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# The application of unmanned aerial vehicles for snow avalanche search and rescue

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*Master thesis in Technology and Safety in The High North, June 2016*





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## Preface and acknowledgements

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The submission of this thesis is a fulfillment of the requirements for completion of my master's degree in Technology and Safety in the High North at the University of Tromsø, Norway. The work for this thesis was completed in the time period from February to May 2016, with a delivery date on the 1<sup>st</sup> of June, 2016.

Firstly, I would like to extend my gratitude to the Tromsø Red Cross organization, and in particular the RPAS/UAV branch of their search and rescue section. Viggo Lorentsen, Ronny Sandslett and Tor André Skjelbakken all provided valuable information and shared their knowledge, aiding in the completion of this thesis.

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Andreas Albrigtsen

Tromsø, May 2016



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## Abstract

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Snow avalanches claim in excess of 200 lives annually on a worldwide basis. However, since the invention of the first effective avalanche transceiver, the process of locating victims has remained fundamentally unchanged. Humans as a carrier for locating devices are perceived to be inefficient when moving over rugged avalanche debris, and potentially exposed to excessive risk from secondary avalanches. The technology of small unmanned aerial vehicles, also known as UAVs, are currently on the up rise as they are a low-cost, simple and effective aerial platform, which can perform a multitude of functions depending on the payload they carry. Therefore, this thesis wants to evaluate if the capabilities of UAVs could be exploited to provide valuable contributions in snow avalanche search and rescue efforts – and if so – what challenges would arise, opposing this application.

Through a thorough literature review, state-of-the-art for avalanche search and rescue, UAV platforms and sensor technology is investigated to establish a theoretical frame of reference. This framework is the foundation for evaluating how to improve the current search and rescue efforts in avalanches, what capabilities current UAV and sensor technology has, and how to best apply UAVs to satisfy the needs of a rescue organization without endangering the rescuers. The subject of UAVs in search and rescue is still in its initial stages, and the amount of research and knowledge is therefore limited. Because of this the attendance of the ReCAMP workshop, Tromsø 2016, was essential with respect to the exchange of information. Tromsø Red Cross is considered pioneers on the aforementioned application of UAVs, and their collaboration was a necessity when establishing the state-of-the-art of UAV use for search and rescue purposes.

The main challenges identified and discussed in this thesis is under the categories of adverse meteorological conditions and technological challenges. Weather conditions such as precipitation, extreme cold, wind and darkness are believed to prove the most challenging for the small type of UAV platforms which could be applicable for avalanche search and rescue. The most prominent technological challenges were in relation to degree of autonomy, collision avoidance, somewhat underdeveloped sensor systems and power plant of the UAV. There were also identified some challenges regarding compliance to regulations and in relation to human and organization, however these were less precarious for the implementation.

The UAV platform was identified to be a sufficient carrier for electronic search devices such as RECCO and avalanche transceiver, however other sensor systems still needs to be developed further. The already limited energy density of batteries and the combination with a cold operating environment could cause problems during a rescue, but can be sufficient for preliminary testing. Furthermore, it was established that UAVs are not yet capable of replacing manned helicopters, but could still be a unique and valuable asset to a rescue operation. It was also identified that the implementation of UAVs with the current technology and organization of rescue resources, is highly unlikely to benefit avalanche victims, primarily due to excessive deployment times. There were identified some hazards due to implementation of UAVs, none of which were believed to pose and excessive risk, especially when considering the expected benefit for the rescuers as it provides them with an alternative in dangerous situations.

**Keywords:** *Unmanned Aerial Vehicles, Avalanche, Search and Rescue, Sensor Systems, Electronic Search Devices, Risk Analysis, HAZID, Technology, Adverse Weather, Regulations*



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## List of Abbreviations

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ACUASI	Alaska Center for Unmanned Aircraft Systems Integration
ADS-B	Automatic Dependent Surveillance - Broadcast
AGL	Above Ground Level
AOA	Angle Of Attack
AT	Avalanche Transceiver
ATC	Air Traffic Control
BLOS	Beyond Line of Sight
CASA	Civil Aviation Safety Authority
CCPM	Collective/Cyclic Pitch Mixing
CG	Center of Gravity
CNC	Computerized Numerical Control
DC	Direct Current
DEM	Digital Elevation Model
EFR	Expected Fatality Rate
EM	Electromagnetic
ESC	Electronic Speed Control
EVLOS	Extended Visual Line of Sight
FAA	Federal Aviation Administration
FPV	First-Person View
GPR	Ground Penetrating Radar
HAZID	Hazard Identification
HD	High Definition
HEMS	Health Emergency Medical Service
HMI	Human-Machine Interface
ICAO	International Civil Aviation Organization
ICAR	International Commission for Alpine Rescue
ICE	Internal Combustion Engine
ICUAS	International Conference on Unmanned Aircraft Systems
IEEE	Institute of Electrical and Electronics Engineers
IR	Infrared
ISSW	International Snow Science Workshop
LED	Light-Emitting Diode
LiDAR	Light Detection And Ranging
Li-Ion	Lithium-Ion
Li-Po	Lithium-Polymer
LTE	Long Term Evolution
MRRW	Multi-Rotor Rotary-Wing
MTOW	Maximum Take-Off Weight
NAA	The Norwegian Air Ambulance
NASA	National Aeronautics and Space Administration
NCAA	Norwegian Civil Aviation Authority

NGI	Norwegian Geotechnical Institute
NKOM	Norwegian Communications Authority
NOK	Norwegian Krone
NRR	Nasjonalt Redningsfaglig Råd
OM	Operations Manual
RAC	Risk Acceptance Criteria
RADAR	Radio Detection and Ranging
RF	Radio Frequency
RO	RPAS (Remotely Piloted Aircraft Systems) Operator
RPAS	Remotely Piloted Aircraft System
RPM	Revolutions Per Minute
SaR	Search and Rescue
SD	Standard Definition
SHF	Super High Frequency
SRRW	Single-Rotor Rotary-Wing
SUMO	Small Unmanned Meteorological Observer
SWD	Supercooled Water Droplets
TCAS	Traffic Collision Avoidance System
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
UiT	University of Tromsø
VHF	Very High Frequency
VLOS	Visual Line of Sight
VR	Virtual Reality

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# 1. Introduction

## 1.1 Background and problem statement

Snow avalanches (hereby referred to as avalanches) are estimated to claim around 250 lives each year (Ranke, 2015), and according to statistics from the Norwegian Geotechnical Institute (NGI) an annual average of 5.7 deaths are directly related to avalanches in Norway (Norwegian Geotechnical Institute, 2016). Most (more than 80%) avalanches that causes fatalities are triggered by the victim or someone in the victim's party (McClung & Schaerer, 1993). In other words; skiers, snowmobilers, climbers and other recreational users, and in Norway this typically entails that the accident site is in a relatively remote location. Avalanches can also be triggered naturally under the right conditions, posing a threat for unsuspecting victims moving through terrain traps or even road users, construction workers or residents.

Nevertheless, the process of avalanche search and rescue (SaR) has remained fundamentally unchanged after the invention of the first effective avalanche transceiver in 1968 by Dr. John Lawton (Dawson, 2013). Even in 2016, the process of locating and rescuing an avalanche victim can be considered to be rather archaic. Firstly, notify first responders who deploy professional rescue crews by helicopters or cars, whom upon arrival uses considerably outdated techniques to manually locate and in turn excavate the victim (Wolfe, Frobe, Shrinivasan, & Hsieh, 2015). This statement might be oversimplified, as there has been some minor progress in the form of development of transceivers, more widely available helicopters and improved organization of the rescue crews. But considering that only one in ten avalanche victims survives when rescued by professionals in a remote area (Skjelbakken, 2016), there is still room for improvement. Additionally, due to the inherent risk of secondary avalanches in an area where an avalanche has occurred, the rescuers are likely to be exposed to what might be considered an undesirably high risk.

The growth strategy consulting and research company Frost & Sullivan identified unmanned aerial vehicles (UAVs) as a discontinuity in the evolution of civil aviation systems (Lake & Shammai, 2004). This can be compared to the impact the invention of helicopters or jet engines had on the same market – being disruptive innovations. In an internal memo evaluating the telephone as a replacement for telegraphy, Western Union once stated “This ‘telephone’ has too many shortcomings to be seriously considered as a means of communication. This device is inherently of no value to us”. Although the technology is not new, it is the recent progress in development of UAV that is considered a disruptive innovation today. The applications for an UAV is virtually limitless, and most of the future applications are likely yet to be discovered. A UAV platform has many advantages over its manned counterpart, some of which is cost efficiency, low altitude capabilities, simplicity, higher degree of autonomy and no safety limitations for onboard crew. And it is advantages like this that can possibly prove to be valuable to a SaR operation.

By combining the need for improvement in avalanche SaR, and the recent development in UAV technology it might be possible to improve the likelihood of survival for avalanche victims. It should be noted that the idea of using UAVs for avalanche SaR is not unique to this thesis, as there are quite a few studies on development of platforms, most of which are proof-of-concept. However, the topic of this thesis is not to develop new technologies and UAV platforms, but rather review how today's assets

can be applied and what challenges exist, resisting the implementation of UAV-assisted avalanche SaR. This is both in regard to the victims of an avalanche and their rescuers.

In Norway the Red Cross is renowned for their knowledge and contributions during SaR operations, especially related to avalanches. The local Tromsø branch of Red Cross, has a subdivision solely dedicated to the application of UAVs in SaR context. A field in which they are one of the country's leading organizations, and are considered pioneers in this type of application. However, the process of implementing UAVs as a valid resource benefiting SaR, is not necessarily a simple task.

By investigating state-of-the-art techniques for avalanche SaR, it may be possible to identify in which areas there are shortcomings, or where the UAV is likely to provide the greatest contributions. The essence of this thesis is to evaluate such use of UAVs in a greater picture to address issues regarding weather, underdeveloped technology, regulations, organization and the inherent increase in risk for rescue personnel. By obtaining multiple viewpoints on these topics, it might be possible to estimate the impact of the UAV platform on the current approach for avalanche SaR.

## 1.2 Aim and objectives

The aim of this thesis is to study in what way UAVs can be applied in avalanche SaR, to estimate their impact on the current approach.

More specifically the objectives of the study are to:

- a) Review the current practice of SaR for avalanche victims, to establish a baseline for comparison to UAV-assisted search
- b) Examine the approach of Tromsø Red Cross (TRC) and their current application of UAVs by conducting interviews and a case study
- c) Identify challenges for implementation of UAVs in civil applications – such as SaR – through literature review and interviews with experienced professionals
- d) Conduct a hazard identification analysis (HAZID) and risk assessment for use of UAVs in avalanche SaR

## 1.3 Research questions

All the following research questions are directly related to the objectives of this thesis, as their answer is intended to fulfill the objectives.

1. What is the current state-of-the-art approach for avalanche search and rescue?
2. How are UAVs being employed as a SaR resource by TRC?
3. What challenges arise when attempting to implement UAVs as a SaR resource in civil airspace, and what facilitates the implementation?
4. Will use of UAVs alongside the conventional rescue effort constitute any additional risk for the rescuers – and if so – is it raised by unacceptable levels?

## 1.4 Scope of work and limitations

- To the extent of the authors knowledge, there are no commercial plug-and-play solutions for avalanche search and snow-pack mapping available today. The thesis will serve as a suggestion for what benefits the UAV platform can provide, as well as considering the challenges for implementation.
- The topics in this thesis are very multidisciplinary, as there are elements of mechanical engineering, electrical engineering, computer science and aerospace engineering. Due to the authors limited knowledge in these fields, and the fact that this thesis will review the UAV platform on a system-level. Description of aerodynamics, mechanics and remote sensing technology will not be described in depth, but rather included to provide the reader with some basic knowledge in these fields. This framework will be used to discuss the different UAV platforms available, applicable sensor technology, associated risk and challenges.
- All UAV platforms discussed in this thesis are meant for civil applications, and therefore the largest of UAV platforms (typically associated with military applications) are henceforth excluded. Therefore, the limiting maximum take-off weight (MTOW) for platforms in this thesis is set to 100 kilograms, in order to provide a finite limit.
- When discussing single-rotor rotary-wing (i.e. helicopter) platforms, only UAVs that apply collective/cyclic pitch mixing (CCPM) will be included. As fixed-pitch platforms are believed to have too great limitations in their characteristics to be considered of any use for applications evaluated in this thesis.
- Due to the fact that over half of the avalanche victims are from the three northernmost counties, the region of Northern Norway will be used as background for discussion regarding operational conditions such as weather, vegetation and topography. However, the contents and discussions of this thesis may be applicable to any area subjected to similar conditions.
- The risk analysis will primarily focus on the safety aspect of the consequences, as the environmental and economic consequences are perceived to be insignificant in comparison, and also of little purpose to this thesis.
- The category of single-wing UAVs will only consist of monoplanes, and wing configuration in relation to the fuselage will be ignored.

## 1.5 Structure of the thesis

The theoretical framework is presented initially to establish a foundation for the reader. First UAVs are described. What they are, how they work, what airframes are commonly used and what sensors are believed to be applicable for UAV-assisted avalanche SaR. Following is an introduction to the regulations concerning aircraft without a pilot on board, where some excerpts are presented as well as a summary of the different technical classifications for UAVs enacted by the Norwegian Civil Aviation Authority (NCAA). As this thesis also focuses on increased risk for the rescue personnel, the theoretical framework includes a description of risk analysis and hazard identification concepts. Finally, snow avalanches are described with a focus on victims and statistics, and a minor focus on

terrain. The emphasis of the avalanche framework is to establish what state-of-the-art techniques are employed for avalanche rescue, to provide a basis for future discussion.

The methodology chapter is included to describe how the data for this thesis was gathered. The primary source of information was an in-depth literature study, but the contributions from interviews and attendance at the ReCAMP workshop was very beneficial as well. As the HAZID analysis is not typically employed for identifying hazards in rescue operations, the procedures were somewhat adapted. All the aforementioned techniques provided the author with a foundation to create a structured approach for hazard identification, and the revised methodology will be described further in its respective chapter.

Following is the discussion and results chapter which is merged together as it was believed to be more appropriate due to the theoretical nature of this thesis. This chapter is very comprehensive due to the broad objectives of this thesis, where each objective corresponds with a subsection of this chapter to keep a certain degree of structure. Firstly, a review of the existing avalanche SaR methods are presented, followed by a case study of the Tromsø Red Cross RPAS-group. The next chapter describes and discuss identified challenges which counteracts the implementation of UAVs for avalanche SaR purposes. These challenges are further divided into subsections related to harsh weather, technology, compliance to regulations and human and organization.

The final chapter presents the conclusion of the author based on the findings during the course of this thesis. Although it is brief, it will reflect the findings from the discussion and results, and present some concluding remarks. With respect to UAV applications in avalanche SaR, some suggestions for future UAV concepts and research will also be presented.

## 2 Theoretical frame of reference

This chapter is intended to provide the theoretical framework which described the major topics on which this thesis is founded. Firstly, the reader is introduced to the concept of UAVs and thereafter the regulations that apply for their operation in Norwegian airspace. Following is a chapter describing the hazard identification and risk analysis process, and lastly avalanches victims and statistics are described.

### 2.1 UAV platform and payloads

The following subsections are intended to provide the reader with insight as to what UAVs are, how they work, what different airframes are commonly used and their applications, as well as a description of sensor systems believed to be applicable for avalanche SaR.

#### 2.1.1 What is an Unmanned Aerial Vehicle (UAV)?

This is a difficult question to answer due to the various definitions used by stakeholders, and the large variety of abbreviations describing and defining unmanned aircraft. According to the Australian Certified UAV Operators Inc. the term “UAV” was adopted by the Civil Aviation Safety Authority (CASA) in July 2002, and is still widely used in most of their certification-, licensing- and guidance material (Australian Certified UAV Operators Inc., 2016). In the past the Federal Aviation Administration (FAA) has termed these aircraft as “remotely piloted vehicles” and later “remotely operated aircraft”, and is currently using the abbreviation UAS which is short for unmanned aircraft system. Another term that is still being used is the National Aeronautics and Space Administration (NASA) “remotely piloted aircraft” or RPA, which in some cases is extended to RPAS (RPA System) to describe not only the aircraft but the entire system that is used in operations.

As there is an extensive use of different terminology, a specific term must therefore be selected and defined for this thesis with respect to what it encompasses. In their UAV Roadmap of 2005, the (Office of the Secretary of Defence, 2005) uses the following definition: *“A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or non-lethal payload. Ballistic or semi ballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles.”*. This is the definition that will be used henceforth as its boundaries is believed to be most appropriate for the contents of this thesis.

In addition, the term RPAS which is commonly used by the NCAA, will be included. This term is a little more imprecise, and its scope only includes autonomous flight to some extent as is implied by the inclusion of “piloted” in the name. According to the International Civil Aviation Organization (ICAO), RPAS is defined as *“A remotely piloted aircraft, its associated remote pilot station(s), the required command and control links and any other components as specified in the type design* (International Civil Aviation Organization, 2015).”, which is the definition that will be used for the purpose of this thesis.

## 2.1.2 UAV definitions and terminology

For the purpose of this thesis the following abbreviations and terms are defined as;

<b>3-axis gimbal</b>	A 3-axis gimbal is a pivoted support device which can move with three degrees of freedom, i.e. in the yaw, pitch and roll. This allows an object mounted on the innermost gimbal independent of the rotation of its support. For UAVs this allows the camera to move independently while still being stabilized, counteracting vibration and shake movement. For the purpose of this thesis gimbals are powered by brushless direct current (DC) electric motors.
<b>AUW (All up Weight)</b>	The total weight of an aircraft during take-off and flight
<b>BLOS (Beyond visual Line of Sight)</b>	<i>“means that an aircraft without a pilot on board is flown beyond the visual line of sight of the pilot, pilot in command or the observer(s)”</i> (Norwegian Civil Aviation Authority, 2015)
<b>Cognitive autonomy</b>	(requires reactive autonomy) – <i>“perform simultaneous localization and mapping; resolve conflicting information; plan (for battery recharge for example); recognize objects or persons; learn”</i> (Floreano & Wood, 2015).
<b>EVLOS (Extended Visual Line of Sight)</b>	<i>“means that an aircraft without a pilot on board is flown beyond the visual line of sight of the pilot or pilot in command, where visual control is maintained by using one or more observers”</i> (Norwegian Civil Aviation Authority, 2015)
<b>Loiter mode</b>	As described by the open-source autopilot suite (ArduPilot, 2016): <i>“Loiter Mode automatically attempts to maintain the current location, heading and altitude. The pilot may fly the copter in Loiter mode as if it were in manual. Releasing the sticks will continue to hold position.”</i>
<b>MRRW (Multi-Rotor Rotary-Wing)</b>	For the purpose of this thesis MRRW is defined as a rotorcraft consisting of four- or more rotors in a fixed pitch configuration.  NOTE: The configuration with one large main rotor and three smaller secondary rotors, known as “triquad” – although technically a rotorcraft with four rotors – is not included in this definition.
<b>MTOW (Maximum Take-Off Weight)</b>	Absolute maximum weight at which the pilot is allowed to attempt take-off due to structural or other limitations. This could be defined by UAV manufacturer for complete systems, or internally for self-built systems.
<b>Pilot</b>	<i>“means the person who operates the aircraft's control systems and is responsible for navigation and safety during the flight”</i> (Norwegian Civil Aviation Authority, 2015)
<b>Pilot in command</b>	<i>“means the pilot who has been appointed to be in charge of navigating the aircraft and of safety during the flight”</i> (Norwegian Civil Aviation Authority, 2015)
<b>Reactive autonomy</b>	(requires sensory-motor autonomy) – <i>“maintain current position or trajectory in the presence of external perturbations, such as wind or electro-mechanical failure; avoid obstacles; maintain a safe or predefined distance from ground; coordinate with moving objects, including other drones; take off and land”</i> (Floreano & Wood, 2015).
<b>Sensory-motor autonomy</b>	<i>“sensory-motor autonomy: translate high-level human commands (such as to reach a given altitude, perform circular trajectory, move to global positioning system (GPS) coordinates or maintain position) into combinations of platform-dependent</i>

*control signals (such as pitch, roll, yaw angles or speed); follow pre-programmed trajectory using GPS waypoints” (Floreano & Wood, 2015).*

**SRRW (Single-Rotor Rotary-Wing)**

For the purpose of this thesis the term SRRW encompasses all unmanned rotorcraft that employs no more than one rotor for lift-generation purposes. In manned aviation this is known as a helicopter.

NOTE: Although a SRRW technically consists of two rotors, the tail-rotor is not included as it does not provide lift.

**VLOS (Visual Line of Sight)**

*“means that an aircraft without a pilot on board is flown in such a way that the aircraft can be observed at all times without aids like binoculars, camera or other aids, other than ordinary eyeglasses” (Norwegian Civil Aviation Authority, 2015)*

### 2.1.3 Principles of flight

The forces that apply to aircraft in flight are often divided into four major groups. The subsections below represent the four groupings of forces which are lift, thrust, drag and weight as are depicted in Figure 2.1-1. Assuming that all forces are acting through the center of gravity, lift opposes the downward force of weight and drag opposes thrust which acts rearward parallel to the relative wind (Federal Aviation Administration, 2004). When an aircraft is either hovering, or in stabilized level flight at a constant speed the forces are equal to each other, effectively cancelling out their counterparts (Federal Aviation Administration, 2012).

In essence UAVs are just miniaturized versions of their manned counterparts, meaning that the aerodynamic principles of flight are the same. Figure 2.1-1 depicts the forces acting on an airplane, all in equilibrium.

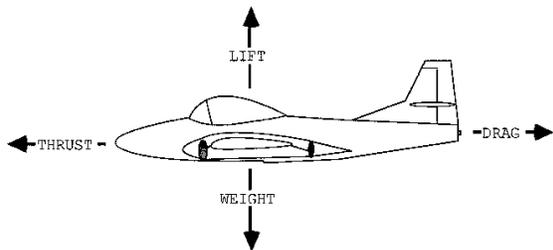


Figure 2.1-1 – Forces acting on an airplane, all in equilibrium. Illustration by: (Globalsecurity, n.d.)

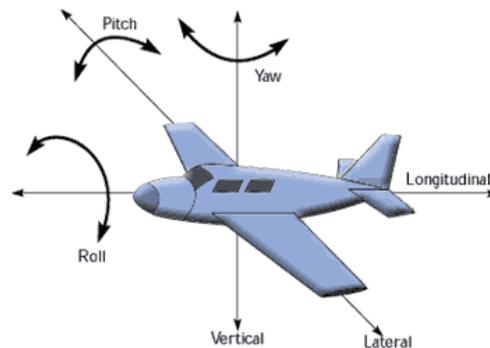


Figure 2.1-2 – The primary motions of an aircraft. Illustration by: (National Aeronautics and Space Administration, 2016)

An aerofoil is the cross-section of a wing or a rotor blade, and its design has a large impact on the generation of lift force. Figure 2.1-2 and Figure 2.1-3 depicts the primary motions of an aircraft and generalized aerofoil cross-section, respectively. These illustrations are presented to the reader, as much of their terminology will be applied throughout the thesis, especially in the following subsections which describes lift, thrust, drag and weight. Figure 2.1-4 is included to show some of the most commonly used airfoil shapes.

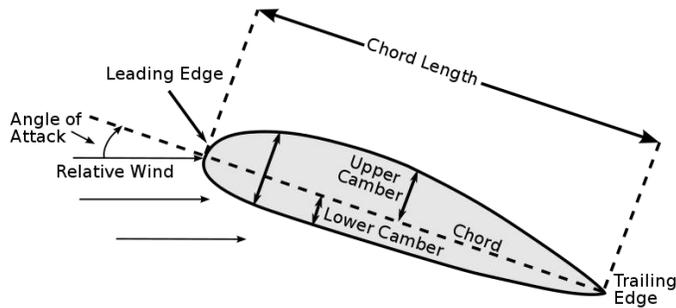


Figure 2.1-3 - Components of an airfoil cross-section. Illustration from: (Jenner, 2012)

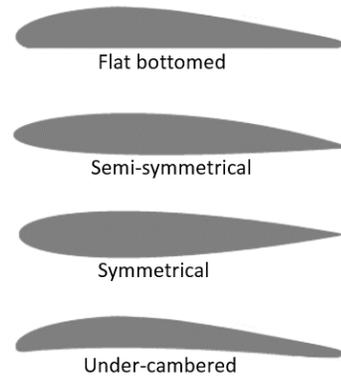


Figure 2.1-4 - Conventional airfoil shapes

### Lift

Any object subjected to airflow will experience lift force to some extent. Lift occurs when air flows over an object introducing curvature in the streamlines around the object. As described by (Babinsky, 2003) “if a streamline is curved, there must be a pressure gradient across the streamline, with the pressure increasing in the direction away from the center of curvature”. This tells us that the curvature introduced in the flowfield around an aerofoil creates lift due to relative pressure differences. Lift force acts perpendicular to the surface of the airfoil, and the net force is transmitted through pressure. Figure 2.1-5 illustrates a curved plate “airfoil” immersed in a flow illustrated by the arrow, with the field lines visualized. When moving perpendicular to the local streamline direction, from point A along the dotted line towards point B, the curvature of the local stream lines increases suggesting that there must now be a pressure gradient across the streamlines. Arriving at point B the pressure is noticeably lower than at point A. When repeating the process but moving from point C towards point D the pressure increases, resulting in a higher than atmospheric pressure. The resultant pressure force on the airfoil is acting upwards, hence generating lift.

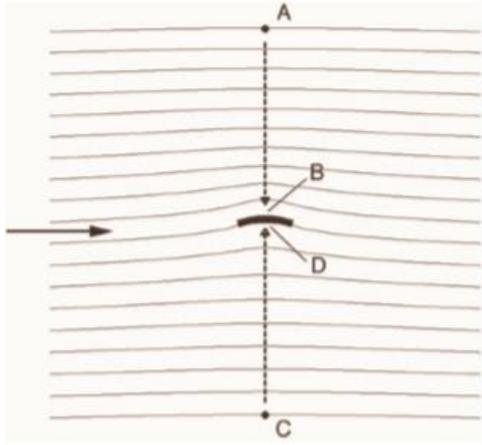


Figure 2.1-5 – Streamlines around a lifting curved plate “airfoil”. Illustration by: (Babinsky, 2003)

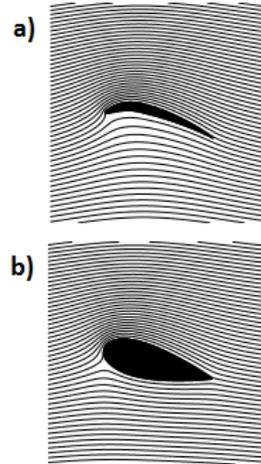


Figure 2.1-6 – Simulated streamlines around thin- (a) and thick (b) airfoils. Illustration by: (Babinsky, 2003)

Figure 2.1-6 is from a simulation illustrating that the shape of an airfoil can have a large impact on the lift force. The flow patterns above both aerofoils is very similar, but the flow pattern beneath is considerably different. In the top simulation with a thin aerofoil the flow patterns curve upwards generating overpressure below the wing, while the thick aerofoil curves the flow downwards which provides a negative contribution to lift. Although originally done by Leonard Euler, (Babinsky, 2003) mathematically derives the relationship between curved streamlines and pressure gradients:

$$\frac{dp}{dn} = \rho \frac{v^2}{R}$$

Equation 1 - Relationship between curved streamlines and pressure gradients

The equation expresses the pressure gradient across streamlines in terms of the local radius of curvature  $R$  and the flow velocity  $v$ , where  $\rho$  is density of air. The formula show that higher velocities and tighter curvatures create larger pressure differentials, i.e. more lift.

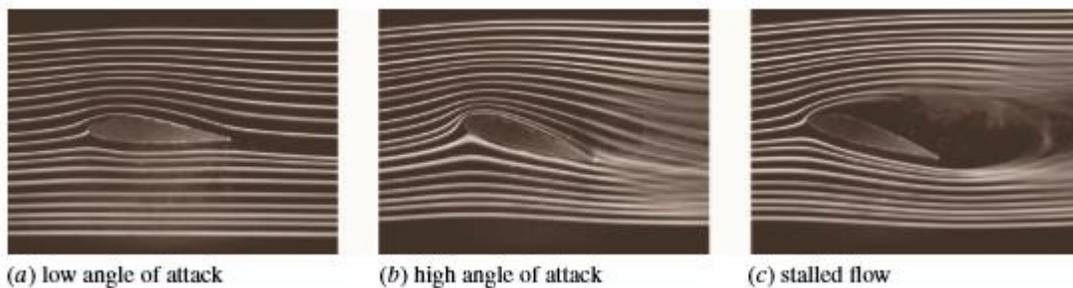


Figure 2.1-7 – Streamlines around an aerofoil at increasing angle of attack (Babinsky, 2003)

The “angle of attack (AOA)”, describes the angle between the chord line of the airfoil and the relative direction of the oncoming air. As the AOA increases the curvature of the flow increases as seen in Figure 2.1-7. Increased curvature implies increased pressure difference, which results in more lift

being generated. Stalled flow occurs when the AOA increases to such an extent that the flow is no longer capable of following the sharp curvature at the leading edge separating itself from the airfoil, which results in an immediate loss of lift.

To summarize; lift is a result of pressure differences around the wing and is dependent on angle of attack, airfoil shape, air density and relative airspeed.

### ***Thrust***

Thrust is the force providing forward momentum which counteracts drag and in turn creates lift by forcing air over the wing or rotor of the aircraft (Federal Aviation Administration, 2012). Thrust is typically generated by electrical motors or by internal combustion engines (ICE) such as piston, wankel or turbines. Fixed-wing UAVs is equivalent to normal airplanes, which apply thrust forward to force airflow over the wings, generating lift. Rotary wing aircraft is the collective term for single- or multi-rotor aircraft, where single-rotor corresponds with regular manned helicopter, and multi-rotor has no manned equivalent. Here the thrust is generated by the rotor(s), and generally acts in the longitudinal axis. The mechanics used to generate thrust are more complex than for fixed wing, and also unique for each platform and will therefore be discussed in depth in the respective chapters for SRRW (Chapter 2.1.4.2), and MRRW (Chapter 2.1.4.3).

### ***Drag***

Drag is the resisting force when moving an object through a medium such as air. Drag force opposes thrust, and acts rearward parallel to the relative wind. The fuselage, rotor, wing or other protruding objects of an aircraft all contribute as a retarding force (Federal Aviation Administration, 2004).

### ***Weight***

The force – here defined as weight – is simply the total mass of the aircraft when in flight, combined with its gravitational pull. The total mass of the aircraft can be the sum of empty weight of aircraft, payload, battery or other fuel source, other communication systems and sensors, etc. For the purpose of this thesis the total mass is referred to as all-up weight (AUW). Weight pulls the aircraft downwards due to the force of gravity, opposing the lift force – acting vertically downwards through the aircrafts center of gravity (CG).

## **2.1.4 Airframes**

The following subchapters is intended to give the reader a short presentation of the different UAV airframe-configurations that are most commonly used today. Pictures and specifications are included to demonstrate platform diversity depending on their design and configuration. There are presented three options under each UAV platform, each categorized under either R01, R02 or R03, which corresponds to the categories applied in the regulatory framework issued by the NCAA (Norwegian Civil Aviation Authority, 2015), which is reviewed in Chapter 2.2. For the comparison of platforms and their characteristics some parameters worth noting are; MTOW, payload capacity, speed and endurance. A variety of UAV platforms are selected to demonstrate key differences in their various parameters, depending on airframe as well as what NCAA classification they belong to.

#### **2.1.4.1 Fixed wing**

As with many other technologies, the fixed wing UAV technology is largely based on military development, and it was in relation to military applications that these platforms first occurred (Darack, 2011). The word “drone” as a descriptive term for UAVs was first used in 1946 in relation to the unmanned fixed wing aircraft developed for military target practice, and refers to the mindless-and driven existence that male bees are renowned for (Merriam-Webster, 2016).

The fixed wing UAV is the most conventional of the platforms, employing the simplest design in terms of lift generation mechanics. As previously described these UAVs generate lift by applying thrust in a forward direction, forcing air to flow over the wings. Due to the fact that generation of lift and thrust are two separate actions, each can be designed for optimal efficiency. In other words, the propeller or turbine generating the thrust can be designed for optimal performance, and the wing which generates the lift can be designed separately with optimal performance for lift. Fixed wing aircraft is also more streamlined and therefore has a lower drag force, allowing it to move faster and with a much higher fuel-efficiency than a rotary wing aircraft.

All platforms discussed in this chapter are configured as single-wing planes or “monoplanes”. Commonly there is a clear distinction between the fuselage of the plane and the aerodynamic wing, but as illustrated by the Trimble platform in Table 2.1-1, it is possible to combine these into a tailless aircraft known as a “flying wing” configuration. The fixed wing category can further be broken down into categories depending on wing configuration in relation to the fuselage, however this distinction will not be included in this thesis.

