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BRANDENBURGISCHES INSTITUT
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Unmanned Aircraft Systems for Civilian Missions

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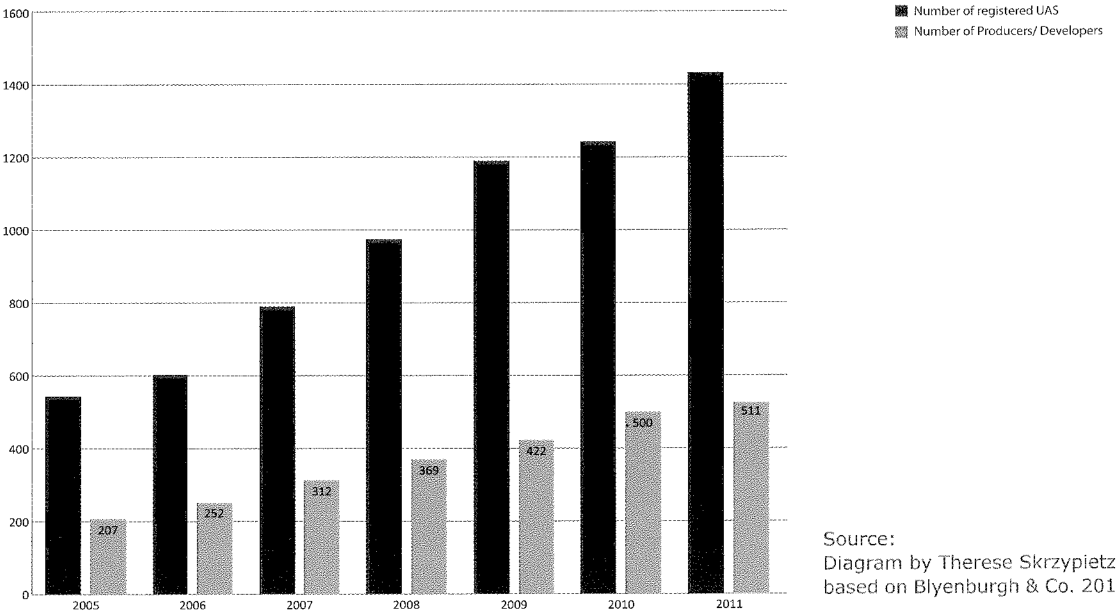
1 Introduction

In the last few years, *Unmanned Aircraft Systems (UAS)* have become more and more important. The number of unmanned aircraft designs registered with *UVS International*, a non-profit society which promotes unmanned systems, more than doubled between 2005 and 2011. During the same time period, the number of producers and developers has also more than doubled. This has been accompanied by a growing interest in the research, development and production of UAS, with a sharp increase in the number of UAS-producing countries over the last six years. Yet, while most air-based reconnaissance systems are currently used for military purposes, it is the civilian and commercial use of UAS which has shown the strongest growth during this period.[1] Considering the fact that civilian research on UAS only began in the early 1990s, these growth figures point to a strong interest in the use of UAS for civilian purposes.

The American *Environmental Research Aircraft and Sensor Technology (ERAST)* project was a very important research project which promoted and enabled the use of UAS in the civilian sphere early on. This nine-year *National Aeronautics and Space Administration (NASA)* project sought to develop unmanned aircraft that could be employed for extended scientific missions while operating from an altitude of up to 30,000 meters (98,000 feet). This project eventually resulted in the Helios, Pathfinder and Altus unmanned systems, among others, which are now used in environmental research and for conducting atmospheric measurements.[2] This early research into the civilian use of unmanned aircraft by American scientists is one of many important reasons which have led to the United States' leading role in the quickly-growing UAS market. To make an international comparison, the United States develops and produces 30.33% of the world's UAS, making them the world leader in 2011. The second-largest market share is held by France, with 6.42%, followed closely by the United Kingdom, Israel and the Russian Federation. Germany holds sixth place in the international rankings, with a market share of 3.85%.[3]

The civilian use of UAS is gaining more and more attention, both at the international and national levels. The goal of this study is therefore to identify and critically investigate the various potential civilian applications of UAS. The study is structured as follows. First, the advantages as well as the limitations of unmanned aircraft will be explored. Next, the special characteristics of UAS will be compared with existing alternatives which are already employed for civilian observation and reconnaissance missions and their potential application will be evaluated. Finally, the market potential of unmanned aircraft in the civilian sphere will be estimated.

Figure 1: The Development of UAS 2005–2011



Source:
Diagram by Therese Skrzypietz
based on Blyenburgh & Co. 2011, 153.

