NCHRP Project 20-44(17)

Implementing the Results of *NCHRP Project 20-68A, Domestic Scan 17-01: Successful Approaches for the Use of Unmanned Aerial Systems by Surface Transportation Agencies*

Final Report

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Prepared for
National Cooperative Highway Research Program

by
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DISCLAIMER

CONTENTS

EXECUTIVE SUMMARY

This project implemented the recommendations presented in NCHRP Project 20-68A, Domestic Scan 17-01. Specifically, the project designed, developed, and deployed Unoccupied Aircraft Systems (UAS) training for DOT personnel. A split training program was employed to accommodate the challenges posed by the COVID-19 pandemic. The first part of the training consisted of ten virtual sessions covering UAS foundational information. The second part of the training was a 5-day, in-person workshop in which participants engaged in hands-on flight operations and data processing activities. The training materials, consisting of recorded lectures and hands-on tutorials were compiled and will be delivered to state DOTs through AASHTO's online learning portal. Access to the materials and additional information can be found on the project website.

https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4827

INTRODUCTION

Unoccupied Aircraft Systems (UAS) have the potential to revolutionize DOT operations. UAS-based bridge inspections can be safer and less costly by reducing the need to put a person in a dangerous position. Right-of-way (ROW) surveys can take place in hours instead of days. Traffic monitoring using UAS provides a unique perspective and is cost-effective compared to conventional aircraft. Aerial surveys of construction sites can confirm contractors are meeting timelines and adhering to environmental regulations. Search and rescue missions can happen more rapidly and at a lower cost by directing rescue teams to persons needing assistance. However, integrating UAS into operations poses human resources, policies, procedures, and information technology challenges as with any new technology.

The report for NCHRP Project 20-68A, Domestic Scan 17-01, made specific recommendations for the successful implementation of UAS in organizational structure, policy and regulation, safety and risk management, training and crew qualifications, public relations, and application and operation. This project drew on the outcomes from NCHRP Project 20-68A, Domestic Scan 17-01 to provide tailored UAS training specifically in the areas of safety, risk management, flight operations near structures, night operations, and thermal sensing.

This project successfully implemented a pilot training program for members of the Vermont Agency of Transportation (VTrans), Vermont Department of Public Safety (VT DPS), Maine Department of Transportation (MaineDOT), Massachusetts Department of Transportation (MassDOT), and the New Hampshire Department of Transportation (NHDOT).

This training enabled these agencies to reduce UAS operational liability, maximize the UAS potential uses, enable DOT staff to perform UAS operations at a higher level more resourcefully, and shorten the response time for UAS-developed deliverables. It also created an online repository of training material, including recorded lectures and self-paced tutorials.

TASKS AND TIMELINE

Initial Proposal

The initial project proposal and work plan included six tasks throughout 2020, as outlined in Figure 1. The objectives of Task 1 were to initiate the project, develop a project work plan, host a site visit (if required), engage stakeholders, and plan for the workshops. Tasks 2-5 were focused on a series of in-person workshops involving safety and risk management, flying in proximity to structures, night operations, and thermal imaging. These multi-day workshops included lectures, data processing, flight operations, and other hands-on approaches to engaging with the topics. The proposed timeline for Tasks 2-5 spanned from June to August 2020. Task 6 activities centered on documentation and finalizing online materials, which were planned to take place from September 2020 until the conclusion of the project.

