalanche control staff that will help them open roadways more quickly.

As noted above, small civilian versions of unmanned aircraft systems are increasingly affordable and easy to operate. Recognizing their potential, in 2006 and 2007 the Washington State Department of Transportation (WSDOT) and one member of this UW project team tested the use of both rotary (helicopters) and fixed-wing UASs in Washington state as a tool to support avalanche control operations. These initial proof of concept tests demonstrated that UASs have the potential to carry sensors and cameras to provide high quality aerial information about snow conditions both on and alongside roadways, inspect avalanche control target zones for people before the use of explosives, and accurately drop charges to trigger snow avalanches to support snow avalanche control operations. The findings also suggested that unmanned aircraft can improve the safety, effectiveness, and speed of avalanche control operations by reducing avalanche control personnel response time while also increasing safety for motorists and control staff. The project also determined that UASs are both affordable and operable by a state DOT. More information on these tests can be found in McCormack (2008 and 2009) and McCormack and Stimberis (2010a and 2010b).

These limited, initial UW/WSDOT flights, which were funded by WSDOT and the U.S. DOT, showed the promise of this technology. This JACTI project supported a continuing evaluation of the UAS technology as a tool to benefit organizations responsible for maintaining roadways in winter conditions.

Potential Payoff for Practice

Many western states have major roads that travel through avalanche prone areas. Table 2 shows the locations of major travel corridors that require state DOTs to manage avalanche control operations.

Avalanche control programs (typically part of state DOTs' maintenance and operations) focus on keeping a state's important travel corridors through the mountains open during winter conditions and, for some states, on protecting maintenance crews re-opening and plowing roadways in the spring. State avalanche control operations are often expensive. One report calculated that state DOTs spent more than \$6 million each year (Winter Alpine Engineering 2004). The WSDOT's avalanche control budget just to keep the three major cross-Cascade highways open (I-90, SR 20, and SR 2) is \$2 to \$4 million per year (WSDOT 2013a).

There are usually few problems justifying a DOT's control program from a cost perspective because any closure of a roadway is often considerably more expensive than a control

Table 2. Roadways Requiring Avalanche Control Operations

Avalanche Hazards on the National Highway System:	
Alaska	SR9 on the Seward Highway from Anchorage
	R7 north of Juneau
California	80 at Donner Summit
	SR 50 at Econ Summit
	R 88 at Carson Pass (California side)
	R 120 at Yosemite National Park
Colorado	70 at the Eisenhower Tunnel
	SR 550 at Red Mountain
	SR 160 at Wolf Creek Pass
Montana	SR 89 at Glacier National Park
	SR 2 at Marias Pass
Nevada	SR 88 at Carson Pass (Nevada Side)
Utah	84 in Ogden Canyon
	SR 189 in Provo Canyon
Washington	90 at Snoqualmie Pass
	SR 2 at Stevens Pass
	USR 12 at White Pass
	US 20 in the North Cascades
Wyoming:	SR 89 at Yellowstone National Park
	SR 14 at Yellowstone National Park
	SR 189 in Hogback Canyon

Source: Revised from Winter Alpine Engineering (2004)

program. In Washington, Interstate-90, the state’s major east-west travel route, crosses Snoqualmie Pass in the Cascade Mountains. Between 2007 and 2013, this pass was closed an average of about 100 hours a year because of avalanche threats and resulting control activities (WSDOT 2013b). WSDOT has estimated that each hour that I-90 is closed costs about \$500,000 to the state’s economy. The winter of 2007-2008 had notably heavy snowfall, and the pass was closed for over 600 hours. During that winter, one four-day closure was estimated to cost the state \$28 million (WSDOT 2008). That closure had a major impact on the freight community, since many stores and manufacturing processes require frequent and reliable deliveries. On a typical day the pass serves 6,500 trucks. During the four-day closure, because an alternative route through the Cascade Mountains (SR 2) was also closed for avalanche control operations, hundreds of trucks were lined up waiting for the pass to open.

Avalanches occur when snow on a slope or in chute can no longer support its own weight, loses grip on a slope, and slides downhill. Such avalanches can be extremely powerful and can travel surprisingly long distances. There are numerous examples of cars and large

trucks being pushed off the road, with occasional fatalities. Current avalanche control efforts involve surveying snow conditions to identify conditions conducive to slides, clearing the run-out zone of people and hazards, and then purposefully triggering smaller controlled avalanches before snow can accumulate to dangerous amounts. This process is part art and part science, and it involves identifying when and where to trigger an avalanche slope or chute. Often this involves using a range of methods to deliver explosives to set off the avalanche. DOTs use surplus military tanks and howitzers to shoot explosives into avalanche prone areas, skiers or snowmobilers to deliver handheld explosive charges, and sometimes helicopters or airplanes to bomb avalanches. Each of these methods has limitations and is expensive, slow, and involves some risk to humans or may require increasingly difficult to obtain military equipment.

Small unmanned aircraft offer an alternative method both for surveying snow conditions and avalanche areas and for triggering controlled avalanches that potentially could be quicker, safer, and less costly than existing methods.

Previous tests with these smaller UASs conducted by this project's researchers indicated that this technology can repeatedly deliver dummy control explosives with 6-foot accuracy to predetermined locations. Avalanche control professionals, through experience, often know the locations of trigger zones. (Many of their howitzers and tanks are pre-sighted to set locations.) One notable advantage of a UAS, operating out of a DOT maintenance vehicle, is that it could deliver the explosive charge to the same pre-determined locations without requiring increasingly difficult to obtain and secure military equipment or sending out skiers or snowmobilers. The use of skiers or snowmobilers often requires a human to make a sometimes dangerous and often slow trip to a trigger zone. Because UASs fly autonomously (without direct human control), they could potentially deliver control explosives with great accuracy and with minimal human risk or discomfort. This could result in roadways opening much sooner.

An obvious use of UASs is to replace a manned aircraft. WSDOT contracts manned aircraft for avalanche control, but this is limited because the aircraft are costly. Hiring a helicopter, for example, can cost WSDOT \$800 to \$1,000 an hour (McCormack and Stimeris 2010). Operations involving "bombing" avalanches can also place the pilot and crew at risk. These aircraft and pilots are also not always immediately available, which can delay control operations and the ability to open roadways.

Water Supply, Hydropower, and Snow Surveys (NRCS)

The Natural Resources Conservation Service (NRCS) is the primary agency responsible for assessing the snow water stored in the mountain snowpacks of the western United States. In most cases, the local agency responsible for a watershed (or with a vested interest in a

given snow water supply forecast) partners with the NRCS in maintaining SNOTEL sites and conducting snow surveys, including shouldering part of the cost for measurements collected and instrument maintenance. Specific operations and needs for additional information vary among watersheds and management agencies. For example, Seattle City Light is particularly interested in monitoring glacier change in the Skagit watershed, and Seattle Public Utilities, which owns its entire watershed, is interested in forest management for overall watershed health. In very large reservoir systems, e.g., the Colorado River, reservoirs can store more than a year's worth of runoff, so the total annual water supply is much more important than runoff timing. However, in watersheds with relatively small reservoirs, runoff timing (i.e., snowmelt timing) is more important, particularly when these reservoirs must also be managed for fish protection.

