SVALBIRD - A sustainable, multi-functional fixed-wing drone research platform

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Abstract

This work explores the potential of a Do-It-Yourself fixed-wing drone research platform to study the aurora borealis at the Kjell Henriksen Observatory, located near Longyearbyen, Norway, on the archipelago of Svalbard (78 º N 15 º E). This method is compared to the state-of-the-art in atmospheric experiments: the weather balloon, and several other drone platforms. In this work a fixed-wing drone was designed and constructed and successfully tested during the Svalbard's polar night. With this it can be concluded that there is indeed great potential in these Unmanned Aerial Vehicle campaigns on Svalbard for both auroral, as other types of empirical sciences that require a camera to face to the air or the ground. This work emphasizes the value of off-the-shelf drone solutions on the market currently, as they are well equipped for the technological problems at hand, though the Do-It-Yourself fixed-wing drone platform can be developed continuously as a low cost option.

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Preface

The work that I have done over the past thirteen weeks on Svalbard, and the months before that in anticipation of this internship, makes me very proud. The way that the University Centre in Svalbard provides students with such freedom in their research, and encouraging challenges that are merely dreams to many students, is really inspiring. I first realized that I wanted to do internship abroad in Svalbard in January 2020, after seeing a documentary on arctic research. The fact that these researchers were able to combine their passion for being outdoors and challenging yourself physically in harsh environments, whilst also challenging the mind in their research gave me intense motivation to achieve this myself. What I did not expect was that my extremely ambitious project would be welcomed with such open arms.

In my short time here on Svalbard, I have learned a lot about finances, electronics, drones, and the environment of Svalbard. A key factor to making this internship so interesting and enjoyable was the fact that there were so many things that I had never done before. I was submerged in all kinds of challenges that I knew nothing about, figuring these things out on my own was difficult and sometimes frustrating in the moment, but so much more rewarding after I had figured out the solution. This does not mean that I had any lack in support from my supervisors, Fred and Hjalmar, and many other researchers and technicians such as Mikko, Marcos, Marius and Stein. But they understood that I wanted to be challenged in this manner, and gave me the space to figure it out on my own.

The experience of living and studying in Svalbard, is something that has changed the way I want to continue my career as a researcher and entrepreneur. I had forgotten how enjoyable these hardware projects are. Something I hadn't done since I went to high school. Furthermore, the attitude of UNIS towards fieldwork has opened my mind that it is possible to combine my love for the outdoors with research. My favorite fieldwork trips must be the ones with their destination at the Kjell Henriksen Observatory. Using the bandwagon from Mine 7, to reach the deserted mountainside of Breinosa in the pitch black polar night whilst we see the dancing green strands of Aurora Borealis above us, is truly the best commuting experience, I think anyone can have.
Helping out the Alaska Fairbanks, and Clemson University researchers with their C-REX-2A rocket launch was among those trips to the KHO. Though, I wasn't able to provide any in-depth support with the data and science behind the project. It was a pleasure to help Lamar with the camera setup on the deck during the snowstorm, and seeing the successful release of all 20 ampules from the rocket payload during the polar cusp event of December 1st, 2021.

In retrospect, the only thing that I will not miss from Svalbard is the infuriatingly long delivery times of packages. The amount of time that I spent refreshing tracking orders on my laptop and phone is nearly worth 1 ECTS by itself! The importance of redundant components for any hardware project has come to my attention in the most harsh possible way. I will never take transport of goods for granted on the mainland anymore. I think if these problems had not occurred, I would have been able to fly SVALBIRD-1 as early as October, though I think that all the troubleshooting has given me the opportunity to really take a deep dive in all the technologies that are under the surface. It has given me a more thorough understanding of the whole system itself.

It has been a great pleasure, and I feel very lucky to have been able to perform my internship on Svalbard throughout the constant uncertainty of the pandemic. Now on my return back to the Netherlands, I will surely reminisce about my adventures and achievements on the beautiful archipelago of Svalbard.

Contents

List of Abbreviations

AMSL Above Mean Sea Level. 2, 7, 11, 24, 25, 29, 32

APRS Automated Packet Reporting System. 17, 18, 23

AUX Auxiliary. 15

CAN Controller Area Network. 16

CAPEX Capital Expenditures. 28

DIY Do-It-Yourself. 1, 11, 27, 28, 31–34

EASA European Union Aviation Safety Agency. vi, 9, 10, 15, 24, 25, 27, 28, 35, 41

ESC Electronic Speed Controller. iii, vi, 13, 20–22, 31, 35, 55

ESTEC European Space Research and Technology Centre. 40

GPS Global Positioning System. ii, 15, 19

HSE Health, Safety, and Environment. 10

HSI Hyper Spectral Imager. 3, 40

I^2C Inter-Integrated Circuit. 15

$kgCO_2eq.$ kilograms of CO_2 equivalent emissions. 28, 31

KHO Kjell Henriksen Observatory. ii, vi, 1–4, 6, 7, 11, 17, 18, 22, 23, 25, 27, 34, 35, 40

LED Light Emitting Diode. 19

MCA Multi-Criteria Analysis. iii, vi, 5, 11, 26–29, 31

NLR Netherlands Aerospace Centre. 4, 5, 40

OPEX Operational Expenditures. 28

Pixhawk Pixhawk flight controller. vi, 15, 16, 19, 25, 34, 55

PWM Pulse Width Modulation. 15

RC Remote Control. 11, 15, 16

SBEC Switching Battery Elimination Circuit. 14, 15

SBUS Serial Bus. 15

SSID Secondary System Identification. 17, 18

TU/e Eindhoven University of Technology. 1, 4, 40

UAV Unmanned Aerial Vehicle. ii, 1, 3, 4, 6, 8–10, 20, 24, 26–28, 34, 41, 56

UNIS The University Centre in Svalbard. 1, 3, 4, 10, 11, 21, 27, 32, 34, 35, 40

USB Universal Serial Bus. 17, 19

VAT Value Added Tax. 4

VTOL Vertical Take-off and Landing. ii, 8, 9, 27, 31, 32, 34

WiFi Wireless Fidelity. 16, 25

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List of Figures

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List of Tables

1 Introduction

The geophysics department at The University Centre in Svalbard (UNIS), performs research on the aurora borealis, commonly known as Northern Lights. A phenomenon resulting from solar particles entering the earth's upper atmosphere [4]. The Earth's magnetic field causes the particles to be redirected to the magnetic poles. This phenomenon could be described similarly to iron filings near a magnet. The particles will be attracted towards the poles along the magnetic field lines. The Earth's magnetic field lines are not symmetric around its rotational axis, as the sun's particles cause the magnetic field to form a shape similar to a tear drop [2]. The magnetic field lines of a magnet and the Earth are illustrated in figure 1. Because of this teardrop shape, the suns particles entering the earth's upper atmosphere mainly get transferred in various complex processes [4] in a latitudinal band ranging between the magnetic pole and the arctic circle, making Svalbard good candidate for spotting the Northern Lights.

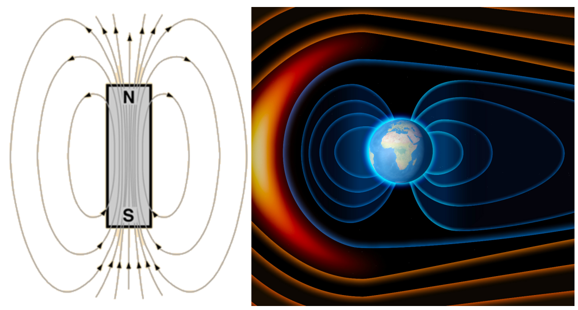

Figure 1: Magnetic field lines of a magnet (left) [1], and the magnetic field lines of the earth with the sun on the left side, skewing the magnetic field to a teardrop like shape (right) [2, 3].

1.1 The Kjell Henriksen Observatory

For this research purpose, among other atmospheric research targets, the Kjell Henriksen Observatory (KHO) was constructed in 2008 to perform permanent experiments in heated domes with various optical and more advanced measurement methods, as an improved version of the old Northern lights station located down the road in Adventdalen, as shown in figure 2. Furthermore the KHO serves as a base far away from any light pollution, located at relatively high altitude on Breinosa, a mountain near Longyearbyen on Svalbard. The KHO is ideally positioned for aurora borealis studies as during the polar night on Svalbard, the aurora can be studied during the day.

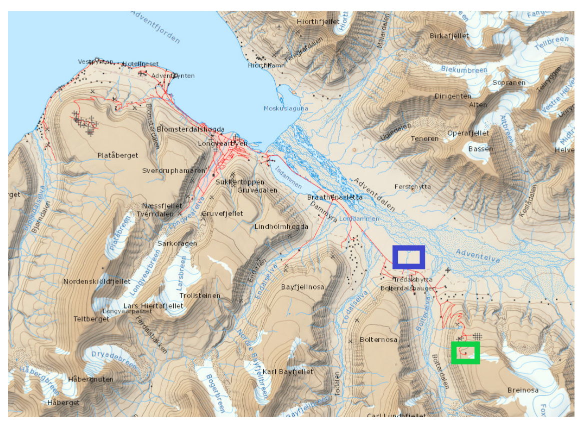

Figure 2: The location of the Kjell Henriksen Observatory in Green, and the old Northern lights station in blue [5]. Near Longyearbyen (78º N 15º E).

The Kjell Henriksen Observatory occasionally assists in the operation of rocket campaigns to study the aurora borealis, and special phenomena in the upper atmosphere. One of these special phenomena is the polar cusp which is located on the 'day side' of the earth, often at similar latitudes as the KHO. This property made the observatory a key part to the recent sounding rocket C-REX-2A, launched on the 1st of December, 2021 [6], which is part of the Grand Challenge Cusp Initiative [7].

1.2 Studying the aurora borealis

The aurora borealis is located in the upper atmosphere with the lowest aurora borealis activity starting far above the operational range of aircraft. Studying the aurora has become a difficult occupation. Studying the aurora from the ground is only an option if there are little obstruction in the form of clouds, and the sun, moon and the light pollution from nearby human activity does not shine too brightly to reduce the signal to noise ratio. The former of which is within reach of innovation to avoid in the future.
The importance of continually studying the aurora borealis is of importance to understand the cause of its appearance, and how the appearance of aurora borealis in a given location at any given time can be predicted. The cloud layer on Svalbard is located between 1000 m Above Mean Sea Level (AMSL) and 3500 m AMSL [9, 8]. This altitude can be easily reached by weather balloons, and by attaching a night vision camera to the payload of such balloons, one can study the aurora borealis on cloudy days for several minutes, whereas normally it would be impossible to collect any data.

1.3 Weather balloons

Throughout all this atmospheric science that is being performed, weather balloons are often launched on Svalbard due to its unique location [10]. This process of launching weather balloons for scientific purposes is often referred to as weather ballooning. Weather balloons are often filled with Helium to generate buoyancy. Below the balloon, a small mass can be attached called the payload. This payload consists of atmospheric experiments such as cameras, hyper spectral imagers, temperature sensors, humidity sensors etc. The balloon rises through the atmosphere due to its buoyancy, while the radio sends back the sensor data to a ground station. As the atmosphere thins, the balloon expands to equalize its pressure, and explodes at a maximum altitude by over-expansion, or by a popping mechanism operated by the research team [11].The payload then falls to the ground rapidly, however the fall is slowed down by a parachute.

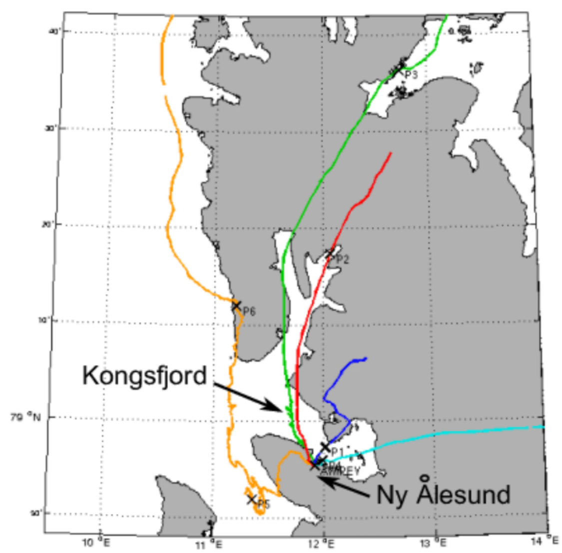

Figure 3: The path of five weather balloon launched near Ny-Ålesund in May, 2011[10].

Though the weather balloons trajectory through the atmosphere is fully governed by the wind, valuable research data can be gathered during the flight. The path of these weather balloons are unpredictable and highly chaotic. As can be seen in figure 3. This makes payload recovery very difficult in most cases, and not financially beneficial in general.
Unfortunately, the weather balloons are single use, and since recovery of the balloon debris and payload is often not performed, the costs of launching weather balloons is relatively large. Furthermore, this debris is detrimental to the environment of Svalbard and the oceans surrounding it. Making weather balloons very undesirable from many perspectives.
But as Svalbard is often cloud covered, the importance of an 'eye above the cloud' is essential to maximize data collection of the upper atmosphere with optical instruments. Traditionally, these single-use weather balloons are used to study phenomena like the aurora borealis from the KHO, and many other research sites on Svalbard [10], as there is a lack of a better alternative.

1.4 The multi-functional research platform: SVALBIRD

Apart from the polar night research, the light season time is used to study various other air- and ground targets on the archipelago, using the similar camera setups as used on the weather balloon. In recent years, the Unmanned Aerial Vehicle (UAV) has become extremely popular for this type of research, such as research on upper atmosphere research targets [12]. On Svalbard in particular, oceanography, glaciology, and marine biology are but a few research topics that are thoroughly studied by The University Centre in Svalbard.

In this sense, a multi-functional research platform seems to be viable as a research tool for the Kjell Henriksen Observatory, and various departments of UNIS. Ongoing work to test the Hyper Spectral Imager (HSI) v4, developed by Moon Labs, includes not only gimbal stabilization during airborne campaigns, but also calibration and data handling [13]. The HSI v4 instrument is a clear candidate for this work during daylight conditions. For polar night conditions, the KHO has developed aurora camera setups for weather balloon launches, for both aurora borealis research aswell as for use during rocket campaigns.

Combining this idea of using a drone platform for both ground and air based research targets with a similar camera setup, a sustainable, and multi-functional drone research platform, called SVALBIRD, was envisioned.
The value proposition of SVALBIRD is based on finances and ease of use, as airborne research equipment is at higher risk and therefore are governed by strict regulations. With the multi-functional platform the project partners (Chapter 1.8) aim to certify a single platform to perform the majority of the KHO and UNIS airborne research, which will then automatically conform with the safety protocols. Simplifying the research preparation significantly by reducing the bureaucratic load of certifying their airborne research equipment.
Previously, quad copter drones have been tested as an alternative for weather balloons for several ground based photographing campaigns, but due to their short range and high energy costs of carrying research equipment, a more suitable alternative has to be found [14].

A logical step for the next iteration of SVALBIRD, is to step away from quad copter drones and move forward toward fixed-wing drones as they have shown recent potential in high altitude and long range missions [15, 12].

1.5 Vision of SVALBIRD

Short term vision statement - The short term vision of SVALBIRD is to choose, develop and construct a first prototype for the sustainable, and multi-functional fixed-wing drone research platform, to test within the open regulations of drone operations of Svalbard. With the means of observing the aurora borealis as a proof-of-concept.
Long term vision statement - On the long term, SVALBIRD envisions to use the lessons learned from the short term vision's goals to develop a sustainable and multi-functional fixed-wing drone research platform that can replace the disposable, expensive, and polluting method of weather balloon activities for various air-, and ground-based targets including studying the aurora borealis above the cloud layer. This platform shall be capable and certified to fly beyond visual line of sight, above the cloud layer on Svalbard.

1.6 Research question

This work aims to fulfill all goals encapsulated in the short term vision statement of SVALBIRD. Therefore, this work firstly describes the safety and regulatory facets of Unmanned Aerial Vehicle flight, and operations in the arctic environment. Continued by the construction and testing of the fixed-wing drone. Comparing the collected data with weather balloon flight data to ultimately perform a multi-criteria analysis of potential solutions for the multi-functional research platform. From this, several different drone types are tested versus weather balloons to conclude the main research question:

Is it technically, environmentally, and financially advantageous for the Kjell Henriksen Observatory and The University Centre in Svalbard to replace the disposable, expensive, and polluting weather balloons by drones for their airborne research projects with various air- and ground-based targets?

1.7 Financial support

The author is honored in personally receiving the Netherlands Aerospace Centre's trust in providing a budget of €2.000, –, excluding VAT, for enabling the international collaboration between the Kjell Henriksen Observatory, The University Centre in Svalbard, and the Eindhoven University of Technology by finding a common ground to explore the capabilities of Unmanned Aerial Vehicles in research applications around the globe.
The detailed description of the context of the financial support and it's conditions, are described in Appendix A.

1.8 Involved organizations

Project partner – The University Centre in Svalbard (UNIS), Longyearbyen, Norway. The University Centre in Svalbard (UNIS) is the world's northernmost higher education institution, located in Longyearbyen at 78º N. They provide research-based education for the next generation of Arctic experts in biology, geology, geophysics and technology. With this vision, UNIS aims to enable better solutions to geophysical surveying on Svalbard and throughout the polar regions [16].

UNIS
The University Centre in Svalbard

Project partner – Kjell Henriksen Observatory (KHO), Longyearbyen, Norway. The Kjell Henriksen Observatory (KHO) is an optical observatory located at the archipelago Svalbard 1000 km north of mainland Norway (78 º N 15 º E). It houses more than 25 optical instruments as well as other non-optical instruments, which are employed for research on the middle- and upper atmosphere. The KHO is a world leader in polar surveying and aims to continue innovating with this project [17].

KHO
The Kjell Henriksen Observatory

International research partner – Eindhoven University of Technology (TU/e), Eindhoven, the Netherlands. TU/e is a leading international university specialized in engineering science and technology and aims to contribute to solving the major issues in the field of sustainability. The TU/e wants to be among the most sustainable universities in the Netherlands and has opted for an integral approach. The TU/e has collaborated extensively with the project partners via internships and graduation exchanges. This work has been facilitated in this exact manner [18].

TU/e

Financial supporter – Netherlands Aerospace Centre (NLR), Amsterdam, the Netherlands. The challenges in the aviation industry are always larger than today. Solely by continuously connecting of profound insights in the customer's needs with leading knowledge and research facilities, makes swift innovation possible. The Netherlands Aerospace Centre is the connecting link between science, business, and government [19].

1.9 Structure of this work

To answer the research question, a Multi-Criteria Analysis is employed. For this purpose the weather balloon and the SVALBIRD research platform will be covered in-depth. To structure the work accordingly, these in-depth discussions will be covered in the following three chapters. Seperately in the Multi-Criteria Analysis section, the results from the in-depth research of these two research platforms will be used to conclude on the original research question.

2 Background

The conundrum of atmospheric experiments is clear. The weather balloon is currently the most viable option to gather reliable data in many weather conditions. Since weather ballooning has been the state-of-the-art in such experiments for many decades, the process has been documented extremely well, and the correct equipment and education to handle these experiments has been completely absorbed into the research environment. Even though it is clear that weather ballooning is not a sustainable option for performing research, the loss of the payload has become the golden standard, because the ease-of-use is unmatched.

