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Civil Unmanned Aerial System Needs in Finland

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Technology

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Preface

This thesis was prepared at the Department of Applied Mechanics in the course of the academic year 2010/2011. I would like to thank Professor Olli Saarela and M.Sc. Timo Brander for the opportunity to study this interesting and rapidly developing field in some depth. Acknowledgements are also due to the further staff at the former Laboratory of Lightweight Structures for the nice and relaxed atmosphere, as well as to all friends and family members for the support over the years.

Otaniemi, May 9, 2011

Ville Raunio

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List of Abbreviations

ACAS	Airborne Collision Avoidance System
AMC	Accepted Means of Compliance
CAA	Civil Aviation Authority
CAP722	Civil Aviation Publication 722
CBRN	Chemical, Biological, Radiological and Nuclear
COA	Certificate of Waiver or Authorization
CR	Communications Relay
E/O	Electro-optical
EASA	European Aviation Safety Agency
EIRP	Equivalent Isotropically Radiated Power
ELOS	Equivalent Level Of Safety
ERP	Equivalent Radiated Power
EUROCAE	The European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration
FINNARP	Finnish Antarctic Research Program
FMI	Finnish Meteorological Institute
FPV	First Person View
FSS	Fixed Satellite Services
FTS	Flight Termination System
GCS	Ground Control Station
GPS	Global Positioning System
GTK	Geological Survey of Finland
HALE	High Altitude Long Endurance
HSDPA	High-Speed Downlink Packet Access
ICAO	International Civil Aviation Organization
IMU	Inertial Measurement Unit
LALE	Low Altitude Long Endurance
LOS	Line Of Sight
MALE	Medium Altitude Long Endurance
MASPS	Minimum Aviation System Performance Standards
Metla	Finnish Forest Research Institute
MI	Meteorological Instrumentation
MRU	Mobile Receiving Unit
MSS	Mobile Satellite Services
NATO	North Atlantic Treaty Organization
R/C	Remote-controlled
RS	Remote Sensing
RVT	Remote Video Terminal
SAC	Special Airworthiness Certificate
SAR	Synthetic Aperture Radar
STANAG	Standardization Agreement
STUK	Finnish Nuclear and Radiation Safety Authority
SUMO	Small Unmanned Meteorological Observer
SYKE	Finnish Environment Institute

TETRA	Terrestrial Trunked Radio Network
TRAFI	The Finnish Traffic Safety Agency
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
VTT	Technical Research Centre of Finland

1. Introduction

Unmanned aerial systems (UAS) have been a subject of great interest in recent years, due to their considerable versatility in missions that would be too uneconomical, dangerous or even impossible to perform using manned aircraft. Such missions include meteorological measurements, radiation detection and various remote sensing tasks. UAS have for a long time been a tool almost exclusively used by the military, but are currently gaining a foothold in the civilian sphere as well.

At the moment the Finnish civil UAS operation branch is still almost non-existent, but will likely grow in importance in the future, once the issues currently hampering this development, such as the lack of comprehensive certification and airworthiness regulation, are resolved.

This thesis was prepared as a part of a technology program for *Measurement, Monitoring and Environmental Assessment* (MMEA), funded by the Finnish Funding Agency for Technology and Innovation (TEKES), and aimed at developing environmental monitoring tools and services. The initiative to integrate UAS-related activities was a result of earlier co-operation of some of the project partners in installation of a radiation measurement system in a UAS of the Finnish Army. The initial research plan called for the development of a scalable UAS fleet of original design, but the program goals underwent significant changes as the objective was shifted to choosing the most suitable alternative from the - at the present already considerable – range of existing systems.

In the beginning of this thesis, the characteristics of unmanned aerial systems are described, after which the current UAS regulations in Europe as well as in the USA are studied. The fourth chapter outlines the findings of a survey of potential future Finnish UAS users, while the fifth chapter surveys the potential existing systems within the confines of the project objectives and budget. The sixth chapter presents a proposal for a system that could be used for the MMEA project and could, in addition, be integrated in the university's curriculum in a valuable manner. Finally, the seventh chapter presents conclusions and recommendations for the future.

2. Unmanned Aerial Systems

2.1 Overview

Unmanned aerial system (UAS) is a commonly accepted term used to refer to the complete system of an unmanned aerial vehicle (UAV) and its supporting elements. A UAS comprises all the elements required to perform a flight mission. Such elements include some or all of the following: a UAV and its payload, a ground control station (GCS), a data link for command, control and communication, as well as launch and recovery elements such as catapults, arresting nets or parachutes.

Unmanned aerial vehicles (UAVs) are generally defined as "uninhabited and reusable motorised aerial vehicles". UAVs may be remotely controlled or they may operate partly or fully autonomously. Combinations of these modes are also possible during a flight mission. [1]

UAVs, like conventional aircraft, can be of the fixed-wing or rotary-wing type. Airships represent the class of lighter-than-air UAVs. Many different propulsion systems are applied on UAVs. Traditional solutions, like internal combustion engines and battery-driven electric motors, are supplemented by emerging technologies, such as hydrogen fuel cells and solar cells.

UAVs exhibit several advantages in comparison to manned aircraft. A major advantage is their ability to perform tasks that would involve significant risks to the flying personnel if manned aircraft were used. In military operation, enemy activity would be an obvious risk. Other risks could be constituted e.g. by adverse weather conditions, low flight altitudes, low separation from obstacles, physical or mental exhaustion of the pilot, or chemical/biological/nuclear contamination. As the UAVs can be very small, they can provide airborne surveillance capability that is easily transportable and can be utilised at will.

Another possible advantage offered by UAVs can be constituted by a considerable reduction of operational costs in comparison to manned aircraft. This is an especially lucrative argument in the realm of commercial operations.

A third important advantage is that a UAV, especially a largely autonomous one, is free from the limitations imposed on it by human physiological performance. Thus, a UAV can exhibit very long endurance without having to take pilots' exhaustion into account. If the vehicle is not autonomous, but continuously remotely piloted, the pilots can work in shifts and are in any case relieved from the normal load factors ("G-forces") and other tiresome physiological effects. Such remotely piloted UAVs are represented e.g. by the Predator and Global Hawk UAVs of the US Air Force.

UAVs are currently severely limited by existing regulations, which limit them to operate within the line-of-sight (LOS) of the operator, unless special measures are taken. The main cause for this restrictiveness is the authorities' concern about possible human casualties or property damage as a result of insufficient situational awareness and detection capabilities.

There are certain issues related to hardware certification as well. The lack of official and universally accepted standards for the payloads and system interfaces is an important drawback, as a result of which the customers often have no alternative but to buy a complete system from a single manufacturer, instead of being able to collect a solution from several sources.

Further limitations, especially in the case of low-cost UAVs, include low sensor performance caused by insufficient autopilot capabilities as well as weight and dimensional limitations imposed on the payload. Such limitations further complicate achieving a sufficiently good level of camera platform stabilisation. [1], [2]

As contemporary UAVs display large variations in size, performance and other capabilities, classifying the various types would clearly be useful. However, such task is complicated by the large amount of possible classification criteria that different UAVs exhibit. Table 1 presents what could be thought of as an example of a generic approach on this matter, partly based on reference [3].

Table 1. An example of UAV classification, along with some typical figures, based on reference [3]

	Mass (kg)	**Range (km)**	**Flight Alt. (m)**	**Endurance (h)**
Micro	<5	<10	250	1
Mini	<20-150	<10	<300	<2
Low Altitude Long Endurance (LALE)	15-25	>500	<3000	>24
Medium Altitude Long Endurance (MALE)	1000-1500	>500	<6000	24-48
High Altitude Long Endurance (HALE)	2500-5000	>2000	<20,000	24-48

The following sections present the essential elements of an unmanned aerial system.

2.2 Airframe

The term "airframe" refers to the mechanical structure of an aircraft. Design philosophies of UAV airframes depend largely on the size of the aircraft. Light UAVs employ structures similar to those used in model aircraft, whereas larger ones are constructed in a manner similar to manned aircraft. Structures inspired by model aircraft include solid styrofoam wings and fuselages, possibly covered by a fiberglass or carbon fiber laminate. As the aircraft gets larger and mechanical loads increase, traditional airframe structural engineering approaches become a necessity. Such approaches include e.g. wings made of spars, ribs and stressed skin as well as fuselages made of frames, stringers and stressed skin. Sandwich/honeycomb composite panels are applied as well.

Operational requirements are an important consideration as far as the vehicles layout and structures are concerned. Methods of launch and recovery are among the first things to consider. Catapult launch and arrester hook/net recoveries impose relatively high loads on the airframe, necessitating a robust structure. When light weight is essential, structures get more fragile and gentler launch methods - such as a car-top cradle - must be devised.

The need to install sensitive sensors in the nose of the aircraft often prohibits the application of a traditional tractor engine arrangement, since many sensors require undisturbed airflow and the exhaust gases of commonly used two-stroke engines contain a relatively large proportion of fuel and unburned gasoline, substances that are likely to e.g. smear camera lenses. A pusher-propeller solution often dictates installing engine on top of a pylon or between a twin-boom tail. Figure 1 presents, as an example, an overview of the Aerosonde UAV.

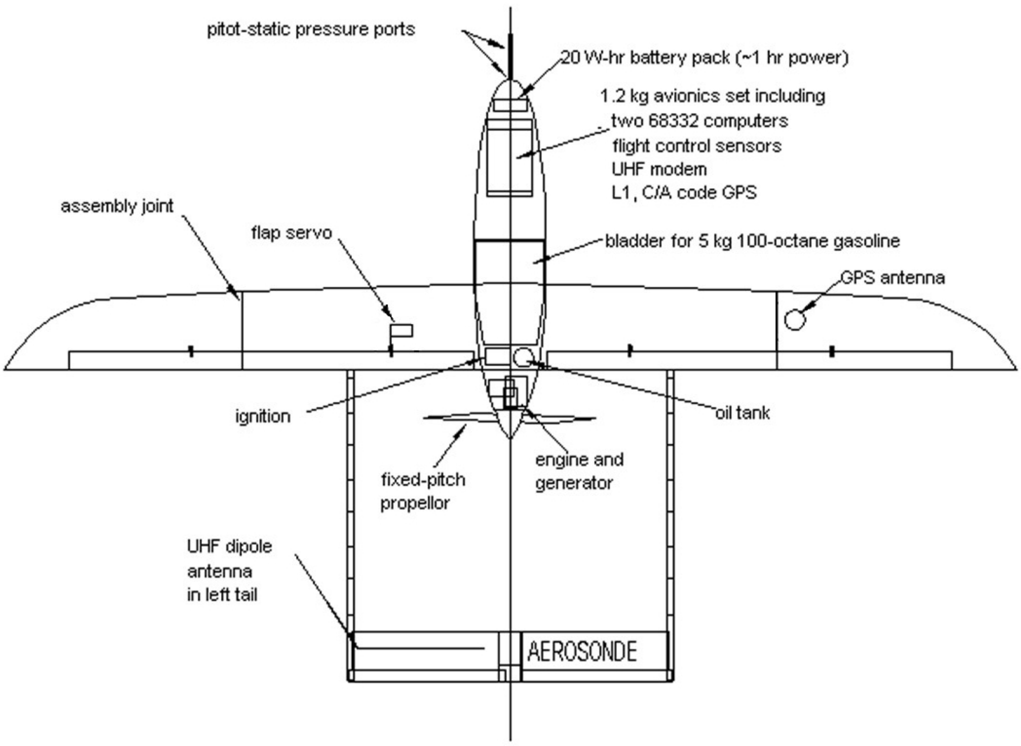


Figure 1. Overview of the Aerosonde UAV [4]

2.3 Propulsion System

UAVs are propelled either by electric motors or by internal combustion engines. The latter include piston engines, Wankel engines and gas turbines.

Electric propulsion is advantageous with respect to noise as well as ease and safety of operation. Energy density of electrical batteries is not comparable to that of hydrocarbon fuels, however, from which it follows that electrically powered UAVs have somewhat limited payload, range and loiter time capabilities. Extremely long-endurance UAVs utilizing solar cells are being considered for use as airborne relay stations for telecommunication purposes, as well as for some meteorological purposes.[2] These applications notwithstanding, electric propulsion is limited to small UAVs, that is to say micro- or mini-class vehicles. Energy densities of the most common battery types are presented in table 2 [5].

Table 2. Energy densities of various battery materials

Battery type	**Energy density (Wh/kg)**
Lead (Pb)	25
Nickel-cadmium (NiCd)	40
Nickel-metal hybrid (NiMh)	60
Lithium-Ion (Li-Ion)	150
Lithium-Polymer (Li-Po)	180
Zinc-air battery (ZnO_2)	400
Hydrogen fuel cell	1000

Piston engines used on light UAVs often utilize the two-stroke cycle since it enables simplicity in construction and thus light weight while retaining acceptable efficiency. There are only few four-stroke engines available in the power range applicable to light UAVs. This is because they necessarily are considerably bulkier than two-stroke engines, a feature that is considered undesirable even though they exhibit markedly better fuel economy. There are few, if any, producers who offer engines specifically designed for small UAVs. Thus, most small UAVs employ ordinary model aircraft engines, either off-the-shelf or slightly modified. The most common fuel used in internal combustion engines is gasoline, but at least the US military has systematically been developing vehicles that run on the same fuels as land vehicles, in order to simplify fuel logistics (Heavy Fuel program).

Wankel (rotary combustion) engines are utilized to some degree due to their low level of vibration and compact size. As a consequence of compactness they offer a high power-to-weight ratio, though at the price of somewhat increased specific fuel consumption (as compared to a reciprocating engine). Disadvantages include that the availability of Wankel engines is limited to a handful of producers and there are no Wankel engines available with power of less than ca. 15 kW.

Gas turbine propulsion is used to propel many kinds of UAVs. However, small gas turbines exhibit low thermal efficiency and poor performance in terms of specific fuel consumption. Consequently, either the possible mission times are quite short, or a large fuel tank is needed. In jet engine’s case the consumption problem is further compounded by the jet engine’s fundamental suitability to high-speed flight, which is not likely to be an important airspeed range for a UAV designed for environmental monitoring. Despite all this, in some applications requiring vibration-free propulsion gas turbines are very well worth considering. Such applications could include e.g. transmitting high quality live image or high resolution still pictures. Some engines applicable to light UAVs are listed in table 3.

Table 3. Some engines applicable to light (less than 150 kg) UAVs

Producer	**Model**	**Type**	**Weight**	**Power/Thrust**
Bental Motion Systems, Israel	B-013	permanent magnet brushless electric motor	0.056 kg	44 W
Bental Motion Systems, Israel	B-047-012	permanent magnet brushless electric motor	1.4 kg	2.6 kW
3W-Modellmotoren, Germany	3W-28i	two-stroke	1.2 kg	2.5 kW

Producer	Model	Type	Weight	Power/Thrust
Göbler-Hirth Motoren, Germany	4101	two-stroke	2.9 kg with exhaust system	4 kW
Limbach Flugmotoren, Germany	L 275 E	two-stroke	7.2 kg with magneto ignition	15 kW
Wren Turbines Ltd, United Kingdom	Wren 44	turboprop	2.0 kg incl. ancillaries	5.62 kW
AMT Netherlands, Netherlands	Titan	turbojet	4.2 kg with air-start	392 N
UAV Engines Ltd, United Kingdom	AR731	Wankel	9.9 kg	28 kW

2.4 Autopilot

If the UAV is to have any autonomous capabilities, some sort of an autopilot is necessary. The autopilots used in UAVs are fundamentally similar to those used in traditional aircraft and many other control applications. Figure 2 shows a schematic block diagram view of a typical UAV autopilot.