Most snow surveys are conducted manually, by human observers probing and weighing the snow. However, the NRCS and their cooperators also use aerial snow markers as one method to measure the depth of the snow. In the state of Washington, there are both permanent and temporary markers. Permanent markers consist of a 3-inch steel pipe that is cemented into the ground. A series of metal paddles—6 inches high, 2 feet long, and 2 inches thick—are secured to the pole 6 inches apart (Pattee 2013). Temporary markers consist of the same type of paddle, but they are secured to existing meteorological towers. The measures taken with aerial markers are not as accurate as those taken by physically measuring snow depth with a probe on the ground because the measurements are in 6-inch increments. However, they provide beneficial results for areas that are distant and difficult for people to access on the ground at a reasonable cost (Julander 2012).

According to the NRCS Washington Snow Survey Measurement Schedule for water year 2012, of the 18 cooperators to conduct snow surveys, two used aerial markers. These two included Bellevue PSP & L, which measured all nine stations with aerial markers (Dock Butte, Easy Pass, Jasper Pass, Marten Lake, Mt. Blum, Rocky Creek, Scheibers, S.F. Thunder, and Watson Lakes) and Chelan PUD, which measured three stations with aerial markers (Cloudy Pass, Little Meadows, and Park Creek Ridge) (Pattee 2013). The snow surveys must be performed within five days before the first of each month, January through June. When the surveys are performed, a fixed wing aircraft or a helicopter flies over the snowfield, and a visual camera takes images of the stakes. Once the images have been processed, the paddles are counted and the snow depth is measured. In Washington, costs are approximately \$2,000/hr (Pattee 2013). In Salt Lake City, Utah, and surrounding areas, approximately 18 sites currently use aerial snow markers. A snow survey takes about one full day with a flight time of approximately two hours. The cost per hour ranges from \$1,600 to \$2,000, depending on the aircraft (Julander 2013). The NRCS has also begun to incorporate automated snow markers in Utah. These systems use iridium satellite telemetry to provide measurements of snow depth and temperature four times a day. A

standard temperature sensor, soil moisture/temperature sensor and a precipitation gauge will be added in the future, which will allow the automated snow markers to have all the capabilities of a standard snowpack sensor (SNOTEL), except for a snow pillow (Julander 2012). Each of these sensors is approximately \$3,000 to \$4,000.

These applications demonstrate that manned aerial snow surveys are valuable. This JACTI project supported an evaluation of the UAS technology as a tool to more efficiently complete these surveys.

Summary of Previous Work on Remote Snow Sensing

Remote snow sensing has been researched for decades (see Dozier and Painter 2004; Nolin 2010; Deitz et al. 2012). Sensors detect electromagnetic waves that are either emitted by or reflected from the land surface. Figure 1 identifies which of these wavelengths are most useful for snow and how they have been used in the past. Specific sections below provide more details on each measurement.

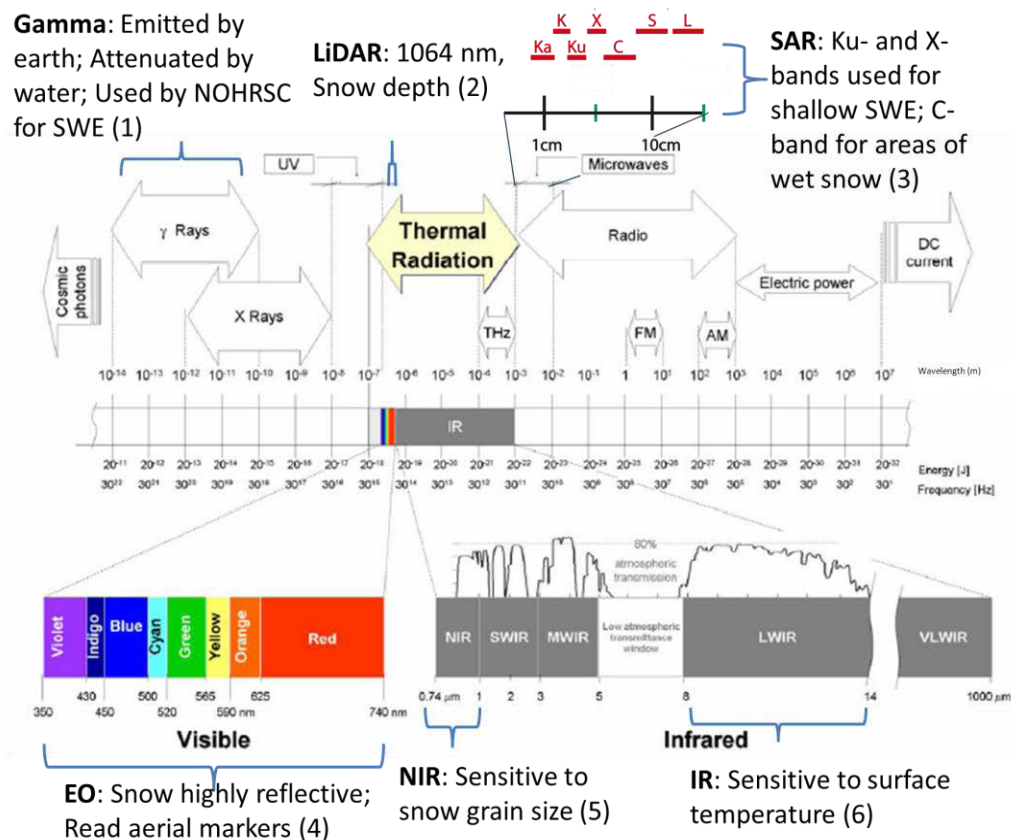


Figure 1. Guide to the electro-magnetic spectrum with relevance to snow. References detailing each waveband are as follows: (1) Carroll 2001; (2) Hopkinson et al. 2004, Deems et al. 2006; (3) Nolin 2010, Dietz et al. 2012; (4) Henderson 1953, Hannaford 1960, Miller 1962; (5) Tape et al. 2010, Matzl and Schneebeli 2006 ; (6) Shea and Jamieson 2011. [Base figure adapted from Ibarra-Castanedo 2005.]

Gamma

The National Operational Hydrologic Remote Sensing Center (NOHRSC) conducts aerial snow surveys by flying an AC-695A jet prop commander aircraft 500 feet above the ground to measure snow water equivalent (SWE), which is the amount of water in the snow pack, as well as additional water content in the upper 8 inches of the soil (Carroll 2001). These flights cover more than 2000 pre-surveyed flight lines (Carroll 2001) over areas of Alaska, New England, the northern U.S. Great Plains, and some large river valleys in the western United States. To measure SWE, a gamma radiation detection system (RSX-5 from Radiation Solutions, weighing 114 kg) is mounted in the cabin of the aircraft. Water attenuates gamma radiation emitted by potassium, uranium, and thorium radioisotopes in the soil. By comparing measurements between snow-on and snow-off conditions, SWE can be determined. Flights for a given basin occur typically three or fewer times per year, and these measurements are typically combined with other snow data sources for water supply prediction (Carroll et al. 1999; Cowles et al. 2002).

LiDAR (Light Detection and Ranging)

Airborne LiDAR is able to very accurately measure distances. When LiDAR data are combined with precise information about an aircraft's altitude, pitch, roll, and yaw (such as can be obtained from an inertial navigation system, or INS), high-resolution (<1 m) digital elevation models can be created for the surface. When flights are repeated in both snow-off and snow-on conditions, the difference between these elevations provides a spatial map of snow depth with ~1-cm vertical resolution and ~1-m² horizontal footprint (Hopkinson et al. 2004; Deems et al. 2006). NASA and the California Department of Water Resources are currently repeating flights of LiDAR to map snow in the Tuolumne River Watershed in California (JPL 2013).