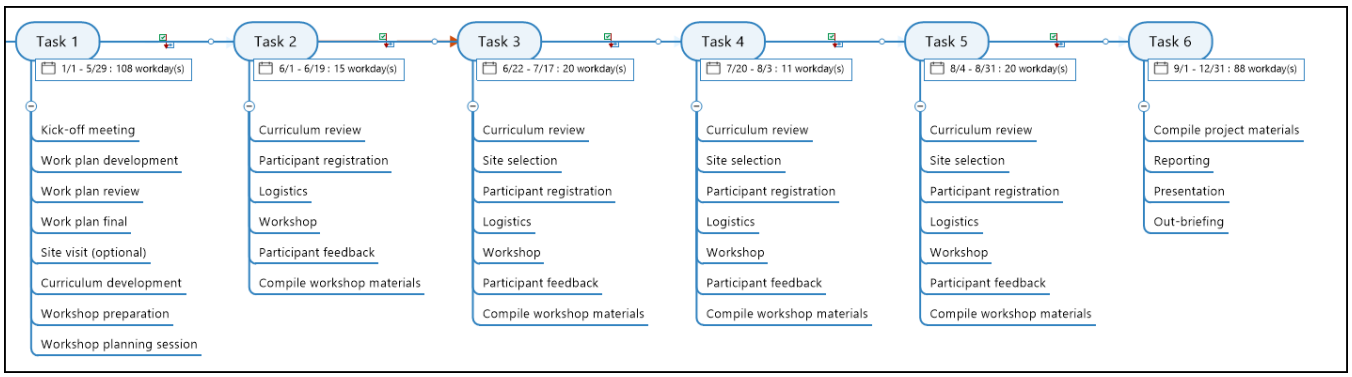

Figure 1: Project proposed tasks and activities

COVID-19 Impact

As a result of the COVID-19 pandemic beginning in early 2020, the original proposed tasks and timeframes were revised and presented to the project committee in May 2020. The revised plan substantially modified the tasks from the original proposal to better align the project with the challenges posed by the pandemic, including the requirement to accommodate the policies, procedures, and recommendations of participating organizations along with those from the federal and state governments. The original main goal of this project was to offer in-person UAS training workshops in the summer of 2020, but COVID-19 gathering and travel restrictions prevented this from happening. The new work plan realigned the tasks and timelines, adding a virtual training component to the project and shifting the training activities of the project into virtual lectures and a week-long in-person workshop during the summer of 2021.

These changes, while not ideal, did provide new opportunities. The move to virtual training enabled the creation of additional training materials, which supports the goal of integrating the project results into AASHTO's online training platform. To accommodate the costs associated with extending the project and adding virtual training sessions, the three separate workshops listed in the initial proposal were consolidated into a single in-person workshop lasting five days. The changes resulting from

COVID-19 required the project to be extended, with a revised project end date in April 2022. This was achieved via a no-cost extension to the project. A list of revised tasks is below, along with a detailed view of task durations and schedules in Figure 2.

Task 1: Kick-off and stakeholder engagement

Task 2: Virtual training

Task 3: Workshop planning and preparation

Task 4: Workshop

Task 5: Compile training materials

Task 6: Reporting

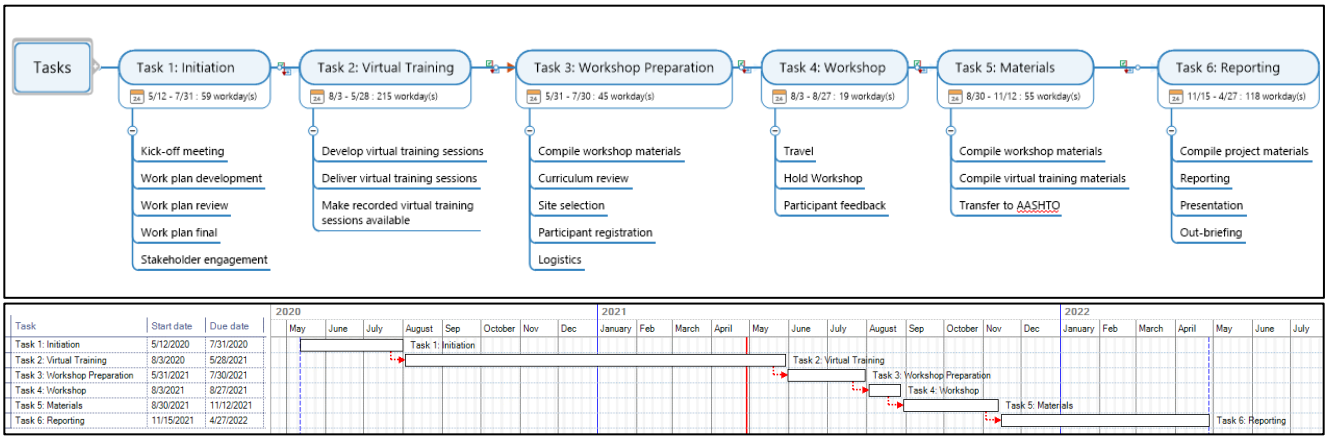

Figure 2: Revised tasks and timeline resulting from the COVID-19 pandemic

Results

TASK 1: KICK-OFF AND STAKEHOLDER ENGAGEMENT

Kick-Off Meeting

An online kick-off meeting was held in May 2020 with the project managers, state DOT stakeholders, and project team. The impact of COVID-19 on the project was discussed with the group, with the project team presenting three proposals on how to proceed. The unanimous decision was made to adjust the project timeline and provide virtual trainings in 2020 and 2021, followed by a single in-person workshop in 2021.

