Aviation Investigation Final Report

Location:	Blacksburg, Virginia	**Incident Number:**	DCA18IA269
Date & Time:	August 14, 2018, 13:30 Local	**Registration:**	FA3HCWCR4X
Aircraft:	DJI Phantom	**Aircraft Damage:**	Minor
Defining Event:	Loss of control in flight	**Injuries:**	1 Minor, 1 None
Flight Conducted Under:	Part 107: Small UAS		

Analysis

The sUAS was operating under the provisions of Part 107 within Class G airspace. The pilot was appropriately certificated for the flight.

Examination of the drone data logs revealed no anomalies with the aircraft or software. The drone responded to control inputs as expected. The pilot erroneously believed that the "down and in" CSC input would result in a landing or in-flight shutdown of the motors. The Phantom 4 user manual specifies that the "down and in" CSC shuts down the motors only when the drone is on the ground. Inputting that command in flight would result in the drone yawing right, pitching backward, and banking left. Logs indicated that the drone maneuvered consistently with the stick inputs. Further, the pilot indicated the drone would not land. Logs indicate that he used the Autoland feature, which scans the landing surface with optical sensors (Visual Positioning System or VPS) to determine if the surface is suitable. Logs indicate the VPS did not calculate a suitable landing surface. This is consistent with the pilot's report of trying to land on a plastic table, which likely created excessive reflections. In order to conduct a normal landing, the pilot would need to switch out of Autoland, or override it by holding the throttle (left stick) fully back for 2 seconds. Logs indicate the aircraft remained in Autoland mode, and the stick was not pulled fully back for more than ½ second at any time.

The demonstration flight was conducted in a small area, confined by trees, and within close proximity of the observers, 10 feet or less according to witness statements. Although there is no evidence that the pilot flew directly over unprotected persons, or purposely in a hazardous manner, at the time that he perceived a problem with the drone and decided to crash it, the close proximity to the observers should have been accounted for either by warning them to clear away, having an assistant do the same, or to conduct the forced landing in an area clear of the observers.

At the time of the incident, the university and CMI did not have any documented procedure for conducting such demonstrations. Although not required by regulation, the incident pilot did not have any documented aircraft-specific training that might have included the flight manual procedures noted above.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this incident to be:

the drone pilot's incorrect control inputs due to insufficient knowledge of the aircraft flight manual procedures.

Contributing to the incident was the close proximity of the observers, and the decision to conduct a demonstration near the observers in a confined area with no assistance.

Findings

Personnel issues	Incorrect action selection - Pilot
Personnel issues	Decision making/judgment - Pilot
Environmental issues	Person - Decision related to condition
Organizational issues	Initial training - Other institution/organization

Factual Information

History of Flight

Landing	Loss of control in flight (Defining event)

HISTORY OF FLIGHT

On August 14, 2018, at 1330 eastern daylight time, at the Mountain Lake Biological Station, Blacksburg, Virginia, a Dà-Jiang Innovations (DJI) Phantom 4 small unmanned aircraft system (sUAS, commonly known as a drone), registration FA3HCWCR4X, operated by the Virginia Tech Conservation Management Institute (CMI), collided with a bystander resulting in minor injuries. There was no damage to the drone. The flight was an educational demonstration flight conducted in Class G airspace under the provisions of 14 Code of Federal Regulations (CFR) Part 107. Visual flight rules conditions prevailed at the time of the incident.

The flight was part of a demonstration for students of the Virginia Tech College of Natural Resources and Environment. There were six students observing the flight. According to the pilot, the demonstration was intended to consist of a short, automated flight over a pond using the DroneDeploy control application (app) to show how mapping surveys were conducted, followed by a manual flight to view wildlife in the pond. On the day of the incident, the pilot conducted a mapping flight prior to the demo. The pilot reported that, during the mapping flight, he attempted an automatic landing but the drone "missed its homepoint," and the Director of CMI hand-caught the drone. The pilot reported that he "used the manual shutdown procedure, which worked correctly."