To drive the innovation in phasing out these disposable, expensive, and polluting weather balloons, one must find an alternative that is at the very least equal in user experience and reliability whilst reducing the financial and environmental impact. To this end, the first step is to define the requirements of the UAV with respect to a weather balloons and weather conditions, and the constraints of UAVs in the target research environment.

2.1 Weather balloons

Weather balloons consist of the balloon which is often filled with Helium gas, or Hydrogen, as these gasses have a lower density than the surrounding air and therefore will generate a buoyant force. The KHO uses a gas called 'Balloon Helium'. This gas is not as pure as the Helium gas used in chemical applications, but is rather of a lower quality to reduce costs. The lower quality implies that there is a higher concentration of particles that are not Helium, which increases the density of the gas slightly. This is mainly a financial consideration as the performance is generally not changed noticeably.
Connected between the opening of the balloon and the payload, is a tether with a tracking instrument. This tether seals the balloon closed and keeps the whole system together.

2.1.1 Launch, ascent and return

To launch a weather balloon the buoyant force of the Helium in the balloon must be greater than the total amount of gravitational force on the mass such that there is a net force upwards. During the ascent, the balloon expands due to the decrease in atmospheric pressure, and the buoyant force increases. Since the expansion of the balloon is limited due to the plastic surface being extremely thin. This surface acts as a thin layer of surface tension increasing the pressure inside of the balloon. The ascent rate slowly levels out to a nominal ascent speed [20]. Consider the following figure from M. Denny, 2016 [20] in figure 4, where a generalization of the atmospheric conditions shows the ascent speed for a typical weather balloon as a function of its altitude.

To calculate the exact amount of Helium required to launch a payload to its desired altitude, there exist calculators which have prepared the properties of commonly used balloons to provide an estimate of the launch volume and buoyant force at launch [21, 22].

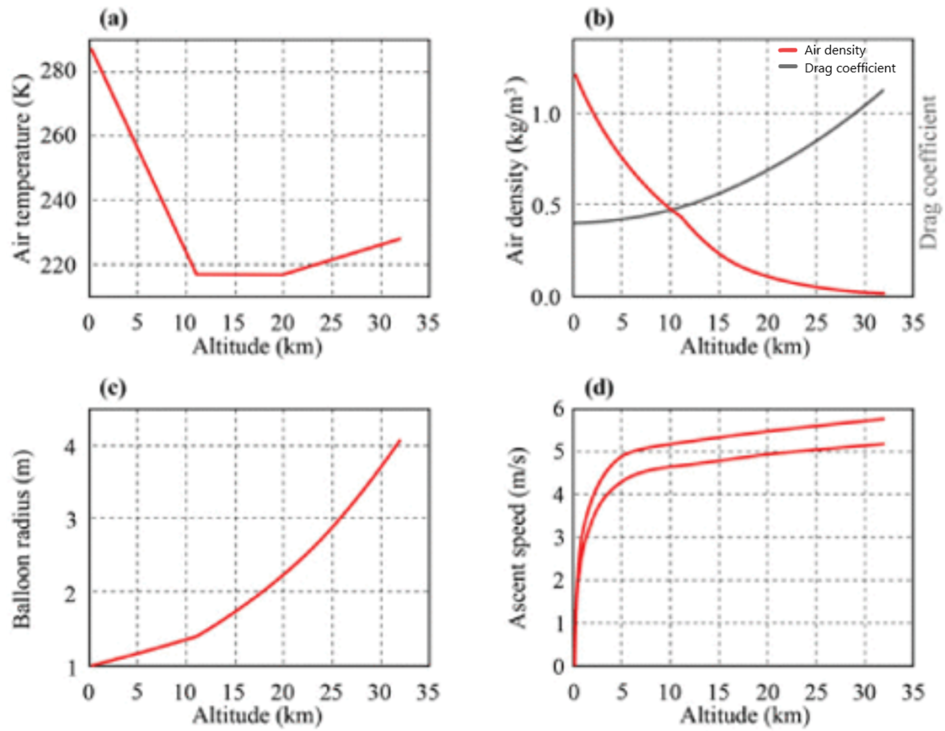

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Figure 4: (a) Standard atmosphere temperature profile for altitudes up to 32 km. The sharp change at 11 km marks the boundary between the troposphere (the atmospheric layer nearest to the Earth's surface) and the stratosphere. (b) Air density as a function of altitude, for the temperature profile of (a). Also shown is the altitude dependence of the weather balloon aerodynamic drag coefficient, inferred from measurement data. (c) Balloon radius as a function of altitude. (d) Ascent speed for a 1-m radius balloon filled with hydrogen (upper curve) and helium (lower curve). Note the near-constant rate above 7 km. Sourced from M. Denny, 2016 in figure 1 [20].

2.2 The requirements for SVALBIRD

According to the previously stated capabilities of weather balloons, and the requirements to observe aurora borealis above the cloud layer on Svalbard, the following requirements for the SVALBIRD system are specified:

- SVALBIRD must be able to fly above the cloud layer at at least 1500 m AMSL, but preferably above 3500 m AMSL
- SVALBIRD must be able to carry a camera payload that weighs approximately 280 grams.
- SVALBIRD must be able to house the payload camera inside the drone such that the camera is pointed upwards, and the antenna is not obstructed.
- SVALBIRD must be able to return to a retrievable position, in a reusable state such that the system can be reused.
- SVALBIRD must transmit its location at least once per minute for logging purposes
- SVALBIRD must be controllable from a hand held controller or laptop from a specified ground station such as the KHO.
- SVALBIRD must be able to fly in twilight and night conditions.

- SVALBIRD must be able to photograph the aurora borealis.

2.3 Principles of Unmanned Aerial Vehicles

With this basic understanding of the weather balloon and what is required to compete with the weather balloon on critera such as; data quality, ease-of-use, user experience, and reliability among others, the options in UAVs should be explored. There exist several types of Unmanned Aerial Vehicles, the principal type of which is the quad copter drone, in recent years the fixed-wing drone has flourished with prospects of surveying applications. These two UAVs operate on distinct basis.

2.3.1 Quad copter drones and Vertical Take-off and Landing

Quad copter drones, or quadcopters, are commonly used Unmanned Aerial Vehicles among many hobbyists and academics alike to study various phenomena. The ease of use of quadcopters makes hard to reach locations accessible and affordable for aerial photography. The quadcopter finds it name its cross formation of four propellers, propelling air vertically such as an helicopter [23, 24].
By controlling each propeller individually with smart algorithms, and by means of using various orientation sensors, a quadcopter can reach high stability during flight whilst carrying camera equipment. This principle is illustrated in figure 5.
By rotating propeller blades, air is accelerated and in turn, a force is exerted in the opposite direction on the UAV. There exist Vertical Take-off and Landing (VTOL) capable UAVs that use the principle of quadcopters by having vertical propellers to assist in take-off and landing to reduce ground area use [23, 24].

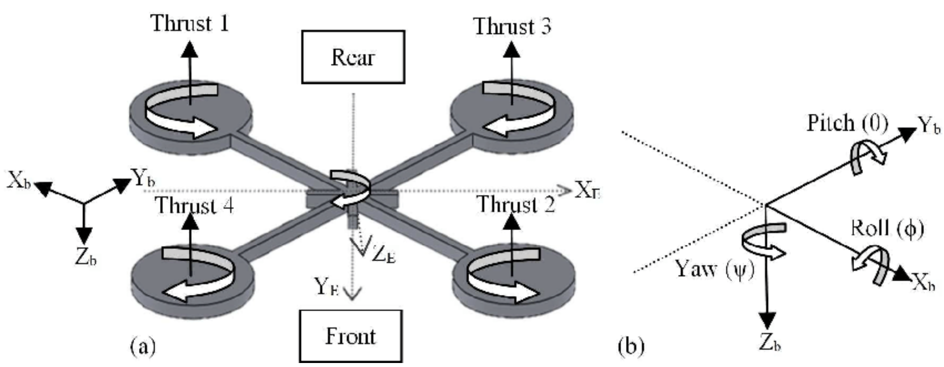

Figure 5: Quadcopter schematic: (a) The structure of a quadcopter (b) Description of Pitch, Roll, and Yaw angles. Sourced from Kuantama et al., 2017 in figure 1 [24].

2.3.2 Fixed-wing drones and gliding

Fixed-wing drones are different types of Unmanned Aerial Vehicles that operate similarly to aircraft. Their propellers generate a force on the UAV in the horizontal direction. This acceleration generates speed such that the wings of the UAV start generating lift. The lift is generated by the shape of the wingfoil that by its shape and angle towards the wind velocity (figure 6), reduces the pressure over the top surface, inducing a net upwards force on the UAV [25].

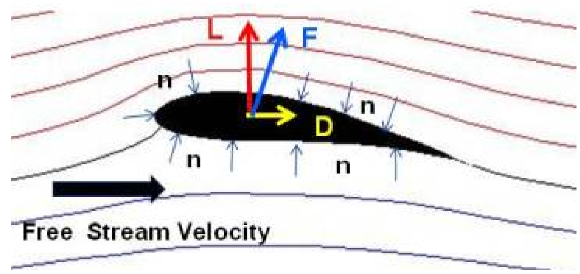

Figure 6: Schematic of forces on a wingfoil surface, from Nancy Hall at `NASA.gov` [25].

Even when the propellers are turned off, the momentum of the UAV keeps the fixed-wing drone at speed, allowing the wings to generate lift such that gliding without power becomes possible. Since generating the lift of the wings is such an efficient process, long distance and high altitude operations with fixed-wing drones becomes much more feasible. Though, the payload capacity of fixed-wing drones is lower than that of quadcopters or VTOL UAVs.

2.4 Limitations of Unmanned Aerial Vehicles

To operate in public airspace, one must adhere to all rules and regulation as defined by the aviation authorities. Since this project operates on the archipelago of Svalbard, it is under jurisdiction of the European Union Aviation Safety Agency (EASA) [26]. The EASA sets out a framework for safe operation of manned and unmanned aircraft. For this purpose, the category of Civil drones (unmanned aircraft) is of interest.

2.4.1 Civil drone categories

There exist three categories of civil drone operations according to the EASA framework. 'Open' category addressing the lower-risk operations. 'Specific' category addressing riskier operations requiring authorisation from national authorities, and 'Certified' category where licensing of the drone pilots is required to ensure safety during operation [27].

Open category regulations

The open category regulations are designated in Cx-labels:

- C0 - Self-built or toys, 0 to 250 grams
- C1 - Micro drones, 0 to 900 grams
- C2 - Mini drones, 0 to 4000 grams
- C3 - General drones, 0 to 25 kilograms
- C4 - Self-built, 0 to 25 kilograms

These Cx labels are split in three open sub-categories: A1, for C0 & C1, the drone has to be kept in line of sight at all times, it may not fly over groups of people nor over uninvolved persons and animals. A2, for C2, the drone has to be kept in line of sight at all times, it may fly over groups within 30 meters, or 5 meters within low speed mode (max. 3 m/s). Finally, A3, for C2, C3 & C4, the drone has to be kept in line of sight at all times, it may fly over groups within 30 meters and may not fly closer than 150 meters of buildings. All activities must be within 120m above ground level with an

exception of flying over buildings larger than 120 meters [27].
Aspiring drone pilots may be educated on these three categories through online teachings through various third-party organizations [27].

Specific and certified category regulations
To fly beyond visual line of sight and above the maximum height of 120 meters above ground level, one may apply for a specific or certified category rating. This requires the involvement of a certified EASA representative to discuss the planned operations of the drone and the risks that are involved in these campaigns. According to the risk of these operations, the different types of categories are advised to the drone owners, where from the process of certifying the UAV can be started. This process requires several test flights to show the capabilities of the vehicle. Certified category test flights are by definition more strict in allowing the pilot and their UAV to be certified for operations [27].

2.4.2 Svalbard environment and surroundings

The arctic environment of Svalbard brings a plethora of challenges. Especially concerning fieldwork, in and around Longyearbyen, requires researchers to adhere to health, safety and environment guidelines as postulated by the Health, Safety, and Environment (HSE) department of The University Centre in Svalbard. In the following subsection, the impact of the environment and the surroundings on Svalbard have on the SVALBIRD project, and what precautions are being taking to ensure the success, and most importantly, safety of the operations [28].

Arctic climate
Longyearbyen is categorized as a tundra climate where, in the months of November and December, the average day temperature ranges from -8C to -14C [29]. These temperatures require special handling for drone operations, in particular the effects of ice forming on propellers and wings which impact lift and handling performance [30]. Furthermore, carrying out missions from remote ground stations requires more preparation to create a comfortable shelter to operate from [31].
This project is operated with a strong understanding of these limitations. Particularly, the first prototype that will be presented in this work serves to quantify these guidelines for this end specifically.

Polar bear safety
A large risk factor in operating at remote ground stations on Svalbard, is the danger of polar bears. During flight testing and campaigns, the fieldwork team includes a designated member responsible for polar bear lookout. The crew is equipped by the The University Centre in Svalbard (UNIS) logistical department with Mauser $30-06$ rifle, flare gun including flare and exploding charges to protect themselves against bears in self defence. Furthermore, emergency beacons are supplied. The risks of the campaigns are discussed with a HSE expert in advance of the expedition, here the risk of encountering a polar bear is discussed thoroughly [28].

Wildlife protection
During drone operations, the crew is focused on ensuring the protection of the wildlife of Svalbard, a distance postulated by the safety framework on civil drone operations by EASA of 30 meters from any unsuspecting animal is yielded. As most of the drone operations are handled at altitudes higher than 30 meters, care is taken during launch and landing to choose the correct locating as to not disturb the ground wildlife. During flight, the pilot is responsible to keeping the drone in visual line of sight, and they are ought to scan the surroundings for animals in crossing trajectories to the drone and adjust the route accordingly. This responsibility continues to exist during autonomous flying as all operations are within visual line of sight, the pilot can intervene the trajectory at any time [27].

3 Procedures

Now that the basic requirements and limitations of atmospheric experiments are clear, the framework of the analysis must be drafted. In this section, a thorough documentation of the construction of the first prototype of the fixed-wing drone will be given, followed by the experimental setup of the weather balloon. Finally, the MCA process will be discussed, after which the potential solutions and criteria that will be addressed in the analysis will be introduced.

3.1 Construction of SVALBIRD-1

For the first prototype of SVALBIRD, called SVALBIRD-1, the 'believer' model fixed-wing drone is used as illustrated in figure 7. It has a wingspan of 1960mm and has a maximum take-off weight of 5.5kg, the total weight of the frame and required electronics excluding the camera equipment is approximately 2.8kg, the payload capability is 2.7kg for additional batteries besides the 8000mAh battery and camera equipment. The cruising speed is 20m/s, and the model is considered to be the most stable fixed-wing drone on the market for DIY projects.

Figure 7: The 'Believer' fixed-wing drone model by MakeFlyEasy.

It is believed that the Believer is able to fly above the cloud layer on Svalbard at at least 1500 m AMSL, however this hypothesis is yet to be tested.
Due to the hardened bottom of the vehicle, the drone can be landed on soft soil or snow. The latter of which is in abundance at the KHO on Svalbard. Furthermore, it is also possible to catch the drone with nets and blankets in an emergency.

In this section, the construction process of SVALBIRD-1 is documented, as there exist no literature on construction manuals for this model, except for a build guide on an RC forum [32], the construction process will documented in detail due to popular request[1]. The construction process is documented according to part location and not in chronological order as to not confuse the positioning of some parts.
In general, the chronological order of construction is to start with introducing the structural reinforcements into the body of the drone, continued by the gluing of small parts to the Styrofoam, after which the servos and motors are positioned in the wings and the V-tail. The electronics are then wired to the connectors and the final electronics in the body are completed.

The drone is divided into five different general parts from least to most complicated: V-tail winglets

[1] In discussion with Associate Professor Marius Jonassen and Head Engineer Marcos Porcires in the Arctic Geophysics department at The University Centre in Svalbard, it was stated that the detailed construction process of the drone would be of great interest.

(Section 3.1.1), V-tail connectors (Section 3.1.2), wings (Section 3.1.3), wing connectors (Section 3.1.4), and main body (Section 3.1.5).

3.1.1 V-tail winglets

The V-tail winglet part is a single-part Styrofoam piece. There are black plastic reinforcement parts that are glued to the Styrofoam, in which a plastic rotating part is situated. This is connected via a small bolt with a nut to a long thin metal rod to the control surface. Both ends of the metal rods are threaded, on which a plastic part with a free moving bearing to fit the bolt and nut on both sides is fitted. On the control surface, there is a small rectangular indent in the Styrofoam, where a small plastic part can be glued to connect to the other end of the metal rod with a similar bolt and nut configuration. The metal rod is located at the top of the drone when attached to the main body.
For extra reinforcement the thinner part of the Styrofoam that acts as a hinge for the control surface can be taped over with strong and broad tape. Make sure to extend the control surface to its maximum angle before taping on the convex side of the hinge.
In figure 8, the separate parts are highlighted for context. In particular, note the dark gray parts of the rotator and the plastic reinforcement piece on the control surface that are connected via the metal rod indicated by the vertical dark gray line.

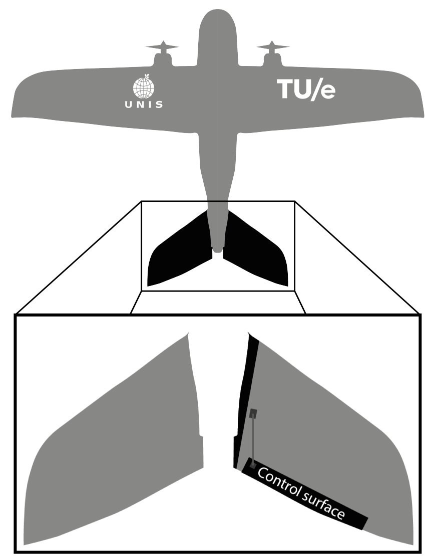

Figure 8: Schematic representation of the V-tail winglets.

3.1.2 V-tail connectors

The V-tail connector parts are glued to the main body, these parts aim connect the main body to the V-tail winglets in the previous section. The reinforcement parts on these winglets are connected by two plastic tubes on either side that fit into the V-tail connector. On the outside of the v-tail connector, an indent is located on the connecting surface where a metal hook part is positioned by two screws to secure the V-tail winglets. With a small button on the reinforcement part of the V-tail winglets, the hook can be disconnected to release the V-tail winglets from the main body. When attaching the V-tail winglets, the hook automatically secures the two parts together. It is paramount that the V-tail connector parts are glued securely as there are many stresses acting on the part during flight as the control surfaces generate large amount of drag and shear forces.
Inside the V-tail connector parts there is a hole where the 3530 type servos fit exactly. On these servos, the counterpart to the rotator part on the V-tail winglet is placed to allow the servo's movement to transfer to the control surface. The servo is secured into place by two bolts and the three jumper cables are threaded through the main body.

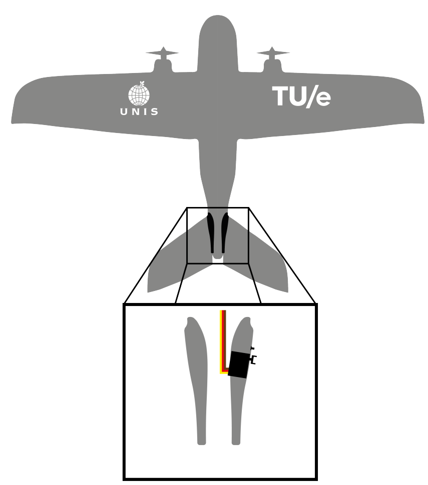

Figure 9: Schematic representation of the V-tail connectors.