Work Plan

The work plan was adapted to address the impact of COVID-19 and then submitted to NCHRP for review and finalization in July 2020.

Stakeholder Engagement

During the project's advisory board meeting in September 2020, the project team presented the workplan and virtual training sample content. Stakeholder agencies provided an overview on the status of their UAS programs. This included a summary of organizational profile, such as structure, personnel, platforms and sensors, and mission types being conducted. Each agency also shared future plans for developing their UAS capabilities, current challenges, expected challenges, and training needs.

TASK 2: VIRTUAL TRAINING

In Task 2, 10 virtual training sessions were hosted for participants. These hour-long sessions were designed to address the training needs identified by stakeholders and prepare participants for the in-person workshop to follow. Offering virtual lectures enabled the in-person workshop to be consolidated into a single week, which provided cost savings and better addressed the challenges posed by COVID-19.

Each session focused on important aspects of successful UAS implementation, providing knowledge, considerations, techniques, case studies, live demonstrations, and other ways of engaging with the material. Another key component of these sessions was connecting with participants to gain feedback on organizational challenges and needs, as well as to foster discussions and communication between participating agencies. An application called Mentimeter was utilized during live sessions to generate interactive questions and polls, gather instant responses, and facilitate these conversations.

Below is a list of the virtual training sessions and the key topics presented in each. Each virtual training session was recorded and the video was then published on the project website, allowing for review by participants who were unable to attend.

UAS Organizational Considerations - October 23rd, 2020

- Strengths and limitations
- Personnel and training
- Platforms and sensors
- Information Technology
- Policies and procedures
- Foundations
- Support
- Challenges

Flight Data Management & Equipment Tracking - November 6th, 2020

- Importance of management and tracking
- What to track
- Flight metadata
- Data logging
- Data retention

- Battery and equipment management
- Logging and management solutions

Geospatial Visualization and Analysis - November 20th, 2020

- Geospatial workflow
- Photogrammetric processing
- Image display
- Imagery analysis
- Terrain data display
- Terrain data analysis
- 3D visualization
- CAD & GIS integration

Principles of Aerial Photography and Videography - December 11th, 2020

- Camera settings
- Composition
- Lighting
- Storytelling and context
- Post-processing of imagery and video

Platform and Sensor Selection - January 22nd, 2021

- Multi-rotor vs Fixed wing
- Types of sensors
- Applications
- Cost considerations
- Accuracy

Risk Assessment - March 26th, 2021

- Aeronautical decision making
- PAVE risk assessment (Pilot, Aircraft, Environment, External Pressures)
- Risk management and mitigation techniques
- Flight Risk Assessment Tool (FRAT) and risk matrices
- Equipment and team management
- Mission and flight checklists
- Real-world examples

Waivers - April 9th, 2021

- Waivable regulations
- Application process
- Airspace authorizations
- Night operations

- Operations over people
- BVLOS
- Special circumstances

Operations Near Structures - May 7th, 2021

- Challenges
- Training and proficiency
- Crew composition
- Platform selection
- Sensor selection
- Collision avoidance and tolerance
- Artificial intelligence technology
- Camera considerations
- Flight planning
    - Structure
    - Height
    - Wind and airflow
    - Fail-safes
- Structural inspection procedures
- Vertical surface mapping
- 3D modeling
- Cost considerations
- Case studies

Night Operations - May 21st, 2021

- Applications
- Updated FAA regulations
- Certifications
- Anti-collision lighting
- VLOS at night
    - Vision considerations
    - Night illusions
    - Dark adaptation
    - Best practices
- Risk assessment
- Preflight preparations
- Success cases

Thermal Imaging - June 4th, 2021

- Principles of thermography

- Electromagnetic spectrum and infrared wavelengths
- Emissivity and reflections
- Heat transfer and thermal capacitance
- Resistance to conduction and other anomalies
- Environmental factors
- Electrical inspections, subsurface lines, and other use cases
- Platform and sensor considerations
- Measurement accuracy
- Potential limitations
- Additional training and standards

TASK 3: WORKSHOP PLANNING AND PREPARATION

Task 3 activities centered around preparing for the in-person workshop. The workshop was designed to be five days in length with the ability to accommodate up to 35 participants.