Table 2.1-1 - A selection of fixed-wing UAV

R01	R02	R03
		
Trimble UX5	Boeing ScanEagle	EPS UK CyberEye II
<ul style="list-style-type: none"> <li>▪ <b>Power plant:</b> Electric brushless motor 700 W</li> <li>▪ <b>Battery:</b> 14.8 V, 6000 mAh</li> <li>▪ <b>MTOW:</b> 2.5 kg</li> <li>▪ <b>Payload capacity:</b> 0.0 kg</li> <li>▪ <b>Endurance:</b> 50 min</li> <li>▪ <b>Wingspan:</b> 100 cm</li> <li>▪ <b>Length:</b> 65 cm</li> <li>▪ <b>Maximum speed:</b> n/a</li> <li>▪ <b>Cruise speed:</b> 43.2 knots</li> <li>▪ <b>Max altitude:</b> 5000 m</li> </ul>	<ul style="list-style-type: none"> <li>▪ <b>Power plant:</b> 2-stroke piston engine: 1.5 horsepower</li> <li>▪ <b>MTOW:</b> 22 kg</li> <li>▪ <b>Payload capacity:</b> 3.4 kg</li> <li>▪ <b>Endurance:</b> 24+ hours</li> <li>▪ <b>Wingspan:</b> 3.11 m</li> <li>▪ <b>Length:</b> 1.55 m</li> <li>▪ <b>Maximum speed:</b> 80 knots</li> <li>▪ <b>Cruise speed:</b> 60 knots</li> <li>▪ <b>Max altitude:</b> 4570 meters</li> </ul>	<ul style="list-style-type: none"> <li>▪ <b>Power plant:</b> 2-stroke piston engine: 10 horsepower</li> <li>▪ <b>MTOW:</b> 60 kg</li> <li>▪ <b>Payload capacity:</b> 20 kg</li> <li>▪ <b>Endurance:</b> 10 hours</li> <li>▪ <b>Wingspan:</b> 4.5 m</li> <li>▪ <b>Length:</b> 2.8 m</li> <li>▪ <b>Maximum speed:</b> 86.4 knots</li> <li>▪ <b>Cruise speed:</b> 54 knots</li> <li>▪ <b>Max altitude:</b> 4570 meters</li> </ul>
<p>Source: (Trimble UAS, 2016)</p>	<p>Source: (Boeing, 2016)</p>	<p>Source: (EPS UK Ltd., 2016)</p>

### 2.1.4.2 Single-rotor rotary-wing (SRRW)

While a helicopter is a far more complex machine than an airplane, the fundamental principles of flight are the same. The rotor blades of a helicopter behave according to the same principles as the wings of an airplane – when air is forced over them, lift is produced. The crucial difference is that the flow of air is produced by rotating the wings or “rotor blades” through the air – as opposed to moving the whole aircraft. When the rotor blades start to turn, the air flowing over them produces lift that allows the helicopter to rise into the air. So, the engine is used to turn the blades, and the turning blades produce the required lift. In general helicopters have symmetrical airfoils, but non-symmetrical are also used depending on the intended application of the machine (Federal Aviation Administration, 2012).

In order to maneuver a helicopter a device named swash plate is used to control collective and cyclic control. When using the collective control, the entire swash plate is raised or lowered by a servo, varying the pitch of the rotor blades collectively. Furthermore, the swash plate can be manipulated in the longitudinal (tilting forward and aft) and lateral directions (tilting left and right) to control the

pitch of the blades individually as they revolve. As we can see from Figure 2.1-8, there is an upper part of the swash plate which is rotating with the rotor mast, as well as a lower part of the swash plate which serves as input for the controls by pushing or pulling on the control rods.

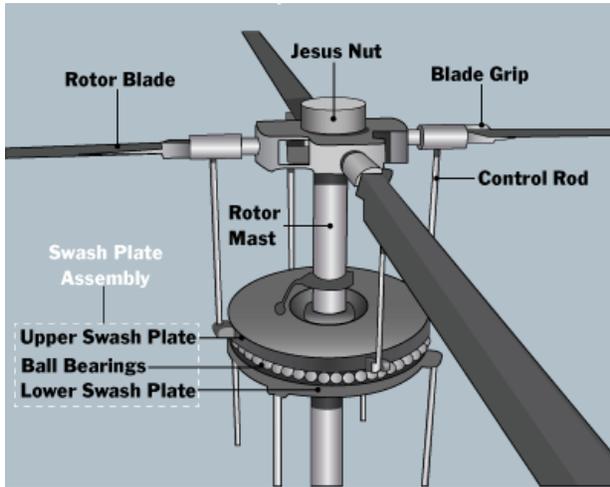


Figure 2.1-8 - The rotor assembly, Illustration: (HowStuffWorks, 2016)

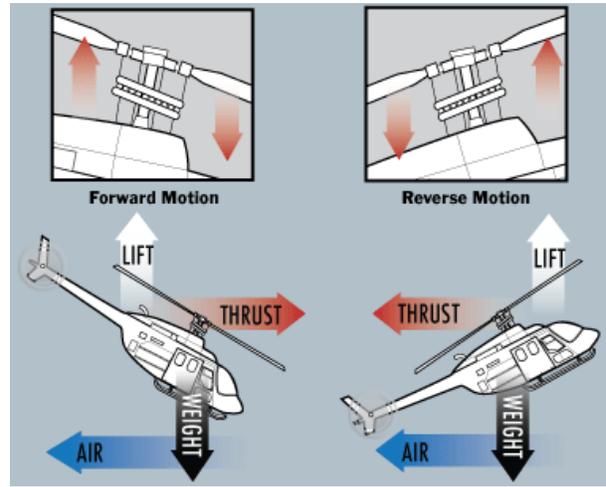


Figure 2.1-9 – Tilting of the swash plate to generate forward and reverse motion, Illustration: (HowStuffWorks, 2016)

The main rotor operates at a constant speed, and the generation of lift and thrust is controlled by cyclic and collective adjustments of the pitch using the swash plate. The adjustment of pitch controls the AOA, which is how lift is generated. As the main rotor spins the engine and fuselage will try to rotate in the opposite direction which is known as the “torque reaction”. This is counteracted by the tail rotor of a helicopter, compensating for the unwanted rotation.

There are several other important concepts of SRRW aerodynamics such as dissymmetry of lift, translating tendency, settling with power, dynamic rollover and gyroscopic precession, none of which will be discussed further in this thesis as the intent of this section is to familiarize the reader with this platform and its most fundamental mechanics.

As stated in the limitations only collective/cyclic pitch mixing (CCPM) platforms will be discussed under SRRW UAVs. CCPM can be further divided into categories for electronic (e) and mechanic (m) mixing. In general, the electronic systems are more widely used, as there are fewer mechanical parts, weight and cost is reduced and the platform is more agile and there is less linkage drag. However, if one servo fails in the electric mixing setup the pilot experiences a complete loss of both cyclic and collective pitch, as opposed to mechanical mixing where the pilot maintains partial control over the aforementioned parameters.

As illustrated by Table 2.1-2, there is not much design variation on the airframe of the SRRW platform, and they are very similar to their manned counterparts, with the exception of the internal cockpit space being eliminated. An increase in size such as; from the Align platform and up to the Yamaha platform, primarily affects the payload capacity and endurance of the UAV.

Table 2.1-2 - A selection of SRRW UAVs

R01	R02	R03
		
Align T-REX 500	AUAVT AT-100	Yamaha R-MAX
<ul style="list-style-type: none"> <li>▪ <b>Power plant:</b> Electric brushless motor 500MX</li> <li>▪ <b>Battery:</b> 6S LiPo 3300 mAh</li> <li>▪ <b>Payload capacity:</b> 0.0 kg</li> <li>▪ <b>Weight:</b> 1.21 kg (excluding battery)</li> <li>▪ <b>Endurance:</b> 8-9 min</li> <li>▪ <b>Main rotor diameter:</b> 989 mm</li> <li>▪ <b>Length:</b> 863mm</li> <li>▪ <b>Maximum speed:</b> n/a</li> <li>▪ <b>Max altitude:</b> n/a</li> </ul>	<ul style="list-style-type: none"> <li>▪ <b>Power plant:</b> 2-stroke piston engine (23cc) / 3,4 kW electric</li> <li>▪ <b>Battery:</b> n/a</li> <li>▪ <b>MTOW:</b> 24 kg</li> <li>▪ <b>Payload capacity:</b> 8 kg</li> <li>▪ <b>Endurance:</b> 2 hours / 45 min</li> <li>▪ <b>Main rotor diameter:</b> 2.01 m</li> <li>▪ <b>Length:</b> 1.47 m</li> <li>▪ <b>Maximum speed:</b> 64.8 knots</li> <li>▪ <b>Max altitude:</b> n/a</li> </ul>	<ul style="list-style-type: none"> <li>▪ <b>Power plant:</b> 2-stroke piston engine (250cc) 15.4 kW</li> <li>▪ <b>MTOW:</b> 94 kg</li> <li>▪ <b>Payload capacity:</b> 28 kg</li> <li>▪ <b>Endurance:</b> 1 hour</li> <li>▪ <b>Main rotor diameter:</b> 3.13 m</li> <li>▪ <b>Fuselage length:</b> 2.75 m</li> <li>▪ <b>Maximum speed:</b> 21.6 knots</li> <li>▪ <b>Max altitude:</b> 50 m</li> </ul>
<p>Source: (Align, 2016)</p>	<p>Source: (AUAVT, 2016)</p>	<p>Source: (Yamaha, 2016)</p>

### 2.1.4.3 Multi-rotor rotary-wing (MRRW)

As mentioned previously the term “drone” originally referred to unmanned fixed wing aircraft used for target practice during the second world war. While this still applies, the massive increase in use of MRRW platforms combined with considerable media attention has caused this platform to more or less adopt the descriptive term “drone”, at least for colloquial language.

As with the SRRW platform, MRRW generates lift by rotors moving through the air. However, there is one key difference between the two. A SRRW maintains a roughly constant number of revolutions per minute (RPM), and adjusts the pitch of the blades to increase AOA and in effect generating lift. However, most, if not all MRRW platforms employ multiple fixed-pitch rotors. “Fixed pitch” implies that there is no way to adjust the pitch of the rotors, and generation of lift relies on adjusting the RPM of the motors instead. To maintain a stable and controllable platform the RPM of each individual motor is adjusted to compensate for changes, or to initiate movement in a desired direction. These adjustments are done by a computer control system using algorithms to maintain stability and

maneuver the UAV. This type of computer assistance has benefited greatly from the advances in component miniaturization, improved electrical engine efficiency and durability, computer processing, battery technology, more advanced and well-developed algorithms and so on. This is one amongst the number of reasons why the popularity of MRRW platforms has increased dramatically the last decade. Also, the astonishing advances in the fields of image- and video technology in combination with communication technology has broadened the applications of the UAV platform, and how it is piloted.

Table 2.1-3 - A selection of multi-rotor UAV

R01	R02	R03
		
DJI Phantom 4	DJI Spreading Wings S1000+	Drone Technology MCFLY-Helios
<ul style="list-style-type: none"> <li>▪ <b>Power plant:</b> Electric brushless motors</li> <li>▪ <b>Number of rotors:</b> 4</li> <li>▪ <b>Battery:</b> LiPo 5350 mAh 15.2 V</li> <li>▪ <b>MTOW:</b> n/a</li> <li>▪ <b>Weight:</b> 1380 gr.</li> <li>▪ <b>Payload capacity:</b> 0.0 kg</li> <li>▪ <b>Endurance:</b> 28 min</li> <li>▪ <b>Diagonal wheelbase:</b> 450mm</li> <li>▪ <b>Maximum speed:</b> 38.9 knots</li> <li>▪ <b>Max altitude:</b> 120 m</li> </ul>	<ul style="list-style-type: none"> <li>▪ <b>Power plant:</b> Electric brushless motors 500W</li> <li>▪ <b>Number of rotors:</b> 8</li> <li>▪ <b>Battery:</b> LiPo 15000 mAh</li> <li>▪ <b>MTOW:</b> 11 kg</li> <li>▪ <b>Weight:</b> 4.4 kg</li> <li>▪ <b>Payload capacity:</b> 6,6 kg</li> <li>▪ <b>Endurance:</b> 15 min (@15000mAh, 9,5 kg MTOW)</li> <li>▪ <b>Diagonal wheelbase:</b> 1045 mm</li> <li>▪ <b>Maximum speed:</b> 39 knots</li> <li>▪ <b>Max altitude:</b> n/a</li> </ul>	<ul style="list-style-type: none"> <li>▪ <b>Power plant:</b> Electric brushless motors</li> <li>▪ <b>Number of rotors:</b> 8</li> <li>▪ <b>Battery:</b> LiPo</li> <li>▪ <b>MTOW:</b> 25 kg</li> <li>▪ <b>Weight:</b> n/a</li> <li>▪ <b>Payload capacity:</b> 10 kg</li> <li>▪ <b>Endurance:</b> 40 min (@ 7 kg payload)</li> <li>▪ <b>Platform diameter:</b> 2136 mm (including blade protectors)</li> <li>▪ <b>Maximum speed:</b> n/a</li> <li>▪ <b>Max altitude:</b> 200 m</li> </ul>

Source: (DJI, 2016)

Source: (DJI, 2016)

Source: (Drone Technology, 2016)

### 2.1.5 Power plant

This chapter will present the two most common sources of power for UAVs today; batteries combined with brushless electric DC motors and liquid-fueled internal combustion engines (ICE). It should be

noted that the mechanical principles of these two technologies will not be the primary focus, but rather their source of energy and degree of efficiency.

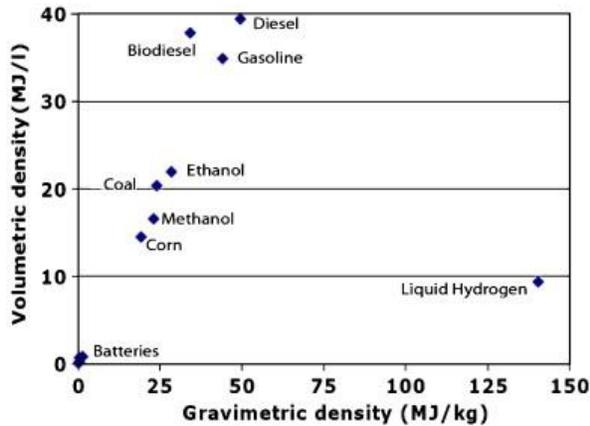


Figure 2.1-10 - Caloric energy density of batteries and liquid fuels. Illustration by (Fischer, Werber, & Schwartz, 2009)

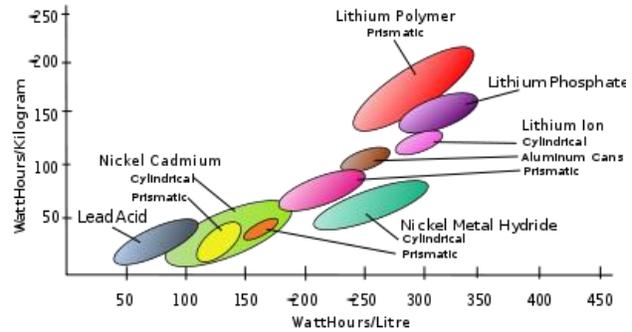


Figure 2.1-11 – Graph of energy densities of several secondary cells. Source: (Wikipedia, 2016)

Internal combustion engines are typically seen in UAV constructions where the engine is dedicated solely to powering a single driveshaft, such as SRRW or fixed wing applications. As we can see from Figure 2.1-10 the volumetric energy density of gasoline is somewhere around 34-35MJ/L, and according to (Baglione, 2007) a typical gasoline engine burns its fuel with an efficiency of about 25%.

Batteries are also represented in Figure 2.1-10, however their volumetric energy density is far lower than that of liquid fuels such as gasoline. Both Lithium-Polymer (Li-Po) and Lithium-Ion (Li-Ion) batteries are in the range of 300 Wh/L as seen in Figure 2.1-11, which translates to around 1 MJ/L. Brushless DC motors has an efficiency in the range of 80-85% above 1000 RPM (Akatsu & Miyamasu, 2012).

Li-ion and Li-Po battery technologies are the most common types for powering small to mid-size UAV platforms such as fixed wing/flying wing and SRRW – up to a certain size, and a very high percentage of the MRRW platforms. On the “Battery University” website managed by (Cadex Electronics Inc., 2016), there is an article describing the differences between LI-Po and Li-Ion, from which the following Table 2.1-4 has been compiled, comparing the two technologies.

Table 2.1-4 - Comparison of Li-Po and Li-Ion batteries

Type	Specifications	Advantages	Disadvantages
<b>Lithium Ion</b>	<ul style="list-style-type: none"> <li>▪ <b>Operating temp:</b> -20°C to 60°C</li> <li>▪ <b>Initial voltage:</b> 3.6 and 7.2</li> <li>▪ <b>Discharge rate:</b> Flat</li> <li>▪ <b>Recharge life:</b> 300-400 cycles</li> <li>▪ <b>Charging temp:</b> 0°C to 60°C</li> <li>▪ <b>Storage life:</b> loses &gt;0.1% per month</li> <li>▪ <b>Storage temp:</b> -20°C to 60°C</li> </ul>	<ul style="list-style-type: none"> <li>▪ High energy density, with the potential for yet higher capacities (typically twice that of the standard Nickel-Cadmium)</li> <li>▪ Does not need prolonged priming when new, only one regular charge</li> <li>▪ Relatively low self-discharge, half that of nickel-based batteries</li> <li>▪ Low maintenance, no periodic discharge needed</li> <li>▪ Specialty cells can provide very high current</li> <li>▪ High cell voltage of 3.6v</li> </ul>	<ul style="list-style-type: none"> <li>▪ Requires a protection-circuit to maintain voltage and current within safe limits</li> <li>▪ Subject to aging, even if not in use – storage in a cool place (15°C) at 40% charge reduces this effect</li> <li>▪ Expensive to manufacture, at 40% higher cost than nickel-cadmium</li> <li>▪ Technology is not fully mature, materials and chemicals change on a continuous basis</li> </ul>
<b>Lithium Polymer</b>	<ul style="list-style-type: none"> <li>▪ <b>Operating temp:</b> improved performance at low and high temperatures</li> <li>▪ <b>Initial voltage:</b> 3.6 and 7.2</li> <li>▪ <b>Discharge rate:</b> Flat</li> <li>▪ <b>Recharge life:</b> 300-400 cycles</li> <li>▪ <b>Charging temp:</b> °C to 60°C</li> <li>▪ <b>Storage life:</b> loses &gt;0.1% per month</li> <li>▪ <b>Storage temp:</b> -20°C to 60°C</li> </ul>	<ul style="list-style-type: none"> <li>▪ Very low profile – batteries resembling the profile of a credit card is feasible</li> <li>▪ Flexible form factor</li> <li>▪ Lightweight as gelled electrolytes allow for simplified packaging, eliminating the metal casing</li> <li>▪ Improved safety as they are more resistant to overcharge and there is a lower chance for electrolyte leakage</li> </ul>	<ul style="list-style-type: none"> <li>▪ Lower energy density and decreased cycle count compared to Li-Ion</li> <li>▪ Expensive to manufacture relative to Li-Ion</li> <li>▪ No standard sizes</li> <li>▪ Higher cost-to-energy ratio than Li-Ion</li> </ul>

Although these two types of batteries (lithium-based) for the last decade has been considered to be the most feasible alternatives for UAVs, battery technology is under constant development and advances are frequently being made in this field.

## 2.1.6 Sensor technology applicable for avalanche SaR

The following subchapters will present some of the currently available sensor technology that theoretically can be applied on a UAV to assist in avalanche SaR operations. Also, working principles of the sensors and how they are currently being employed in their respective fields will be included. It should be noted that this is a presentation and not an in-depth review of each sensor system.

### 2.1.6.1 Avalanche transceivers (AT) and RECCO system

Currently the only commercially available electrical devices used to locate avalanche victims, are avalanche transceivers (AT) and the RECCO reflector system, both of which will be discussed below.

Avalanche transceivers are fairly simple devices which emits a pulsed radio signal. ATs are typically strapped on the someone who perceives themselves to be at risk of avalanches. The device commonly has two modes; transmit and receive. Transmit mode is used during decent, and if a person is buried by an avalanche other party members or rescue teams arriving can switch their ATs to “receive mode”. This mode is used to locate the signal from other ATs that are still in transmit mode, in other

words to locate the victim wearing it. Transceivers are commonly worn around the waist or over the shoulder, under the outer layer of clothing. There are both analog and digital transceivers available, but the majority of the sold units are digital models (BackcountrySafety, 2016). The digital models are considered a superior technology, with multiple antennas as well as a microprocessor to translate the signal to a visual display, which shows the direction and distance to the nearest transceiver in transmit mode.

As previously mentioned the AT emits a pulsed signal, which is in the form of flux lines that are identified and traced as illustrated in Figure 2.1-13. The first step of the search process is a primary search, where the intent is to cover as much ground as possible. When an AT signal is detected a secondary search is initiated to minimize the distance to the victim. Finally, a fine search is initiated to pinpoint the location of the victim using the transceiver and probe, allowing rescuers to start excavation.

All transceivers today operate on the 457kHz frequency as standardized by The International Commission for Alpine Rescue (ICAR) in 1986. However, some high end ATs are equipped with a supplementary frequency commonly referred to as W-link, operating at the 868 or 915 MHz frequency depending on which region it is intended for (Arva, 2016). According to manufacturers like Arva, the W-link function can increase data reliability, ensure quicker and more precise victim/signal list as well as transmit and receive additional data such as the wearers vital signs or identification.

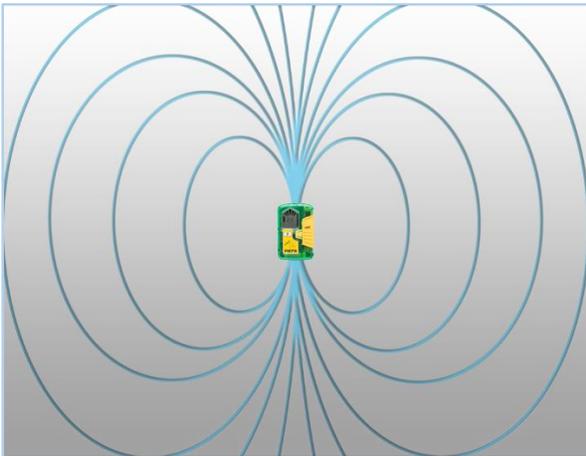


Figure 2.1-12 - Avalanche transceiver flux lines, illustration: (Neuman, 2015)

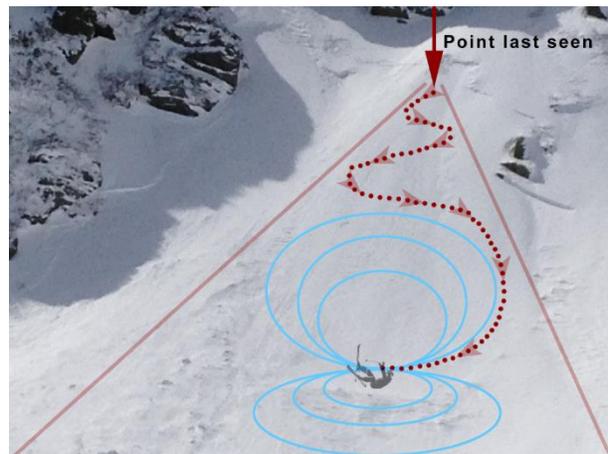


Figure 2.1-13 - Avalanche victim and the ATs flux lines, illustration: (Neuman, 2015)

The digital transceivers are generally easier to use but offer a shorter range of typically 40-50 meters, while analog transceivers offer a range of up to 80 meters. Parameters that reflect the robustness of the ATs is battery life, temperature, weight, dimension and number of antennas. Although none of these parameters are standardized, manufacturers present very similar numbers. The ATs are small hand-held modules with a weight of about 200 grams, a temperature range from around -20°C to 45°C, battery life is commonly about 250 hours in transmit mode and modern transceivers typically have 3 antennas.

The second electronic locating device for avalanche victims is the RECCO system, which consists of two parts: a reflector and a detector. As seen in Figure 2.1-15 RECCO reflectors are small tags weighing less than 4 grams, and are designed to be integrated into outerwear, helmets, boots and other protective gear, making it less likely to be forgotten at home or in the car. The reflector itself is a passive system requiring no electricity, and requires no activation before use. According to RECCO manufacturers the tags reflective properties will not degrade, it requires no maintenance and therefore has a virtually unlimited life span.

Currently the 9<sup>th</sup> generation of the detector device is in use, weighing less than one kilo and is hand held as demonstrated in Figure 2.1-14. According to the manufacturer (RECCO Rescue System, 2016), the device is based on radar technology and has a theoretical range of 200 meters in air and 30 meter through snow. However, the working range is a complex calculation dependent on several factors such as moisture content of snow, direction of burial and orientation of searching device. Apart from RECCO reflectors, the 9<sup>th</sup> generation systems can also locate the standard 457kHz ATs. It is emphasized by RECCO that their rescue system is not a substitute for avalanche transceivers or companion rescue.



Figure 2.1-14 - RECCO handheld detector (RECCO Rescue System, 2016)



Figure 2.1-15 - RECCO reflector (RECCO Rescue System, 2016)

### 2.1.6.2 Optical sensors

Optical sensors such as infrared (IR) and high definition (HD) has become significantly more cost-effective in the last decade, due to great advances in detector technology and manufacturing techniques. Regular HD cameras have more or less become standard equipment on UAVs, although quality varies.

#### ***High Definition (HD) cameras***

These cameras produce images or video of the visible light in the electromagnetic spectrum as seen in Figure 2.1-17. Visible light is focused through a lens and converted to a signal by an electronic

image sensor. The signal is converted from analogue to digital, and processed before it is stored or transferred. Camera technology has improved drastically in the last decade, as can be demonstrated by the image quality of smartphone cameras. Sensors are smaller and lighter, and produce sharper images with higher resolution than ever before. Figure 2.1-16 is an image from a video recorded by a 1080p HD video camera mounted on TRCs hexacopter UAV. The image shows a natural avalanche, which was being inspected by TRC during one of their flights. Such video footage provides rescue organizations with a new tool that can collect valuable information from an aerial perspective.



*Figure 2.1-16 - Inspection of a natural avalanche using an HD camera mounted on TRCs hexacopter UAV, source: Tromsø Red Cross*

### ***Infrared (IR) cameras***

Thermal imaging is a technique that exploits the infrared wavelengths of the electromagnetic spectrum, which is just above visible light as seen in Figure 2.1-17. Every object that has a temperature above absolute zero emits heat, and can therefore be depicted using thermal imaging. Visible light does not affect the thermal emission, meaning that thermal images can be created during the daytime as well as in pitch black conditions (FLIR, 2016). Much like a visible light camera an IR camera uses a lens to focus the infrared light emitted by all object in view, which is converted into an electronic signal by infrared detectors. This signal is further processed digitally to create a thermal image or video.

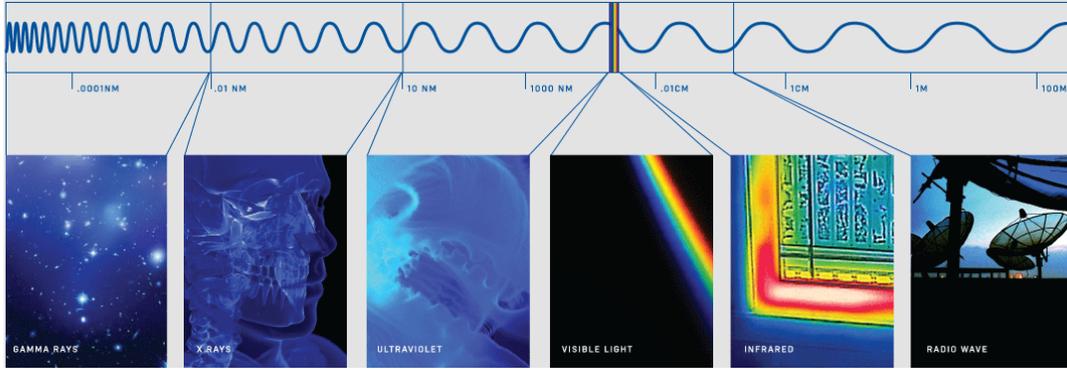


Figure 2.1-17 - Electromagnetic spectrum. Illustration by (FLIR, 2016)

According to (FLIR, 2016) recent innovations in detector technology, the incorporation of built-in visual imaging, automatic functionality and infrared software development, allows them to deliver more cost-effective thermal analysis solutions than ever before. In Figure 2.1-18 we can see a still frame from a video made using the FLIR thermal imaging camera, which is employed by TRCs hexacopter drone intended for use in avalanche SaR operations. The picture is of a man walking through a deep layer of snow in a flat field, and it perfectly illustrates the capabilities of thermal imaging.



Figure 2.1-18 - Infrared image using FLIR TAU2 camera mounted on TRCs hexacopter UAV. Source: Tromsø Red Cross

### 2.1.6.3 Ground Penetrating Radar (GPR)

GPR is a commonly used method used to study subsurface structures, and gathers data about these structures by emitting electromagnetic (EM) waves from a sending antenna. As the EM waves propagate through the measured medium they are partially reflected by layers whose dielectric properties differ from those of the previous layer (Jaedicke, 2003), and the reflections are picked up by the receiving antenna. The radio detection and ranging (RADAR) system measures the travel times for the different interfaces, i.e. from the sender to one interface and back to the receiver as seen in Figure 2.1-19. By gathering several measurements following a pattern an image of the different interfaces can be generated by the data acquisition system. However, in order to estimate the depth,

velocity of the EM wave in each interface material must be known as we only have a travel time measurement. As stated by (Jaedicke, 2003) *“The velocity of the EM wave in the ground and the strength of the received signals depend on the dielectric properties of the subsurface materials”*. The frequency of the emitted EM wave is also important as low frequencies provide good penetration capabilities but lower data resolution, and high frequencies have much better data resolution but provide limited penetration.

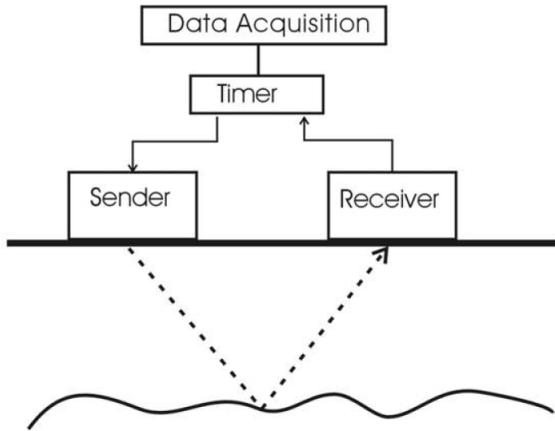


Figure 2.1-19 – Technical principle of ground penetrating radar. Illustration by: (Jaedicke, 2003)

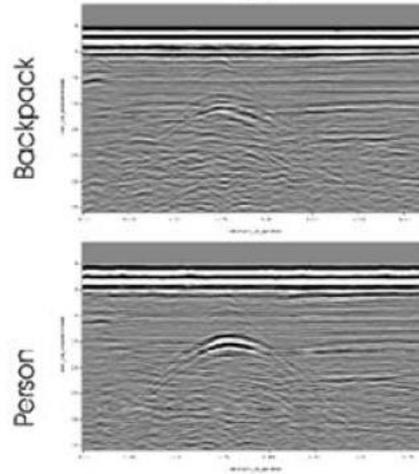


Figure 2.1-20 - GPR detection of objects in the snow pack (density  $\sim 380\text{kg/m}^3$  and depth of 2m) at 900 MHz frequency and step size of 0.1m. Source: (Jaedicke, 2003)

As can be seen from Figure 2.1-20, both a person and backpack at a depth of 2 meters is easily identifiable on images created using GPR. It should be noted that the study by (Jaedicke, 2003) from which the above results in Figure 2.1-20 were obtained, was not conducted using an airborne platform but a ground-based sledge.

#### 2.1.6.4 Smartphone locating systems

Smartphones are rapidly increasing in popularity and according to a report by (Statistics Norway, 2016), 85 percent of the population has access to this type of device in 2015. As this type of phone generally have very high-tech hardware, they also come with multiple areas of use that one can take advantage of by developing applications to exploit the hardware capabilities. In a report for the Canadian Avalanche Centre (Floyer, 2013) it was stated that smartphone avalanche search apps make use of various two-way communication technologies, such as the call network, Wi-Fi, Bluetooth and GPS. By employing one or more of the aforementioned technologies in combination with an application, the device is capable of communicating its location to another smartphone. In the same report (Floyer, 2013) further notes that both Wi-Fi and Bluetooth signals are *“strongly affected by transmission through water-based mediums, including snow”*.

During the 2015 International Conference on Unmanned Aircraft Systems (Wolfe, Frobe, Shrinivasan, & Hsieh, 2015) presented their findings when using fourth generation (4G) long term evolution (LTE) technology to locate cell phone signals from completely buried avalanche victims. The primary focus of their study was modelling of radio frequency (RF) propagation through mediums such as snow and air. According to their findings during modelling and field trials, detection of cell phone signals up to

2.13 meters in depth is considered feasible. It should be noted that these findings did not consider situations where the victim is lying on top of their cellphone.

Use of telecommunication technology for avalanche search is very much still in its infancy stages, are much more research is needed to establish its validity, however the few results available today indicate that this is a possibility that should be studied further. Due to the widespread use of smartphones, they are highly available throughout the day during almost any activity. Smartphones are also capable of fulfilling multiple needs as compared to a dedicated AT which only has one function, are easily forgotten and a relatively expensive.

## **2.2 NCAA – Regulations concerning aircraft without a pilot on board etc.**

This chapter contains a review of the regulations regarding operations with unmanned aircraft in Norwegian airspace. All information presented here is gathered from the NCAA as presented in their document “regulations concerning aircraft without a pilot on board etc.”. As the original document is quite lengthy, only parts of it will be reproduced in the subsections of this chapter, whereas the complete legal document is available at the website of the NCAA (Norwegian Civil Aviation Authority, 2015).

### **2.2.1 General regulations**

Due to the amount of information in the legal documents, Table 2.2-1 has been created to provide a more organized visual presentation of technical specifications regarding UAV operations, as well the organizations relation to the NCAA. In their legal framework NCAA separates UAVs into 3 categories, namely R01, R02 and R03, based on the aforementioned technical specifications. The classifications are arranged from lower (R01) to higher (R03), and are elaborated upon in Table 2.2-1.

