GLOBAL TRENDS OF UNMANNED AERIAL SYSTEMS

DANISH TECHNOLOGICAL INSTITUTE 2019

AUVSI ALL THINGS UNMANNED

DANISH TECHNOLOGICAL INSTITUTE

Titel
Global Trends of Unmanned Aerial Systems

Danish Technological Institute [DTI]
Gregersensvej 1
2630 Taastrup
Centre for policy and business

In cooperation with

Association for Unmanned Vehicle Systems International [AUVSI]
2700 S Quincy Street,
Suite 400
Arlington VA 22206
USA

DTI has received funding from Danish Agency for Science and Higher Education for this report.

2019

Authors (DTI):
Rina Valeur Simonsen
Malene Hartung
Kirstine Clemens Brejndal-Hansen
Stig Yding Sørensen
Kristian Oluf Sylvester-Hvid
David Klein (AUVSI)

Contact:
Senior Specialist Stig Yding Sørensen
Danish Technological Institute

Phone +45 72 20 27 04
Email stys@dti.dk

Table of content

Global trends for Unmanned Aerial Systems

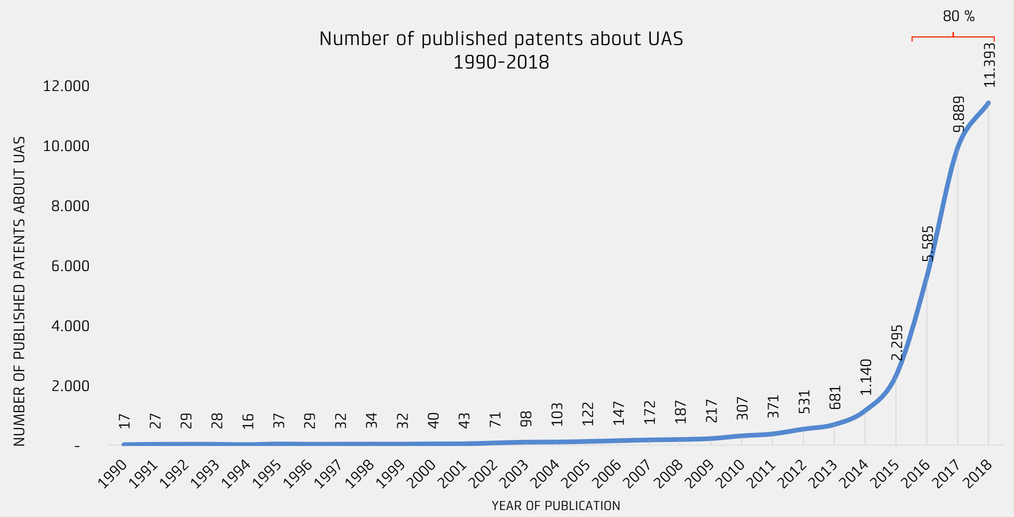
Unmanned Aerial Systems (UAS) have become increasingly popular in recent years, and operators of the technology are constantly finding more practical and innovative uses. This is reflected by significant increases in research and innovation relating to UAS technologies as well as the diversity and sheer number of UAS platforms offered by manufacturers worldwide.

UAS have been referred to by many names – drones, Unmanned Aerial Vehicles (UAV), Remotely Piloted Aircraft Systems (RPAS), etc., but this report will use the UAS abbreviation.

The Association for Unmanned Vehicle Systems International (AUVSI) maintains the Unmanned Systems & Robotics Database that captures a range of information on UAS platforms. In this analysis, Danish Technological Institute and AUVSI have cooperated in making a deep dive into the database to acquire a better understanding of the vast potential of UAS technology.

UAS technology has seen considerable development over the last decade and even more significant advances in the last two years. While early UAS applications were limited to military missions, academic research, and model airplane enthusiasts, they are now being used for several commercial applications, and have even found their way into

FIGURE 0.1. NUMBER OF PUBLISHED PATENTS ABOUT UAS 1990-2018



Source: Calculations by Danish Technological Institute based on a search in global patent databases via PatSnap. 34.811 patent families identified. Syntax: TAC:(drone*) or TAC:("Unman*" $w2 "Aircraft*") OR TAC:("remote*" $W2 "aircraft*") OR TAC:("Micro Air Vehicle*") or TAC:("Unman*" $w2 "Aerial*"). Extract 6. dec. 2018.

the homes of consumers. In the United States (US) alone, over 100,000 remote pilot certificates have been issued by the Federal Aviation Administration. Figures from the Danish Transport, Construction and Housing Authority show that the number of remote pilot certificates issued in Denmark doubled from approx. 14,000 in 2017 to more than 28,000 in 2018.