A major part of this task involved development of the workshop schedule, learning modules, flight demos, and additional activities for hands-on training. Other tasks included organizing the technology component of the workshop, arranging lodging and meals for all participants, and preparing participant travel and meal reimbursement. Organizations received pre-registration surveys to identify their personnel that would be attending the workshop. These attendees completed an online registration to facilitate their lodging accommodations and dietary preferences in advance of the workshop.

TASK 4: WORKSHOP

This task consisted of the five day in-person workshop on campus at the University of Vermont from August 2nd -6th, 2021.

Attendees

A total of 17 participants attended the workshop. Attendees were members of the Massachusetts DOT, New Hampshire DOT, Maine State Police, Vermont State Police, VTrans, and Vermont Forests, Parks, and Recreation. Participants were led by an instructional team of eight from UVM and ARE Corporation.

Schedule

Figure 3 presents the workshop schedule during the event.

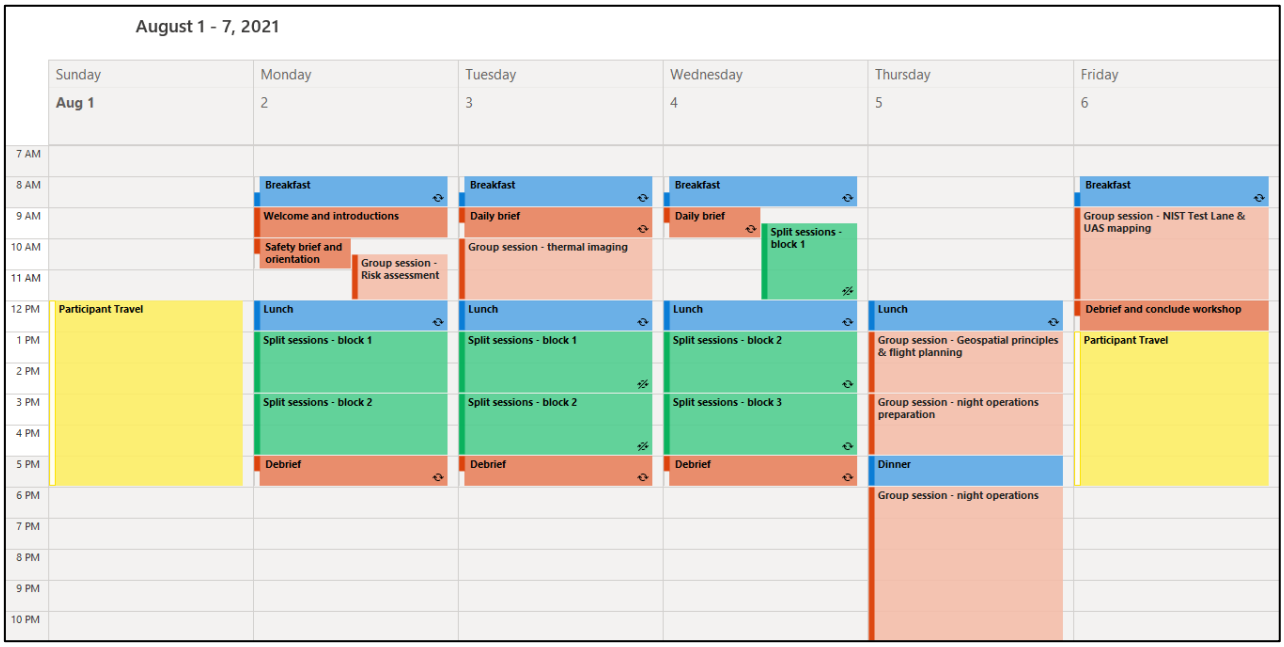

Figure 3: In-person workshop schedule

Activities

Morning briefs provided an overview of the day's activities and the sessions that would take place. Group sessions gathered all participants for presentations, discussions, safety briefings, and demonstrations. During split sessions, participants were divided into groups to create smaller learning environments and promote higher levels of engagement. Initially, members of the same organization preferred to be in the same group to strengthen communication and teamwork skills throughout the workshop. Groups consisting of participants from multiple agencies were also formed in order to facilitate discussion and collaboration between the organizations.

Lectures and Discussions

Several group lectures and discussions were held during the workshop.

Risk Assessment & Risk Management

This series of presentations and conversations focused on discussing participants' organizational approaches to assessing and managing risk before, during, and after UAS missions.