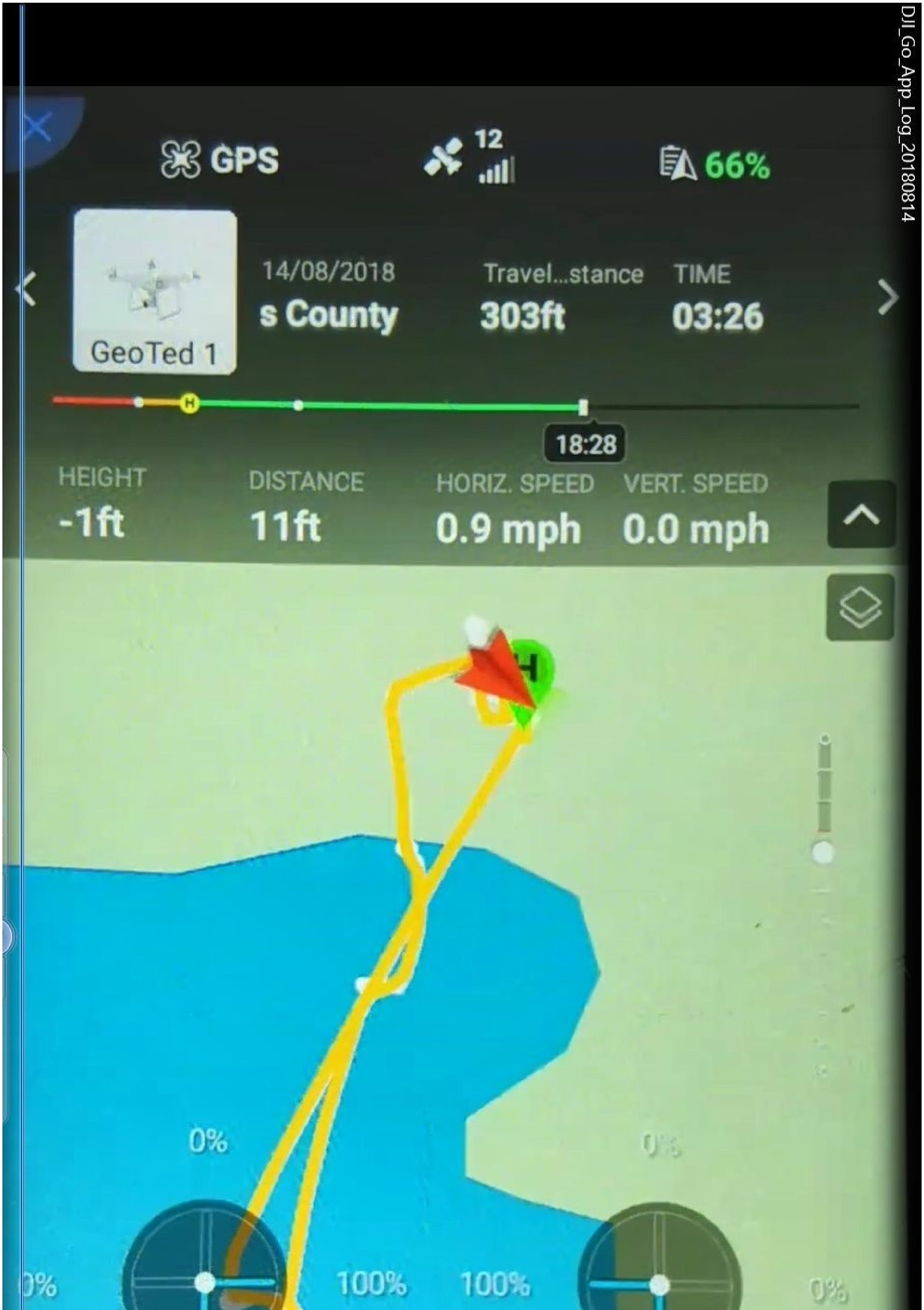
The flight demonstration area was near a small beach and grassy area adjacent to the pond (figure 1). The area and the pond were surrounded by trees. Plastic lawn chairs and tables were in the area.