Research in the global patent databases has identified almost 35,000 patent families associated with UAS technologies. The graph in Figure 1.0 displays the total number of patents year by year since 1990 and gives an illustration of the recent exponential growth in technology developments relating to UAS. 80 percent of the identified patents have been published since 2016.

The patents that were captured could be related to the platforms themselves, supporting technologies, such as materials, communications, navigation, or energy systems, or they could be application technologies, such as imaging or data analysis by means of a UAS paltform. What the patents in question have in common is that “UAS” (or variations thereof) is mentioned in the title or the patent abstract.

This report provides an overview of information on 2,185 UAS platforms across five markets based on AUVSI’s Unmanned Systems & Robotics Database.

The data extraction for this report is from November 2018 and only includes vehicles that are actively being manufactured, operated, or developed. The AUVSI dataset is the largest comprehensive and searchable database for all unmanned vehicles operating in the air, ground and maritime domains. Since 2010, the AUVSI team has been collecting information on every unmanned platform they could identify. Each platform is categorized by market(s) for which it is being applied, i.e., academic, civil, commercial, consumer, or military. AUVSI have also identified over 30 specific application areas for each vehicle in the database ranging from imaging to precision agriculture and search & rescue. This report analyzes platforms from nine of these application areas. Further detailed information for each platform is based on publicly available specifications released by the UAS manufacturers. These specifications are divided into two main categories, i.e., technologies and capacities.

The following section presents the overall report findings.

For the purposes of this report, we distinguish between five market areas where the UAS platforms are used:

1. Academic market
2. Civil market
3. Commercial market
4. Consumer market
5. Military market

One platform can essentially be used for several purposes, and therefore it belongs to more than one market. Likewise, one UAS platform can be included in the analysis of several application areas. How the platform is used depends on the integrated payloads and subsystems.

Definition of UAS markets

The two most dominant markets are the civil and commercial markets. Nearly 80 percent of the total number of UAS platforms are used for the civil market and 65 percent of them are used for the commercial market. Over half of all the platforms can currently be used on the military market. Platforms developed for the academic and consumer markets account for less than 10 percent of UAS models in the AUVSI database. Descriptions of these markets follow below:

- **Academic market:** UAS in this category include vehicles developed for or by universities and other academic institutions. Specific applications for these vehicles include scientific research such as environmental monitoring, prototype development to advance new technologies, and educational platforms.

- **Civil market:** UAS in this category include vehicles intended for use by government (non-military) entities. They include first responders such as police and fire departments using UAS for search & rescue, disaster response, patrol & security, etc.

- **Commercial market:** UAS in this category include vehicles intended for use by service providers and for-profit businesses. Commercial operators continue to find new and innovative uses for UAS technology, and applications range from basic imaging and photographic inspections to more advanced surveys using payloads like LiDAR (Light Detection and Ranging) and multispectral sensors. Commercial UAS provide significant benefits to companies in agriculture, mining, real estate, construction, oil & gas, utilities, cinematography and many others.

- **Consumer market:** UAS in this category include vehicles intended for use by individual consumers and hobbyists. The Unmanned Systems & Robotics Database will only include a consumer aircraft when it is capable of being used for imaging applications and generally it will also be classified in the commercial market category. Examples of these types of vehicles are those offered by the Chinese company DJI Technology. Though it is not reflected in the market category percentages presented above, these low-cost aircraft account for most of the vehicles currently operated by remote pilots. Research released by AUVSI in August 2016 showed that 60 percent of operators intended to use UAS manufactured by DJI Technology.

- **Military market:** UAS in this category include vehicles intended for use by militaries. Some of the smaller vehicles can be deployed by a single soldier for rapid environmental assessment to identify potential threats or scout a specific location. The larger vehicles offer extended endurance to survey a battlefield, provide communication relays, acquire/attack potential targets, etc.