Thermography

Rob Spring of The Snell Group, a renowned thermography trainer, presented on key topics of thermal imaging and UAS applications, including properties of infrared radiation, the impacts of environmental conditions on thermography, requirements for accurate measurements, applications of thermography, and imaging system characteristics and capabilities.

Remote Sensing Principles

Presentations covered the basics of remote sensing and its applications with a more in-depth look at LiDAR and multispectral imaging techniques. This session also introduced advanced analysis of point clouds derived from both UAS LiDAR and UAS photogrammetry, including exploratory analysis, viewshed analysis, cross-section creation, and generation of digital surface models and digital elevation models.

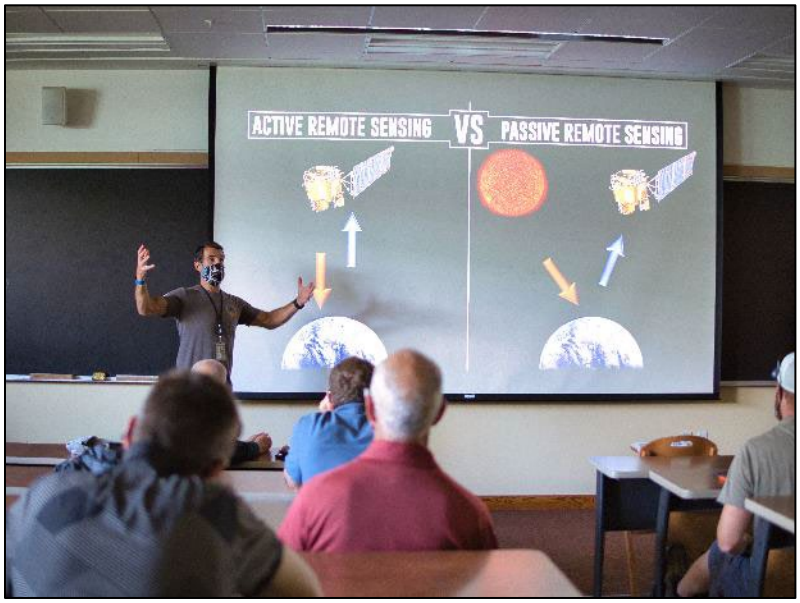

Figure 4: Discussion of remote sensing principles

Advanced Flight Planning

Participants engaged with the project team to review advanced flight planning techniques for data capture in complex terrain, such as areas with significant topographical relief. This interactive session used examples suggested by participants to review flight planning applications and workflows in the context of real-world locations in which these organizations would like to fly more safely and efficiently.

Night Operations

Prior to conducting nighttime operations, this lecture reviewed regulations, risk assessment, pre-mission and preflight checklists, and other best practices for flying UAS at night. Emphasis was placed on safety and risk management, ensuring all participants were prepared to engage in the subsequent nighttime operations.

Participant Feedback

Participants split into groups to reflect on the topics and activities offered throughout the week and discuss future workshop considerations. Mentimeter was used to foster conversation and gather this feedback.

Technology Sessions

Technology sessions took place in a computer teaching lab. Workstations were pre-configured to provide participants with access to the latest versions of different UAS processing software, GIS and remote sensing software suites, and online data publishing. The training modules, developed by the project team, allowed participants to gain practical first-hand experience in simulated UAS flight planning and flight operations, and generating, analyzing, and disseminating UAS-derived data products. Training modules were developed and accessed through the Rise360 online learning

management system. Descriptions of the training modules are below, with each providing first-hand experience in solving transportation-focused scenarios.

Technology Orientation
Introduction to software packages and IT infrastructure at UVM that was used during the workshop.

Train Derailment Mapping
Introduction to an end-to-end workflow for photogrammetric mapping for a train derailment response scenario.

Rock Slope Modeling
Introduction to concepts of generating and analyzing a 3D model of a rock slope near a roadway.

Construction Monitoring
Photogrammetric mapping of new roadway construction, comparison to historical geospatial data, and GIS analysis.

Volume Estimation
Generation of 3D models using photogrammetry to calculate stockpile volumes. These principles can also be applied to calculating volume loss due to wash-out or erosion along road corridors.

Coastal Change Monitoring
End-to-end workflow of flight planning, data capture, processing, and analyzing coastal change.