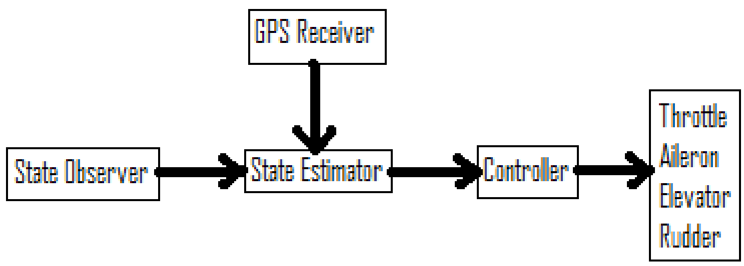


Figure 2. Block diagram of an autopilot

A prerequisite for effective control is obtaining the values of the vehicle's state variables, and this is achieved by measurement of these variables with some or all of the following methods [6]:

- GPS Receiver: measurement of the vehicle's absolute position
- Magnetic sensors: measurement of roll, pitch and yaw (attitude)
- Gyroscopic sensors: measurement of rates of roll, pitch and yaw (angular velocities and accelerations)
- Acceleration sensors: measurement of linear accelerations
- Pitot-static system: measurement of values of and changes in speed and altitude

To take a more general view, the most important features of a modern autopilot are listed in reference [7] as follows:

- Stability and damping
- Manoeuvrability
- Gust alleviation
- Accuracy of the flight path
- Passenger comfort
- Economy
- Envelope protection

Many of the features listed above are essential to UAV autopilots as well, while some can be neglected. Perhaps the most important requirement with regard to the projected use in measurement flights is that of flight path accuracy, which is also very important in aerial photography and other remote sensing tasks; the position and attitude of the vehicle must be accurately known at all times, if the raw data provided by the sensors is to be processed usefully [8].

The purpose of gust alleviation and envelope protection is mainly to ensure structural integrity and extend the lifetime of the airframe. These are important considerations for manned aircraft and large (HALE/MALE) UAVs but less important in the case of inexpensive and small vehicles. Same applies, obviously, for passenger comfort and economy. The autopilot of a small UAV cannot make an important difference in economy and in general the effects of the autopilot on economy are limited to issues such as avoiding unnecessary changes in power settings and optimising flight profiles.

Autopilots of modern UAVs are highly integrated; they usually include most of the hardware necessary for control purposes. An inertial measurement unit (IMU) as well as a GPS receiver is often to be found integrated in the board. Other ancillaries, such as magnetic sensors or a Pitot-static system and various antennas are connected by means of tubing or wiring.

2.5 UAV Payloads

The most important set of payloads carried by UAVs is constituted by cameras and other electro-optical sensors. Electro-optical sensors include digital cameras in the ultraviolet, visible and infrared wavelengths as well as multi- and hyperspectral scanners.

High-performance military UAVs are increasingly often equipped with Synthetic Aperture Radars (SAR) and laser scanners, technologies that are making their way to smaller and civilian UAVs as well.

2.6 Data Links

The data link includes all means of communication between the vehicle and the ground station. Usually the data link consists of an up-link and a down-link. Through the up-link the ground station is capable of controlling the vehicle or altering its commands. The down-link often utilizes a two-channel arrangement, one channel providing the ground station with vehicle telemetry data, and the other reserved for the payload. The payload may also be passive if real-time data flow is not required. The data link can also be used to determine the vehicle's location with reasonable accuracy, which is potentially useful as a back-up for the vehicle's GPS unit.

The range of the data link is limited by the so-called "radio horizon"; due to the Earth's curvature, the vehicle cannot fly indefinitely far whilst staying within line-of-sight (LOS) of the ground station. The radio horizon is a rough approximation because transmittance power of the radio system and damping limit the range still further. Especially the payload link suffers from damping, because high frequencies (in Gigahertz-range) - that are necessary for high data transfer rates - are more severely affected by the so-called free space damping than lower frequencies (such as VHF and other frequencies traditionally used in analog communication systems). As a consequence, the payload link often requires direct LOS conditions. Such conditions may be compromised by obstacles, such as buildings, trees or terrain. Thus, the antenna must often be brought to an elevated position by means of e.g. a telescopic mast. [5], [9]

If the vehicle is to fly beyond the radio horizon, the data link must be arranged using other means, such as relaying the transfer via a further ground station or aircraft, or using an existing telecommunication network. Relaying via a satellite is an alternative as well.

Many network operators have prohibited solutions that use GSM networks, because transceivers that are simultaneously within reach of several ground stations are found to cause problems with the network operation. However, reference [10] studies radiation measurement experiments in which the data link was arranged flawlessly utilising a government officials' terrestrial trunked radio network (TETRA). Reference [11] investigates the applicability of 3G commercial networks for this purpose. The network studied in reference [11] utilises the HSDPA technology, which provides data transfer rates of up to 11 Mb/s, thus creating a possibility to transmit even high-definition video image. As a consequence of 3G network's extensive terrestrial infrastructure, small UAVs benefit from the possibility to use lightweight, compact equipment whose power consumption is very moderate. Utilisation of existing networks is beneficial from the viewpoint of limited bandwidth as well; reserving sufficiently wide bands of the spectrum dedicated solely to UAS use would likely prove very difficult at the present as well as in the future. It is noteworthy, however, that the volume of radio traffic needed can be substantially reduced by effective on-board data processing methods offered by recent advances in electronics. [12]

Arranging the data link via satellite is common practice in high-performance military applications, but is only slowly emerging on the civil market. Since most UAV operators cannot afford possessing an own satellite, the most practicable solution is to use commercial telecommunications satellites. At any rate, such operation is subject to certain technical limitations as system performance depends heavily on the applied frequencies. *Mobile Satellite Services* (MSS) operating in the so-called L-band (1-2 GHz) are applicable to light UAVs, since in their case data transmission can be taken care of using an omni-directional antenna, which facilitates a light system. MSS, however, are limited by their data transfer rate, the maximum of which is around 400 Kb/s and often considerably less. This limits their suitability to command link applications and to transfer of basic payload data, such as pressure or humidity values in the case of a meteorological application. Higher data transfer rates can be achieved with the so-called *Fixed Satellite Services* (FSS), operating in the higher frequency bands X (8-12 GHz), C (4-8 GHz), Ku (12-18 GHz) and Ka (26,5-40 GHz). FSS require much heavier and more complicated antenna, transceiver and amplifier equipment than MSS. In addition to technical complexity and cost, further difficulties in the satellite-based data link are caused by transmission latencies of up to several seconds. This is problematic especially if the vehicle is to be remotely piloted. [13]

2.7 Ground Control System

A ground control system (GCS) is needed to provide an interface between the flying vehicle and the human operator/user. GCS vary greatly in size and capability: a ruggedized laptop and a lightweight antenna are usually enough for a small UAS, whereas in the case of large UAS the GCS is often built in e.g. a ship container.

A class of devices related to GCSs is that of passive receivers, known as Remote Video Terminals (RVT) or Mobile Receiving Units (MRU). Such equipment are much lighter than a complete control station and can be used to distribute the data gathered by the UAV to a larger audience than merely to the system operator, which is beneficial especially in tactical situations. [9]

2.8 Launch and Recovery Elements

Launch and recovery elements of a UAS include all the equipment necessary to get the vehicle airborne and to recover it from flight. Small UAVs often are simply thrown by hand, but if the vehicle is heavier than approximately 3-4 kg, some kind of takeoff assistance is needed. A catapult is usually chosen, because it reduces the open space requirements in comparison to a conventional rolling takeoff. Light catapults are often of the bungee type, in which an elastic cord is brought under tension and released to produce the necessary takeoff velocity. Heavier catapults are hydraulic or pneumatic and some military UAVs use even solid rocket boosters in order to facilitate very short takeoff distances.

As a conventional landing requires a relatively wide open space, several further solutions have been devised to recover a UAV from flight. A parachute is used to some extent, but it is not very useful in ship-borne operations, where accurate landing is essential. The parachute is very useful, however, as a back-up system in the case of command link failure, and as such it is likely to become a certification requirement in the future. Further methods are arresting nets and wires. Nets occupy a lot of space on a ship's deck, but on the other hand make a gentle recovery possible. The operating principle of a vertical arresting wire is that the vehicle catches the wire with a hook attached to the wingtip. This results in small system footprint, but sets requirements on the vehicles configuration and structural integrity.

3. Civil UAV Applications

So far the realm of UAVs has been heavily dominated by military applications. However, UAVs are becoming increasingly prevalent and important in civilian applications as well. The basis for civilian UAV development is in many respects different to that of the military. In military applications function is usually the overriding concern, whereas in civilian applications significant emphasis must also be laid on issues such as cost efficiency, reliability and ease of operations. Further difficulties are constituted by perceived restraints, such as high initial implementation costs, absence of airspace regulation and airworthiness requirements, as well as lack of sufficiently long track record. [14] A very large amount of civilian applications can be envisioned for UAVs, the following sections providing a cursory overview.

3.1 Civil Government Applications

Civil government authorities are increasingly important users of UAVs. Potential applications include at least the following:

- Border patrol
- Traffic surveillance
- Smuggling surveillance and interdiction
- Monitoring of sensitive sites, such as harbours or oil/gas pipelines
- Search and Rescue
- Forest fire monitoring
- Mapping of land use
- Communications relay
- Sensing and tracking of nuclear, chemical or biological substances

3.2 Scientific Applications

UAVs hold a lot of promise for scientific applications, especially in the case of smaller vehicles. Measurements, images etc. can be taken in an affordable manner and often in places that are inaccessible to manned aircraft. Potential applications are, for example:

- In-situ measurements in e.g. meteorology
- Various remote-sensing applications, such as multi-/hyperspectral imaging or laser scanning. These applications are used in several branches, such as forestry, geological surveys or in mapping of e.g. sea ice, algae or soil moisture.
- Aerosol measurements. Aerosols can be found in the air e.g. as a result of volcano eruptions, forest fires or air pollution.

In keeping with the essential objectives of the MMEA project, this study pays particular attention to possible environmental monitoring tasks. The following paragraphs introduce some of the distinctive features of UAVs currently used in meteorology, earth science and other branches of environmental monitoring, followed by a brief glance at some applicable UAVs already on the market.

An important group of payloads in environmental monitoring, as in all UAV operations, is that of electro-optical sensors. Such sensors can be used for image transmittance for surveillance purposes, such as flood detection and monitoring of oil and gas pipelines. Further applications include remote-sensing, such as gathering data to be used in e.g. cartography, forestry, biomass measurements or surface mineral surveys. It is to be expected that many of these remote-sensing applications will in the future be supplemented by the miniaturization of laser scanners and synthetic aperture radars, technologies that are usually found in full-sized aircraft or earth-science satellites.

Measuring pressure, temperature and humidity values are important tasks in meteorology. So far, this has usually been performed using weather balloons, but UAVs can be applied as well, especially in the lower layers of the atmosphere. Detecting and measuring gas and aerosol concentrations are also quite essential tasks in meteorological research, the aftermath of the eruption of the Icelandic volcano Eyjafjallajökull in April-May 2010 providing a recent example. Further applications of gas/aerosol detection include pollution measurement tasks, such as taking samples of ship exhaust fumes in order to determine whether legal fuel is being burnt. Samples could also be taken in the case of, e.g., a powerplant accident or an accident involving a ship, train or truck transporting dangerous chemicals.

Radiation measurements constitute another example of important tasks in environmental monitoring. Radiation measurements can be performed in several ways. Passive sensors collect fallout samples for later analysis and can be as simple as hollow tubes with a filter to catch particles of a certain size. Beta-radiation can be detected using relatively light particle counters. Gamma ray detectors, on the other hand, are somewhat larger and heavier since their operating principle dictates the need of a certain amount of mass to interact with the radiation. The more mass is given, the more accurate the detector. The same holds for most magnetic field sensors used in search of iron ore or other minerals.

3.2.1 Aerosonde

The Aerosonde meteorological UAV (Figure 3) can be described as a pathfinder among environmental UAVs. Developed in the 90s to meet the requirements of the Australian Bureau of Meteorology, the Aerosonde has since evolved to be a popular platform for various civil and military applications.

Today the Aerosonde is marketed by the AAI Corporation, which belongs to the larger Textron defence industry conglomerate. Since Textron is primarily a defence company, the AAI has a rather restrictive public relations policy. Previously, as the aircraft was still intended exclusively for environmental observations and marketed by the Aerosonde Robotic Aircraft Corporation, the main emphasis was not on selling vehicles and other systems, but on selling flight hours and resulting data [16]. The idea was to establish a world-wide net of Aerosonde-equipped bases and to control the vehicles operating from these bases from a global command centre situated in Australia. The resulting data would then be relayed to the customer via Internet. Figure 4 illustrates the idea.

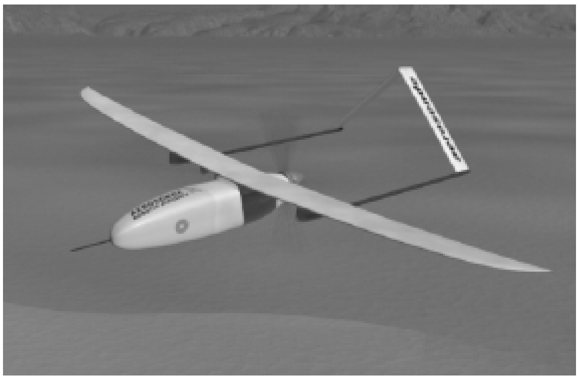


Figure 3. The Aerosonde UAV [16]

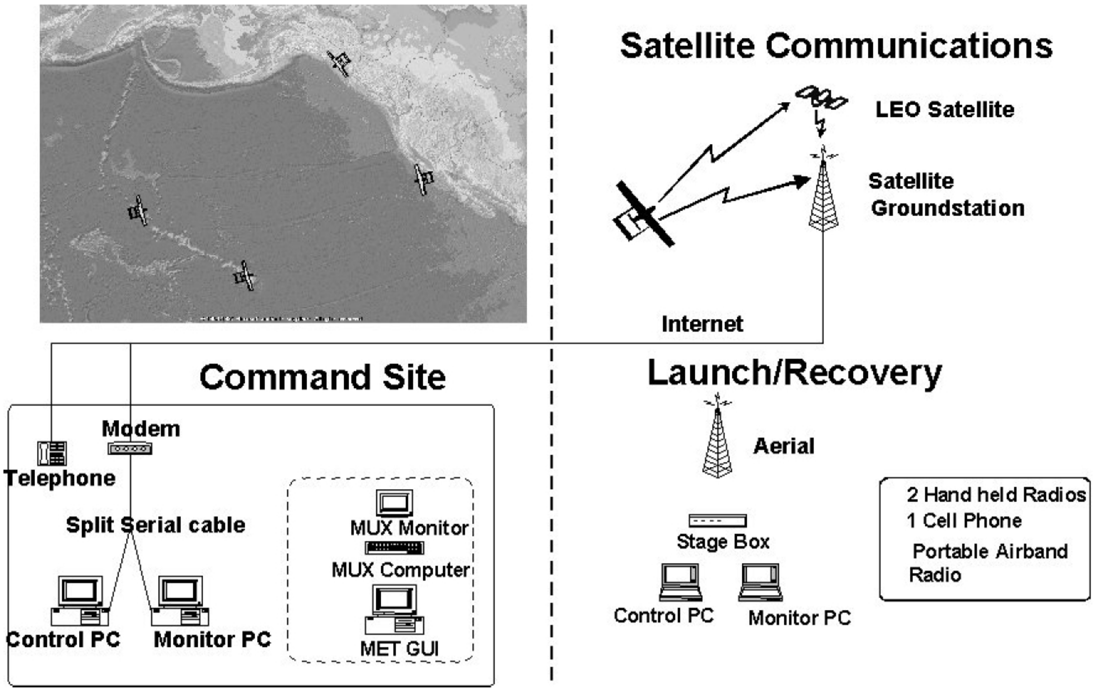


Figure 4. Schematic figure of the Aerosonde operating principle [16]

The most distinctive features of the Aerosonde are its very long endurance of up to 40 hours and, consequently, very long range (up to 4000 kilometers). The vehicle has a maximum payload of 5 kg and a maximum mass of 15 kg. The wingspan is 2.9 meters. Earlier versions used a car-top cradle for takeoff and landed on their belly, but more recent versions can be launched using a catapult and recovered using an arresting net, thus facilitating e.g. ship-borne operation. The vehicle is propelled by a modified model aircraft engine. The most important modification is the installation of a power generator, which considerably decreases the size of batteries required.

