EVALUATING UNMANNED AIRCRAFT SYSTEMS FOR SNOW AVALANCHE MONITORING IN WINTER WEATHER AND IN MOUNTAINOUS TERRAIN

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ABSTRACT

The Norwegian Public Roads Administration (NPRA) completed an evaluation of Unmanned Aircraft Systems' (UAS) ability to operate in winter weather and in mountainous terrain in support of snow avalanche monitoring. Vendors flew nine multi-rotor, rotary-wing, and fixed wing aircraft on four increasingly difficult missions ranging from flights over a nearby road and bridge to a 2.3 kilometer flight to a 1300 meter mountain to inspect avalanche features. Results indicated that there is no single UAS that meets all of the road administration's needs. The fixed wing aircraft were more capable in bad weather and could fly greater distances to view avalanche release zones. However, they are not always stable camera platforms and required more skill to operate. Multi-rotors were easier to operate and more stable but are less capable in winds and had more limitations when flying to distant features. In general, the photo and video output of the UASs was usable for avalanche assessment. The UAS all flew following the national aviation authority's line of sight and distance regulations which reduced their ability to travel to out of sight terrain. This suggests that NPRA should work with the authorities to establish permanent danger areas above avalanche zones where beyond line of sight flying is routinely permitted. A multilevel NPRA institutional approach to using UAS was proposed were small multi-rotor aircraft are owned and operated by NPRA and used to look at close-in snow features. For longer flights, fixed wing aircraft flown by a contractors may be the best solution.

Keywords: winter maintenance, unmanned aircraft, drones, snow avalanche, natural hazards

INTRODUCTION

The Norwegian Public Roads Administration (NPRA) is responsible for 55,000 kilometers of roads. Norway is a northern country with mountainous terrain, severe winters, and frequent snow falls. As a result, the NPRA has an active winter maintenance program which includes roadside snow avalanche monitoring and control. The NPRA recognizes that unmanned aircraft systems (UAS) (also commonly known as drones) are increasingly available and potentially have applications that support NPRA's data collection, natural hazards detection, and transportation system monitoring needs. The NPRA, working in collaboration with the Norwegian University of Science and Technology (NTNU), funded a three day demonstration evaluating UAS usability to support snow avalanche monitoring while operating in winter weather and in mountainous terrain. The findings will be used to develop guidelines for UAS usage by the NPRA.

BACKGROUND

Part of the NPRA's mission is to monitor and react to snow avalanche hazards in steep areas above their roads. A common situation is where a road is closed due to a snow avalanche (this also applies for rock falls and landslides). NPRA avalanche staff (usually geologists) are required to determine as quickly as possible if it is safe to reopen the road or if it is necessary to do clearance work. NPRA staff uses a variety of means to view and evaluate the slide area including roadside observations with binoculars and travel by foot, ski, snowmobiles, and manned helicopters. Given the urgency to open roads, manned helicopters, while expensive, are often used by NPRA. Because of pre-arranged contracts, a helicopter can quickly be mobilized to fly a NPRA geologist above an avalanche site. If the geologist is able to adequately view the release area and the avalanche path, they typically can make a quick assessment whether to open the road or to keep it closed.

Small unmanned aircraft are increasing capable, affordable, and commercially available. There has been a wide range of transportation-related applications of this technology including for natural hazards monitoring, infrastructure inspection, surveying, and mapping (1, 2). Given the growth of commercially available UAS, the NPRA wanted to evaluate if this technology could replace or enhance their current methods of monitoring avalanches. One notable motivation was the possibility that UASs could make avalanche monitoring safer by permitting staff to view avalanches without traveling close to a possibly dangerous release site or without having to fly manned helicopters in the mountains. So one question was if UAS technology may provide comparable or additional capabilities for manned helicopters contracted by the NPRA. As with UASs, weather is a limitation for using manned helicopter. However, manned helicopters may be more restricted than UAS in bad weather because a helicopter's operational failure can put human life at risk whereas a UASs operational failures almost always only involve equipment loss or damage. In addition, a manned helicopter use maybe limited because they often have to travel some distance from a base at an airport where flights can be grounded due to localize bad weather while the avalanche site itself could still be in flyable weather.