Multispectral Mapping
Planning, collection, processing, and analysis of multispectral imagery to quantify the growth of aquatic invasive species.

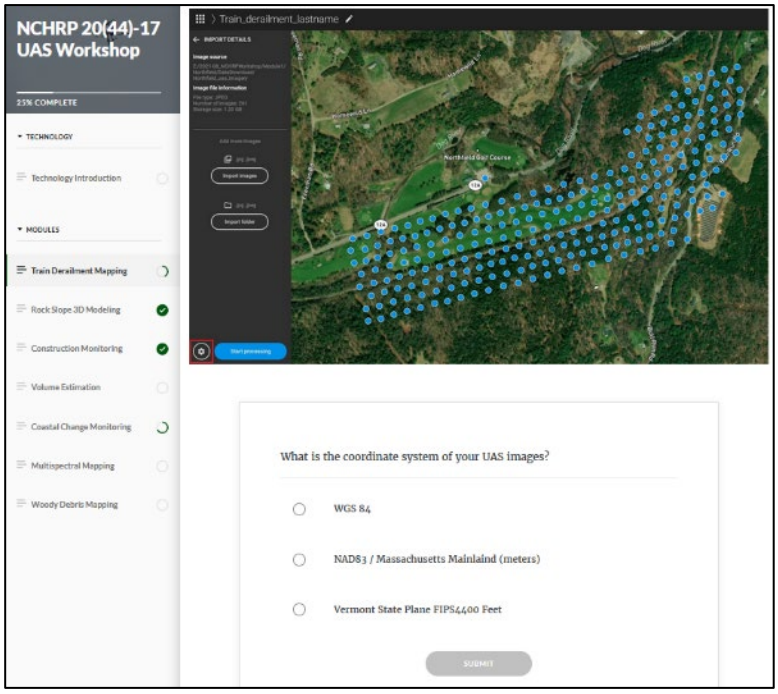

Figure 5: Example of learning module for train derailment mapping

Woody Debris Mapping
End-to-end exercise on quantifying the change in woody debris in a stream corridor following a storm using UAS imagery.

Field Sessions

Outdoor training sessions took place at UVM's Redstone Green. A wide range of the project team's platforms, payloads, and additional equipment were made available during these sessions and participating organizations also brought their own UAS to utilize during training excercises. A mixture

of demonstrations and hands-on activities each day provided participants with the opportunity to gain real-world experience with topics presented during lectures and modules.

Platform/Sensor Demonstrations

Flight demonstrations provided insight into the different platform and sensor options being used by the involved agencies in the region, including a variety of sensors and multirotor and fixed-wing UAS. The project team and participating organizations shared details about their equipment, facilitating exposure to a wide range of systems and promoting conversations surrounding varying organizational preferences and approaches.

Photogrammetric Mapping

Participants gained first-hand experience in planning and executing mapping missions with UAS, focusing on a variety of key flight planning considerations including imagery overlap, flight speed, resolution, altitude, and flight line orientation. These skills were developed using UAS from several manufacturers and with multiple flight planning applications to provide details about varying approaches to developing a mapping workflow. Collected imagery sets were processed by participants and the project team to generate geospatial outputs.

Figure 6: Instruction on creating efficient flight plans for mapping

Inspection and 3D Modeling

Participants practiced structural inspection and modeling techniques at a water tower on UVM's campus, which offered a safe yet challenging location for flight. In gaining first-hand experience with flying near structures, participants furthered their understanding of risk assessment and management for this type of mission profile. Simulated inspection tasks were assigned to pilots, which developed proficiency in planning and executing flights for imagery collection in varying lighting conditions near a large complex structure.

Thermal Imaging

The water tower was also used as a training ground to develop familiarity with thermal imaging techniques and results. Participants built on their knowledge from the previous training sessions and lectures to conduct manual flights and collect meaningful thermal imagery and video for interpretation.

Figure 8: Participants plan and execute collection of thermal imagery

NIST sUAS Test Lane

The National Institute of Standards and Technology's (NIST) standardized test methods for sUAS were developed to provide an objective way to measure and track the proficiency of remote pilots. Throughout the workshop, participants developed and honed their piloting proficiency by flying multiple configurations of the test lanes. The bucket lanes offer a variety of arrangements and courses to test different skills such as orbiting, maneuvering, landing, and more.