How to read the report

This report presents the capabilities and technological specifications for UAS within each of the above markets.

Before the detailed presentation of the UAS specifications, we present an introduction to global UAS trends.

The analysis for this report has concerned the five above-mentioned markets. We present an overview for each market below:

- Applications - the top six application areas
- Capabilities of the platforms.
- Technological specifications

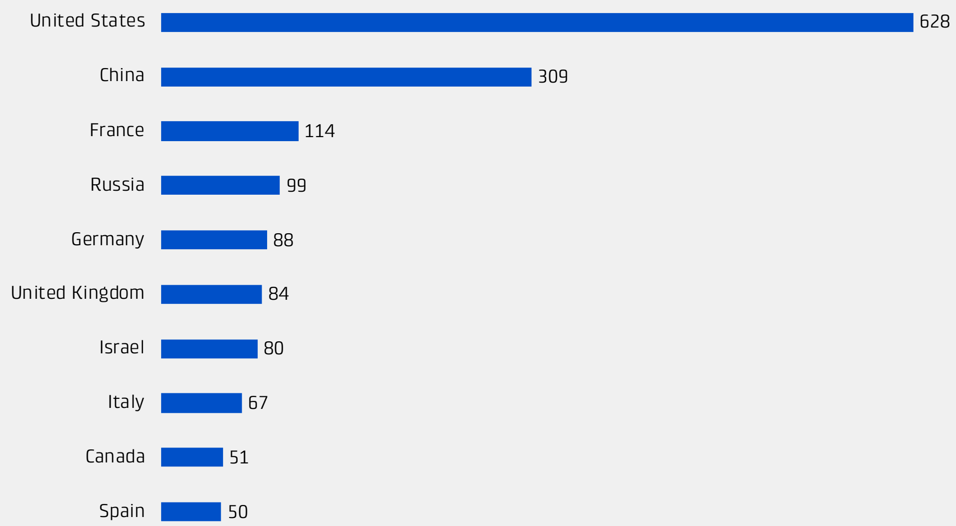
In addition to the five markets, we also present three selected application areas, i.e., precision agriculture, search & rescue, and hobby.

Where are the UAS platforms developed?

Chapter 1 provides an overview of the distribution of UAS platforms developed worldwide. The US is leading other countries with the highest number of unique UAS models. However, as a continent, Europe takes the lead in this regard. Figure 1.1 shows the top 10 countries in terms of completely unique UAS models offered by manufacturers in that region.

The United States leads the market for UAS platforms with 628 unique UAS models. China ranks second but only accounts for half as many platforms as the US corresponding to a total of 309 unique UAS models.

FIGURE 1.1. TOP 10 LEADING COUNTRIES IN DEVELOPING UAS PLATFORMS



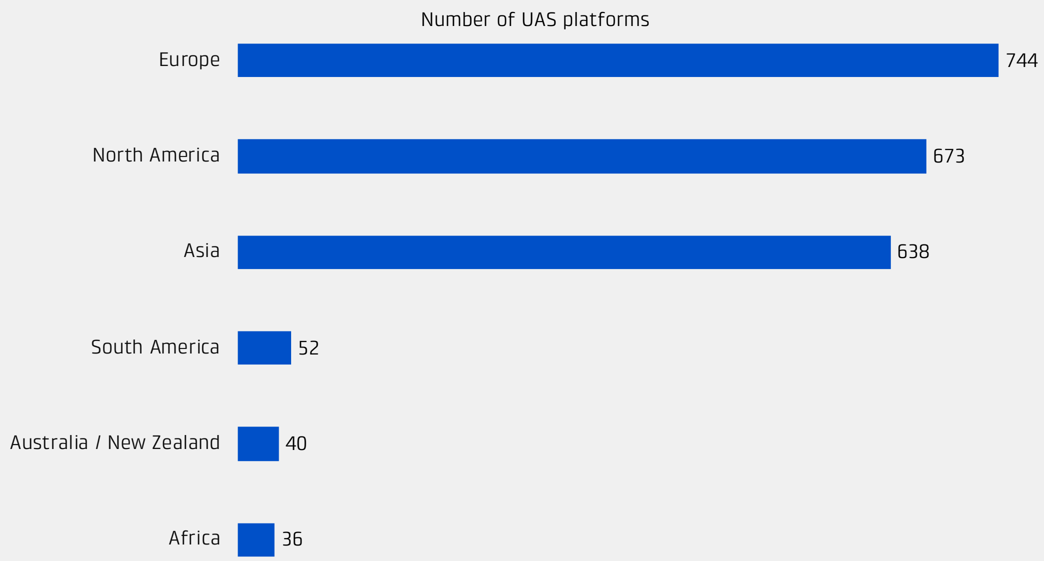
Interestingly, when considering the continents instead of the individual countries the distribution tips. Figure 1.2 shows how Europe is the continent with most UAS platform types on offer.