2 Functions and Properties of UAS

A scientific examination of UAS must always consider it as a system which is composed of three different components: An important part of the system is the *Ground Control Station (GCS)*, via which the aircraft can be controlled and its operation observed. Another component is the communications infrastructure needed for the connection between the transmitter and the receiver. The third component is the aerial platform, i.e. the vehicle itself, formally termed the *Unmanned Aerial Vehicle (UAV)*. In German the term "drone" is also widespread. The terms UAS and UAV are sometimes used as synonyms; however, in correct usage, UAV only describes the aerial platform, not the system as a whole. The scientific literature therefore primarily uses the term UAS, as this implicitly includes all three components, thereby covering the entire system.

UAS may be characterized by very different features and characteristics, with the market made up of a large number of diverse systems. For example, *UVS International* lists 1,424 different systems which are in development worldwide. These include prototypes as well as systems which are completely market-ready and in operation, as well as those which are obsolete and no longer in use.[4] The platforms themselves can be divided into different categories based upon size. Depending on their size and available functions, certain UAS can be employed for specific civilian missions.

The extent to which certain unmanned systems are suited to specific civilian applications will be evaluated in the fourth chapter. To gain a better understanding of the wide variety of characteristics and functions of UAS and to demonstrate UAS' diversity, this chapter shall provide a short overview of UAS and group them into broad categories. Four characteristics can be used to categorize unmanned aerial vehicles:

- *Range*
- *Flight altitude*
- *Endurance and*
- *Maximum Take-Off Weight (MTOW).*

The following table groups UAS into several categories. The ranges of values given for each characteristic are examples which need not necessarily be strictly applied to all systems in a defined category. Based upon the values listed for each of the four characteristics, it is clear that a strict separation between different categories or classes is not possible, as certain characteristics overlap one another or are identical.

Table 1: Possible Classification of UAS

Category	Range (km)	Flying Altitude (m)	Endurance (h)	MTOW (kg)	Example
Micro & Mini UAV (MUAV)	< 10	300	< 2	< 30	md4-200
Medium Altitude Long Endurance (MALE)	> 500	15,000	24 – 48	1,500 – 7,000	Talarion, Predator
High Altitude Long Endurance (HALE)	> 2,000	20,000	24 – 48	4,500 – 15,000	Global Hawk
Vertical Take-off and Landing UAV (VTOL UAV)	x – 204	x – 6,100	0.18 – 8	0.019 – 1,400	Nano Hummingbird, MQ-8 Fire Scout

Source: Diagram by Therese Skrzypietz based on Blyenburgh & Co. 2010, 120.

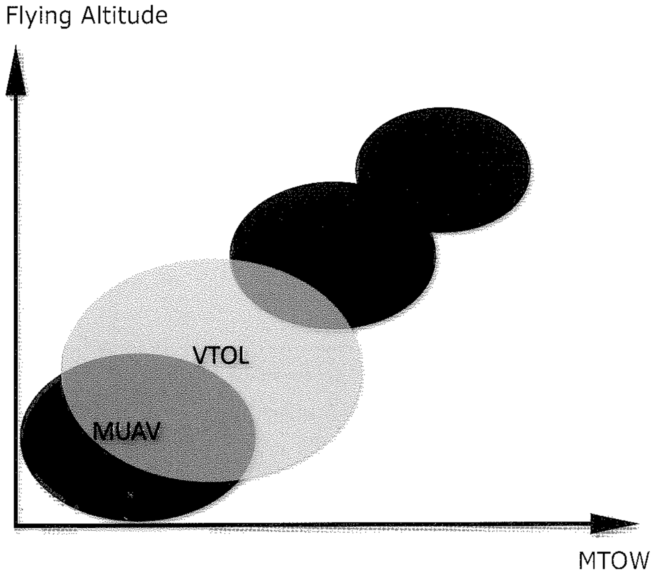
For example, there are very small platforms, the so-called micro and mini-UAVs, which in the table both fall under the category *Mini Unmanned Aerial Vehicle (MUAV)*. Because they only differ slightly from each other in respect to these characteristics, here they are included in a single category. MUAVs have only a relatively short range of a few kilometers and a minimal altitude of about 300 meters (990 feet). Their endurance of a maximum of two hours is very limited compared to the other categories and their MTOW, usually less than 30 kg, is relatively low. MUAVs include, for example, the *Aladin* reconnaissance system, developed by the German company *EMT*. *Aladin* stands for *Abbildende luftgestützte Aufklärungsdrohne im Nächstbereich*, or close-range air-based imaging reconnaissance drone. The *md4-200*, produced by Germany's *microdrones GmbH* is also a MUAV. An additional platform which can be included MUAV category is the Nano-UAS. These unmanned reconnaissance systems have a wingspan of only a few centimeters, with a correspondingly low weight of just a few grams. The *Nano Hummingbird*, developed by the American company *AeroVironment* and presented to the public in February 2011, is an example of such a Nano-UAS. As its name suggests, it is about the size of a common hummingbird.