3.2.2 CryoWing

The Norwegian Northern Research Institute (Norut), a research establishment owned mainly by the University of Tromsø, has developed a UAV system called the CryoWing (Figure 5). In performance terms the CryoWing is quite similar to the Aerosonde, but considerably larger with a payload of up to 15 kg and a maximum weight of 30 kg. The size imposes certain limitations to operation, e.g. operating from a ship or use in tactical surveillance would probably be problematic. Unlike the Aerosonde, which is now heavily marketed for military applications as well, complete emphasis of this project is on scientific applications. The airframe is designed and produced to Noruts specifications by a Slovakian company (ET-Air Slovakia S.R.O) and costs approximately 5500 €. Hardware has been acquired from commercial sources, whereas software is largely developed within Norut. Data link is arranged using a combination of commercial satellite services (Iridium) and communication networks (GSM, UMTS). [17]

3.2.3 SUMO

The Small Unmanned Meteorological Observer (SUMO) is developed by scientists from the Norwegian University of Bergen and from the French Ecole Nationale de l'Aviation Civile. The SUMO exhibits a true low-cost approach to UAV-based environmental monitoring. The currently used airframe is that of the Multiplex FunJet kit plane (Figure 5), the airframe of which costs just 60 €. The airframe is made of expanded propylene, which is a lightweight foam material that can be easily repaired e.g. with instant glue. The vehicle is propelled by a brushless electric motor.

The SUMO is designed to act as a "recoverable radiosonde" in meteorological boundary layer research. Modest payload capabilities limit the current version to basic meteorological measurements (i.e. pressure, temperature and humidity), but the Paparazzi autopilot system is based on the open-source principle and readily adaptable to many kinds of airframes, thus facilitating versatile applications in the future. [18]

The Finnish meteorological institute utilises the SUMO in conducting research of the lower atmosphere, as a part of the FINNARP 2010 expedition on the Antarctic. The most important advantage of the SUMO, as compared to a weather balloon, is that the atmosphere can be mapped in all directions, not just along an ascent path. [19]

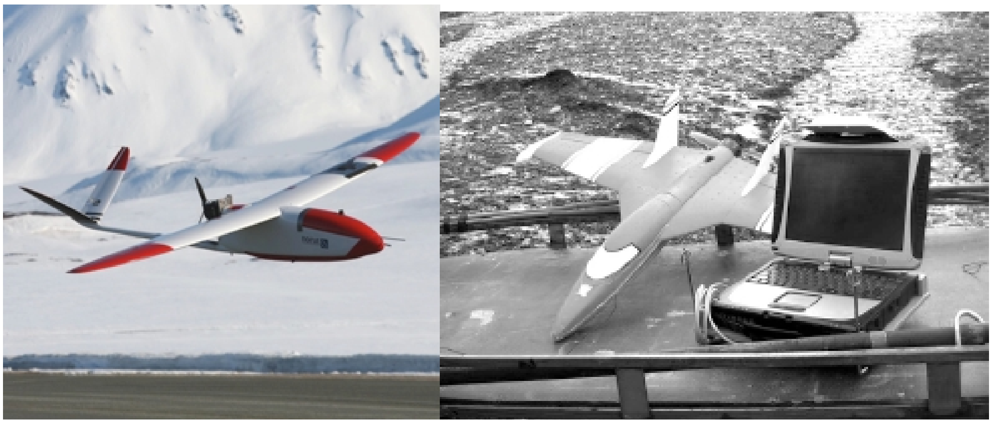


Figure 5. CryoWing and SUMO UAVs [17],[18]

3.2.4 Insitu ScanEagle

The ScanEagle is a UAV developed by the Insitu Company in co-operation with the Boeing Company. The vehicle is designed primarily with marine operation in mind: launched from a pneumatic catapult and recovered using a vertical wire. The manufacturer claims that, as a result of such launch & recovery arrangements, the size requirements imposed on the vessel are modest and operation is possible in high winds (up to 35 knots) and heavy seas. The vehicle offers very long endurance (24 hours) and can carry a payload of up to 7 kg (including fuel) in a dual-bay arrangement. The dual-bay arrangement enables the vehicle to carry multiple payload units simultaneously. [20]

Figure 6. The Insitu ScanEagle [74]

3.3 Commercial Applications

Commercial UAV market is currently very lean, due to several reasons. The unresolved issues in regulation are one important factor, but others can be found as well. Financial insecurity resulting from lack of cost/benefit and client awareness is an important consideration. Absence of standards and regulations complicates component interchangeability and defining reasonable liability insurance costs as well. High initial costs of UAV systems result mainly from small production series, but nevertheless constitute a further limitation.

Commercial applications include many of those already mentioned in previous paragraphs, such as remote-sensing or utility inspection/monitoring, but there are certain applications peculiar to the civil market, such as:

- Crop monitoring and other agricultural purposes
- Motion picture as well as news and media support
- Communication network relay (aimed at ad-hoc needs as well as replacing/augmenting satellites on the low Earth orbit)
- Aerial advertising
- Commercial imaging

3.4. Probable Future Developments

It is essential to note that the global UAV market is evolving at a tremendous rate. The reference [2] lists already a total quantity of 1190 different UAV systems from 422 manufacturers. Of these 209 are considered "developed & market ready", whereas the rest are still in various phases of development. Thus it seems likely that several new UAV types will enter the market in the near future. It would be equally reasonable to assume that many of these vehicles could be usefully applied also in environmental monitoring.

Reference [15] states that the volume of the civil UAV market is likely to exceed that of the military market in the long term, since the military market is already relatively mature and the potential scale of the civil market is much larger than the military market (due to the multitude of applications). Experts believe that in the near future the UAV use will be heavily driven by civil government applications, while more ambitious applications, such as communications relays will only appear in the more distant future.

Both the industry and the users are relatively fragmented at the moment. This results in weak research and development possibilities in the case of many manufacturers and, on the other hand, to limited acquisition possibilities in the case of many potential users. Furthermore, production runs remain modest, which keeps prices on a high level.

4. UAV Regulations

4.1 Background

The purpose of the following sections is to introduce some of the most important unresolved issues in UAV operation and regulation. The status quo of UAV regulations in the USA and in Europe is surveyed, and a look is taken at some of the few existing national regulations.

The regulatory landscape concerning UAVs is under development and likely to remain so for several years. Especially commercial operation of UAVs remains problematic until clear regulation is in force. The creation of regulations is further complicated by conflicting interests. The UAS manufacturers and operators generally present a desire for light regulation whereas traditional airspace users demand that the UAS must not be allowed to cause any changes to existing procedures or level of safety.

4.1.1 Awareness

The “sense-and-avoid”-capabilities of UAVs are a very important limiting factor as far as practical operation is concerned. This encompasses all methods that the UAV may have to detect, assess and avoid obstacles. The purpose of all regulatory work on this issue is to guarantee an “equivalent level of safety” (ELOS) to that of conventional manned aircraft. When the UAV is flown manually within line of sight of the pilot, detection and avoidance is automatically taken care of, but the situation gets more complicated in autonomous UAV operation.

The concept of autonomy is important in respect to awareness and sense-and-avoid matters. The traditionally held view has been that a human pilot presents constant situational awareness and is able to intervene rapidly at any flight phase. An autonomous UAV, however, is capable of performing all flight phases by itself. This is in contrast with the presumable human-in-the-loop requirements of future regulation; it is to be expected that complete autonomy will not be accepted by the authorities, especially because the person operating the UAV is responsible for the safety of the flight and therefore needs the possibility to interfere with the UAV flight without delay [21].

Particular difficulties are constituted by other air traffic flying in accordance with Visual Flight Rules in uncontrolled airspace. Such traffic includes light general aviation aircraft, sailplanes, hang gliders as well as other vehicles and objects – even parachutists –, that usually are not equipped with a transponder. Even transponder is not an all-encompassing solution, as the Airborne Collision Avoidance System (ACAS) is not intended to be installed on "tactical military" or unmanned aircraft. Additionally, ACAS would be of direct use only in the case of a remotely piloted UAV. Autonomously flying UAVs would additionally need reliable automatic control methods and algorithms to assess the situation and perform a suitable evasive manoeuvre. In controlled airspace air traffic management is further complicated by the weak radar signature of many UAVs, especially at low altitudes [22].

4.1.2 Spectrum Issues

A further major issue in UAS deployment is constituted by the fact that currently UAS lack a radio frequency band reserved solely for them. The possibility of outside interference compromises the safe operation of UAS. On the other hand, UAS operation must not have an effect on existing services, such as mobile communication networks. [23]

This problem will be addressed at the next World Radiocommunication Conference, scheduled to take place in Geneva in 2012. National radiocommunication authorities will only be able to publish their regulations after the aforementioned conference, since global harmonization of regulations is considered necessary. Thus, the UAS industry must define its radio spectrum requirements in time for the aforementioned conference. Even if the agreement over allocation of some bandwidth is reached, it is unlikely that a protected allocation is available before 2015. [21]

4.1.3 Civil Operator Qualifications

Qualifications required from people operating UAVs are a subject of interest, since operation of UAVs may differ from that of conventional aircraft in some essential aspects. For example, it is likely that operators flying for commercial gain are required to gain a qualification similar to a commercial pilot's license. Whether requirement of class or type ratings in the case of UAVs is a feasible path of advancement remains to be resolved as well.

Operating in segregated airspace or operating vehicles of low weight within line-of-sight such dangers may be deemed modest. Thus, requiring UAV operators to obtain qualifications similar to those expected from pilots of manned aircraft is likely to be too onerous and inflexible a solution in such cases, whereas in non-segregated airspace or when operating heavy UAVs beyond line-of-sight, requirements naturally take on a much more rigorous form. [22]

4.1.4 Systems Reliability

Most statistics available concerning UAS reliability tell of UAS exhibiting relatively poor reliability figures. From all UAV accidents, 75-85% are attributed to equipment failure. To a great extent, these poor figures are due to little emphasis on reliability in design. It should be borne in mind, however, that most UAS experiences so far have been gathered with military UAS, some of which have been originally designed as expendable vehicles.

Table 4 presents the mishap rates and mean times between failures (MTBF) of several manned aircraft in comparison to those of the Predator UAV of the US Armed Forces. The table shows that the reliability of the UAV is significantly worse than that of even the worst military aircraft. General aviation aircraft are much more reliable and civil airliners even orders of magnitude more reliable.

Table 4. Reliability figures of some manned and unmanned aircraft. [14]

Aircraft	**Mishap Rate (per 100,000 hrs)**	**MTBF (hours)**	**Availability**	**Reliability**
General Aviation	1.22	*Data proprietary or otherwise unavailable*		
AV-8B	10.7		*Data unavailable*	
U-2	3	105.0		96.1%
F-16	3.5	51.3		96.6%
F-18	3.2			

Aircraft	Mishap Rate (per 100,000 hrs)	MTBF (hours)	Availability	Reliability
Boeing 747	0.013	532.3	98.6%	98.7%
Boeing 777	0.013	570.2	99.1%	99.2%
Predator/RQ-1 (UAV)	32	55.1	93%	89%

The reliability of UAVs can be improved mainly in two different ways: improving the integrity of components and building in redundancy. Both of these approaches affect the cost of operation as well. The costs vs. reliability issues are and will continue to be important considerations in preparing various UAV regulations; for example, should a UAV that is used to spray fields with pesticides be subject to as strict regulations as a UAV used over urban areas? System reliability requirements are likely to be motivated by fear of UAVs falling from the sky and causing damage to persons or property. It is interesting to note, however, that during the Vietnam War the US Armed Forces lost 544 UAVs in operations over densely populated Southeast Asia, yet not a single person is known to have been killed as a result. [14]

4.2 State of Regulation in the United States of America

In the USA the airworthiness and qualification issues are in the sphere of responsibility of the Federal Aviation Administration (FAA). The FAA makes a distinction between public and civil UAS, the public being those used by the military, police, coast guard etc. and the civil including all recreational and commercial applications. FAA states that UASs interfere with the manned aviation and, in addition, potentially cause risk to other airborne vehicles, as well as people and property on the ground. Consequently, measures must be taken to ensure an acceptable level of safety. Such measures at the moment include the requirement of a specified Pilot in Command (PIC) and a separate qualified visual observer who may be either on the ground or in a chase aircraft. [24], [25] If operators wish to conduct operations outside Restricted, Prohibited or Warning Area airspace, specific authorizations are required. Public entities are eligible to apply for a Certificate of Waiver or Authorization (COA) and the airworthiness certificate applicable to civil operators is the Special Airworthiness Certificate (SAC). Both authorizations are issued for a period of up to one year. Furthermore, the SAC can be granted only for the following purposes:

- Research and development
- Crew training
- Market survey

A prerequisite for the issuance of both COA and SAC is that continued airworthiness procedures are addressed in the application. It is "highly recommended" that all applicants describe at least a *Continuing Airworthiness Program* and a *Maintenance Training Program*, as well as all skill sets or maintenance practices that are unique to their aircraft or in their scope.

In flight operations main emphasis is laid on the systems compliance with the FAAs *Right-of-Way Rules: except Water Operations* [26]. Sense-and-avoid requirements are derived on the basis of this document. FAA does not regard cameras or other electro-optical sensors as sufficiently reliable to fulfil these requirements. In the case of other sensors, such as radars, the applicant is obliged to demonstrate that "injury to persons or property along the flight path is extremely improbable." when using the sensors in question. Automatic recovery capability in the case of a lost link is a further requirement. If the vehicle systems are not deemed redundant enough, a *Flight Termination System* (FTS) is required as well.