Figure 1 – Photo of Operating Area

The six students who were observing the demo flight were located less than 10 feet from the pilot. There was no visual observer or other assistant to the pilot for this flight. He started the demo in manual flight mode, and took off from a plastic picnic table on the berm of the pond. He reported the flight was normal, although the wind picked up a little bit during the flight. He flew the drone back to the picnic table for landing but reported that it would not touch down onto the table. The pilot reported that he made numerous attempts to land and attempted "the shutdown procedure," but the drone flew off to the side. He then reported that he climbed the drone back up and attempted an automatic landing and a landing in the grass, again using the "shutdown procedure," but the drone did not respond as he expected. He reported that he did not feel comfortable having one of the students try to hand-catch the drone, so he decided to crash it. The drone flew laterally and struck one of the students resulting in the injury, then continued into bushes where it stopped.

The pilot reported that the "shutdown procedure" that he used was to position the two control sticks (called a Combination Stick Command, or CSC) "down and in," meaning that the left (throttle/yaw) stick is pulled fully back and to the right, and the right (pitch/bank) stick is pulled fully back and to the left.

Examination of the logs revealed that, at 1 minute10 seconds before the end of data, the drone was being maneuvering at low altitude near the home point in GPS mode. Then the pilot partially decreased throttle followed by the "down and in" CSC.



DJI_Go_App_Log_20180814

Figure 2 – First CSC command 1:10 prior to end

According to the DJI Phantom 4 User Manual, the "down and in" command shuts down the motors immediately when the drone is on the ground. Alternatively, a method to stop motors on the ground is to retard the throttle straight back and hold for 3 seconds (figure 3). The method for emergency stop of motors in flight or prior to the drone sensing that it has landed is to pull the throttle back and to the right while simultaneously pressing the Return to Home button (figure 4).

Stopping the Motors

There are two methods to stop the motors.

Method 1: When Phantom 4 has landed, push the left stick down ①, then conduct the same CSC that was used to start the motors, as described above ②. Motors will stop immediately. Release both sticks once motors stop.

Method 2: When the aircraft has landed, push and hold the left stick down. The motors will stop after three seconds.

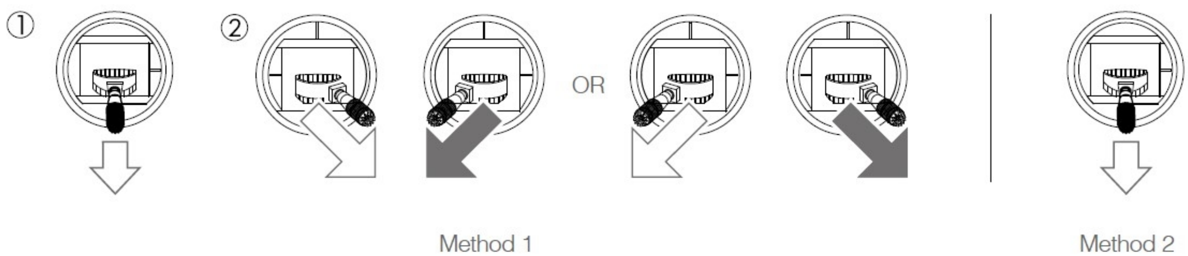


Figure 3 – Excerpt from Phantom 4 User Manual, Stopping the Motors

Stop the motor mid-flight

Pull the left stick to the bottom inside corners and press the RTH button at the same time. **Only stop the motors mid-flight in emergency situations when doing so can reduce the risk of damage or injury. Refer to the user manual for details.**

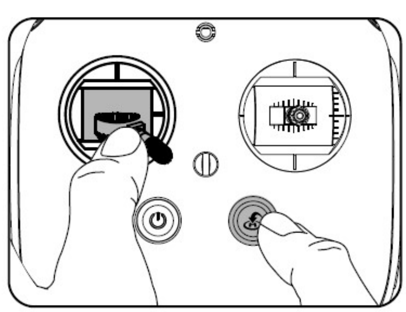


Figure 4 - Excerpt from Phantom 4 User Manual, Stopping the Motors in Flight

The log data showed that, while the drone was still in the air, it responded to the pilot's "down and in" CSC input by pitching up, yawing right, and banking left. Logs indicated a "braking" message indicating the obstacle avoidance/visual positioning system (VPS) was activated.