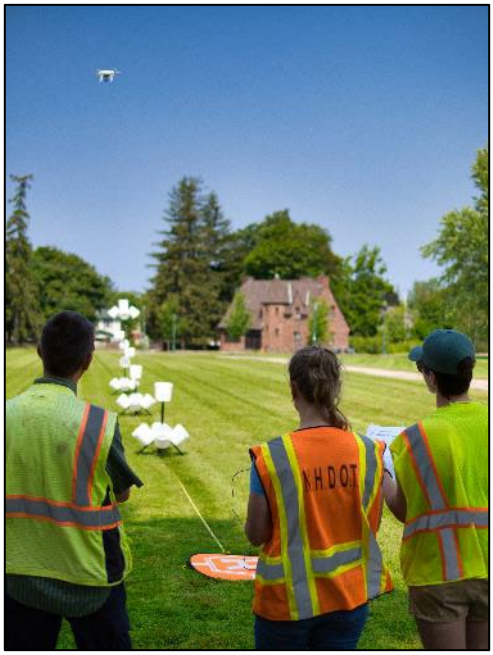

Figure 7: Participants practice flight proficiency on a NIST sUAS Test Lane

Photography

An instructional session was held to review concepts of aerial photography including camera settings, composition, lighting, and framing. Participants gained insight about the challenges of UAS photography and practiced capturing high-quality imagery and video using the available UAS platforms during sunset and 'golden-hour' conditions.

Night Operations

After an in-depth safety briefing, nighttime UAS operations were conducted with an emphasis on safety, risk management, and regulatory compliance. Participants gained experience in preparing equipment for night operations, including configuration of UAS anti-collision lighting, lighting landing pads, and preparation of PPE including high-visibility vests and headlamps.

Participants used their organization's UAS platforms and those supplied by the project team to become familiar with basic flight characteristics at night and to understand the capabilities of their visible-light and thermal sensors in low-light conditions.

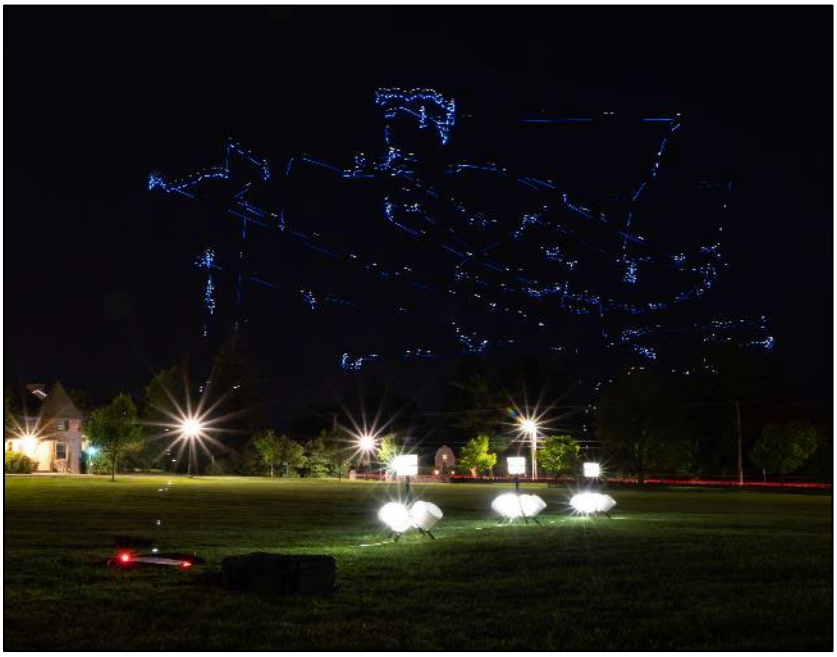

Figure 9: Light trails highlighting UAS trajectory at night around a NIST Test Lane

The NIST test lane was set up and equipped with lights for participants to practice manual flight skills and maneuvers at night. The test lane configuration also included several heated targets to allow for practice with thermal sensors.

Additionally, participants carried out mock search and rescue scenarios to gain practice with flight planning and sensor performance as related to emergency response efforts at

Figure 10: A pilot conducts a search & rescue simulation to locate a person using a high-resolution thermal sensor (right)

night. These scenarios focused on the use of thermal sensors and both automated and manual flight to locate humans and static objects in an open field and below forest canopy.

Workshop Feedback

During the final phases of the workshop, the project team convened with the participants to collect feedback about the training sessions. Open discussions, along with anonymous live polling via Mentimeter, were conducted to solicit feedback about this workshop and for future follow-on training opportunities.