FAA further acknowledges the low cost, low risk level, applicability to tactical reconnaissance and other special characteristics of small UAS and has set up the *Small Unmanned Aircraft Systems Aviation Rulemaking Committee* to address issues such as [27]:

- Integrating small UAS into the NAS *(National Airspace System)*
- Economic and societal influence of small UAS

- Risks and mitigations involved with small UAS operations
- Preparing a draft rulemaking proposal
- Guidance and implementation processes
- Global regulatory harmonisation
- Technical documentation

Certain commercial operators in the USA operate in adherence to FAA's *Advisory Circular* 91-57, which describes the rules applicable for remotely-controlled model aircraft. The FAA stresses, however, that this is not legal practice and must be avoided until the FAA has issued a detailed "flight authorization instrument" on the subject. [29]

In addition to FAA, the Radio Technical Commission for Aeronautics (RTCA) has set up the Subcommittee 203 (SC203), which co-operates with the UAS industry to create a framework for future regulation in the form of Minimum Aviation System Performance Standards (MASPS) for unmanned aircraft systems as well as for related command, control, communication and sense-and-avoid systems. The SC203 has not yet published any regulations.

4.3 State of Regulation in Europe

Within the European Union the UAV regulations are mostly being developed by the European Aviation and Safety Agency (EASA). EASA has been considering two possible approaches to UAV certification [30]:

- The conventional approach, which is based on application of defined, comprehensive airworthiness codes to the design of all aircraft, but avoids making assumptions as to what the aircraft will be used for.
- The safety target approach, which is based on taking into account all the factors affecting the overall safety level, especially risks to third parties. For example, vehicles operating over desolate areas or in segregated airspace could be subject to less severe requirements than vehicles operating in other

areas. Instead of vehicles and systems, different "safety cases" would have to be certified.

The proponents of the safety target approach claim that such an approach facilitates concentration on the "key risks", and that it diminishes the need to consider aspects that are unessential to the envisaged mission. The critics of such an approach refer to the difficulties it would pose on achieving the level of transparency and equitability required of EASA, e.g. in the case of two competing commercial operators applying for certificate with differing equipment and safety cases. The commonality of standards that has been achieved in the course of several decades is seen to be at risk as well. A further difficulty is constituted by the fact that if such a safety case were to be modified, complete reassessment would likely be necessary, whereas the conventional approach facilitates limiting the study of a modification to its immediate effects on the airworthiness. As a result of these considerations, EASA is going to adopt the conventional approach in the case of UAVs as well. The regulation 216/2008 states that civil aircraft certification procedures apply to UAS. Thus, *Acceptable Means of Compliance* (AMC) of Part 21 must be adhered to. The requirements laid out in Part 21 include [21]:

- Type Certification
- Design Organisation Approval
- Production Organisation Approval
- Certificates of Airworthiness
- Application of Part M Continuing Airworthiness requirements

According to EC Regulation 1592/2002 Annex II, UAVs with an operating mass of less than 150 kg are regulated by national authorities. However, both the UAS industry and authorities feel that harmonized regulations should exist below this threshold as well. As a result, a European group of national authorities called JARUS (Joint Authorities for Rulemaking Unmanned Systems) has been formed to develop harmonized operational and technical regulations for UAVs weighing less than 150 kg.

The European Organisation for Civil Aviation Equipment (EUROCAE) Working Group 73 (WG73) has been established as an "expert group to propose technical inputs to EASA for additional airworthiness criteria and/or Special Conditions that have not been detailed in the earlier rule-making proposals". [31] The WG73 also includes the Subgroup 4 (SG4), the objective of which is to define a regulatory concept for light UAS that are to be flown using "visual management of separation/avoidance of collision". However, the work of the SG4 has not yet produced any published results. [2], [32]

Eurocontrol presents views largely similar to those of the other agencies, stating that UASs must achieve a similar level of safety as manned aircraft do, that UASs must not deny airspace to other users and that UASs must be "transparent" to the air traffic management system i.e. requiring no additional measures to be taken by the air traffic controllers.

4.3.1 Finnish UAV Regulations

Currently no set of Finnish airworthiness or operational regulations for UAVs exists. Neither does a framework for operator licensing exist. The Finnish Transport Safety Agency (TraFi) handles requests to operate on a case-by-case basis. Some general directions have been published, however. Unless the safety of third parties or anyone involved is compromised, UAVs are allowed to fly in airspace that is prohibited from other air traffic. Operation is allowed according to the following terms [33]:

- If the UAV is being flown in uncontrolled airspace under the altitude of 150 meters and it remains within the line of sight of the operator, no permission is needed. Flying above 150 meters in uncontrolled airspace is prohibited.

- If the UAV is being flown in controlled airspace under the altitude of 150 meters and it remains within line of sight of the operator, permission is to be requested from the local air traffic control.

- In order to fly above 150 meters in controlled airspace and/or beyond the line of sight of the operator, the mission area must be declared a "danger zone" and closed to other traffic. The height of the closed airspace volume is determined by the air traffic department of the Transport Safety Agency.

Application for such a closure must be issued at the latest 10 weeks in advance and a fee of 250 € is collected. The duration of the closure is at most 2 weeks and permanent closures are not allowed in accordance with the principle of flexible airspace use.

- Vertical clearance from obstacles must be at least 30 meters in all operation and the vehicle may not be flown e.g. over people.

4.3.2 UAV Regulations in the United Kingdom

The United Kingdom Civil Aviation Authority (UK CAA) has been among the first national authorities to develop regulations for UAVs. The UK CAAs rulemaking philosophy is based on the notion that traditionally, as originally dictated by the Annex 8 to the 1944 Chicago Convention of the International Civil Aviation Organisation (ICAO), airworthiness requirements consist of a set of standards for the protection of third parties, supplemented by cabin safety requirements aimed at the protection of the occupants. As UAVs carry no occupants, the UK CAA considers that a suitable starting point for UAV regulation can be found by modifying the existing regulations in such a manner that the cabin safety requirements are replaced by special requirements specific to UAVs, such as requirements on the remote guidance. As the vehicles capability to cause harm or damage is broadly proportional to its kinetic energy, requirements are categorised accordingly. [21]

Light UAVs are equated with model aircraft in the UK CAA regulation and are subject to similar flight rules. In these rules, a light UAV is defined as one that satisfies the following conditions [21]:

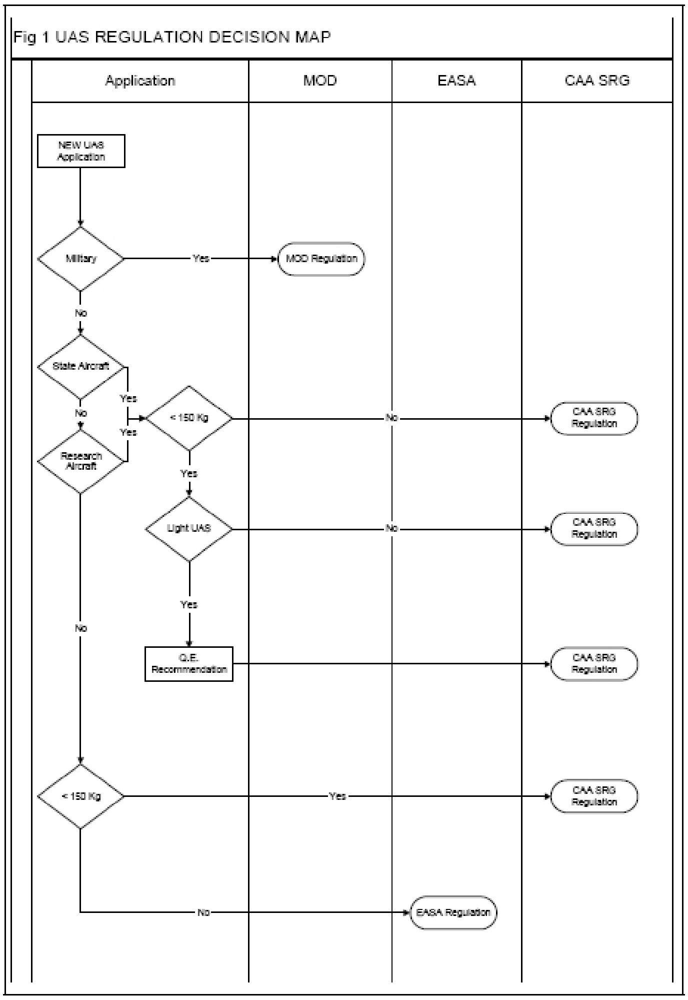
- Mass – up to 150 kg
- Maximum level speed 70 kts
- Maximum operating altitude 400 feet above surface
- Max operating distance 500 meters
- Max impact energy 95 kJ, calculated using either $1.4V_{max}$ or free fall velocity

- Flown at least 150 meters from buildings and 100 meters from people (50 meters for take-off and landing)
- Operation in Day Visual Meteorological Conditions (Day VMC) only
- Airworthiness/safety assessment by an accredited organisation

Vehicles with an operating mass (without fuel) of less than 20 kg are exempt from the requirement of airworthiness certification. Vehicles with an operating mass between 20 and 150 kg are required to have a Certificate of Airworthiness or a permit to fly.

The UK CAA has published its policy on UAVs in a document called the *Civil Aviation Publication 722* (CAP722) [22], which is a joint civil-military document, thus covering the whole spectrum of UAV aviation. The CAP722 is a relatively comprehensive work and is likely to act as a model for the common European framework on UAV-related regulation. [32] A decision map outlining the spheres of responsibility of the relevant authorities is shown in Table 5.

Table 5. CAA decision map for UAS regulation [22] Abbreviations: MOD = Ministry of Defence; EASA = European Aviation Safety Agency; CAA SRG = Civil Aviation Authority's Safety Regulation Group.



4.3.3 UAV Regulations in Sweden

The Civil Aviation Department of the Swedish Transport Agency has published regulations for light UAVs. These regulations employ a so-called "total system approach" instead of certifying the components on a one-by-one-basis. This point of view has been reached after considering the unmanned system's complexity and interactive nature (vehicle, control stations, data link and software) as opposed to the manned aircraft's self-contained nature. In short, the Swedish authorities find that component certification does not produce sufficient results in the case of UAS.

The regulations are structured along categories presented in table 6. The category 1A is subject to the lightest regulation and the category 3 to the most stringent. Depending on category, some or all of the following topics are covered [34]:

- Competence, age and health requirements for the pilot/operator
- Requirements on the organisation conducting flight operations
- Planning and conducting of, as well as reporting on flight operations
- Requirements on technical characteristics and equipment
- Communication with the air traffic control

Table 6. UAV categories of the Civil Aviation Department of the Swedish Transport Agency [34]

Category	Conditions
1A	An unmanned aerial vehicle with a maximum start mass of 1.5 kg which develops a kinetic energy of at most 150 J and is flown within line of sight of the pilot.
1B	An unmanned aerial vehicle with a maximum start mass of more than 1.5 kg but at most 7 kg and that develops a kinetic energy of at most 1000 J and is flown within line of sight of the pilot.
2	An unmanned aerial vehicle with a maximum start mass of more than 7 kg which is flown within line of sight of the pilot.
3	Unmanned aerial vehicles that are certified to be flown and controlled beyond the line of sight of the pilot.

4.4 Conclusions

Current regulatory situation in UAV matters can be described as a deadlock situation [35]: the industry is waiting for airworthiness standards and operational rules to be able to offer certified airframes expected by the potential Civil UAV users. The regulators, on the other hand, are waiting for user experiences and statistics on which to base their decisions. Approaches adopted to solve this situation consist mainly of common European committees and working groups.

Some countries have already developed national regulations on UAVs, but some important issues remain to be solved, the most important being achievement, verification and validation of sufficiently reliable sense-and-avoid capabilities.

Figure 7 presents a schedule estimate presented in reference [15]. The current situation limits especially the adoption of large UAVs, which must be provided access to controlled airspace. Thus, it is safe to assume that most UAVs adopted in the near future will be representatives of the micro- and mini-classes.

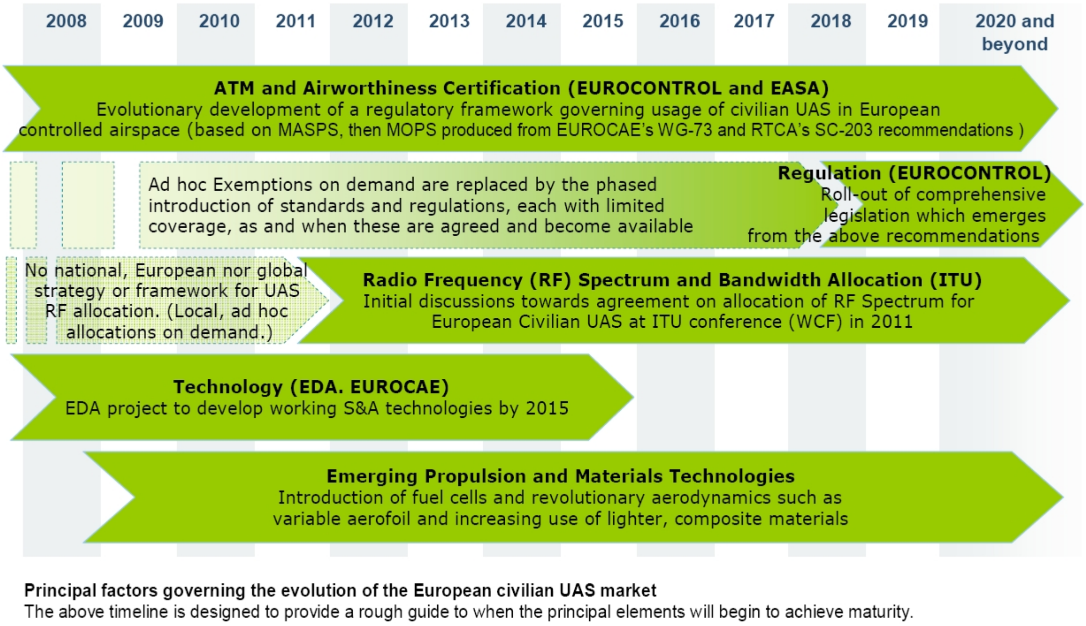


Figure 7. Estimated schedule of UAV-related developments [15]

5. User Survey

5.1 Overview

User survey of a possible environmental monitoring UAV was conducted in a series of discussions. Most of the discussions were conducted in collaboration with Sensor Centre Ltd. The following users were interviewed:

- Ministry of the Interior, Department of Rescue Services [36]
- Helsinki Police Department [37]
- PIEneering Ltd [8]
- Finnish Environment Institute [38]
- Finnish Meteorological Institute [39]
- The Finnish Border Guard [40]
- Finnish Nuclear and Radiation Safety Authority [41]
- Geological Survey of Finland [42]

In addition, the opinion of the Finnish Forest Research Institute was inquired by e-mail and information about activities of the Finnish Geodetic Institute and the Technical Research Centre of Finland was obtained from second-hand sources. After the discussions were completed, preliminary specifications for possibly applicable UAVs were drafted.

5.2 Ministry of the Interior, Department of Rescue Services

Department of Rescue Services is responsible for the safety of people in all kinds of everyday incidents, such as fires, as well as in all kinds of catastrophes and in state of war.

The most important UAV application of this agency would be enhancing the situational awareness of rescue leadership in many potential cases, such as house fires or traffic accidents. In such use a small UAV would suffice since the payload would most likely consist of only cameras (in visible as well as in IR-spectrum). Since the area to be surveyed would most likely be small, this kind of use would not present demanding range or endurance requirements, thus facilitating the use of rotary-wing UAVs. The hovering capability of rotary-wing UAVs would constitute an obvious advantage in surveillance and such vehicles have already been studied by the rescue authorities (reference [43]).