Synthetic Aperture Radar (SAR) and Microwave Remote Sensing

Synthetic aperture radar (SAR) is active microwave remote sensing. SAR instruments are typically mounted on the side of an aircraft, pointing from the horizon to straight down. Post-processing uses the correlation between phase shifts of all wavelengths returned to the aircraft or satellite, combined with records of the craft's movement (generally from an inertial motion unit), to simulate an infinitely long phased array of sender/transceivers. The use of SAR in snow science is relatively new. C-band SAR instruments can map areas of wet snow and retrieve snow liquid water content (Nagler and Rott 2000; Pulliainen et al. 2004). Scatterometry can also map where snow is actively melting by using Ku-band measurements (Nghiem and Tsai 2001; Wang et al. 2008). Rott et al. (2010) combined Ku-band and X-band measurements to estimate SWE in Alaska.

Passive microwave remote sensing is available on many satellites and for global applications. However, these techniques work best for shallow snow (Deitz et al. 2012). Because this report is focused on the Pacific Northwest, which typically has deep snow, we will not further detail passive microwave remote sensing techniques.

Visible (Electro-optical)

Snow is highly reflective in the visible wavelengths and so is easy to see in standard photography using visible wavelengths. The earliest applications were to visually read snow depth off aerial markers (Henderson 1953; Hannaford 1960; Miller 1962; Bruce 1967), as described previously (see Figure 2).

Satellite imagery uses snow's high reflectivity in the visible wavelengths (Figure 3) as a tool to identify snow-covered areas, and various algorithms exploit differential reflectivity across multiple wavelengths to identify fractional snow covered areas (e.g., ASTER, Vogel 2002; MODSCAG, Painter et al. 2009; and MOD10A1, Hall et al. 2006). See Deitz et al. 2012 for an excellent review of satellite-based optical sensors.

Photogrammetry combines multiple visual images to recreate a 3-dimensional surface (Baltsavias 1999; Pollack 1965). These techniques, also termed structure from motion, have been applied in ecosystems/forestry sciences (Dunford et al. 2009; Järnstedt et al. 2012; Dandois et al. 2013), for the creation of digital elevation models (Fonstad et al. 2013), for glacier surveys (Welty et al. 2013), and for studies of geomorphology (Westoby et al. 2012). In many instances, an UAS has been flown to gather the visual imagery used in processing 3-D models (Wallace et al. 2012; Miller et al. 1998; Bryson et al. 2011) or to otherwise classify a subject of interest, ranging from archaeology to vegetation (Chiabrando et al. 2011; Sugiura et al. 2005; Laliberte et al. 2011).

Near-Infrared (NIR)

The reflection of light in the near-infrared (NIR) wavelengths (0.75 to 1.4 μm) is sensitive to snow grain size (Dozier et al. 1981), and several researchers have used NIR cameras to map out snow stratigraphy and snow grain size (Matzl and Schneebeli 2006; Tape et al. 2010). These parameters are incredibly useful for avalanche forecasting. Most digital cameras are sensitive to NIR wavelengths but contain a filter to remove them from the photograph. With a change of filters, widely-available EO (electro-optical, i.e., visible wavelengths) cameras could be converted to NIR cameras.



Figure 2. (left) Aerial snow depth marker in Humphreys Basin (near Cony Lakes and Mt. Humphreys) (from <http://www.summitpost.org/aerial-snow-depth-marker-in/28710>) (right) Aerial marker in Utah with iridium technology (Julander 2012).

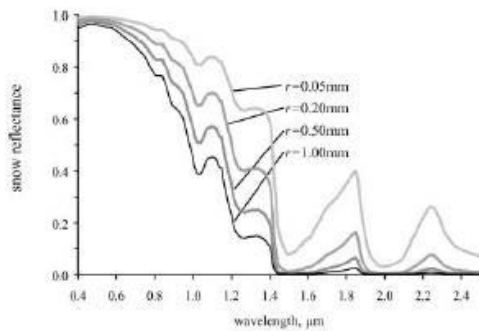


Figure 3. Snow reflectance as a function of snow grain size (r) and wavelength (from Figure 2 in Dozier and Painter 2004, which used the model of Wiscombe and Warren (1980) to generate the spectral reflectance). Snow is very reflective in the visible spectrum but not reflective in the near infrared.

Infrared (IR)

Thermal infrared (IR) cameras focus on 7.5- to 13.5- μm wavelengths. Snow has less than 2 percent reflectance in the 6- to 10- μm bands but can have as much as 4 percent reflectance with coarse granular crust in the 10- to 12- μm bands (Salisbury et al. 1994; Dozier and Warren 1982). For practical purposes, many investigators assume that snow is a black body (an idealized physical body that absorbs all radiation) with an emissivity of 1 (e.g., Morin et al. 2012). Shea and Jamieson (2011) investigated snow surface thermography with a handheld camera (FLIR B300). Howard and Stull (2013, in press) used a FLIR E40 IR digital camera with a manufacturer-stated accuracy of ± 2 percent (up to 6°C for their case study), with a spectral range of 7.5 to 13 μm , to determine the temperatures of trees

near snow. They carefully corrected for atmospheric emission between the camera and the trees by recording the air temperature, the relative humidity, and the distance between the camera and the object.

What Is Required to Make UASs Feasible for Operations?

For a UAS to be used for basic water resources applications, it must be more cost-effective than the cost of the salary and flight time of the people in a helicopter who visit sites and take human measurements. Because aerial IR imagery has not been historically available, further ground truth work (from a hand-held or pole-mounted camera) must be completed to demonstrate its economic value to avalanche and water resources applications. LiDAR measurements of cloud-points of surfaces have proved to be useful for snow water assessment (as in current operation in California), so if photogrammetry can provide information comparable to or even slightly less accurate than LiDAR, it would be favored as long as the cost (of both data collection and analysis) was less than that of LiDAR. The logistics of flying the UAS would need to be no more difficult than hiring a manned aircraft (such as an agency owning a UAS with in-house expertise and standing permission to fly over its watershed).

SENSOR PACKAGES FOR AERIAL SNOW SENSING

Flexrotor Specifications and Applications

This effort is a proof of concept based on the capabilities of the AeroVel Corporation's Flexrotor. This UAS is a 19-kg (42-lb), 3-m (10-ft) wingspan aircraft capable of flying for more than 40 hours with a 0.9-kg (2-lb) payload (<http://www.flexrotor.com/>). Flexrotor is capable of both efficient wing-borne cruising and helicopter-like hovering, enabling vertical take-off and landing (VTOL) from sites with limited access or space. Portability is aided by small size, light weight, and the VTOL characteristics. Currently under development, Flexrotor has demonstrated autonomous flight, including automatic VTOL (<https://www.youtube.com/watch?v=M6Lq2BJtYvY>). Flexrotor has been equipped with a Hood Technology stabilized video camera imaging system, mounted in the nose bay forward of the rotor/propeller (<http://www.auvsishow.org/auvsi12/public/Booth.aspx?IndexInList=&Upgrade=&FromPage=&BoothID=103831&Task=PressReleaseDetails&PRID=377>).