The use of UAS potentially could support more effective monitoring and perhaps with a quicker response time. Beyond some tests in Washington state (3) and test flights by NPRA in 2014, there have been minimal explorations or applications of UASs for snow avalanche monitoring and control.

While UAS could extend the capability of NPRA's avalanche monitoring staff, there are some notable operational challenges. One obvious limitation is that avalanches only occur in the mountains where steep terrain present obstacles for safe flights. Mountains often generate strong and gusty winds. Small UASs often do not perform well in winds either because they cannot fly against strong winds or because they are not stable enough to be usable camera or sensor platforms. Snow avalanche risk often rises during winter storms so monitoring avalanches requires that the aircraft are able to fly in poor weather. Many UASs operate using batteries and cold temperatures degrades a battery's capacity and reduce an aircraft's flight duration. Poor visibility due to snowfall and fog can also limit UAS's range particularly if they have to follow rules requiring them to fly in line of sight. Other winter conditions such as icing and freezing rain are potentially a limitation on flights.

GOALS

The purpose of the demonstration were to evaluate the use of UASs by NPRA to support avalanche monitoring operations. The specific goals were to:

1. Allow vendors an opportunity to present the capabilities of their unmanned aircraft systems to staff from the Norwegian Public Roads Administration (NPRA).

2. Provide unmanned aircraft vendors an opportunity to demonstrate that their systems can operate in winter weather and mountainous terrain and can support NPRA's interest in routinely using this technology for snow avalanche monitoring.

In support of these goals, the NPRA circulated a tender inviting Norwegian UAS owners, operators, and manufacturers to apply to demonstrate the capabilities of their aircraft during winter. Only Norwegian vendors were invited both because the UAS industry is advanced in Norway and because using foreign operators would have complicated the flight approval process with the Norwegian aviation authorities (Luftfartstilsynet). This tender requested that the vendors complete flights that would indicate if their UASs can support existing and future aerial surveillance needs of the NPRA in winter weather. The demonstration's six member evaluation team who conducted the test, and documented the findings had professional expertise in avalanche monitoring, UAS piloting and operations, winter road maintenance, and technology evaluation.

The evaluation criteria listed in the tender and used to select the vendors are listed below along with the ranking percent assigned to each:

1. operate in colder temperatures (desirable is an ability to operate in temperatures down to -15 C), (5%)
2. fly in winds (desirable is an ability to operate in winds of up 10 meters per second), (10%)
3. fly at altitudes (desirable is an ability to operate up to 500 meters above the launch site), (5%)
4. have sufficient flight endurance and flight speed to be able to complete an effective surveillance and return to a safe landing site (desirable is an ability to conduct an surveillance at a location up to 2000 meters from a launch site), (15%)
5. fly pre-determined courses either partially-autonomously or fully autonomously, (15%)
6. be sufficiently portable so they can be transported in standard vehicles and be launched beside roads, (5%)
7. have safety features beyond a required return-to-home capabilities, (5%)
8. provide a live video feed (potentially including technology known as first person view, point of view, or video goggles) of selected geological feature (slide paths, snowfields, etc.) and manmade features (bridges, roads, etc.), (15%)
9. provide high quality recorded images of the features investigated, (10%), and
10. demonstrate the use of any other innovative viewing, sensor, or detection capabilities (15%).

Norwegian vendors with both fixed and rotary wing aircraft were encouraged to apply. Successful applicants were awarded 30,000 Norwegian Kroner (about $3,700) to support their participation in the flight test. Eleven vendors applied and seven were selected based on the evaluation criteria. One vendor later dropped out because their systems were not ready at the time of the test. This resulted in nine different aircraft systems being available through the participating companies. The type of aircraft and aircraft capabilities, and approximate cost, if known, are shown in table 1.

TABLE 1 Aircraft and vendors used in the test.