Table 2.2-1 – Summary of regulations concerning aircraft without a pilot on board etc. Issued by the NCAA

General requirements	NCAA classification		
	RO1	RO2	RO3
<b>NCAA/operator relation</b>	Operator must notify the NCAA before a new business is established	Operator must have permission from the NCAA before the business is established. Application must include a <i>risk analysis</i> and a <i>manual of operation</i> .	
<b>MTOW</b>	<2,5 kg	<25 kg	>25 kg
<b>Max velocity</b>	<60 knots	<80 knots	>80 knots
<b>Max altitude</b>	120m AGL	120m AGL	Normally 120m AGL. Above this, special regulations apply
<b>VLOS</b>	<u>Only during daylight</u> and within set safety distances	Operation within set safety distances	
<b>EVLOS</b>	Not allowed		
<b>BLOS</b>	Not allowed	Only if NCAA approval	Only if NCAA approval
<b>BLOS &lt;120m</b>	Not allowed	Special regulation apply, see regulations concerning aircraft without a pilot onboard etc., §56-58	
<b>BLOS &gt;120m</b>	Not allowed	Not allowed	Special regulation apply, see regulations concerning aircraft without a pilot onboard etc., §63-64
<b>Propulsion</b>	N/A	N/A	RO3 required for jet turbine propulsion
<b>Flight in the dark</b>	Not allowed	Navigation light required	Navigation light required
<b>Mandatory lighting</b>	N/A	White low-intensity lights, minimum 10 candela strength, rotary strobe-light with minimum 10 flashes/min.	
		When: BLOS	When: BLOS, in controlled airspace and above 120m in non-controlled airspace
<b>Operation</b>	It is <u>not</u> allowed to operate the aircraft above 120 m AGL, or within 50 m of other persons, buildings or vehicles that are not under the control of the operator. It is not allowed to operate within 150 m of a crowd over 100 people.	Same regulations as RO1 and RO2, however RO3 operators can apply for special permits	

## 2.2.2 Excerpts of regulations concerning aircraft without a pilot on board etc.

This subsection presents some excerpts from “regulations concerning aircraft without a pilot on board etc.”<sup>1</sup> which is part of the legal framework regulated by NCAA (Norwegian Civil Aviation Authority, 2015). “Chapter 3” describes general requirements and restrictions applicable to all RPAS operators (RO), whereas “Chapter 7” is in regard to operational provisions applicable to all RO. The content of these two excerpts has not been modified in any other way than formatting.

<sup>1</sup> Numbering of the following two excerpts and their paragraphs corresponds to that of the original legal document

## **Chapter 3 – General requirements and restrictions applicable to all RPAS operators (RO)**

### ***§11. Requirements for leading personnel***

Flights may only be conducted if the undertaking has an accountable manager, an operations manager and a technical manager.

### ***§12. Transport of goods or passengers***

Transport of passengers is not permitted.

Transport of goods is only permitted where this is specified in the license from the CAA Norway.

### ***§13. Requirements for altimeter or similar***

The pilot and pilot in command shall use an altimeter or another method to ensure that the aircraft does not fly more than 120 meters above ground or water.

### ***§14. Fail-safe system***

All rotor-operated aircraft shall have a built-in system to ensure that the aircraft can land automatically in the event of loss of control on the part of the pilot or pilot in command. All aircraft without a pilot on board (fixed wing) shall have a redundant system that ensures control of the aircraft in the event that the main radio communication system fails.

### ***§15. Display flying***

Display flying may only take place if authorized by the CAA Norway.

### ***§16. Aerodromes***

Landings and take-offs of aircraft without a pilot on board may not be performed on aerodromes.

In special cases, landing and take-off on an aerodrome may take place by agreement with the local air traffic services unit, provided that local procedures are in place to ensure the safety of other air traffic. The management of other air traffic operations shall take precedence. The air traffic service is responsible for establishing sufficient safety distances.

### ***§17. Strict liability for damage to third parties etc.***

The operator is invariably liable for damage or losses suffered outside the aircraft as a result of the aircraft being used for flying. This does not apply, however, to damage to another aircraft or injury to persons or damage to objects in such an aircraft.

### ***§18. Insurance***

The operator is responsible for ensuring that it has insurance cover for third-party liability; cf. Section 11-2 of the Aviation Act.

### ***§19. Under the influence of alcohol etc.***

Nobody must fly aircraft without a pilot on board under the influence of alcohol or other intoxicating or narcotic substance. Sections 6-11 and 6-13 of the Aviation Act shall apply accordingly.

### ***§20. Weapons etc.***

It is not permitted to fly aircraft without a pilot on board armored with weapons or weapon systems. It is not permitted to fly aircraft without a pilot on board armored with rockets, fireworks or other dangerous devices, except by authorization.

### ***§21. Duty to notify of discontinuation***

The operator shall notify the CAA Norway if the undertaking is discontinued.

## **Chapter 7 – Operational provisions applicable to all RO operators**

### **§47. Rules of the air**

The general rules of the air apply to aircraft without a pilot on board.

### **§48. Airspace**

The pilot and pilot in command have a duty to familiarize themselves with the applicable airspace management. The pilot and pilot in command also have a duty to familiarize themselves with the applicable airspace classification and the air traffic services unit that is in charge of the area in which they plan to perform an operation.

### **§49. Right of way for other aircraft**

Aircraft without a pilot on board shall give other aircraft right of way.

### **§50. Flight preparation**

Prior to each flight, the pilot and pilot in command shall familiarize themselves with all available information that may have a bearing on the planned flight, including information about the weather conditions. The pilot and pilot in command shall ensure that the aircraft is airworthy before the flight is conducted. All flights shall be conducted in accordance with applicable provisions, the operations manual and the limitations of the aircraft.

### **§51. Safety distances, maximum flight altitude**

All flights must be conducted in a considerate manner so that there is no risk of harm to aircraft, people, birds, animals or property and so as not to otherwise constitute a public nuisance

The aircraft must be clearly visible to the operator at all times. Necessary safety distances must be maintained for all flights. It is not permitted to fly

- a) at altitudes of more than 120 meters above ground or water;
- b) closer than 150 meters to a crowd of more than 100 people;
- c) closer than 50 meters to people, motor vehicles or buildings not controlled by the pilot and pilot in command.

Aircraft with an MTOW of 250 grams or less may be used for VLOS, EVLOS or BLOS flying, though not at altitudes of more than 50 meters above ground or water. The safety distances provided for in the second paragraph (b) and (c) do not apply.

Flights other than in accordance with the safety distances in the second and third paragraph may only be conducted by RO 3 operators in accordance with the provisions set out in Chapter 9 and other conditions set out in the license.

### **§52. First person view (FPV)**

FPV flying without BLOS authorization, cf. Sections 57 and 64, is only permitted if the flight is conducted as a VLOS operation and the pilot in command has visual contact with the aircraft at all times.

### **§53. Extended visual line of sight (EVLOS)**

EVLOS flying may only be performed if the license from the CAA Norway covers this type of operation.

Two-way radio communication or continuous telephone communication between the pilot and observer is required for EVLOS flights.

### **§54. Areas in which flying is not permitted**

An aircraft without a pilot on board may not be flown over or in the vicinity of military areas, embassies or prisons.

An aircraft without a pilot on board may not be flown closer than 5 km to an aerodrome, unless the flight has been cleared with the local air traffic control service or flight information service.

### **§55. Flying when extraordinary incidents have occurred**

Flying over or in the vicinity of places where an incident site has been established by the emergency services or the Armed Forces in connection with an accident or other extraordinary event may only be performed by permission from the accident site commander.

## 2.3 Hazard identification and risk assessment

According to (ISO 17776, 2000) the hazard identification and risk assessment process consists of three generic steps, which are described below in paraphrasing based on the contents of this thesis.

- a) **Step 1: Identification of the hazard** – This step is based upon consideration of factors such as operating and maintenance procedures, training of personnel and inclusion of external hazards such as extreme environmental conditions and impact with other objects, persons or vehicles.
- b) **Step 2: Assessment of the risk** – which arise from the hazards identified and of its tolerability to personnel, the public, the organization and the environment. Acceptability of the estimated risk must then be judged based upon criteria appropriate to the particular situation.
- c) **Step 3: Elimination or reduction of the risk** – Where this is deemed necessary. This involves identifying opportunities to reduce the probability and/or consequence of an accident.

### 2.3.1 Risk analysis definitions

<b>Barrier</b>	Measure which reduces the probability of realizing a hazard's potential for harm and which reduces its consequence (ISO 17776, 2000)  NOTE <sub>1</sub> : Barriers may be physical (materials, protective devices, shields, segregation, etc.) or non-physical (procedures, inspection, training, drills, etc.).  NOTE <sub>2</sub> : In this thesis barriers are separated into two categories. Proactive barriers are intended to prevent an unwanted event, whereas reactive barriers are intended to minimize consequences of an unwanted event.
<b>Hazard</b>	Potential source of harm (ISO 17776, 2000)  NOTE: In the context of this thesis, the potential harm may relate to human injury, damage to the environment, damage to property, or a combination of these.
<b>Hazardous event</b>	Occurs when the hazard's potential to cause harm is realized (ISO 17776, 2000)
<b>Risk</b>	Combination of the probability of an event and the consequences of the event (ISO 17776, 2000)
<b>Risk analysis</b>	Use of available information to identify hazards and to estimate risk (ISO 17776, 2000)

### 2.3.2 What is risk?

In (ISO 17776, 2000) risk is defined as *“a term in general usage to express the combination of the likelihood a specified hazardous event will occur and the severity of the consequences of that event. Using*

*this definition, the level of risk may be judged by estimating the likelihood of the hazardous event occurring and the severity of the consequences that might be expected to follow from it.”*

As risk – in this thesis – is founded on an experience-based qualitative approach, it will be portrayed as the product of the perceived probability- and consequence of occurrence. All hazards identified during the HAZID analysis should be rated based on the aforementioned attributes for risk, and further evaluated in the risk assessment. The categories used for describing probability and consequence in this thesis are as follows:

### **Probability of failure**

1. Highly unlikely – Failure has occurred in industry
2. Unlikely – Failure has occurred a few times in industry
3. Moderate – Failure has occurred in the operating company
4. Likely – Failure has occurred several times in the operating company
5. Almost certain – Failure has occurred several times a year in the location

### **Consequence of failure**

Perceived consequences are usually considered in broad categorizations of their impact such as safety, environmental and economic. However, as described further in HAZID methodology in Chapter 3.4, it is more appropriate for this thesis to only focus on the safety consequences of a hazardous event. Consequences of failure related to safety is separated into the following categories:

- A. No injury
- B. Minor injury
- C. Major injury
- D. Single fatality
- E. Multiple fatalities

Probability and consequence categories directly correspond to a 5x5 risk matrix as presented in Figure 2.3-1, Chapter 2.3.3. In order to estimate the risk one must first identify potential hazards. There are several methods for identifying hazards but only the HAZID analysis will be presented and applied in this thesis.

#### **2.3.2.1 Qualitative Risk Analysis**

In his book regarding risk analysis in engineering, (Modarres, 2006) indicates that qualitative risk analysis perhaps is the most widely used technique as it is simple and quick to perform. In this type of analysis linguistic scales describing the probability and consequence are used, which are defined in Chapter 2.3.2 above. A matrix is used to characterize risk in the form of probability of a hazardous event and the corresponding consequences of this event occurring. (Modarres, 2006) also states that *“because this type of analysis does not need to rely on actual data and probabilistic treatment of such data, the analysis is far simpler and easier to used and understand, but is extremely subjective”*. This type of risk assessment is believed to be most appropriate for straightforward processes, single product safety or simple physical security.

### **2.3.2.2 Quantitative Risk Analysis**

The qualitative approach of risk analysis attempts to quantify all parameters used in the analysis, and as identified by (Modarres, 2006) the quantitative approach is *“clearly the preferred approach when adequate field data, test data, and other evidences exist to estimate the probability (or frequency) and magnitude of the losses”* and furthermore *“when evidence and data are scarce, uncertainties associated with the quantitative results play a decisive role in the use of the results”*. As the latter statement is most applicable for this thesis, qualitative risk assessment may be considered most applicable, however quantitative risk analysis is likely to have a much more solid foundation for its results.

### **2.3.3 Hazard identification analysis (HAZID)**

The HAZID technique will be used qualitatively in order to identify all significant hazards that are associated with a specific activity. This can be achieved by several different methods, whereof a selection of them which will be applied in this thesis are briefly described below:

#### **1. HAZID meeting with experienced personnel (brainstorming)**

This method relies on the acquired expertise of persons working in a field related to the topic of the HAZID analysis. For this thesis, all fields related to professional use- and construction of UAVs for civil applications is regarded as relevant experience. Participants of a HAZID meeting are guided through a hazard-identification form where categories or guidewords for potential hazards is the driving force for a brainstorming process with the intention of identifying all conceivable hazards. Ideally, the meeting should include multiple persons from relevant disciplines to best stimulate the brainstorming process. However, it can also be executed in several sessions with one or two participants, where the results of each session are compiled to a complete list of identified hazards. Participants should be guided through the process by a HAZID leader, which for the purposes of this thesis, is the author.

As stated in (ISO 17776, 2000) in regards to the role of expertise and judgement *“An often adequate approach is one in which the knowledge and expertise of staff, having appropriate experience, is used for hazard identification and assessment. This is particularly useful where the activity under consideration is similar to activities undertaken previously at the same or different locations. Practical staff experience gained in the field and feedback from hazardous events and near misses that have occurred is essential in this respect.”*

#### **2. Review of checklists, codes and standards**

The review of checklists, codes and standards allow the analyst to evaluate previously identified hazards. Codes and standards are developed from previous experience gained by industry in similar operating conditions. When reviewing this information *“a high level of safety can be achieved by checking for compliance with these standard practices in design, construction, operation and maintenance”* as described in (ISO 17776, 2000). NCAA demands that all certified UAV operators in Norway present an operation manual (OM) which must be approved by them, in order to gain clearance for operation. As there are no standards for design, construction, operation or maintenance of UAVs, the OM is regarded as a valuable source of previously identified hazard. This is particularly true for the operation of UAVs, as each operator must develop a risk analysis for all intended operations, identifying hazards and barriers. Pre-flight checklists are also a common requirement for professional organizations, which contains valuable information concerning barriers implemented with respect to mitigating previously identified hazards.

### 3. Review of hazard registers of previous accidents

If available, hazard registers of previous accidents are an important resource for identifying potential hazards. Similarities in operating conditions, platform design and mission type can provide indications of an inherent hazard for the intended operation.

#### 2.3.4 Risk matrix, risk acceptance criteria (RAC) and ALARP

Upon identification, hazards are assigned a consequence category (A-E) and a Probability of Failure (1-5), as to be implemented into a risk rating matrix. This is a qualitative technique that can be used for operational issues for which it may be difficult or unnecessary to undertake a more rigorous quantitative analysis (ISO 17776, 2000). The following Figure 2.3-1 is an example of a 5 by 5 risk ranking matrix where risk acceptance criteria is defined by color schemes in the grid. The risk acceptance criteria define what level of risk is considered acceptable as per organizational standard. For this matrix the RAC is defined as described in Figure 2.3-2, including broadly acceptable (D), tolerable (C), marginally tolerable (B) and intolerable (A) levels of risk, all corresponding to the colors in the matrix below.

PoF Ranking	Probability of failure	A	B	C	D	E
5	(1) Almost certain (2) Failure has occurred several times a year in the location					
4	(1) Likely (2) Failure has occurred several times a year in operating company.					
3	(1) Moderate (2) Failure has occurred in the operating company.					
2	(1) Unlikely (2) Failure has occurred a few times in industry.					
1	(1) Highly unlikely (2) Failure has occurred in industry.					
<b>Consequence of failure (safety)</b>		No injury	Minor injury	Major injury	Single fatality	Multiple fatalities
<b>Category</b>		<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>	<b>E</b>

Figure 2.3-1 - 5x5 Risk Matrix modelled after the DNV-RP-G101 Standard (Det Norske Veritas, 2010)

Risk Class	Acceptance Criteria
A	Intolerable
B	Marginally tolerable
C	Tolerable
D	Broadly acceptable

Figure 2.3-2 - Definition of risk acceptance criteria



Figure 2.3-3 - ALARP triangle

Through a “screening process” all hazards that are rated broadly acceptable or tolerable are eliminated. Hazards that are in the category of marginally tolerable, is where the “as low as reasonably practicable” (ALARP-principle) is applied. “Practicable” usually refers to a cost/benefit perspective, where the risk is to be reduced to a level that is economically feasible with respect to safety. However, when considering the difficult balancing of creating an applicable UAV platform, the acceptable level of risk might be assessed against limitations of design, technology, organization and regulations. Hazards that are in the intolerable region must have additional safety barriers implemented to reduce risk to an adequate level.

### 2.3.5 Bow-tie analysis

The bow-tie analysis is a tool to visualize what hazard can lead to a hazardous- or unwanted event, and what the consequences of such an event might be. All hazards identified through the HAZID analysis have the potential to become an unwanted event if it penetrates all the proactive barriers put in place to prevent said event. If the hazardous event occurs, there are reactive barriers implemented to mitigate the severity of the potential consequences as seen in Figure 2.3-4 below.

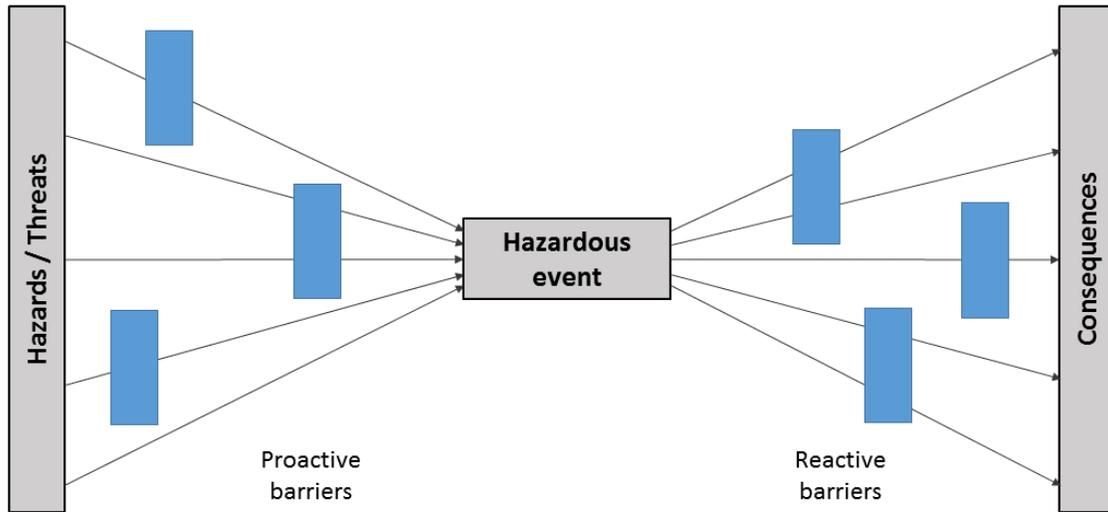


Figure 2.3-4 – Conceptual presentation of a bow-tie model

### 2.3.6 Expected fatality rate (EFR)

In the Arctic Science Remotely Piloted Systems (RPAS) Operator’s Handbook by (Storvold, et al., 2015), Equation 2 – as presented below – is used to calculate the EFR of UAV operations. This equation will be used in this thesis to calculate EFR for a hypothetical UAV-assisted avalanche SaR operation.

$$EFR = \frac{1}{MTBF} A_{exp} \rho (1 - f_{prot} + f_{prot} p_{pen}) p_{kill} \quad \text{Equation 2 - Expected fatality rate}$$

where,

- $EFR$  = expected fatality rate (persons killed per hour of operation)
- $MTBF$  = mean time between failures (i.e., loss or crash of aircraft)
- $A_{exp}$  = area exposed to aircraft ground crash
- $\rho$  = population density in area
- $f_{prot}$  = fraction of people protected by shelter (e.g., housing)
- $p_{pen}$  = probability of UAV penetrating shelter
- $p_{kill}$  = probability of UAV killing a person when hit

## 2.4 Snow avalanches

Avalanches claim hundreds of lives annually on a world-wide basis. Mountainous areas characterized by a high-relief topography is particularly vulnerable. Generally speaking, avalanches occur when the snowpack fails, i.e. the load exceeds the strength. The load on the snowpack is simply the weight of the snow, but the strength is far more complex to define, depending on a multitude of physical properties such as density, hardness, temperature, rate of deformation and quality of bonding to adjacent layers (McClung & Schaerer, 1993).

### 2.4.1 Avalanche terrain and victims

According to the avalanche handbook by (Lied & Kristensen, 2003), the groups of people most exposed to avalanches in Norway are as follows:

- Residents and – to some extent – seasonal residents in cabins, living in avalanche prone areas
- Road users
- Operations and maintenance personnel, hereby highway authorities, electric power companies, telecommunications companies and alpine resorts
- Construction workers
- Military personnel
- Skiers, snowboarders, climbers, etc.
- Hunters
- Snowmobilers

As the above list implies, there are several groups of people directly threatened by avalanches in Norway, all of which could potentially benefit from an improved SaR system, and also better forecasting of avalanches. According to (Lied & Kristensen, 2003) on average there occurs a high frequency avalanche season approximately every 13 years in Norway, causing 10-20 deaths and 100-200 MNOK in damages. These numbers are from 2003, and are likely even higher today. Although the most severe consequence of an avalanche is loss of human life, physical- and psychological injuries and damages to infrastructure can also be extensive. Costs related to evacuation, rescue operations and traffic delays and re-routing must also be included when estimating the economic impact caused by avalanches. Figure 2.4-1 below illustrates at what low inclinations avalanches can occur as well as the immense amounts of snow that are set in motion.



Figure 2.4-1 - Crown of a dry slab avalanche, with an estimated height of 4m. Photo: Kjetil Brattlien

Figure 2.4-2 illustrates the survival rates of completely buried avalanche victims as a function of burial duration. According to (Haegeli, Falk, Brugger, Etter, & Boyd, 2011) the existing Swiss avalanche survival model is what “forms the foundation for current international recommendations for rescue and resuscitation as well as the rationale for safety and rescue devices”. In an article by (Lunde & Kristensen, 2011) findings indicate that conditions of avalanches and victims in Norway correspond with similar studies in Switzerland. Due to this, the curve describing the probability of survival in Swiss avalanche victims will be used for this thesis.

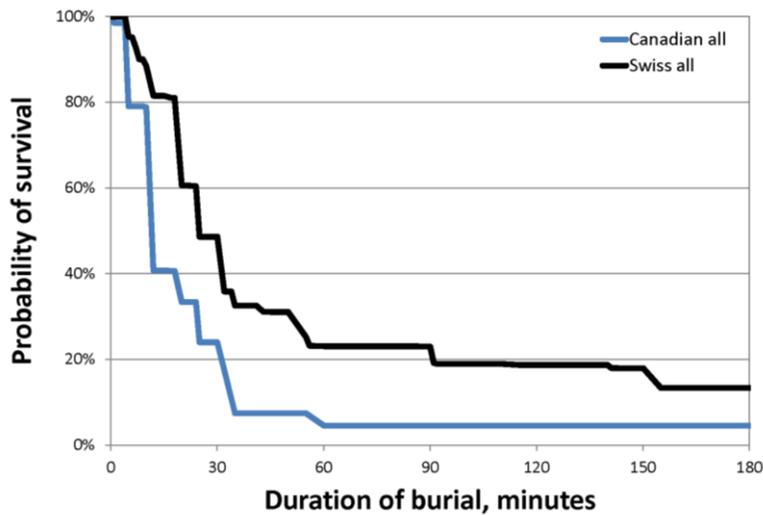


Figure 2.4-2 – Comparison of avalanche survival patterns in Canada and Switzerland. Illustration by: (Haegeli, Falk, Brugger, Etter, & Boyd, 2011)

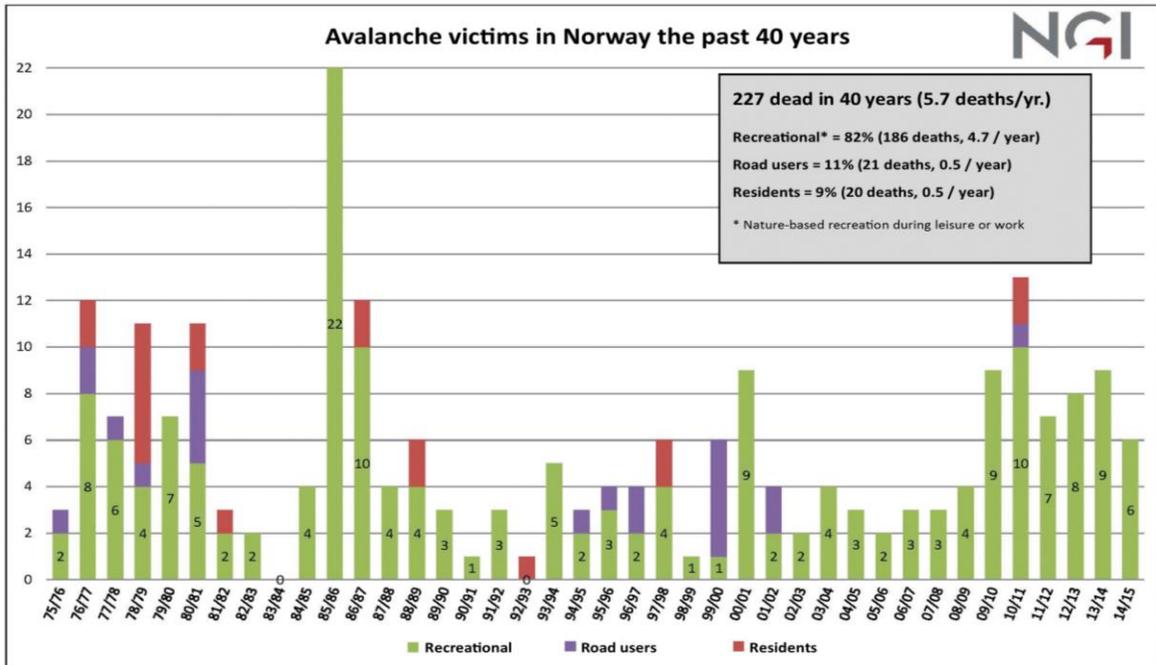


Figure 2.4-3 - Avalanche victims in Norway the past 40 years, English adaptation of (Norwegian Geotechnical Institute, 2016)

Figure 2.4-3 shows a statistic of all avalanche victims in Norway in the past 40 years, averaging a number of 5.7 deaths per year. As we can see the majority of avalanche victims is related to recreational activities, which typically implies that the accident occurs in a remote area due to the nature of recreational skiing, snowboarding and snowmobile use in Norway. Figure 2.4-4 and Figure 2.4-5 below is created based on avalanche accident reports from NGI, and statistically illustrates during what months and in what counties lethal avalanche accidents occurs. It should be noted that these statistics are based on the number of avalanche victims rather than number of avalanches, to more clearly portray the distribution. As can be seen, most accidents occur during early and mid-winter viewed from the perspective of Northern Norway, as over half (51.73%) of the victims of avalanches are from the counties of Troms, Nordland and Finnmark.

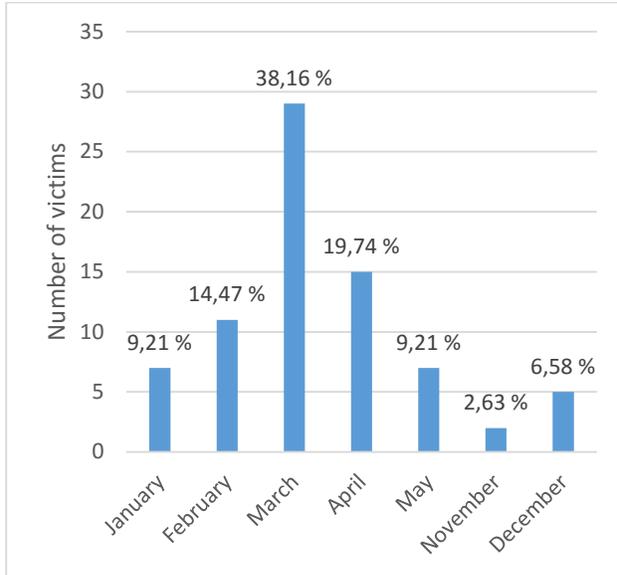


Figure 2.4-4 - Avalanche victims by month (2002-2016), created with data from (Norwegian Geotechnical Institute, 2016)

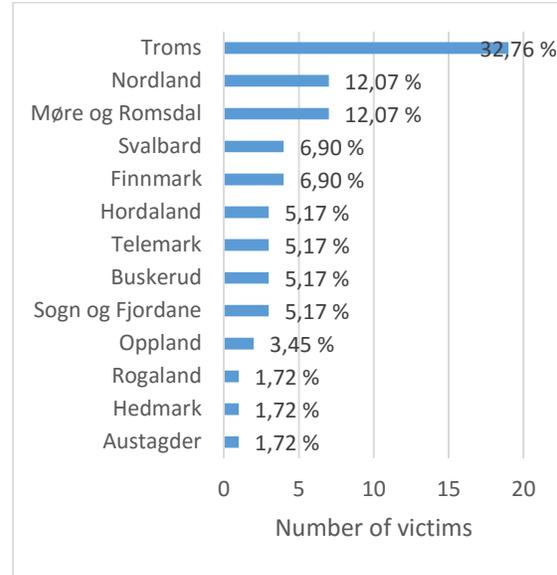


Figure 2.4-5 - Avalanche victims by county (2002-2016) created with data from (Norwegian Geotechnical Institute, 2016)

## 2.4.2 State-of-the-art for avalanche SaR

In essence there are two ways a victim can be rescued after an avalanche. Assuming that there are members of the group not affected by the avalanche or otherwise incapacitated, companion rescue can be initiated immediately after an avalanche. This category also includes first responders that are in vicinity to the avalanche and have the equipment and skill needed to initiate a SaR effort immediately. Secondly there is organized rescue where specially trained personnel arrive at the accident site upon being notified by direct- or indirect witnesses. Organized rescuers often have specialized equipment available to aid in locating and excavation of victims. As the primary focus of this thesis is organized rescue this will be described first, followed by companion rescue.

### 2.4.2.1 Organized rescue

#### **Background and organization**

After an avalanche is reported and there are believed to be possible victims, a SaR effort is initiated. The organization of the rescue team varies with location and available resources such as personnel and equipment and their level of competence. Although the participants during a SaR operation may consist of personnel from several different organizations, there are still common guidelines for conduct and search techniques. These guidelines are essential to the SaR effort, as the attending rescue personnel's different organizational background makes coordination of the rescue effort a complex task. The rest of this subsection (unless stated- or referenced otherwise) regarding state-of-the-art for avalanche SaR is translated and reproduced from guidelines provided by NRR (Nasjonalt Redningsfaglig Råd, 2012).

Table 2.4-1 - Visual model of Norwegian avalanche rescue organizations and resources

<b>Aerial resources</b>	<b>Dedicated avalanche rescue resources</b>	<b>Other organized rescue services</b>
<ul style="list-style-type: none"> <li>▪ Air ambulance</li> <li>▪ Police helicopter</li> <li>▪ Rescue helicopter</li> </ul>	<ul style="list-style-type: none"> <li>▪ Operative management and emergency response personnel from the police</li> <li>▪ Avalanche rescue groups</li> <li>▪ Professional ski patrols</li> <li>▪ Norwegian Armed Forces avalanche rescue groups</li> <li>▪ Approved avalanche rescue dog teams (Norwegian Search and Rescue Dogs, Norwegian Armed Forces, Police)</li> </ul>	<ul style="list-style-type: none"> <li>▪ Ski patrols</li> <li>▪ Ambulance service</li> <li>▪ Norwegian Red Cross</li> <li>▪ Norwegian People’s Aid – Medical Service</li> <li>▪ Norwegian Alpine Rescue Groups</li> <li>▪ Rovernes Emergency Response Group</li> <li>▪ NORTIND – Norwegian Mountain Guides</li> <li>▪ Fire department and rescue services</li> </ul>

Table 2.4-1 summarizes the different avalanche rescue organizations and resources in Norway as presented in the NRR guidelines. The intention of the guidelines is to provide a common foundation for procedures and techniques, so that the rescue teams do not have to rely on improvisation during SaR. As a result, the rescuers can rather focus on what specific measures needs to be taken, to ensure that the most effective means of locating the victim is utilized. According to NRR; experiences from avalanche training drills, seminars and debriefs has identified a need for further development and coordination of the different avalanche response units.

The general development of alpine recreational activities in Norway is an increase in popularity, activities may be more extreme and skiing in the dark has become more common. Due to this rescue services has to continuously adapt to the changes by reorganizing and adopting new equipment and techniques to be prepared for new challenges that arise (Skjelbakken, 2016). However, it is recognized that SaR equipment and methods are only useful to the extent that they are well-known, applied correctly and at the right time, as well as in compliance with other rescue personnel and activities.

The techniques presented in NNRs guidelines are based upon international guidelines from ICAR as well as national practices, research and development. These methods are mutual for all organizations attending an avalanche SaR operation, both professionals and volunteers.

**Search**

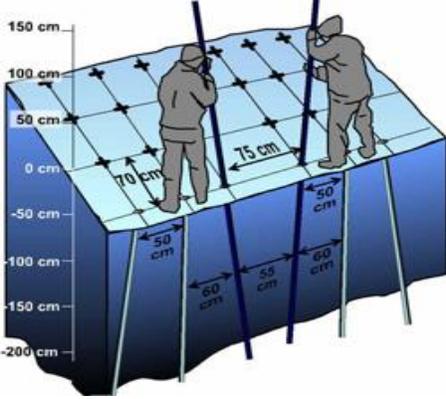
The goal is to have the rescue effort carried out as effectively and safely as possible. Participants should have communal methods for search, rescue and coordination, as this leads to a more cooperative approach. When first arriving it is important to acquire specific information regarding the avalanche, such as size, number of victims and their possible locations, and probability for secondary avalanches in order to map out upcoming search efforts and dimensioning of the operation. Selection of the primary search area should be based on available information and observations from

the avalanche area. Table 2.4-2 is created to summarize the guidelines from NRR for official search methods and techniques.