Sensor payload integration for Flexrotor, or indeed any aircraft, involves a number of factors, perhaps the most obvious of which is payload mass. Payload integration involves more than just the capability to carry mass. The payload must be mounted so that the resulting drag characteristics, weight and balance, etc allow acceptable aircraft performance and control for the desired mission. Furthermore, the sensor payload must be given a satisfactory view of the sensor target environment and be able to operate effectively in the aircraft load and vibration environment, and both payload and aircraft must be capable of tolerating electromagnetic interference. Mounting options on Flexrotor include a non-rotating nose bay forward of the rotor/propeller, providing a low-drag payload location with a more than hemispherical view of the environment (<http://www.aerovelco.com/images/FlexrotorThreeView-1.gif>). The payload must also have sufficient electrical power, an interface for command and status messages, and capability for recording and/or transmitting sensor data. Motorized gimbals may be necessary or desired for stabilization, pointing, or sensor operation in multiple aircraft attitudes.

There are options if multiple sensor packages are desired. One aircraft may carry all of the sensors, or multiple aircraft can be used, with each carrying a subset of the desired sensors. An alternative is to add or remove sensors as required. For example, Flexrotor may use swappable nose modules containing either a visible or IR camera. This last option will allow the selection of sensor(s) appropriate for the mission, or possibly different sensors in consecutive flights.

A small aircraft such as Flexrotor is not capable of carrying heavy sensor packages, but it may compensate for this by flying a lighter, reduced-capability sensor closer to the sensor

target. This can be achieved because of the smaller risk in comparison to a manned aircraft or because of the smaller size and slower speed, including capability for hover. An aircraft capable of flying closer to terrain may potentially fly “below the weather” in conditions unavailable to other aircraft because of safety or sensor view concerns.

Ideally, a mission-specific UAS would be sized and designed for the mission and associated sensor packages. However, the cost and effort involved would be prohibitive, especially for a proof of concept or small market. Given these issues, an existing aircraft capable of being adapted to economically perform the desired mission could be the best and indeed only choice.

Sensor Summary

One of this project’s tasks was to select or design sensor packages. Several sensors were evaluated to determine the feasibility of using them in UASs, given the specifications discussed in the previous subsection. These sensors included thermal and near infrared cameras, visual cameras, LiDAR, synthetic aperture radar (SAR), and gamma radiation. This section discusses the appropriate uses, specifications, and limitations of each instrument. Table 3 summarizes the sensors that were evaluated and the conclusions about the feasibility.

Three of the cameras were evaluated for the unmanned aircraft: thermal infrared, near infrared, and visual. Infrared cameras can measure the heat the snowpack radiates by detecting infrared energy and converting it into an electronic signal. This signal is processed, and the camera produces a thermal image (FLIR 2013). Thermal infrared wavelengths used in commercial cameras commonly fall between 7 μm and 14 μm and measure surface temperature, which can be used to estimate snow covered area. Near infrared wavelengths fall between 0.74 μm and 1 μm and are measured to approximate grain size. The estimations of snow covered area and grain size can then be used to calculate albedo (Dozier and Painter 2004). With weights ranging from 21.5 g to 1150 g and costs ranging from \$3,400 to \$40,000, thermal IR, near IR, and visual cameras are a feasible instrument for UAV use. Tables 4 and 5 include the specifications for different models of thermal and near IR cameras, respectively.

Visual cameras or EO cameras can be used for various UAS applications, but two specific uses include reading aerial snow stakes and photogrammetry. As discussed previously, snow depth is measured by flying over a snowfield and taking pictures with a visual camera. Table 6 provides specifications for visual cameras, while Table 7 includes the weights and prices of different lens options.

Table 3: Sensor Feasibility Summary

Sensor	Feasible?	Limitations
Thermal IR Camera	Yes	---
Near IR Camera	Yes	---
Visual Camera	Yes	---
Visual Camera Accessories	Yes	---
GPS Unit and Accessories	Yes	---
LiDAR	No	Weight and Cost
Gamma Radiation	No	Weight and Cost
SAR	No	Cost

Lens selection is an important component of visual camera use, especially for measuring snow depth with aerial snow stakes. As can be seen in Table 8, as the zoom becomes greater, the visibility is clearer, but the cost and lens weight increase as well. Therefore, the desired visibility must be balanced against the allowable weight and cost. Selecting a camera with the most effective pixel resolution and determining an acceptable flight elevation are also important. As shown in Figure 4, by using the mathematical equation,

$$L = 2H * \tan(\alpha/2)$$

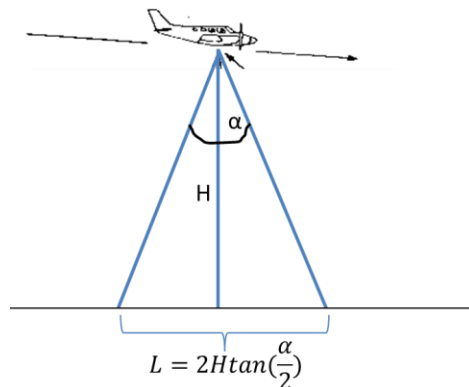


Figure 4. Illustration of a camera's spatial footprint on the ground, as a function of field of view (fov, α) and height (H). The resolution of a pixel is Number of pixels/L. (Plane graphic adapted from <http://www.fao.org/docrep/003/t0355e/t0355e04.htm>)

Table 4: Thermal Infrared Camera Specifications and Costs

Camera Model	Resolution	Lens Options	Spectral Band	Size Without Lens	Weight	Cost
Tau 640 ¹ (LWIR)	640 x 480 (NTSC) 640 x 512 (PAL)	7.5 mm - 100 mm	7.5 - 13.5 μm	1.75 x 1.75 x 1.18 in	70g - 429g	\$3.4K - \$10K (Depending on Lens)
Tau 336 ¹ (LWIR)	640 x 480 (NTSC) 640 x 512 (PAL)	7.5 mm - 100 mm	7.5 - 13.5 μm	1.75 x 1.75 x 1.18 in	70g - 429g	
Tau 324 ¹ (LWIR)	640 x 480 (NTSC) 640 x 512 (PAL)	7.5 mm - 100 mm	7.5 - 13.5 μm	1.75 x 1.75 x 1.18 in	70g - 429g	
Quark 640 ¹ (LWIR)	640 x 480 (NTSC) 640 x 512 (PAL)	6.3 mm - 35 mm	7.5 - 13.5 μm	0.67 x 0.87 x 0.87 in	21.5g - 28g	\$7.5K - \$9K (Depending on Lens)
Quark 336 ¹ (LWIR)	640 x 480 (NTSC) 640 x 512 (PAL)	6.3 mm - 35 mm	7.5 - 13.5 μm	0.67 x 0.87 x 0.87 in	21.5g - 28g	
IR-TCM 384 ²	384 x 288	25 mm (Standard)	7.5 - 14 μm	6 x 3.6 x 4.4 in	1050 g Without Lens	\$12K (Without Lens)
IR-TCM 640 ²	640 x 480	30 mm (Standard)	7.5 - 14 μm	---	1050 g Without Lens	\$18.5K (Without Lens)
IR-TCM HD ²	1024 x 768	30 mm (Standard)	7.5 - 14 μm	---	1150 g	\$40K (With Standard Lens)

1: Manufactured by FLIR (<http://www.flir.com/US/>)

2: Manufactured by Sierra-Olympic Technologies (<http://sierraolympic.com/>)