Aircraft Type/ Power	Aircraft Brand, Country of Manufacture	Stated Capabilities and Costs						
		Portability	**Duration in minutes**	**Minimum Operating Temp. (Centigrade)**	**Winds (meters/ second)**	**Camera/ Sensors used**	**Payload (Kilogram)**	**Cost in Norwegian kroner NOK (8 NOK ~= 1$)**
helicopter jet engine	SkyRobot RX100, Norway	trailer used for transport	120 with payload	-20°	10	video and still camera, Sonar a7R and Flir Vue infra-red	Up to 12	2,500K
multirotor electric	Drona HL, Norway	catapult launch	30 s	-10°	16	video and still camera , Sonar a7R and Flir Vue IR	10	180K
fixed wing electric	C-Astral Bramor C4Eye system, Slovenia	catapult launch, parachute landing, van used for transport and operations	Up to 180	-23°	15	sandard definition video with 640 resolution and long-wave infrared.	NA	600K
multirotor electric	Camflight T X8 ROBOT, Norway	van used for transport and operations	45	-20°	12	Nikon Coolpix still camera and video camera	1.5	NA
multirotor electric	MR MC001 Quadcopter, Norway	trailer used for operations	30	-20°	15	Sony A6000 in 3-axis moveable with HD video link	2.5	200K
fixed wing electric (gas option)	MR Dolphin, Norway	catapult launch, trailer used for operations and transport	30	-15°	25	video and still camera	8	300K
multirotor electric	AscTec Falcon 8, Germany	operated outside	12-22	-5°	15	video and still camera	1.8	419K
fixed wing electric	eBee, Switzerland	operated outside, hand launchable, back-packable	50	-15°	12	still camera	0.700	229K
multirotor electric	Lockheed Martin, Indago 2, United States	operated outside, back-packable	45 - 50	-34°	17	standard definition video with 640 resolution and long-wave infrared.	0.2	700K

THE TEST SCENARIOS AND FLIGHTS

Bjorli airfield in central Norway was used as a base for the three day (March 1 to 3, 2016) demonstration. This small airfield is at 575 meters above sea level and was closed for flight operations for the winter and was leased by the NPRA for winter tests. The area was ideal for this demonstration because it had a large open area for flights, buildings where the vendors could wait between flights, and accommodations were available at a nearby ski resort. Next to airfield was a motocross course which could represent a NPRA roadway. The airfield was located in valley with several nearby rugged mountains. Two of them, Brennhø 1148 meters and Kvernhushø 1316 meters, were used for the demonstration.

The project team wanted difficult weather which did occur. As one vendor noted the tests *"were carried out under very challenging meteorological conditions as well as difficult terrain."* The temperature ranged from -3 to -10° C and winds averaged 8 meters/second (m/s) at ground level and up to 15 to 18 m/s at 120 meters above ground level. Gust of up to 22 m/s were measured by several aircraft during the demonstration. The sky was overcast but for the most part the visibility was good. There was around 30 centimeters of soft snow on the ground.

A limiting factor for the flights was the way the demonstration was set up with the Norwegian aviation authorities. All vendors used visual line of site (VLOS) or Extended Visual Line Of Sight (EVLOS) rules requiring observers and limiting flight distances. Table 2 has more details about different types of flight rules (4). An observer was used for all the scenarios except for flights over the nearby motocross course which was visible from the UAS vendor's ground stations located at the airport.

TABLE 2 Flight Rules

Visual Line Of Sight (VLOS) operations	Requires keeping the unmanned aircraft in visual-line-of-sight at all times and the aircraft is not allowed to fly more than of 120 meters above ground.
Extended Visual Line Of Sight (EVLOS)	The pilot is required to use one or more remote observers to keep the unmanned aircraft in visual sight at all times. The observers relay critical flight information via radio and assist the pilot in maintaining safe separation from other aircraft. The aircraft is not allowed to fly more than 120 meters above ground.
Beyond Visual Line Of Sight (BLOS)	This involves flying an unmanned aircraft without observers and there is not a requirement to keep the unmanned aircraft in visual line of sight. The pilot flies the aircraft by instruments from a remote ground station. BLOS flying at altitudes up to 120 meters in controlled airspace may only be performed in active danger areas or restricted areas.

Several vendors were certified to use BLOS but the demonstration's arrangements with the aviation authorities only supported VLOS and EVLOS operations. If BLOS were to be allowed, additional arrangements with the authorities would have been required.

Four mission scenarios were developed which were designed to test the aircraft in missions as might be routinely required by NPRA staff. In addition to the ability to perform the scenarios, the UASs were assessed throughout the demonstration for overall usability for the NPRA in terms of:

1. equipment transportation,
2. maintenance, set up and operation including software input for autonomous flight,
3. refueling or recharging,
4. available sensors,
5. operator input such as first person view,
6. number of operators required, and
7. operator training.