Larger and considerably more complex systems are represented by the *Medium Altitude Long Endurance (MALE)* and *High Altitude Long Endurance (HALE)* systems. Compared to MUAVs, these have much a longer range of several thousand kilometers, as well as better endurance, up to or exceeding 24 hours. In regard to altitude, a MALE system can reach up to 15,000 meters (49,000 feet) and a HALE system can reach up to 20,000 meters (65,500 feet). The maximum takeoff weight for both vehicle types can measure up to several tons and enables a correspondingly large payload. Fundamentally, these unmanned platforms are comparable in size to manned aircraft. One example of a HALE UAS is the *Global Hawk*, by *America's Northrop Grumman*. The MALE category includes, for example, the Predator, produced by the American company *General Atomics*; the *Heron*, made by *Israel Aerospace Industries (IAI)* and used by the *Bundeswehr (German Federal Armed Forces)*; as well as the *Talarion*, produced by *Europe's European Aeronautic Defence and Space Company (EADS)*.

Vertical Take-Off and Landing (VTOL) provides another opportunity to further classify unmanned aerial vehicles by dividing UAS into "fixed wing" and "rotary wing" groupings.[5] An examination of the characteristics in Table 1 makes it clear that great variation exists in the properties of VTOL-UAVs. Unmanned rotary-wing vehicles may be as small as a hummingbird or as massive as a helicopter. For this reason, MUAVs, for example the *md4-200*, are also often included in this category. Additional examples of VTOL-UAVs are the *RQ-16 T-Hawk*, from the American company *Honeywell*, and the *Camcopter S-100*, produced by the Austrian company *Schiebel*. VTOL-UAVs are also often propelled by four downward-facing rotors, and are in such cases termed quadrocopters. Figure 2 provides a clear overview of these categories and a way to differentiate between them based upon flying altitude and maximum take-off weight.

The following section will consider MUAVs, MALE and HALE systems, as well as VTOL-UAS. These systems are marked by various characteristics which are present to different degrees in each category, making it possible to draw conclusions about their various potential applications.

Figure 2: Categories of UAS



Source: Diagram by Therese Skrzypietz.

3 A Comparison of UAS to Alternatives

To be able to evaluate the possible uses of unmanned aerial vehicles in the civilian sphere, it is necessary to determine the advantages and disadvantages of UAS compared to satellites and manned aircraft. These existing alternatives are already used for various civilian observation and reconnaissance missions, and are potential candidates for substitution by UAS.[6] The advantages and constraints of unmanned systems are partially dependent upon the characteristics discussed in Chapter 2. The different UAS categories also result in respective differences in the advantages and limitations of UAS in carrying out such missions; these will be summarized in Chapter 3.

3.1 Disadvantages of UAS

The greatest limitation of UAS lies in the **absence of legislation and regulation** for operation in non-segregated airspace. The problem posed by allowing unmanned aircraft to operate in the same "civil" airspace as traditional aircraft has been a controversial subject among pilots, airlines and aviation safety authorities for several years. To address the unresolved issue of aviation security and the operation of UAS, the legal basis for the operation of unmanned aircraft in Germany was changed and clarified to a rudimentary degree by the German federal government in early 2010. According to §1 paragraph 3 of German air traffic regulations, the LuftVO, the operation of unmanned aerial vehicles is prohibited if the vehicle is flown out of the range of view of the operator or if the total mass of the device exceeds 25 kilograms.[7] However, the LuftVO goes on to specify that this ban can be lifted through a waiver issued by the responsible air transportation authority. Yet, at the national and international levels, the operation of UAS in general air traffic, alongside manned aircraft, is fundamentally prohibited at the current time.

Because future investments in and development of unmanned aviation systems are dependent upon their integration into non-segregated airspace, this topic is currently a subject of intense inquiry by various research projects. Attempts are being made to develop "Sense and Avoid" systems[8] and to work out guidelines for the certification of UAS and their integration into controlled airspace. In the meantime, however, it has been possible to successfully demonstrate techniques and procedures for the successful control of unmanned aircraft in German airspace, for example the project *Weitreichende Abstandsfähige Signalerfassende Luftgestütze Aufklärung – HALE (Long-Range and Distance Air Supported Signals Reconnaissance* – WASLA-HALE), funded by the *Bundesamt für Wehrtechnik und Beschaffung (Federal Office for Defense Technology and Procurement)*.[9] Within the framework of the WASLA-HALE project, the *Advanced Technologies Testing Aircraft System (ATTAS)* was used as an experimental platform, with a back-up pilot onboard, to carry out test flights at the German Bundeswehr's airfield at Manching.