3.1.3 Wings

The wings have the largest control surfaces, which are controlled by a servo located in an indent in the Styrofoam in the middle of the wing. This servo has a single arm which sticks through the plastic servo protector plate which is connected with the same metal rod and plastic reinforcement part on the control surface as the V-tail winglet in section 3.1.1. With a thin opening the servo cable is routed to the engine bay in which the motor is located connected to its propeller via three smaller bolts that has a larger bolt in the rotational axis on which the carbon propeller can be mounted with a small plastic ring, to secure the propeller to the motor, a washer ring and a nut are tightened. The motor is mounted on a wooden part that is glued into the large Styrofoam wing part.

In the engine bay, the three three-phase cables from the brushless motor are connected to the ESC which has two high voltage power cables and three motor controller cables. The middle wire of both the ESC and the Servo are the 5.2V + cable of the low voltage system, and are therefore combined. On top of this engine bay, a smaller Styrofoam part is glued to the main wing part to complete the wing shape.

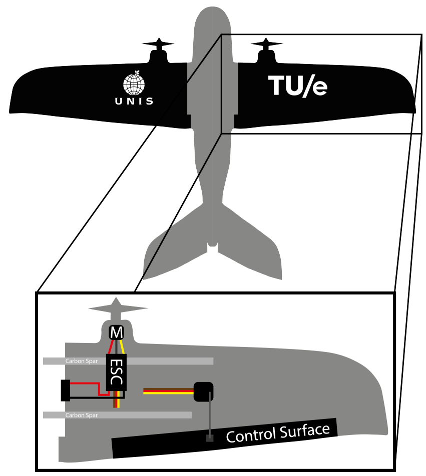

Figure 10: Schematic representation of the wings.

A plastic reinforcement part with two holes for two carbon spars that fit through the main body to reinforce the wings, is glued to the surface of the wing that is connected to the main body. In this reinforcement part, an electrical connector, called a D-sub connector, with a high voltage + and - connection, and five low voltage jumper cable connectors is place to which the three servo cables are soldered, next to the two auxiliary cables of the ESC, as the + cable of the ESC is combined with the + cable of the servo.

3.1.4 Wing connectors

The wing connectors are glued to the main body with the opposite side of the seven-cable electrical connector. It is paramount that this part is glued tightly to the main body as many forces are working on this part. The carbon spars thread through the connector pieces to both wings with a carbon tube in the main body for extra reinforcement. The electrical connector has two large connectors for the high voltage 4S (4 cells) DC battery + and - wires, and three top connectors that have the +, - and single wire of the servo. On the bottom two connectors, the - and signal cable for the ESC are housed.

Since the servo and ESC cables are too short, 1m long male-female jumper cables are used to extend the low voltage jumper cables. The same colors are conserved for the servo extension cables, however the - and signal cable of the brushless motor is replaced with a gray and white cable respectively.

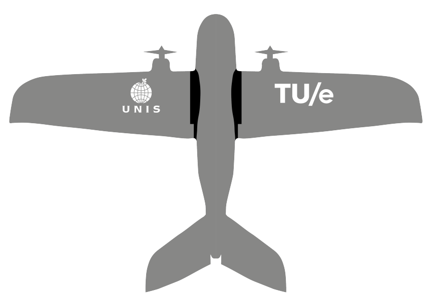

Figure 11: Schematic location of the wing connectors.

3.1.5 Main body

The main body is constructed out of two mirrored pieces of Styrofoam that are glued over the center line of the drone. Within these two pieces, many reinforcement pieces of wood and plexiglass are installed. There are three latches on the top of the main body, starting with the largest in the front of the body, followed by a smaller one in similar width in between the two carbon spars and the smallest latch in the back of the drone near the V-tail connectors. On the bottom of the main body, a parachute bay has a similar trapdoor but without the mechanical locking system as there is space for a fifth servo to release the trapdoor at will. This trapdoor is taped shut in this project as the functionality is of little use to this end. These mechanical locking systems have a Plexiglas reinforcement with hole for the locking system. On the doors itself, there is a plastic part that is glued to the Styrofoam door. These pieces line up without tweaking in the main body. On the bottom of the drone there are two landing pads made of strong but flexible plastic, a larger one in the front and a smaller one near the back. In between these landing pads a small indent is made not to damage the most vulnerable part of the drone.
In total there are 2x3 cables coming from the back two servos, and 2x(2 motor cables + 3 servo cables + 2 high voltage cables) coming from the wing connectors, in total 20 cables coming into the main body.
To power the drone, a 4S LiPo battery (14.8V) with a male XT60 connector is placed in the front of the main body with Velcro tape. This battery is connected to the current sensor that governs the power output of the battery and has smaller jumper cables that power the flight computer at 5.2V. After this current sensor, the power cable is split into three high voltage lines at 14.8V. Two go to the motor cables on both wings and the latter is connected to the Switching Battery Elimination Circuit (SBEC). The SBEC transforms the 14.8V line into two 5.2V outputs that will power all the jumper cables later on.
In between the two carbon spars, the camera payload is positioned facing upwards through the front most latch door. A custom part is 3D printed (appendix C) to fit the camera to secure the camera in the latch door and give it the best field of view of the sky. On the same axis of this hole in the hatch door, a smaller hole is made in the bottom of the main body for the antenna to fit through. The antenna folds backwards to fit within the landing pads of the drone. Similarly a custom 3D printed part (C) is fitted in this hole for security, this part features an extended half cylindrical protector for the antenna in case of a hard landing, to not damage the antenna.

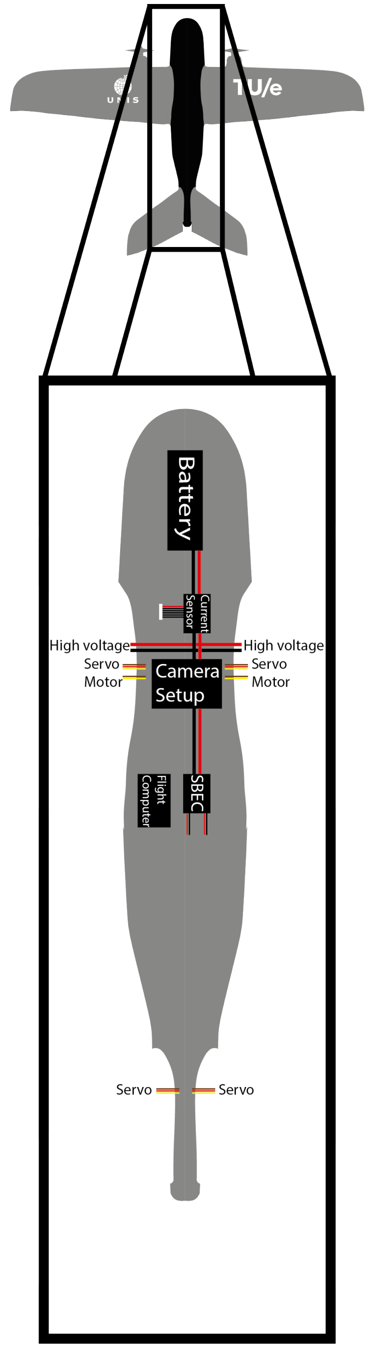

Figure 12: Schematic representation of the main body.

Further back in the main body of the drone, a wooden plate is placed in the main body that acts as reinforcement for the flight computer. Which is placed in the flight direction with Velcro tape to this

plate. The GPS and antenna thread through a hole in the side of the main body to outside the drone. The GPS is fixed at the top of the drone with Velcro tape, whereas the antenna is freely hung outside of the body. On the bottom of the drone behind the parachute bay, there is a blinking green light. This light should be turned to blinking mode when flying in twilight or night conditions to adhere to EASA regulations.
Finally, in the nose of the main body, a Pitot tube is place through a hole in the main body to face directly in the direction of flight.

3.1.6 Electronics and flight computer

All the low voltage cables are connected to the servo rail of the Pixhawk, located on the back of the Pixhawk, as illustrated in figure 13. The servo rail consists of 3x16 pins. The first two columns of are the RC and SBUS pins, respectively. The former of which connects to the receiver of the radio. Next to this, the Main output rail consists of 3x8 pins. which are connected to the following cables.

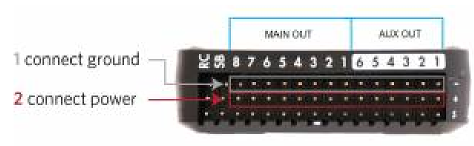

Figure 13: Servo rail of the Pixhawk flight controller [33].

1. Servo left wing (Elevon Left)
2. Servo right wing (Elevon Right)
3. Servo left V-tail (Vtail Left)
4. Servo right V-tail (Vtail Right)
5. Left Motor (Throttle)
6. Right Motor (Throttle)
7. SBEC
8. SBEC

The two SBEC connections are to provide the power, as all the ground pins on the top row are connected in the servo rail, similar to the power pins on the middle row. The bottom rail of pins sends the signal to the electronics via Pulse Width Modulation (PWM) signals. Finally, there are six AUX out pins that are not used in this build.

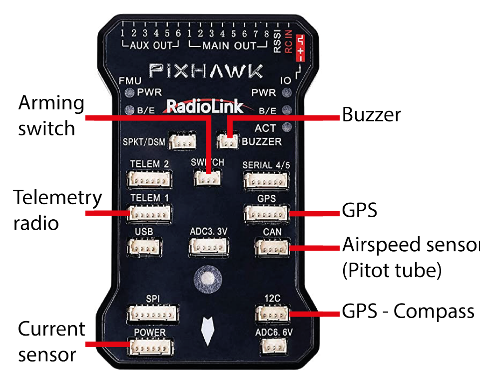

Figure 14: The main board of the Pixhawk flight controller.

Furthermore, some auxiliary electronics and sensors are connected to the main board of the Pixhawk flight controller, as illustrated in figure 14. The arming switch is a small electronics component that is used as a second step to the arming process of the drone, which is elaborated in section 4.1.3. The Telemetry radio is connected to the telemetry radio wires from the receiver, the other wires from the receiver are connected to the servo rail on the RC column as described in the previously in this section. The current sensor is connected with the six-wire connector as can be seen on the left of the current sensor in figure 12, which powers the flight computer with the battery power. This current sensor connector does not power the servo rail on the back of the Pixhawk, which is powered by the main output columns 7 and 8 as noted above in this section. Furthermore, the buzzer is connected to the buzzer connector, which gives audio information of the status of the flight computer [34]. The GPS + Compass has two connector, which are connected to the GPS and I^2C port, respectively. Finally, the airspeed sensor, which is connected to the Pitot tube in the nose of the main body of the drone, is connected to the CAN port on the main board.

3.1.7 Radio

The radio that is used to communicate with SVALBIRD-1 is a telemetry radio, that communicates radio signals from the hand held controller to the flight computer, and the sensor data from the flight computer back to the ground station. For this the the RF Design RFD 900x TXMOD v2 [35] is used. This external radio communication unit is connected to the hand held controller Taranis Q X7 [36] as illustrated in figure 15. This setup operates at 900MHz frequency, and with the 1W power limitation, this setup can communicate over 40km in range. The telemetry radio is connected to the RC port on the servo rail of the Pixhawk, and on the telemetry 1 port on the main board. The transmitter module on the handheld controller serves as its own WiFi hotspot, to which a laptop can be connected to serve as a ground station and substitute to the hand held drone. Via MissionPlanner, the drone can be tracked on a map, and waypoints can be set to which the drone navigates in autopilot mode. The general communication structure is illustrated in figure 16.

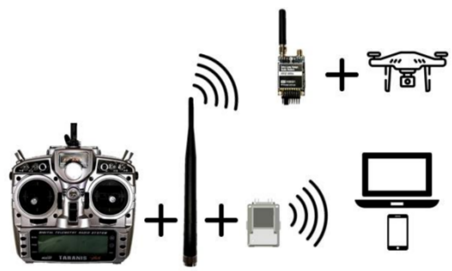

Figure 15: The general communication structure of the RF Design RFD 900x TXMOD v2 setup [35].

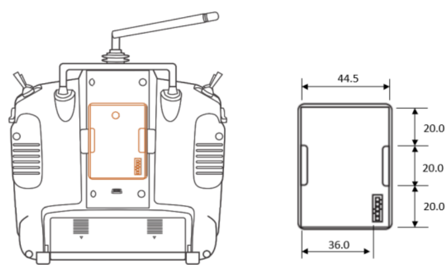

Figure 16: Transmitter module modification to the Taranis Q X7 [35].

3.2 Weather balloon experimental setup

In this section, the experimental setup of the weather balloon is described. After which the total costs are summarized. The experimental setup of the balloon train excluding the payload is copied directly from `HighAltitudeScience.com`. The reader is referred to their website for a detailed description of weather balloon setups, and thorough analyses of weather balloon activities. [37]

3.2.1 Balloon

The 1m balloon weighing 350g from HighAltitudeScience [38] is made of highly elastic plastic with a strong neck to fill and seal the balloon from. The helium is pumped in via a hose through the neck of the balloon until a certain positive lift is generated. The balloon is designed in such a manner that it will pop at a certain air pressure that corresponds to the desired maximum altitude of the balloon. By varying the amount of Helium in the balloon, one can differ the ascent speed and maximum altitude. More Helium corresponds to a faster ascent, but a lower maximum altitude.

After the balloon has reached its desired buoyancy, the balloon is shut by two zipties to the neck of the balloon, after which the balloon's neck is folded in half, ziptied and taped over to avoid the sharp edges. The balloon is the first part in the whole balloon train, and the balloon wire is threaded through this folded balloon neck, and is securely knotted in place.

3.2.2 Parachute

Five meters further down in the balloon train, the wire is connected to the apex of the 1 meter parachute by HighAltitudeScience [38]. In the lower loop of the parachute a new wire is threaded through, but not yet secured, to continue the balloon train.

3.2.3 Tracking device

The tracking device used in this experiment is the StratoTrack from StratoGear [39]. The device weighs 30g including its AA battery powering the tracking device from 24h up to 168h depending on the transmission frequency ranging from one per minute to one per fifteen minutes. The StratoTrack has a built in antenna that can reach up to 400km. Together with the StratTrack USB converter cable, the callsign and SSID of the tracker can be changed [40].

Callsigns and SSIDs are standardized protocols for the Automated Packet Reporting System (APRS). The callsign serves as an alias for a specific weather balloon or any other moving device transmitting its precise location and data. The weather balloons launched by the Kjell Henriksen Observatory operate under the callsign JW5JUA.

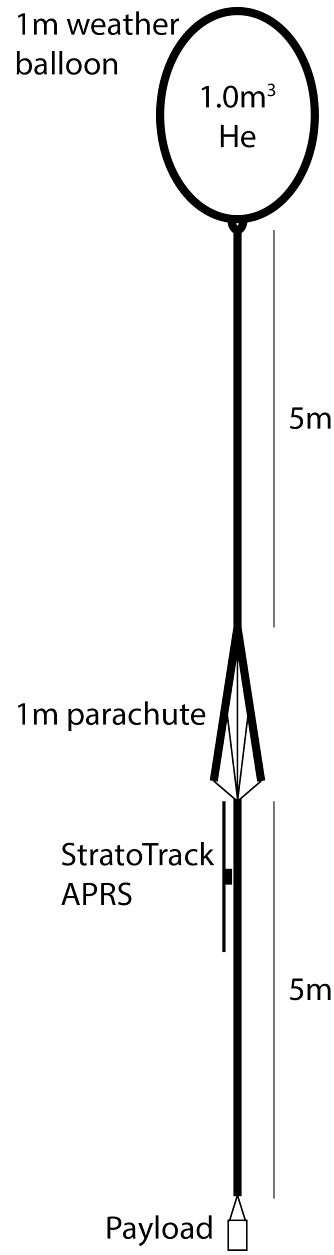

Figure 17: Schematic of the weather balloon experimental setup, to scale.

The SSID stands for the Secondary System Identification, to make sure that multiple devices running on the same callsign can be separated. For example ground stations and balloons can operate under the same callsign but a different SSID. There exist 16 different possible SSIDs, e.g. 10 is the standard SSID for ground stations, 11 for a weather balloon, and 12 is a general tracker box. Therefore the StratoTrack device operated by the KHO operates as JW5JUA-11 [41].
To track the movement and basic data of the weather balloon, a ground station at the KHO is installed, and via a so-called 'Digipeater' [41], the APRS data is transmitted to the internet, where the weather balloon can tracked by everyone who can access the internet at `aprs.fi` [42].

The wire is threaded through the lower and top hole in the battery compartment, after which the wire is threaded through the lower loop of the parachute. The excess wire is threaded through the top loop of the antenna of the StratoTrack and knotted in place.

3.2.4 Payload

The payload consists of a black-and-white night vision camera, RunCam OWL Plus [43, 44], illustrated in figure 18. The RunCam is placed in a custom 3D printed mount including On-Screen display and transmitter for the video signal. This camera setup is connected with a fishing wire to the bottom of the balloon train at five meters below the parachute. The payload is stabilized by a swivel that is placed in between the wire from the balloon train and the fishing line on the camera setup.
The full experimental setup is illustrated, to scale, in figure 17.

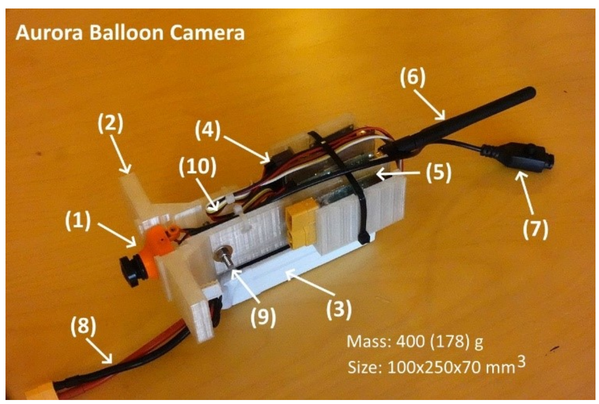

Figure 18: The black-and-white night vision camera, RunCam OWL Plus

3.2.5 Bill of materials

The total list of materials for the weather balloon research platform are summarized below in table 1.

Table 1: Bill of materials for the weather balloon, including costs.

Item	**Costs [€]**
StratoTrack APRS	200
Flight Train Kit	15
Weather Balloon 350g	35
Near Space Parachute 1.0 m	35
Night Vision Camera	100
Total	385

4 Results and Discussion

Following the construction of SVALBIRD-1, the process of testing SVALBIRD-1 may be described. The story will be told in chronological order, in reflection of the troubleshooting that occurred during the pre-flight, and ground testing sessions. This is continued by the aurora photography experiments with both SVALBIRD-1 and the weather balloon.

4.1 Pre-flight checks for SVALBIRD-1

After the drone has been constructed physically, the flight computer must be configured to have the correct parameters to fly a fixed-wing drone with SVALBIRD-1's control surfaces, weight, and inertia for fly-by-wire or autonomous flying. After configuration, all systems are checked to be running correctly before the drone can be armed. If the drone is armed, the motors and servos are responding to the input on the handheld radio. When all these systems are working, the drone can be taken outside for the first time for ground tests where the propellers are connected to the motor to check if all systems respond well to the high power and force on the drone and its electronics. These steps are described in chronological order to avoid any errors in pre-flight testing.

In appendix E, a comprehensive checklist before flight is given. This protocol should be followed before every single flight of SVALBIRD-1 to assure safe flying conditions.