The mission scenarios and the resulting flights are as follows.

Mission A (Day 1)*: Norway's Motocross Way is blocked by a snow avalanche. NPRA staff wishes to quickly inspect the route for additional blockages, roadway damage, stranded vehicles, and view snow depth poles next to the roadway. Rather than walk or ski the road, the NPRA wants to use a UAS to follow the road and provide high quality images*.

The purpose of this scenario was to operate the aircraft in a less complex environment to explore their setup time and operational characteristics and their ability to view roadways. The motocross course next to the airfield was used to replicate a NPRA roadway. The course was snowplowed the day before the test. In addition, six traffic cones were placed on the course as targets to locate. All six vendors flew aircraft supporting this scenario. A number of vendors flew over the route guided in real time by cameras in the aircraft and operating by manual control. Another vender used a GPS to first map the course and then had the aircraft autonomously follow the course. This mission highlighted several vendors' ability to effectively survey and map a road or site. One vendor also had after-flight documentation that showed the coordinates of the six cones. Figure 1 show a UAS's camera view of the course and of a traffic cone on the course.

FIGURE 1 UAS view of the motocross course.

Mission B (Day 1)*: Reports from local people indicate the Bjorli Airport bridge might have been damaged by ice flows in the river. The NPRA can only access one end of the bridge and wants to inspect the bridge without the danger of walking out on a possibly damaged bridge. NPRA staff wishes to inspect the bridge with a UAS to look for damage of any type. This will require images from all sides of the bridge, and, if possible, from underneath the bridge.*

This scenario, using a small bridge near the airport, was designed to replicate the inspection of fixed facilities at a known locations that might be difficult to access. All the vendors participated in this test and there were many high quality photos and infra-red views of the bridge. Examples are seen in figures 2 and 3. None of the vendors were willing to fly under the bridge. Of note, one vendor used first person view googles which suggested increase versatility in examining a UAS's camera view in real time.

FIGURE 2 Bridge image from UAS

FIGURE 3 Infrared-red bridge photo

Mission C (Day 2) *Brennhø (1148 meters) is located directly above a county road that serves a number of houses and farms. After many centimeters of new snow, avalanche hazards were extreme so the NPRA closed the road. As predicted, an avalanche occurred blocking and closing the the road. NPRA staff needed to locate the release area to determine if there is any chance of a secondary avalanche before they reopen the trail. Rather than using a snowmobile or skiing to the top to check Brennhø, NPRA staff wishes to use a UAS to check for snow features related to avalanches - cracks, snow sluffs and what areas do or do not have snow. Adding to urgency of the need to fly the area, a skier might have been caught in the avalanche while skiing on Brennhø. The flight, as secondary task, should also look for any signs of this person. The nearest safe and flat area to operate from is a parking area 2 kilometers from the top of Brennhø.*

This replicated a situation where the NPRA's avalanche control staff needs to evaluate avalanche generating terrain above a roadway. In some situations, a primary avalanche occurs and the NPRA staff wishes to inspect the trigger zone to check that the initial avalanche has not created a situation that could lead to a secondary avalanche. A simulated slab avalanche was dug into the mountain (a 50 meter long and 1 meter deep trench) near the top of Brennhø (Figure 4). A pair of skis and poles were also placed 100 meters below the simulated avalanche to replicate the skier accident.

Two vendors, one with a fixed wing and one with a quad-rotor aircraft completed this scenario. Both UAS produced high quality images of the avalanche and the rotary wing aircraft also located the skis and poles. Figure 5 show UAS images of the simulated avalanche. Figure 6 is an infra-red view of the avalanche which clearly shows the avalanche's wall.

FIGURE 4 Simulated avalanche on Brennhø

FIGURE 5 UAV view of the simulated avalanche

FIGURE 6 UAS infra-red view of the simulated avalanche

Mission D (Day 3) *The famous Asbjørndalen tourist route travels beneath Kvernhushø (1316 meters) and is closed in the winter. In order to support touristic activity, the NPRA hopes to open this route up as soon as possible. Typically the NPRA hires a manned helicopter to survey Kvernhushø but that is expensive and can be dangerous. In order to survey cliffs, rock, and snow features on Kvernhushø, the NPRA hopes to use UAVs. These flights will operate from same area as mission C, which is 2.3 kilometers from the top of Kvernhushø. The main avalanche zones of interest to the NPRA is a large cornice located in the area northeast of the top of Kvernhushø. NPRA wants information on cracks and other snow features that may affect the stability.*