Table 2.4-2 - Official search methods recognized by NRR

	<b>Search method</b>	<b>Description</b>
<b>Specialized avalanche SaR resources</b>	<b>Avalanche rescue dogs</b>	<p>Avalanche rescue dog teams should be employed as quickly as possible. Other means of searching should not in any way hinder the dogs search effort, and if there is a simultaneity conflict the dog should always have priority. The following aspects should be attended to:</p> <ul style="list-style-type: none"> <li>▪ Observe and assist the dog handler</li> <li>▪ Avalanche rescue dogs can be disturbed by rescue-crew and - equipment</li> <li>▪ Coordinate avalanche rescue assignments with dog handler</li> <li>▪ Multiple avalanche rescue dog teams can work simultaneously</li> <li>▪ Ensure a sheltered resting area</li> <li>▪ Equip the dog handler with blue markers/flags</li> </ul>
<b>Electronic device search</b>	<b>Avalanche Transmitter</b>	The aim of search using AT is to exploit their capabilities in the most efficient manner, with the purpose of locating victims with active transceivers as quickly as possible. Use of AT equipment should be done in appliance with the manufacturers guidelines and ICAR recommendations.
	<b>RECCO Rescue System</b>	The aim of search using the RECCO Rescue System is to exploit their capabilities in the most efficient manner, with the purpose of locating victims with passive reflectors as quickly as possible. Use of RECCO should be done in appliance with the manufacturers guidelines and ICAR recommendations.
<b>General search methods<sup>2</sup></b>	<b>Rapid search</b>	It is observed that this method saves the most lives. The method is very quick and there are no aids required, and can be executed in parallel with avalanche rescue dogs. It is vital that this technique is executed as quickly as reasonably possible. The search is to be conducted as a preliminary quick surface search, looking for apparent traces of a missing person.
	<b>Thorough surface search</b>	This technique follows the rapid search, and is intended to locate small but visible traces of an avalanche victim.

<sup>2</sup> Note that the “general search methods” described in Table 2.4-2 differs from the search methods described in Chapter 2.1.6.1, due to the latter being from an AT user manual which describes companion rescue assuming that the victim is wearing an AT.

	<p><b>Probe search</b></p>	<p>An individual search using a probe within a limited area. This technique is used upon discovery of items possibly belonging to a victim, indication by dog or signal detection by ATs or RECCO Rescue System. Additionally it might be effective to execute probe searches around natural interception points such as large rocks and trees.</p>
	<p><b>3-point coarse search</b></p>	<p>During organized searches with probes a 3-point coarse search should be conducted as illustrated in Figure 2.4-6 below.</p>  <p><i>Figure 2.4-6 – The method for 3-point coarse search with probe (Illustration by NGI)</i></p>
	<p><b>Detailed search with probe</b></p>	<p>Detailed searches with probes are only executed in areas of particular interest when a 3-point coarse search yields no results.</p>

**Helicopter-assisted search**

If a helicopter crew is primary responders to an avalanche, the following is done before landing:

- Danger of avalanche assessment
- Reconnaissance of the surrounding area
- A preliminary visual surface search

According to NRR, helicopter-assisted searches with electronic devices are highly effective and can be used in areas with high probability for secondary avalanches or where there are multiple- or particularly large avalanches. The currently employed electronic search devices are ATs with external underslung antennas and/or RECCO systems.

Table 2.4-3 – Helicopter-assisted search with electronic devices; technique, elements of safety and other tasks

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<b>Description</b>
<p><b><i>Search method when electronic devices are available</i></b></p> <ul style="list-style-type: none"><li>▪ Start the search in the lower end of the avalanche debris on the lee side</li><li>▪ Maintain helicopter orientation with the cockpit facing the wind</li><li>▪ Scan the avalanche area in a straight line</li><li>▪ Maintain the linear formation and ensure a search corridor distance of 30 meters for AT and 20 meters for RECCO</li><li>▪ If a strong signal is acquired a marker is dropped, no time should be spent on detailed searches</li><li>▪ Follow-up searches for identification of a victim is done manually on the ground</li><li>▪ If helicopter-assisted search and avalanche rescue dog teams are working simultaneously, their search sequence and designated areas must be coordinated</li></ul> <p><b><i>Some elements of safety when helicopters are used, according to NRR:</i></b></p> <ul style="list-style-type: none"><li>▪ If there are multiple helicopters present, frequency 123:10 is used</li><li>▪ Ensure that all emergency response personnel conduct their work calmly and as instructed</li><li>▪ There is strong wind due to the helicopter rotors</li><li>▪ Remove loose objects and secure all equipment (skiing equipment should not be in an upright position)</li><li>▪ Always approach the helicopter from the front, and stop at a safe distance</li><li>▪ Use ski goggles</li><li>▪ Never approach the helicopter without instructions from the helicopter crew</li><li>▪ Be particularly attentive in terrain with inclination</li></ul> <p><b><i>Other helicopter-related tasks</i></b></p> <ul style="list-style-type: none"><li>▪ Transport</li><li>▪ Communication relay</li><li>▪ Reconnaissance for on-scene management</li><li>▪ Illumination of the search area</li><li>▪ Documentation</li><li>▪ Transferal of live images (police helicopter)</li></ul>

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Table 2.4-3 is intended to establish a baseline for how a manned helicopter contributes during an avalanche rescue operation, as well as some of the safety elements that follows. This is done in order to evaluate what contributions are exclusive to a helicopter, when evaluating implementation of a UAV.

### **2.4.2.2 Companion rescue**

Companion rescue is predicated upon a party of more than one skier, where some of the party members are unaffected by the avalanche and are equipped and able to initiate a search for the avalanche victim. A large advantage, as opposed to organized rescue, is the advantage of observation. Upon realizing one or more of the group members are victims of an avalanche, it is important to track the victims path in order to better predict his or hers stopping location (Nes, 2013). However, as

stated by (Brattlien, 2012) personal safety is of utmost importance, therefore one should stop and assess the situation before entering the avalanche debris.

In the vast majority of avalanche accidents, the companion rescuers only have an AT and a probe as available tools for locating victims. The few tools available in combination with often limited manpower makes the task of locating a victim difficult, even with an approximate location. However, it is this technique that most often saves lives according to the (Royal Norwegian Armed Forces, 2010), which is not surprising considering the statistical survival rate for completely buried victims as shown in Figure 2.4-2. For companion rescue the use of tools such as the AT and probes does not differ from the techniques used in organized rescue as described in Chapter 2.4.2.1 above.



## **3 Methodology used in this thesis**

### **3.1 In-depth literature review**

Application of UAVs in avalanche SaR is a fairly recent, and therefore not a well-researched topic. However, there is an increasing interest in research exploring the applications of various sensor technology mounted on UAVs. Also, even though the field of avalanche is rather well studied, the process of locating victims during SaR seems to have remained very static. In order to establish a foundation for avalanche SaR statistics and reports from NGI has been evaluated, and for organization and rescue technique guidelines from Red Cross and NRR has been used.

When evaluating UAV and sensor technology peer-reviewed articles and publications has been used. The primary goal is to review studies, where complete UAV systems are equipped with sensor systems designed for a specific task, and the results of these studies. However, this is a limited resource and studies using non-airborne sensor systems has also been included as the author believes that these sensors can be applicable for UAV use. Most of the aforementioned studies are proof-of-concept, done as either empirical or theoretical research. Empirical studies are typically primary sources, as the author(s) of these studies has conducted the research themselves, whereas the theoretical research is done based upon information from other research or other established theories, i.e. secondary sources.

Conference proceedings from internationally renowned conferences like the ISSW (International Snow Science Workshop), IEEE (Institute of Electrical and Electronics Engineers) and ICUAS (International Conference on Unmanned Aircraft Systems) has been used as a resource of information. Also, articles and publications from scientific online journals such as Science Direct, Research Gate, BMC Emergency Medicine and Munin are used as credible sources of research.

Information on aviation and UAV application has been gathered from official training handbooks from Federal Aviation Administration, reliability studies from U.S. Department of Defense, and the RPAS operator's handbook as produced by the Arctic Monitoring and Assessment Program. The legal framework for this thesis is set by the NCAA.

Published books were also a valuable source of information for this thesis, especially on the topics of telecommunication, sensor technology and avalanches. As all the literature review is based upon the findings of other people's research, established theories or regulations, the author of this thesis can be considered a secondary source as the intent is to interpret information and data from primary sources.

### **3.2 Interviews**

Interviews with experienced professionals is a vital source of information for this thesis. Contributions from the following interview subjects provided valuable insight into the organization of avalanche SaR as well as the application of UAVs as a tool for this purpose. A summary of their experience relevant for this thesis is presented in Table 3.2-1, however their knowledge extends far beyond their respective descriptions.

Table 3.2-1 - Interview subjects

Interview subject	Date	Relevant experience
Tor André Skjelbakken (TAS)	26.04.2016	<ul style="list-style-type: none"> <li>▪ Member of the TRC Search and Rescue team</li> <li>▪ Has attended several avalanche SaR operations since his first avalanche rescue in 1981.</li> </ul>
Viggo Lorentsen (VL)	18.03.2016 02.05.2016	<ul style="list-style-type: none"> <li>▪ A core member of the TRC UAV/RPAS group since it was established</li> <li>▪ RO3 certified UAV pilot with experience from several SaR missions</li> </ul>
Ronny Sandslett (RS)	02.05.2016	<ul style="list-style-type: none"> <li>▪ A core member of the TRC UAV/RPAS group since it was established</li> <li>▪ RO3 certified UAV pilot with experience from several SaR missions</li> <li>▪ Responsible for the development, construction and maintenance of all UAV platforms used by TRC RPAS</li> </ul>
Kjell-Sture Johansen (KSJ)	11.05.2016	<ul style="list-style-type: none"> <li>▪ Background: Norwegian Armed Forces – Drone Services, Master in Jurisprudence (UiT) and Aviation Academy</li> <li>▪ RO3 certified pilot for NORUT Tromsø</li> <li>▪ Attended several campaigns in regions such as Antarctica, Spitsbergen, Greenland, Iceland, Finland and Norway</li> <li>▪ Lawyer/researcher at NORUT, responsible for education and test piloting. Lecturer at UiT for the drone technology program.</li> <li>▪ Around 2000 hours of flight experience</li> </ul>

Furthermore, the interviews were conducted in a semi-structured approach, meaning that there were several key questions that defined the areas in which the answers were most beneficial for the subject of this thesis. However, the subjects of the interviews were allowed to diverge from the questions and elaborate on related topics. All interviews were recorded and structured through transcribing, presenting the information believed to be most relevant to this thesis in Appendix 2. The semi-structured approach was chosen as it guided them with respect to topics of interest, while still allowing them to express and elaborate on information that is believed to be of importance to them. This information later proved to be of importance to the thesis, which is why some of the questions were formulated with a certain degree of freedom.

### 3.3 Attendance at ReCAMP workshop

The Remote Controlled and Autonomous Measurement Platforms (ReCAMP) Flagship Workshop was held in Tromsø between the 5<sup>th</sup> and 6<sup>th</sup> of April, 2016. The workshop was hosted by the Arctic Centre for Unmanned Aircraft – ASUF, which is “a national and international focal point in the use of unmanned aircraft for emergency preparedness, environmental monitoring and technology development in the arctic” (ASUF, 2016). The ReCAMP workshop was a collaboration between several distinguished organizations including NORUT, the University of Tromsø and Lufttransport AS, whereof the latter is Norway’s leading operator of air ambulances. According to the ASUF webpage the objectives of the workshop were to:

- Present the ReCAMP Flagship objectives, present and future activities;
- Provide an international and interdisciplinary forum to scientists, researchers, operators and students to exchange experience and knowledge on Remote Controlled and Autonomous Measurement Platforms (RAMPs) technology;
- Discuss the main challenges when operating RAMPs in the Arctic, including Communication, Platform navigation, Platform robustness, Cross platform opportunities, Sensor inter comparison, Platform independency and Remote power solutions.

There were a total of 66 registered international participants, representing universities, research teams, companies and organizations that are involved in research and application of unmanned vehicles (primarily aerial vehicles). The author of this thesis attended all presentations, and the information gathered through attendance and review of the conference proceedings is presented throughout this thesis with reference to the presenting author.

### **3.4 HAZID methodology**

As previously mentioned in the theoretical framework the HAZID technique is used qualitatively in order to identify all significant hazards that is associated with a specific activity. To establish a foundation for the HAZID analysis contributors, the intended use of the UAV must first be described with a focus on organization, operational settings, UAV specifications and mission description. As is established in the introduction of this thesis, it is the authors intention to investigate how UAVs can be applied in avalanche SaR. As Tromsø Red Cross already has initiated an experimental project on this topic, a case study was conducted in collaboration with them. In Chapter 4.2 the results of this study is presented and discussed, and will for the purpose of this chapter provide the foundation for the HAZID analysis, with respect to the previously mentioned attributes. The three methods established in Chapter 2.3.3 was applied in order to identify all perceivable hazards associated with use of UAVs in an avalanche SaR setting. It should be noted that the primary focus of the HAZID analysis will be regarding safety critical issues, as economic and environmental consequences are believed to relatively small in the avalanche SaR setting described in the following case study.

#### **1. HAZID meeting with experienced personnel**

Firstly, it must be noted that there are some logistical challenges when assembling a HAZID team consisting of people from different organizations and companies. A prerequisite is that each member must have a sufficiently high level of skill in their respective fields in order to contribute to the analysis. Also, in order to get a sufficient spread in disciplines and field of knowledge, a list of optimal contributors was generated<sup>3</sup>:

- a) One or more pilot(s)
- b) Someone experienced with construction and maintenance of a UAV
- c) A participant with extensive avalanche SaR experience
- d) Someone with unique insight into the TRC organization

Due to logistical problems, HAZID sessions were executed individually while the participants were informed of each other's contributions. Some of the information were gathered in the form of formal

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<sup>3</sup> Note that multiple roles can be fulfilled by the same person

interviews or by e-mail correspondence, and some through true HAZID meetings. The hazard identification sheet used was developed solely by the author based on an in-depth literature review and attendance on the ReCAMP workshop as described in the chapters above. All contributions or corrections are noted in the complete HAZID sheet which is available in Appendix 1. A presentation of the interview subjects and HAZID contributors is summarized in Chapter 3.2 above, describing their experience and fulfillment of the previously set criteria.

## **2. Review of checklists, codes and standards**

As far as the author is aware, there are no official codes and standards describing the manufacturing, operation and maintenance of UAVs. However, in the legal framework enacted by NCAA there are requirements for maintenance plans, organization, documentation of air-worthiness etc. which is all contained within the OM of each licensed operator. Pre-flight checklists are also common to have available internally in the organization, which is considered a valid source for previously identified hazards. However, gaining access to an OM proved difficult as it is a comprehensive and difficult document to create, and therefore not openly shared by an organization or company. The author was able to access and review the OM of Peek AS, courtesy of (Glad, 2016).

## **3. Review of hazard registers of previous accidents**

Hazard registers of previous UAV accidents are commonly not available to the public, probably because the few that are known to exist are directly related to military aerial vehicles and hence confidential. However, these registers would be of limited use to this thesis both because these types of vehicles are typically of a fixed wing design and are also much larger aircraft than those applicable for this thesis. Also, military UAVs are typically designed as expendable or experimental vehicles due to the nature of their intended missions (DeGarmo, 2004).

However, some identified hazards based on previous accidents was obtained through attending the ReCAMP workshop described in the previous subchapter. An important objective of the workshop was the exchange of obtained information through experience, and therefore there were several presentations on the topic of UAV operations in cold climate, harsh environment and other field experience as presented by (Cahill, 2016), (Kral, 2016), (Storvold R. , 2016) and (Wik, 2016). The identified hazards and issues directly related to their accumulated operative experience is used as an “unofficial hazard register” in this thesis.

## **3.5 Criticism of methodology**

- Even though the amount of UAVs created specifically for industry purposes (typically more robust, reliable, and with high grade components) are increasing in availability, a major share of the commercial UAV market is still intended for recreational- or semi-professional use. This causes the sources of information applicable for the theoretical framework for UAVs in this thesis to be somewhat unreliable as it is either produced with commercial intent or by RC enthusiasts, both of which typically presents a limited scientific foundation for their statements.
- Although qualitative hazard- and risk assessments are very helpful, they are limited by their lack of statistical data. Access to a comprehensive accident and hazard database for UAVs

would allow for quantitative assessments, which in combination with the qualitative assessment presented in this thesis, would be much more descriptive of the actual risk.

- The HAZID analysis would likely have benefited from a formal meeting with all contributors present at the same time to discuss potential hazards. However, due to logistical challenges this was not an alternative, and therefore the methodology was adapted as best as possible, to accommodate for individual meetings.
- It should also be stated that a qualitative risk analysis is extremely subjective, and therefore the results of the risk analysis in Chapter 4.4 must be applied with caution. However, the results correspond with the perceived hazards and risk levels as identified by the industry, which may support their validity.



## 4 Discussion and results

This section directly relates to the objectives stated in Chapter 1.2, which are repeated here as each of the following subsections corresponds with an objective.

- a) Review the current practice of SaR for avalanche victims, to establish a baseline for comparison to UAV-assisted search
- b) Examine the approach of Tromsø Red Cross (TRC) and their current application of UAVs by conducting interviews and a case study
- c) Identify challenges for implementation of UAVs in civil applications – such as SaR – through literature review and interviews with experienced professionals
- d) Conduct a hazard identification analysis (HAZID) and risk assessment for use of UAVs in avalanche SaR

### 4.1 Review of current practice for avalanche search and rescue

As the first objective is to review the current practice of SaR for avalanche victims, the findings presented in Chapter 2.4.2 will provide the foundation for the content and discussion in this section. The reader should note Table 2.4-2 and Table 2.4-3 which summarizes the methods typically employed by the rescue crew and helicopter during avalanche SaR, respectively.

Since the invention of the first effective avalanche transceiver in 1968 by Dr. John Lawton (Dawson, 2013), the process of locating avalanche victims has remained fairly unchanged. In essence there are two SaR responses after an avalanche occurs and there are known- or believed to be victims. Firstly, there is companion rescue where unburied party members or other people in the area initiate a search effort to locate potential victims. This could be done by visually locating partially buried victims, or using electronic search devices to locate completely buried victims.

As the AT is the only device that can both function as a beacon broadcasting the victim's location and as a receiver that is used to locate said victim, this is the most commonly used electronic device used to assist companion rescue. Because the RECCO system is comprised of passive reflectors located on the victims and active locating devices which are rather expensive, these systems are most commonly used by professional rescue crews. However, both of these systems are recognized as highly efficient for locating avalanche victims and are therefore preferred if available and the prerequisites for using them are met (i.e. victim has a sending transceiver or reflector). When electronically-assisted search is possible it is far quicker than other manual alternatives such as probing (Skjelbakken, 2016), and as illustrated by Figure 2.4-2, time is of the essence during avalanche SaR.

For the purpose of this thesis professional rescue crews that arrives on the accident site within the first 15 minutes are considered a part of the companion rescue. This typically only occurs when accidents occur in close proximity to ski resorts, where professional ski patrols have a very short response time. For SaR in remote areas, the deployment is far slower as described both in Chapter 2.4.2.1 – state of the art for organized rescue, 4.2.3.1 – access and deployment for TRC and 4.3.4.1 – ease of access, deployment and use. Companion rescue also includes probing but this is commonly used to pinpoint a victim that is already roughly located by use of electronic devices. Probing for

victims without knowing their location is considered far too time consuming when trying to locate a victim alive, but it may be the only option if no electronic devices are available (Skjelbakken, 2016).

When organized rescuers arrive on a remote location there is little hope of finding a victim alive, as approximately 9 out of 10 professional avalanche SaR operations has a deadly outcome (Skjelbakken, 2016). The methods used to locate victims are essentially the same as for companion rescue, however with more manpower available. RECCO systems are also available as most aerial support vehicles for avalanche SaR are equipped with these systems, as well as most avalanche rescue organizations. If a victim cannot be located visually or by the means of any electronic search devices, there are two options. The first option is to form a search line and probe in areas that are believed to be appropriate, or it is possible to apply sensor systems such as a ground penetrating radar (GPR). The latter has only been done in a handful of incidents, two of which were in the Swiss Alps and Svalbard in 2001 as described in a publication by (Instanes, Lønne, & Sandaker, 2003).

## **4.2 Case study – Use of UAV for avalanche SaR by Tromsø Red Cross**

In order to better understand how UAV platforms can be applied in avalanche SaR in the future, this section will investigate and discuss how they are used today, which corresponds with the second objective for this thesis. The RPAS/UAV branch of Tromsø Red Cross is one of the leading rescue organizations in Norway when it comes to use of UAVs in avalanche SaR operations. Because of this they are considered a valuable resource when examining how UAVs currently are employed in avalanche SaR. Information about their organization has been gathered through formal and informal interviews as well as conversations and attendance during their training sessions. Technical information about their UAV platform was primarily gathered from a builder's log by (Sandslett, 2016) who was responsible for designing and manufacturing TRCs UAV system. Missing technical details were later established in an interview.

### **4.2.1 Organization and certification**

As with many of the other rescue services in Norway, Tromsø Red Cross is a voluntary organization. Although they have several undertakings, it is their SaR resources and capabilities that is of particular interest. More specifically their RPAS/UAV sub-division which, in coordination with the rest of TRC, contributes with aerial support during all types of SaR operations. Their group consist of a small number of RC enthusiasts who are pioneers in the field of UAV-assisted SaR, as the first voluntary organization in Norway to utilize a UAV platform for this purpose, an activity for which they already have received national attention.

Members of the group that contributes during rescue operations are trained after the national standards set by the Red Cross. In addition, the UAV operators are fully certified by the NCAA to conduct airwork and commercial operations with RPAS, and they are perceived by the author to complete their missions with a high level of professionalism.

All pilots covered by TRCs OM are R03 licensed as of today, meaning that they can operate the most complex UAVs. This certification allows them to pilot UAVs which have an MTOW above 25 kilograms, a maximum speed of 80 knots or more, is operated by turbine engines, will be used for BLOS operations above altitudes of 120 meters or in controlled airspace. On the 1<sup>st</sup> of January, 2016 the

regulations were changed by the NCAA. As opposed to previously when there was no distinction between UAVs and regular manned aircraft, there are not a specific regulation for UAV in Norwegian airspace. However, TRCs operation permit was approved before the 1<sup>st</sup> of January 2016, and is valid until its original expiration date. As of today, TRC fulfills all organizational and technical requirements as put forth by the NCAA.

#### **4.2.2 Description of platform and sensors**

In order to establish operational boundaries and capabilities the platform currently employed by TRC is described in detail in this section. The UAV is intended to be used for SaR operations during all seasons, but as this thesis is related to avalanches, this will be the primary focus of the discussion. Table 4.2-1 presents a summary of the technical specifications for “TOR”, the UAV used by TRC for SaR operations.

Table 4.2-1 - Specifications for the Tarot T960 Hexacopter (TOR) used by TRC. Source: (Sandslett, 2016)



### Airframe: Tarot T960 Hexacopter (TOR)

Platform specifications	Sensor and equipment specifications
<ul style="list-style-type: none"> <li>▪ <b>Power plant:</b> 8x Dualsky 5015 320kv electric brushless engines</li> <li>▪ <b>Battery:</b> 2x 10000mAh 6S 10C LiPo Pack</li> <li>▪ <b>Weight without payload:</b> 6.5 kg</li> <li>▪ <b>MTOW:</b> 10 kg as set in OM</li> <li>▪ <b>Payload capacity:</b> 3.5 kg</li> <li>▪ <b>Endurance:</b> 18.5 min. flight time @ 7.6 kg or 10 min. @ 11.0 kg</li> <li>▪ <b>Diagonal wheelbase:</b> 960mm</li> <li>▪ <b>Maximum speed:</b> 27 knots</li> <li>▪ <b>Logged flight hours:</b> 20 hours</li> <li>▪ <b>Max altitude:</b> n/a</li> <li>▪ <b>Build time:</b> 700 hours</li> <li>▪ <b>Range:</b> typically around 2 kilometers, tested to 4 kilometers (80-90% signal strength) and 8.5 kilometers VLOS with usable FPV quality</li> </ul>	<ul style="list-style-type: none"> <li><b>Infrared camera: FLIR Tau2</b> <ul style="list-style-type: none"> <li>▪ Video quality: 640p</li> </ul> </li> <li><b>Zoom camera: SONY sensor</b> <ul style="list-style-type: none"> <li>▪ 30x optical zoom</li> <li>▪ Video quality: Standard Definition (SD)</li> </ul> </li> <li><b>HD camera: Mobius Action Cam</b> <ul style="list-style-type: none"> <li>▪ Video quality: 1080p H.264, 30 fps</li> </ul> </li> <li><b>Gimbal: SONY NEX 2-axis</b> <ul style="list-style-type: none"> <li>▪ The gimbal is completely rebuilt to 3-axis</li> <li>▪ 360-degree rotation</li> <li>▪ Brushless electric motors</li> </ul> </li> <li><b>FPV Cam: FatShark 600TVL CMO S Cam</b> <ul style="list-style-type: none"> <li>▪ Video quality: high resolution</li> <li>▪ Lens: 2.8 mm IR coated</li> </ul> </li> </ul>

The hexacopter currently used by TRC is built around a Tarot T960 airframe, and is designed as a multipurpose platform, meaning that it is intended for all kinds of SaR operations and not restricted to only avalanche SaR. Due to the fact that it was designed as a multipurpose platform, a modular design was chosen in order to easily change the sensor systems, altering the capabilities of the platform if needed. It is an electric multicopter where most of the parts were custom built using a computerized numerical control (CNC) machine and 3D-printer.

Primary sensors on this platform consist of the first person view (FPV) camera, altimeter and a GPS transceiver for navigation. These sensors are vital for operation of the UAV. The payload consists of

secondary sensors which include an IR camera, HD camera and a 30x zoom camera, all of which are mounted on a rebuilt 3-axis gimbal for stabilization during flight. The camera operator has access to all the sensors mounted on the gimbal, whereas the pilot has access to the FPV camera as well as the IR and zoom camera (Sandslett, 2016).

For avalanche SaR it is highly likely that the UAV will be operated at close range or “VLOS”, as opposed to other SaR operations when TRC apply all modes of operation, i.e. VLOS, EVLOS and BLOS. According to (Sandslett, 2016) the practical limit for a normal operation is typically 2 kilometers, as the operator will move closer to the target area if necessary. TOR can be operated by one person, but during a typical mission there is one pilot, one camera operator and one spotter. When flying FPV they have the options of flying with virtual reality (VR) goggles or on screen, where the latter is the most preferred method for VLOS operations as it is easier to maintain control of the UAV (Sandslett, 2016). During BLOS the VR goggles is the preferred option. If the UAV is operated FPV using the IR camera, VR goggles is preferred due to the additional darkness.

### **4.2.3 Use of UAVs in avalanche SaR**

As the TOR platform is still being developed and the organizational implementation of UAVs is still in its infancy stages, TRCs UAV has not yet participated actively in any avalanche SaR operations. However, there seems to be a positive attitude towards integrating this platform into the official emergency response coordination. Based upon interviews with TRC the process of deployment and SaR are described in the following subsections.

#### **4.2.3.1 Access and deployment**

Upon being alerted the TRC RPAS/UAV group members must access their UAV system and prepare for deployment. Currently the UAV is stationed in the private residence of one of the core members, depending on who is believed to be most available to participate in a rescue mission. Due to the fact that the implementation of UAVs for rescue purposes still is in the experimental stages, there is not yet any official routines specifying the location of the drone at any given time. When the UAV is more integrated into the rescue routine and its capabilities are established, the storage of the UAV will probably be governed by a rotation-based system to ensure that it is immediately available for deployment.

According to (Lorentsen, 2016) the expected deployment method for their UAV would be by car and/or snowmobile, which has a relatively long response time. Also, considering that the both the UAV, trained pilots and operators are a very specialized resource, it is not guaranteed that they will be available to contribute in the SaR operation at all times. As an alternative to car or snowmobile deployment, helicopter transportation has been discussed for the UAV and its crew, so that they are readily available on site as first responders. The ambulance helicopter based in Tromsø has a capacity of 3 crewmembers and 2 passengers (Skjelbakken, 2016), which implies that one or two of the passenger spots will be occupied by UAV operators if they were to attend. Due to the importance of manpower and the fact that it is very limited upon arrival of first responders, it may be considered a problem to dedicate one or two persons for an experimental application, seeing as their effectiveness is not yet established. However, there are several other methods for deployment which will be discussed further in Chapter 4.3.4.1

#### 4.2.3.2 Search and rescue

Upon arrival the search effort is initiated, and the contribution of an UAV as it is today, is expected to be in the rapid search phase as described in Table 2.4-2. From an aerial perspective the UAV is likely to identify victims or their personal belongings, indicating their position or path, as long as they are not completely buried below the surface of the avalanche debris. In addition, it is believed that an aerial view of the accident site will provide valuable information to help the accident site commander coordinate the rescue effort. Previously TRC experimented with the use of a handheld AT suspended below the UAV in order to help assist in locating victims. The suspended positioning was done to counteract large amounts of noise and interference when mounted directly onto the UAV. However, this mounting method resulted in difficulties operating the vehicle, and therefore a new custom-built omnidirectional AT was commissioned. Mammut will produce the AT which will be tested immediately upon arrival. When TOR is deployed in an avalanche SaR operation it is believed to result in the following benefits and challenges as described in Table 4.2-2.

*Table 4.2-2 - Perceived advantages and disadvantages of UAVs in snow avalanche SaR*

<b>Advantages and contributions</b>	<b>Disadvantages and hazards</b>
<ul style="list-style-type: none"> <li>▪ Reduced risk for personnel in avalanche-prone areas (secondary avalanches)</li> <li>▪ Possibly quicker search efforts when using integrated electric search devices and optical devices for rapid surface searches. This is perceived to be particularly true for; large-, multiple-, and dangerous avalanches.</li> <li>▪ UAVs can serve as an aerial relay node for communication</li> <li>▪ Provide a valuable overview of the avalanche debris and surrounding area, making it easier to manage and coordinate the rescue operation</li> <li>▪ Provide a safer alternative to aerial support, as compared to use of helicopters, provided that the UAV is highly reliable</li> <li>▪ UAVs are much smaller and therefore cause much less downwash from the propellers, i.e. less impact on operational conditions for the rescue crew and rescue dogs (less dispersion of scent etc.)</li> <li>▪ Is a valuable aerial support resource when helicopters are not available</li> </ul>	<ul style="list-style-type: none"> <li>▪ Possibly increased organizational complexity and allocation of resources and personnel</li> <li>▪ Limited payload capabilities compared to helicopters</li> <li>▪ An increase in risk for personnel on ground, as opposed to not having a UAV participating in the rescue</li> <li>▪ An increase in risk for other aircraft, especially those involved in the rescue operation</li> <li>▪ Transportation and deployment can be time consuming, arguably with limited positive effects</li> <li>▪ Must have trained personnel available for operation</li> <li>▪ Helicopter downwash can severely influence UAV stability</li> </ul>

According to (Skjelbakken, 2016) all experiences with helicopters using electronic search devices validate their efficiency in the search effort, as they can cover large areas and multiple avalanches using ATs and RECCO. This type of search could likely be replicated by a UAV, albeit somewhat slower, indicating that a UAV can contribute during the search phase. However, assuming that the victim is wearing an electronic search device, locating them is often the least time-consuming part of avalanche SaR (Skjelbakken, 2016). Time consumption of the deployment and excavation phases often

overshadow the locating phase, indicating that increased effectivity for the latter has a minor impact on the overall rescue time.

#### 4.2.4 Management of hazards and implementation of barriers

The following two sections identifies and describes some perceived hazards for the rescue crew due to attendance of the SaR operation, and TRCs barriers for hazards that could cause loss of control over their aircraft. The hazards described in Chapter 4.2.4.1 are presented specifically as to demonstrate how they could be mitigated by the use of a UAV.

##### 4.2.4.1 Hazards and challenging conditions for the rescue crew

According to (Hohlrieder, et al., 2008) *“the potential hazard for rescuers during avalanche rescue missions comes mainly from self-triggered avalanches, hence thorough mission planning and critical risk–benefit assessment are of utmost importance for risk reduction”* and it is further stated that *“the majority (61.6%) of the rescue missions were conducted under considerably dangerous avalanche conditions”*. Based on these statements it is obvious that the most prominent hazard for the rescue crew during avalanche SaR is the imminent threat of secondary avalanches. A barrier to avoid exposure to potentially hazardous situations is rescue crew experience and training, allowing them to assess the risk of entering an accident area based on their expertise in this field. However, as identified by (Skjelbakken, 2016) during an interview, it is not impossible for the situational awareness of the rescue crew to become obscured, causing them to unintentionally put their own lives at risk. This is illustrated in Figure 4.2-1 below, where an identical avalanche path poses a threat to the rescuers.



Figure 4.2-1 – Is it safe to do the rescue? Illustration by (Tremper, 2001)



Figure 4.2-2 - Downwash in snow from a Eurocopter EC 135 machine. Photo: Håkon B. Abrahamsen

It is suggested by (Abrahamsen, 2015) that downwash and noise from manned helicopters participating in an avalanche SaR effort, may impair the operation itself. This statement applies for the manned helicopter EC 135 P2+ produced by Eurocopter, which is a commonly used machine in the Norwegian air ambulance service. As seen in Figure 4.2-2 downwash from the rotors causes the snow to swirl up, reducing visibility considerably. According to the flight manual of this helicopter,

noise levels during flyovers exceeds 85dBA (Eurocopter, 2016). During helicopter-assisted search with electronic devices the machine hovers at low altitudes subjecting the rescue crew to excessive noise levels, which according to (Abrahamsen, 2015) causes the need for hearing protection and makes communication by conventional radio or telephone without active noise reduction almost impossible.