The Validierung von UAS zur Integration in den Luftraum (Validation of Unmanned Aircraft Systems Integration into the Airspace – VUSIL) project, funded by the German Federal Police, also aims to determine whether safe participation in air traffic by unmanned systems is possible through various tests with a MUAV. The project is testing emergency landing procedures, radio connections, sensor function, separation of the airspace and vertical separation.[10] Since September 2009, the *Mid Air Collision Avoidance System (MIDCAS)* project has worked to arrive at a common international solution for the integration of unmanned vehicles in the airspace. This international project, funded by the *European Defense Agency (EDA)*, is a joint effort by Sweden, France, Germany, Italy and Spain. Supported by a consortium made up of 13 companies from these five countries, it aims to develop an acceptable collision avoidance system and demonstrate it in the air within four years.[11]

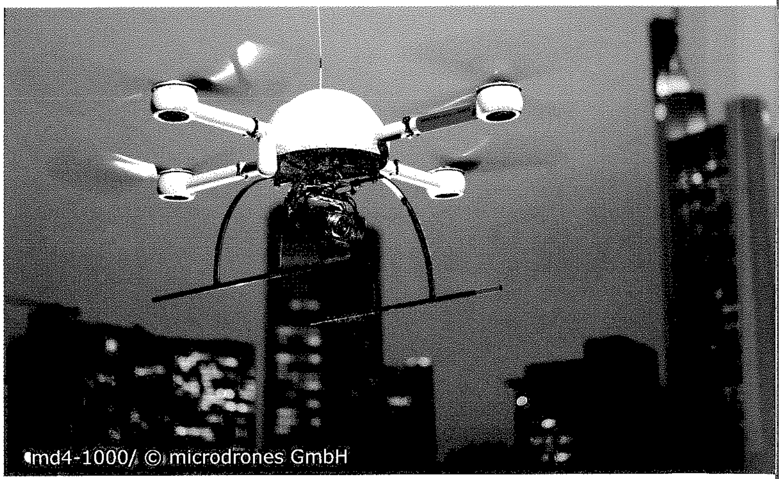
A functional "Sense and Avoid" system approved by the aviation safety authorities would create the basis to allow UAS to operate in the same airspace as manned aircraft without restrictions. The European countries are planning, in close cooperation with these authorities, to completely integrate UAS in general air traffic by 2015. In the past, several waivers have already been issued to certain unmanned aircraft to operate within controlled airspace, lending credibility to the prediction that the "act of regulatory approval" as well existing technical hurdles will be resolved in the next five to eight years.

The **political and societal acceptance** of the use of UAS in the civilian sphere poses an additional hurdle, as the use of unmanned aerial vehicles inobservation missions is very controversial. Opinions in this regard differ depending on the kind of mission and result mainly from two heated lines of argument: On the one hand the problems of data protection and infringements on the right to privacy are raised, on the other hand, the safety of the technology and its potential for accidents are viewed skeptically.

The use of MUAVs by the police in Lower Saxony during the Castor nuclear waste transport in November 2010 and the procurement of a quadrocopter by the Ministry of the Interior of Saxony have been especially criticized by data protection officer. To clarify these privacy protection issues and to ensure the privacy and freedom of individual citizens during the use of UAS, legal clarification and further legislation regarding the use of data collected in such operations is needed. Furthermore, the advantages for civil defense which are offered by unmanned aircraft must be better communicated to the public. For example, the use of smaller UAS during large public events in Germany, such as demonstrations, is often criticized, while their use during disasters has been overwhelming welcomed by relief professionals. In a poll of professional firemen, a total of 73% of those asked viewed the use of UAS technology positively and supported it. In respect to the concrete use of unmanned systems in disaster management, acceptance was even higher at over 82%.[12] Despite these high rates of acceptance, the use of UAS in disaster management in Germany has so far been prevented by regulation.

Within the context of UAS flights, including actual missions as well as test flights, reports of accidents and uncontrollable unmanned aircraft surface regularly.[13] Such reports, as well as a lack of acceptance of the technical abilities of UAS, have led to skepticism of UAS technology. However, when considering the question of increased risk of accidents with completely automated unmanned aircraft, it is important to note at approximately two-thirds of all airplane accidents are due to human error.[14] In regard to the technical requirements placed upon UAS, these should be the same as for manned aircraft.[15] The risk of accidents with UAS can therefore not be considered higher, per se, than that of manned aircraft. In this regard, the societal acceptance of UAS is especially dependent upon trust in the technology of the automated control centers and in the information which is made available about manned and unmanned flight.

However, the public has yet to show such trust. A study by the American aircraft company Boeing revealed that, even if ticket prices were reduced by 50% through the use of UAS, only 17% of people would consider flying in an "unmanned" aircraft. It has been suggested that the cause of this skepticism and unease is that the general public has too little information about and experience with UAS technology.[16] This skepticism is therefore more an emotional reaction than something which based in logical reasoning process. Providing more and better information about unmanned aircraft systems would lead to a better public understanding of this technology, its reliability and its potential for civilian use. This in turn would help society to form a more rational opinion about this subject and reduce general misgivings about automated technology. This has been the case in the past, when political and societal acceptance for new revolutionary technologies was established, once practical examples demonstrated the value of these technologies to the public.


md4-1000/ © microdrones GmbH

High development and procurement costs could also represent an additional barrier to the use of UAS. In the case of small unmanned aerial vehicles, it is often possible to use inexpensive off-the-shelf systems. However, for the larger MALE and HALE systems, considerable financial investments are necessary.[17] Especially the development of new and larger aerial platforms and the improvement of their sensor arrays are large drivers of higher costs. The sensors, which are continually being improved and redeveloped, are an important contributor to increase costs. The development and procurement costs of complex UAS therefore do not always correspond to those of manned aircraft and may exceed them substantially. However, UAS is still considerably much less expensive when compared to investments in new satellite systems.