The data showed that, when the pilot then neutralized the sticks, the drone hovered. Another braking message was recorded consistent with proximity to objects or persons. Fifty-four seconds prior to the end of data, the pilot activated the drone's "Autoland" feature, and the drone hovered briefly before the pilot input another "down and in" CSC. The drone again responded in pitch, yaw, and roll.

The data showed that, 49 seconds prior to the end of data, the pilot increased the throttle, and the drone climbed while still in Autoland mode. Ten seconds later, the pilot released the throttle, and the drone descended with no stick input, consistent with its Autoland feature. During the descent, another "down and in" CSC was given by the pilot, and again, the drone responded consistently. The logs indicated that, following each CSC, the drone's obstacle avoidance activated, consistent with the low altitude and proximity to objects and persons.

The drone subsequently climbed and then reentered an Autoland mode descent, and, at 28 seconds prior to end of data, the pilot reduced the throttle and held it fully back for less than a half second. The drone's automatic Landing Protection feature activated, consistent with the drone detecting an unacceptable surface to complete a landing while in Autoland mode. Twenty-two seconds before the data ended, the sequence repeated, with the pilot reducing the throttle, but not fully and only for 1.2 seconds. The DJI Phantom 4 User Manual describes numerous factors which will prevent the Autoland feature from completing the landing (figure 5).

Landing Protection Function

Landing Protection will activate during auto landing.

1. Landing Protection determines whether the ground is suitable for landing. If so, the Phantom 4 will land gently.
2. If Landing Protection determines that the ground is not suitable for landing, the Phantom 4 will hover and wait for pilot confirmation. The aircraft will hover if it detects the ground is not appropriate for landing even with a critically low battery warning. Only when the battery level decreases to 0% will the aircraft land. Users retain control of aircraft flight orientation.
3. If Landing Protection is inactive, the DJI GO 4 app will display a landing prompt when the Phantom 4 descends below 0.3 meters. Tap to confirm or pull down the control stick for 2 seconds to land when the environment is appropriate for landing.

⚠

- Landing Protection will not be active in the following circumstances:
  a) When the user is controlling the pitch/roll/throttle sticks (Landing ground detection will re-activate when control sticks are not in use)
  b) When the positioning system is not fully functional (e.g. drift position error)
  c) When the downward vision system needs re-calibration
  d) When light conditions are not sufficient for the downward vision system
- If an obstacle is within 1-meter of the aircraft, the aircraft will descend to 0.3 m above the ground and hover. The aircraft will land upon with user confirmation.

Figure 5 - Excerpt from Phantom 4 User Manual, Landing Protection

The drone was maneuvered at low altitude until the pilot input a "down and in" CSC 4 seconds prior to the end of data; the drone responded in pitch, yaw, and bank, followed shortly by an ESC (electronic speed controller) error, which is consistent with the propellers striking objects. According to witnesses, the drone struck the ground and moved laterally toward the bystanders. The injured person attempted to jump out of the way, but the propellers struck her in the lower legs. The drone continued into nearby shrubbery, and the pilot retrieved it and shut down the power.

INJURIES TO PERSONS

First aid was conducted at the incident scene. The injured bystander received multiple lacerations to both legs requiring nine stitches, glue, and butterfly bandages at a hospital outpatient urgent care.

PERSONNEL INFORMATION

The drone pilot held a Federal Aviation Administration (FAA) Part 107 Remote Pilot Certificate and had logged a total of 3.7 hours as Remote Pilot in Command (RPIC), most of which was on the senseFly eBee fixed-wing drone and the 3D Robotics (3DR) Solo quadcopter. He had logged 8 minutes RPIC on the Phantom 4 but reported about 2 hours of experience with it as a hobbyist. He was also experienced acting as Visual Observer and other crew positions. He did not hold any manned aircraft certificates.