This was the most complicated scenario with longer flight distances and was designed to replicate a situation where the NPRA needs information on terrain up to 700 meters above roadway. The NPRA sometimes evaluates this type of mountain area using a manned helicopter. A parking area was set aside for launches (600 meters altitude). Two vendors flew this scenarios and the previous scenario at the same time. A vendor using a fixed wing aircraft was able to fly both missions from the valley below the mountains. This vendor later did not have enough motor power to fight against a downdraft and force landed their aircraft near the top of Kvernhushø (a controlled flight into terrain) and had to recover it using a snowmobile and travel on snowshoes.

Another vendor used a snowmobile to travel part way into the area closer to mountains at about 700 meter altitude and launched their small multi-rotor aircraft. This was the most portable system used in the demonstration and it fit in two small bags that could easily be carried in a backpack. Figure 7 is a view from this aircraft of the cornice on the top of Kvernhushø. The ability to travel closer to the area of interest using a snowmobile simplified the mission and likely would have increased the feasibility of using any portable UAS for this mission.

FIGURE 7 Screenshot from video showing cornice on of Kvernhushø

OVERALL RESULTS AND CONCLUSIONS

Six vendors flew nine different aircraft which were classified as quad-rotors, multi-rotors, helicopters, and fixed wing aircraft. Perhaps reflecting the overall state of the UAS industry, there were 17 successful flights, one vendor cancelled due to software problems, one aborted flight, one controlled flight into the terrain (a forced landing with only minor damage to one aircraft but with a several hours long recovery mission on foot), and several flight cancellations due to malfunctioning equipment. In addition, as expected, most of the vendors only flew the missions A and B adjacent to the airfield and not the later missions to the mountains Kvernhushø and Brennhø due to concern about the wind or the flight distance or a mismatch between what the system was designed to do (such as surveying) and the needs of the different scenarios.

The following points is a summary of the evaluation team’s conclusions from the demonstration. While demonstration was oriented toward the Norwegian Public Roads Administration, the result are also valid for any public agency considering using UASs for snow avalanche monitoring.

While the aircraft systems demonstrated enormous potential, there was is no single UAS that meets all of NPRA’s needs. The fixed wing aircraft were more capable of flying in winter weather and the greater distances and heights required to see some avalanche features. However fixed wing aircraft, because of their need to always move forward are not as stable of camera and sensor platforms as a multi-rotor which can hover. Fixed wing aircraft also required more skill to operate and taking offs and landings were more complicated often requiring launching catapult and a clear area or a parachute system to land. Multi-rotors were more stable sensor and camera platforms, easier to operate, needed minimal area to launch and land, and can fly closer to an area under observation. Conversely they are less capable in winds and do not currently have the range to fly to terrain features above a certain height or at some distance from the ground station’s location.

The UAS industry is growing rapidly and the NPRA should continue to explore the capabilities of drones. The UAS technology, capabilities, availability, and affordability have improved greatly over the last 5 years. This growth has enhanced the potential of this technology to address NPRA’s need in terms of avalanche control and winter operations. One product of this demonstration was that the participating vendors now had a better idea of the needs and operational requirements of a transportation agency such as the NPRA. Several vendors indicated that in the future they could better customize their systems and add new technology to address the challenges seen in the demonstration. In addition, the members of the demonstration team general felt UAS usage had a considerable potential to address the NPRA's needs.

Camera quality and sensor technology are critical to the usefulness of UAS for avalanche monitoring. The aircraft are simply a vehicle to carry cameras and sensors to an area of interest. In the demonstration, the photo and video quality general was good and several were exceptional. For example, the simulated avalanche in Mission C was quite easy to see using the camera on small quad-rotor. As an added benefit, this system fit in two small cases, was highly portable, and could be carried by skiers. This suggests in some cases, this use of this UAS and camera could replace the need for NPRA observers to travel into avalanche areas.

The greatest potential from UAS is the possible ability to enhance the NPRA's missions using evolving sensor technology. There are already research and applications that indicate sensors such as infra-red (IR), LiDAR and camera-based photogrammetry can provide information about snow pack and avalanche risk (5-8). Interestingly, the simulated avalanche in Mission C was identifiable on an IR camera. The research team recommend that NPRA should monitor sensor technology and consider testing technology that is mature, commercially available, and could be flown on small UASs.