Table 5: Near Infrared Camera Specifications and Costs

Camera Model	Resolution	Lens Options	Spectral Band	Size Without Lens	Weight	Cost
Tau SWIR 25 ¹	640 x 512	---	0.9 - 1.7 μ m	1.5 x 1.5 x 1.9 in	---	\$25K
Tau CNV ¹	1280 x 720	---	0.9 - 1.7 μ m	1.9 x 1.9 x 2.5 in	0.175 kg	\$7K

1: Manufactured by FLIR (<http://www.flir.com/US/>)

Table 6: Visual Infrared Camera Specifications and Costs

Camera Model	Resolution	Total Pixels	Size Without Lens	Weight	Cost
Nikon D800 DSLR ¹	7,630 x 4,912	36.8 million	5.7 x 4.8 x 3.2 in	0.9 kg	3,281.66

1: Manufactured by Nikon (<http://www.nikon.com/>)

Table 7: Nikon Lens Options for D800 DSLR

Lens Options	Weight	Cost
50 mm	0.19 kg	\$238
28 - 300 mm	0.8 kg	\$1146
16 - 35 mm	0.68 kg	\$1370
85 mm	0.38 - 0.66 kg	\$489 - \$1699

Table 8: Examples of Different Pixel Options and Flight Elevations

Pixels	Field of View	Elevation (m)	Total Meters Viewed	Meter Viewed per Pixel
640	30	1000	535.6	0.837
480	23	1000	406.7	0.847
640	30	100	53.6	0.084
480	23	100	40.7	0.085
7360	30	1000	535.6	0.070
4912	23	1000	406.7	0.083
7360	30	100	53.6	0.007
4912	23	100	40.7	0.008

an appropriate pixel resolution and flight elevation can be selected to provide the desired visibility. For example, with a 640 x 480-pixel camera and a flight elevation of 1000 meters, 0.837 m x 0.847 m can be seen with each pixel. This can be compared to a 7360 x 4912-pixel camera, which, if flown at the same elevation of 1000 m, will show 0.070 m x 0.083 m with each pixel. Table 8 provides examples of different pixel combinations and flight elevations.

Photogrammetry uses a visual camera to take images of an object or landscape from different views, and then common points of interest between the photos are mathematically intersected with a software program in order to produce a 3-dimensional image (The Basics of Photogrammetry, 2013). Therefore, additional instruments are needed to complete the photogrammetry process, including software, processors, and GPS units to track the locations of each image. Table 9 provides cost information for additional instruments for photogrammetry. These additional instruments are used on the ground and are not physically incorporated into the UAS. Therefore, with acceptable costs, all additional instruments are feasible for UAS use. Table 10 provides specifications for GPS units and accessories. All items in this table are deemed feasible as well. Other open source software, including VisualSFM Software, Ames Stereo Pipeline, GDAL, QGIS, GIMP, and Imagemagick, would be beneficial and are offered at no cost. A photogrammetry set-up is available for University of Washington students through their student technology fees (Greenberg 2013).

LiDAR maps the terrain of the snow survey area, which is used to determine snow depth. At this time, with weights ranging from 24 to 27 kg and costs ranging from \$540,000 to \$1.2 million, LiDAR is not feasible for UAS applications. Table 11 includes specifications for LiDAR instruments.

Gamma radiation measures snow water equivalent (SWE) by using thallium-doped sodium, NaI(Tl), crystals. At this time, with weights ranging from 91 kg to 114 kg and costs ranging from \$125K to \$160K, gamma radiation is not feasible for UAS applications. Table 12 includes specifications for gamma radiation instruments.

Synthetic aperture radar (SAR) measures the quantity of snow by using the instrument's line-of-sight and perpendicular azimuth to generate a two-dimensional remote sensing image. At this time, with costs ranging from \$500,000 to \$3 million, SAR is not feasible for UAS applications. Table 13 includes specifications for SAR instruments.

Table 9: Cost of Additional Photogrammetry Instruments

Additional Photogrammetry Instruments	Cost
ERDAS Image software with Leica Photogrammetry Suite	\$5,913
AgiSoft Photoscan Software	\$602.25
12-core processing workstation	\$4k - \$6k

Additional instruments and costs gathered from Greenberg 2013.

Table 10: GPS and GPS Accessories for Photogrammetry

Model	Vertical Accuracy	Horizontal Accuracy	Size	Weight	Cost
GeoXH ¹	4 cm + 1.5 ppm	2.5 cm + 1 ppm	9.2 x 3.9 x 2.2 in	0.925 kg	\$2500
Zypher 2 Antenna ¹	---	---	6.35 in dia x 2.3 in height	0.45 kg	\$1450
GP - 1 GPS Unit ²	---	---	2 x 1.8 x 1 in	0.024 kg	\$265

1: Manufactured by Trimble (<http://www.trimble.com/>)

2: Manufactured by Nikon (<http://www.nikon.com/>)

Table 11: LiDAR Specifications and Costs

Model	Operational Altitude	Laser Wavelength	Laser Repetition Rate	Size	Weight	Cost
ALTM Orion H300 ¹	150 - 4000 m	1064 nm	50 - 300 kHz	Sensor: 340 x 340 x 250 mm, PDU: 415 x 100 x 100 mm	Sensor: 27 kg PDU: 6.5 kg	\$900K - \$1.2 mil
ALTM Orion M300 ¹	100 - 2500 m	1064 nm	50 - 300 kHz			\$900K - \$1.2 mil
ALTM Orion C300 ¹	50 - 1000 m	1541 nm	100 - 300 kHz			\$800K - \$1 mil
Lite Mapper 2400 ²	10 - 200 m	905 nm	30 kHz	---	24 kg	\$540K

1: Manufactured by Optech (<http://www.optech.ca/>)

2: Manufactured by Ingenieur – Gesellschaft (<http://www.igi.eu/litemapper.html>)

Table 12: Gamma Radiation Specifications and Costs

Model	Channels	Detector	Power	Weight	Size	Cost
RSX-5 ¹	1024	4+1 x 4L Nal(Tl)	9-40 VDC, 55 W	114 kg	28.8 x 22.46 x 11.32 in	\$150K - \$160K
RSX-4 ¹	1024	4 x 4L Nal(Tl)	9-40 VDC, 50 W	91 kg	28.8 x 22.46 x 6.97 in	\$125K - \$130K

1: Manufactured by Radiation Solutions (<http://www.radiationsolutions.ca/>)

Table 13: Synthetic Aperture Radar Specifications and Costs

Model	Weight	Size	Frequency	Power	Cost
miniSAR ¹	30 kg	Radar Assembly: 49 cu in Gimbal Assembly: 100 cu in	Ku - Band (16.8 GHz)	60 W	\$3 mil
NanoSAR ²	1.5 kg	100 cu in, 6.2 x 7.5 x 5.5 in, + antenna	X-Band (8 - 12 GHz)	30 W	\$500K

1. Manufactured by Sandia National Laboratories (<http://www.sandia.gov/RADAR/minisar.html>)

2. Manufactured by ImSAR (<http://www.imsar.com/>)

MANNED TEST FLIGHT

Instruments, Aircraft, Flight Details

On 14 May 2013, the research team flew two IR cameras and one visual camera on a Cessna 172 (Figure 5). The visual camera was a Point Grey Chameleon (1280x960, 1/3-in. sensor RGB CCD) with a 45-degree fov lens and polarizing filter. The IR cameras were 40-degree and 25-degree fov DRS UC640 VOx microbolometers, with 640x480 sensors sensitive to 8- to 12-micron LWIR. All cameras were attached to a mount on the belly of the Cessna (Figure 5) and were pointed straight down. The IR sensors were contained in boxes with reference temperature lids (Figure 5), which consisted of aluminum plates with embedded Dallas thermal probes (model DS18B20, -55 to 85°C, and calibrated in a calibration bath for better accuracy). The Cessna was equipped with a Novatel SPAN INS-GPS system (0.009 roll, 0.013 pitch, and 0.024 heading accuracy, RMS degrees with 1.3-m horizontal and 0.6-m vertical position accuracy). The entire system was built through a partnership between the Air-Sea Interaction group in the UW Applied Physics Lab (APL) and Regal Air and had previously been used for river, estuary, and ocean experiments.