Neither North America nor Asia lacks far behind. The biggest jump is to South America, Australia/New Zealand and Africa. These numbers are expected to rise in the next few years if we are to expect the exponential growth from Figure 1.1 to continue.

As expected, the development of types of UAS made for the military market have the largest concentration in the United States. Since the United States has a continuously and highly developing military force it makes sense that UAS for military uses should be manufactured in this region. When taking the map in Figure 1.3 into account, there is a very dense clustering of platforms being developed on the east coast of the United States near Washington, D.C.

Developments of consumer platforms appear to be growing in China compared to other parts of the world. This reflects the general expansion of the Chinese consumer market for other products as well.

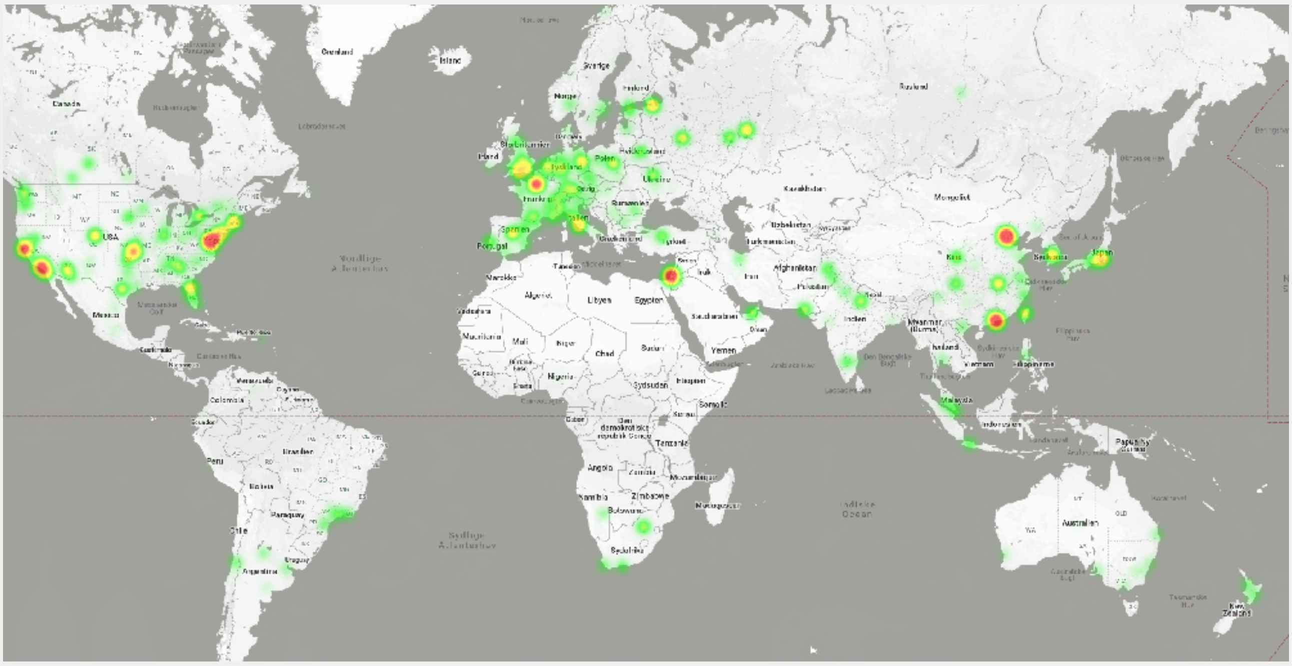
FIGURE 1.2. DEVELOPMENT OF UAS PLATFORMS BY CONTINENT



The map shows that even though the density of UAS platform development is highest in France, UAS development is evenly distributed across all of Europe. In comparison with the other continents, this shows how the whole of Europe is following the trend of developing UAS technology, whereas the development is dispersed into smaller pockets in other parts of the world.