Further possible UAV applications of this authority would include performing measurements of gas/aerosol concentrations in the aftermath of e.g. chemical factory or tank truck accidents. Radiation monitoring was mentioned, too, but it falls on the responsibility of the Finnish Radiation and Nuclear Safety Authority (STUK). Augmenting the communication networks of rescue officials by airborne radio repeaters would permit more effective coordination of operations, especially in remote areas.

UAVs could be applied to surveillance of forest fires in the summer. So far this has been acquired as an outsourced service from the Finnish Aerial Search and Rescue Association (Suomen Lentopelastusseura ry). General aviation aircraft, manned with a pilot and two or three observers, regularly fly on 26 fixed routes. Cost of this operation has been up to 500 000 € annually, depending on weather. The Department of Rescue Services is satisfied with this arrangement, but is ready to consider other options as well, depending on the costs and manpower involved. Performing this task using a UAV would necessitate quite a long endurance since on one hand, the routes currently flown are rather long and on the other, monitoring smaller areas at a time would probably tie up too much resources and workforce. To cover wide enough areas, flight altitude would also have to be relatively high, which is problematic in view of the current regulations.

Altogether, emphasis was laid on the requirement that in all operation the UAV should be very rapidly deployable. This would effectively mean quite a dense network of UAV-equipped fire stations.

5.3 Helsinki Police Department

The Finnish Police comprises 24 local police stations as well as three nation-wide authorities: the National Traffic Police, the Finnish Security Intelligence Service and the National Bureau of Investigation. Helsinki police department was chosen for the interview, because it is the largest police department in Finland and also the one confronted with the most versatile assignments. Main police use of UAVs would likely be tactical surveillance and enhancement of situational awareness. Supervision of demonstrations and other large gatherings of people are examples of the latter, whereas tactical surveillance of raid targets and pursuit of suspects represent the former. The police are especially interested in rotary-wing UAVs, since they are well suited to surveillance in an urban environment and monitored areas are usually not very large. Rotary-wing UAVs with sufficiently large payload could conceivably also drop sensors or surveillance devices to areas of interest.

An important area of responsibility for the police is constituted by search-and-rescue missions, tasks that often involve combing through tens, even hundreds, of square kilometres. UAVs with quite a long endurance (several hours) would clearly be needed for these missions to be practicable. The Police is entitled to get assistance from the defence forces and the border guard. This arrangement is perceived as one that functions very well, and is likely to rule out the need for an own long-endurance UAV.

Police authorities are very interested in enhancing the capabilities of their communications networks by utilizing ad hoc airborne radio repeater systems (UAV as a communications relay). Need for such solutions could arise e.g. in operations in rural areas.

The Police's enthusiasm for UAV is weakened by several user experiences of other agencies. These experiences often tell of unrealistic performance and functionality figures presented by manufacturers.

5.4 PIEneering Ltd

PIEneering Ltd is a software enterprise based in Helsinki and has recently operated UAVs to demonstrate the feasibility of their use in aerial photography. The company's main business is in producing software for aerial image processing purposes. UAVs are perceived to offer numerous advantages due to their affordable and flexible operation. It is therefore possible to photograph even very small areas with reasonable cost. Novel technological solutions open up new business possibilities. Such solutions include 3D-mapping based on combining digital aerial images. To some degree, such maps can be used even as replacements for laser scanning, facilitating estimation of e.g. forestry damages or the volume of wood reserves of a paper mill. This kind of operation does not necessitate long endurance or high payload capacity, since photography is performed using ordinary digital cameras installed in the airframe.

In the course of one day, an area of approximately 10 square kilometres can be mapped (2-3 square kilometres per flight). It must be stressed that possibilities to operate easily and quickly within a light regulatory framework are needed to maintain flexibility and a reasonable cost level. The use of a UAV in mapping sets stringent requirements on the vehicle's flight control because in order for the image processing to succeed with acceptable accuracy, the vehicle's position and attitude must be known quite precisely when a photograph is taken.

5.5 Finnish Environment Institute

Finnish environment institute (SYKE) is an organization that is partly a research institute and partly a centre of environmental expertise. The tasks of this organization include long-term monitoring of the natural environment and seeking to find effective means to control environmental changes.

Oil slick detection and monitoring is an important task of SYKE and one well suited for UAV-based applications. Currently, all airborne monitoring relies on relatively heavy turboprop aircraft (of the type Dornier 228) of the Finnish Border Guard. These aircraft have an extensive set of environmental monitoring equipment, but their loiter times are rather short and achieving constant situational awareness is further complicated by the fact that the Border Guard only has two of these aircraft.

IR sensors suffice for detecting an oil slick and, furthermore, for estimating its size. Since the miniaturization of electronics has brought about very small IR-sensors, a small, light and affordable UAV would be enough for this purpose. Radiometers constitute another branch of sensors that could be carried aboard an UAV. The usefulness of radiometers in ship- or land-based surveillance systems is severely limited by the fact that in order to obtain good results they should be able to view the water surface from a steep angle.

Further applications could include monitoring seaweed and other marine or coastal vegetation. Hyperspectral scanners are an emerging sensor technology and very likely will in near future achieve a degree of maturity that enables them to be used in small UAVs. UAVs hold promise in gas detection as well. Risk of an explosion prevents flying a manned aircraft directly above or downwind of an oil slick. UAVs could perform such tasks, especially if they are propelled by sealed electric motors.

5.6 Finnish Meteorological Institute

The Finnish Meteorological Institute (FMI) is responsible for providing weather, oceanographic and air quality services as well as conducting research on diverse topics. Main research areas of FMI are:

- Meteorological research, which includes atmospheric & wind energy modelling and boundary layer research.
- Air quality research, which includes atmospheric dispersion modelling, atmospheric chemistry and air quality monitoring.
- Research of the middle and upper atmosphere, where main emphasis is on ozone and UV-radiation research.
- Space research, which includes research of the Earth's magnetosphere as well as research of deep space topics, such as the atmosphere of Mars or the moon Titan of the Jupiter. Space dust and radiation in the solar system are researched as well.
- Climate change research, which includes long-term research on the effect of man on the climate.
- Polar research is an increasingly important topic as the natural resources in the Polar Regions attract growing interest. Furthermore, almost every year, including 2010, a Finnish expedition (FINNARP) is sent to conduct research in the Antarctic.

Weather forecasting is based on a network of ground stations and weather balloons. A total of six balloons are launched every day from three different locations in Finland. The data from this measurement system is fed to diverse computer models, the most important of which is currently run four times a day. UAVs could conceivably replace the weather balloons to some degree, if they offer economic savings or important additional capabilities. The main difficulty for a UAV to be used in this operation would be the required attainable altitude. The balloons reach a height of approximately 20 km, and a ceiling of at least 10-12 km would be required for a UAV to be able to provide meaningful results. However, if the achievement of such altitudes is not possible at a reasonable cost, there are many other possible applications as well. Such applications could include measuring aerosol concentrations and boundary layer research, as well as measurement of seawater surface temperature or seaweed distribution. Some research has already been performed using the SUMO platform and in the winter 2010/2011 the SUMO was used to conduct wind profile measurements in the Antarctic as a part of the FINNARP 2011 expedition. Tasks related to aerosol measurements include also measurement of ice crystal and condensation nuclei concentration as well as liquid water content measurements using a hot-wire probe.

Research of the polar marine environment is an increasingly important topic in many respects and one the FMI wants to engage in. Mainly the research interest is fuelled by the polar areas' status as one of the few remaining untapped sources of natural reserves. The Northern Sea Route is of specific interest to FMI because of its relative proximity to Finland. It is unlikely, however, that this interest could result in need for small UAVs. On the contrary, preliminary discussions have taken place about whether NASAs high-performance UAVs could be applied in this area, e.g. for dropping radiosondes [44].

More exclusively academic interests could include measuring the Earth's balance of cosmic and solar radiation. Determination of radiation balances is an essential task especially in climate change research.

5.7 The Finnish Border Guard

The Finnish Border Guard is responsible for surveillance of land and sea borders, as well as for law enforcement and search and rescue operations in Finnish territorial waters. Environmental monitoring constitutes an important further responsibility, since the Finnish Environment Institute has very limited possibilities to enforce the environmental regulations, and is therefore dependent on other authorities in practical matters, such as in oil spill detection and monitoring. The heavy and constantly increasing ship traffic on the Gulf of Finland can give rise to UAV needs as well: one bleak scenario would be e.g. a collision of a tanker ship with a cruise ship or another tanker. In such a case a UAV could be rapidly sent to measure concentrations of possible poisonous/flammable gases, thus not risking the rescue helicopter unnecessarily.

Fishery protection is a further responsibility of the border guard and one that can partly be performed by UAVs as well; the species and amount of the catch cannot likely be monitored, but enforcement of legal fishing areas is another matter. Such activity is of great importance on the Mediterranean and the North Sea, but should not be neglected on Finnish waters either.

The Border Guard has been actively searching for suitable UAVs for several years, but has not purchased any vehicles yet. The most important applications for UAVs are going to be found in enhancement of the monitoring capabilities and situational awareness of marine vessels and land patrols.

Acquisition is likely to take place in co-operation with the Finnish Defence Forces, in order to benefit from the economics of scale. Studies conducted by the Border Guard have shown that the use of relatively heavy military UAVs (such as the RUAG Ranger of the Finnish Army) does not bring economic savings or marked operational advantages compared to the use of ordinary manned helicopters. Thus, the emphasis has shifted towards light UAVs. However, within the realm of light UAVs it has become evident that there exists no single platform capable to fulfil all the requirements set by the Border Guard. Most likely this will be solved by acquiring at least two different platforms, one representing the fixed-wing and one representing the rotary-wing type.

The nature of the Border Guards responsibilities sets certain requirements on the systems control solutions. Ideally, to reduce the workload of the field personnel, after take-off the vehicle should be controlled from a remote command centre, with the field personnel equipped only with receivers. Control could be transmitted over the internet or utilising a mobile communications network. At the moment the latter alternative is not possible, however, because the data transfer rates achieved in the current mobile networks are not high enough for transmitting high-resolution live image which would be an important objective. Furthermore, using these networks in an airborne vehicle is prohibited by the operators.

5.8 Finnish Forest Research Institute

The Finnish Forest Research Institute (Metla) is responsible for conducting research on matters involving the forest environment and forestry. Metla is among the most important users of remote sensing data in Finland; photographic and laser scanner data is needed to estimate changes in forest biomass. At the moment the data is collected by manned aircraft mapping large areas (hundreds to thousands of square kilometres) at a time. Such operation cannot be performed using small UAVs and light sensors. Thus, a small UAV could potentially be used if the need to gather data from a small area was to arise, the applied methods were proven reliable enough and the costs of operation were reasonable. Further applications could include forest damage assessment and monitoring forest fires or surveying game animals, such as deer or moose.

It is not likely that Metla would acquire own UAVs, as the activities are mainly directed towards utilising the data rather than collecting it. However, Metla is keeping an eye on the branches' development and is potentially interested in useful remote-sensing data offered by the operators. [45]

5.9 Finnish Nuclear and Radiation Safety Authority

The Finnish Nuclear and Radiation Safety Authority (STUK) has already been involved in two different UAV projects, the first one being a radiation detector installed on the Finnish Army's RUAG Ranger tactical UAV, and the other being a particle sampling tube installed on the Patria MASS UAV. Both of these projects have been documented in scientific journals. [10], [46] The equipment used in the Ranger was considered versatile and effective, but the system as a whole was unnecessarily heavy, which limited its effectiveness and resulted in tedious operation. Furthermore, mapping a radioactive plume would have necessitated the use of a UAV swarm; such a task most likely cannot be performed fast and reliably enough with a single vehicle.

With the Patria MASS, the purpose was to develop a solution that could be rapidly deployed with minimal crew and support system resources. The vehicle flew carrying a passive filter designed to collect representative samples from the air flow. After the flight, the filter was analysed in a laboratory (as opposed to the Ranger, the system of which provided real-time data on radioactivity and nuclides in the plume). The system was deemed sufficient for detecting strong radiation sources and localising a radioactive plume in the close vicinity of the ground control station. However, the system was not considered adequate for mapping wide plumes or fallout areas.

At the moment the STUK is not active in UAV matters. Furthermore, the STUK considers UAVs useful only in emergency situations, but unnecessary in augmenting routine radiation monitoring tasks.

5.10 Geological Survey of Finland

The Geological Survey of Finland (GTK) serves as Finland's main geological information centre and produces information for the industry as well as the society.

The GTK is interested in utilising UAVs in its operations, as airborne measurement tasks in geology necessitate flying at a low speed and at a very low altitude. Using UAVs could reduce risks in such operation to a great extent, with the added benefit of potential cost reductions.

The GTK has performed gamma-spectrometric measurements in the beginning of the new millennium, with the objective of comprehensively mapping the mineral resources in Finland. These measurements were performed using a relatively large twin-engine turboprop aircraft (de Havilland Canada DHC-6 Twin Otter) equipped with very sensitive and heavy equipment. The results of these measurements are considered satisfactorily accurate and as a result GTK is not going to embark on large-scale airborne research in the future. This means that many remaining needs are local by nature and could likely be performed by UAVs.

One potential UAV application could be generating accurate elevation models of the landscape. Such models are needed, since certain regular characteristics give away information on the bedrock structure. For example, cracks in bedrock often present themselves as vertical displacements in the terrain. Such displacements can be very small but are often found along long distances (up to 100 km). Obtaining information on bedrock structure is essential in e.g. large civil engineering projects, such as in end-storage of nuclear waste. Such solutions would require a laser altimeter, or possibly photogrammetric sensors could be used as well.

Further possible geological applications could include hyperspectral measurements of rock surfaces as well as magnetometric measurements. Sensors that can be carried by a light UAV are already available for both purposes (hyperspectrometers and fluxgate magnetometers).

5.11 Others

The Finnish Geodetic Institute has developed a "low-cost multi-sensorial mobile mapping system" that can be carried by a UAV. The system consists of a positioning system, two laser scanners, a CCD camera, a spectrometer and a thermal camera. The system has been tested on an R/C helicopter, and has produced promising results in tree measurements in thick forests, where traditional airborne laser scanning (ALS) is not accurate enough [47]. The Geodetic Institute is interested in developing this system into a commercial product in the future.

The Technical Research Centre of Finland (VTT) has developed a light (<350 g) hyperspectrometer that can be carried by a light UAV. The hyperspectrometer has been tested on a rotary-wing UAV (Draganfly X6) and has produced promising results in vegetation monitoring. VTT is interested in developing the hyperspectrometer into a commercial product, but some work remains to be done until the associated sensor software is satisfactory. [48], [49]

5.12 Conclusions on User Needs

UAVs attract a lot of interest, but most authorities have not yet taken concrete measures towards UAV acquisition or operation. Most interviewees brought out a considerable amount of possible UAV applications, but also told that their respective organisations had not made any decisions about the kind of vehicles they most likely would be using in the future. Consequently, getting numerical requirements proved out to be very difficult.

Table 7 presents the most likely applications disclosed by the interviewees. The applications are typical UAV tasks and a large proportion of the UAVs currently produced and marketed are designed to fulfil requirements inherent in such tasks, especially in reconnaissance and surveillance.

Table 7. Overview of the UAV needs of the authorities interviewed. Abbreviations: E/O = electro-optical; CBRN = chemical, biological, radiological, nuclear; CR = communication relay; RS = remote sensing; MI = meteorological instrumentation.