The flight path (Figure 6) was designed with two primary objectives: 1) take images in the Cascades Mountains of the Snoqualmie Pass measurement site, where several meteorological towers obtain data both for avalanche control and for observational reference for snow model comparisons; and 2) take images of snow in conjunction with many different forest types, ages, and densities in the Cedar River Watershed (which is Seattle's water supply and managed by Seattle Public Utilities). This second area also overlapped with four NRCS SNOTEL stations (Figure 6). The team also deployed aerial snow markers at the Snoqualmie measurement site to test the aircraft camera's ability to see them (Figure 7).

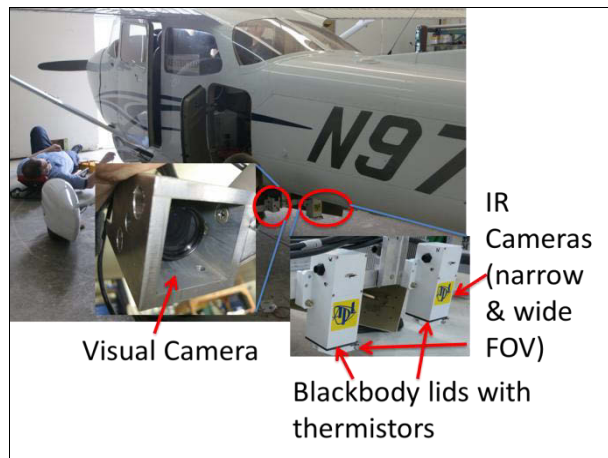


Figure 5. Photograph of Cessna 172 with insets showing the cameras and housings.

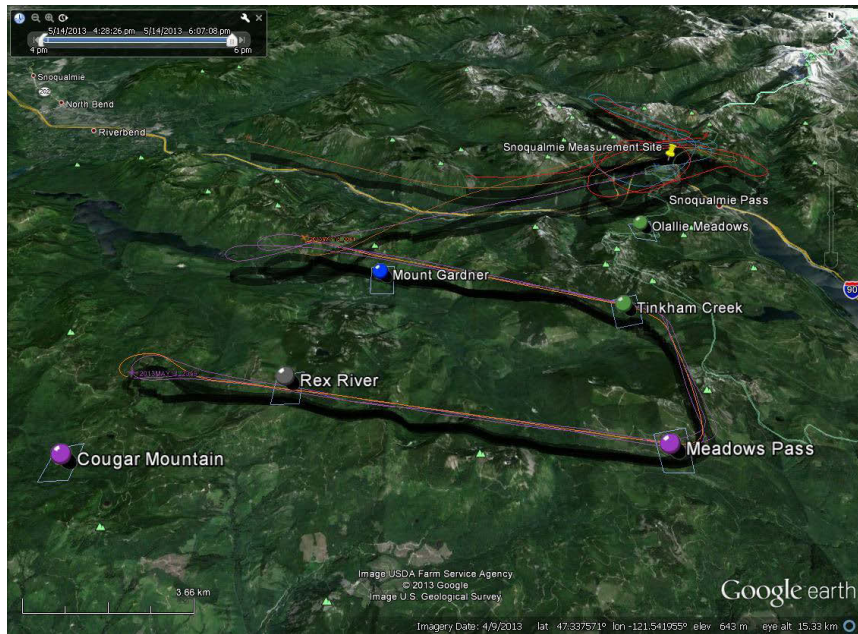


Figure 6. Map of flight paths flown on 14 May 2013. Also shown are NRCS SNOTEL stations in the region (circles) and the Snoqualmie Pass snow measurement site (thumbtack).



Figure 7. Aerial snow markers deployed at Snoqualmie Pass tower.

Results

Flying over the Snoqualmie Pass snow measurement site revealed that the atmosphere between the land surface and the plane had minimal effects on the sensed snow surface temperature. In other words, the aerial camera read the same temperature as the tower-mounted IR sensor (Figure 8). However, while the tower could be seen in both the IR and the visual imagery (Figures 8c, 8d), the aerial snow depth markers could not be read. This was a function of both the low resolution of the visual camera (960 x 1280, pixels labeled in Figure 8d) and of the plane's height above the station. Because Snoqualmie Pass is at about

900 m (3000 ft), with surrounding peaks exceeding 1750 m (5800 ft), the plane had to fly at a safe altitude in relation to the higher terrain, which kept it substantially above the measurement site.

In-flight recalibration of the microbolometers was essential because of changing plane elevations and the resulting changing temperatures of both the camera body and lens. By closing the instrument housing lids (which consisted of black bodies with a measured temperature), the researchers were able to determine an appropriate offset value for each pixel by using the following equation:

$$T = I_R g + I_O$$

where I_R is the measured intensity (or counts) at a given microbolometer, g is the gain ($^{\circ}\text{C}/\text{count}$) calibrated in the laboratory, and I_O is the offset, which includes corrections for the ambient temperature of the camera and lens.

Preliminary data (Figure 9) illustrate the potential of combined IR and visual imagery to better quantify the spatial snow energy balance, accounting both for local variations in snow surface temperature (e.g., the ice channels in the snowfield on the image's right-hand-side) and for variations in longwave emissions from the surrounding terrain (e.g., trees and rocks).