His training on the Phantom 4 consisted of performing some basic maneuvers at a practice field using various DJI GO 4 functions, and practicing using the DroneDeploy flight control app. He reported experiencing no incidents during this training.

AIRCRAFT INFORMATION

The Phantom 4 is an sUAS of quad-copter configuration, about 13 inches in diameter. It is powered by four electric brushless motors and a 4-cell 15.2v lithium-polymer battery. The maximum takeoff weight is 3 pounds, maximum altitude is about 19,685 feet msl, and its maximum endurance is 28 minutes. Specified maximum range of the remote controller is 3.1 miles. The drone is equipped with a GPS/GLONASS navigation system and a flight controller enabling various automated functions. The drone is equipped with a 12-megapixel digital camera capable of still or video recording, and first-person view display. Aircraft telemetry and video is transmitted to the remote controller in the 2.4 gHz band and displayed on a smartphone or tablet of the pilot's choice using an app supplied by the manufacturer (DJI GO 4) or various third-party app developers.

The Phantom 4 includes a feature to provide automatic obstacle avoidance under certain conditions. Obstacle avoidance uses optical and ultrasound sensors to detect obstacles up to about 43 to 50 feet away from the drone and initiate braking or avoidance. The forward obstacle avoidance covers approximately a 60-degree field of view and downward covers approximately a 40-degree field of view. There is no obstacle avoidance in other directions.

The incident drone was being operated using firmware revision dated November 16, 2017. The pilot reported that he was controlling the aircraft via a Samsung Galaxy J7 smartphone using the DJI GO 4 app and that he normally conducted mapping flights using the DroneDeploy app. All obstacle avoidance and vision positioning systems were turned on.

The incident drone had been involved in a crash in May 2017, resulting in a tear to the shell and a misaligned motor. The drone was repaired in November 2017, and the compass and IMU (inertial measurement unit) recalibrated at that time. The compass and IMU had not been recalibrated since then.

METEOROLOGICAL INFORMATION

The weather station at the Biological Station reported temperature 80 degrees Fahrenheit, visibility 10 miles, wind at 8 knots. The weather observation at Blacksburg Airport, about 12 miles southeast of the accident site, reported wind from 240 degrees at 5 knots, 10 miles visibility, with scattered clouds at 4,100 feet above ground level.

AIDS TO NAVIGATION

Data logs from the drone indicated sufficient GPS signals throughout the flight. There were no NOTAMs of any GPS outages or anomalies in the area.

COMMUNICATION

The pilot filed a UAS Operating Area notice, commonly known as a "DROTAM" prior to flight. There were no applicable airspace restrictions in the area.

FLIGHT DATA

The Phantom 4 records full flight parameters on non-volatile on-board memory, and video or still photography on a micro SD card in the aircraft. The aircraft was retrieved by the CMI UAS lead, and the downloaded data was sent to the NTSB for examination.

The DJI GO 4 app records select telemetry parameters to the pilot's display tablet. CMI provided a text download of the tablet log, and screen captures of the log replay.

Data from the above sources is cited in the History of Flight section of this report and included in the public docket.

The NTSB investigator consulted with DJI engineering when reviewing the data logs; results are contained in History of Flight.

ORGANIZATIONAL AND MANAGEMENT INFORMATION

Structure of University UAS Operations

According to the Virginia Tech UAS Safety Manager, the university had a wide variety of departments, laboratories, and individual operators involved with UAS in support of coursework, research, and flight operations. Each of these offices and operators, some under the direction of individual professors and managers, are responsible for their own training, planning, safety management, and operations. The university is also associated with the Mid-Atlantic Aviation Partnership (MAAP), an FAA test site program, as well as the Virginia Integration Pilot Program (see below). The Safety Manager described the various university UAS organizations and their relations to each other as "confusing."

The UAS Safety Manager position was an independent position and consultation resource to the university UAS community, as well as to the MAAP. The UAS Safety Manager did not hold oversight authority over specific labs or organizations.