4.1.1 Flight computer configuration

The Pixhawk flight controller can be flashed with a program called ArduPilot [45], a flight computer program that is operated by a large open-source community. ArduPilot recommends to use the MissionPlanner software [46]. From which the Pixhawk, can be connected by USB cable to the computer. Inside MissionPlanner, the ArduPlane section of software from ArduPilot is installed to the Pixhawk, as SVALBIRD-1 is a plane-like drone. After the software is flashed to the Pixhawk, several sensors have to be calibrated in the Pixhawk, the GPS and the Pitot tube.

Firstly, the accelerometers in the Pixhawk and GPS are calibrated by aligning the two with arrows on the Pixhawk and GPS to the same direction, and aligning the all three Cartesian directions with gravity. The MissionPlanner software indicates on which side the setup should be place to calibrate the accelerometers.
Secondly, the compass is to be calibrated, for this the same setup must be rotated in all three degrees of freedom until enough distinct data points are collected to establish the compass' direction.
Thirdly, the radio is calibrated. The transmitter and receiver are connected by the simple press of a button on both devices to pair. After which, the MissionPlanner software will register the movement of the radio on 16 of the main channels. All sticks and switches should be moved to maximum deflection to calibrate the operating range of the radio.

4.1.2 GPS lock

Fourthly, the drone setup must be taken outside, or to a place where GPS is easily received. The GPS is placed on top of the aircraft, and starts looking for satellite to connect to. On first setup, this process takes up to 15 minutes after which, multiple LEDs on the GPS start blinking green.

4.1.3 Arming the drone

Fifthly, after all the previous steps have been completed successfully, the left stick of the radio can be moved to the maximum bottom right position. After holding the stick there for several seconds, the Pixhawk buzzer will make a long constant frequency beep, after which, the button on the arming switch can be pressed for several seconds. The main LED on the Pixhawk will turn solid blue. It is of the greatest importance that the propellers are disconnected from the motor before performing this step.

4.1.4 Servo calibration

Sixthly, all servos must be documented in the servo calibration window on MissionPlanner according to the enumeration in section 3.1.6. The sticks on the handheld radio can be moved to its maximum positions to check the movement of the servos. Make sure to not move the throttle at all at this point. The input of the radio may correspond to some servo's to move in the opposite direction than expected. In this case, one can change press the inverse button in the servo calibration window of MissionPlanner. If this step is performed correctly, the servos should respond accordingly.

4.1.5 ESC calibration

Seventhly, the high voltage power cables must be disconnected from both ESCs. After which the throttle of the radio must be set to maximum. Now the power cables can be reconnected after which the ESCs will make a musical melody indicating that the ESCs have entered calibration. After the melody has stopped, the throttle must be set to minimum. Again, the ESCs will emit a melody indicating the finalization of the calibration.
Eigthly, make sure that the propellers are disconnected from the motor and that there are no loose items in the vicinity of the motors. In particular metal and magnetic items should be kept far away from the motor. Now the throttle can be moved throughout its operation range and the motors will respond accordingly.

4.1.6 Ground tests

Finally, the ground tests can be performed on the drone to verify that all systems are operating accordingly. The ground tests consists of three consecutive tests that must be confirmed before the drone is cleared to fly.

1. **Servo and propeller test.** In this test the propellers are tightened to the motor axis, and the system is armed. The drone is held off the ground in a safe, outdoor area where the pilot throttles up to 20% of maximum power and confirms that the propellers are moving in the correct direction and at approximately equal power. When the motors are powered, all servos are tested to confirm they move in the correct direction for any input.

2. **Peak power test.** In this test, the propellers are tightened to the motor axis, and the system is armed. The drone is held off the ground in a safe, outdoor area where the pilot throttles up slowly over the course of approximately five seconds to maximum power, after which the pilot immediately throttles back to 0% throttle in approximately three seconds.

3. **Sustained maximum power test.** In this test, the propellers are tightened to the motor axis, and the system is armed. The drone is held off the ground in a safe, outdoor area where the pilot throttles up slowly over the course of approximately five seconds to maximum power, after which maximum power is held for at least ten seconds before the pilot throttles back to 0% throttle in approximately three seconds.

If the drone system passes all three ground tests consecutively and successfully. The drone is cleared to fly from the pilot's point of view. Of course the regulations for UAVs still apply in any condition. These ground tests are designed to confirm that the drone will operate correctly when in operation, and that the chance of any mechanical or electrical failures during flight is drastically reduced.

4.1.7 Troubleshooting of SVALBIRD-1

During the testing of SVALBIRD-1 the author ran into several problems related to the radio communications, ESCs, and motors of the drone. The following subsections describe the point at which the problem occurred and how this was subsequently solved.

Figure 19: Example of a USB to FDTI cable [47].

Radio troubleshooting In step three of section 4.1.1, Flight computer configuration, the radio is calibrated. During the process of calibration, the transmitter unit on the hand held controller is connected to the laptop to set up the details of the connection between the transmitter and receiver.
The transmitter was updated to the newest drivers via the WiFi connection. However, to establish a connection between a transmitter and receiver, both pieces of hardware must be on the same version of drivers. To update the receiver module a special FDTI to USB cable is required.
Since there is no way to downgrade the version of drivers on the transmitter, a new order had to be made from mainland Europe to get the cable to update the drivers on the receiver. With the timescale of the project being very limited, the decision was made to exchange the RFD 900x radio communication setup for an existing radio communication setup from a colleague in UNIS.

The new radio setup is similar in being an external radio communication setup. The Crossfire nano receiver is not a telemetry radio however, which means that the sensor data can not be sent back to the ground station. However, the handheld inputs can be transferred to the flight computer. This new setup was borrowed in full for the sake of time limitations, and will be returned after the finalization of the project.
In figure 20, the new Crossfire setup is illustrated. The system has similar capabilities to the RFD 900x system, with a range of over 40km, and capabilities to connect to a remote ground station such as a laptop to input flight routes via way points in auto pilot mode.

Figure 20: Crossfire radio communication setup.

ESC problem During the second ground test, peak power test, in section 4.1.6, the motors seemed to stutter significantly nearing 60% of full power. After approximately two seconds of this stuttering, the right wing ESC caught fire, and the ground test was aborted.
After consideration of the burn marks on the ESC, as in figure 21, it was concluded that a short circuit had occurred in the internal electronics of the ESC due to some kind of voltage peak [48].

To avoid this problem in the future a total of 1500 μF in capacitors was installed parallel to each ESC [48]. Though the author was delayed two weeks in continuing testing due to delivery delays of a replacement ESC.

Motor problem With the new capacitors and ESC installed, the peak power test was successful. However in the third and final ground tests, the sustained maximum power test, the ESC connected to the same motor as in the previous problem caught fire. After consideration of the cause of this fire by looking at the burn marks. It was noted that the burn marks were nearly identical to the burn marks on the previous ESC problem. From this it was theorized that a short was generated between two of the three-phase cables connecting from the ESC to the motor. As it is highly unlikely for two ESCs to fail in similar ways on the motor. The cause of this motor short is likely caused by small metal filings being pulled inside the motors windings by the permanent magnets and the high wind speed caused by the propeller.
To solve this problem, a replacement motor and several replacement ESCs were ordered, with a similar two week delivery time delaying the testing process further.

Figure 21: ESC burn marks after the peak power test.

Flight computer problem During the sustained power ground test, the power module connected to the indicated voltage drop on the flight computer. This caused the fail safe of the flight computer to cut the power supply to the flight computer. Since no redundant power system was connected to the flight computer, the system lost all computation power.
To by-pass this, the was subsequently powered via the servo rail on the back board of the flight computer on a separate line from the power module.

Camera receiver problem In the maiden flight of SVALBIRD-1, the night vision camera was connected to the remote receiver and display. During field testing, the battery of this remote receiver reached critically low voltage levels rendering the camera system unusable.
In future flights, an effort should be made to retain the battery temperature by logging data from a warm location such as the KHO, or a car with heating on. Furthermore, chemical hand warmers can be used as a makeshift solution to a battery heater.

4.2 Aurora borealis photography experiment with a weather balloon

On Wednesday 8 December, a weather balloon was launched from Kjell Henriksen Observatory, to collect a baseline of data to understand what the state-of-the-art entails for optical weather balloon data.

4.2.1 Preparation

In preparation to launch the weather balloon, all materials, including a large Helium steel-compressed bottle, were moved to the KHO via bandwagon. This bottle houses approximately six weather balloon charges of Helium in it. This process takes approximately 30 minutes, or 5 minutes per launch. After this, the construction of the weather balloon train was a simple process. From starting to measure the lengths of wire until the balloon was ready for launch, lasted approximately 50 minutes. Since this was the first attempt at a weather balloon launch, this process could be easily optimized to take 30 minutes.

To get permission to launch a weather balloon, a letter was written to the Norwegian air authority. This was swiftly accepted within a week. The affiliated documents to this interaction are attached in appendix F.

4.2.2 Flight

Launching a weather balloon is a straightforward procedure. Check all trackers and data collection is running before the balloon is let go in an open area. The night vision RunCam in the payload could send data to the ground station at the KHO. For approximately 20 minutes, the camera generated data from above the cloud layer.

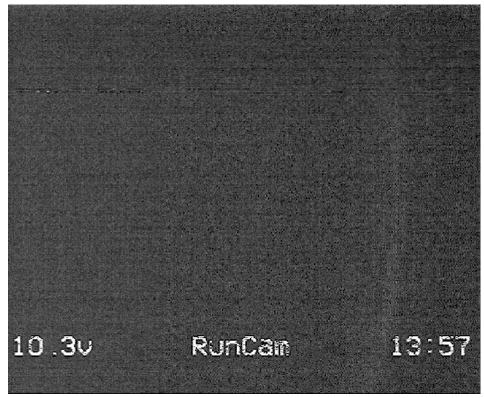

Figure 22: The most clear frame including aurora borealis of the weather balloon experiment. The aurora strand can be seen on the right side of the picture, in a thin vertical strip.

A key instance that showed the vulnerability of the data quality of the weather balloon is that the balloon shook violently approximately 30 meters after launch, when the balloon hit a large gust of wind. This caused the camera to rotate rapidly with a frequency of $\approx .5Hz$ throughout the measurement phase. Since the sample frequency of the camera is $1Hz$, and out of phase with the rotation of the camera, the images are hard to analyze. In particular, it was unclear in which direction the camera was making photos. Because neighboring photos did not have the same field of view, and the signal to noise ratio of the images was low, it was nearly impossible to confirm that the faint clouds of light were either aurora borealis or light pollution from Longyearbyen. On 1.51% of the frame of the weather balloon data, aurora borealis is undoubtedly seen. In figure 22, the best distinguishable frame of this video is shown. On the right of this frame, the vertical strand of aurora borealis can be seen. The fact that the strand is vertical displays the fact that the camera is rotating around the vertical axis rapidly.

Besides the payload, the StratoTrack APRS stopped operating during flight. The likely cause of this is the large decrease in temperature, lower the battery voltage below the minimum. As the payload descended on the parachute, and the ambient temperature increased above -52C, the StratoTrack continued logging. Because of this, 35 minutes of balloon sampling, after the camera had stopped transmitting was lost, and the position of the weather balloon was unknown.

4.2.3 Points of improvement

In future weather balloon launches it is paramount to increase the stability of the payload, by introducing a long rod to increase the rotational inertia of the payload. Furthermore, this rod should be shaped like a wing to align the camera with the wind direction. In addition to this, the RunCam was unable to reach a satisfactory signal to noise ratio. A better, and likely more expensive, camera should be used as a payload to allow for a increased signal to noise ratio in the logged footage. Furthermore he data connected from the payload to the KHO was insufficient. The 20 minutes of useful data is the bare minimum of data to make a weather balloon launch worthwhile. This is mainly due to the weather balloon keeping vertical speed as the balloon reaches above the clouds, making the time window where the balloon is above the clouds and within transmission range very small. Finally, the fact that only one frame per second was logged at the ground station, even though 25 frames per second were transmitted in real time made the final analysis much more challenging. The use of compression algorithms during the logging is therefore very important. In post processing of the weather balloon data the H264 compression was used to compress the original footage. This resulted in a compression factor of 100 in 1, emphasizing the improvement that can be made in this.

4.3 Aurora borealis photography experiment with SVALBIRD-1

In succession of the weather balloon launch to collect baseline data of aerial aurora borealis footage, SVALBIRD-1 performed two flights to collect data of the aurora borealis in a aerial campaigns.

4.3.1 Preparation

To fly SVALBIRD-1 in the open airspace of Svalbard in Adventdalen near the old northern light station (figure 2), the author has acquired the certificates to fly any UAV within the EASA 'open' category framework. These documents are attached in appendix B.

4.3.2 First flight

The first flight was performed in Adventdalen near the old northern light station on 13 December 13:15 universal time. The weather conditions were clear with a 6m/s ESE wind with 9m/s gusts was measured by the Adventdalen weather station. The drone was launched in headwind conditions from standing position at 50% throttle. The drone was stable in flight, in particular the crosswind conditions were surprisingly stable. An important trait for a drone platform to fly above the cloud layer. With tailwind conditions, the drone required less than 10% throttle to maintain altitude as it reached a peak altitude of 50m AMSL. In tailwind conditions, the motors were turned off for landing. The landing on soft snow caused a soft landing where the drone slid for approximately 15m over the snow before coming to rest with no apparent damages.
Due to the problem described in section 4.1.7, no camera data was collected during this flight.

4.3.3 Second flight

The second flight was performed in the same location as the former on 14 December 7:35 universal time. The weather conditions were clear with a 2m/s E wind with 4m/s gusts. The drone was launched headed west with tailwind conditions at 70% throttle. This deemed to be insufficient throttle as the wings were not able to create sufficient lift.
The drone was inspected for any damages which were not noted at the time. After which the drone was relaunched at 90% throttle with the same heading. The drone pitched up aggressively after launch as control surfaces had no authority over the orientation of the plane as the torque induced by the misaligned moter was far greater. In a large arch the drone came down, vertically, into the snow after 38 seconds.
During this flight, 25 frames per second data of the camera inside the fixed-wing drone was recorded and logged. Although in post processing the aurora borealis was not distinguished from the background noise, it was noted that from outside light sources showing up on the camera display, the platform was significantly more stable in flight. No vibrations or rotations were noted in this recording besides the curving of the plane in this large arch.
Furthermore, after the crash landing that brought an abrupt ending to the data collection, the damages on SVALBIRD-1 were observed. It was concluded that the repairs of the fixed wing drone platform would take up to one week of work, where most damage was done to the fuselage of the UAV. There was no damage noted on camera system further strengthening the argument that the drone platform is indeed reusable in the worst possible landing conditions.

4.3.4 Reflection on SVALBIRD requirements

Referring back to section 2.2, the following reflections are given to the requirements.

- SVALBIRD must be able to fly above the cloud layer at at least 1500 mAMSL, but preferably above 3500 mAMSL.
  SVALBIRD-1 was not able to ultimately prove that it can be flown at these altitudes as this would require more advanced EASA drone certificates. Though the impressive stability of the plane in the crosswind conditions with 9m/s crosswind gusts on the first flight only encourage the success of a drone platform at this altitude.
- SVALBIRD must be able to carry a camera payload that weighs approximately 280 grams.
  The total weight of the SVALBIRD system is 3080 grams including the camera payload. This is far within the 5500 gram maximum take-off weight of the SVALBIRD.
- SVALBIRD must be able to house the payload camera inside the drone such that the camera is pointed upwards, and the antenna is not obstructed. The SVALBIRD system can house the camera setup within its fuselage with a camera hole in the top of the drone and a antenna hole in the bottom part of the fuselage.
- SVALBIRD must be able to return to a retrievable position, in a reusable state such that the system can be reused.
  The second flight of SVALBIRD-1 has proven that even in the worst possible landing conditions, such as a vertical impact with the ground at cruising speeds still makes the plane system reusable after the minor damages to the fuselage are repaired.
- SVALBIRD must transmit its location at least once per minute for logging purposes.
  The SVALBIRD-1 did not use the telemetry radio options, and therefore did not log its location back to the ground station. However, the Pixhawk flight controller system has a large track record of having these logging systems working seamlessly at much higher frequency. [45]
- SVALBIRD must be controllable from a hand held controller or laptop from a specified ground station such as the KHO.
  SVALBIRD-1 has proven that the drone is controllable from a hand held controller. The WiFi connections to a laptop of phone have not been tested out in the field, however they have been tested in the ground testing phase successfully.
- SVALBIRD must be able to fly in twilight and night conditions.
  Both flights of SVALBIRD-1 have proved that flying within twilight and night conditions were both legally and physically possible.
- SVALBIRD must be able to photograph the aurora borealis.
  SVALBIRD-1 has yet to make its first distinguishable aurora borealis photograph, but with the data collected from the second flight, the stability of the frame undoubtedly will allow the system to make many aurora borealis photographs in the future.

5 Multi-Criteria Analysis

With a solid understanding of the requirements and limitations in designing an alternative to the weather balloon, a methodical, and objective method of decision making should be introduced. A Multi-Criteria Analysis (MCA) is method of scientifically, objectively judging potential solutions to any problem according to a large sum of criteria ranging from technical requirements to social and environmental topics. The MCA is often used in social science and has recently become popular in the renewable energy scene as a combination of these various criteria becomes of importance in decision on these topics [49]. They operate by firstly defining the methodology of the analysis in which, the process of carefully choosing the various potential solutions to be tested in this process, followed by determining the criteria which should used to evaluate the potential solutions. It is of key importance here to choose criteria that are independent of each other, as double counting of criteria that are similar may cause a skewed end result of the analysis. Furthermore, the weighting of the criteria is usually determined by interviewing stakeholders on the problem at hand to reach a consensus on which criteria are of most importance. Finally, all potential solutions are evaluated on the criteria and by considering the weight of these results, a ranking of the preferred solutions is given [50].

5.1 Methodology

A Multi-Criteria Analysis (MCA) is used to compare the potential solutions. The objective of the MCA is to rank the potential solutions on their performances on various carefully selected criteria; giving insight into the best option for the stakeholder on whether is worth pursuing Unmanned Aerial Vehicles as opposed to weather balloons. The criteria are assigned with weighting factors to differentiate in their subsequent priority.

These priorities are based on the views of the main stakeholder of the project which are researchers at these facilities. An overview of the MCA process is described in figure 23. This starts with the criteria evaluation, where the criteria on which the potential solutions are evaluated, are formulated. Followed by the weight assignment to all criteria according to the view of the main stakeholder. These two steps are performed in section 5.1.2 and 5.2.2, respectively. From this, the evaluation matrix can be drafted in section 5.2. In this section, the calculation process is performed. Here the quantitative and qualitative data is analysed separately by standardisation, and conversion to numerical data, respectively. From this the overall dominance scores are generated. Though the overall dominance scores may be considered as the objectively best next step in the continuation of research, the process lacks a go/no-go evaluation on whether one of the criteria is located outside of the realistic limitations of the research project, therefore penalties may be assigned to potential solutions that are considered unrealistic for the research project. The penultimate step is to rank the potential solutions before the potential solution is taken as the next logical step in the continuation of the research.