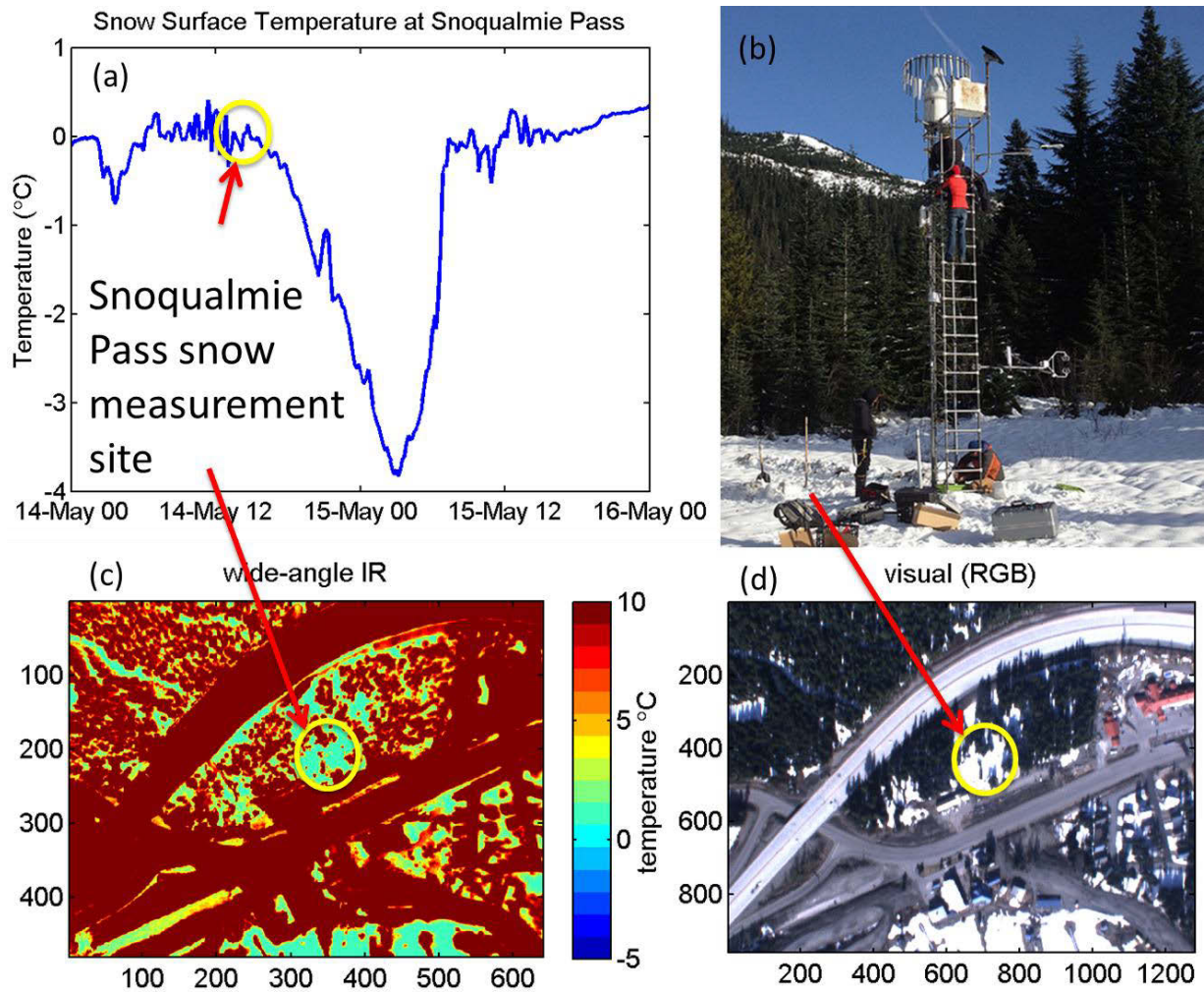


Figure 8. (a) Measurement of snow surface temperature during the fly-over from Apogee surface temperature sensor mounted on the tower shown in (b). (c) IR image and (d) visual image of the site taken from the aircraft.

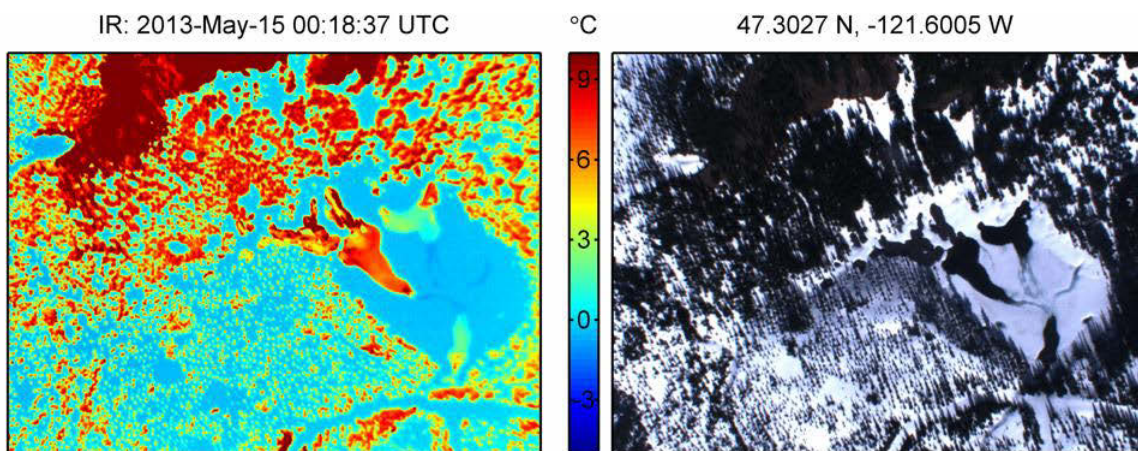


Figure 9. IR (left) and Visual (right) imagery of forests, rocks, snow and ice near the Rex River SNOTEL station in the Cedar River Watershed (see Fig. 6 for approximate location), reveal a wide variability in thermal temperatures.

DISCUSSION

FAA Requirements for UASs (and How They Affect Feasibility)

A significant institutional barrier for public agencies flying UASs in the United States is related to the limited ability of a UAS operator to “see and avoid” other aircraft. This concern is the main reason that the Federal Aviation Administration (FAA) requires UAS flights to obtain a Certificate of Authorization (COA) (Dalamagkidis et al. 2008, 2009) to fly in the national airspace (NAS). At this time only public agencies can obtain a COA to operate UASs in the NAS. (Private sector operators can obtain a different type of operating certificate.)

Obtaining an FAA COA application is an online process that requires several months. The application requires technical details about the aircraft; operation information about the plans for the UAS, including data and the flight area; performance information about the aircraft; and a certificate of airworthiness for the unmanned aircraft. As a public agency, the UW has an advantage in that it can certify the airworthiness of any UAS in the test. The COA, which is good for a year, stipulates a number of communications and operational protocols (FAA 2013a).

Fortunately, avalanche control and snow measurement activities typically occur over sparsely populated land, which reduces risks in terms of ground impact (Weibel and Hansman 2004), falling debris, and mid-air collision, and this simplifies justifying and obtaining a COA. Smaller or portable UASs with less mass also reduce these risks (Weibel and Hansman 2004, Anand 2007). Avalanche control and snow measurement operations, at least in Washington state, would typically occur in class G airspace, which has the lowest level of FAA regulation.

The FAA recognizes the increasing interest in civilian UAS use. The number of applications to obtain permission to fly has been steadily increasing, and the FAA has made an effort to streamline the application process and to better integrate UASs into the NAS (FAA 2013b, GAO 2013). The FAA has an Unmanned Aircraft Program Office that is specifically developing regulations and guidance for the use of UASs. This FAA office is also part of a team developing an annually updated five-year roadmap for the integration of UASs into the NAS (Joint Planning and Development Office 2012, GAO 2013).

Dalamagkidis et al. (2008, 2009), in an extensive review of the issues related to the integration of unmanned aircraft in the NAS, concluded that safety concerns will ultimately guide the regulation of UASs. The study also concluded that successful integration of UASs in the airspace will require “enabling” technology. Fortunately, a number of technology-based solutions, such as in-aircraft sensors, ground control radar systems, and

transponders, are being researched or are under development (Anand 2007, UAS Vision 2013, Joint Planning and Development Office 2012).