A guide for flying UAS at Virginia Tech, for various purposes was hosted on a MAAP webpage (https://maap.ictas.vt.edu/index.html) linking to instructions for using the university "drone park" and various other facilities, and included an online flight request form which it indicated was reviewed and passed to "the UAS Oversight Committee."

In August 2017, the university enacted a UAS policy, as well as protocols (Virginia Tech Policy 5820 Operation of Unmanned Aircraft Systems) to cover a variety of situations and areas. These established a baseline of qualification and approvals necessary for university-affiliated flights. The policy was administered by a UAS Oversight Committee (UASOC). This policy generated flight operations protocols for various locations, including one for university aircraft operated on non-university property.

The intent of the UASOC was to provide oversight of UAS operations at the university by putting in place the protocols that guide the safe operation of the drones. Operational oversight of the daily operations was the responsibility of the organization under which the operations are occurring. The Policy 5280 document described a requirement for online submission of a Flight Operations Request, reviewed by the UAS Safety Manager for safety, operability, and legality. and the UASOC, for review and deconfliction with other campus activities. However, these approvals were not used for operations conducted off university property.

The Policy 5280 document stated that it:

"*…doesn't require that the UAS Oversight Committee approve each operation…[however] The basic requirements for Virginia Tech flight still apply: ... Complete Virginia Tech UAS Training*"

The Virginia Tech UAS Pilot Safety Training course included:

- *A review of 14 CFR Part 107*
- *Virginia Tech Policy 5820, location Protocols, and the online VEOCI UAS Flight Request*
- *Virginia Tech UAS Incident and Accident Reporting*
- *Virginia Tech Airspace*
- *A review of UAS operation "best practices", performance, and technical data*
- *General UAS Emergency Procedures*
- *UAS Privacy and Security Issues*
- *Virginia Tech UAS Insurance and Liability information*
- *A review of ITAR and EAR information*
- *UAS Crew Resource Management (CRM)*
- *UAS Safety Awareness and Responsibilities*

At the time of the incident, according to the UAS Safety Manager, the training requirement had not been validated or employed. The RPIC had not received this training.

External Cooperative Programs

The MAAP is FAA UAS Test Site that is one of the many UAS-related programs at the university, albeit a well-known program that works with many external companies and agencies. The Test Site agreement with the FAA governs MAAP's flight operations that are conducted under the Test Site umbrella. MAAP has developed detailed risk management, airworthiness, and safety review processes for Test Site operations, but those processes only apply to MAAP operations and are not applicable across the university's other UAS activities that are not part of the Test Site program. MAAP administratively falls under the Virginia Tech Institute for Critical Technology and Applied Science (ICTAS), which is a research institute that focuses on investing in programs to support the research mission of the university. MAAP is not affiliated with any academic college, department, or program, but MAAP does support numerous groups by providing expertise on the operation of UAS.

The Commonwealth of Virginia's Integration Pilot Program (IPP) is led by the Innovation and Entrepreneurship Investment Authority (IEIA) and the Center for Innovative Technology (CIT). MAAP has an agreement with IEIA to run the daily operations of the IPP, based on the Test Site experience and structure. Operations for the IPP and UAS Test Site are subject to the same policy and UASOC oversight as any other program on campus, and MAAP does not administer or provide operational oversight of any other university operations beyond its own activities.

Virginia Tech CMI

CMI uses UAS to conduct research, outreach, and education. CMI focuses on natural resource related applications such as habitat mapping, wildlife monitoring, and burn monitoring. Outreach programs include demos for prospective students, remote sensing, and natural resource-related classes, and working with university extension agents for events such a Forage and Fields Day. Educational work includes assisting with the UAS GeoTED program, which is aimed at educating the educators, instructing community college teachers how to operate a UAS safely, obtain a Part 107 certificate, and on different types of UAS and sensor payloads.

CMI's UAS team is a staff of two and operates the senseFly eBee fixed-wing drone and 3DR Solo quadcopter, in addition to the DJI Phantom 4.