The costs of acquiring an unmanned system vary widely depending on the size of the vehicle in question. An MUAV, for example the md4-200, costs about €47,000, depending on the features it is equipped with. In comparison, the per-unit cost for a MALE-UAV, such as the Predator, is about $4.5 Million.[18] The per-unit cost for already developed and operational larger UAS can be significantly less than those for manned aircraft and helicopters. For example, according to report by the *Congressional Research Service (CRS)*, the cost for manned aircraft systems which are used in US border protection operations lies between $8.6 million for the *CBP Blackhawk* helicopter and $36 million for the *Lockheed P-3 Orion aircraft*. At the same time, the report also notes that the operating costs for UAS are twice as high as those for manned aircraft. This is due to the fact that UAS requires a large amount of logistical support and specially trained personnel, among other factors.[19] This illustrates the problem of separating the various costs related to UAS operation.


md4-200 / © microdrones GmbH

To determine the costs associated with selecting a certain UAS system for a particular purpose, it is not sufficient to merely consider the development and procurement costs of unmanned systems compared to the alternatives. Instead, it is necessary to also consider the cost advantages offered by all UAS platforms in operation, as well as those which could be developed. This important consideration will be pursued further and in more detail in Chapter 3.2.

3.2 Advantages of UAS

The most important advantage of unmanned aerial vehicles lies above all in their high **endurance** and the constant availability for operations which results from this. This advantage only applies to larger unmanned systems, however. As shown in Chapter 2 in the categorization of UAS systems, the maximum duration of a flight is up to 24 hours for MALE systems and 48 hours for HALE systems. In contrast to manned aircraft, UAS can therefore operate within a very long time horizon, as they are not dependent upon the physical endurance of a single pilot. Pilots, working from the ground control station, can work in shifts, allowing the unmanned platform to operate continuously. This is especially relevant for ongoing, repetitive observation missions and represents an important advantage, as these kinds of missions are not only typically long in duration, but are also characterized by monotonous flight operations.

A further advantage of unmanned reconnaissance systems over manned aircraft is that of **safety**. Because the pilot is now located in the ground control station rather than in the aircraft itself, he is not in any danger during the flight. This is especially relevant for dangerous civilian missions, such as observational flights over forest fires or research missions in the arctic. This advantage applies to all size categories of UAS.

Increased **flexibility** is yet another advantage. Because of their size and aerodynamic characteristics, UAS are more maneuverable than manned aircraft.[20] Thus, for example, smaller systems can also be used inside buildings which are in danger of collapse. Compared to satellites, they can also be used at any time to observe the area required and can instantly provide dynamic imagery of a given subject. Satellite imagery, in contrast, is usually available no sooner than 24 hours from when it is requested, so that the information needed about a specific situation can only be provided with a significant delay - sometimes as much as 72 hours.[21] This flexibility in respect to time of operation is therefore especially important in disaster management.

UAS can also overcome the atmospheric distortions which affect satellite imagery, as they operate from a much lower, more flexible altitude. Drawing upon the categorization in Chapter 2, it can be seen that the different platform sizes also cover different operational altitudes, so that different flights at different altitudes are possible.

The use of highly developed **sensors** for reconnaissance purposes is also an important advantage of unmanned systems. A UAS vehicle may carry and use different sensors, depending upon the size of the aerial platform in question and its MTOW. The variety of sensors available is very great. Smaller UAS typically employ high quality video and digital cameras. These can be accompanied by infrared sensors which ensure observational capabilities at night. However, other instruments may also be used, for example gas sensors which provide current information during atomic, biological or chemical (ABC) accidents. Larger UAS can also be equipped with radar sensors, owing to their larger payload capabilities. To be able to provide data independent of current weather conditions, sensors with *Synthetic Aperture Radar (SAR)* can be employed.[22] In contrast to a satellite, the sensors employed on a UAS can be changed throughout its lifetime, ensuring that they are always state of the art, and UAS be retrofitted with newer, more innovative sensors. In the case of satellites, on the other hand, the technology onboard has to be "frozen" some years ahead to allow proper system verification and validation.[23] The sensors in a UAS can be used for specialized civilian missions, or can be used for more general tasks, as they can be installed and exchanged as needed. This great benefit which is a result of the modularity of different sensor technologies reinforces UAS' advantage of flexibility, as it enables an unmanned vehicle to accomplish a variety of civilian missions.