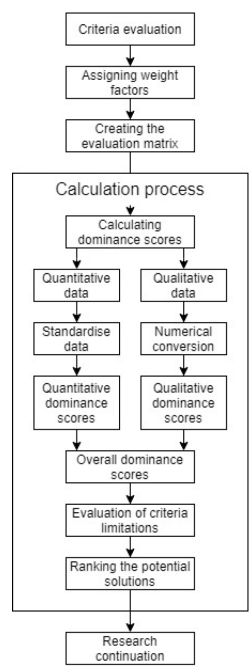

Figure 23: Overview of the MCA process

5.1.1 Potential solutions of the MCA

In this project, the Do-It-Yourself (DIY) fixed-wing drone called SVALBIRD-1 is compared head-to-head against the weather balloon. To enrich the understanding of what the future goals of the SVALBIRD vision should entail, several potential solutions that have similarities with SVALBIRD-1. The author's choice to opt for a DIY setup as a first prototype originates from the limited budget available for these development projects. Buying off-the-shelf solutions are much more expensive, but costs much less in development time. The consideration of these two facts can be simply modelled by a lump sum salary of €50 per hour for development is assumed. The potential solutions that have common grounds to the DIY fixed-wing drone are three distinct types of UAV systems that could replace the baseline in the future. Since this study focuses on building a fixed-wing drone, the data on this solution will be the most accurate, and the latter UAV types are estimated on the criteria according to their relative position to the fixed-wing drone.

Weather balloon The weather balloon is commonly used to study the higher atmosphere, and perform meteorological studies. A weather balloon is a single use tool for such measurements and can reach heights of up to 30km above sea level. During this time, data can be measured and transmitted to ground stations. The weather balloons are largely uncontrollable, the rotation of the payload during flight can be minimised by stabilisation during launch, however the course of the payload is controlled by the wind direction on different altitudes. There exists a large arrangement of literature [51, 41, 20] on weather balloons and their characteristics in different conditions and have therefore been used previously on rocket campaigns performed by UNIS and the KHO.

DIY fixed-wing drone (SVALBIRD-1) The fixed-wing drone excels in surveying applications. It is often used for agricultural and built-environment applications due to its ability to cover large distances on a single charge [25]. Fixed-wing drones require a large amount of energy to speed up to generate sufficient lift for level flight and therefore the payload capabilities of a fixed-wing drone is less than that of a quad copter. However, once up to speed, the ascent to higher altitudes is considered to be more efficient and therefore is capable of operating longer at high altitudes. The positioning of fixed-wing drones in the sky is relatively easy with flight computers that are able to fly by waypoints set by the operator on the ground. Though positioning is not a problem, the stability of the measurements due to the high cruising speed may cause disturbances in the measurements. The fixed-wing drone has yet to be used by UNIS and the KHO.

DIY quad copter drone The quad copter drone has recently become popular in commercial and private use due to its cheap costs and its ease of use in many different applications. The stability of a quad copter drone is considered one of its main assets for many uses in the field. Furthermore, the payload capability of a quad copter is considerable, however the range of flight and maximum altitude is strongly limited by these payloads. Especially on high altitude missions, the payload weight is extremely costly on its flight time. The simplicity and widespread use of quadcopters in many applications has lead to the use of quad copter drones in previous research projects for rocket campaigns by UNIS and the KHO [23, 24].

DIY VTOL fixed-wing drone The VTOL fixed-wing drone aims to combine the best qualities of a quad copter drone and a fixed wing drone, with Vertical Take-off and Landing (VTOL), the drone is capable of launching large payloads whilst accelerating to generate lift on the wing surfaces, and uses the large wing area to efficiently glide to higher altitudes. At high altitudes, the drone can be decelerated again by activating the VTOL rotors to generate lift for level flight such that the disturbances in measurements is reduced. The control of VTOL fixed-wing drones is more complicated than the previously mentioned solutions and therefore requires highly skilled drone pilots and will need to adhere to more strict regulations in the framework of civil drone safety of EASA as described in the previous chapter [25, 23, 24].

Off-the-shelf fixed-wing drone Similar to SVALBIRD-1, the fixed-wing drone excels in surveying applications. This potential solution distinguishes itself in the increased price tag in exchange for simplicity of the user. All construction and troubleshooting work is avoided by outsourcing. Furthermore, these off-the-shelf solutions tend to have the state-of-the-art technologies included such as autonomous flying, and are often certified to 'specific' and 'certified' categories in the civil drone regulations by EASA.

5.1.2 Criteria of the MCA

The five potential solutions will be evaluated on various criteria which are split into three subsequent categories: financial, environmental and technical.
During the MCA process, it is paramount that properties of the potential solutions are not double counted in different criteria, for example in user friendliness and regulation rigidity which overlap in the fact hat the regulation rigidity impacts the user friendliness of a potential solution. To avoid double counting, preventive measures are taken in the weighing process.

Financial

Long-term investment costs (CAPEX) - represent the purchase costs of a potential solution in first order, commonly referred to as Capital Expenditures (CAPEX). As some potential solutions are reusable, the Long-term investment costs include only the costs that are to be used over multiple campaigns such as ground equipment or materials and components that are returned without any apparent damage after a rocket campaign. Furthermore, the construction and troubleshooting work performed for the DIY UAV systems are considered with a lump sum salary of €50 per hour. These costs should be as low as possible to minimize the impact of the stakeholder's investment. The long-term investment costs are quantifiable costs expressed in Euros [€].

Campaign costs (OPEX) - represent the operational costs such as maintenance and expendable materials and components of a potential solution during a rocket campaign, commonly referred to as Operational Expenditures (OPEX). These costs are recurring on ever rocket campaign and are therefore kept as low as possible. The campaign costs are quantifiable costs expressed in Euros per campaign $\left[€ \cdot campaign^{-1}\right]$.

Environmental

Campaign emissions - represents the total emissions of CO_2 equivalent in the complete life-cycle of the expandable materials and components, and the maintenance of potential solution. For this criterium, a life-cycle assessment is drafted to quantify the emissions. The emissions are to be kept as low as possible to have a minimal impact on the environment. The campaign emissions is a quantifiable criteria expressed in kilograms of CO_2 equivalent emissions (kgCO$_2$eq.) per campaign $\left[kgCO_2eq. \cdot campaign^{-1}\right]$.

Campaign waste - represents the total waste material in kilos that is dumped in the Svalbard environment before, during, or after a campaign. For this criterium, the total mass of the potential solution that is launched during a campaign is multiplied by the chance of loss in the Svalbard environment. This campaign waste is to be kept as low as possible to have a minimal impact on the Svalbard environment. The campaign waste is a quantifiable criteria expressed in kilos per campaign $\left[kg \cdot campaign^{-1}\right]$.

Technical

Operational duration - represents the effective time of measuring that a potential solution can manage during a single launch. For this criteria, the time that a potential solution can be located above the cloud-layer of Svalbard at a theoretical altitude of 1500 m Above Mean Sea Level (AMSL) and within controllable distance to the ground station such that data can be transferred. The operational duration is preferably as large as possible to maximise the data collection. The operational duration is a quantifiable criterium expressed in minutes $[min]$.

Preparation time - represents the amount of work that is required to prepare the potential solution before every launch. If multiple persons are required to prepare the potential solution for launch, the total time is multiplied by the amount of personnel. This does not include the time of initial assembly. The preparation time is to be kept as low as possible. The preparation time is a quantifiable criterium expressed in minutes by person per campaign $\left[min \cdot person \cdot campaign^{-1}\right]$.

Data quality - represents the reliability of the data in image quality, the ability to control the imaging location, and the signal to noise ratio which is limited by the movement of the craft during launch. These three separate criterium are combined in a quantitative criteria as it can only be theorised at this moment. The overall data quality is to be kept as high as possible to gain as much knowledge as possible from launches during campaigns. This criterium is qualitative and therefore represented with a ranking from + to + + ++.

User friendliness - represents the difficulty of construction, preparation, maintenance, and control of the potential solution, before, during, and after a campaign. As in the previous criteria, various aspects are combined in one as these factors can only be theorised at this moment. The user friendliness is to be kept as high as possible to make the tool more accessible, and not to become a nuisance to the stakeholders during campaigns. User friendliness is a qualitative criterium and therefore is represented with a ranking from + to + + ++.

Regulation flexibility - represents the strictness of the regulatory framework surrounding the launch of the potential solutions outside, and during rocket campaigns. Furthermore, it represents the amount of preparation work that needs to be performed and presented to authorities for launch approval. The regulation flexibility is to be kept as high as possible to allow for sufficient room for experimentation and research during rocket launches without the craft being limited in their research capabilities due to regulations. The regulation flexibility is a qualitative criterium and there is represented with a ranking from + to + + ++ as it has a positive impact on the dominance score.

5.2 Results

According to the MCA process described in the previous section, the four potential solutions are graded according to the chosen criteria. Furthermore, the weighting factors have been determined by means of an interview with the main stakeholders of the project. In the following section, the three categories of criteria are discussed, followed by the final MCA results.

5.2.1 Stakeholder interview

From various discussions and interviews with the project leads and stakeholders the position from which the potential solutions should be evaluated is formulated. According to the stakeholders, better

data is always the goal of the research, however this is balanced by mainly the time and money that is required to reach this level of data. In particular, the time spend on bureaucratic processes such as regulations are heavily weighed upon their consideration. If regulations are strict to the point where the freedom of launching the platform is limited to such a degree that more time is spend on paper work than on the actual mission, it is considered to be outside of the limits of use.
Since it is unclear how many missions are to be flown with reusable potential solutions, the weight of campaign costs is hard to estimate according to the stakeholders. However, a low campaign cost allows for freedom in operation such that ideas can be tested with a significantly lower barrier. This is considered to be highly desirable. Moreover, the reusable platforms are highly desirable due to the possibility of using higher value payloads in future missions.

The environmental impact of the potential solutions is not considered to be of high priority as the impact is considered to be relatively small, the most emphasis is placed on the waste materials that are lost in the Svalbard environment. The environmental criteria are considered to be of lowest priority.

A permit to fly at any time with consideration of the authorities is considered to be the highest obtainable. Even if the data quality is considerably worse, the freedom of launching at any time is worthwhile.
Furthermore, importance of operational time was stipulated. Smooth operation with a small crew is considered to be ideal, for many of the potential solutions a crew is required for operations, this is considered to be less desirable than a long preparation time. Operation time of 50 minutes is considered to be sufficient, as longer missions are usually not performed.
According to the stakeholders, the possible flight conditions are considered to be of low importance for craft that are controllable in the air, in particular the user friendliness of the weather balloon is considered to be low due to the uncontrolled travel throughout its mission.

5.2.2 Criteria weighting

From the stakeholder interview, an overview of the importance of the three categories of criteria can be made. It was clearly stated that Technical criteria (50%) are a leading factor in decision making for research, this is closely followed by the Financial criteria (40%) as funding is often the limiting factor in continuing with research. The importance of the Environmental criteria (10%) is recognized, but from the research stakeholder point of view this is of least importance as the scale of waste that is generated is considered to be reasonably small.

From this, the financial criteria are given 10%, and 30% weights to the long-term investment costs and campaign costs, respectively. The campaign costs are considered to be more important as they are recurring for every operation. Since it is highly uncertain how many flights may be performed with the reusable solutions, the costs may not be easily combined. With the current weighting, it is assumed that the reusable platforms can be used thrice before decommissioning.
The environmental criteria consist of the kgCO_2eq. which is considered to be less important than the amount of waste dropped in the nature. Since the amount of emissions is relatively small, the waste material that is littered in nature is examined to be considerably more important.
Finally, the technical criteria consist of the operational duration, the least weighted criteria in this category due to the indifference in operational duration after the 30 minute flight time. Furthermore, the preparation time is considered to be similar in weighting. The three qualitative categories are considered to be of greatest importance in the multi-criteria analysis and are graded accordingly in direct interview of the stakeholders. From this the Regulation rigidity is considered of most value, after which it is shortly followed by Data Quality and User friendliness, respectively.

5.2.3 Multi-Criteria Analysis Results

In consideration of the various criteria for the four potential solutions, the following MCA matrix is generated. In this subsection, the content of this matrix will be elaborated upon for all criteria, respectively.

Table 2: Multi-Criteria Analysis table for the potential solutions of SVALBIRD.

Criteria / Potential solutions	Weather balloon	DIY Fixed-wing drone (SVALBIRD)	DIY Quad copter drone	DIY VTOL fixed-wing drone	Off-the-shelf fixed-wing drone	+ / -	Dimension	Weight [%]
Financial criteria								40
Long-term costs (CAPEX)	€ 1,000	€ 8,000	€ 7,000	€ 16,000	€ 30,000	-	€	10
Campaign costs (OPEX)	€ 400	€ 5	€ 8	€ 10	€ 25	-	€ per campaign	30
Environmental criteria								10
Campaign emissions	5	0	0	0	0	-	$kgCO_2eq.$ per campaign	5
Campaign waste	0.5	0	0	0	0	-	kg per campaign	5
Technical criteria								50
Operational duration	60	30	0	20	60	+	minutes	5
Preperation time	90	15	15	15	30	-	minutes by person per campaign	6
Data quality	+	++	+++	+++	++++	+	Qualitative	13
User friendliness	+++	++	++	+	++++	+	Qualitative	12
Regulation flexibility	+++	+	+	+	++	+	Qualitative	14
OVERALL SCORE	-80.57	29.11	-963.09	14.55	92.55			
RANKING	4	2	5	3	1			

Financial

Long-term investment costs - In the long-term investment costs, both the material costs and work required to construct the system were considered. This work was valued at a lump sum salary of €50 per hour. For the weather balloon this price consists solely of construction costs, as all material costs are included in the campaign costs. In the DIY fixed-wing drone, €2.000 is dedicated to the materials of building the drone, in addition to €6.000 in working hours (120 hours). Similar work hours for the quad copter are used whereas for the DIY VTOL fixed-wing drone the working hours were increase to 200 hours in total. Finally, the off-the-shelf solution was evaluated at €30.000 according to a quote from the market leader in fixed-wing surveying drones Wingtra. [52]

Campaign costs - The weather balloon campaign costs are quoted from the auroral balloon camera experiment proposal in appendix F.3. Furthermore the campaign are estimated on the likelihood of parts malfunctioning or breaking during regular operations. The most common breakages are ESCs and propellers, both these parts cost approximately €15 per piece. Since, the quad copter drone has double the amount of parts the chance of malfunctioning is increased. In particular for the VTOL fixed-wing drone, the moving motor mounts are more prone to breakages. Finally, for the off-the-shelf solution the price of these parts are increased because these logistics go through a third-part company.

Environmental

Campaign emissions - The campaign emissions of the drones are estimated to be negligible. Considering that the lifetime emissions of these drones is relatively small and that these drones can be reused for many times, this assumption is justified. For the weather balloon, this assumption does not hold, as the camera, battery, balloon, parachute and Helium are disposed after each flight the emissions are significant. The majority of the emissions are related to the batteries as they are by far the most impactful to the environment [53]. According to the international council of clean transportation the emissions related to LiPo batteries such as the one used for the night vision camera is estimated to be between 56 and 494 $kgCO_2eq.$ per kWh of battery. The battery used for this camera is 11.1 Wh, and therefore equals to 5 $kgCO_2eq.$ in its largest estimate.[54]

Campaign waste - Similarly to the campaign emissions, the drone systems are assumed to have negligible waste to the environment as the systems are proven to be reusable. Since the weather balloon weight approximately 500 g in total the the amount of waste per campaign is estimated to be 0.5 kg.

Technical

Operational duration -The operational time of the weather balloon has been estimated to 60 minutes as with the cloud layer ending on 2000 m AMSL, and the service ceiling of the balloon being 20000 m AMSL, the weather balloon will be in this altitude for 60 minutes with an average ascent speed of 5 m/s. SVALBIRD-1 the operational time of SVALBIRD is estimated to be 50 minutes approximately which includes climbing above the cloud layer which may take up to 20 minutes for ascent. The VTOL fixed-wing drone is estimated to have a slightly shorter operational time due to the extra weight it carries in the VTOL system. The off-the-shelf solution has a much larger battery on board which is capable of travelling twice the distance as SVALBIRD-1 [52].
In particular the DIY Quad copter drone is an interesting case, as previous projects at UNIS have shown little promise to a quad copter being able to carry the required camera equipment to above the cloud layer at all. Therefore the quad copter is not fit for its purpose here and will therefore get a hefty penalty in its scoring.

Preparation time - As we found during the auroral weather balloon experiment, the preparation time for the weather balloon is approximately 90 minutes. The SVALBIRD-1 preparation took approximately 14 minutes. It is estimated that there is a similar preparation time for the other DIY drones. However for the off-the-shelf solution, the protocols are much more advanced and the data that can be collected from those systems are much more advanced, increasing the preparation time.

Data quality - As discussed in the weather balloon experiment, the data quality of the weather balloon experiment is extremely poor, although the SVALBIRD-1 platform has proven to be far superior in stability, the data quality can still be improved upon. With the hovering capabilities of quad copters and VTOLs, the data quality is estimated to be even better. Finally, for the off-the-shelf fixed-wing drone platform, the data quality is estimated to be the best as the off-the-shelf solutions have a proven track record of years in experience from surveying various ground and air-based targets.

User friendliness - During the balloon experiment, the simplicity of the weather balloon showed in the preparation phase, all preparatory steps were clear and easy to execute. Furthermore, after launch, the data was logged automatically, and no there was no more work to be done on the flight itself making it a very user friendly method. The DIY drones are less user friendly as they have to be controlled by a dedicated pilot for the whole mission, whilst colleagues have to take care of the data and logging. The VTOL drone is the least user friendly as the control of the drone requires much more advanced technologies to fly. With autonomous flying the user friendliness of these drones would increase dramatically, and therefore the off-the-shelf solution is granted the top scoring rating in this category.

Regulation rigidity - The weather balloon launch was easily authorized by air authority and therefore is granted the highest rating versus the drone systems. The DIY drones must currently all operate in the 'Open' category which does not allow them to fly above the cloud layer, although the 'Specific' category rating is definitely feasible in a follow-up research project to allow this to happen. The off-the-shelf solution already is certified to the subsequent categories to fly above the cloud layer, however still permission has to be granted to fly above the cloud layer for every flight.

And thus from the results of table 2 it can be concluded that the off-the-shelf solution is the highest ranked potential solution. The main factor in this lies within its ease of use and simplicity of installation for the stakeholders. Furthermore, the rest of the drones such as the DIY fixed-wing or SVALBIRD-1 are highly ranked. This shows the potential of drones for auroral research in the future. The weather balloon will become much more expensive after many missions will be sent out and that is why the campaign costs are highly penalized in the overall score. Finally it must be noted that the DIY quad copter drone is disregarded as a possible solution to the research platform as it shows no capabilities of flying above the cloud layer on Svalbard and therefore is not fit for the requirements of SVALBIRD. Therefore the scoring of this potential solution is penalized.

6 Conclusion

In this work a vast process of ideation, design, construction, and testing has been considered to form a clear understanding of the possible solution space for an airborne research platform. The current state-of-the-art of weather ballooning has been proven to be outperformed by Unmanned Aerial Vehicles. In particular the case for using an off-the-shelf fixed-wing drone for a multi-functional research goal, such as using it for auroral studies during the polar night on Svalbard, and for oceanography or glaciology in the light season makes a strong financial argument for The University Centre in Svalbard. The Do-It-Yourself approach to developing a first prototype of a fixed-wing drone research platform for such purposes has brought great insight in the requirements and limitations to atmospheric research. In particular, the value of outsourcing the troubleshooting and development of already well established features in the current state-of-the-art in UAVs. This makes the case for the off-the-shelf solution so strong, as these, although expensive, solutions conform perfectly with the requirements of the stakeholders in their research plans.
Furthermore, a quadcopter drone and a VTOL fixed-wing drone are considered as a DIY option, however the quadcopter is not suitable for auroral studies as it is unable to carry a sufficient payload above the cloudlayer. The DIY VTOL fixed-wing drone has a mediocre performance due to the added costs and complexity of the setup.