#### 4.2.4.2 Barriers implemented for the use of UAVs in avalanche SaR

Hazards can lead to a hazardous- or unwanted event if not managed by proactive barriers. As it is of utmost importance to have control over the UAV at all times, the hazardous event of “loss of control” is deemed most crucial for the use of UAVs in SaR operations. Following are some proactive barriers (**P**) implemented to ensure that loss of control over the aircraft never occurs, and if it occurs there are reactive barriers (**R**) to reduce the severity of potential consequences. The following subsections contains lists of preventive and reactive measures done.

##### *Operative conditions and weather*

Because of the adverse effects operative conditions and weather can have on a relatively small UAV platform, it is in this category most barriers for failure are implemented. During an interview (Sandslett, 2016) emphasized the importance of preventive measures done during the design of the UAV. This applies to both the building and design of the platform, as well as rigorous testing to ensure that harsh weather has as low as possible impact on the performance of the platform.

<b>Barrier</b>	<b>Type</b>
• A hexacopter design was chosen, as more rotors increase the performance of the UAV in windy conditions	<b>P</b>
• Several different propellers were tested based on their RPM during hover and efficiency. By mounting propellers with smaller diameter the RPM was increased substantially, which directly translates to better handling in windy conditions	<b>P</b>
• Electrical components potentially exposed to precipitation and moisture are coated in various “spray-on-tape” solutions to make them more resistant to short circuiting and other electrical malfunctions	<b>P</b>
• To mitigate effects of cold weather for the pilots/operators a special RC-muff is used to keep their hands warm and agile	<b>P</b>
• A clear 2mm polycarbonate dome is attached on the top of the drone to protect all vital electronics from water- and impact damage	<b>P R</b>
• During operations in adverse weather conditions the pilot/operator always makes a continuous assessment of the operating conditions. The OM restricts operations in wind speeds above 10 m/s, however this is a restriction with very large safety margins.	<b>P R</b>
• Micro-soldering a resistance over a capacitor was done to avoid inability to arm for flight in very low temperatures	<b>P</b>

Before the UAV is deemed fit for operations, there is done extensive testing on its capabilities in various adverse weather conditions, such as in high wind speeds, low temperatures (down to -22°C)

and in relatively high amounts of precipitation. If hazards are discovered during testing, fixes or barriers are implemented to ensure safe operations.

***Human and organizational***

Barriers that relates to human and organizational challenges are primarily in the form of NCAA regulations and internal guidelines such as the OM.

<b>Barrier</b>	<b>Type</b>	
• Two of the six arms are colorized with bright tape in order to improve pilot orientation	<b>P</b>	<b>R</b>
• Maintain safety distances to large buildings, objects, powerlines or vegetation	<b>P</b>	<b>R</b>
• Regulations and guidelines both by the NCAA (Table 2.2-1) and internally in the organization to help protect rescue crew, other participants and bystanders from harm, especially with respect to safety distances and flyovers	<b>P</b>	<b>R</b>
• Certification issued by the NCAA and internal TRC training programs	<b>P</b>	<b>R</b>
• When there is more than one aircraft in the local airspace at the same time, visual physical barriers are used to described designated areas for manned aircraft and UAVs.	<b>P</b>	<b>R</b>
• The TOR UAV has a minimum of one pilot and a camera operator to ensure that they can focus on their own tasks	<b>P</b>	
• Maintenance and inspection program	<b>P</b>	
• Pre-flight checklist	<b>P</b>	
• Required insurance		<b>R</b>

It should also be pointed out that TRC applied a modular design of the platform to improve ease of use during rescue operations. This enables use of different sensors and equipment depending on operational requirements, as well as easy and efficient assembly on site without having to remove too much clothing etc. The UAV used by TRC has the possibility to complete take-off, a pre-programmed search grid and landing autonomously. This has been tested in an operative environment and all systems functioned perfectly (Sandslett, 2016).

***Mechanical and electrical***

Failures due to mechanical and electrical issues are not uncommon in the initiating phase of UAV operations in harsh climate, at least until the sufficient knowledge and experience is attained (Cahill, 2016). The following barriers are based on compliance with operators and instruction manuals, general knowledge and unique experience and test observations by (Sandslett, 2016).

<b>Barrier</b>	<b>Type</b>
• Batteries are normally never drained below 25% of their total capacity to avoid unnecessary wear or damage to the batteries.	<b>P</b>
• All bolts are tightened and secured with liquid adhesive solutions or safety pins	<b>P</b>
• Batteries are mounted below the UAV in protective casings, which are attached with Velcro and movable in order to adjust CG.	<b>P</b>
• Passive heat sinks are installed to mitigate overheating of the electronic speed control (ESC)	<b>P</b>
• A hexacopter (six separate motors and propellers) design provides redundancy as flight is still possible if one of the electrical motors were to fail	<b>R</b>
• Use of materials and components rated for the intended operational conditions	<b>P</b>

### ***Sensors and communication***

One of the most crucial failures during flight is communication failure, as this causes the pilot to lose control over the UAV. As this type of failure is of such importance is specifically stated in the legal framework (§14 regarding fail safe system, page 25) that *“All rotor-operated aircraft shall have a built-in system to ensure that the aircraft can land automatically in the event of loss of control on the part of the pilot or pilot in command. All aircraft without a pilot on board (fixed wing) shall have a redundant system that ensures control of the aircraft in the event that the main radio communication system fails”*. This is likely the most important reactive barrier for UAVs. In the case of a multi-rotor aircraft such as the one used by TRC, it allows for hovering until regained connection, return home or to a predefined designated area or immediate autonomous landing. The aforementioned actions are dependent upon configuration.

<b>Barrier</b>	<b>Type</b>
• Special shielding and ground planes are used to improve the GPS connectivity, which provided positive results on ground tests.	<b>P R</b>
• Fail-safe functions such as; return home, emergency landing in predesignated area, or hover until reestablished connection	<b>R</b>
• Redundancy in altitude measurements if the altimeter fails	<b>R</b>
• Geofencing to separate areas or avoid exceeding range	<b>P R</b>
• Use of a well-tested autopilot system	<b>P R</b>

### **4.2.5 Choice of platform**

On the topic of fixed wing versus MRRW, (Sandslett, 2016) states that there are many advantages with the fixed wing platform, where the most prominent one is flight time. When using a MRRW platform the operation time is limited to about 20 minutes with payload attached, whereas fixed wing can easily achieve flight times exceeding one hour. *“It is always nice to have good range capabilities, but it is not the most important parameter as its limitations intertwine with other factors as well. There will*

*always be some missions where it is more appropriate to use MRRW, and others where fixed wing is the better choice.”*

Although MRRW and SRRW shares many capabilities like hover and very agile 3D maneuverability, there are also vital differences such as lift capacity and flight time. The single rotor design is capable of generating a significantly higher lift and is more energy efficient than the MRRW design. Also, it is much easier to use internal combustion engines on a SRRW platform as there is only one rotor. Based on these statements a SRRW platform should be the preferred choice for TRC? When asked, (Sandslett, 2016) explains that there is a very limited amount of research and programming for computer-assisted flight for SRRW platforms. Also, there are completely different safety issues when employing a large single rotor aircraft as it retains great amounts of energy that can cause substantial damage if an accident occurs. This means that several new safety issues arises when operating close to rescue personnel. There are not many flight controllers that support a single fixed wing platform completely, and those that do tend to be very expensive which is a problem with limited funding. Nevertheless, increased capabilities for lift and flight time for a SRRW platform is recognized by Sandslett.

TRC is currently working on two more identical MRRW platforms in a Tri-X configuration. This means that the UAV has three arms with dual electrical motors (above and below each arm) for a total of six propellers which effectively increases redundancy. These platforms will be much lighter, more portable and are intended to be operated by a single pilot. There will also be an increase in availability as there are two identical UAVs at disposal for the rescue crew.

#### **4.2.6 Time vs. benefit**

The following Figure 4.2-3 shows the statistical survival rate of victims based on burial times where the first 40 minutes are shaded blue as this is the SaR phase where companion rescue is more likely in remote areas. Organized rescue effort is shaded red and covers everything beyond approximately 40 minutes, as this is the realistic best case scenario for deployment in remote areas. As previously stated the Swiss statistics will be used as they are identified to coincide better with the Norwegian statistics.

It is important to note that the 40-minute mark only represents the deployment time of an organized rescue in remote areas. When factors such as locating time and excavation is included it becomes obvious that there is a high probability that the victim is dead, even when using the Swiss statistic. The fact that organized rescue is unlikely to locate victims alive in remote areas, even with the application of UAVs, is recognized by all interview subjects of TRC (Lorentsen, 2016), (Sandslett, 2016) and (Skjelbakken, 2016).

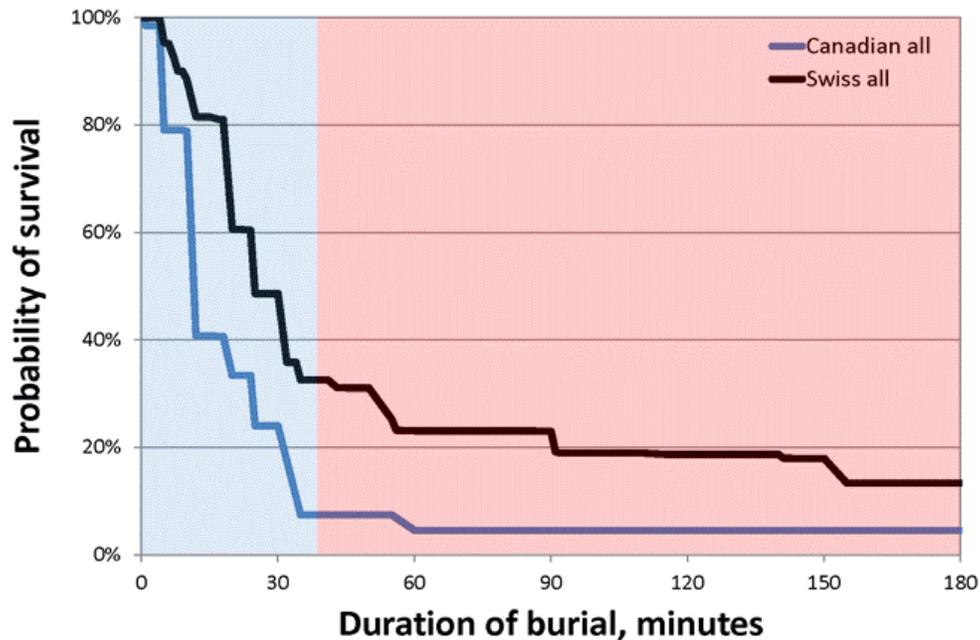


Figure 4.2-3 - Probability of survival for snow avalanche victims where the duration of burial is shaded blue for typical companion rescue time, and red for organized rescue. Remodeled from illustration by: (Haegeli, Falk, Brugger, Etter, & Boyd, 2011)

Based on the time-perspective of the rescue operation it is not unreasonable to conclude that the implementation of an UAV platform is unlikely to improve chances of locating victims alive. However, there are other benefits as described in previous chapters during this case study.

### 4.3 Identified challenges for utilization of UAVs in avalanche SaR

The third objective of this thesis was to identify challenges that resist the implementation of UAVs for avalanche SaR, therefore the following subsections in this chapter will present and discuss challenges that were identified during the course of this thesis. The primary challenges identified were with respect to weather conditions, technology, compliance to regulations, and human and organization. During this chapter possible solutions are discussed based on the authors obtained knowledge and the operative experience of the interview subjects from TRC.

#### 4.3.1 Challenges with respect to adverse meteorological conditions

As seen in Figure 2.4-4, avalanches with a deadly outcome predominantly occurs during winter and spring. Based on this, the following subsections will discuss some weather phenomenon that has been considered as obstacles for use of UAVs during avalanche SaR in the aforementioned time period. As with regular manned aircraft the impact of weather on a UAV can vary greatly depending on factors such as size, configuration, equipment and power plant of the aircraft (DeGarmo, 2004). Type of weather encountered, exposure time and severity are also vital factors for the UAVs capability. (Storvold R. , 2016) and his team from the Northern Research Institute (NORUT) has, through their years of experience working with UAVs in cold climate, identified that care has to be taken regarding

the design of the aircraft so that assembly is easy and time effective as exposure to rapid changes in weather can cause problems during their missions.

#### **4.3.1.1 Precipitation during winter**

As the average temperature in areas that are prone to avalanches usually is well below 0°C during wintertime, precipitation almost entirely presents itself as snow. There is a strong correlation between amount of precipitation and snow avalanche danger as described by (Skjelbakken, 2016), and it is therefore not unreasonable to assume that areas with high amounts of precipitation during winter also has a high frequency of avalanches – and subsequently – avalanche victims in high exposure areas.

During- or after periods with high amounts of precipitation it is not unusual to expect the probability of avalanches to be elevated. Ironically, these conditions are also the most alluring to mountaineers seeking the optimal conditions for off-piste skiing. An increase in avalanche victims is often seen during good weather periods following a longer precipitation period, which results in good skiing conditions as well as high avalanche danger (Skjelbakken, 2016).

According to (Sandslett, 2016) TRC has done several tests in conditions with varying degree of precipitation, all of which has demonstrated the UAVs ability to fly during adverse conditions. It is recognized that moisture in electrical circuits and components can cause short-circuiting or other problems, but there are done several modifications to avoid these issues, as described in Chapter 4.2.4.

#### **4.3.1.2 Extreme cold**

The impact of extreme cold temperatures on batteries is widely recognized as a problem for battery capacity. During the ReCAMP workshop reduced battery-life were mentioned in several of the presentations by organizations with years of experience in cold climate operations, such as the Alaska Center for Unmanned Aircraft Systems Integration (ACUASI) (Cahill, 2016). Maintaining sufficient battery temperatures pre-flight is a common problem, which for example can be solved using a heated and thermally insulated box (Kral, 2016). For smaller battery-packs it might be sufficient to keep them warm with body heat. According to (Storvold R. , 2016), battery capacity could be reduced as much as 50% in extreme conditions, and pre-heating was identified as an important factor to extend the flight times of electric UAVs. During flight the internal resistance will keep the batteries sufficiently warm, and the impact of low temperatures is decreased (Storvold R. , 2016).

Extreme cold also has an impact on the UAV operators, and some observations made by (Storvold R. , 2016) and his team were as follows: all parts for the UAV system must be easy to assemble, there should be no modifications needed for the payload and glove removal should not be necessary. As with any operation where humans are exposed to cold climate, several measures must be taken in order to reduce the effects of the cold, especially with respect to wind chill effect.

#### **4.3.1.3 Wind**

All the UAV platforms discussed in this thesis are relatively small as compared to the larger platforms used for military operations, which can weigh several thousand kilos. However, even larger drones can be affected negatively by wind and turbulence, as proved by NASAs Helios Prototype that failed in part due to turbulence in 2003 (Noll, et al., 2004). Compared to their manned counterparts, today's

UAVs are more fragile, lighter and slower, and consequently more uniquely sensitive to certain metrological events such as surface/terrain-induced winds and turbulence. Small UAVs and those having a light wing load are especially sensitive (DeGarmo, 2004).

Surface/terrain-induced winds and turbulence is the result of airflow encountering obstacles such as topography and vegetation. This causes the flow to change direction and speed becoming turbulent and causing vertical mixing. At small elevations where the UAVs discussed in this paper typically will operate, the effects of this phenomenon can cause large variations in relative wind velocity which can have a devastating impact on the UAVs ability to generate lift (Johansen, 2016). As smaller UAVs in general have relatively low maximum speeds, high wind speeds can severely limit the performance of UAVs. In worst cases the wind speeds can exceed the UAVs forward thrust, resulting in backwards movement relative to the ground.

During a concept feasibility study by (Abrahamsen, 2015) regarding RPAS in major incident management, it was established that in calm air the UAV could be positioned with high precision. During periods with wind gusts and turbulence the operation of the UAV was greatly affected, which made it difficult for the pilot to maintain a steady hover and fixed altitude above the ground. This study was done with a smaller UAV with diameter of 84 cm and a AUW between 1.7 kg and 1.9 kg, however this likely also applies to TOR.

Answering the question – what UAV platform performs best in windy conditions? – is very difficult. It depends on type of mission, the direction of the wind with respect to where the UAV is desired to fly and the general characteristics of the platform. Fixed wing platforms obtain lift by moving through the air forcing it over the wings of the aircraft. Lift is generated by the airspeed relative to the UAV, meaning that headwind increases the relative airspeed (thus increasing lift generated), while tailwind decreases it. This can cause some control issues, especially during take-off and landing. Crosswinds are more difficult, but mostly with respect to fulfilling a mission that is dependent on alignment of the aircraft (offset due to lateral drift) and can have stability issues (turbulence) making it difficult to maintain the aircraft in level flight. In general, an increased wing load give fixed wing platforms better characteristics in windy conditions.

Because rotary-wing UAVs can maneuver freely around their own axis while in place, flying in crosswinds is comparatively easier than fixed wing, with respect to maintaining alignment during a mission. However, the shape of rotary wing aircraft is much less aerodynamic than a fixed wing. This means that rotary wing aircraft in general will be more affected by wind, but they also handle wind differently as compared to fixed wing UAVs. By using smaller rotor blades, it is possible to achieve better performance in wind for both SRRW and MRRW, as the RPM increases and the blade itself is less affected by relative wind (Sandslett, 2016). Maintaining a hover position is generally regarded easier for an MRRW as the loiter function is heavily computer-assisted, while for a SRRW it mostly manually controlled.

#### **4.3.1.4 Darkness**

By reviewing data from the avalanche victims reports from NGI, Figure 2.4-4 and Figure 2.4-5 were generated. Based on these figures it can be observed that 58.63 percent of the victims are from accidents occurring in Norway's three northernmost counties, including Svalbard. During the period between November to March it is not unreasonable to state that the length of daylight is fairly short in these counties. If we sum up all the avalanche victims in this period, we can see that 71.05 percent

of them were due to accidents that occurred between November and March. Although general recreational activities often occur during daylight, it is becoming increasingly popular to do this activity after dusk as well. This implies that many rescue operations may be carried out in less than optimal lighting, which could delay or even disable use of UAVs, as it may be difficult to navigate in the darkness.

A possible solution to issues of working in the dark is to use external lighting on the ground, or mounted onto the UAV itself. Lighting based on light-emitting diodes (LED) generally have highest energy efficiency, and the most recent record is just over 300 lumens per watt (Royal Swedish Academy of Sciences, 2014). As the LEDs are so energy efficient it is possible to create complete low-weight lighting systems, as for example the “Bright as Day” lamps which weigh 270 grams and has an output of 10000 lumens for 45 minutes (Moonlight Mountain Gear, 2016).

During interviews with TRC, darkness was identified as a severely disrupting factor for rescue operations, both complicating an individual person’s work and the general situational awareness, as it is difficult to establish a good comprehension of the surrounding area. TRC is currently working on a 12x10W LED light fixture to be mounted onto their hexacopter. It is designed as an individual payload that can be mounted onto the UAV if necessary for the rescue mission.

### **4.3.1.5 Icing**

Icing occurs due to the presence of supercooled water droplets (SWD) that freezes immediately upon impact with a surface. Most clouds are comprised of SWD with a temperature between 0°C and -20°C (Sørensen & Johansen, 2016). Water droplets do not necessarily freeze to ice when cooled down below the freezing point of water, but rather remains in a liquid supercooled state, partly due to surface tension of the water droplet (Federal Aviation Administration, 2012). For full-scale manned aircraft common methods for de-icing is thermal pneumatic, thermal electric, chemical and pneumatic, all of which are rather invasive and cause a considerable amount of additional weight (Sørensen & Johansen, 2016).

On fixed wing aircraft icing usually occurs on the leading edge of the wings, which causes a significant reduction in aerodynamic ability, i.e. decreasing lift and maneuverability, icing drag, weight, and consequently increasing power consumption (Sørensen & Johansen, 2016). There are currently no commercial anti-icing systems for UAV and very few available for conventional aircraft, and the technology is considered to be non-transferrable as the systems are very invasive and high-weight.

For rotary wing aircraft icing is quite different and possibly more hazardous. Ice accretion on the rotors is difficult to estimate as the rotor blades are exposed to different relative airspeeds span-wise, from where they are attached to the rotor mast. If there occurs a buildup of ice on the rotor it could cause severe imbalance if the shedding of ice is asymmetrical (Flight Safety Foundation, 1990). It is not unreasonable to assume that MRRW UAVs intended for avalanche SaR, will operate at relatively low altitudes, and thus avoiding most icing issues and the associated aerodynamic repercussions. However, icing on primary instrumentation and sensors can also be dangerous as described by (Cahill, 2016) during her ReCAMP presentation on UAV operations in the Alaskan Arctic. In ACUASI’s experience icing in the pitot tubes (that measures airspeed) was a major issue for their UAV systems, which they now mitigate by replacing the off-the-shelf tubes with tubes that has a built-in heating system. There were also some issues with icing in the carburetors, which was solved by changing to fuel-injection systems.

The “Small Unmanned Meteorological Observer (SUMO)” is a small electric fixed-wing UAV which is designed for atmospheric research purposes. Since 2007 this UAV platform has performed nearly 1000 scientific flight missions, many of which were executed in harsh environments such as the Arctic. According to a presentation by (Kral, 2016) there had been some observations of icing during their missions, mostly on the propellers, which caused a slight decrease in climb rate.

As previously mentioned the technology used for de-icing in manned aircraft is non-transferrable, at least for smaller UAVs. However, a research project performed at AMOS (Centre for Autonomous Marine Operations and Systems) is working on use of carbon nanomaterial to create an intelligent icing protection system. By insulating copper strips and carbon Nano-material paint over the leading edge of the wing, and applying electrical energy, they achieved positive results. Uniform heating was achieved on the ground, while in the air the heating was non-uniform. However, power consumption was identified as a major problem, at least for smaller UAVs with conservative weight limitations (Sørensen & Johansen, 2016).

#### **4.3.1.6 Weather window**

Norway in general – but maybe more so the region of Northern Norway – is widely known for squalls during the winter season, which previously has caused problems for traditional airborne rescue resources like helicopters (Skjelbakken, 2016). In general, harsh weather conditions can severely limit- or disable use of helicopters, even though there are shorter periods of relatively good weather in between squalls. For the purpose of this thesis, this phenomenon is defined as a “weather window”.

As UAVs are quick and easy to deploy, they can take advantage of such a weather window (Lorentsen, 2016). According to (Skjelbakken, 2016) being airborne for just a short period of time may provide information that could benefit the SaR operation. He further describes that several- if not all rescue operations could benefit from video or images from an aerial perspective, of course to a varying degree. Additionally, an UAV can provide other contributions during the time it is airborne as listed in Chapter 4.2.

### **4.3.2 Technological challenges**

The following subsections present and discuss the challenges for utilization of UAVs for avalanche SaR, which were identified during the course of this thesis.

#### **4.3.2.1 Reliability**

UAVs are inherently unreliable due to their original developed as experimental and expendable vehicles intended for military purposes, where cost, weight, function and performance have traditionally been primary concerns, and not reliability (DeGarmo, 2004). But as stated by (U.S. Department of Defence, 2003) in the OSD reliability study of UAVs, *“the aerospace technology and operational experience are present today to enable significant UAV reliability growth and make them highly reliable, capable, and cost-effective contributors”*. This statement concerns military UAVs, but the author believes that this statement is just as applicable for UAVs intended for civil use.

Designing a UAV platform for high reliability can be done by either improving the quality of the components used or to build in redundancy as demonstrated by the RQ-5/Hunter platform (U.S. Department of Defence, 2003). However, both these options come with an increased cost, and

increased redundancy can also add weight which would be a problem for smaller UAVs. When operational, increased reliability can be achieved through a well-developed maintenance program. The OSD reliability study (U.S. Department of Defence, 2003) provided some guidelines when designing for reliability while keeping costs manageable, as presented below:

- Use of standard systems engineering and layout practices
- Simplicity of design
- Testability of the design to enhance prognostic and diagnostic capabilities
- Insuring future availability of replacement materials and parts
- Sensitivity to human factors with respect to manufacturing, operation, and maintainability
- Use of redundant or fail-safe designs based on a failure modes and effects analysis
- Producability of design
- Use of preferred or proven materials and parts
- Maintaining control over material and parts quality

#### 4.3.2.2 Communication

Communication issues is a highly relevant topic when discussing use of UAVs in remote regions, as communication infrastructure is often underdeveloped or non-existent in such areas. As stated by (Wik, 2016) a guest speaker from Kongsberg Defense Systems, during the ReCAMP Flagship Workshop, *“you have two choices for communication in areas with no infrastructure, either build infrastructure (permanent or temporary) or accept low bandwidths”*.

Choice of wireless communication technology is highly dependent on data transfer rate requirements, and currently the most well-developed and applicable communication for UAVs is RF. Any of the electromagnetic wave frequencies that lie in the range extending from 3kHz to 300 GHz are categorized as RF by the (International Telecommunication Union, 2012). The RF spectrum is further divided into frequency and wavelength bands, where VHF, UHF and SHF was suggested as the most applicable bands during ReCAMP (Wik, 2016), and their specifications and applications are presented in Table 4.3-1 below.

*Table 4.3-1 - VHF, UHF, SHF radio frequency bands produced with data from (International Telecommunication Union, 2012) and suggested applications from (Wik, 2016)*

<b>Designation</b>	<b>Frequency</b>	<b>Wavelength</b>	<b>Application</b>
<b>VHF</b> Very High Frequency	30MHz – 300MHz	10m – 1m	Control and telemetry
<b>UHF</b> Ultra High Frequency	300MHz – 3GHz	1m – 10cm	Medium range data communication
<b>SHF</b> Super High Frequency	3GHz – 30GHz	10cm – 1cm	Low range, high data capacity

All of the above bands propagate as space waves, meaning that diffraction and reflection gives rise to propagation beyond the horizon (Agrawal & Zeng, 2015). The amount of data you want to send, i.e. the data transfer rate is dependent on the frequency of the signal. When discussing travel distance

and penetration the general rule is that signals with longer wavelengths travel a greater distance and penetrate through and around objects better than signals with shorter wavelengths (Boyes, 2009).

Because a great amount of wireless communication is done through RF today, the frequency bands available are heavily regulated (Wik, 2016). This causes some issues for communication between the operator and the UAV as the transfer rate is limited by the designated bandwidth, as regulated by NKOM (Norwegian Communications Authority, 2016).

With avalanche SaR in mind, the limitations for communication frequencies are not causing any operational issues. The Hexacopter UAV platform used by TRC was tested at a range of approximately 8.5 kilometers (Lorentsen, 2016), and the test points can be seen in Figure 4.3-1, which was an unobstructed VLOS test over the ocean.



*Figure 4.3-1 - Measurement of communication link for TRCs hexacopter (total distance 8.36km), created using google maps*

Some problems related to communication between pilot and UAV were identified during this thesis. These problems seemed to be commonly recognized by several of the stakeholders in the industry, as identified during interviews and attendance of ReCAMP. The most prominent barriers are listed below:

1. Range of communication
2. Data transfer capacity
3. Interference
4. Security of communication and encryption

Although use of military RF bands is a possibility to increase range of rate of data transfer, TRC currently have no needs for improved communications due to the parameters of their assignments (Sandslett, 2016). Also, there were identified no needs for encrypted communication as the probability for hacking or malicious attacks is believed to be incredibly low, this can of course change in the future and is assessed continuously. Interference is a much more prominent issue, but there

are safety systems in place to mitigate the consequences of radio link interference of temporary loss of control, which will be described more elaborately later.

### 4.3.2.3 Sensor systems

In this thesis the sensors that are not vital for the UAVs ability to fly is considered the secondary sensor system which is part of the payload, and is what will be discussed in this section. Sensor technology that is believed to have current- and future applications for avalanche SaR are optical sensors, electrical search devices and radar-based sensors. In order to present the contribution and limitations of the various sensors they are all presented in Table 4.3-2.

Table 4.3-2 - Contributions and limitations of sensors for avalanche SaR using a UAV platform

Sensors		Contribution	Limitation
Optical	<b>High Definition camera</b>	<ul style="list-style-type: none"> <li>Provides high definition imagery from an aerial perspective to improve situational awareness</li> <li>Allows the rescue crew to assess risk for secondary avalanche before entering the area</li> </ul>	<ul style="list-style-type: none"> <li>Cannot locate completely buried victims</li> <li>Poor light conditions severely reduce the information of provided images, and has no use in pitch-black conditions</li> <li>Should be mounted on a gimbal for optimal results</li> </ul>
	<b>Infrared camera</b>	<ul style="list-style-type: none"> <li>Is equally good for locating victims during conditions with good lighting and no lighting, assuming that the victim is not completely buried</li> <li>Can be used to support FPV flight during night</li> </ul>	<ul style="list-style-type: none"> <li>Cannot locate completely buried victims</li> <li>Should be mounted on a gimbal for optimal results</li> </ul>
Electronic search devices	<b>Avalanche transceiver</b>	<ul style="list-style-type: none"> <li>Can help locate victims rapidly in large avalanches, multiple avalanches, in rough terrain or in powder avalanche debris with low load bearing capacity, i.e. low mobility for rescuers</li> </ul>	<ul style="list-style-type: none"> <li>Can only locate victims wearing an active AT in send mode</li> <li>The device is susceptible to interference from a multitude of sources, such as other electromagnetic fields from other electronic devices or high voltage powerlines, metals, head lamps etc. (Genswein, et al., 2013)</li> <li>Shielding for interference may prove to be difficult, and the device might have to be suspended beneath the UAV</li> </ul>
	<b>RECCO system</b>	<ul style="list-style-type: none"> <li>Can help locate victims rapidly in large avalanches, multiple avalanches, in rough terrain or in powder avalanche debris with low load bearing capacity, i.e. low mobility for rescuers</li> </ul>	<ul style="list-style-type: none"> <li>Can only locate victims wearing a RECCO reflector</li> <li>Can provide false positives from objects that mimic RECCO reflectors, such as LED diodes and certain types of highly mineralized rock (Skjelbakken, 2016). LED diodes are very common for both headlamps and snowmobile lights.</li> <li>RECCO reflectors on rescuers is also a strong source of interference</li> </ul>

<b>Radar-based<sup>4</sup></b>	<b>Ground penetrating radar</b>	<ul style="list-style-type: none"> <li>▪ It has been proved to locate avalanche victims not wearing any electronic search devices (Heilig, Schneebeli, &amp; Fellin, 2007)</li> </ul>	<ul style="list-style-type: none"> <li>▪ Cannot locate buried victims in avalanche debris with high water content (Heilig, Schneebeli, &amp; Fellin, 2007)</li> <li>▪ Signals / resolution decrease with height</li> <li>▪ Even the smallest systems are relatively heavy for UAV application (Altdorff, et al., 2014)</li> <li>▪ Research on application and integration with UAV is still on a conceptual level</li> </ul>
<b>Other</b>	<b>Cell phone signals (4G LTE)</b>	<ul style="list-style-type: none"> <li>▪ Field tests have proven that this technology is sufficient for effective SaR of buried avalanche victims (Wolfe, Frobe, Shrinivasan, &amp; Hsieh, 2015)</li> <li>▪ The vast majority of avalanche victims in Norway has a cell phone on their body when located (Skjelbakken, 2016)</li> <li>▪ No interference issues with the UAV (Wolfe, Frobe, Shrinivasan, &amp; Hsieh, 2015)</li> <li>▪ Receiving sensor is low weight and power consumption</li> </ul>	<ul style="list-style-type: none"> <li>▪ Can only locate victims with a cell phone on their body using the 4G LTE technology, with an app active to broadcast the phone position</li> <li>▪ As of 2015 there were very few studies done on this technology, and most are proof-of-concept</li> </ul>

All the aforementioned sensor systems in Table 4.3-2 (excluding the optical systems) are vulnerable to interference generated by the UAV and its sub-systems. A common solution to this problem – at least for electronic search devices – is to have the antenna suspended a certain distance below the UAV to minimize the amount of interference. Specially designed antennas or shielding can also be used to limit the amount of interference (Sandslett, 2016).

The optical sensors mentioned in this section is somewhat vulnerable to vibrations and therefore measures should be taken in order to reduce vibration and introduce a vibration abortion or dampening system. Reduction of vibration can be achieved by balancing the propellers, use dampeners, and avoid flying in loiter too much (Sandslett, 2016). For a MRRW leveling of motors and calibration of ESC can also help reduce vibration. Although it is not a necessity the optical sensors can benefit of the ability to move independently of the aircraft, so that no elaborate movement must be done in order to observe and follow an object of interest. This can be done by introducing a gimbal which allows for independent movement in three axes (yaw, pitch and roll). Assuming that their payload is not exceeded, gimbals are highly applicable for MRRW and SRRW platforms, due to their state of operation with high agility movement and hover capabilities. MRRW has the additional benefit of being able to adjust stability due to an offset CG by changing rotor RPM. Gimbals are also applicable for fixed wing UAVs, but this requires a certain platform size, due to the potentially offset in CG, change in aerodynamic characteristics and payload limitations.

#### 4.3.2.4 Degree of autonomy and data management

Degree of autonomy is related to what extent a UAV can control itself without input from a pilot or operator. This may relate to both the flight itself and the control of sensor systems used to gather

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<sup>4</sup> Excluding the RECCO system, even though it is a radar-based technology

data. The following list presents some of the autonomous functions<sup>5</sup> discovered during the course of this thesis.

- **Failsafe function** – autonomous landing in predesignated area or other action to be executed upon loss of communication
- **Return Home** – UAV climbs to a designated altitude and returns to a designated point or to where the operation was initiated
- **Self-leveling** – UAV attempts to maintain a constant altitude based on sensor input
- **GPS waypoint navigation** – A pre-programmed flight plan is executed based on GPS waypoints / coordinates
- **Hovering/loitering** – Upon releasing controls the UAV attempts to maintain its exact position and altitude by autonomous control of the pitch, roll and yaw axes
- **Take-off and landing** – both of these functions can be done autonomously based on sensory input
- **Geofencing** – A virtual 3D fence can be applied, where the autopilot will not allow movement above a certain altitude or beyond a certain distance
- **Follow-me function** – The UAV follows a target wearing a transceiver
- **Obstacle avoidance** – Detection and avoidance of obstacles in real-time based on sensory input
- **Swarming** – a network of UAVs operates collectively towards a common goal with a spatial awareness of other UAVs part of the same network.