Therefore, the potentially high development and procurement costs associated with UAS may be offset by lower operating costs and UAS' longer operational lifecycle. However, opinions differ widely on the question of cost advantages of UAS compared to manned vehicles and helicopters. While *UAVNET* at al. assume that UAS entails cost advantages, a 2011 article about UAS in the German publication *BehördenSpiegel* is more skeptical and does not anticipate such advantages.[24] Currently, the total per flight-hour costs of modern UAS exceed those of manned aircraft.[25] However, in an evaluation of operating costs, different arguments may be made to suggest that overall costs may be lower when using a UAV. For example, the cost of operating a helicopter lies at about €3,000 - €6,000 per hour. If the area or situation under observation is relatively compact, or if a situation only requires observation for a short time period and manned vehicles are not required, the use of a MUAV would be an alternative to a helicopter.


Camcopter S-100 // Shipboard Operation // © Schiebel Corporation

The use of a smaller UAS could therefore reduce the relatively mission cost. If a very large field of observation over a longer time period is necessary, a MALE-UAS would be a better option because of their greater endurance, as fewer systems would be required to observe the area in question. A single system is able to collect a much larger volume of data. Therefore, in addition to overall operating costs, the cost per unit of information would also seem to be an appropriate basis for making a cost-based decision.

In addition, the fact that the pilots are based in the ground control station leads to lower "maintenance costs". The pilot himself no longer needs to learn to fly using the actual vehicle, but can gain the necessary practice in a simulator. The pilot is also freed from the burden of regular health checks which are required at frequent intervals in the case of manned aircraft and which then often lead to absenteeism. Fuel costs are also reduced by the lower operational weight of UAVs. Furthermore, a UAV's highly developed sensors offer optimal support in analyzing data, as the "digital flood of information" can be reduced to the needed parameters under observation.

Therefore, the various advantages of UAS must be viewed as a holistic, comprehensive package when deciding whether UAS offers cost advantages when it is employed in civilian observation missions. To date, almost no quantitative studies exist which examine or compare the difference in cost between manned and unmanned systems. To be able to make a direct comparison between the two alternatives, a cost analysis is necessary which takes potential applications in civilian fields into consideration.

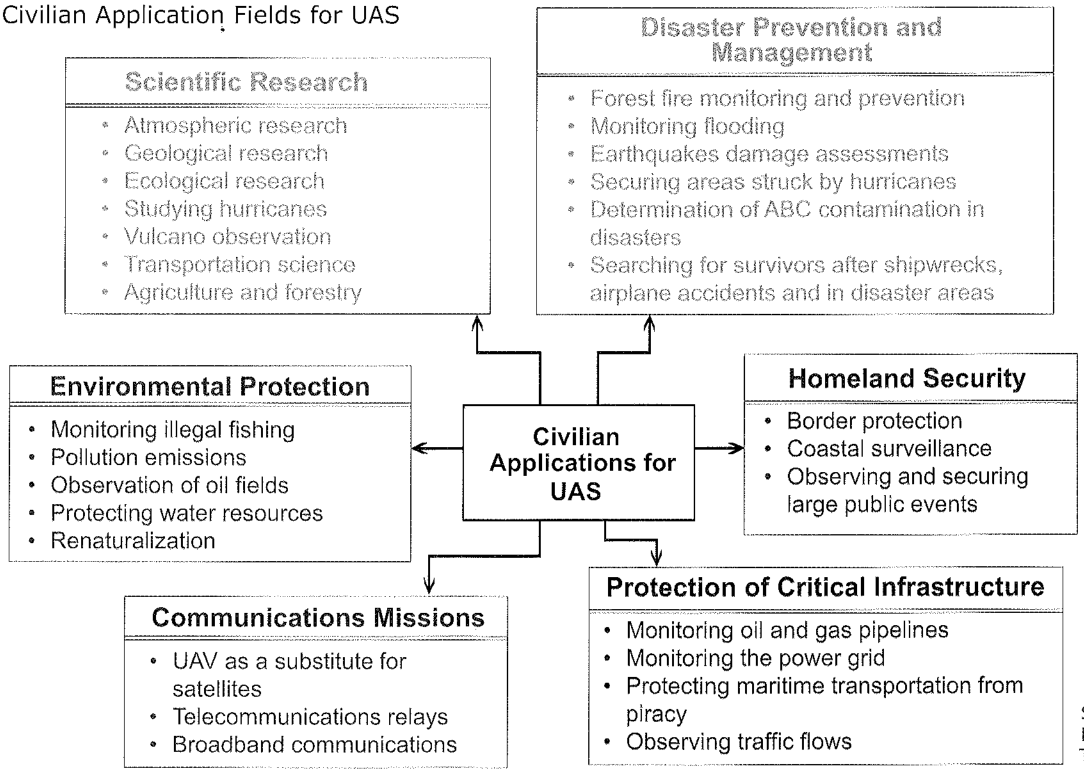
4 Potential Applications in Civilian Fields

The literature describes and discusses numerous areas in the civilian sector in which UAS could be applied, often in case examples. To provide more structure and order to this rather eclectic collection of individual cases, the following section shall attempt to categorize them. Civilian application fields can be subdivided into six categories which are presented in figure 3.