User	Use	Payload
Department of Rescue Services	Reconnaissance, support of rescue operations	E/O, CBRN, CR
Helsinki Police Department	Reconnaissance and surveillance	E/O, CBRN, CR
PIEneering Ltd	Aerial photography	E/O
SYKE	Oil spill detection, other environmental monitoring tasks	E/O
FMI	Meteorological research, possibly routine measurements as well	MI, E/O
Border Guard	Reconnaissance and surveillance	E/O, ABC
Metla	Remote sensing	RS, E/O

User	Use	Payload
STUK	Radiation monitoring	CBRN
GTK	Remote sensing	RS

6. UAS Specifications

6.1 Initial UAS Specification Based on the User Survey

Since the authorities (with the exception of the Border Guard) had not yet made detailed plans about UAV acquisition, the discussions remained on a rather general level and, consequently, specifications for UAVs that would fulfil the expressed needs were prepared relying on own judgement. The original idea was to iterate the specifications after getting feedback from the interviewees, but very limited feedback was eventually received and thus the idea was abandoned.

The proposed specifications were based on the idea that the needs could largely be fulfilled by two different vehicles, one being a light, electrically propelled vehicle carrying only electro-optical sensors, and the other being a larger vehicle capable of carrying measurement payload weighing several kilograms and propelled by a piston engine.

Functional requirements of a very general nature were set on the vehicles to provoke thoughts and comments. The requirements were as follows:

- Ground equipment of the system should be easily portable and the system must be operable by two persons. It must be possible to get the vehicle airborne in less than 15 minutes.
- The structure of the vehicle must be simple and easy to repair.
- Payload must be modular and rapidly changeable.
- The vehicle must be capable of at least taking off from and preferably also landing on a small area, such as a ship’s deck. Conventional take-off and landing runs are inacceptable. Practically this means take-off from a catapult and landing on an arresting net or wire. If landing on a ship is not required, landing by a parachute is probably the best option.

- When operating e.g. in forest environment, take-off and landing must not require an open area, whose longest side is longer than 75 m, if bordering obstacles with a height of 15 m are assumed.

- The smaller (electrically propelled) vehicle should be sealed in such a way, that it can be flown into clouds of combustible gas or over oil spills without fear of ignition.

- Real-time data transfer capability as well as data recording capability are essential requirements.

- Data link solution must be chosen from among readily existing, commercial alternatives. Navigation by GPS will suffice, no back-up systems are needed.

- For loss-of-link situations, the vehicle must be equipped with a flight termination system that either brings the vehicle to the take-off point or to the point where the signal was lost. Emergency landing by deployment of parachute would also be acceptable.

- The system must be equipped with built-in test equipment and a warning system notifying the operator of malfunctions, signal problems and deviations from the ordered flight path (position, height, velocity).

Afterwards, some of the requirements no more seem reasonable. For example, a set-up time of 15 minutes is perhaps acceptable for a scientific vehicle, but not for one employed in law-enforcement tasks.

Comments were also requested on sensor needs and desired sensor performance, but no replies were received on these issues either. It is presumable that these questions will be seriously considered only in case of serious acquisition intentions, and such intentions clearly are years away.

6.1.1 Light UAV for Surveillance Purposes

The numerical requirements set on the vehicles were rather unspecific and mainly intended to give an impression of what might be realistically expected.

It may be stated that the surveillance needs could to a large part be satisfied by a rotary-wing UAV and that especially ship-borne operation would likely be simpler if such vehicles were used. A decision was made, however, to confine the study to fixed-wing aircraft.

Table 8. Specifications for a surveillance UAV

Feature	**Target Value**
Payload mass	min. 1 kg
Maximum mass	max. 10 kg
Endurance	min. 60 minutes
Range	min. 10 km
Maximum wind	min. 12 m/s
Maximum airspeed	min. 50 km/h
Ceiling	min. 2000 m
Take-off	hand throw or catapult
Landing	parachute or net
Propulsion	electric
Price of a single UAV	max. 15 000 €
Price of a complete system	max. 50 000 €

In retrospect, some requirements seem less than sensible. For example, sufficient sensor capability can easily be incorporated in a payload of approximately 500 grams and almost all vehicles are capable of meeting the flight speed requirement which was set with operation in windy conditions in mind. Thus, it possibly would have been more reasonable to set a highest allowable minimum speed or a desirable speed range, instead of just a maximum airspeed.

6.1.2 Larger UAV for Environmental Monitoring

The actual environmental monitoring needs could presumably be fulfilled by a UAV with a maximum mass of approximately 10-15 kg. This would effectively mean a vehicle that is propelled by a piston engine and has considerable endurance and range, but is nonetheless light enough to operate within light regulatory framework (20 kg is probably going to be an important threshold in the future as well as it is now).

The following specification was drafted, and realism of the figures was estimated by comparing the figures to those found in reference [2].

Table 9. Specifications for an environmental monitoring UAV

Feature	**Target Value**
Payload mass	min. 3 kg
Maximum mass	max. 20 kg
Endurance	min. 4 hours
Range	min. 50 km
Maximum wind	min. 16 m/s
Maximum airspeed	min. 100 km/h
Ceiling	min. 3500 m
Take-off	catapult
Landing	parachute or net
Propulsion	piston engine; non-poisonous, readily available fuel
Price of a single UAV	max. 75 000 €
Price of a complete system	max. 300 000 €

6.2 Specific Demands of the MMEA Project

The funds available at the initial phase of the MMEA project are somewhat limited, unavoidably leading to compromises with respect to the requirements presented earlier. The purpose of the following sections is to present some considerations potentially important in the selection.

Altogether, there are practically no readily-available alternatives within the given budget of 30 000 € for a complete system. Typical representatives of the performance class desired cost in the order of 150 000-200 000 €, even considerably more in some cases. The most reasonable solution would seem to be the acquisition of a separate airframe and equipping it with a commercial autopilot and other electronics. Affordable R/C model aircraft components can be utilised to a large extent.

High ceiling and long range are probably less important requirements too, since the agreed project goal in the initial phase is mainly sensor development that can be performed to a large extent by operating the vehicle within line of sight and at low altitude. Tests can be performed by operating e.g. from a model aircraft “aerodrome” or similar area.

Payload of the vehicle will consist of sensors developed within the project, mainly gas and radiation detectors. One commonly applied type of radiation detector is the Geiger-Müller tube, and another is the scintillation counter. Sensitivity of these types of detectors increases with increasing size and mass, especially in the case of the scintillation detector, whose operating principle necessitates the existence of a solid crystal made of, e.g., sodium iodide or phosphor and the larger the crystal, the more sensitive the sensor. Thus, it is reasonable to set a payload requirement of at least 3 kg, preferably 5 kg. If lighter sensors were used, the extra payload capacity could possibly be taken advantage of by setting up an arrangement of multiple sensors.

Range is largely dictated by the data link employed, but changing the data link is possible, thus rendering the vehicle’s endurance a more important requirement. To ensure flexibility in operation, endurance of at least two hours is required. This kind of a requirement is easy to satisfy in the case of piston-engine vehicles, but may prove demanding in the case of electrically propelled ones. Power consumption of the payload and other systems is a noteworthy issue as well, since such systems may be responsible for a considerable proportion of the total electric power consumption. Many long-endurance piston-engine vehicles are indeed equipped with generators to compensate for this issue.

Maximum take-off mass should be at most 20 kg, since this is the maximum mass for a vehicle to be exempt from special requirements, according to the current interpretation of the Finnish Transport Safety Agency. Low weight would provide additional advantages with regard to the ease and safety of operation.

The vehicle should have a service ceiling of at least 3000 meters, in order to facilitate use of the vehicle in varying tasks, such as in meteorology. Height of the ceiling may improve the vehicles range as well, unless the signal is weakened too much by atmospheric damping, which again is dependent on the frequency band selected for the data link.

Minimum flight speed of the vehicle should be no more than approximately 20 m/s, since the accuracy of radiation measurements improves with decreasing airspeed. Possible geophysical applications would benefit from slow flight speed as well. In the projected operation (sensor development) there is no need to define a requirement for the maximum achievable airspeed, at least not in the initial phase.

Costs can be further reduced by eliminating the catapult launch and parachute/net recovery requirements, although in order to avoid the need of a runway or other large, smooth area, it would be preferable if the vehicle could be launched from a catapult or thrown by hand. However, a vehicle of the considered size should be capable of taking off from a rather short strip (50 meters or less), thus rendering this requirement less important. Landing is not critical either; because of the low weight of the applicable UAVs the vehicles can land e.g. on their bellies under manual control. Lack of launch and recovery elements would obviously offer the possibility of getting along with minimal support systems, albeit at the cost of rendering ship-borne operations impossible.

Configuration of the vehicle should represent the pusher-propeller type, as is the case with the overwhelming majority of available vehicles. For the sake of simplicity, compact dimensions and structural integrity, a tailless or “flying wing” configuration would provide further advantages. However, although the flying wing configuration is widely used in small UAVs and advanced military vehicles, there seem to be few vehicles available at the lower end of the price range in the case of vehicles with a maximum mass of around 15-25 kg. This is probably due to the flying wing configuration’s inherent flight dynamics that inevitably necessitate a trade-off decision: one has to either accept demanding flight characteristics that require a sophisticated flight control system, or to build into the vehicle such a high degree of longitudinal and directional stability that performance (e.g. payload or maximum lift coefficient available) is restricted. As the reasonably-priced systems are mostly offered by small enterprises, it is understandable from these premises that a conventional configuration is usually chosen.

6.3 Educational Use

In the course of the work it became increasingly apparent that a UAS could also present a valuable addition to the aeronautical engineering curriculum of the Aalto University, particularly since the system most likely will be purchased and ready for use earlier than there will be sensors or other payloads developed by the project partners. Later the system probably is not going to be constantly occupied by the MMEA project either. Consequently, measures were taken to initiate the definition of possible future UAV-related education. An example of such measures was the recruitment of one student to conduct, as a personal project work, a feasibility study as to how the current courses and the possible future UAS could be combined to achieve the best possible learning outcome.

It is possible that the system acquired for the MMEA project is used mainly to gather insights and experience whilst the actual courses later on cover the entire process of design, manufacture, assembly/system integration and flight testing. Verification and validation practices could probably be incorporated in the curriculum as well, at the latest once the regulations achieve a mature enough state.

Low costs are to be desired, due to both budget limitations and the probably rather consuming nature of the projected utilisation in education. A highly customisable solution would be desirable as well, since such a solution would facilitate the accumulation of practical experience on as many facets of UAS aviation as possible.

Relatively low performance in terms of payload and range could be deemed necessary in the aeronautical engineering education but the situation may be different if some sort of a cross-disciplinary approach is adopted with e.g. other departments developing sensors or other payloads as student projects. In any case, it may be stated with relative confidence that the requirements set by the MMEA are also those of a solution that lends itself to educational use quite easily, since the MMEA project already has a strong emphasis on low costs and high customisability as well as on a relatively large payload.

7. Initial Assessment of Existing Systems

7.1. Background

The purpose of this chapter is to conduct an initial assessment of UAVs to be considered for the MMEA project. As the user survey revealed, electro-optical sensor carrying capability clearly seems to be the most important task, followed by nuclear, biological and chemical sensors. One of the main tasks of the MMEA-projects UAV-subgroup was to define specifications for a UAV that would satisfy real user needs, as well as provide a platform for airborne sensor research and development.

Defining characteristics according to which to choose a vehicle presents certain difficulties. As the market is perceived as one that is booming or at least beginning to boom, the amount of companies offering UAVs is immense and many vehicles are designed and built by research groups and enthusiasts, instead of traditional aerospace companies. Sorting out companies that can be taken seriously is not always an easy task and same applies to getting information about the vehicles in general, as a result of which one is often forced to turn to second-hand sources. The latter problem is compounded by many vehicles being of more or less military nature.

As UAVs are sold as a part of a complete system, a truly reasonable selection of a UAV would correspondingly presume knowledge on many disciplines, not just aeronautical engineering. Such disciplines include at least electronics, software and radio technology. Lack of such knowledge dictates the assessment to be based merely on the most essential requirements that affect the airframe, propulsion system as well as elements of launch and recovery. This simple approach facilitates consideration of complete systems as well as partly equipped vehicles and mere airframes.

7.2. Assessment Criteria for the Environmental monitoring UAV

The purpose of the following sections is to propose requirements as well as assessment criteria for a UAV to be used within the MMEA project for sensor development. The adopted approach is based on setting up target values for the vehicles performance and other characteristics, in compliance with the considerations presented in chapter 6. In the case of characteristics that can only exhibit discrete values, the different variants are given a discrete amount of points. In the case of characteristics that can exhibit non-round values, the target value equates to a certain even number of points, while exceeding values equate to more points and values that are under the target value equate to less points. The point/value-relation is linear.

Table 10 presents, in a condensed form, the assessment criteria discussed above.

Table 10. Assessment criteria for an environmental monitoring UAV

Feature	**Grading Basis**
Weight	0 kg = 1 point; 20 kg = 0 points; more than 20 kg = negative points
Payload	3 kg = 0 points; 5 kg = 0.5 point; less than 3 kg = negative points; more than 5 kg = more than 0.5 point
Endurance	2 hours = 0 points; 4 hours = 1 point; less than 2 hours = negative points; more than 4 hours = more than 1 point
Take-off	Hand launch or catapult = 1 point; other = 0 point
Configuration	Pusher = 1 point; tailless = 1 point; other = 0 points
Service ceiling	0 m = 0 points; 3000 m = 1 point; more than 3000 m = more than 1 point
Minimum flight speed	20 m/s = 1 point; 30 m/s = 0 point; more than 30 m/s = negative points

Although an overriding concern, system price was not included in the assessment because all solutions considered were not complete systems, as a result of which the prices were not directly comparable with each other. However, the costs were surveyed and systems with a (confirmed or estimated) price of over 100 000 € were excluded.

7.3. Assessment Results

The UAS supply was studied, and contact was established with manufacturers offering potential solutions. Several companies were unwilling to distribute comprehensive information freely, but rather would have required an underwritten non-disclosure agreement, a detailed business plan or some other kind of formal document. Moreover, some were simply not interested in merely selling airframes and would have wanted to provide comprehensive engineering, training and other services. It was decided to consider only manufacturers that were willing to exchange information open-mindedly. The vehicles finally included in the assessment, and their assessment results are listed in table 11.

Table 11. Vehicles included in the assessment.

Manufacturer	Model	Total points
Draganfly, Canada	Tango	2.97
Cyberflight, UK	Zygo (electric)	4.63
Cyberflight, UK	Zygo (piston engine)	5.63
Surveycopter, France	DVF2000	4.38
ET-Air, Norway	Cruiser	6.67
Nostromo Defensa, Argentina	Zonda	4.22
UAV Factory, Latvia	Penguin B	7.55

Most suitable vehicles according to this assessment are the “Penguin B” and the “Cruiser” (Figures 8 and 9). Both are propelled by a piston-engine, have a maximum mass in the order of 20-25 kg and are offered as basic airframes or as packages including engine, servos and wiring but excluding radio control system, data link and ground control station/software. Both are available at a price of less than 20 000 €, even significantly less, depending on the configuration.