The general issue with a high degree of autonomy is that it requires an increased amount of computing power as high updating frequencies of sensor measurements creates more data to analyzed. This is particularly true for reactive autonomy which has a high rate of data generation, and therefore must have correspondingly high data analysis rate. To achieve a high degree of autonomy the UAV must therefore be able to do a large amount of real-time data processing, which requires complex hardware which in turn requires power. UAVs are typically compact and no larger than necessary with limitations in payload and power generation capacities, making a high degree of autonomy challenging as of today. However, it is believed that the technology development and more efficient algorithms will allow for a higher degree of autonomy in the future.

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<sup>5</sup> Some of the autonomous functions are unique to MRRW and SRRW platforms due to their hover capability

Table 4.3-3 - Three levels of increasing autonomy. Reproduced from the works of (Floreano & Wood, 2015)

	<b>Exteroceptive sensors</b>	<b>Computational load</b>	<b>Supervision required</b>	<b>Readiness level</b>	<b>Validated on UAV type</b>
<b>Sensory motor autonomy</b>	None or few	Little	Yes	Deployed	All types
<b>Reactive autonomy</b>	Few and sparse	Medium	Little	Partly deployed	Fixed wing and rotorcraft
<b>Cognitive autonomy</b>	Several and high density	High	None	Not yet deployed	Mostly rotorcraft

As we can see from the from Table 4.3-3, there are identified three levels of increasing autonomy as are described in chapter 2.1.2. As we can see the computational load increases with number of sensors, whereas the supervision required for the UAV decreases. The readiness level reflects to what extent each degree of autonomy is currently used, and further it is described for which type of UAV platform the technology is validated for.

#### 4.3.2.5 Collision avoidance

In the regulations concerning aircraft without a pilot on board, as seen in Chapter 2.2.2 §49, regarding right of way for other aircraft, it is stated that aircraft without a pilot onboard shall give other aircraft right of way. This implies that the operator of the UAV must be able to reliably sense-and-avoid all other aircraft. As a safety feature, this is of utmost importance, as any collision or close-call accident is likely to severely hurt the integration process of UAV into civil airspace.

Technology used for air traffic collision avoidance today is based on radars and transponders such as the Automatic Dependent Surveillance - Broadcast (ADS-B) transponder. Information from these systems is being managed by local air traffic control (ATC), and a cooperative and open communication between ATC and manned aircraft pilots is vital. However, integration of such systems can prove to be difficult for UAVs, at least the smaller ones, as todays transponders and radar systems are heavy and require a lot of power, as well as being costly systems (DeGarmo, 2004). Integration with UAVs limited payloads and power-generation capabilities can prove to be difficult.

There are currently being explored numerous technologies for UAV collision avoidance according to a report by the MITRE corporation (Lacher, Maroney, & Zeitlin, 2007). In the report they review several sensor technologies such as transponders, optical, thermal, laser, radar and acoustic, upon which they conclude that it is likely that no single sensor will be sufficient to address all UAV collision avoidance requirements, and multiple sensors may be necessary.

The focus of this thesis is application of UAVs for avalanche SaR where the mission is carried out in a finite space with altitude limitation, and therefore it is more applicable to discuss how a UAV can interfere with other rescue resources in the operative area. As helicopters are the only airborne resources expected to occupy this finite area, collision avoidance with them is considered the most interesting subject. For this purpose, a ADS-B transponder which broadcasts information about altitude, heading, speed and distance to aircraft can prove to be sufficient. Considering application on an UAV, this system is dependent on two avionics components; a high-integrity GPS navigation source

and a datalink in the form of a ADS-B unit equipped to receive data (Lacher, Maroney, & Zeitlin, 2007). This would allow the UAV to keep a minimum distance to helicopters, adhering to predefined minimum limitations. Use of these transponders were previously unfeasible with many UAVs, but recent technology development has proved that a low-cost, lightweight and portable ADS-B transponders with sufficient transmission power is technically viable (Strain, DeGarmo, & Moody, 2007).

Another collision avoidance issue is collision with objects or people, which is less severe than impact with manned aircraft, but still not acceptable in any way. However, this is primarily an issue during autonomous flight, as avoidance would be ensured by the UAV operator during manual flight under normal circumstances. Nevertheless, autonomous obstacle avoidance is believed to be a valuable function for UAVs and is therefore being researched by several entities. Even though there are no fully functional solutions to obstacle avoidance, promising results are seen in this area of research such as the use of push broom stereo for high-speed navigation in cluttered environments, as proposed by (Barry & Tedrake, 2015) during the IEEE – International Conference on Robotics and Automation.

#### **4.3.2.6 Applicability and development of parts and software**

During the ReCAMP workshop (Storvold R. , 2016) stated that *“the UAV industry is blessed and cursed with the option of using a lot of consumer electronics”*. This statement relates to the fact that the market of consumer electronics is often a lot cheaper and has a wider selection as compared to the specialized markets for industrial and research applications. Extreme applications of consumer electronics were likely never intended when the manufacturer designed the component, which naturally means that they are typically not rated for their desired application in adverse operative conditions. In the same presentation (Storvold R. , 2016) further states that *“this does not necessarily mean that the component will not work in such conditions, but that the manufacturer does not guarantee it”*.

The segment of UAV platforms currently gaining a lot of popularity are relatively small in size, and has their origins in the RC community for hobbyists. All the applications for these platforms are likely still not identified, as new discoveries are made all the time. Therefore, there are no universal standards for design, development of software and sensor packages, and operational capabilities. It is suspected that large portions of the UAV community, both hobbyists and professionals, use open-source autopilots and other software, which makes it difficult to establish requirements for quality and reliability of design as is done with manned aircraft.

Using avalanche SaR as an example there is a lack of commercially available ATs that can be easily integrated with an UAV platform, autonomous or not. A good integration of sensor systems and the UAV is vital for a best as possible result, where the sensor systems communicate seamlessly with the UAV. Communication between the UAV and the operator is also an important factor. The human-machine interface (HMI) should be intuitive and easy to use, in order to communicate the necessary information to achieve the wanted results, which – in this case – would be to locate the victims as quickly as possible. Only the most vital data for human judgement calls should be presented to the end-user.

#### **4.3.2.7 Power plant**

When discussing power plant for an UAV it will only be distinguished between batteries and liquid fuels for internal combustion engines (ICE). Such liquid fuels may be different variations of gasoline

as well as nitro-fuels which typically is a mix of methanol and nitromethane. For an UAV, flight time will vary greatly depending on selected power plant and platform. For fixed wing even electric platforms can achieve relatively long flight times easily exceeding one hour (Sandslett, 2016), and the ICE platforms can be used for long endurance mission in exceedance of 10 hours. Due to the design of the MRRW platform an ICE-based propulsion system is not desirable, as there are multiple rotors that need to be powered. In general, the flight times achieved with the MRRW platform is relatively low, but decent flight times can be achieved through design and lowering requirements for other parameters. The SRRW platform can be powered by both batteries and ICE, however best results are currently achieved through ICE. Table 4.3-4 is a rough illustration of the capabilities of the different UAV platforms depending on power plant. It should be noted that this table is a very rough estimate made by the author to illustrate platform differences.

*Table 4.3-4 – An illustration of characteristic endurance and payload capabilities of different UAV platforms based on power plant*

<b>Platform</b>	<b>Power plant</b>	<b>Endurance</b>	<b>Payload</b>
<b>MRRW</b>	<i>Electric</i>	Low-Med	Low-Med
	<i>ICE</i>	N/A	N/A
<b>SRRW</b>	<i>Electric</i>	Low	Low-Med
	<i>ICE</i>	Med	Med-High
<b>Fixed-wing</b>	<i>Electric</i>	Med-High	Med
	<i>ICE</i>	High-Very High	Med-High

### **Battery**

In chapter 2.1.5 the energy density of commonly used batteries is presented and from Figure 2.1-11 we can see that energy densities of the two most commonly used batteries for UAVs – Li-Po and Li-Ion – are typically in the range of 250-350 Wh/L which translates to 0.9-1.26 MJ/L. Compared to energy densities of liquid fuels such as methanol-based (17 MJ/L) and gasoline (34 MJ/L) it is obvious that battery powered electrical motors are a far inferior option, when discussing endurance, weight and payload capabilities. However, brushless DC engines are statistically much more reliable (Johansen, 2016), more quiet and very applicable for MRRW platforms as it is common that each propeller has its own power source allowing stability adjustments and maneuvering by adjusting the RPM of the motors.

It should also be noted that some battery technologies like to Li-Po is considered to be quite volatile and fragile, meaning that transportation and storage should be done with care. Also, Li-Po's are typically not designed to withstand water, should not be over-discharged, stored with lower charges (50-70%) and – due to the lack of metal casings – are vulnerable to impact damage. All of these factors needs to be considered for a rescue operation as they all cause unique challenges for the operation, maintenance and logistics. As rescue operations typically are pressed on time, storage of batteries on low charges can prove to be difficult as there is no time to recharge the batteries after a rescue

operation is initiated. This could be done by applying a rotating charge cycle to ensure that some fully-charged batteries are always available. However, it is very expensive to invest in multiple battery packs, and time consuming to manage such a charge cycle. Storage of fully charged batteries primarily reduces the number of charge cycles, therefore TRC manages this problem as “calculated damage” to their batteries in order to ensure a high level of availability for the UAV (Sandslett, 2016). Although there are some differences, the characteristics and challenges of Li-Ion batteries are very similar to Li-Po, and will not be discussed further.

Today there is a constant development in battery technology, increasing the energy density and improving battery characteristics. During the ReCAMP presentation regarding SUMO operations in harsh environment, the initial flight time of 20 minutes for their fixed wing is extended to over an hour today, mostly credited to battery development (Kral, 2016). As one of the major challenges for battery-powered UAVs is energy density, a revolution in battery development is likely to have a great impact on such platforms. Although it is not the primary focus of this thesis it should be noted that large-scale manufacturing and disposal of batteries is an important issue with respect to environmental consequences.

### ***Internal combustion engines (ICE)***

Even though the ICE are much more inefficient in converting the stored energy of liquid fuels into mechanical energy, the far superior energy density makes ICE a preferred option to achieve longer flight times. However, these types of engines are typically best suited for single driveshaft applications which is typically seen in larger fixed wing and SRRW platforms.

During this thesis only single cylinder two-stroke engines will be discussed as they are well suited for application in relatively small UAV platforms. They have the advantage over the four-stroke engines, as they are both lighter and less complex, making them more reliable (Menon, 2006). The fact that two-stroke engines produce a power stroke once every two strokes also allows them to achieve a higher power-to-weight ratio, which is beneficial for smaller UAV platforms. The most prominent issue with this type of engine for UAV application in cold environment is the freezing of the carburetor intake according to (Cahill, 2016) & (Storvold R. , 2016). A problem which was fixed by designing for a fuel-injection system instead.

### **4.3.3 Challenges regarding compliance to regulations**

When discussing compliance to regulations it is important to address what UAV application is in question. Using UAVs as described in the TRC case study, there are very few regulations that impose limitations with respect to their operations. TRC has fulfilled all general requirements as included in chapter 2.2.1 in this thesis, such as §13 and §14 stating the requirements for altimeters and fail-safe systems for rotorcraft. For avalanche rescue it is highly unlikely that their operations will take place in controlled airspace of any form, therefore regulations describing aerodromes, military- or otherwise restricted airspace can be neglected to some extent. Seeing as they have an approved permit for RO1, RO2 and RO3 operations, all requirements for organization is fulfilled as of today, however as the new regulations from 1<sup>st</sup> of January 2016 accedes, some issues might arise.

Despite TRCs compliance to regulations there are some issues related to the use of UAVs in avalanche rescue as it is highly likely that there will be helicopters present who are also involved in the rescue. In a consultation paper to NCAA, on behalf of The Norwegian Air Ambulance Foundation (NAA)

(Normann, 2015) states that NAA is exempted from the requirements of minimum altitude operations during their health emergency medical service (HEMS) missions. Most of TRCs operations are in uncontrolled airspace where the maximum altitude for UAVs are set to 120m above ground level (AGL), which in combination with NAAs operations below minimum altitude regulations can cause a conflict. Currently this conflict is resolved by the accident site commander designating airspace for aerial resources during a rescue operation.

It is further noted by (Normann, 2015) that the requirement to “see and be seen” may be difficult to fulfill as UAVs in general are small and difficult to spot, regardless of TRCs compliance with lighting requirements as regulated by §59-§60. However, for a UAV operated at VLOS the pilot complies with the regulations to “see and be seen”, considering that manned aircraft have priority over unmanned and therefore UAVs are required to give right of way to other aircraft as stated in §49. (Sandslett, 2016) stated in an interview that preventive measures in the form of landing the UAV are initiated immediately upon detection of manned aircraft such as helicopters. This limits the need for NAA pilots to “see and be seen” as preventive actions are already in place in the event that the two aircraft pilots are not aware of each other. During an organized rescue, operators of all aircraft should be made aware of each other’s presence, which is currently managed by the accident site commander or other designated personnel.

In the consultation paper by NAA, (Normann, 2015) states that their helicopters are equipped with “traffic collision avoidance system (TKAS)” which – based on their experience – has contributed greatly to situational awareness. It is further identified that use of a transponder on UAV systems operating in unmanned airspace is likely the greatest safety barrier if applied. This can be compared to the ADS-B transponder discussed in chapter 4.3.2.5 regarding collision avoidance, as some TCAS systems are capable of processing ADS-B messages. Although not a requirement today, it is not unlikely that such a requirement may be set in future regulations, depending on the development of the UAV market.

According to (Johansen, 2016) who is the legal advisor for Norut, “*the regulations as of today can be interpreted as to not allow for fully autonomous UAV systems*”. This interpretation of the regulation severely limits some UAV systems, like for example fully autonomous systems for companion rescue, as discussed in Chapter 4.3.4.1. However, if such systems are developed they will not be commercially available for several years, and the regulations may have addressed this issue in that time.

On a final note it should be mentioned that TRC identified the fee regulation act, §29 regarding annual fees for approval of aircraft without a pilot onboard, as a challenge for their future operations as they have limited funding. The authorization fee for RO3 operators will be determined by calculation of hours spent to process the application, whereas the annual fee for RO3 operators is set at 11000 NOK. As it is necessary for TRC to have a large stable of pilots available due to emergency response availability, the aforementioned fees (for each operator) is likely to greatly exceed their budget.

#### **4.3.4 Human and organizational challenges**

During ReCAMP 2016, (Cahill, 2016) presented the ACUASI’s lessons from the field based on their operation of UAVs in the Alaskan Arctic, where human failure was identified as their main cause of failures during missions. Many of the challenges related to human error during UAV operations has already been identified and discussed during the previous subsections of Chapter 4.3.

Naturally there will occur some challenges when humans are subjected to harsh weather conditions, as is often the circumstance during avalanche SaR. Weather challenges due to snow, cold, wind and darkness should be taken into account and mitigated as best possible by using the correct clothing and protective gear, designing for easy assembly and operation, and by organizing a rescue mission with respect to limiting the exposure of the rescuers. A pre-mission brief should also be done to inform the UAV pilot of potentially hazardous meteorological conditions.

As with most other civil applications for UAVs, their use in avalanche SaR is still very experimental and not yet established as viable. The preliminary use of UAVs for SaR operations in Norway appears to be very well organized with respect to safety for rescuers and other aircraft. However, considering a future widespread use of UAVs for the aforementioned application, there is without a doubt a need for more statutory and regulative framework on an organizational level. Furthermore, the organization providing UAV resources should facilitate a sufficient training program for the operators and pilots to ensure that they possess the necessary skill to operate a UAV both efficiently and safely. This includes piloting skills, data management capabilities and the ability to perform under pressure.

In a paper presented during the International Congress of the Aeronautical Sciences (ICAS), (Asim, Ehsan, & Rafique, 2010) separates unsafe acts due to human errors into four categories; skill-based errors, decision errors, perceptual errors and violations. Skill-based errors reflect the training received and the pilot's ability to acquire knowledge, while decision errors are attributed to a pilot's inability to respond quickly enough or accurately analyze a situation. Furthermore, perceptual errors occur due to operating environment or the operator's mental state, while violations are a cause of casual behavior or inadequate knowledge of the pilot.

Finally, it should be stated that a well-organized rescue effort is believed to be vital for the successful implementation of UAVs, as an accidental UAV impact with manned aircraft could have dire consequences, both for the rescue crew and the future application of UAVs in avalanche SaR. TRC has discussed applying their knowledge as a foundation for a national standardization process describing the use of UAVs in SaR operations. If this is applied, it is likely to greatly benefit all SaR organizations in Norway who intendeds to use UAVs.

### **4.3.4.1 Ease of access, deployment and use**

#### ***Access***

As briefly mentioned in Chapter 4.2.3.1 ease of access is vital to ensure that the UAV is deployed to the accident site as quickly as possible, which is crucial during avalanche SaR as time is of the essence. For rescue operations in remote regions of Norway, the UAV must either be deployed through volunteer organizations or professional rescue teams in helicopters. A hybrid solution is also a possibility, where volunteer organizations provide the UAV pilots to be deployed in helicopter managed by professional rescuers. Nonetheless, ease of access must be ensured. If an UAV system is to be deployed through members of a volunteer organization, it should follow the persons on duty and rotate with their internal on-call schedule. If the UAV resource were part of professional dedicated avalanche resources like the Air Ambulance, system availability would always be ensured as it would be located at their base.

**Deployment**

The deployment phase relates to the transportation of the UAV and trained operators to the accident site, as well as assembly and arming of the UAV before it is airborne. Due to the short response times inherently necessary for emergency response during avalanche SaR, resources brought along on the missions must be readily available and easy to transport. In effect this means that both deployment and retrieval of the UAV should not require any large equipment that is difficult to transport and assemble. For rotary wing UAV platforms this is not an issue as both take-off and landing can be done vertically in any reasonably large open space. For fixed wing on the other hand, take-off and landing can be more complex. Their generation of lift requires forward momentum forcing air over their wings which means that they cannot land vertically, and horizontal landings either requires a large space, a very light UAV or some device to assist the landing, such as a net or a combination of a wing hook and wire-arrangement.

Table 4.3-5 presents a summary of all practical deployment methods for UAVs to contribute in avalanche SaR. Due to the remoteness of the operational area covered by TRC deployment methods 1 and 2 are the only ones currently considered applicable, where they – in a best case scenario – arrive within 30-45 minutes after the avalanche is reported (Skjelbakken, 2016). Based on Figure 4.2-3 this indicates that statistically very few victims will be alive upon arrival.

*Table 4.3-5 - Identified methods of deployment for UAVs contributing in avalanche SaR*

<b>Rescue effort</b>	<b>Location</b>	<b>Deployment method</b>
<b>Organized</b>	<b>Remote</b>	1) Car, snowmobile or by foot 2) Helicopter 3) Direct deployment from local base
	<b>Local (ski resort etc.)</b>	4) Rapid deployment using snowmobile or by foot 5) Direct deployment from local base
<b>Companion</b>	<b>On-site</b>	6) Immediate deployment of portable UAV

As we can see from Table 4.3-5, another option for deployment to remote avalanche locations is a direct deployment from base 3). This option would require a platform capable of high speeds and long endurance missions to provide any benefits for the rescue operation. With the technology available today a relatively large fixed wing platform is the best match to these requirements, but it would have limited capabilities upon arrival. Larger fixed wings are reasonably fast and have sufficient flight times, but such large machines are typically heavier meaning that they need to maintain higher speeds to generate sufficient lift. Higher speeds make it difficult to maneuver with agility in a limited space as well as fly at very low altitudes which would benefit an avalanche rescue operation. This is one of the reasons MRRW is a popular choice for such operations, they have hover-capabilities, are agile in a limited amount of space and are also able to maneuver and take-off / land in very small areas.

During the course of this thesis there has been little focus on UAV applications for ski resorts. This is because such an application would likely require a large resort with a relatively high density of professional rescue crews in order to be viable, and resorts of this scale are very scarce in Norway. In the European Alps there are numerous ski resorts which could possibly benefit from use of UAVs. These areas typically have a very high density of professional ski-patrols who have immediate access to transportation, and the victims are likely relatively close due to the positioning of ski patrols and slopes. Therefore, rapid 4) or direct 5) deployment of an UAV system is possible, which may reduce the search time in demanding terrain.

Companion rescue is considered the technique that is most likely to save a victim's life, primarily due to the short response time before a search is initiated. Therefore, deployment of UAV during companion rescue 6) might be considered the most viable application for UAVs with respect to saving lives. Such a concept was studied by five engineering students from the Swiss Federal Institute of Technology Zurich, using a foldable quad combined with an AT to roughly locate victims and mark them with a beacon (Grauwiler, Gschwend, Leuzinger, Wyss, & Oth, 2010). The project was called Alcedo, and won the European Satellite Navigation Competition in 2010. Their findings indicate that a portable UAV and autonomous search is possible, but is to be considered a proof-of-concept rather than a real-world emergency solution. An UAV system for this application should be close to fully autonomous, require very little to no training and be very robust. If such a system is developed and available for the commercial market, it could have a large impact on the survival probability of victims as the search efficiency during companion rescue can be improved. This system could be deployed by party members who were unaffected by an avalanche, allowing them to do a rapid search over large areas, roughly locating their companions and enabling fine search and excavation. However, such a system must be proven to work and be low-cost in order for it to be considered a valid investment to the same extent as an AT. Also, the regulatory restrictions on fully-autonomous systems must be changed by the NCAA, as they do not allow for such operation of UAVs in Norway, which is discussed in Chapter 4.3.3.

### ***Ease of use***

As the UAV is intended to be used in stressful situations with limited time to spare, it should be designed with the intent of being easy to transport, assemble, launch and operate. Although TRCs TOR is quite large, the arms are foldable and it fits in a protective box which can be carried by two persons. As explained by (Sandslett, 2016) a modular design is used for their UAV, enabling various sensors to be used based on type of mission. All assembly and adjustments can be done easily with gloves on, as most attachments are secured by sliding pins or Velcro.

Operation of the UAV should also be relatively simple, and this is where the MRRW platforms has their greatest strength as they are considered to be very simple to fly compared to other platforms. The loiter function during hovering allows the operator to keep the UAV almost completely still if needed, and it was stated by (Lorentsen, 2016) that anyone could fly the TOR UAV. Launching is also very simple using a MRRW as it can take-off from virtually any small clearing, assuming that wind conditions are not excessive. An SRRW- or small fixed-wing platform may be equally easy to launch, but provides different capabilities and characteristics as compared to MRRW.

Although a MRRW platform generally is easy to operate, operation and data interpretation of a complex sensor payload might be a challenge. Optical sensors mounted on a gimbal with a dedicated operator should cause no problems, but applying ATs, RECCO or a GPR system might need a skilled

operator to ensure proper utilization. This is likely to be particularly true for experimental sensor systems. Integrated solutions with a high degree of autonomy would be preferable, as it allows the pilot to assume a supervisory role of the entire system, possibly achieving better results as compared to manual operation. However, such solutions are not yet commercially available.

## 4.4 Hazard identification and risk analysis

This chapter presents and discuss the identified hazards and the risk analysis that was included with the intent to answer the final research question and the last objective of this thesis.

In Chapter 3.4 HAZID methodology was divided into three sections: HAZID meeting, review of checklists, codes and standards and review of hazard registers of previous accidents. Although all the aforementioned sections contributed to the overall identification of hazards related to implementation of UAV in avalanche SaR, it was primarily the HAZID meeting that provided the most valuable results. Initially hazards were identified by the author of this thesis, as a product of the research on this topic. Through a structured HAZID-meeting additional hazards and barriers were identified as described in the comments of Appendix 1, where the responsible for the comment or change is noted in initials corresponding with Table 3.2-1 describing the interview- and HAZID attendees.

As stated in the HAZID methodology, not all information gathered for the HAZID sheet in Appendix 1 were done through structured HAZID meetings. Contributions were also done through interviews which were transcribed and are available in Appendix 2. However, a sufficient spread in disciplines was achieved, as compared to the list of optimal contributors presented in Chapter 3.4. The contributors field of expertise is listed in Table 4.4-1 below:

*Table 4.4-1 - List of contributors and their experience*

<b>Experience</b>	<b>Contributor</b>
a) Pilot (RO3) with experience	KSJ, RS, VL
b) Construction and maintenance of UAV	KSJ, RS
c) Avalanche SaR	TAS
d) Unique insight into the TRC organization	RS, VL, TAS

Due to the fact that the UAV industry is still in its infancy stages there is still limited information available in the form of standards. Checklists and codes can be related to the OM contents of each licensed UAV organization. Furthermore, the author is unaware of any hazard registers and if they exist they are not openly available. Data collection and processing for accidents or near accidents regarding use of UAVs in professional civil applications is very scarce, and likely subject to under-reporting issues. However, the inability to access such information has been partially resolved by attending the ReCAMP workshop, gathering data based on presentations of other people’s experience from years of operation in similar conditions.

### 4.4.1 HAZID sheet

As the complete HAZID sheet is too extensive to present in this section, a small excerpt is shown in Figure 4.4-1 to explain its contents and provide a foundation for further discussion.

ID	Category	Hazards	Probability (1-5)	Consequences (A-E)	Hazardous event	Controls or barriers	Comments	Responsible
1.10		Pre-flight check and technical procedures	3	D	Vital components / connection unchecked and fails, complete or temporary loss of control	Follow pre-flight checks as stated in the OM	Added hazard as advised by KSJ Time for pre-flight control may be limited during SaR operations	KSJ
2.1	Loss of propulsion	Exhausted fuel/power supply	2	D	Complete loss of control over the UAV, crash landing	Operate with sufficient safety margins	Especially important when returning home against the wind	KSJ/AA
2.2		Failure of motor	1	C	Emergency or crash landing	Multicopter with more than 4 engines can maintain flying capabilities to some extent with one motor failure		
2.3		ESC failure	3	C	Inability to control electrical motor RPM, uncontrolled descent / emergency landing	Regular maintenance and sufficient dimensioning and cooling of ESC	Added hazard as advised by KSJ	KSJ

Figure 4.4-1 - Excerpt of the HAZID sheet from Appendix 1

Firstly, the ID column provides a reference number for each unique hazard identified. In order to structure the discussion around one topic categories were introduced, all of which are listed below;

- a) Human
- b) Loss of propulsion
- c) Mechanical failure
- d) Communication failure
- e) Mid-air collision
- f) Battery failure
- g) Operative conditions
- h) Assembly and take-off
- i) Landing
- j) Electrical and primary sensor failure
- k) Restricted areas or airspace
- l) Environmental

Upon identification all hazards were rated qualitatively based upon the expertise of the contributors, where probability ranged from 1 (lowest) to 5 (highest) and consequences from A (least) to E (most). Following is a description of the unique hazardous event that could occur, and the proactive and reactive barriers in place for each respective hazard. If there were some comments related to changes or implementation of additional hazards they were noted in the comment section including the responsible person.

### 4.4.2 Identified hazards and risk acceptance

Identified hazards from the HAZID analysis are further processed in this chapter by applying a risk matrix. The numbering seen in Figure 4.4-2 below, corresponds with the ID given to each unique hazard in Appendix 1.

PoF Ranking	Probability of failure	A	B	C	D	E
5	(1) Almost certain (2) Failure has occurred several times a year in the location					
4	(1) Likely (2) Failure has occurred several times a year in operating company.		6.2, 7.6	6.4, 7.7		
3	(1) Moderate (2) Failure has occurred in the operating company.		4.1, 5.5, 7.3	1.2, 1.4, 2.3, 7.5	1.6, 1.10	
2	(1) Unlikely (2) Failure has occurred some times in the industry.	4.4	1.7, 5.1, 5.4, 5.6, 6.1, 7.1, 7.2, 8.1, 10.1	1.3, 3.2, 10.5, 12.2, 12.4	1.5, 1.8, 1.9, 2.1, 3.6, 4.3, 7.8, 10.2, 10.7	5.2, 10.6
1	(1) Highly unlikely (2) Failure has occurred in industry.	6.3, 10.4, 12.1	3.4, 4.5, 4.6, 10.3, 12.3	2.2, 3.1, 3.3, 5.3, 8.2, 9.1	3.5, 7.4	1.5, 4.2, 5.3, 11.1, 11.2, 11.3
<b>Consequence of failure (safety)</b>		No injury	Minor injury	Major injury	Single fatality	Multiple fatalities
<b>Category</b>		<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>	<b>E</b>

Figure 4.4-2 - Identified hazards presented in risk matrix with RAC implemented

By applying RAC as defined in Figure 2.3-2, all hazards rated as a risk class of broadly acceptable (D) or tolerable (C) are “screened out” as they are considered to be ALARP. All hazards in the risk class of marginally tolerable (B) are further evaluated to either demonstrate that they are ALARP or identify additional barriers to reduce the probability- or consequence of failure. Hazards rated as intolerable (A), must be evaluated as to identify risk reducing measures. Table 4.4-2 below, lists all identified hazards with a risk class  $\geq$  B. As we can see there are no hazards that currently are considered as intolerable.

Table 4.4-2 - Identified hazards with risk class  $\geq B$

ID	Description	Prob.	Cons.	Risk class
1.2	Insufficient piloting skills / training	3	D	B
1.4	Pilot exposure to extreme operative conditions (pressure/stress)	3	C	B
1.6	Human / machine interface misinterpretation	3	D	B
1.10	Pre-flight check and technical procedures	3	D	B
2.3	ESC failure	3	C	B
5.2	Manned aircraft (helicopter)	2	E	B
6.4	Lower than expected capacity due to cold	4	C	B
7.5	Heavy wind	3	C	B
7.7	Topography induced wind deflection and turbulence	4	C	B
10.6	Autopilot failure	2	E	B

#### 4.4.2.1 Discussion of identified hazards with risk class $\geq B$

The following Table 4.4-3 provides discussion around each identified hazard with a risk class of B or above. Numbering of the hazards corresponds with their ID in the HAZID-sheet, and all hazards identified discussed with respect to why they were assigned their respective rating, their preventive barriers and how they are currently handled by TRC.

Table 4.4-3 - Discussion of hazards with risk class  $\geq B$

ID	Discussion
1.2	<p>Insufficient piloting skill and training is an issue that is purely organizational. It must be ensured that all pilots are certified and have undergone a training system for the specific UAV they are to be operating. Further, all pilots should train regularly, preferably in a realistic setting. Camera operators, pilots and spotters should all train together so that they are familiar with each other.</p> <p>This can potentially be a problem for TRC when they are fully operational as they are on preparedness alert if an avalanche should occur. They need several people working in shifts to fully cover a round the clock preparedness, which means that it would be a lot of work to maintain everyone's level of training. Also, some pilots/operators might be unavailable upon request, which could force less experienced pilots to step in.</p>
1.4	<p>Pilot exposure to extreme operative conditions in the form of pressure and stress during a rescue operation also relates directly to amount of training in a realistic setting, and how to best cope in these situations. However, the only possibility for reducing the probability of these hazards is to have a sufficient training regime and have multiple pilots/operators available for rescue operations.</p>

- 1.6** Human/machine interface misinterpretation is also an issue that relates to training as well as what interface is used on the UAV communication system. However, the probability for this particular hazard is likely overstated as TRC has built their own UAV, and (Sandslett, 2016) has a very good insight into all the systems used. His experience can be used to create a more than sufficient training program for new pilots.
- 1.10** The pre-flight check for TRCs missions is likely to be more difficult to execute as they are under a severe time pressure during avalanche SaR. A good maintenance regime might support a shorter checklist as the UAV is then regularly inspected. However, the most vital checkpoints should always be done prior to flight.
- 2.3** ESC failure is not an uncommon fault, and has caused a minor accident for TRC previously. Based on this experience the ESCs were re-dimensioned and repositioned to ensure their capacity and sufficient cooling during operations. Tests have been executed to assess their performance, which seems to be well within limits. With this in mind the probability for this hazard is likely somewhat overrated.
- 5.2** Impact with manned helicopter during a rescue operation with several active aircraft is a major concern. The probability is considered rather low as the accident site commander is responsible for allocating the airspace, often with visible physical objects or structures as an area separation limit. It should also be noted that there are no studies on impact between UAVs and helicopters, and the consequence for this scenario is based on “worst case”. It is not unlikely for the UAV to operate in an area below the manned helicopter, where the downwash from the helicopter rotors would likely blow away the UAV before impact. Even though they should never occur in the first place, many of the unwanted interactions between a helicopter and an UAV could possibly be completely harmless with respect to the helicopter.
- 6.4** Reduced capacity due to cold is a very realistic issue for UAVs, especially for battery powered ones as discussed previously. Due to this there are barriers in place reducing the probability of failure, such as keeping the battery packs warm and constantly monitoring their parameters before and during operation. This is ultimately the pilots responsibility, and consequences are easily reduced by performing an emergency landing if battery levels are too low.
- 7.5** Both turbulence and heavy- or topography induced wind deflection has to be assessed on-site prior to- and during the rescue operation. The OM provides guidelines as to operational limits of the UAV platform, which should be adhered to. There have been done some modifications to improve the UAVs performance in wind, but nevertheless this is a very light aircraft and is very susceptible to acute changes in wind conditions.
- 7.7**
- 10.6** Autopilot failure is very difficult to do anything about, as this feature controls the entire aircraft and its development is beyond TRC. Choice of autopilot is the only active measure that can be taken, and should be based on the reliability and previous unwanted incidents for autopilot systems in question. System updates (especially for open source programs) should be postponed until faults and bugs have been identified. A major progress in this area would likely come with standardization of these systems and requirements for NCAA approval. Currently the only reactive barrier for this hazard is to have good routines for actions upon failure.