Though the case for the DIY fixed-wing drone solution which was constructed during this work, called SVALBIRD-1, is still not neglected. The first prototype has shown great promise with regards to ease-of-use during troubleshooting. The open source platform of the Pixhawk flight controller has shown great potential in its active fora and community to help in the construction of a drone. Furthermore, the outstanding results during the flight testing has shown great hope for the stability of the platform at higher altitude and therefore is likely to be successful as a cheap option to auroral research before sufficient funding is acquired for the more complete off-the-shelf solutions. This success is formed in two ways, firstly the stability of the platform in crosswind conditions. The time pressure that was experienced in the flight testing phase of the project caused the author to accept a larger criteria of weather conditions for flight testing. In the first flight a 6 m/s mean wind speed with 9 m/s gusts was measured. This reached far beyond the expected capabilities of the SVALBIRD platform. Though it proved to be stable in even these conditions. Secondly, the second flight contributed greatly to the success of SVALBIRD-1 by showing the stability of the video platform and the reusability even after the worst possible crash conditions. The plane suffered minor damages from the impact and can be salvaged within a reasonable amount of time.

The ease of use for launching weather balloons still seems to be a feasible case, however greatly out performed by drones, the simplicity of launch and the fact that preparation requires only 90 minutes before a balloon launch without any prior construction or troubleshooting is tempting. The weather balloon may serve as a platform to verify that the vast increase in funding for permanent drone systems at the KHO is worthwhile in there studies for aurora borealis.

It is therefore unequivocally the case that it is advantageous for the Kjell Henriksen Observatory and The University Centre in Svalbard to replace the disposable, expensive, and polluting weather balloons by drones for their airborne research projects with various air- and ground-based targets. In the short term with the SVALBIRD-1 platform which can be developed continuously in further research projects, and in the long term with off-the-shelf fixed-wing drone solution.

7 Recommendations

Following this work, the author advises the stakeholders to continue to explore the capabilities of fixed-wing drone research platforms for their airborne campaigns. The first step in this is employing more researches at The University Centre in Svalbard, which may be in the form of interns or exchange students similar to the nature of this work. These researchers may continue the work on the SVALBIRD-1 prototype. For this, the budget of does not have to be increased dramatically, as most material requirements are in place to advance the project. The repairs on SVALBIRD-1 are feasible with materials at the logistics department of UNIS, and the operations of SVALBIRD-1 may be continued. In particular an interesting next opportunity is to start working towards a type certificate for SVALBIRD-1. This must be performed in close relation with the European Union Aviation Safety Agency, and therefore UNIS must make an effort to form a close partnership with this organization. As this work has concluded that the drone platforms form a great potential for research throughout many departments of UNIS, the efforts of this project may be spread to more departments. The arctic biology department is a great candidate for this. As in particular the head of this department has continued to show its interests in drone projects, as can be seen in his prior support to this work.
Further work, and publications on this topic will strengthen the argument and storyline of the stakeholders in applying for sufficient funding to get off-the-shelf solutions for a permanent airborne research division. The promise of drone systems for this type of research has been a clear outcome of this work, and it will undoubtedly be the case for these further projects.

With these funding applications, new research opportunities open up. Such as the market research for the best and most suitable off-the-shelf solution for the stakeholders. This work has merely assumed a basic understanding of the state-of-the-art in the privatized drone business, and therefore can not make a strong recommendation on which system to aim for at this point. Furthermore, it is expected that the process of acquiring this funding will take a vast amount of time, in which the state-of-the-art in this business has rapidly advanced. It is therefore paramount that the state of this market is monitored closely during the funding application process.

There are also more practical matters that can be recommended in succession of this work. In particular the importance of redundancy is key to the success of the airborne research division for the stakeholders. If the gap in the aurora data due to cloud coverage must be sealed permanently, multiple drone systems must be employed. The logistics of this matter are no simple task and will require full-time leadership. Furthermore, it is inevitable that. even with with an autonomous drone, accidents during campaigns will continue to happen and the stakeholders must be prepared for this. In particular parts such as propellers, motors and Electronic Speed Controllers are to be in stock at all times in further research.

The author is positively inclined in concluding that the future of drone operations on Svalbard will be successful and wide-spread for multiple applications, and that the Kjell Henriksen Observatory and The University Centre in Svalbard can be the leader in this rapid technological advance.

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A Financial support: context and conditions

In anticipation of the author's visit to Svalbard, Norway over a thirteen long week internship at The University Centre in Svalbard, to construct the first prototype of SVALBIRD: SVALBIRD-1. The fourth quartile of the academic year 2020/2021 was dedicated to draft the SVALBIRD project proposal (Appendix D), and use this to secure a budget. To this end, several potential financial supporters were contacted from organizations such as European Space Research and Technology Centre (ESTEC), the University fund at the Eindhoven University of Technology, and ultimately the Netherlands Aerospace Centre. The latter of which agreed to fund the SVALBIRD project with a budget of €2.000,- excluding VAT, in exchange for a Kjell Henriksen Observatory in-house developed Hyper Spectral Imager.
The transaction was agreed upon on September 1st, 2021, from which the budget was transferred to a separate project account at Eindhoven University of Technology accessible to the author for materials, shipping costs, and courses. The project account will be accessible until the end of the internship.

The author is free to declare purchases to the project account with regard to the project, the proposed bill of materials int he proposal has varied over the project's span, and therefore the costs have changed. Furthermore, in troubleshooting several packages were mailed to UNIS's post address with replacement parts which have been declared, separately.
The full list of declarations is given in table 3.

Table 3: Complete list of invoices that have been declared to the project's account within the project budget.

Item	Description	Quantity	Price [original]	Price [euros]	Invoice
Hand-held controller	FrSky ACCST Taranis Q X7	1	€ 106.47	€ 106.47	BangGood
Banggood Transport	Shipping & Insurance	1	€ 2.13	€ 2.13	BangGood
Flightcontroller	Radiolink Pixhawk with GPS	1	€ 129.27	€ 129.27	RobotShop
RobotShop Transport	Verzenden	1	€ 6.89	€ 6.89	RobotShop
Heat shrink tubing	Krimpkousen set 120-delig	1	€ 5.70	€ 5.70	P&D Products
Drone license	EU Dronebewijs (compleet)	1	€ 199.00	€ 199.00	DroneClass
Brushless Motor	PROPDRIVE V2 3530 1400KV Brushless	2	$ 53.18	€ 45.97	HobbyKing
Electronic Speed Controller	Turnigy MultiStar 32 ARM 41A Race Spec ESC 2~5S	2	$ 36.56	€ 31.60	HobbyKing
Single Board Engine Computer	YEP 20A HV (@~12S) SBEC	1	$ 18.99	€ 16.41	HobbyKing
Propellor	Carbon Fiber Propeller 12x6 (2pcs)	2	$ 23.98	€ 20.73	HobbyKing
Hobbyking Transport	Shipping & Handling	1	$ 10.20	€ 8.82	HobbyKing
Drone	MFE Believer - KIT	1	£ 241.58	€ 286.36	3DXR
Airspeed Sensor	Holybro Digital Airspeed Sensor	1	£ 51.25	€ 60.75	3DXR
Buzzer	Pixhawk 2, Cube USB & Buzzer	1	£ 2.42	€ 2.87	3DXR
Power Module	Hlybro - PM02 Power Module Support to 12S	1	£ 15.00	€ 17.78	3DXR
Battery	Gens Ace - Bashing - 4S 8000mAh 80C LiPo	1	£ 83.29	€ 98.73	3DXR
Servo	EMAX ES3054 17g Digital Servo with Bearing	4	£ 33.16	€ 39.31	3DXR
Power Switch	Mauch 059 - PC - Series 'V3'	1	£ 13.00	€ 15.41	3DXR
Transmitter Upgrade	RF Design - RFD900x TXMOD V2 (RC Transmitter Modulle)	1	£ 204.17	€ 242.01	3DXR
3DXR Transport Svalbard	DHL Economy Select	1	£ 132.20	€ 156.70	3DXR
XT60 Male Connectors	XT 60 stekker, Man (4 stuks)	2	€ 9.00	€ 9.00	TopRC
XT60 Female Connectors	XT 60 stekker, Vrouw (4 stuks)	2	€ 9.00	€ 9.00	TopRC
Battery Charger	iMAX B6AC V2 Professional Balance Charger/Discharger	1	€ 65.95	€ 65.95	Bol.com
Jumper Cables	DuPont Jumper draad Male-Female 100cm 10 draden	4	€ 14.00	€ 14.00	TinyTronics
High gauge wire	Luidsprekerkabel vol koper - rood/zwart - 2x2.5mm^2 (3meter)	1	€ 7.50	€ 7.50	Brigatti Electronics
Batteryclip	Batterij houder 6x AA	1	€ 1.95	€ 1.95	HobbyElectronica
HobbyElectronica Transport	Verzending	1	€ 2.95	€ 2.95	HobbyElectronica
Batteries	24 x AA Energizer Alkaline Power	1	NOK 119.00	€ 11.86	Svalbardbutikken
Transport to Svalbard	Bagagge on commercial aircraft	1	NOK 600.00	€ 59.80	Norwegian
Zipties and velcro tape	Zipties and velcro tape	1	NOK 123.00	€ 12.26	Svalbardbutikken
Troubleshooting 1	Various cables for drone reparation	1	€ 10.45	€ 10.45	TinyTronics
Shipping	International shipping without track and trace	1	€ 6.00	€ 6.00	PostNL
Troubleshooting 2	ESC for drone reparation	1	€ 18.70	€ 18.70	HobbyKing
Shipping	International shipping with track and trace	1	€ 18.50	€ 18.50	PostNL
Troubleshooting 3	Various ESCs and motor for drone reparation	1	€ 132.41	€ 132.41	HobbyKing
Shipping	International Express shipping	1	€ 52.45	€ 52.45	ParcelParcel
Transport to Netherlands	Bagagge on commercial aircraft	1	NOK 600.00	€ 59.80	Norwegian
Drone Certificate A1-A3	RDW administration fee for drone certtificate A1-A3	1	€ 10.00	€ 10.00	RDW
Drone Certificate A2	RDW administration fee for drone certtificate A2	1	€ 10.00	€ 10.00	RDW
		Total		**€ 2,005.49**	

The budget is rounded down to €2.000,00 and the remainder is waived on behalf of the author.

B Civil drone certificates for the open category

As stated in section 2.4.1, to fly a UAV in the Open regulations on Svalbard, one must be educated for these three categories through online teachings through various third-party organisations. As part of this internship, the author has taken part in such online teachings at a private organization Drone Class, at `eudronebewijs.nl` [58]. From which the author has received two certificates to operate any kind of UAV in the Open regulations of EASA, in Svalbard and any other EASA member state.
The following two documents, were received on September 24th, 2021. The former of which is the proof of graduation from the online theory exam (figure 24), the latter is the certificate of proficiency in all Open category regulations of Civil drone activities (figure 25).

Figure 24: The author's proof of graduation from the online theory exam of EASA open category regulations for Civil drones. Received on September 24th, 2021.

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

EASA European Union Aviation Safety Agency

Nederland

RDW

A2 OPEN CATEGORY

Vaardigheidsbewijs

Voornaam: **Brandon J A**
NLD-RP-dt2c7eil3ju7

Achternaam: **van Schaik**
Datum geldig tot: **24.09.2026**

Figure 25: The author's certificate of proficiency in all Open category regulations of Civil drone activities. Received on September 24th, 2021.

C 3D prints for SVALBIRD-1

The author designed several custom made mounts for the aurora camera to fit in the drone fuselage. In this appendix, the designs of the prints are shown including a brief description of the purpose of the part. These designs were made in Autodesk Fusion 360.

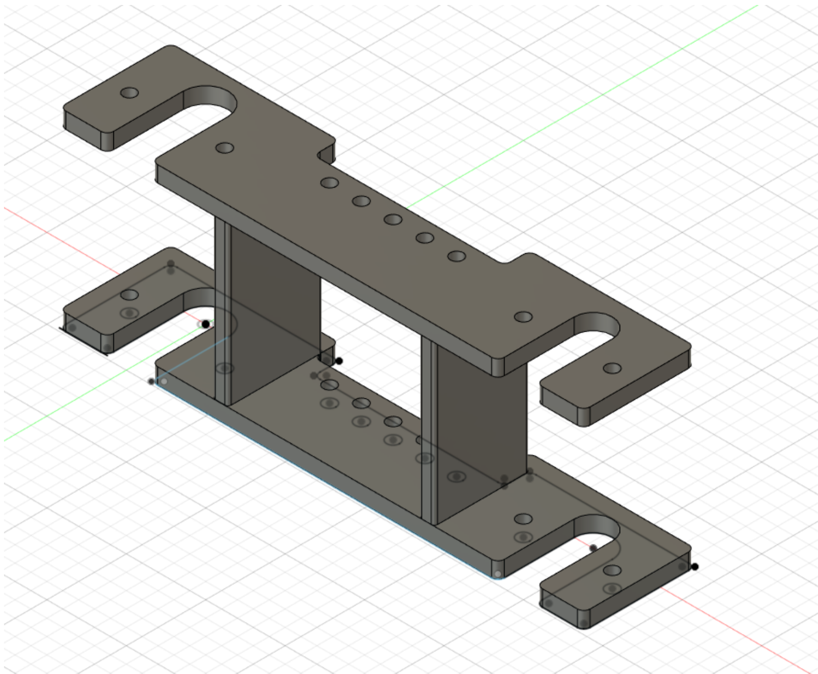

Figure 26: The camera mount used to fit the aurora camera between the two carbon spars in the middle of teh drone fuselage.

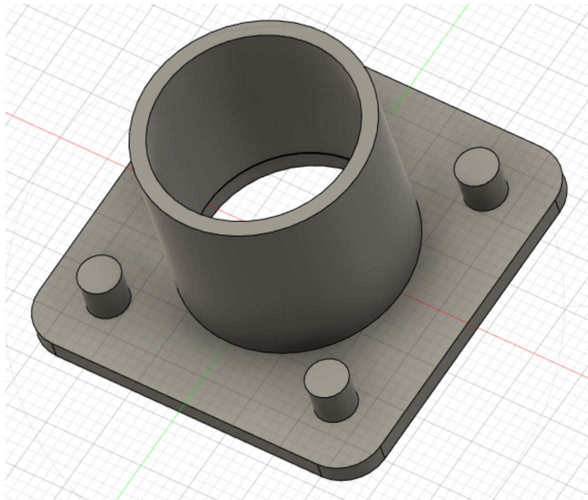

Figure 27: The reinforcement cap for the top of the drone fuselage to fit the camera through and reinforce its position.

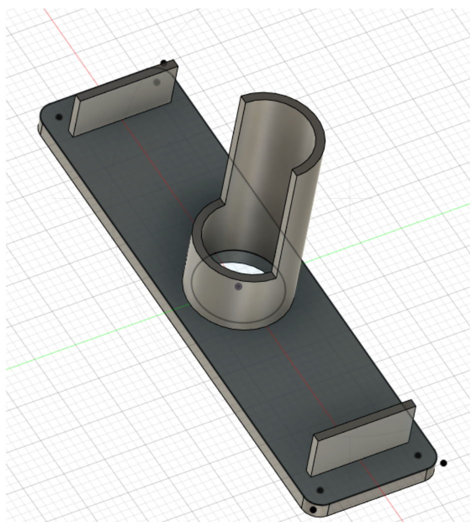

Figure 28: The reinforcement cap for the bottom of the drone fuselage to fit the antenna and protect the external part of the antenna during impacts due to landing.

D SVALBIRD project proposal

Below the final proposal for the SVALBIRD project, drafted on May 25th, 2021.

SVALBIRD – A fixed-wing drone photography platform above the cloud layer on Svalbard

Brandon van Schaik[1,2], Fred Sigernes[1] & Hjalmar Mulders[2]

[1] The University Centre on Svalbard (UNIS), N-9171 Longyearbyen, Norway

Correspondence concerning this proposal can be addressed to:
b.j.a.v.schaik@student.tue.nl (Brandon van Schaik)

Summary

The project to develop a fixed-wing drone photography platform that provides a sustainable solution for aurora imaging above the cloud layer on Svalbard. Furthermore, the platform should also be sufficiently multi-functional to photograph ground-based targets for surveying applications. Ultimately, the platform aims to provide real-time footage (25fps) of air-, and ground-based targets. This project serves as a steppingstone to enable a hyper spectral imaging platform above the cloud layer in future research, which has a large potential market (e.g. military, surveyors, prospectors, geophysicists, meteorologist, marine biologists, glaciologists, etc.).

Contents

1. Introduction

The Kjell Henriksen Observatory (KHO) operates rocket campaigns to study the aurora borealis near Longyearbyen, Svalbard (78° N 16° E). As Svalbard is often cloud covered, the importance of an 'eye above the cloud' is prevalent. Traditionally, single-use weather balloons are used to study the dayside cleft aurora and airglow from the KHO. Though, this solution works is limited in its use conditions, the problem of losing the payload after a single launch limits the capabilities of using more expensive equipment, like hyper spectral cameras, on such expeditions.

The financial and environmental waste that is created calls for a sustainable alternative that both cuts costs, and 'travels' with it's time to ensure minimal waste to the pristine environment of the Svalbard archipelago. A fixed-wing drone platform can satisfy all these requirements whilst also providing valuable information on ground- and air-based targets with large potential markets, without competitors yet, by using hyper spectral imaging.

Hyper spectral imaging

The recent developments in drone technology, CMOS (Complementary Metal Oxide Semiconductor) image sensors, gimbals based on MEMS (Micro Electro Mechanical Systems), IMUs (Inertial Measurements Units) and 3D printing open new possibilities on how to construct and use our instruments from airborne platforms. One example is our small size and low weight (<200 g) serial produced Hyper Spectral Imager version 4 (HSI v4) made for medium sized commercially available Quadcopters capable of handling payloads less than 1 kg [1].

Figure 1: Three out of ten serial produced Hyper Spectral Imagers (HSI) version 4 by Moon labs.

Ongoing work to test the HSI v4 includes not only gimbal stabilization during airborne campaigns, but also calibration and data handling [2,3,4,5]. This instrument is a clear candidate to our project during daylight conditions.

The main drawback is the operational range, short flight time and payload capability of medium sized commercially available drones. We therefore propose to develop a fixed-wing drone platform with new operational possibilities in range and speed with 700g payload to test our already developed instruments. The complete system named SVALBIRD will handle both traditional daylight remote sensing of the ground surface and low light detection of aurora above the cloud layer of the Kjell Henriksen Observatory (KHO).

Kjell Henriksen Observatory

Note that KHO is operated by UNIS and is a world-class optical observatory located 12 km from Longyearbyen, Svalbard (78° N 16° E). Its main target is the dayside cleft aurora and airglow. KHO, located on the same hilltop as the EISCAT Svalbard radar, hosts instruments from 24 different institutions. This includes 17 non-optical instruments and 28 optical instruments that run 24 hours a day (within typical sunlight constraints), including eleven all-sky cameras, meridian scanning photometers, fluxgate and induction coil magnetometers, and a variety of spectrometers. These instruments supported the SCIFER, CAPER, SERSIO, SCIFER2, CREX, CAPER2, CHI, ICI-1-5, RENU and RENU2 rocket campaigns by NASA. The data from KHO provided important information regarding context in making the decision to launch, as well as complementing the in-situ observations of future rockets and radar campaigns.