Figure 8. The UAVFACTORY Penguin B [67]

Figure 9. The ET-Air Cruiser [69]

The other interesting pair of vehicles is that of the “Zonda” and the “Zygo” (Figures 10 and 11), both of which utilise electric propulsion (Zygo is optionally available with a piston engine as well), have a payload capacity of 3 and 2.5 kg, respectively, and are offered as complete systems but excluding payload. Both vehicles further offer the additional advantage of being hand-launchable.

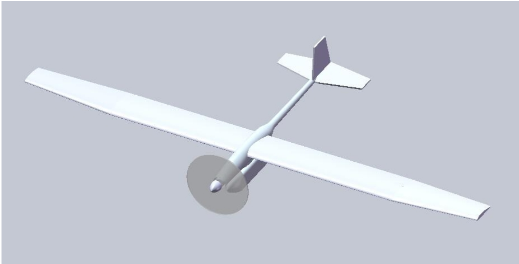


Figure 10. Sketch of the Nostromo Defensa Zonda [70]

Figure 11. The Cyberflight Zygo [71]

The remaining two systems “Tango” and “DVF2000” (Figures 12 and 13) seem to be very capable as surveillance platforms but exhibit some serious drawbacks with respect to their projected use in the MMEA project: both have very limited payload capacity of just over one kilogram, the Tango has rather limited endurance (50 minutes) and the DVF2000 is relatively expensive with a price of approximately 90 000 €.

Figure 12. The Draganfly Tango [72]

Figure 13. The Surveycopter DVF2000 [73]

8. UAS Proposal

8.1 General Considerations

During the process of preparation of this thesis, the objectives of the MMEA projects UAV part underwent some significant changes. As the payload requirements remained unclear, a decision was made to begin the definition phase nonetheless and, in addition, to choose a system that could also be used for educational purposes e.g. in the form of student projects. The following sections present issues to be considered with respect to such projected use of the UAS.

There are two possible lines of advancement in selecting the vehicle for the MMEA project: either a complete system is chosen and purchased or the system is assembled and integrated of components purchased individually.

Purchasing a complete turnkey solution is easier but - depending on the manufacturer's willingness to provide information about the systems characteristics - possibly does not provide a good opportunity to gain insight to the system or to facilitate modifying the system in response to varying needs. In the case of turnkey systems the manufacturer also expects to get a premium for the integration work and prices the system accordingly. Moreover, many existing systems are built to comply with military specifications such as NATOs *Standardization Agreement (STANAG) 4671* [50], which on the one hand may set exceedingly demanding requirements with respect to many civil applications, and on the other may complicate the design process and cause additional expenses.

Assembling a system from independently purchased components provides the possibility to tailor the solution better with respect to available funds and objectives. In addition, understanding of technology can be gained through practical experience and participation in meaningful projects. Such projects would probably be very valuable, especially in education, and would potentially offer experience of broadly interdisciplinary nature. Courses aimed at familiarising the students with aircraft project methodology already exist at Aalto University, but so far the approach has been solely of academic nature, whereas a UAS would provide the possibility of augmenting the education in a very cost-effective manner.

However, it is possible that such work may prove overwhelmingly difficult and laborious without previous experience. This kind of a situation might be alleviated through adoption of a systematic approach to the work at hand. Useful tools in such an approach include those used in systems engineering and quality control; Functional Hazard Analysis, System Safety Analysis and Common Cause Analysis are prominent examples of techniques well established in the aerospace industry. [51]

8.2 Airframe

In the projected use within the MMEA project, the main objective is to provide a robust platform with sufficient payload capability and performance. Vehicles capable of fulfilling this requirement were found to exist as shown in chapter 5. The following sections present general considerations with regard to the various components and aspects of an unmanned aerial system.

8.2.1 Airframe Modification Possibilities

As most vehicles have an arrangement of interchangeable payload modules, many sensor carrying needs could presumably be fulfilled by furnishing such modules, thus largely avoiding the need for further modifications. Such an approach would limit the modification needs (apart from the payload modules) to those of providing functional electronic system interfaces between the payload and the rest of the system.

If the need to install equipment on the wing, especially near the tip area, should arise, the structure can be either strengthened locally using e.g. strips of carbon fibre laminate or by preparing detachable outer wing sections for different purposes. The latter approach would be quite versatile; for example, if the need should arise for the maximum mass or the ceiling of the vehicle to be increased, the wing could be lengthened, whereas if a more stable camera platform at low altitude were needed, the wing loading could be increased by using a shorter wing.

Flight dynamics of many vehicles could easily be adjusted, because the aft fuselage consisting of a single composite tube - or a pair of such tubes - could easily be shortened or lengthened. Another simple but effective method would be the installation of additional weights to adjust the centre of gravity, an approach that, however, has the disadvantage of additional weight as a result. Especially in autonomous flight the flight dynamics could further be affected by adjusting the autopilot's control parameters.

Range and endurance can be affected by changing the engine/motor, fuel tank or battery. Such selections constitute obvious trade-off situations with respect to payload. In the case of piston-engine vehicles the battery's capacity may be augmented by installing a generator, but considering the performance of contemporary batteries this is necessary only in the case of extreme endurance or payload with high power consumption.

8.3 Systems

Electronic systems often constitute a bottleneck to UAS operation. Especially in the case of small UAVs, the airframe design and manufacture is a relatively affordable and straightforward process, but the airframe's performance potential may be constrained by low-performance electronics dictated by price considerations.

The price of commercial-grade electronic systems is often high as a result of requirements on certification, system redundancy, encryption and further considerations. As a result, in particular with respect to educational use, many existing solutions are quite complex and prohibitively expensive.

The rapid development of embedded electronic systems in recent years has brought with it a considerable variety of components useful also in UAS applications, thus opening new possibilities to affordable system development for amateurs and small enterprises. A prominent example of this development is formed by so-called First Person View (FPV) vehicles, which consist of a miniature video camera installed on a model aircraft transmitting live image to the ground. Autonomous capabilities can be added by the use of programmable circuit boards, of which dedicated varieties exist for this purpose [52], [53]. Simplified programming languages and readily available libraries of computer code lower the threshold for such activity and, through the avoidance of arduous study of language-specific technicalities, provide the possibility for the developers to concentrate on the most essential tasks and features.

8.3.1 Autopilot

The autopilots potentially useful for this project are limited to a handful of alternatives, the first group of which comprises commercial, more or less established solutions, and the other comprises open-source solutions.

Open-source solutions are based on the idea of using commercial components such as microcontroller boards, as well as equipping and programming them in such a way that a functioning autopilot results. While this sounds attractive due to the low price of such components and the perceived freedom in arranging the system, the disadvantages are also considerable; large amount of work may be necessary to get the combination working and a reasonable quality and dependability of readily existing software cannot be guaranteed as it is developed as a hobby by private individuals. Moreover, the open-source solutions generally do not offer an amount of functionalities comparable to that offered by commercial solutions. It may be concluded that such solutions might be well suited for light vehicles operated in the operator's close vicinity, but are less advisable for heavier vehicles that provide longer range and are operated in a more businesslike manner.

The most prudent solution would therefore probably be the selection of a proven commercial autopilot. The most popular more or less "low-cost" autopilots at the moment seem to be those developed by the Canadian company MicroPilot and the American companies Procerus Technologies and UNAV LLC. Products of these companies are widely used in civilian and military UAVs as well as in target drones and other expendable vehicles. They also offer some rather advanced capabilities, such as smart loiter around a user-defined location or ability to operate in the case of a GPS outage. Examples of applicable autopilots are presented in Table 12. The Piccolo is possibly not a good alternative since, although the manufacturer did not answer any inquiries, it was told to be significantly more expensive than other alternatives and described as a "high-end" autopilot. [54]

Table 12. Some autopilots applicable for light UAS

Producer	Procerus Technologies, USA	Micropilot, Canada	UNAV, USA	UNAV, USA	Cloud Cap Technology, USA
Model	Kestrel Autopilot v2.4	MP2128[g]	3500FW	3550	Piccolo SL
Mass	17g	26g	35g	36g	110g
Size	53x35x12 mm	100x40x15 mm	102x51x 19 mm	51x25x13 mm	131x55.6x11 mm
GPS included	no	yes	yes	yes	yes
Power supply	500 mA @ 3.3V or 5V	140 mA @ 6.5V	100 mA @ 5V-7V	250 mA @ 5.5V-7V	4W (typical – including 900 MHz radio)
Max. number of servos	4	8/16/24	7	2	14
Max number of waypoints	-	1000	64	32	100
In-flight programmability	-	yes	yes	yes	yes
Allowable temperature range	-40°C to +85°C	-	-20°C to +60°C	-20°C to +60°C	-40°C to +80°C
Price	5000$	6000$	3000$	1500$	-

Figure 14 illustrates the compactness of the autopilots listed above, showing the Kestrel v2.4 as an example.

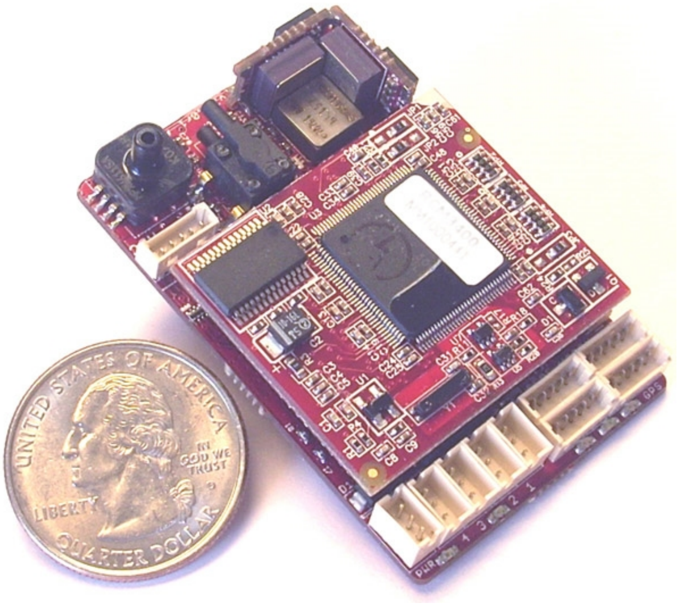


Figure 14. The Procerus Kestrel v2.4 autopilot next to a quarter dollar coin [62]

8.3.2 Data Link and Ground Control Station

Data link can easily be assembled from wireless electronic components available from several manufacturers. In Finland, the data link can be arranged on two different frequency ranges: 868 MHz or 2.4 GHz. In terms of range, a high transmittance power is desirable. The transmittance power is measured in terms of *effective radiated power* (ERP) or *effective isotropically radiated power* (EIRP), both of which are figures describing an equivalent omni-directional antenna that would exhibit in all directions a radiated power of comparable magnitude as the described antenna does in the direction of maximal gain. ERP and EIRP generally depend on transmitter's power, system losses and antenna gain [55].

The frequencies 869.400-869.650 MHz are preferable with regard to range, since they allow an ERP of 500 mW, while other frequency bands in the 868 MHz range are limited to 10-25 mW ERP. In the 2.4 GHz band, an EIRP of 100 mW is allowed, but the higher frequency allows a higher data transfer rate. The considerably higher permissible power of the 868 MHz band in combination with the inherently weaker damping of a lower frequency electromagnetic radiation provides the 868 MHz band with a range far superior to that of the 2.4 GHz band.

The frequency band above 2.4 GHz is unregulated and therefore also used by many other applications, today the most prevalent being *wireless area networks* (WLAN) used by personal computers, “smartphones” and other devices. Consequently, channels are quite saturated and cannot be reserved for arbitrarily long periods of time; on the contrary, it is necessary – especially in urban areas - for the radio traffic to be packet modulated instead of continuous, which leads to latencies of up to several seconds.

Short latencies as mentioned above do not constitute a technological problem; the data immediately necessary to flight control is obtained autonomously by the vehicles own measurement systems and many autopilots are capable of managing loss-of-link or “GPS denial” situations. The latencies could possibly become a problem if the vehicle were to be flown in a remotely-piloted manner in unsegregated airspace, but such a scenario seems unlikely under current regulatory framework and with regard to the project’s current objectives.

For the 2.4 GHz band there are no requirements concerning channel reservation, whereas in the case of 868 MHz modems of more than 5 mW output a requirement of 10 % “duty cycle” exists, meaning that the modem may transmit on average only 10 % of the time, measured over a time interval of one hour. At least two manufacturers (XBee and Aerocomm) offer modems compatible with this requirement [56]. Moreover, it is worth mentioning that the standard relevant to these requirements (ETSI EN 300 328-1) is currently under revision, the most important issue being the development of a “polite protocol”, i.e. a practical method of detecting whether a channel is reserved or not and dividing channel capacity in a feasible manner. Further regulations can be found in order 15 of the Finnish Communications Regulatory Authority (Viestintävirasto) and in recommendation 70-03 of the European Communications Office [57].

Physically, a low-cost data link would consist of a wireless modem connected to the vehicles autopilot via a serial port, a modem connected to or included in the ground station and corresponding antennas. Such modems and antennas are very affordable, because they are not produced exclusively to aerospace customers, but are produced in vast quantities for various applications such as industrial automation, robotics or oil/gas leak detection systems [58]. Table 13 presents examples of modems applicable to UAS use [59], [60], [61].

Table 13. Radio modems suitable for UAS use.

Model	Aerocomm AC4868-250	Aerocomm AC4424-100	XBee-PRO 868	XBee-PRO 802.15.4
Frequency	868 MHz	2.4 GHz	868 MHz	2.4 GHz
Transmittance power	250 mW	100 mW	315 mW	10 mW
Data rate	up to 28.8 Kbps	up to 28.8 Kbps	up to 24 Kbps	up to 250 Kbps
Price	appr. 80 US $	appr. 100 US $	149 US $	179 US $ (incl.2 modules)
Mass	21 g	20 g	-	-

The ground station antenna can be chosen according to mission requirements and may be of omni-directional, sectorised array or directional type, the last one possibly requiring a tracking or guidance system, which clearly would add to the complexity of the system. The vehicle antenna, on the other hand, must be a simple dipole (wire) antenna for weight and size reasons.

A low-cost ground station could consist of a laptop computer equipped with a separate module including the radio modem as well as connections to antenna and other ancillaries. Such modules are offered by autopilot manufacturers: figures 15 and 16 present, as an example, the Commbox v1.1 ground control module offered by Procerus Technologies [62].

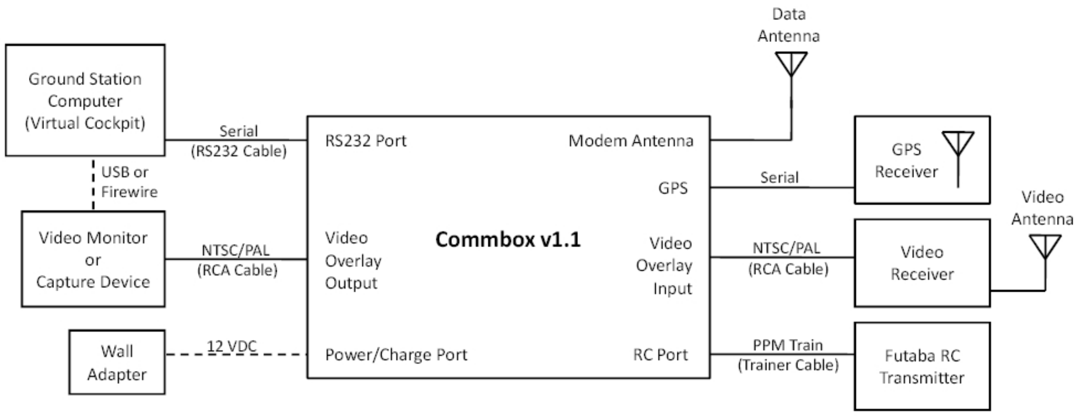


Figure 15. The Procerus Commbox v1.1

Figure 16. Picture of the Procerus Commbox v1.1

As figure 15 presents, manual control of the vehicle is possible by the means of an ordinary RC transmitter that is connected to the Commbox via a “trainer cable”. The transmitter should be of a type that provides enough channels: a minimum of four channels (aileron, elevator, rudder and throttle) are likely to be required for flight control alone and at least 2-3 should be reserved for other applications such as flap or payload operation.