### 4.4.3 Expected fatality rate

To calculate the EFR Equation 2 as presented in chapter 2.3.6 is used. For these calculations as with the risk analysis, we assume the operational context of a rescue operation after an avalanche as executed by TRC using their hexacopter UAV presented in chapter 4.2.2.

$$EFR = \frac{1}{MTBF} A_{exp} \rho (1 - f_{prot} + f_{prot} p_{pen}) p_{kill}$$

where,

- $EFR$  = expected fatality rate (persons killed per hour of operation)
- $MTBF$  = mean time between failures (i.e., loss or crash of aircraft)
- $A_{exp}$  = area exposed to aircraft ground crash
- $\rho$  = population density in area
- $f_{prot}$  = fraction of people protected by shelter (e.g., housing)
- $p_{pen}$  = probability of UAV penetrating shelter
- $p_{kill}$  = probability of UAV killing a person when hit

According to (Johansen, 2016) a MTBF value of 100 hours of operation before a loss or crash of aircraft is a modest estimate, which will be used here. The area exposed to aircraft ground crash is believed to be circular as the UAV airframe is fairly circular including the spinning rotors on all arms. By setting the radius of the airframe to 0.6m, the area of the circle that is the UAV will be equal to 1.13 m<sup>2</sup>. Considering a rescue operation with 20 participants covering an avalanche of 200m x 600m, we get a population density of 1 person per 6000 m<sup>2</sup>. We assume that none of the rescuers are protected by shelter.

The final assumption is the probability of UAV killing a person on impact, which is a rather difficult estimate to make as this probability is dependent on so many variables. Some of which are; type of person being impacted (adult or child, protection from clothing etc.), posture of the person upon impact or where on the body the impact occurs (chest and head is considered worse). For the purpose of this calculation the probability of the TOR UAV killing upon impact is estimated by the author to be 0.4, based upon interviews and literature study<sup>6</sup>.

Based on the aforementioned values the EFR calculation is as follows;

$$EFR = \frac{1}{100} * 1.13 * \frac{1}{6000} (1 - 0.0 + 0.0 * p_{pen}) * 0.4 = 7.53 * 10^{-7}$$

This calculation assumed a crash occurs as a falling object only affecting the area it impacts with; however, crashes could possibly occur as a “swipe” or horizontal motion covering larger areas in the region up to two meters above the ground, which would affect a standing adult person. Another element to consider is the fact that the  $p_{kill}$  factor was estimated based on the assumption that the impact is of a high velocity nature, which is not always the case as can be seen in Figure 4.4-3. According to (Johansen, 2016) the accepted EFR during NORUTs campaigns is 10<sup>-7</sup>, whereas for

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<sup>6</sup> Note that this number is a very rough estimate, and could possibly be a severe under- or overstatement depending on situation.

common manned aviation the target is  $10^{-9}$ . Based on this it is not unreasonable to state that the calculated EFR in this fictive scenario is within the limits of what is deemed acceptable.

It should also be noted that the previously calculated EFR only includes fatalities as a result of a loss of control event that causes an impact with humans on the ground (in this case the rescue operation participants). However, mid-air collisions can also occur which has the potential to cause multiple fatalities under the right circumstances. As we can see from the loss of control diagram presented in Figure 4.4-3, uncontrolled flight following a permanent or complete loss of control can cause impact with other aircraft, including manned aircraft. This is based on the assumption that the UAV will operate on a lower altitude than manned aircraft in all other circumstances.

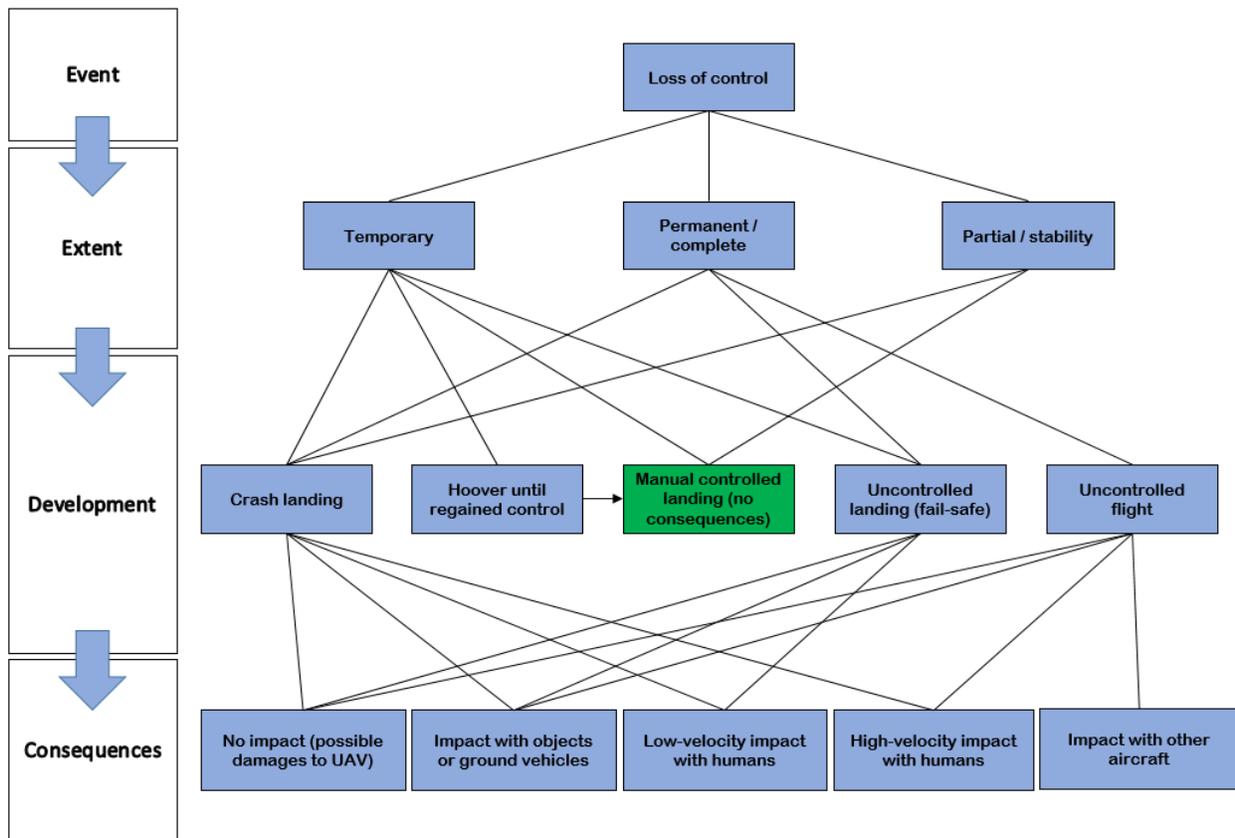


Figure 4.4-3 - Loss of control development

It is also possible to do a midair collision risk analysis, but this will not be executed in this thesis as it believed to be of little value and due the amount of unknown variables. If such an analysis was done is should be combined with the probability for an uncontrolled flight scenario, as it is believed that impact with other aircraft during controlled flight is highly unlikely as there are designated airspaces for manned and unmanned aircraft during a rescue operation as described by (Lorentsen, 2016).

#### 4.4.4 Discussion of the risk assessment

Due to the lack of any risk registers, accidents databases or statistics related to operation of relatively small UAVs the HAZID analysis in this chapter was done qualitatively, relying on the knowledge of interview subjects with experience from the industry. Following comes the risk matrix which was

done semi-qualitatively, which means that the qualitatively identified hazards are rated using quantitative values for consequences and probability, combined to express risk in a visual representation. EFR was also done semi-qualitatively as the quantitative parameters used in the calculation were gathered from a fictive scenario proposed by the author based on qualitative approximations.

As previously mentioned many of the identified hazards were “screened out” based on the RAC set for this thesis. During the review of hazards with a risk class  $\geq B$  several hazards were identified as likely to have an unrealistically high probability rating. Due to the “worst case scenario” approach of the qualitative risk assessment some hazards are given ratings that would only apply under certain unique operational circumstances. This is not necessary representative for an average operation, but is rather a statement of the lack of actual statistics and databases needed to properly assess and analyze the identified hazards using quantitative methods. Such an overstatement of risk could be related to the immaturity of the industry, whilst having a strong desire to be considered legitimate.

UAV impact with manned aircraft (especially helicopter during rescue operations) is an important topic to discuss. If the use of UAVs during avalanche SaR becomes widespread in the future, organization and management of the accident site is of utmost importance as it is likely for UAVs and manned aircraft to be working simultaneously. Typically, it is the accident site commander’s responsibility to manage the aerial resources during avalanche SaR. However, UAVs are a completely new asset and the challenges that comes with managing both UAVs and manned helicopters are not completely charted. This particular challenge should be accounted for, and could possibly require a reevaluation of the organization of an avalanche accident site as it is today.

Nevertheless, the hazards presented in Table 4.4-2 are not considered by the author to be ALARP, but as TRC are aware of them and are constantly striving to improve their platform, these identified hazards should not be a valid argument as to not implement UAVs as a SaR tool. By being aware of the most safety critical hazards and constantly improving upon their implemented barriers, a satisfactory safety level can be achieved for their operation. This is further underlined by EFR estimate which is within the accepted limits.

The increased risk for rescuers due to implementation of UAVs in avalanche SaR should be weighed against the added value of having it available, particularly in safety critical situations where there is a high risk for secondary avalanches. As all avalanche rescue operations carry an inherent risk for all personnel attending, it is not unreasonable to say that UAV applications that effectively limits the rescuers exposure time to hazardous situations is a valuable asset to the operation. However, if a UAV is used to remotely locate a victim several ethical challenges arises, as to whether or not rescuers should initiate a rescue which effectively endangers their own lives.



## 5 Conclusion

### 5.1 Capabilities of UAVs

It has been established through the work of this thesis that a small UAV platform will not be able to replace the manned helicopter in avalanche SaR. However, it was also identified that helicopters are not always available due to them being otherwise occupied or adverse meteorological conditions. Even though UAVs are not able to replace the manned helicopters, they can execute some of the helicopter functions with an equal quality. Established UAV capabilities as of today today are the use of electronic search devices and optical sensors to assist in locating victims, and also provision of aerial images which helps rescuers better assess risk on-site, thus allowing them to manage the accident site with increased situational awareness. Furthermore, if radar-based sensors such as GPR were fully developed and capable of identifying victims with no electronic search devices on their body, an airborne GPR system could likely reduce the locating time by a great amount for said victims.

As a resource for SaR, UAVs have a much higher availability than helicopters, especially considering that they can always transported to the accident area regardless of weather, and be airborne in a very short time if a suitable weather-window presents itself. The possibly invaluable information that can be gathered by an UAV during a short amount of time, in combination with the relatively low cost as compared to other rescue resources, should be an implication of the UAVs value to a rescue operation. When compared to a human rescuer, UAVs have the capacity to cover a much larger area in a short amount of time as it is not impaired by rugged avalanche debris, but moves effortlessly above it. Also, an UAV is not confined by a ground perspective.

Based on the statements above, it is not unreasonable to conclude that UAVs have the capabilities and capacity needed to provide some beneficial contributions to avalanche SaR. Even though smaller UAVs are somewhat sensitive to adverse meteorological conditions, their contribution is unique and an addition to the established rescue mission.

#### Summary:

- Technological challenges for UAV-assisted SaR with ATs and/or RECCO are almost completely resolved. There are some minor details to work out with positioning of underslung antennas, interference, HMI, degree of autonomy for UAVs etc.
- Battery technology is somewhat limiting, but satisfactory for preliminary applications
- Airborne GPR and location of victims using telecommunication devices both show promising results but requires more research to be viable
- UAVs cannot replace helicopters in avalanche SaR, but are likely to be a valuable supplement

### 5.2 Use of UAVs in avalanche SaR

At its current state, the implementation of UAVs as an avalanche SaR tool is not considered to increase a victim's chance of survival. This is directly related to the deployment time of rescue crews in remote areas. According to (Skjelbakken, 2016) ,based on his experience, the typical deployment time for a professional rescue crew in remote areas using a helicopter is at best 30-45 minutes due to response- and transportation times. Considering that the time needed to locate and excavate the victim is not

included, rough estimates indicate that only one in ten victims survives (Skjelbakken, 2016). This implies a 90% mortality rate for victims not rescued by companion rescue, which roughly correlates with Figure 4.2-3 when excavation times are included.

Deployment and excavation are considered the most time consuming phases during an avalanche rescue, both of which cannot be affected by the application of UAVs as of today. However, the search phase can be greatly elongated by dangerous-, large-, or multiple avalanches. All the aforementioned situations are likely to be better resolved by implementing an UAV as it can allow rescuers to assess dangerous areas before entering, or to enter with only with the UAV if conditions are perceived to be of an unacceptable risk to the rescuers. Because UAVs are likely to be more efficient in covering large areas, the search phase in large- or multiple avalanches can possibly be significantly reduced. However, it should be noted that UAVs are currently not capable of replacing humans when pinpointing and probing is necessary prior to excavation.

A concern for use of UAVs in avalanche SaR, but also in general civil applications, is the increased risk for humans on the ground. This is addressed during the course of this thesis, and evaluated using risk analysis methods. Preliminary findings do not indicate that the risk is increased by unacceptable levels for the case of Tromsø Red Cross, considering their intended use of UAVs for avalanche SaR. However, there is a great lack of quantifiable data and statistics available to support this claim. It is also important to consider the advantages of applying an UAV, as it simultaneously increases and decreases risk. Increased risk is caused by the UAVs operation in close proximity to personnel and other aircraft participating in the rescue, while the decrease is attributed to the opportunity of applying UAVs in rescues where the risk is unknown, or perceived to be unacceptable.

### Summary:

- Deployment of UAVs by professional rescue crews is currently too time-consuming to have any impact on the survival rate for avalanche victims in remote areas.
- During the risk analysis there were identified no hazards that posed an unacceptable high level of risk with respect to the current small-scale application of UAVs in avalanche SaR
- Application of UAVs can provide rescuers with a viable alternative for accessing an accident site where risk for personnel is believed to be excessive. However, remotely locating a victim under these circumstances has ethical ramifications for the rescuers

## 5.3 Facilitating the implementation of UAVs

There are a number of challenges before large-scale use of UAVs for avalanche SaR is feasible. The list below proposes some fields that could benefit from further research or work in order to better facilitate the implementation of UAVs as a state-of-the-art avalanche SaR resource.

- Standardization of; component and platform manufacturing, electronic search devices intended for UAV platforms and software development for UAVs
- More focus on commercial development of UAVs specifically intended for SaR applications
- Publicly available hazard register for UAVs and open exchange of information to allow for quantitative risk assessment
- Increased research in battery technology, collision avoidance and autonomous robotics

- An open dialogue between SaR organizations and the NCAA, and also an improved organizational framework incorporating UAVs as a SaR resource. This is especially important with respect to potential conflict between manned and unmanned aerial resources during a collaborative SaR operation

## 5.4 Concepts of future applications

A list of concepts for future applications of UAVs is mostly limited by the imagination, however some of the more interesting concepts in relation to avalanches are identified by the author and described in the following list:

- 1) Application of UAVs as an airborne platform for electronic search devices is not limited to avalanche SaR. An UAV equipped with RECCO, light-sensitive HD cameras, smartphone locating devices and IR cameras could easily contribute in SaR any time of the year. This could include, but is not limited to; onshore SaR for missing persons and maritime SaR following shipwreck accidents.
- 2) Traditional state-of-the-art methods for avalanche forecasting and snowpack monitoring are believed to be unnecessarily time consuming and expensive. Based on this statement and the progress in UAV- and sensor development, it might be beneficial to evaluate airborne remote-sensing for snowpack monitoring, which could provide better forecasting for avalanches. This is not only limited to snow, but also other geological surveys as addressed by (Smebye, 2016) during the ReCAMP workshop in Tromsø, 2016. Some sensor systems of interest are Synthetic Aperture Radar, GPR and Light Detection and Ranging systems. The latter can be used to create digital elevation models (DEM) and by overlapping different data-sets it is possible to estimate changes or movement in large quantities of masses, or to estimate snow depth.
- 3) In Norway it is not allowed to remotely trigger an avalanche using explosives from helicopters, as it is perceived to be too dangerous to transport both an ignition source and explosives simultaneously in a manned aircraft (Lied & Kristensen, 2003). The possibility to apply UAVs for this task could be considered as an alternative to manned helicopters, as they are likely to have sufficient payload capabilities, range and endurance for such as mission.
- 4) A small, portable and highly autonomous UAV which could be part of a mountaineer's personal equipage. Equipped with an AT or a RECCO system, it could greatly assist during companion rescue as it is capable of covering large areas relatively fast. A proof-of-concept has already been demonstrated by (Grauwiler, Gschwend, Leuzinger, Wyss, & Oth, 2010), but it needs to be further developed, and fully demonstrate its capabilities with respect to autonomy, HMI, cost-efficiency, robustness and portability.



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# **APPENDICES**



# Appendix 1

## Content: HAZID sheet

**Topic** Use of UAVs during snow avalanche search and rescue (SaR)  
**Prepared by** Andreas Albrigtsen  
**Date** 4<sup>th</sup> April, 2016

**Description** Application of a UAV during a snow avalanche rescue operation in the region of Northern Norway. Tromsø Red Cross – Search and Rescue – RPAS/UAV group. UAV is a hexacopter platforms with the following sensor equipment mounted on gimbal: IR and HD camera.

ID	Participant	Qualification	Contribution
KSJ	Kjell-Sture Johansen	<ul style="list-style-type: none"><li>▪ RO3 certified pilot (approx. 2000 hrs.)</li><li>▪ Lawyer/researcher at NORUT Tromsø</li><li>▪ Attended multiple campaigns in regions such as Antarctica, Spitsbergen, Greenland, Iceland, Finland and Norway</li></ul>	HAZID meeting
RS	Ronny Sandslett	<ul style="list-style-type: none"><li>▪ RO3 certified pilot with operational experience from SaR</li><li>▪ Responsible for the development, construction and maintenance for all UAV platforms used by TRC</li></ul>	Interview and review of HAZID sheet
VL	Viggo Lorentsen	<ul style="list-style-type: none"><li>▪ RO3 certified pilot with operational experience from SaR</li></ul>	Interview and review of HAZID sheet

ID	Category	Hazards	Probability (1-5)	Consequences (A-E)	Hazardous event	Controls or barriers	Comments	Responsible
1.1	Human	Pilot influenced by alcohol or narcotic substances	1	E	Inability to operate the UAV harming the rescue effort or loss of control during flight	Regulated in the internal OM and in the legal framework (paragraph 9)		
1.2		Insufficient piloting skills / training	3	C	Loss of control over the UAV, unaware of emergency procedures	Official UAV pilot training required as well as internal training as specified in the organizations OM		
1.3		Pilot fatigue	2	C	Wrongful decision making, loss of situational awareness and control of the UAV	Multiple pilots/operators available for service		
1.4		Pilot exposure to extreme operative conditions (pressure/stress)	3	C	Wrongful decision making, possible loss of situational awareness and control of the UAV	Several people responsible for the UAV operation; pilot, camera operator and spotter	Specified to pressure / stressful conditions for pilot	KSJ/AA
1.5		Loss of situational awareness	2	D	Loss of control over the UAV possible impact with humans or other aircraft	Several people responsible for the UAV operation; pilot, camera operator and spotter		
1.6		Human / machine interface misinterpretation	3	D	Misinterpretation of data and/or wrongful input of controls. Possibly causing loss of control or otherwise unexpected maneuvers	Training for HMI internally in the organization, as well as a well-developed machine interface / autopilot		
1.7		Exceeds operational limitations	2	B	Pressure to fulfill obligations of the mission can cause exceedance of operational limitations. This can lead to instability of changed aerodynamic properties of the UAV	Keep within the operational limits as stated in the OM. Pilot and operator make continuous assessments during the mission		
1.8		Incorrect input for flight plan	2	D	Impact with unanticipated obstacles or people possibly causing harm	Redundant check of flight plan and input / programming		
1.9		Communication failure	2	D	Temporary or permanent loss of control over the aircraft	Ensure that pilots/operators have necessary training and shared terminology, as well as a pre-flight brief		

ID	Category	Hazards	Probability (1-5)	Consequences (A-E)	Hazardous event	Controls or barriers	Comments	Responsible
1.10		Pre-flight check and technical procedures	3	D	Vital components / connection unchecked and fails, complete or temporary loss of control	Follow pre-flight checks as stated in the OM	Added hazard as advised by KSJ Time for pre-flight control may be limited during SaR operations	KSJ
2.1	Loss of propulsion	Exhausted fuel/power supply	2	D	Complete loss of control over the UAV, crash landing	Operate with sufficient safety margins	Especially important when returning home against the wind	KSJ/AA
2.2		Failure of motor	1	C	Emergency or crash landing	Multicopter with more than 4 engines can maintain flying capabilities to some extent with one motor failure		
2.3		ESC failure	3	C	Inability to control electrical motor RPM, uncontrolled descent / emergency landing	Regular maintenance and sufficient dimensioning and cooling of ESC	Added hazard as advised by KSJ	KSJ
3.1	Mechanical failure	Material defect (plastics in cold become brittle etc.)	1	C	Loss of control, or loss of equipment / sensors	Use materials with correct temperature rating	High grade UAVs are typically made with composite materials which are rated for very low temperatures	KSJ
3.2		Rotor detachment or failure	2	C	Complete or partial loss of control if during flight, emergency or crash landing	Ensure that the correct mounting momentum is used to avoid damaging attachment mechanisms		
3.3		Fire during flight	1	C	Emergency landing, possible loss of or damage to the aircraft	Inspection and maintenance of the UAV to identify possible battery- or other electrical damages.	Fire in ESC due to incorrect battery type has occurred	KSJ
3.4		Excessive payload	1	B	Instability during flight and lowered flight times	Ensure that the MTOW as stated in OM is not exceeded	Payload for TRC is static and tested	AA
3.5		Fabrication defect	1	D	Induced vibration or damages to the platform. Partial or complete loss of control if failure occurs during flight	Inspection and testing of new UAVs and parts		
3.6		Screws and other fasteners	2	D	Loss of equipment or vital parts of the airframe such as the engine mounts	Use screw fasteners and adhesives or safety pins	Actuator linkages has detached during flight due to vibration (no adhesive on bolts)	KSJ

ID	Category	Hazards	Probability (1-5)	Consequences (A-E)	Hazardous event	Controls or barriers	Comments	Responsible
							Electrical motor mounts are the most crucial part	
4.1	Communication failure	Interference	3	B	Temporarily or permanent loss of control	Hover activated until reestablished connection, return home function activated if not reestablished. Channel and frequency switching function on controllers has reduced impact of interference.	Channel and frequency switching was noted by KSJ	KSJ
4.2		Hacking / malicious attacks	1	E	Loss of control over the aircraft, can be used to cause harm to others	Use encoded communication systems	Highly unlikely and no safety barriers implemented for TRC	KSJ/AA
4.3		Power supply	2	D	Complete loss of control over UAV, autonomous flight and landing, or crash landing	Separate power supply with monitoring capabilities / alarms for communication		
4.4		Exceeding range	2	A	Uncontrolled autonomous flight and landing, likely temporary loss of control	Return home or similar backtrack function activated until reestablished connection	There could be issues with headwind on the return, where the UAV does not have enough energy available to return.	KSJ
4.5		Exhausted battery in RC ground unit	1	B	Uncontrolled autonomous flight and landing	Hover activated until reestablished connection, return home function activated if not reestablished. Additional batteries should be available		
4.6		Complete loss of communication	1	B	Uncontrolled autonomous flight and landing	Return home function activated. Contact with local flight control authorities, and have emergency procedures in place	This hazard was added by KSJ	KSJ
5.1		Mid-air collision	Wildlife / birds	2	B	Bird-strike causes temporary or permanent loss of control or damages to the UAV	Operator is aware of surrounding and wildlife. Lands the UAV if wildlife become a nuisance	There are previous incidents of birds attacking UAVs in the air. Accidental bird strikes could also happen
5.2	Manned aircraft (helicopter)		2	E	Damages to the UAV and possibly devastating damages to manned aircraft, with severe third-party liability	Airspace segregation in vertical and horizontal direction and designated areas of operation	Coordinated by ATC and/or accident site commander for SaR operations	

ID	Category	Hazards	Probability (1-5)	Consequences (A-E)	Hazardous event	Controls or barriers	Comments	Responsible
5.3		Manned aircraft (airplanes)	1	E	Damages to the UAV and possibly devastating damages to manned aircraft, with severe third-party liability	Airspace segregation in vertical and horizontal direction and designated areas of operation	Coordinated by ATC and/or accident site commander for SaR operations	
5.4		Unmanned aircraft	1	C	Damage to the UAV as well as third-party liability issues	Airspace segregation in vertical and horizontal direction and designated areas of operation	Experience from flight in shared airspace with other UAVs illustrates that the probability for impact is very low	KSJ/RS
5.5		Vegetation	2	B	Damage to UAV	Avoid flying in areas with heavy vegetation, especially in heavy wind / turbulent conditions	Vegetation absorbs most of the energy, and low probability for impact with persons afterwards	KSJ
5.6		Overhead Powerlines	3	B	Damage to the UAV as well as third-party liability issues	Avoid flying unnecessarily close to powerlines, especially in heavy wind / turbulent conditions	Powerlines can be very difficult to see for UAV pilot, especially during FPV flight	KSJ
5.7		Other structures	2	B	Damage to the UAV as well as third-party liability issues	Avoid flying unnecessarily close to structures or ground vehicles, especially in heavy wind / turbulent conditions		
6.1	<b>Battery failure</b>	Overheating	2	B	Battery explosion or fire	Correct maintenance and dimensioning of the battery pack		
6.2		Wrongful use (charge/discharge)	4	B	Severely reduced battery life, possibly reduced capacity	Charging process described in maintenance section of OM is followed. Dimensioning of discharge capacity should be sufficient. Discharge below 25-30% is avoided	TRC is aware of misuse and is a calculated battery maintenance strategy	VL/RS
6.3		Physical damage	1	A	Battery explosion or fire, permanent damage to the battery	Keep battery protected during transport and use. Check for damages before flight and charging.		
6.4		Lower than expected capacity due to cold	4	C	Inability to complete mission or return home, emergency or crash landing	Pre-heating of battery packs, flight mission planning with large safety margins		

ID	Category	Hazards	Probability (1-5)	Consequences (A-E)	Hazardous event	Controls or barriers	Comments	Responsible
7.1	Operative conditions	Icing on aircraft	2	B	Instability during flight, reduced aerodynamic performance and in extreme cases loss of control	Heating of vulnerable parts / components, or other de/anti-icing equipment. Otherwise do not fly during icing conditions, continuous evaluation by pilot/operator	Not conceived to be a hazard for TRC, and no barriers are implemented	VL/RS
7.2		Icing on vital instrumentation or sensors	2	B	Ice obscuring visual conditions for the pilot during BLOS FPV flight. Loss of control or unusable data	If icing is detected avoid icing conditions (i.e. altitudes/areas), or cancel mission		
7.3		Extreme cold (pilot)	3	B	Decreased agility in hands and slight loss of situational awareness	Correct clothing and protective RC muffs		
7.4		Lightning storms	1	D	Damages to UAV, complete loss of control likely	Avoid flying during this condition, continuous assessment made by pilot/operator	Highly unlikely, no barriers present	
7.5		Heavy wind	3	C	Inability to fly or return to designated area, emergency or crash landing	Fly the UAV within wind limitations suggested by manufacturers or as stated in the OM. Land if excessive wind, continuously monitored on-site by pilot/operator		
7.6		Precipitation	4	B	Short-circuiting of electronics causing loss of control	Protection and coating of electronic components. Precipitation amount and direction assessed on-site by pilot/operator		
7.7		Topography induced wind deflection and turbulence	4	C	Sudden wind gusts causing temporary or complete loss of control over UAV,	Avoid flying in areas with micro topographic climates causing rapid changes of wind. Conditions assessed on-site by pilot/operator		
7.8		Fog or other factors obscuring visibility	2	D	Pilot is unable to navigate possibly causing loss of control, also other aircraft are not able to see the UAV			
8.1	Assembly and take-off	Assembly is difficult or harmful to the operator due to operative conditions	2	B	Possibly frostbite for assembly personnel	Designed as a modular system with focus on easy assembly that can be done with protective clothing		

ID	Category	Hazards	Probability (1-5)	Consequences (A-E)	Hazardous event	Controls or barriers	Comments	Responsible
8.2		Unintended contact with the rotors during manual or autonomous take-off	1	C	Human injury	Maintain proper distance during take-off phase until the UAV is disarmed. Mechanical shielding or foldable propellers can limit damage		
9.1	Landing	Unintended contact with the rotors during manual or autonomous landing	1	C	Human injury	Maintain proper distance during landing phase until the UAV is disarmed. Mechanical shielding or foldable propellers can limit damage		
10.1	Electrical and primary sensor failure	Gimbal failure	2	B	Inability to navigate efficiently and/or provide its necessary functions	Maintenance plan for gimbal		
10.2		GPS failure	2	D	Partial or complete loss of control over the UAV, possible emergency or crash landing	Continuous inspection and maintenance of the unit		
10.3		RC failure	1	B	Loss of direct control, autonomous landing	Automatic activation of return home function		
10.4		Altimeter failure	1	A	Redundancy in system, GPS altitude can be used	Redundancy in system (GPS altitude, altimeter, and accelerometer with z-axis measurements)	Redundancy as explained by KSJ	KSJ
10.5		Failure of FPV camera during BLOS	2	C	Inability to navigate FPV	Several other optical sensors available, or activation of return home function	Specified to BLOS	AA
10.6		Autopilot failure	2	E	Aircraft unintentionally moves during loiter or does not follow the pre-programmed routing, or the pilots' instruction. Possibly complete loss of control over UAV causing impact with other aircraft or crash landing	Use of well-tested autopilot system, with updates for bugs and faults	Following a new firmware release of autopilot systems, one should wait a while before updating until bugs are identified and patched	KSJ
10.7		Faulty wiring	2	D	No redundancy in vital wiring, possibly complete loss of control and lift if failure	Pre-flight checks and a good maintenance regime to identify need for repair		

ID	Category	Hazards	Probability (1-5)	Consequences (A-E)	Hazardous event	Controls or barriers	Comments	Responsible
11.1	Restricted areas or airspace	Too close to airdrome	1	E	Possible impact with other air-traffic and likely to have legal repercussions	Follow regulations from NCAA and internal OM regulations. Geofencing is possible	All these situations would occur due to procedural failures	KSJ
11.2		Over military areas	1	E				
11.3		In restricted airspace	1	E				
12.1	Environmental	Excessive noise	1	A	Wildlife could be disturbed	Maintain distance to wildlife as far as reasonably possible	2-stroke RC engines has been used in immediate proximity to penguins without disturbance	KSJ
12.2		UAV platform is lost and not located	2	C	Surrounding nature can be exposed to hazardous materials / chemicals over time	Use environmentally friendly materials to a practicable extent		
12.3		Incorrect disposal of UAV causing harm to the environment	1	B	Environmental damage due to hazardous materials / chemicals	Dispose UAV and related parts / products correctly		
12.4		Incorrect storage of batteries causing harm to humans	2	C	Humans exposed to hazardous materials / chemicals / fumes	Follow maintenance plan as suggested by manufacturer and OM		

## Appendix 2

### Content: Interview with Tromsø Red Cross (TRC)

**Topic** Use of UAVs during snow avalanche search and rescue (SaR)  
**Prepared by** Andreas Albrigtsen  
**Date** 4<sup>th</sup> April, 2016

**Description** Establishing the current organization of TRC, and how they intend to implement a UAV into their snow avalanche SaR operations

ID	Interview Subject	Date	Description
TAS	Tor-André Skjelbakken	26.04.2016	<p>He is a trained as the head of the avalanche rescue group, and shares this position with 14 other people. During their on-call period there are 3 people available, one week at the time. He has been involved in avalanche rescue operations since 1979, and his first avalanche rescue was in 1981. Currently he is employed as an engineer at UNN.</p> <p>The interview was conducted in his office. TAS contribution was mostly regarding description of the rescue operation and organization, as well as some input on operational conditions and his visions for the application of UAVs in avalanche SaR. The entire interview was recorded and transcribed with emphasis on retaining the wording.</p> <p><b>Interview location: UNN Tromsø</b></p>
VL	Viggo Lorentsen	18.03.2016 02.05.2016	<p>VL works in the Building and Property Management branch of UIT, and is a core member of the Tromsø Red Cross SaR RPAS team. He is a certified operator (RO3) and has attended several SaR operations where a UAV system has been used.</p> <p>The interview was conducted at a local café, where VL was accompanied by RS. As RS is the constructor of the UAV system currently employed by TRC, the interview revolves around drone specifications and applications in the field. Both VL and RS has a wealth of experience with RC equipment and SaR operations in TRC, and their knowledge around the use of UAV systems is very valuable, as they design their own systems and they are tried and tested in harsh weather conditions.</p> <p><b>Interview location: Eide Handel Café</b></p>
RS	Ronny Sandslett	02.05.2016	<p>RS works as a computer engineer for Geoservices, Stavanger, Norway. He is a member of the Tromsø Red Cross SaR RPAS Team, and a certified drone operator (RO3). He is also a RC model enthusiast, and has decades of experience as a UAV operator. He has also attended a campaign to the west ice to operate UAVs for NORUT.</p>

## **Section 1 – Description of the rescue operation**

### **1. How many participants are there in an average rescue operation, and from what organizations?**

- i) Varies greatly from 15-20 to 2-4 persons, all depending on available resources, mode of transportation and so on.

### **2. Who is typically the first on the scene?**

- i) It is very common for there to be other members of the group that was caught in the avalanche, to be on-site performing companion rescue if they are unharmed. Of the organized rescue crews, it can vary greatly. Helicopter crews from Evenes and Tromsø are very well trained and equipped, and if the operational conditions permit it, they are always in the air and typically the first on-site. The helicopter crew consists of a rescuer who is trained as a head of avalanche rescue, as well as medical personnel with experience from avalanche SaR. The helicopter based in Tromsø has a capacity of 3 crewmembers and 2 passengers.
- ii) When a rescue operation is put in motion there is a lot happening at once, where crews in cars are dispatched immediately as well as helicopters if they are available and the weather allows it.