The points listed under each of the six categories in figure 3 suggest interdependencies between the individual application fields. Thus, for example, it is possible to use data which are collected for **disaster management** or in the **protection of critical infrastructure** for **scientific research.** The *protection* of maritime transportation against piracy, which falls under the category of protection of critical infrastructure, also overlaps with coastal surveillance under **homeland security**. Coastal surveillance, in turn, is also useful in the field of environmental protection, as this can help uncover illegal fishing practices. The observation of oil fields, an additional application in the **environmental protection** category, could provide important information for disaster management. These examples make it clear that these civilian fields of application cannot be considered in complete isolation from one another. Rather, the application of UAS in the civilian sphere brings with it **economies of scale**, as a reconnaissance mission undertaken for one purpose can also be used to generate data for another purpose. Because of the aforementioned payload modularity, a platform can in principle be equipped with different sensors, so that only one platform can be used to carry out several different civilian missions.

Next, the application fields of scientific research, disaster management, protection of critical infrastructure and homeland security will be examined in more detail. The benefit of UAS for selected civilian missions will be analyzed using the advantages discussed in Chapter 3.

Figure 3:
Civilian Application Fields for UAS



Source:
Diagram by
Therese Skrzypietz.

4.1 Use in Scientific Research

Unmanned reconnaissance systems can be of great importance for science. The variety of potential fields of application is very diverse and covers a very wide array of scientific disciplines. In particular, UAS is ideal for atmospheric research and the observation of volcanoes and hurricanes. Unmanned systems can also be very helpful in agriculture and forestry as well as in transportation science. As explained in the introduction, unmanned systems were developed in the United States for scientific research in the early 1990s. The use of UAS for scientific purposes was tested at a very early stage and UAS is now used to an ever-increasing degree. To examine and analyze the various scientific applications of UAS more closely, it is helpful to look at a few practical examples.

From May to June 2002, a MALE-UAV was tested above the *North European Aerospace Test Range-Area (NEAT)* in the north of Sweden, including its use for atmospheric research. The NEAT is commonly used for the aeronautical testing due to the low population density in the northern part of Sweden. An *Eagle* UAV, developed by IAI and operated by EADS, was used for the mission and equipped with a condensation particle counter. Using the instruments installed in the Eagle, it was possible to collect data at altitudes between 4,000 and 7,500 meters (13,100 and 24,600 feet), enabling an analysis of different levels of the atmosphere. From a scientific perspective, the flight was a complete success.[26]

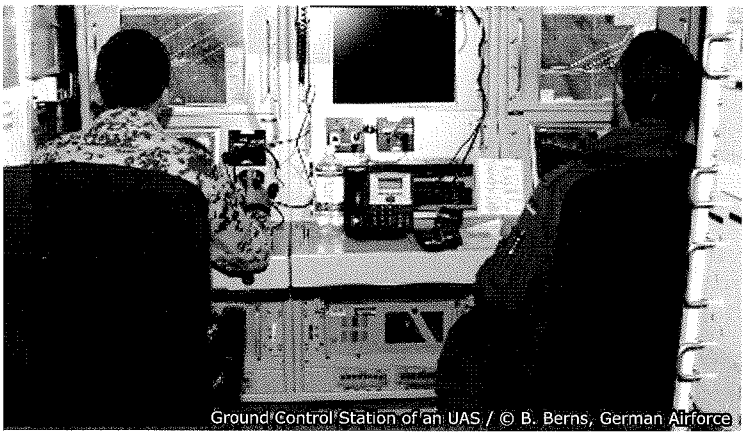
In November 2005, a UAS demonstration project by the American *National Oceanic and Atmospheric Administration (NOAA)* successfully concluded following an almost 20-hour mission over the eastern Pacific. Carrying a 140 kg payload, the UAS Altair, a Predator variant, was able to collect atmospheric data from the lower stratosphere (altitude 13,000 meters / 42,500 feet) for scientific purposes.[27] One year after the successful NOAA mission, a civilian version of the predator was acquired by NASA's *Dryden Flight Research Center (DFRC)* to support geoscientific research and to help develop aerospace technology. This unmanned system, named Ikhana, is also used as a platform to develop and test technologies and techniques to improve the use of UAS.[28] Furthermore, in 2010 the *Global Hawk* was used for hurricane observations and was able to collect very detailed data about how hurricanes develop and evolve over time.[29] "It would be like parking a satellite above the storm"[30] is how the director of NASA's UAS program in Boulder, Colorado, characterized the use of large, unmanned systems for hurricane research. This statement also highlights UAS's flexibility compared to satellites, which, owing to their great distance from the storm, cannot provide as detailed data about the storm and cannot shadow its movements.