Regulatory issues will impact the usability of UASs for the NPRA. The aircraft in the demonstration all flew following line of sight rules (VLOS and EVLOS) which required the aircraft to be observed by a person at all times and with height and distance limitations. These rules, required by Norwegian aviation's authorities, are very similar to UAS flight rules as required by many other countries. For example, see the US Federal Aviation Administration's UAS rules (9). Because the evaluation team wanted a range of aircraft types and vendors for the demonstration BLOS certification was not required. This clearly limited the usability of the aircraft to observe terrain features that were out of sight over the tops of mountain and ridges or down valleys. One of the evaluation team noted this limitation and commented that:

> *"I was not impressed by the vendor's capabilities in fulfilling the tasks. If there will be more similar tests, only BLOS-operators and EVLOS-operators should be invited."*

One vendor noted that the inability to legally use beyond line of sight (BLOS) rules contributed the controlled flight into terrain of their aircraft because they had to take an indirect and lower route (due to BLOS altitude rules) between the Mission C and D objectives. Their recommendation was that the NPRA:

> "*in collaboration with the CAA (*i.e. the Norwegian Aviation Authority*), should establish permanent UAS airspace danger areas in critical avalanche zones. These may then be activated/deactivated when needed for UAS flights. Otherwise, the time consuming process involved in establishing an airspace danger area would not make it feasible to establish these with short notice."*

This is a reasonable approach if the NPRA identifies known areas that need to be routinely monitored or areas require seasonal plowing operations to open roads after winter closures.

These comments highlighted one potential capability of UAS that is underutilized – these aircraft can fly autonomously. In theory no or minimal human input is required. This suggested that these aircraft could fly missions without observers involved and could be used in inaccessible areas and in poor visibility. This would require a notable change in the regulatory environment but may be worthwhile in situations involving risk to humans.

The NPRA needs to evaluate their institutional approach to use UASs. If the NPRA did purchase UASs, there would be applications beyond just winter snow surveillance including geological surveys, mapping and potentially emergency usage such as searching for missing persons or mapping the extent of floods or mud slides. So the possible benefits of a UASs to the NPRA or any roadway operations organization, beyond just snow avalanche monitoring, could be large. A multi-level approach to the usage of UAS seems workable. For many NPRA needs, a small multi-rotor aircraft UAS owned by NPRA and operated by trained NPRA staff could be used to look at snow and geological features. As noted by a member of the evaluation team:

> *"For NPRA, one road ahead could be to buy some small drones or similar, and deploy them around Norway. .... experts in the NPRA could use them as an additional tool for inspection purposes. This would give more insight into what the needs are, and how to best get there."*

This option would only be usable for VLOS operations which limits the flight to times of good visibility and a maximum altitude of 120 meters. Another member of the evaluation team noted:

> *"a geologist drone may be a good solution. Today there are three geologist drones* (in the NPRA)*. These are used in VLOS operations and are useful tools."*

If there was enough of these systems owned and operated by the NPRA and spread throughout the NPRA regions, this type of aircraft could be available on short notice if needed for urgent projects or emergencies.

For longer flights in windy weather, a fixed wing UAS, assuming it has a usable sensor or camera and there is enough clear operating space to circle above an area of interest, may be the best solution. Because these aircraft are more complex to transport, setup, and operate, NPRA should consider using vendors. The use of a vendor might not have the short response time needed after avalanches suggesting this type of system is best used for planned events such as the spring snow plowing to open up roads closed over the winter. It is uncertain if these fixed wing aircraft could replace manned helicopter flights as contracted out by the NPRA. As one of the evaluation team noted:

> "*At the time being it is difficult to see how fixed wing UAV operations can compete with manned helicopters when short response time at different locations all over Norway is required."*

Again it may depend on the quality of the camera and/or sensor images and the cost of contracting with the vendors. In fact, another reviewer noted:

> *"I viewed the video from the cornice mission …, I think, in some cases, we can get better quality/information from video/pictures than a manned helicopter. This is because the drone can fly closer to the mountainside than a manned helicopter. In this case the drone flew only few meters from the cornice. Impressive!"*

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