2. The fixed-wing drone platform

The fixed-wing drone platform consist of three main elements: the fixed-wing drone model, the telemetry, and the payload. In the following section the three elements are discussed:

Fixed-wing drone

In this project, we aim to use a 'believer' model fixed-wing drone as the first prototype. It has a wingspan of 1960mm and can carry a payload of up to 700g additionally, next to the UAV and telemetry. The maximum take-off weight is 5.5kg and the recommended flying speed is 20m/s.

Figure 2: The 'Believer' fixed-wing drone model.

With correct telemetry and electronics, the Believer can fly above the cloud layer in Svalbard, at approximately 1500m AMSL.

Due to the hardened bottom of the vehicle, the drone can be landed on soft soil or snow. The latter of which is in abundance at the KHO on Svalbard. Furthermore, it is also possible to catch the drone with nets and blankets in an emergency.

Electronics and telemetry

The drone requires two motors, four servo motors, an Electronic Speed Controller (ESC), and a Battery Elimination Circuit (BEC), LiPo battery, current sensor and a controller. Moreover, several sensors are required in the telemetry, such as: GPS, pressure, temperature, humidity, airspeed sensor and a small RGB camera. Controlled by a RasberryPi.

Payload

The payload consists of a camera with a logging device connected to its own transceiver. Consider figure 3 of the aurora balloon camera. The RunCam Night Eagle FPV camera has a transmitting range of up to 5 km with the 2.4GHz, 500mW transmitter.

This payload is supplied by the Kjell Henriksen Observatory and therefore isn't included in the final parts list. The payload as an approximate worth of €500,-.

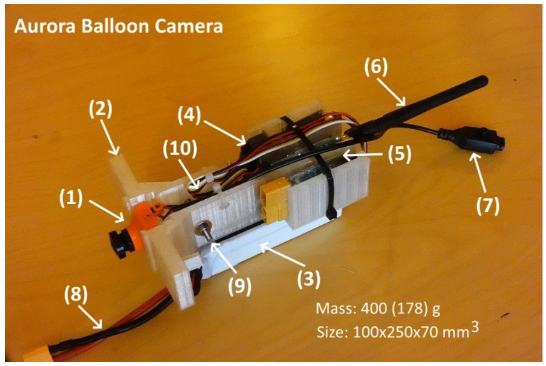

Figure 3: Camera mounted to 3D printed mount frame. (1) RunCam Night Eagle camera, (2) 3D printed mount frame, (3) 11.1V 3S 1000mAh LiPo battery, (4) On Screen Display module (OSD) with GPS, (5) OSD Current sensor, (6) 2.4GHz 500mW A/V – Tx Video Transmitter, (7) OSD setup mouse, and (8) battery power cord. Left shows experimental setup.

Experimental setup

From this the following experimental setup is derived in figure 4:

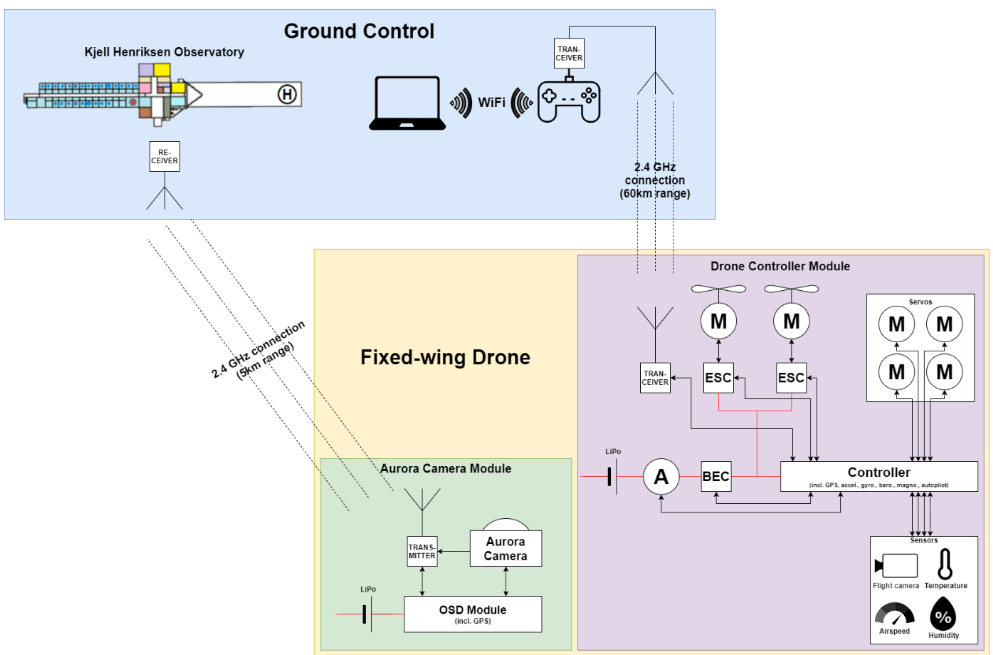

Figure 4: Experimental setup

In the first tests, the Aurora Camera Module will be a separate unit inside of the Fixed-wing drone airframe, as the camera module is already constructed as its own entity. In further prototyping, the aurora camera may be connected to the drone controller module, making the second transmitter and receiver connection, directly to the KHO redundant.

Complete system

The complete system combines the three elements, from which we find the following bill of materials and budget for this project:

3. Value proposition

In this section, the details of both expedition modes are discussed. From these examples, a deliberation will be made on the cost and benefits of the subsequent options. Firstly, a typical weather balloon expedition is described after which a typical fixed-wing drone expedition is covered. Finally, a simple calculation for the added value is

Example expedition: Weather balloon

According to KHO staff experienced with launching weather balloons, launching a weather balloon is a two-person job of 30min. The equipment on-board is expendable as there is no recovery of the balloon and the payload after launch.

Furthermore, the control of the weather balloon is extremely limited as the trajectory is based on the wind. Consider the following trajectory of a weather balloon traveling over 42km in ascent with a payload of 1050g, and a total of 60km over the whole trajectory:

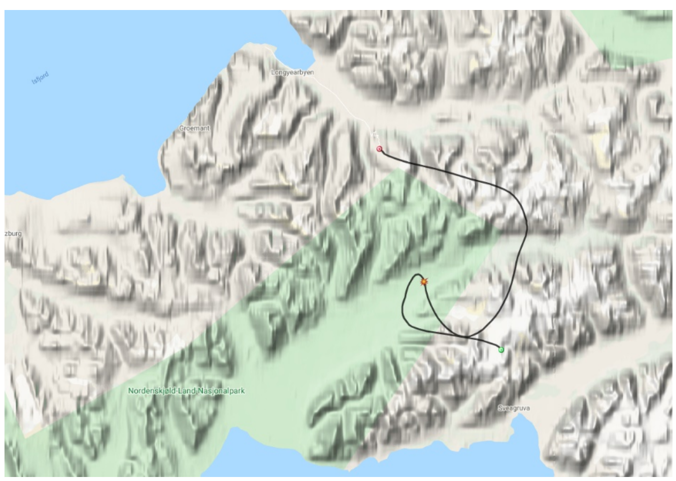

Figure 5: A typical trajectory of a weather balloon launched at the KHO. Including bursting and landing positions on Svalbard.

In total, the balloon travelled 25.9km from launch to landing, as the crow flies. The balloons ascend at an approximate speed of 5m/s and have a bust altitude of approximately 30,000m. Since KHO is located at 500m, the total flight time is about 100min. Finally, the weather balloons are filled with 0.6kg of Helium, sourced locally from Longyearbyen.

Example expedition: Fixed-wing drone

According to drone experts from TU/e, the operation of a VTOL airplane drone is a one person job lasting the whole mission flight time with about 30 minutes of preparation (programming mission plan, charging batteries, unpacking drone, calibrating IMU and GPS etc.). The on-board equipment is 100%

reusable after recovery of the drone which can be landed practically 'on a dime' with the VTOL capabilities.

According to the believer drone manufacturer capable of carrying a payload of 700g, to up to 3000m in altitude. With a cruise speed of 20m/s and large range potential due to the large payload. This drone may fly up to 300+km according to estimates of the drone experts from TU/e.

A large concern of using survey drones in Svalbard is crosswinds and icing on propellers. Crosswinds up to and above 25km/h are manageable. Furthermore, the impact of icing on the drone's stability is unclear and will be investigated in this project.

Added value

Man-hours

Assuming a similar mission length for a balloon and drone flight. The weather balloon mission totals at 1 man-hours (excluding data processing) spread over two staff members, whereas the drone requires 30min preparation + 100min of flight time totaling at 1.7 man-hours (excluding data processing) for one staff member. A forfait salary of €100 per hour is assumed.

Investment costs

Every balloon launch requires the investment in a balloon, Helium and payload. For a regular camera set-up these costs are approximately €500,- per launch. In the case of using a hyper spectral imager, the costs rise over €10.000,- per launch due to the preciousness of the device. The drone is reusable and therefore only requires a small investment in maintenance and charging of less than €5 per flight,

next to the initial investment of €1.000,-. A drone can be flown for 500+ flights before retirement. Totaling at less than €7 per flight.

Applicability/User friendliness

According to the UNIS weather balloon experts, balloon is effectively measuring from above the cloud layer until burst. (1.500m – 30.000m AMSL). Reducing rotation of the camera at launch is key and under high wind the camera footage may be unusable due to the fast rotation. The drone can fly at constant altitude and a sufficiently low speed such that the impact of the movement will not impact the footage. Furthermore, due to the large payload capacity a great value is created by opening the market to ground-based targets as well as multiple air-based target options besides aurora.

Summary

In conclusion the following deliberations can be made:

Cost-benefit deliberation for both expedition platforms

Platform / Criteria	Weather balloon	Fixed-wing drone	Dimension
Man-hours	€ 100	€ 170	€ per expedition
Investment costs	€ 500 (> €10.000 for Hyper spectral setup)	< € 7	€ per expedition
Applicability/User friendliness	Single application. (- - -) Susceptible to wind. (-)	Ground and air targets (+ + +) Can operate in worse conditions (+)	Qualitative

For a regular camera setup, the fixed-wing drone platform costs less than a third of the weather balloon. With the hyper spectral camera setup, the fixed-wing drone platform is more than 50 times cheaper with more capabilities in the harsh Svalbard conditions.

4. Involved parties

Project partner – University Centre in Svalbard (UNIS), Longyearbyen. The University Centre in Svalbard (UNIS) is the world's northernmost higher education institution, located in Longyearbyen at 78º N. We provide research-based education of the next generation of Arctic experts in biology, geology, geophysics and technology. In this vision, UNIS aims to enable better solutions to geophysical surveying on Svalbard and throughout the polar regions.

Project partner – Kjell Henriksen Observatory (KHO), Longyearbyen. The Kjell Henriksen Observatory (KHO) in Svalbard is an optical observatory located at the archipelago Svalbard 1000 km north of mainland Norway (78 º N 16 º E). Here more than 25 optical instruments as well as other non-optical instruments, are employed for research on the middle- and upper atmosphere. The KHO is a world leader in polar surveying and aims to continue innovating with this project. **KHO LOGO**

Involved Party – Eindhoven University of Technology (TU/e), Eindhoven. TU/e is a leading international university specialized in engineering science and technology and aims to contribute to solving the major issues in the field of sustainability. The TU/e wants to be among the most sustainable universities in the Netherlands and has opted for an integral approach. The TU/e has collaborated extensively with the project partners via internships and graduation exchanges.

5. Activities and Deliverables

This project is intended as a feasibility study for imaging ground and air targets using a fixed-wing drone above the cloud layer in Svalbard. Therefore, within the project trajectory, the following activities will be performed:

1. In the research phase, a study on the possible design solutions that have been researched previously will be carried out. During this phase, the following aspects will be detailed:
   a. The test requirements will be determined. What are the basic requirements for a fixed-wing drone above the cloud layer on Svalbard?
   b. The fixed-wing drone platform, and what capabilities it has. There is particular focus on whether this platform adheres to the test requirements.
   c. The payload will be detailed, consisting of maximum weight, data streams and its ability to reach all targets.
   d. The telemetry and electronics will be detailed on the platform to communicate with the ground control.
   e. The goals of the experimental test plan will be determined.

   After completion of this phase, the project group will deliver a report on the possible design solutions for ground and air targets using a fixed-wing drone above the cloud layer in Svalbard, detailing the required components.
2. The construction phase follows with the ground testing of the critical success factors of the fixed-wing drone platform and its payload and finally the construction of the platform. In this phase, the following aspects will be considered.
   a. The operation conditions of the payload. Here, the stability conditions of the payload camera are determined.

   b. The communication and data streams will be tested to ensure flawless communication during flight.
   c. The fixed-wing drone platform will be constructed and connected to the ground control. This includes proper pre-flight testing.
   d. The goals of the experimental test plan from phase 1 will be reconsidered and detailed to fit within the project's capabilities and requirements.
   e. Finally, the first images will be taken from the ground-laying platform of the aurora.

   After completion of this phase, the project group will deliver an extension of the report detailing the experimental setup with finalized components including, but not limited to wiring diagram, payload details and communication systems.
3. Finally, the experimental phase succeeds the construction phase. In this phase, the fixed-wing drone platform will be flown in different experimental conditions as determined in the previous phases. In particular, the following deliverables will emerge:
   a. What are the operational conditions of the fixed-wing drone platform? This includes, but is not limited to temperature ranges, windspeed, humidity, light level and illumination, operational range and visual contact with the platform
   b. Aurora images taken during flight of the fixed-wing drone platform above the cloud layer of Svalbard.
   c. Ground based images of requested locations on Svalbard including its nearby coastlines.

These three phases are the main contents of this first technical feasibility study of the SVALBIRD project. In succession to this project, further research will be performed on implementing the hyper-spectral camera setup on the fixed-wing drone platform. In the long term, the Kjell Henriksen Observatory and the University Centre in Svalbard have a research agenda including autonomous fixed-wing drone surveyors which will be able to supply large quantities of data of the air and ground based targets on Svalbard for many research applications and the calibration of research equipment.

To this end, the project phases can be listed in subsequent work packages:

1. **Create a list of Requirements, Preferences and Constraints (RPCs)**
   The list of RPCs of the intended research subjects is determined including their respective goals. These will be detailed further in work package 6. **Deliverable:** RPC list.
2. **Design solution research**
   The platform, payload, telemetry and electronics will be researched, and a complete list of materials is created. **Deliverable:** Report on possible design solutions for ground and air targets using a fixed-wing drone above the cloud layer in Svalbard, detailing the required components
3. **Ground testing**
   The operational conditions of the payload are determined. **Deliverable:** Operational conditions of the payload.
4. **Design-focused modelling**
   Using the previous work package's deliverable, the intended fixed-wing drone platform will be modelled including the components and their internal wiring and communication streams. **Deliverable:** digital model of the fixed-wing drone platform
5. **Basic imaging**
   The first Aurora will be taking from the ground laying drone to test all equipment and communications. **Deliverable:** Aurora images, go/no-go on drone flight.

6. **Experimental testing**
   The drone will undergo several experimental tests as determined in work package 1. **Deliverable:** the operational conditions of the fixed-wing drone platform.
7. **Advanced imaging**
   The drone will image requested target such as the Aurora using the standard payload camera as detailed in figure 3. **Deliverable:** fixed-wing drone images above the cloud layer on Svalbard.
8. **Project management and planning**
   The project will be managed and guided by the chief of the Kjell Henriksen Observatory, Fred Sigernes and the project coach, Hjalmar Mulders.

The project group aims to perform the above-mentioned work packages according to the following planning in figure 6:

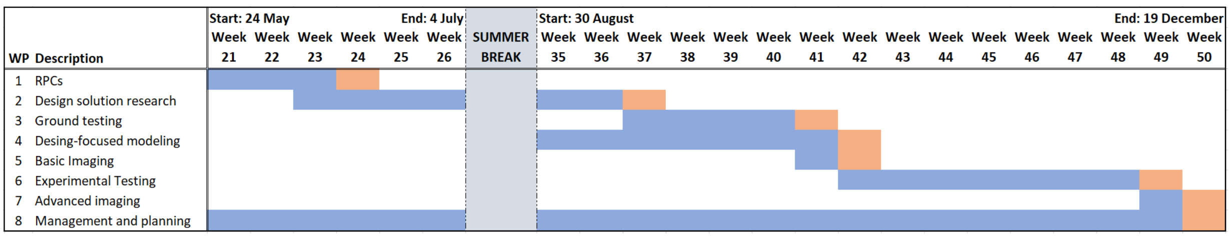

Figure 6: Project planning

6. Future plans

This project is meant as a first prototype to greater drone imaging plans for the main stakeholders: University Centre in Svalbard and the Kjell Henriksen observatory. In succession to this project, the stakeholders aim to scale up the drone to a larger variant which enables long term flight on Svalbard. In addition to this, the possibility of introducing solar panels to the aircraft would increase the operational time even further. Potentially, the drone can be scaled up to fly indefinitely during the 'midnight sun' days on Svalbard for extensive surveying research.

References

1. Fred Sigernes, Mikko Syrjäsuo, Rune Storvold, João Fortuna, Mariusz Eivind Grøtte, and Tor Arne Johansen, "Do it yourself hyperspectral imager for handheld to airborne operations," Opt. Express 26, 6021-6035 (2018), https://doi.org/10.1364/OE.26.006021
2. Marie Bøe Henriksen, Joseph Landon Garrett, Elizabeth Frances Prentice, Fred Sigernes, Annette Stahl and Tor Arne Johansen (2019), Real-time Corrections For A Low-cost Hyperspectral Instrument, *IEEE,* https://doi.org/10.1109/WHISPERS.2019.8921350
3. *Marie Bøe Henriksen,* Master, May 2019, Hyperspectral Imager Calibration Characterisation and Image Correction, Department of Engineering Cybernetics, Norwegian University of Science and Technology.
4. *Charlotte Maartje Van Hazendonk*, Erasmus+ Trainee, Calibration of a Hyper Spectral Imager, Eindhoven University of Technology, The Netherlands, August - December 2019.

5. *Adrienne Esmeralda Oudijk*, Erasmus+ Trainee, Hyperspectral Data Cube Compression Techniques and Quality Assessments, Eindhoven University of Technology, The Netherlands, February - June 2020.