These examples clearly illustrate the wide variety of civilian tasks for larger UAS in scientific research. However, smaller UAS are also frequently used for scientific research. For example, in the ANDROMEDA (Application of Drone-Based Aerial Photographs - Mosaic Creation, Rectification and Data Analysis) research project, a smaller UAS was developed which makes it possible to capture, automatically process, and analyze aerial imagery, so as to collect geographic data from the air.[31] In 2010, with the help of this system, it was possible to determine the extent of damage following a storm in the Thüringer forest region of Germany. The unmanned *Carolo P 200* vehicle was flown over 3,100 hectares (7,657 acres) of forest, collecting more than 3,000 images during its one-hour flight.[32] These images made it possible to create a very good, practical map of damaged trees, which was then quickly provided to the forestry workers, who were then able to use the information to prevent additional damage by bark beetles. Thus, in the future, the use of smaller, unmanned systems in forestry could represent an important civilian application of UAS, if the regulatory framework is clarified. In Japan, smaller VTOL-UAVs have also played a supporting role in agriculture.

The Institute for Geoinformatics at the University of Münster is using MUAVs to investigate possible applications for smaller unmanned systems in the earth sciences.[33] The project has developed and uses its own *ificopter*, which can both collect aerial data from a bird's eye perspective as well as process it.

MUAVs can also be put to excellent use in vulcanology. Staff of the Institute of Aerospace Systems at the *Technische Universität Braunschweig* have used a version of the Carolo UAS, similar to the one mentioned above, to successfully carry out volcano observations in Ecuador.[34] The unmanned system was able to fly into the crater of the active volcanoes *Cotopaxi* and *El Reventador* and collect images of lava flows.

The possibility of undertaking risky missions, such as volcano and hurricane observations, without endangering the lives of aircraft crews underlines the safety advantages of UAVs compared to manned aircraft. Thus, MUAVs can be used in regions, such as volcano craters, which are not reachable by manned aircraft. Research missions over the poles or across the open ocean, where an emergency landing would entail considerable risk for a pilot, are especially well-suited for a UAS.[35] Additionally, the additional flexibility offered by UAS is very important, as unmanned vehicles can be employed relatively independent of weather conditions. Furthermore, the examples cited above illustrate that, in the scientific area, it is necessary to collect data over a long, continuous period of time. Here, MALE and HALE systems represent an important option, due to their better endurance compared to manned vehicles.


Ground Control Station of an UAS / © B. Berns, German Airforce

In regard to their sensor capabilities, modular, unmanned reconnaissance systems also represent a more advanced option for collecting data when compared to satellites, which can make important contributions to research. The collection of atmospheric data in the air column itself using instruments installed in UAVs also offers a broader basis of data than collecting the information from above, via satellites. The automated processing of imagery also facilitates the analysis of the results.

All in all, UAS represents a very promising tool, especially for researchers in the earth and atmospheric sciences. Regardless of the size of the platform, its endurance, or its specific capabilities, there will always be scientists who will use UAS and who will demand new developments in this field.[36] Smaller systems are also well suited for temporary use in research in small, predefined, spatially-limited areas.

Because of their high endurance, MALE and HALE UAS are of great interest to researchers in situations in which these systems can offer a view into largely unresearched areas, enabling us to gain new insights in atmospheric science.

4.2 Disaster Prevention and Management

The use of UAS to prevent disasters and help address them once they have occurred is of particular value. For example, UAS can be used in natural disasters such as forest fires, floods, earthquakes and dangerous storms to observe and analyze the situation. At the same time, they support specific search and rescue operations, for example searching for survivors of shipwrecks or airplane crashes or for victims buried in avalanches or other disasters. UAS can also be used to gather information in other types of disasters, for example ABC accidents or oil spills. In the past, the use of UAS in disaster situations has proven to be very helpful. As in the previous chapter, a number of practical examples will be cited which will then be evaluated against existing alternatives.

In October 2007, the UAS *Ikhana*, mentioned previously, was used for reconnaissance operations during the disastrous forest fires in California.[37] Using specially installed thermal imaging sensors, it was possible to pass the exact coordinates of the flames on to the fire-fighting aircraft, making it possible to better fight the fires. When compared to satellites, the UAS' capability to capture dynamic images at a higher resolution proved to be very beneficial for the firefighters. Their high endurance and the minimal risk to pilots are two leading criteria which support the use of UAS in forest fires. While the *Ikhana* was carrying out its successful mission in support of the firefighters, sensors it was carrying were also collecting a very large amount of data about the fire itself. Later, it was possible to use these data sets in research, an example of two different fields benefiting from a single UAS mission.

UAS can not only be helpful during large forest fires, but can also support smaller, more limited firefighting missions. For example, since 2007 Britain's *West Midlands Fire Service (WMFS)* has employed the *Incident Support Imaging System (ISiS)*, which uses a German md4-200 MUAV, to