Figure 11: Workshop feedback from participants

Based on captured responses and group discussions, participants appreciated the networking and collaboration opportunities with other organizations and the ability to learn from both the instructional team as well as other participants. The focus on practical, hands-on learning with various UAS platforms, sensors, and software packages was also highlighted as particularly valuable.

Participants shared that they may have preferred a workshop longer than 5 days, which may have alleviated the 'software saturation' in being exposed to many different workflows and software packages in such a short amount of time. Other feedback touched on requests to have even more hands-on flight experience during the field excercises. This could be accomplished in a future workshop by both increasing the number of UAS platforms available for participants to fly and further increasing the number of instructional staff.

Future Training Interests

Participants were asked to rank the types of activities they would most like to see in future workshops. Attending a technology demo day, highlighting different hardware and software solutions was popular, as were a similar in-person workshop and simulated disaster response exercise. Participants were least interested in online lectures as future training activities.

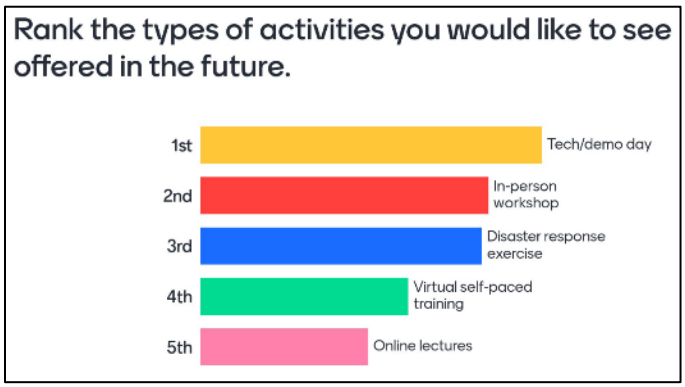

Figure 12: Ranking of future training activities

When asked about topics they would most like to see covered in future workshops, the most interest was shown in flight operations, organizational considerations, and flight planning, risk assessment, and data processing.

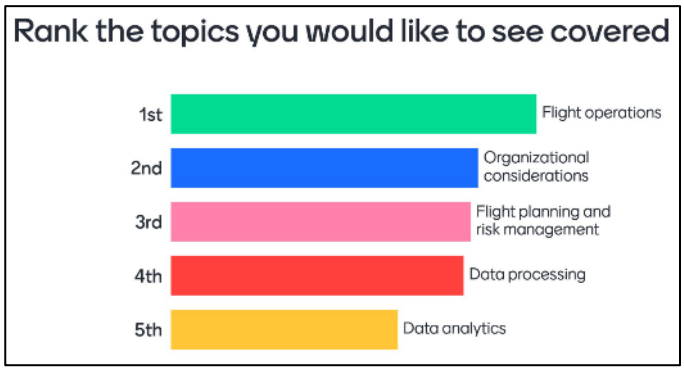

Figure 13: Ranking of future training topics

In terms of flight operations, specific interests were primarily in spending more time training on the NIST Test Lane and practicing mapping missions. Main organizational considerations that were requested to be covered are related to IT/data management, improving support from leadership, and selecting platforms and sensors. Thermal, LiDAR, and true-color imagery were the sensor types that participants would most like to learn more about. Photogrammetric processing, 3D analytics, and GIS analysis were the most requested software and data workflows for future trainings.

Participants also provided several suggestions for future training topics. Primarily, these involved request for different types of simulated scenarios and excercises

- End-to-end photogrammetry mapping excercises, including flight planning, flight operations, data processing, analysis, and data dissemination
- Specific instruction and excercises for specific types of near-structure operations, including in GPS-denied environments
- Emergency and disaster response simulations and excercises
- Facilitation of collaborative use case and project development between involved organizations

TASK 5: COMPILE TRAINING MATERIALS

To support the dissemination of the materials generated as part of this project, the project team has assembled and compiled the virtual training and workshop materials.

Project Website: https://go.uvm.edu/vci0t

Self-Paced Online Learning Modules: https://go.uvm.edu/d2at4

Virtual Lecture Series Video Recordings: https://go.uvm.edu/i7m3b

Virtual Lecture Series Slides (PDF): https://go.uvm.edu/9wnbo

TASK 6: REPORTING

This document is the final project report. The project team will host an online meeting to present the project results to the funding agency.