E Pre-flight checklist

- ☐ Check battery charge on drone battery.
- ☐ Connect USB cable to laptop and Pixhawk.
- ☐ Check all high voltage cables to be connected correctly.
- ☐ Check all servo and control cables to be connected correctly.
- ☐ Align GPS module and Pixhawk body in the flight direction.
- ☐ Calibrate the accelerometers through MissionPlanner.
- ☐ Calibrate the compass through MissionPlanner.
- ☐ Turn on hand held radio.
- ☐ Check hand held radio battery charge.
- ☐ Calibrate radio in MissionPlanner.
- ☐ Verify GPS lock on GPS module and MissionPlanner.
- ☐ Verify the main LED on the Pixhawk is blinking blue (blue, off, blue, off...).
- ☐ Arm the drone by pushing the left handle on the handheld to the bottom right for several seconds.
- ☐ Press and hold the arm switch connected to the Pixhawk, the LED on the switch should. turn solid green.
- ☐ Calibrate the servos through MissionPlanner, make sure all servos move correctly with all stick movement.
- ☐ Calibrate the ESCs by unplugging the high voltage cables to the ESCs. Throttle up to maximum throttle. Reconnect the high voltage cables as before. The ESCs will make a musical melody. When the melody finishes, throttle down to minimum. Another ESC melody will play.
- ☐ Verify the drone is assembled securely.
- ☐ Close all latches on the main body.
- ☐ Perform ground test 1: Servo and propeller test. In this test the propellers are tightened to the motor axis, and the system is armed. The drone is held off the ground in a safe, outdoor area where the pilot throttles up to 20% of maximum power and confirms that the propellers are moving in the correct direction and at approximately equal power. When the motors are power, all servos are tested to confirm they move in the correct direction for any input. Continue if successful.
- ☐ Perform ground test 2: Peak power test. In this test, the propellers are tightened to the motor axis, and the system is armed. The drone is held off the ground in a safe, outdoor area where the pilot throttles up slowly over the course of approximately five seconds to maximum power, after which the pilot immediately throttles back to 0% throttle in approximately three seconds. Continue if successful.
- ☐ Perform ground test 3: Sustained maximum power test. In this test, the propellers are tightened to the motor axis, and the system is armed. The drone is held off the ground in a safe, outdoor area where the pilot throttles up slowly over the course of approximately five seconds to maximum power, after which maximum power is held for at least ten seconds before the pilot throttles back to 0% throttle in approximately three seconds. Continue if successful
- ☐ Turn on LED blinker light to blink in green.

- ☐ Check for suitable landing zone in the vicinity. (Look for soft snow or grass/moss, reasonably flat, of slightly inclined uphill. Minimum width of three meters, Minimum length of ten meters. Make sure there are no tall obstructions within a range of 50m in the landing approach direction. Check for cross winds, the landing should preferably be done in head wind conditions.)
- ☐ Check for any unsuspecting humans and, or animals within a range of 150m around the launch and landing site.
- ☐ Check for other air traffic (planes, helicopters, UAVs, birds). Make sure there is a clear area of 150m in radius around the launch and landing site before continuing.
- ☐ Turn on aurora camera.
- ☐ Turn on receiving setup for aurora camera.
- ☐ Check battery charge on aurora camera and receiving setup.
- ☐ Check SD card in receiving setup.
- ☐ Check current weather conditions.
- ☐ Check the forecasted weather conditions for the total expected flight time, plus one hour.

You are ready to fly!

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

F Weather balloon launch application: related documents

F.1 Letter to Norwegian air authority

UNIS
The University Centre in Svalbard

Luftfartstilsynet
Postboks 243
8001 Bodø

Deres ref. Vår ref. FS03112021-1 Dato: 03.11.2021

Søknad om tillatelse å sende opp værballonger fra Kjell Henriksen Observatoriet (KHO).

KHO planlegger å sende opp 6 værballonger under C-REX-2A rakett kampanjen som blir skutt opp fra Andøya Space i perioden 29.11.2021 til 16.12.2021. Hovedmålet er å utvikle et verktøy for å detektere nordlys når det er overskyet.

Ved KHO har vi lang erfaring med nordlys målinger fra Svalbard. Her måler vi øvre atmosfæriske parametere og utnytter de unike forutsetninger og data som Svalbards lokasjon gir under dagnordlys ovalen.

Utstyret består av en rød farget ballong på volum 1 m^3 som er fylt med helium. Under ballongen er det festet en rød 1 m diameter fallskjerm, en radio amatør sender for posisjon og selve nyttelasten som består av ett analogt video kamera med sender. Vekten er under 300 gram. See vedlegg for detaljer.

Ballongen er beregnet til å stige med 4 meter per sekund til en makshøyde på 20 km. Ett ballong opp slip vil vare ca. 3 timer når været tillater det og eventuell tillatelse fra dere gis. Naturligvis innebærer det også at vi skal ha direkte kontakt med tårnet ved Longyear lufthavn og at klare rutiner for bruk blir etablert. Vi beregner å sende opp 6 stykker i måle perioden. Tidsrommet er fra 03:00 til 12:00 lokal tid. Kun en per dag vil sendes opp.

Vi vil derfor be om tillatelse fra Luftfartstilsynet til å kunne sende opp ballongen i begrensede perioder i det aktuelle tidsrommet og på det aktuelle stedet.

Aktuell måleperiode: fra og med 29/11 2021 til og med 16/12 2021.
Område: Kjell Henriksen Observatoriet (78° 8' 52.8''N, 16° 2' 34.8''E) 525 moh.
Tidsrom: 03:00-12:00 lokal tid.

Kontakter før og under måleperioden:
Professor Fred Sigernes, tlf: +47 915 31203,
Epost: freds@unis.no

Kopi av søknad sendes Kontrolltårnet på Svalbard lufthavn

Adresse: Postboks 156, N-9171 Longyearbyen | Telefon: (47) 79 02 33 00 | Faks: (47) 79 02 33 01
E-post: post@unis.no | Web: www.unis.no | Organisasjonsnummer: 985 204 454

F.2 Norwegain air authority response

Luftfartstilsynet

Universitetssenteret på Svalbard UNIS
Postboks 156
9171 LONGYEARBYEN
Norge

v/ Fred Sigernes

Saksbehandler:	Arild Rasmussen
Telefon direkte:	+47 98261853
Vår dato:	09.11.2021
Vår referanse:	20/20507-30
Deres dato	03.11.2021
Deres referanse:	FS03112021-1

Fred Siegernes - Tillatelse til slipp av friballong med last

Bakgrunn

Vi viser til din søknad om slipp av ubemannet friballong med kamera og GPS ved Kjell Henriksen Observatoriet (KHO) i perioden 29.11.2021 - 16.12.2021.

Regelverk

Saken har blitt behandlet etter forskrift 22. desember 2014 nr. 980 om lufttrafikkregler og operative prosedyrer, publisert som BSL F 1-1 som gjennomfører forordning (EU) nr. 923/2012.

Vilkår

Luftfartstilsynet fastsetter følgende vilkår for slipp av ballong:

1. Tillatelsen gjelder for et slipp i perioden 29.11.2021 til og med 16.12.2021.
2. Vekten av ballongen inkludert nyttelast skal være mindre enn 4 kg.
3. Ballong som sendes over 150 meter skal være utstyrt med elektronisk følgeutstyr som kan opplyse om ballongens posisjon i nåtid.
4. Slipp av ballong skal være koordinert med Longyear lufthavn.

Luftfartstilsynet / Civil Aviation Authority
T: +47 75 58 50 00
F: +47 75 58 50 05
E: postmottak@caa.no
Postadresse: Postboks 243, 8001 BODØ
Besøksadresse: Sjøgata 45-47, 8006 BODØ
Fakturaadresse: fakturamottak@caa.no
Fakturamottak DFØ, Postboks 4746, 7468 TRONDHEIM

F.3 Weather balloon proposal

The Auroral Balloon Camera Experiment

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1. Short background

This document describes the development of a weather balloon camera launched to detect the occurrence of aurora and Sun illuminated artificial clouds released into the dayside ionosphere above Svalbard. Six prototypes are proposed launched from The Kjell Henriksen Observatory (KHO) during the C-REX-2A (Cusp Region Experiment – 2A) rocket campaign in the moon down period of November to mid December 2021. The rocket will be launched from Andøya Space. The main purpose is to be able to optically detect aurora even if there are low altitude clouds obscuring our field of view from the ground.

2. Sky view conditions and target position

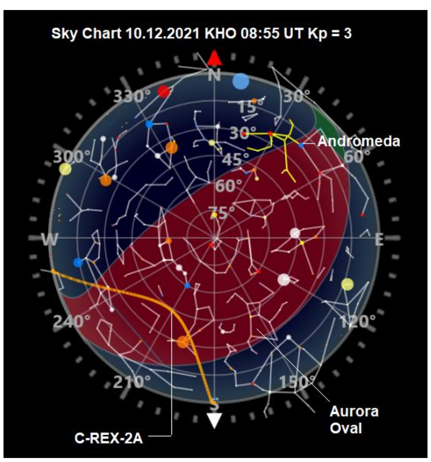


Figure 1. Theoretical sky map for C-REX-2A as seen from KHO 10.12.2021 at 08:55 UT.

Fig. 1 shows the expected sky conditions for the C-REX-2A rocket at 10th December 2021 at 08:55 UT (Red dayside cusp aurora) as seen from Longyearbyen. The aurora is classified as a Kp = 3 sized oval at normal geomagnetic activity level.

The artificial clouds should be detected to the South-West at an elevation close to 45 degrees. The rocket trajectory is plotted in orange color. The apogee of the rocket is close to 630 km. At these high altitudes any artificial cloud will be illuminated by the Sun as seen from Svalbard.

The cloud layer altitude at Svalbard is typically 2-3 km above KHO during the winter (personal communication Torgeir Mørk). Our aim is to use a Helium filled balloon to lift the optical payload above this level for a limited time to check the sky conditions.

2. Experimental setup

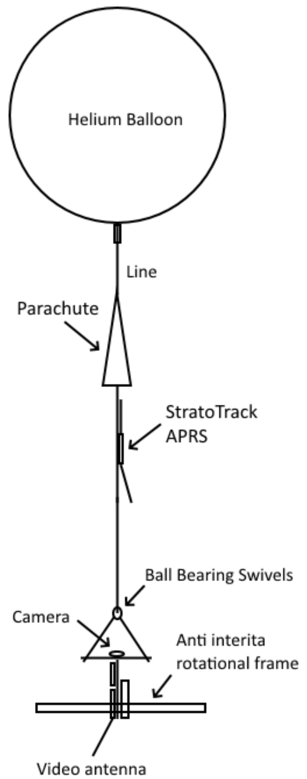


Figure 2. The Auroral Balloon camera experimental setup.

The experimental setup is shown in Fig. 2. A standard 350 g weather balloon filled with Helium is used. A 1m diameter parachute is attached to the balloon line to deaccelerate the payload on return to prevent damage when it lands.

Below the parachute, an APRS (Automatic Packet Reporting System) transmitter with an internal GPS (Global Position System) is installed to keep track of the balloon during flight. The frequency of the StratoTrack APRS is set to 144.800 MHz. The transmitting power is typically 20 dBm. The receiver station is connected to internet (APRS iGate) and installed close to the SuperDarn radar at Breinosa (JW5JUA-10), respectively. It reports the position of the balloon each minute to the website http://aprs.fi . The callsign of the balloon is JW5JUA-11.

The items described above are well tested and used for near-space flights the last decade by the weather balloon community. The balloon parts are listed in Table 1 below.

Item	Detailed description	Cost[$]
1	StatoTrack APRS	199.00
2	Flight Train Kit	15.00
3	Weather Balloon 350g	35.00
4	Near Space Parachute 1.0 m	35.00

Table 1. Balloon part list with links and costs.

Note that all balloon parts are ordered from the company High Altitude Science to keep the logistics simple.

The payload is located at least 4m below the StratoTrack to allow it to transmit freely without interference as recommended by High Altitude Science. A ball bearing swivel and a light weight pool noodle is used to minimize rotation of the camera mount.

3. The payloads

Technology developed for radio controlled aircrafts using First-Person View (FPV) analog video cameras are used in this experiment. The Audio Video (AV) signal is transmitted to our ground receiving stations located at KHO.

The frequency for the first prototype is 5.8GHz with a transmitting power of 600 mW. For this unit an On-Screen Display (OSD) module overlays flight data using an internal GPS onto the camera AV signal.

This track data is also transmitted via the audio channel to the ground receiver. Furthermore, an iPhone is connected to the receiver to listen to the audio signal to track the payload. The second prototype (5 units) transmits a 250 mW signal at frequency of 1.3 GHz. The latter units do not have OSD modules. For all payloads the parts are assembled using 3D printed mount frames. Fig. 3 shows the assembled prototype payloads. Table 2 and 3 list all the components used.

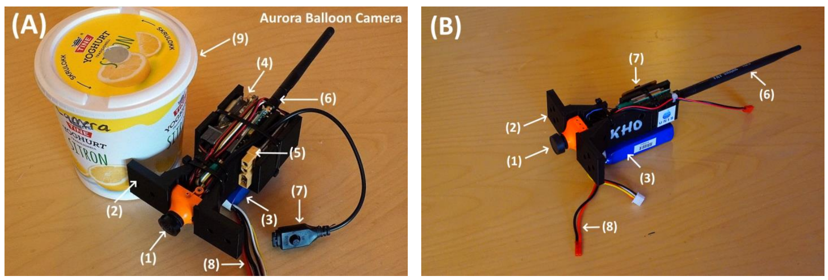


Figure 3. Cameras mounted to 3D printed mount frames. Panel (A) is the first prototype using an OSD module and a 5.8 GHz video transmitter. Panel (B) is one out of five prototype 2 cameras with the 1.3 GHz video transmitter. (1) RunCam, (2) 3D printed mount frame, (3) 11.1V 3S 1000mAh LiPo battery, (4) On Screen Display Module (EzOSD) with GPS, (5) OSD Current sensor, (6) 5.8G/1.3Hz 600/250mW A/V – Tx Video Transmitter, (7) camera OSD setup mouse, (8) battery power cord, and (9) plastic bucket weather protection.

Item	Description 5.8 GHz prototype 1	Cost [EUR]
1	RunCam OWL Plus	41.19
2	On Screen Display Module (EzOSD) with 10Hz GPS	162.51
3	5.8GHz 600mW A/V - Tx	23.60
4	iTelemetry audio receiver for iPhone	17.25
5	SkyZone HD02 5.8GHz 40CH DVR FPV monitor - Rx	81.88
6	Camera battery (11.1V 3S 1000mAh LiPo)	10.89

Table 2. Main camera parts to prototype 1 with links and costs.

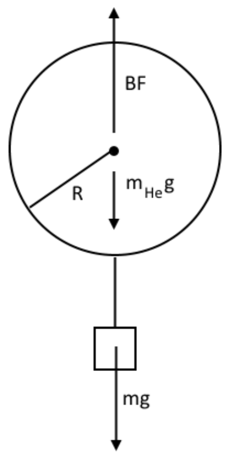
Item	Description 1.3 GHz prototype 2	Cost [EUR]
1	RunCam Night Eagle 2 PRO	72.65
2	1.3Gz 250mW A/V-Tx	36.19
3	RMRC 900MHz-1.3 GHz-Rx	49.92
4	Camera battery (11.1V 3S 1000mAh LiPo)	6.60

Table 3. Main camera parts to prototype 2 with links and costs.

The 3D printed camera mount frames are Y shaped with slots to mount electronic accessories. The cameras are press fit mounted. Prototype 1 camera mass is 169 g. The mass is increased to 266 g with the battery (97 g). Furthermore, it is increased to 306 g if plastic bucket protection (40 g) is needed. Prototype 2 camera is only 96 g without the battery (87 g).

Prototype 1 will then have a total component cost of approximately 238 EUR, while prototype type 2 costs approximately 50% less (115 EUR).

4. Size of Balloon?



Basic balloon equations

$$BF = m_{He}g + mg$$

$$\rho_{air} V g = m_{He}g + mg$$

$$\rho_{air} V = (m_{He} + m)$$

$$m_{He} = \rho_{He} V$$

$$V = \frac{m}{\rho_{air} - \rho_{He}} \qquad (1)$$

$$V = \frac{4}{3}\pi R^3 \qquad (2)$$

$$\rho_{air} = 1.20 \text{ kg/m}^3$$

$$\rho_{He} = 0.18 \text{ kg/m}^3$$

Figure 4. Basic balloon equations.

Case	Total mass (kg)	Volume m^3	Radius (m)
1	0.1	0.098	0.286
2	0.2	0.196	0.360
3	0.3	0.294	0.413
4	0.4	0.392	0.454
5	0.5	0.490	0.489
6	0.6	0.588	0.520
7	0.7	0.686	0.547
8	0.8	0.784	0.572
9	0.9	0.882	0.595
10	1.0	0.980	0.616
11	1.1	1.078	0.636
12	1.2	1.176	0.655

Table 4. Helium balloon size calculations.

The radius R of the Helium balloon may be calculated from equations (1) and (2). A prototype 1 payload of m = 306 g with a balloon weight of 350 g and parachute of 75 g gives us a total mass of 0.731 kg. A factor of 1.5 should be applied to create sufficient lift (guesswork), which corresponds to a positive lift of

366 g. Total mass then becomes m = 1.5 x 0.656 kg =1.1 kg using a R = 0.64 m radius balloon with volume V = 1.1 m^3. For prototype 2 the payload mass is only 183 g, which leads to R = 0.6 m and V = 0.9 m^3 with a positive lift of 304 g. These values are compatible with the Balloon Performance Calculator by High Altitude Science listed in Table 5.

Key parameters	Prototype 1	Prototype 2
Balloons size (g)	350	350
Payload mass (g)	381	258
Positive lift (g)	365	304
Volume (m3)	1.12	0.93
Burst altitude (km)	27	28
Ascent rate (m/s)	4.2	4.1
Ascent time (minutes)	106	114

Table 5. Balloon Performance

Note that a 50 L Helium cylinder at pressure 200 bar will according to Boyle's law provide ~10 m^3 of Helium at 1 atm.

5. Video range calculations

Frequency	Tx Power (mW)	Range (km)
900MHz	500	21.03
1.2GHz	500	15.77
1.3GHz	250	10.29
2.4 GHz	500	7.88
5.8GHz	600	3.57

Table 6. Video range calculations from http://www.maxmyrange.com.
Tx and Rx antennas are pigtails (rubber ducky-whip-3dBm).

Note that the range of the video signal is highly dependent on type of antennas. Using a Crosshair tracker receiver antenna and a simple whip transmitter antenna should increase the range up to 16 km for prototype 2.

6. Optical tracking

Optical tracking of the balloon may easily be conducted by the Svalpoint tracking system at KHO. The narrow beam video receiver antenna could either be mounted to our existing optical trackers or to a designated stepper motor tracker.

Preliminary conclusion

Our Helium balloon powered payloads will travel at an average ascent rate of approximately 4 m/s up to bursts altitudes of 28 km. The ascent time is in the order of 2 hours. Descent is approximately 45 minutes with the 1 m diameter parachute. The prototype 2 video signal will be lost on ascent after about 42 minutes using simple Rubber ducky antennas, which should give us sufficient time to decide whether it is aurora above the cloud layer or not during a rocket campaign window.

Budget and order list

Item	Description	Cost [$]	#	Sum [$]	Order
1	RunCam Night Eagle 2 PRO	80.00	5	400.00	x
2	Fat Shark 1.3Gz 250mW A/V-Tx	40.00	5	200.00	x
3	Camera battery (11.1V 3S 1000mAh LiPo)	7.50	10	75.00	x
4	RMRC 900MHz-1.3 GHz-Rx	55.00	2	110.00	x
5	Crosshair XTreme 1.3GHz (RHCP)	65.00	1	65.00	x
6	StatoTrack APRS	199.00	5	995.00	X
7	Flight Train Kit	15	10	150.00	X
8	Weather Balloon 350g	35.00	10	350.00	X
9	Near Space Parachute 1.0 m	35.00	10	350.00	x
10	Tools / misc.	500.00	1	500.00	-
11	APRS iGate, software radio and antenna	600	1	600.00	X
	Diamond X30N antennas 1024NOK	120	2	240.00	
				Sub $4035.00	-
12	Pole Position Helium Balloon gas (50L)	762.00	1	762.00	x
13	Rent of Helium cylinders/day	1.5	30	45.00	x
				Total $4842.00	-