CMI staff indicated that their demonstration flight procedure was not formally documented, but they typically followed the below actions:

CMI UAS Demo Procedure

- Check airspace.
- Get permission for the property the demo will be conducted at.
- File DROTAM.
- Conduct DJI Self-Unlock if necessary.
- Update software/firmware/apps to be used.
- Preflight check.
- Check weather.
- Preflight Safety Brief
    - Abbreviated version of full brief for demonstration attendees.
    - Inform all present to stand back at a designated location or distance from the UAV.
    - Inform them that if the UAV appears to be heading towards them to move to the side, do not try to out run the UAV.

    - Inform all present that all UAV's must yield right away to manned aircraft and if they see or hear any other aircraft to inform the RPIC, even if they think the RPIC is aware of the other aircraft.

- RPIC should, if at all possible, place themselves between onlookers and UAV.

CMI provided an Operating Guide and Checklists for the eBee and Solo but did not have one for the Phantom 4.

The Mountain Lake Biological Station was University of Virginia property; therefore, the operation did not require any request through the Virginia Tech system. The CMI chief pilot explained that they had been conducting demos there for 3 years with departmental approval and the Station management. It was not specified what the clearance entailed, and there were no records of any flight operations clearances or requests for the Biological Station site.

Information

Certificate:	**Age:**
Airplane Rating(s):	**Seat Occupied:**
Other Aircraft Rating(s):	**Restraint Used:**
Instrument Rating(s):	**Second Pilot Present:**
Instructor Rating(s):	**Toxicology Performed:**
Medical Certification:	**Last FAA Medical Exam:**
Occupational Pilot:	**Last Flight Review or Equivalent:**
Flight Time:	

Aircraft and Owner/Operator Information

Aircraft Make:	DJI	**Registration:**	FA3HCWCR4X
Model/Series:	Phantom 4	**Aircraft Category:**	Helicopter
Year of Manufacture:		**Amateur Built:**	
Airworthiness Certificate:	None	**Serial Number:**	unk
Landing Gear Type:	Skid	**Seats:**	0
Date/Type of Last Inspection:		**Certified Max Gross Wt.:**	4 lbs
Time Since Last Inspection:		**Engines:**	
Airframe Total Time:		**Engine Manufacturer:**	
ELT:		**Engine Model/Series:**	
Registered Owner:	Virginia Tech Conservation Mgt Institute	**Rated Power:**	
Operator:	Virginia Tech Conservation Mgt Institute	**Operating Certificate(s) Held:**	None

Meteorological Information and Flight Plan

Conditions at Accident Site:	Visual (VMC)	**Condition of Light:**	Day
Observation Facility, Elevation:		**Distance from Accident Site:**	
Observation Time:		**Direction from Accident Site:**	
Lowest Cloud Condition:		**Visibility**	
Lowest Ceiling:		**Visibility (RVR):**	
Wind Speed/Gusts:	/	**Turbulence Type Forecast/Actual:**	/
Wind Direction:		**Turbulence Severity Forecast/Actual:**	/
Altimeter Setting:		**Temperature/Dew Point:**	
Precipitation and Obscuration:			
Departure Point:	Blacksburg, VA	**Type of Flight Plan Filed:**	None
Destination:	Blacksburg, VA	**Type of Clearance:**	None
Departure Time:		**Type of Airspace:**	Class G

Wreckage and Impact Information

Crew Injuries:	1 None	**Aircraft Damage:**	Minor
Passenger Injuries:		**Aircraft Fire:**	None
Ground Injuries:	1 Minor	**Aircraft Explosion:**	None
Total Injuries:	1 Minor, 1 None	**Latitude, Longitude:**	37.207778,-80.407775

Administrative Information

Investigator In Charge (IIC):	English, William
Additional Participating Persons:	
Original Publish Date:	August 23, 2019
Last Revision Date:	
Investigation Class:	Class
Note:	The NTSB did not travel to the scene of this incident.
Investigation Docket:	https://data.ntsb.gov/Docket?ProjectID=98099