### **3. What is the average size of a rescue area during an avalanche SaR operation? (Answer is intended to establish the area and number of participants in order to calculate population density during rescue operations)**

- i) This also varies greatly. A large avalanche can be 200 meters wide and 1 km long, and there are smaller slides that can be 50 meters wide and 200 meters long. The search area at the bottom of the slide also varies a lot, such as the avalanche at Svalbard, December 2015, where there were several houses affected.

### **4. Explain - What is the traditional way to conduct a search for potential avalanche victims?**

- i) Firstly, it is important to get an overview of the situation and start a “hasty search” to locate persons or belongings at the surface of the debris. From a technical standpoint it is possible to use IR and HD cameras mounted on a drone to make the search more effective. IR traces heat signatures of a potential victim, and the HD cam provides an overview and helps locate items in the surface as they tend to be of high contrast compared with the snow. Victims are often located on the surface. During this stage of the search AT and RECCO is used as well to identify possible signals from electronic devices.
- ii) The next stage is what is called a “scuff search” where the rescue crew forms a search line spaced by an arm’s length, and has a more structured approach. During this stage it is also common to do point searches around terrain traps such as trees and rocks.
- iii) The third stage is search lines with probing.

### **5. How often are avalanche rescue dogs used and is there any risk for interference with drones and vice/versa?**

- i) Avalanche rescue dogs are almost always attending rescue operations. Drones does not have any impact on the efficiency of the dogs due to neither smell nor noise, as they are used to work when helicopters are present which comparatively is a much larger disturbance.

### **6. How do you currently assess the risk for secondary avalanches before entering an area? Has any rescue crew in Norway ever been exposed to secondary avalanches?**

- i) The attendants of an avalanche SaR operation have extensive knowledge of avalanche danger prior to the rescue. When they enter an area they already have a general perception of the levels of danger the specific area has. The head of the rescue operation keeps track of avalanche danger, and weather prognosis to estimate the risk and to be prepared and well-informed. Before entering the avalanche debris, assessments are done on-site, to establish the risk levels for the rescue crew.
- ii) If an avalanche is triggered by a skier, the avalanche danger is defined as human triggered avalanche possible. If an avalanche is naturally-triggered, then that is the current avalanche danger level. In 1971 an avalanche killed seven people in Molaupen, Sunnmøre. The majority of the victims were part of the rescue crew who were caught by a secondary avalanche.
- iii) Secondary / multiple avalanches can also cause confusion as to which avalanche the victim was caught by. There are several incidents where the rescue crews have been unsure as to what is the correct avalanche, some of which are Røddbergtinden, Lyngen and Ringvassøy, Troms

**7. *How does a victim move in the snow masses of an avalanche? Where are victims most commonly found, and what influences their location in the space of avalanche debris?***

- i) This is impossible to determine exactly and varies with several parameters. Victims are typically found in terrain traps, or at the end of the avalanche debris flow. Deeper burials result in longer search times as well as longer rescue times (excavation of the victim). For straight avalanche paths, if there are tracks, the path of a victim can be estimated. Observations by possibly other party members can also be valuable in order to estimate location of the victim. Curves in avalanche paths can be a terrain trap for victims (as described in Henrikskaret, Ramfjord incident)

**8. *In which types of avalanches are UAVs likely to be most useful for SaR?***

- i) In “normal” avalanches the victims are typically located before a UAV can be deployed. However, in “difficult” avalanches UAVs are believed to possibly provide benefits. Difficult avalanches are typically large-, multiple- or dangerous avalanches.

**9. *What is the order of prioritization regarding what equipment should be used to search? Dogs? Avalanche transceivers? Manual search? RECCO equipment?***

- i) Avalanche rescue dogs are very high priority, and they attend most of the rescues. If the victim is wearing a RECCO reflector or AT it is highly efficient to use electronic search devices. Of course, hasty search and electronic devices can be used simultaneously, which make them highly efficient, and these techniques should be used in collaboration with the dog team.

**10. *How often do the victims use electronic devices for avalanche SaR? How often do they have cell phones on their person? What about RECCO tags, are the corresponding search devices often used?***

- i) The rescue crew ALWAYS use both RECCO and AT, and as victims often are mountaineers they tend to have this equipment as well. ATs are primarily for companion search as they do not require a special device like RECCO. However, the ATs are not operating on an optimal frequency (which was standardized years ago, chosen due to low cost), meaning that they are not as efficient as they theoretically could be (too low frequency). The RECCO system is more directional and precise, which means that – in most cases, if you get a signal you have a confirmed location. These two devices do not interfere with each other, and the RECCO search system can also locate ATs at standard frequency.
- ii) Almost every avalanche victim had a cell-phone on their body when they were located, meaning that they could potentially be located by Wi-Fi signals or Bluetooth. RECCO tags are used by many of the victims, and has been used as a locating device for several rescue operations.

**11. Is it difficult to move over the avalanche debris?**

- i) It varies greatly with the composition of the snow masses. Sometimes the avalanche debris is very dense and it is possible to walk on the surface without even leaving footprints. Other times one may be waist-high in power snow, with slabs and possible cracks underneath making it impossible to move in the debris (this was the case during an avalanche search in Kroken, Tromsø)

**12. What is – in your opinion – the most effective search tool you currently have at your disposal?**

- i) For companion rescue the ATs are without a doubt the most efficient tool for locating a victim. From a pure technical standpoint, the RECCO system is at least as good as the ATs, however this system is only deployed with organized rescue services, meaning that the deployment is too late to be a life-saving device.
- ii) For large alpine parks where there is a high population density and professional rescue crews on standby, the RECCO system is a very good option, as it is deployed rapidly and used by trained personnel. There have been some successful finds with RECCO in the 2016 season in the European alps. Most of the skiers and snowboarders in the alps do not use AT in the prepared slopes, but they unknowingly have RECCO reflectors in their clothing.

**13. How do you predict where to search for potential victims if there are no indicators? What about when there are indicators? What kind of indicators could be used to guide the search effort?**

- i) The best place to look is where you believe a victim might be. (TAS draws an illustrative sketch of an avalanche) Areas around rocks and trees commonly stop avalanche victims in their path and can be good places to start. Other indicators might be tracks that enter the avalanche path, which in turn allows for estimation of the victims' path. When there are no indicators of where the victim might be, and he or she is not wearing electronic search devices, the locating process might take several days (as the slide in Tromdalen, Senja in March, 2013). Devices such as GPR can be used to help locate victims if they are buried deep or have AT or RECCO on their person.

**14. How often are the victims rescued alive by professional rescue operations (as compared to buddy rescue etc.)? Could the implementation of UAVs influence this statistic?**

- i) When the victim is located and dug out by the professional rescue crews, the result is fatality in 90% of the rescues, meaning that approximately 10% of the professional rescue operations actually locate a victim alive.

**15. What is the average rescue time for a rescue crew? Best- / worst case scenario?**

- i) It is impossible to state an average rescue time, at least not for the northern part of Norway where most of the rescue operations are in remote areas, and there are a lot of factors that has an impact on time. Weather, available resources, remoteness of area etc.
- ii) Two examples from 2015, one in Nordreisa, snowmobiler missing, bad weather with snow and wind. As it was unclear when the avalanche had been released it is difficult to estimate time, but the entire rescue operation lasted around 6 hours before locating the victim. The other one was at Fastdalstinden, Lyngseidet. Weather conditions were good, and the time was about 12.00-13.00 so there was still some light (February). The victim was located on a depth of around 2.5 meters. Response time for this incident was around 30-45 minutes, location and excavation of the victim took about 1 hour, and the entire operation about 2 hours in total. However, in both cases the outcome was fatal for the victims.

## Section 2 – Operational conditions

**16. What type of weather causes the highest elevation in avalanche probability?**

- i) Longer periods with precipitation and wind, or periods with increased temperatures during late winter.

**17. Have you seen a trend in the most common weather conditions rescue operations are most likely to be needed?**

- i) One can say that longer periods of wind and snow causes buildups of snow deposits. When the weather improves, following this period, people wish to go out and enjoy it. It is therefore common that rescue operations are needed in periods of fairly good weather. However, there is an increasing trend in the past few years, where people tend to go out skiing in increasingly bad weather, as well as during periods of darkness, which makes rescue operations more difficult.

**18. Is bad weather a large disruptive factor when considering UAV-assisted rescue, and what are the limitations for TRCs UAV platform (wind, rain and snow)?**

- i) Wind conditions is limited at 10 m/s in the OM, however flight in higher wind speeds is possible and has been tested in a controlled environment. Gusty winds and turbulence are a specific problem, which the operator must take into consideration on site, before and during the operation. The performance of the UAV depends greatly on configuration and design of the UAV. Heavy precipitation in the form of both rain and snow, can cause issues with electronic failures and poor visibility for the operators. It is possible to fly in such conditions as the UAV is designed for precipitation, by coating all electronics with a clear plastic film which protects against water.

**19. Is the platform vulnerable, and are there any measures taken to prevent adverse effects of weather?**

- i) As mentioned all electronics are coated with “liquid tape” a thin and elastic plastic film, which protect against precipitation and moisture that can cause short circuiting or malfunctioning. Also, there is a Lexan (polycarbonate) dome mounted on top of all the most vulnerable electronics which is strategically placed on the top of the UAV. All secondary sensors are water-proof by themselves, but are further protected against moisture and fall damage by 3D-printed capsules made of plastic. Screws and bolts can loosen in cold conditions and are therefore secured using “Loctite” glue, which secures screws and bolts in place.

**20. Are there issues with operation in the dark? If so, how are they solved? Is there external lighting? Can this possibly restrict the use of UAVs?**

- i) It is possible to operate the UAV using Virtual Reality (VR) Goggles for FPV flight in combination with the IR camera or a camera with high light sensitivity. IR lighting is also a possibility for illuminating the ground, but the response of the FLIR camera is unknown.

## Section 3 – Helicopters in avalanche SaR

**21. How often do helicopters provide any benefits to the rescue operation, and what benefits do they most commonly provide?**

- i) When the rescue crew enters the area with a helicopter they usually circle around the area to get an overview of the avalanche debris, and potential indicators for risk of secondary avalanches. They assess if there are any masses of snow or ice still lodged in the mountainside that could potentially harm the rescue crew. This is considered the most important contribution of a helicopter.

- ii) Transportation with helicopter is also an asset, as it makes it easier to quickly get more manpower into the area. However, the helicopter available in Tromsø has a limited carrying capacity.
- iii) Helicopter can also be used to illuminate the rescue area, but this has to be evaluated as opposed to use it for transportation of additional manpower.
- iv) As electronic search devices are obligatory for all helicopters participating in an avalanche search, they naturally provide a more rapid coarse search of the area using RECCO and AT. If a signal is identified a marker is dropped for a more detailed search / probing.
- v) All their experiences made with helicopter-based searches imply that it is a valid tool for avalanche SaR. All rescue helicopters and ambulance helicopters are required to have AT and RECCO systems onboard, due to their high efficiency in avalanche SaR. A smoke grenade as a marker was deemed unfit, as the downwash from the rotors extinguished the grenade, therefore they currently use a weight with plastic ribbons attached.

**22. How important are helicopters for the rescue operation? Is it often that helicopters are wanted but not available for use?**

- i) Helicopters are used in almost all rescue operations for avalanche accidents, but are sometimes not available, or they are limited by operational conditions such as heavy snow, fog, darkness, wind etc.
- ii) Sometimes the helicopter can transport the crew in to start the search, and may not be able to return due to (often minor) changes in operational conditions such as wind or precipitation.

**23. Does the presence of a helicopter have any impact on the organization of the rescue operation?**

- i) As a rescue operation can be chaotic and people are eager to assist in the search, there can be hazards in relation to interaction with helicopters and snowmobiles.
- ii) There is no risk for the helicopter to trigger avalanches as the energy in the soundwaves is too low. This has been documented and there are reports available on this subject.

**24. What operational parameters can make use of helicopters difficult?**

- i) Snow, wind, precipitation etc.
- ii) Lighting conditions can also often prove to make use of helicopters difficult as contours in the ground can be hard to spot.

## **Section 4 – Use of UAVs in snow avalanche SaR**

**25. How does the SaR effort today benefit from the application of a UAV?**

- i) The TRC RPAS group has not attended any avalanche SaR operations, but have attended 15 regular SaR operations where they have been called upon to help locate victims. During some of these operations the UAV has provided positive results, and shown itself as an asset.

**26. What are (in your opinion) some of the potential future applications for UAVs in SaR for avalanche victims?**

- i) One of the greatest potential of UAVs during avalanche SaR, is to use it to distribute overview pictures or live-feed footage to the rescue crew that are not yet on site. This is done to help prepare and assess the situation before they enter the area. This could be particularly helpful in steep terrain and gulches, where aerial photos or video could greatly benefit the operation (Henrikskaret,

Ramfjord). When the crew is in the avalanche debris, it is difficult to get an overview. Use of UAVs for this is interesting for ALL avalanche accidents.

- ii) If there are multiple avalanches a UAV or helicopter equipped with electronic search devices can cover ground much faster than the rescue crew on foot.
- iii) When powder snow avalanche debris are difficult to move through a UAV could likely be of great help as it would locate potential signals very quickly. An example is the avalanche in Kroken, Tromsø where there were large blocks covered with fine powder snow which made movement in the area very difficult.
- iv) An important note for dangerous avalanches, is if a UAV is used to locate a person buried. Such a situation can cause the rescue crew to become reckless and overeagerly enter an area with high avalanche danger, putting themselves at great risk.
- v) The goal of the rescue operation is to spend as little time in the area as possible, as there is always an inherent risk of being there. The perceived benefit of drones is in large-, multiple- and dangerous avalanches, and if a drone could reduce the time for these rescue operations, it would be an asset.
- vi) VL identified to possible uses for UAV to contribute during an avalanche SaR operation, which is electronic search devices and overview imagery in particularly dangerous operations such as terrain traps with high probability for secondary avalanches. Another use could be for improved pictures for reporting of avalanche accidents, which could provide valuable information for future research.

**27. How often does the weather allow for UAVs to be used during search? Is there a benefit with drones and the “weather window” during squalls?**

- i) There have been several occasions when helicopters could not participate in the rescue effort due to bad weather or other factors. As drones can be quickly deployed they can exploit small changes in the weather to provide some of the services that a helicopter can, the most important one being aerial images for overview.
- ii) Some drones are so cheap in design and payload package that they are considered “expendable” during a SaR operation. These systems can be used in harsh weather under the presumption that they will be lost.

**28. How is the drone transported to the avalanche area? Is weight and portability an issue? What would – in your opinion – be the most effective way to transport the UAV?**

- i) The complete UAV system is transported in a crate containing all necessities, which is protected against weather and impact damage. The common method on ground is transportation by snowmobile. Aerial transportation in ambulance helicopters as first responders has also been discussed as a possibility. This is however, at the cost of capacity for other rescuers as the helicopter used today has limited personnel capacity. The UAV itself is relatively light as well as portable seeing as the arms can be folded back to fit it into the crate. Transportation with helicopter is considered the most efficient way, but the usefulness of the UAV must outweigh the drawbacks of transporting one or two pilots occupying capacity in the helicopter. The UAV operators must also be easily available for pick up immediately after the avalanche alarm is sounded.

**29. Are your UAVs currently being applied in actual rescue operations? If not; why, and what needs to change in order to integrate them?**

- i) UAVs are currently being applied in SaR operations, and has attended 15 missions. However, none of these were related to avalanches.

**30. How often would a UAV (in the current organizational state) arrive on time to be a useful rescue resource?**

- i) One of the problems when using an UAV in an avalanche rescue operation is to get it to the search area rapidly. If it is to be of any use for the rescue crew, it must arrive on-site with the first responders. Qualified personnel must also be on site, to operate it safely. If a UAV is deployed with the helicopter crew, there is limited space for operators, as bringing along a designated UAV crew would mean sacrificing some of the rescuer spots, which is not a preferred choice.
- ii) Another alternative would be to have a completely autonomous UAV, that could operate unsupervised alongside the rescue operation.
- iii) VL and RS agrees that the application of a UAV system in avalanche SaR is very unlikely to contribute to a point where it helps to save lives, at least when it arrives at the same time as the professional rescue organizations.

**31. How long does it normally take to locate victims? Is it possible to improve this time by using drones?**

- i) If the victim(s) are wearing electronic search devices the locating process is very quick. However, as previously stated, UAVs might prove themselves useful in situations where the search area is very large, there are multiple avalanches or the secondary avalanche risk is believed to be high.
- ii) Opposing the implementation of a UAV is the fact that it is only believed to be of help during the search-phase. The entire operation could be summarized as: establishment-phase (unknown amount of time), search-phase (5-10 minutes), pinpointing-phase (5-10 minutes) and excavation (5 minutes – 2 hours). This means that the increase in search efficiency would have minimum impact on the total operation time, and therefore provide minimal benefits with respect to locating the victim alive.

**32. Is it common with a high amount of obstacles in the search areas (in the space immediately above the ground and 5-6 meters up in the air), or does the search areas generally consist of open terrain?**

- i) This varies greatly, but obstacles such as trees could potentially cause problems. A common problem during low flight over avalanche debris is the inclination of the ground.

**33. How many persons are needed to operate an UAV efficiently?**

- i) The TOR platform is designed to be operated by two persons, one that controls the aircraft itself, and one that controls the sensors (in this case IR, HD and zoom cameras). It is possible to operate this platform with only one person, but it would be much less efficient. TRC RPAS usually have 3 operators for TOR, where there is one pilot, one sensor operator and one “spotter” which only pays attention to the surroundings of the UAV keeping his eyes open for aircraft in the area or other potential dangers.

**34. Are there any issues related to operation in cold environment?**

- i) Live tests in -10° Celsius have been conducted with no drawbacks identified. The machine itself has been cooled to a temperature of -23° Celsius and flown immediately afterwards, where problems with the 3D Robotics Pixhawk Flight Controller was identified. In very low temperatures the controller would not arm for flight due to the cold. This was fixed by micro soldering a resistance over a capacitor in the flight controller, which has been documented to work.
- ii) For the operators cold can affect the fine motor skills, and TRC uses a specially designed muff which houses the radio controller.

## **Section 5 – Compliance to regulations**

### ***35. Are the current regulations for UAV operations restricting the current use of drones in rescue operations?***

- i) The primary issue with the new regulations are high costs due to certificate fees which are very costly for a voluntary organization with limited funding. There is some discussion with the NCAA to remove this fee for voluntary organization providing a civil service. Training of new operators is also an issue, but of course identified as a necessity. The training consists of an online course and an official examination, followed by an internal training program specific to the UAV used by TRC.

### ***36. After the new regulations in 2016, did you have to downsize, or otherwise make changes to your drone or organization to accommodate these changes?***

- i) There were no changes necessary to accommodate the changes in regulations.

### ***37. What is the current certification of your drone pilots? Under what class does your drone operate? R02 or R03?***

- i) TRC still operates under their license from 2015, which is valid for a two-year period, meaning that they are not yet affected by the new regulations of 2016. Renewal of their license mainly depends on economic challenges, and they have to assess their needs for a R03 license. Currently, they frequently exceed one kilometer flight range, which means that a BLOS

### ***38. Is your operation manual available for assessment?***

- i) Yes, sections can be made available for use if needed. However, the production of an Operation Manual (OM) is time consuming, and is therefore not openly shared. It is discussed internally in the national division of Red Cross whether or not the OM produced by the Tromsø branch for RPAS operations, could be used as a standard for all sub divisions that wish to use UAVs in SaR context. The OM currently in use is valid for a 2-year time period, meaning that it is outdated with respect to the new regulations that took effect on the first of January, 2016. It is likely that the risk analysis section of the OM will have to be revised in order to gain new certification for operations.

### ***39. Is it possible to get a permit to operate on military frequencies for extended range and improved bandwidth? What bandwidths are used for your operations today?***

- i) Currently the 2.4 GHz and 5.8 GHz frequencies are used for RC communication, and this works well in practice. For longer range 433 MHz and 1.3 GHz has been used, but this is a direct conflict with other non-profit organizations such as Norsk Radio Relæ Liga (NRRL) which often attends SaR operations. For telemetry purposes the 433 MHz frequency is actively used.
- ii) For multicopter purposes the frequencies available are sufficient as they have limited range capabilities. Flying a multicopter at 2 kilometers range is considered a relatively long flight. In general, higher frequencies provide higher data transfer rates but shorter ranges, and vice versa.

### ***40. How do you currently operate the UAV? VLOS, EVLOS, BLOS?***

- i) The UAV is operated differently depending on the missions. In close proximity missions, it is flown VLOS typically with a spotter present. EVLOS is not used, as it is easier to fly FPV during BLOS operations. When flying FPV they have the options of flying with VR goggles or on screen, where the latter is the most preferred method for VLOS operations as it is simpler to maintain control of the UAV. During BLOS the VR goggles is the preferred option. If the UAV is operated FPV using the IR camera, VR goggles is preferred due to the additional darkness.

## **Section 6 – UAVs as a disruptive device**

**41. *If there is a helicopter present, how often do they actively participate in a rescue operation? (Electronic Search Devices). Is there a possible conflict between a helicopter and a UAV? Is there a clear communication between the helicopter pilots and potential drone pilots?***

- i) All helicopters that are used in avalanche SaR operations are equipped with electronic search devices (AT and RECCO), as it is mandatory. It is not uncommon to conduct a coarse search with the helicopter (if available) to locate any signals quickly.
- ii) If there is a helicopter in the airspace in close proximity to the UAV there needs to exist a physical barrier (visible on the ground) that separates the designated areas for the two aircrafts. A bridge, road or otherwise recognizable barrier can be used to separate the designated areas of operation. However, UAVs shall always give right of way to manned aircraft. During SaR this is all coordinated by the accident site commander, which is in direct contact with all participating organizations as well as the local control towers for aviation. It is also possible to use Geofencing in order to maintain a controlled area in which the UAV can operate in.
- iii) For TRC the ambulance helicopter, military helicopter and overhead powerline inspection helicopters are the main concern, as they operate at low altitudes. However, as helicopters approaches the UAV pilots/operators can hear them and safely land or otherwise give way for the helicopter in good time before it passes.

## **Section 7 – Organizational challenges**

**42. *How is the RPAS rescue team organized?***

- i) The RPAS group is a sub-division of TRC. All sub-division of the Red Cross are alerted du the police depending on need during SaR operations. For avalanches this is primarily sub-division such as avalanche, snowmobile and ATV transport etc.

**43. *Are the participants from different organizations, and could this cause communication issues?***

- i) As previously stated the accident site commander is in charge of communication and coordination of the rescue effort. When the RPAS group arrives they contact the accident site commander to authorize any activity.

**44. *Which organization should be responsible for UAV SaR?***

- i) To achieve best possible results, the RPAS SaR branch could possibly benefit from being a standalone organization which were contacted directly by the police for participation in SaR operations.

**45. *Is funding a major concern for the UAV/RPAS branch of TKR?***

- i) This is the main barrier for future progress of the RPAS group as much of the equipment is expensive. Some of the equipment is experimental and might not even be applicable, but still investigated.

## **Section 8 – UAV platform description**

**46. *Size (diagonal rotor base)***

- i) 960 mm as indicated by the name of the UAV frame (Tarot T960).

**47. *Weight and MTOW***

- i) The UAV itself weighs 6.5 kilograms, and MTOW is set to 10 kilograms in the OM. The UAV was tested with a AUW of 11 kilograms, and is according to RS, designed for even greater payloads.

**48. Payload capacity**

- i) 3.5 kilograms if the OM is followed regarding MTOW. Although there is a capacity for greater payloads, it is avoided as it severely limits the flight times.

**49. Battery specifications**

- i) A set of two 10000mAh 6S 10C LiPo Battery packs

**50. Mission / flight time**

- i) 10 minutes @ 11 kilograms AUW or 18.5 minutes @ 7.6 kilograms. However, a new set of propellers are being tested, where preliminary testing indicates an increase in flight time of about 10-15%.

**51. Speed**

- i) Maximum speed has been reduced to gain more sensitivity, and is currently at around 50 km/hour. It has the capacity to flight at much greater speeds, but this has no practical purposes.

**52. Primary / secondary sensors – what is onboard?**

- i) Primary: GPS, altimeter and a FPV cam (FatShark 600TVL). Also a LiDAR sensor has been tested for autonomously maintaining a fixed altitude above ground level. The use was discontinued due to poor results, but they believe it is possible with the correct sensors and programming.
- ii) Secondary: FLIR TAU2 640p, SD quality 30x optical zoom camera based on a SONY sensor, Mobius HD Action Cam. The camera operator can switch between all these sensors, and the pilot can use the FPV, IR and optical zoom camera. The three cameras mounted to the gimbal is connected to an onboard recording system.

**53. What other modules are available for payload on the TOR system?**

- i) Currently they are working on a lighting module which can be mounted beneath the UAV during nighttime operation. However, the system is not fully developed and it is recognized that there may be other solutions that are more beneficial in terms of weight and performance.
- ii) Standard handheld ATs has also been tested by there were too much electronic noise and interference when mounted directly onto the UAV. To reduce interference to acceptable levels the AT was hung 1.5 meters below the UAV, but this resulted in a pendulum effect when there were large accelerations in different directions. However, this is something that can be resolved, and TRC has ordered a specially designed Barryvox AT from Mammut which will be tested in the future. On this AT the antenna is external with increased range and better shielding against interference and noise, and is also omnidirectional.

**54. Is the AT susceptible to interference?**

- i) The standardized frequency used for all ATs is very susceptible to interference as most modern day electronics generates noise at that specific frequency.

**55. What gimbal is used?**

- i) The gimbal is a SONY NEX 2-axis gimbal, completely rebuilt to a 3-axis gimbal for TRCs purposes, with full 360-degree rotation.

**56. What is the range of operation for your platform?**

- i) During actual operations a range of 2 kilometers is rarely exceeded as the base station is rather moved closer. However, tests indicate that it is possible to operate the UAV at 8.5 kilometers range, but this is never done in practice.

**57. Lights to comply with regulations?**

- i) All lights are in compliance with the “regulations concerning aircraft without a pilot onboard etc.” paragraph §59. The UAV is fitted with white low-intensity flashing lights with at least 10 candelas, as well as directional lights in green and red, fitted on the sides.

**58. Has there been any failures or incidents that has caused the UAV to malfunction or crash?**

- i) During a test of the platform the Electric Speed Control (ESC) units overheated causing an emergency landing. The rate of descent of around 5 m/s, which caused minor damages on impact with the ground. The design fault was corrected and has caused no further problems.

**59. Is your platform build after modular design principles?**

- i) Yes, the gimbal system is disconnected within a matter of seconds, and requires no delicate “finger work” in order to assemble or disassemble. All electronics from the sensors mounted on the gimbal are connected with one universal cable to reduce clutter. The design allows for lighting modules, drop modules, and mounting of individual sensors based on need.

**60. How do you solve battery storage issues, and how is this solved for operational issues when there is little time to spare for charging etc.?**

- i) These batteries should be discharged to 60-70 percent for optimal storage. Since TRC is on a preparedness alert and they have few batteries, the batteries are kept fully charged at all times. According to RS this only affects the lifespan of the batteries, but is a calculated loss as the alternatives are inapplicable. As an alternative, Li-Ion batteries are being evaluated. These batteries have a higher capacity and lower weight as compared to LiPo, but has a lower discharge rate.

**61. Is your UAV system difficult to use in its current state (to gather useful data)? Will it require substantial amounts of training for operators?**

- i) The system is relatively easy to use, but there is the added responsibility of operating a machine of such a size and weight. Also, the machine is complex and very expensive due to the intricate payload, and training to operate safely is required.

**62. What are the maintenance procedures for the UAV?**

- i) The maintenance program is described in the OM, and is followed to a large extent. However, the UAV is undergoing revisions frequently and is in practice maintained during every revision, which should be sufficient.

**63. Why use a hexacopter instead of a quadcopter?**

- i) This was decided based upon safety concerns as the hexacopter offers more stability if one of the electrical motors were to fail. Octocopter is also a possibility for improved safety, but it is even larger. The hexacopter design is the smallest of designs which offers added redundancy as compared with the quadcopter. For a quadcopter it is theoretically possible to surrender control of the UAVs yaw, allowing it to rotate freely around the axis, making emergency landings possible upon engine failure. The “X” design is also a possibility with motors and propellers over and under each arm, meaning that a quadcopter X has 8 propellers instead of four. Such a configuration has increased redundancy but also weight and size.

**64. WHY did you decide to use a MRRW platform instead of SRRW (i.e. RC helicopter) or fixed wing? What are each platforms applications?**

- i) There is a limited amount of research and programming for computer-assisted flight done for SRRW machines. Also there are completely different safety issues with such a model as a large single rotor has a great amounts of energy and can cause substantial damage if an accident occurs. This means that there are several new safety issues that occurs when operating close to rescue personnel. There are not many flight controllers that support a single fixed wing platform completely, and those that do tend to be very expensive which is a problem with limited funding. However, the increased capabilities for lift and flight time for a SRRW platform is recognized.
- ii) The production of a fixed wing UAV is on the to-do list as it has a much better performance (for some characteristics) compared to a MRRW platform. Flight times of a fixed wing far exceeds those of a rotary wing platform, allowing them to cover much larger areas. However, for avalanche SaR applications there is no need for a large range and very long flight times. Smaller fixed wing platforms can be very light, are hand-launched and have great flight time capabilities and are therefore thought to be good platforms for repeaters in areas with poor communications possibilities, as tested by a Red Cross group in Bergen.
- iii) A small lightweight fully autonomous fixed wing platform which can track a person wearing a sender, can provide good aerial photography for an avalanche accident site with a negligible increase in risk for the rescue personnel. A small platform as described above can be produced at very low costs, but they are vulnerable to windy conditions.

**65. Are there any barriers implemented to reduce the consequences of UAV impact with rescue personnel (protective guards around rotors, foam padding etc.)?**

- i) There are no mechanical barriers to protect personnel from damages due to impact, but there are several organizational and official regulations that describe how to operate the UAV to best protect people. These safety routines include not flying over, and maintaining distance to persons etc. Mechanical barriers are avoided as they have a large negative impact on efficiency.

**66. Is it likely that you will encounter issues with icing on the TOR vessel (or any other that you currently have in use)? If so, are there done any mitigating measures?**

- i) Icing is not perceived to be an issue for this machine as the operating altitude is very low. Icing could occur due to unique metrological conditions causing freezing rain, but this is very unlikely and is not considered to be a problem.

**67. Are there any other possible external factors that can cause failure of the UAV during flight?**

- i) "Bird-strike" is not unlikely, and was encountered by an organization in the Midt-Troms region. Such an event is considered unavoidable and complete loss of the UAV is expected.

**68. When discussing reliability; have you done any measures to increase the reliability of the platform? Have you considered dual-propeller set-up?**

- i) TRCs UAV platform is more or less custom build, therefore the platform is not factory tested as a complete system. To increase reliability, the platform was designed around a hexacopter airframe. Various tests (such as extreme cold, precipitation and general flight conditions) are conducted in order to identify weaknesses of the platform. All faults are rectified to improve the design; this includes problems such as overheating of the ESC, failure of GPS system and failure to arm the radio controller in extreme cold.

**69. What weather conditions can prove challenging for use of UAV? Are there any formal limitations for use during bad weather? Do you have any operational experience in bad weather?**

- i) The only official limitation state in the OM is a wind limit at 10 m/s as described earlier. Weather conditions such as cold or precipitation are considered continuously on site. An example was a situation where TRC were requested to fly 300-meter strait in -10° C, where the conditions were deemed too high risk, and the flight was cancelled. Extensive testing is also an indicator for the operators as to what the limitations of TOR is.

**70. Have there been done any changes or adjustments to better cope with weather conditions?**

- i) The propellers have been changed multiple times, both to increase flight time and to better cope with bad weather. By mounting the UAV with smaller diameter propellers the RPM was increased substantially, and this directly translates to better handling in windy conditions. This adjustment had some impact on the thrust generated, but not in any significant way. The new propellers at 50% load had a 700 RPM increase compared to the old set.

**71. How do you think operators will be able to handle the information from the sensor systems on the UAV during a search? Will there be camera and sensor systems operators in addition to the pilot? How is the information presented?**

- i) For the TOR machine there will be two operators, meaning that the pilot can focus on flying only, and the camera / sensor operator will only have to control these systems. When conducting a search, the pilot typically releases the throttle and the multicopter will hang still in the air allowing both the pilot and the operator to focus on their jobs. The two multicopters currently under construction by TRC will have only one pilot that will operate the UAV and the cameras / sensors. This will increase the load somewhat, but is not believed to be a problem.
- ii) If there are two UAV multicopter machines in the air at the same time, there must be some kind of separation, but an in-air impact is still highly unlikely.

## **Section 9 – Future applications and TRCs use of UAVs for avalanche SaR**

**72. How do you think the use of a UAV platform will develop within the TRC volunteer organization? What needs do you have in order to progress?**

- i) Funding is always an issue for TRC as it is a volunteer organization. Recruitment of pilots and camera operators is another important step in order to improve operability and be able to attend all SaR operations. TRC currently have around 10 educated pilots/operators and wish to double that number to around 20 people.

**73. Do you think it is possible to use UAVs to drop payloads in the form of explosives in order to trigger secondary avalanches in rescue situations?**

- i) It is absolutely a possibility. The TOR platform is designed to be able to drop its payload, however were explosives never a part of the scope of work.

**74. Are you planning any new investments for the future?**

- i) Currently, two new identical UAV platforms are being constructed for use in SaR operations where TRC is attending. These aircrafts are smaller compared to the TOR platform, and only require one operator. These UAVs are based on an airframe called Y6 Tri-Trooper, which has three arms with dual mounted propellers, making it six propellers in total for one UAV.