Congress recently mandated that the FAA develop and obtain social benefits from this technology and required that the FAA develop test site programs for the “purposes of gathering safety and technical information relevant to the safe and efficient integration of UAS into the NAS”(Brito et al. 2013, GAO 2013). The FAA is also in the process of selecting six national UAS test sites from 25 applications, including a consortium from Washington state that includes the UW (FAA 2012). The availability of test areas where UASs can more routinely fly without the FAA COA process should support the development of new UAS capabilities, including snow measurement.

This federal activity suggests that permission to operate UASs may become easier to obtain both because of technological improvements and bureaucratic streamlining of the authorization processes. This, in turn, supports snow-related and environmental sensing by UASs. One possible complication is concern about UASs and privacy. This issue remains unresolved. A 2012 Government Accountability Office study noted that no federal agency has specific responsibility to regulate privacy matters relating to UASs for the federal government (GAO 2012). However, most snow-related operations tend to occur in lightly populated or unpopulated areas, which may reduce concerns about privacy.

Further Research Needs

Testing of the UAS

Mountain snowpack sensing with UASs needs to be tested. As discussed earlier, sensor payload integration and mission profiles are unique to aircraft type, sensor package, and mission, so there is value in testing with a candidate UAS such as Flexrotor.

Experience with visible and IR cameras on UASs, often for surveillance, is extensive. However, snowpack sensing missions have sensor data requirements that differ from surveillance missions, and in certain cases specialized hardware is required. For example, using IR sensors for snow surface temperature measurement requires additional onboard hardware for calibration. Such hardware is not available in a standard UAS IR camera package. That is why additional testing for snowpack sensing missions, even for situations when “off the shelf” sensors can be used, would doubtless provide important insights about usefulness and economics. Such analysis and testing would reveal needs specific to snowpack missions, such as operational protocols and UAS autonomy improvements for maintaining flight safety and economically gathering high quality, snowpack-specific data in mountainous terrain.

Previous research using UASs for avalanche control indicates that these aircraft have the capability to visually survey avalanche control areas before explosives are used and to drop charges to trigger controlled avalanches. In addition, the ability to use sensor on UASs to evaluate snow surfaces and snow stability could have notable value. Further research is needed to both determine if UASs can efficiently and economically complete these avalanche control tasks and also to evaluate if the existing or future regulatory environment will permit the routine use of UASs.

Testing of the Sensors

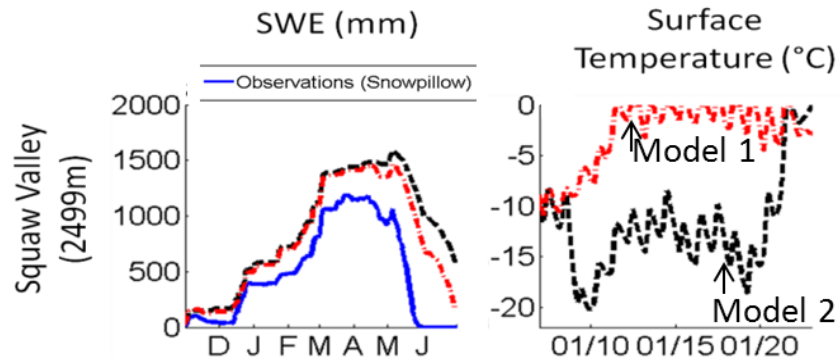
Some of the most promising sensors for use on snow-sensing UASs, specifically IR and near-IR photography, are just starting to be used by the snow science community. Therefore, further work is needed to determine their strengths and weaknesses and how to best use them in operations. For example, are errors on the order of 2°C in actual snow surface temperature acceptable when such measurements are used to predict locations of hoar frost formation or for improving snow modeling? Preliminary data (based on model runs detailed in Wayand et al. 2013) suggest that even with 2°C errors, such data would be able to select the best model out of an ensemble of runs (Figure 10) because modeled snow surface temperature differences often vary by 10°C or more. Therefore, work is needed on measuring and using these data types from ground-based collectors before the aerial potential can be fully utilized.

Testing by Management Agencies

UASs could enhance a public agency's overall operational efficiency by adding aerial surveillance capability where it would not have been previously considered because of cost, manned aircraft flight limitation, or simply the time required to set up and contract for a manned flight. For example, for resource agencies, a UAS could be used for snow measurement in the winter and spring, wildfire monitoring in the summer, and landside mapping in the fall. For a state DOT outside of the avalanche control season, UASs could provide traffic counts and surveillance along roadways where fixed cameras are not feasible.

The numerous applications for which UASs could be considered include the following:

- Forest mapping (height, density)
- Soil moisture (drought, fire)
- Forest fires and impacts (visual, IR)
- Stream temperatures (fish habitat)
- Agriculture
- Landslide mapping
- Downscaling NASA satellite images
- Identifying ecological impacts of climate or land-use change
- Search and rescue
- Transportation monitoring (volumes, roadway conditions).



- **Figure 10. Snow model simulations (from Wayand et al. 2013) highlighting that in January, simulated surface temperature varies by more than 10°C at a time when simulated snow depth is identical. The model errors in the energy balance only appear in the snowpack in late May and June when melt is under way.**

SUMMARY

Mountain snowpack is important as both a hazard (avalanches, floods) and a resource (water supply). Therefore, snowpack monitoring is essential for predicting the times and places of avalanche hazard and to quantify the snow water equivalent (the amount of water if the snow melted) within a watershed. Currently, snow is monitored through time at point locations (avalanche snow pits and water resources SNOTEL stations), and local knowledge of spatial variation is used to extrapolate from the points to areas of interest. These methods work well as long as spatial patterns remain fixed through time, but they present difficulties when spatial variability differs from average (which occurs frequently in extreme events that matter most to society).

Aerial monitoring of the snowpack allows agencies to map spatial variations in snow properties in real time and to quantify, with repeat flights, how snow varies in space and time. The instruments most suited for mounting on a UAV, such as the Flexrotor, are visible and IR wavelength cameras. These instruments are lightweight, robust, and can map snow at less than a 1-m spatial resolution (depending on height flown and specific camera resolution). For avalanche forecasting, visible wavelength imagery can identify areas of cornice formation and verify that no people are below an avalanche control area, and IR imagery can identify spatial patterns of surface hoar formation and faceting (which lead to weak layers and avalanches following subsequent snowfall). For water resources, aerial imagery can be used to map snow presence and absence spatially across the landscape (visible wavelength), to identify snow depth from aerial markers (visible), and to map snow surface temperature (IR). Potential exists to map snow depth across the landscape by using digital photogrammetry, and researchers are beginning to investigate this technique. Snow depth is much more variable than snow density, and therefore, spatial maps of snow depth (from multiple aerial markers or photogrammetry) can be converted to spatial maps of snow water equivalent on the basis of a one-point location density measurement (available at SNOTEL sites). Snow surface temperature can be used as a snow model calibration and validation tool where snow is being modeled spatially across a watershed (as is true for most high-value Northwest watersheds). Watershed-wide snow data are critical for water resource managers to use in forecasting summer water supplies and planning hydropower operations.

Currently, SNOTEL stations provide daily snow data at fixed points. These are supplemented by monthly human snow surveys (to fill in information about spatial variability) during the spring. In California, LiDAR is being flown weekly on a test basis to fill in all spatial data for the Tuolumne River Watershed. For Washington, morning flights following clear winter nights would be ideal for mapping regions of surface hoar formation. Regular flights following storms that added substantial snowfall would be ideal for both avalanche and water resources applications, followed by weekly flights during the melt season to assess snow melt rates and snow disappearance.

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