8.3.3 Software

In addition to the hardware presented above, compatible software is needed as well. Such software is necessary for configuring the autopilot as well as for planning and conducting flight operations.

The programs constituting the actual user interface usually consist of a map display that can be utilised to define the vehicles route as well as to control the payload. The maps required for such use may be obtained e.g. from Google Maps or some other service offering maps that are fixed in a coordinate system compatible with the Global Positioning System (GPS) [63]. A "virtual cockpit" display of some sort is often provided as well: at least basic information such as altitude, speed and heading are usually displayed on the screen, accompanied by an attitude indicator (also known as "artificial horizon").

Some manufacturers offer complete "developer's packages" including hardware as well as software for circuit board programming, development of ground control station software and simulation testing, one example being MicroPilot that offers a package called XTENDER^{mp} for such purposes. However, there are some important economic and legal viewpoints to consider in the case of such packages; for example, in the case of the aforementioned package the customer is exempt from paying software royalties only if the code written using the XTENDER^{mp} software is used in a system employing an autopilot produced by MicroPilot [64].

At least part of the software could be developed within the Department of Applied Mechanics; the department already is in possession of several simulation tools which could be augmented with sub-programs or –routines. Furthermore, selecting a commonly used software package such as Matlab/Simulink as the development platform would offer at least two important benefits:

- The staff and students could get familiarised with and to a certain degree drilled in the use of a tool widely used in the aerospace industry and academia.
- The university already has software licences for Matlab, as a result of which no additional costs would be induced.

Matlab is also well suited to hardware-in-the-loop simulation in which measurements normally provided by the Pitot-static system and other sensors are fed to the autopilot using auxiliary hardware [65]. Such an approach facilitates rapid prototyping and provides the possibility to test changes in the system configuration without risking the vehicle. Hardware for the aforementioned purposes is produced e.g. by the Swiss company Speedgoat GmbH which offers a wide range of such *target machines* [66].

In principle, when the vehicle's attitude, position, velocity and acceleration vectors are known, it is a relatively straightforward matter of geometry and vector analysis to create software that enables controlling both the vehicle's flight as well as payload operation (e.g. camera orientation), provided that the system is properly calibrated. In practice, this may not be completely trivial, but at any rate should be well within the capabilities of a technical university and would provide possibilities for fruitful interdepartmental co-operation within the university or with external partners.

8.4 UAS Proposal

The preceding sections described the most important issues to be considered in the definition of an unmanned aerial system; the plausible next step is the presentation of a system that could feasibly fulfil the emerged needs as well as possible.

8.4.1 Airframe

Airframes were studied in Chapter 5 and the most promising alternatives according to the applied methodology were found to be the Penguin B of the Latvian manufacturer UAVFACTORY Ltd and the Cruiser of the Slovakian manufacturer ET-Air. The vehicles are in many terms quite similar, but the Cruiser is heavier (maximum take-off masses 30 kg and 21.5 kg) and larger (wing spans 3.8 and 3.3 metres). Since the mass threshold of 20 kg probably remains important in the future, the lower weight of the Penguin B puts it at an advantage; with empty weight of 10 kg a useful load capacity of another 10 kg remains, whereas in the Cruiser's case an empty weight of 15 kg facilitates the installation of only 5 kg worth of payload.

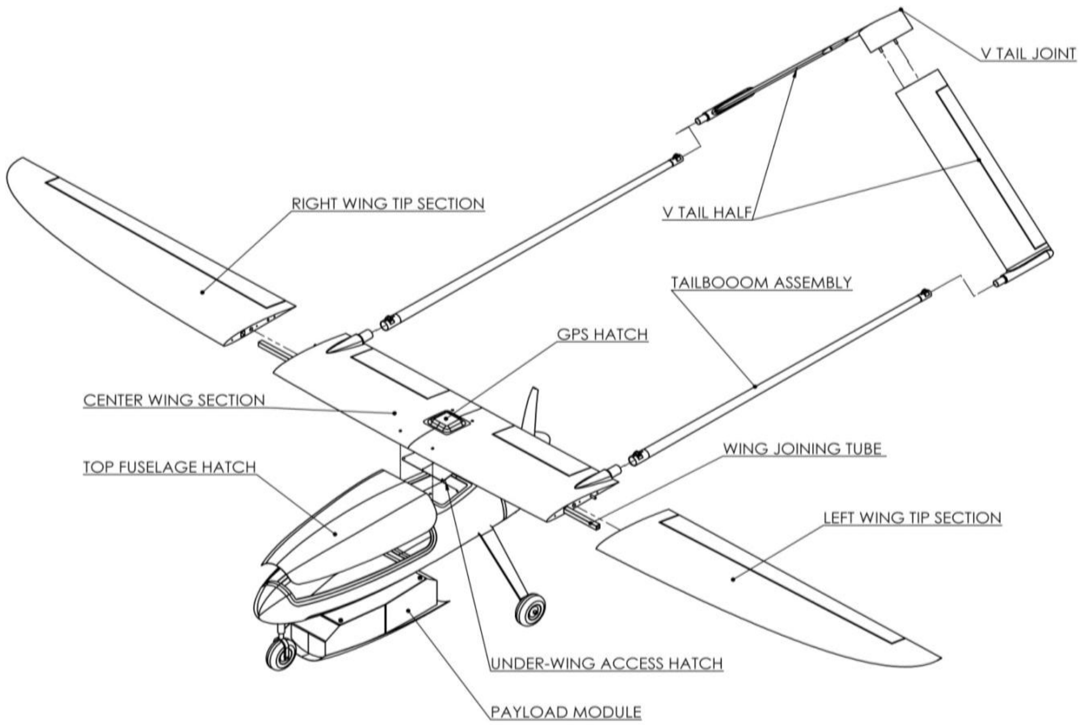


Figure 17. An overview of the Penguin B UAV [67]

The Penguin B is available in various configurations: at the lower end of the range a bare airframe can be purchased for 6172 €, while a vehicle that has been furnished for long endurance (up to more than 20 hours) and completely equipped apart from the autopilot and data link costs 17 500 € (prices in February 2011). [54] The latter version has certain features that are impractical in the sort of use that the vehicle is likely going to experience within the MMEA project: the extreme endurance is achieved by installing a large (7.5 litre) fuel tank and an economical 35cc four-stroke engine. In such a configuration the vehicle easily reaches its maximum take-off mass even with a light payload, resulting in a lengthened take-off run and increased take-off speed. The manufacturer has either considered the self-start capabilities insufficient, or has simply decided to improve performance by reducing weight and drag through removal of the landing gear. Either way, the long-endurance version is confined to a take-off from a car-top cradle. The manufacturer offers such a cradle (that can be mounted on standard Thule car roof rails) as additional equipment, albeit at a relatively high price of 4850 €, resulting in a total price of 22 350 €. In addition, the engine of this version is equipped with a 100 W electric generator which is, in all likelihood, unnecessary for the sort of endurance required in the projected use, given the performance of modern batteries.

The most reasonable alternative for the MMEA project would probably be a version of the Penguin B that is offered at a price of 10 078 € and equipped with a landing gear, 3 litre fuel tank and a 28cc two-stroke engine as well as pre-installed fuel tubing, servo wiring and servos. According to the manufacturer, this version has an endurance of approximately six hours.

8.4.2 Autopilot

As discussed earlier, the most prudent autopilot solution would probably consist of a commercial solution that has been already established on the market. The manufacturers that were mentioned before (UNAV, Procerus and Micropilot) all have certain advantages as well as disadvantages in comparison with each other. The products of Micropilot are probably the most established on the market, and also the most commercialised while the products of UNAV and Procerus are largely similar to each other and perhaps more affordable as well. Altogether, the choice is largely a matter of taste. A representative of the Penguin B manufacturer reported that customers have successfully integrated both Procerus and UNAV autopilots to the Penguin B airframe and he would personally recommend the Procerus Kestrel v2.4 for its straightforward configuration and ease of use. He further added that they are currently testing the Micropilot 2128LRC which, in their opinion, is complicated to use, but has a lot of capabilities [54]. The UNAV autopilots seem to have fewer capabilities than the two others; it would seem reasonable to choose either a Micropilot or Procerus product.

In conclusion, since Procerus is recommended by the airframe manufacturer and the company offers most other necessary hardware and software components as well, selecting the Kestrel v2.4 autopilot for this project would probably be quite a safe and sensible solution. Such a solution effectively dictates choosing the ground station and data link from the same manufacturer as well; seamless integration must be achieved since very limited software expertise is available and the lack of standards considerably complicates assembling a system from components provided by several manufacturers.

8.4.3 Ground Control Station and Data Link

The ground control station would consist of a laptop computer equipped with a radio modem and an antenna as well as necessary software. The computer is not subject to demanding performance requirements, but field use should be considered to a reasonable degree; at least a rugged casing as well as a long battery life are beneficial features, as are a display of sufficient resolution and matte surface (for outdoor use). Such computers command a price premium over ordinary consumer laptop computers but should in any case be available for at most approximately 2000 €.

Since the Procerus Kestrel was chosen as the autopilot, the ground control software would have to be the Virtual Cockpit v2.6 produced by the same manufacturer. The computer would further have to be equipped with the Procerus Commbox v1.1, a scheme of which was presented above.

"Developer's kits" and other more advanced software solutions might become necessary in the course of the further sensor integration, but software that enables mission planning and in-flight control is enough for the initial phase of the project. At any rate, the sensor integration is not within the responsibility of the Department of Applied Mechanics.

In order to achieve maximum range, the radio modem should be one that uses the 868 MHz spectrum. To retain simplicity of operation, the ground station antenna should be of the omni-directional type. Should the need arise, the antenna can later be easily changed to an array antenna or a directional antenna. A comprehensive assortment of antennas is offered, for instance, by the American company L-com [68]: a simple omni-directional antenna with a gain of 6 dBi can be purchased for 54.99 US $ and a highly directed antenna with 18 dBi gain and 16.5^{o} beam width can be purchased for 327.99 US $ (Prices in March 2011). The performance of the latter potentially enables a range of several tens of kilometres, and a range of 20-30 kilometres could be expected even within the confines of the current transmittance power limitations. [54] Array antennas are more expensive than the types discussed above, since they contain more elements, but provide the possibility of achieving wide coverage while avoiding the need of a tracking system.

As discussed in section 8.3.2, means of manual control must be provided by a remote controller. The Japanese company Futaba is perhaps the best-established name on the market and produces a wide range of such controllers. As sufficiently capable versions can be acquired for ca. 500 €, no compromises regarding capabilities are likely to be necessary for cost reasons.

8.4.4 Launch and Recovery Elements

In order to achieve a maximum degree of operational flexibility, the system should include appropriate means of launch and recovery; in practice this would most likely mean a launch catapult or a car-top cradle, combined with either an arresting net or a parachute installed in the vehicle. Such equipment is probably not needed in the early flight operations and could therefore be self-devised as well. In the beginning, the vehicle can be tested e.g. on a model aircraft "airfield" or some other suitable, flat area.

A bungee catapult could probably be designed by the laboratory's staff or even as a student project since it contains relatively few parts and would unlikely be an exceedingly hazardous construction, especially if tensed using a hand-crank or a weak electric motor. A pneumatic catapult would probably be a feasible and sufficiently simple alternative as well.

If conventional landing is considered impractical, the most reasonable recovery solution would most likely be a parachute installed in the airframe, perhaps, if possible, in combination with bringing the vehicle to a state of deep stall. An arresting net would most likely be somewhat unwieldy to operate, since the net would have to be relatively large to achieve a good probability of "catch", thus leading to large support structures as well. The kinetic energy of an airborne 20 kg vehicle is not negligible either, and probably sets further requirements on the recovery system's structural strength and therefore mass and dimensions as well.

8.4.5 Summary of the Proposal

Table 14 presents a division of the system and the corresponding approximate expenses. As can be seen, many components are quite generic by nature and need not be defined on a manufacturer or model level.

Table 14. Division of the systems components and costs

Component	**Model**	**Price**
Airframe	Penguin B	10 078 €
Autopilot	Procerus Kestrel v2.4	5000 US $
Ground control software and communications module	Procerus Commbox v1.1 and Virtual Cockpit 2.6	3695 US $
Radio modems (2 pc)		max 600 €
Antennas (2 pc)		max 600 €
Laptop PC		max 2000 €
R/C controller		max 500 €
Miscellaneous other hardware (additional batteries, cables etc.)		max 2000 €
Total price		ca. 22 000 €

9 Conclusions

Civil UAS applications are likely to gain importance and attract increased attention in Finland. So far, probably the largest hindrances have been constituted by immature regulatory environment and constrained budgets of many otherwise potential users.

Regulatory work on UAS is at the moment largely unfinished, so it is quite early to make predictions as to the shape of the future regulations. It seems probable, however, that in the case of light UAS the European regulations will be largely shaped by the Civil Aviation Publication 722 published by the UK Civil Aviation Authority. Furthermore, there is and will continue to be a strong tendency to harmonise regulations across Europe.

The work done during the preparation of this thesis was largely insufficient for a valuable determination and analysis of user needs, mainly because most of the interviewees had not yet prepared any specifications for the systems to be acquired. The work was further complicated by the less than enthusiastic attitude exhibited by other project partners. However, the situation will in all likelihood gradually improve as more domestic experiences are gathered and regulations defined. At any rate, it may be noted that such development could be considerably accelerated by intelligent nationwide pooling of resources and knowledge. There are already signs of such activity at the time of writing of this thesis.

In view of the sprawling global UAS industry that already exists, there seems to be a surprisingly narrow selection of well-engineered civil UAS that both have a payload capacity sufficient for versatile environmental monitoring tasks and are financially within reach of the MMEA project. The market is clearly polarised into very affordable “amateur-grade” systems on one hand and rather expensive high-end solutions on the other. A few reasonably capable mid-range systems can be found – and were studied in chapter 7 – but doing the systems integration by oneself is a viable alternative as well and offers the possibility to learn and gain valuable insights in the process.

A small UAS could conceivably provide the university with a useful and cost-effective addition to the curriculum: manned aircraft (with the possible exception of gliders and ultralight aircraft) are subject to increasingly stringent regulations, which, in combination with the need of qualified pilots, expensive spare parts and fuel – to say nothing of capital costs – render them out of reach of most universities. If students with a sufficient degree of commitment can be found and study group sizes kept within reasonable bounds, tinkering with a UAS could offer a most welcome opportunity for the performance of e.g. bachelor’s thesis, especially for the more practically-minded students. In such use, a system that could be easily configured and modified would be the most suitable, and a wide enough selection of commercial components exists for the vehicle to be assembled within the university.

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