The map gives a clear view of where in the world UAS platforms are being developed. With the continued adoption of the UAS technology and the growing list of applications for which UAS are being used, we can expect UAS development to spread worldwide in the years to come.

FIGURE 1.3: LOCATION OF UAS MANUFACTURERS



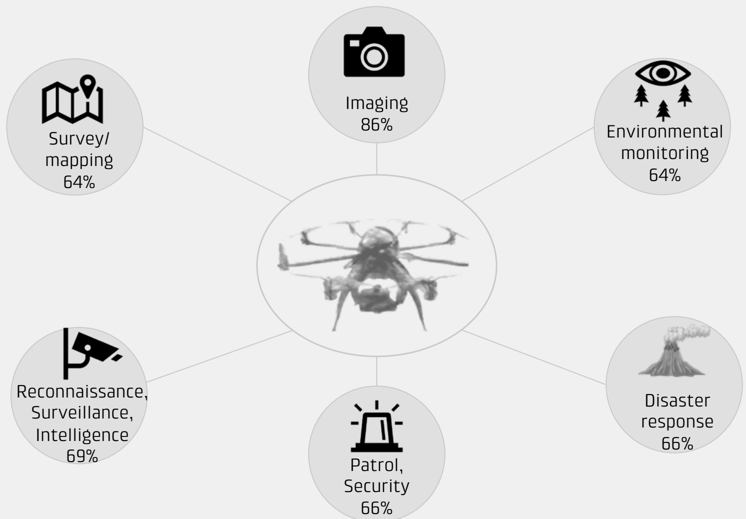
Note: Danish Technological Institute and AUVSI calculations based on the dataset from AUVSI November 2018. Addresses extracted from the AUVSI dataset. N: 2185. Active UAS in the world as of November 2018. Map made in BatchGeo.
Heatmap color codes: Green shows one or two UAS being developed in the same area. Yellow areas have some concentration of UAS being manufactured in the same area. Red areas mean a high concentration of the UAS platforms manufactured in the same area.

Most frequent application areas

In the Unmanned Systems & Robotics Database, UAS have been classified based on their intended applications with over 30 different categories in the full dataset. This analysis has been limited to the six most common application areas. How the UAS platform is equipped determines what it can be used for, which is why most UAS platforms can be applied for all of the six tasks which are accounted for in this report.

The most common application is imaging, i.e., using UAS to capture images of a specific area or object. UAS offer a low-cost solution relative to their manned counterparts and provide aerial imaging capabilities for companies that would not be able to afford the manned alternatives. This technology assists companies involved in adverti-sing, real estate, agriculture, and many others. UAS used for intelligence, surveillance and re-connaissance are the next most popular usage. It includes, for instance, traffic surveillance where UAS replace stationary cameras or people.

FIGURE 2.1. PERCENTAGE OF APPLICATION AREAS FOR ALL UAS PLATFORMS.



Note: The six most common application areas for UAS platforms. N: 2185. Danish Technological Institute and AUVSI calculations based on the dataset from AUVSI November 2018. Infographics made by Danish Technological Institute .

UAS used for patrol & security or disaster response each take up 66 percent of the applications, representing the third most common application areas for UAS. UAS can be used as a camera to live stream what lies ahead to avoid dangerous situations. Or, in the case of disaster response, UAS can assist in locating survivors from a natural disaster, provide people with survival packages, support first responders with situational awareness during a catastrophic event or provide damage assessment after the event, etc.

UAS can operate in areas that are difficult or dangerous for humans to access and thus offer tremendous benefits in the areas of survey/mapping and environmental monitoring. Surveying involves the creation of topographical maps that are used, for example, to document planned construction developments, monitor worksite progress, or conduct volumetric surveys. UAS for environmental monitoring use a variety of payloads like multispectral sensors to assess crop health or air quality samplers for pollution monitoring.

Speed

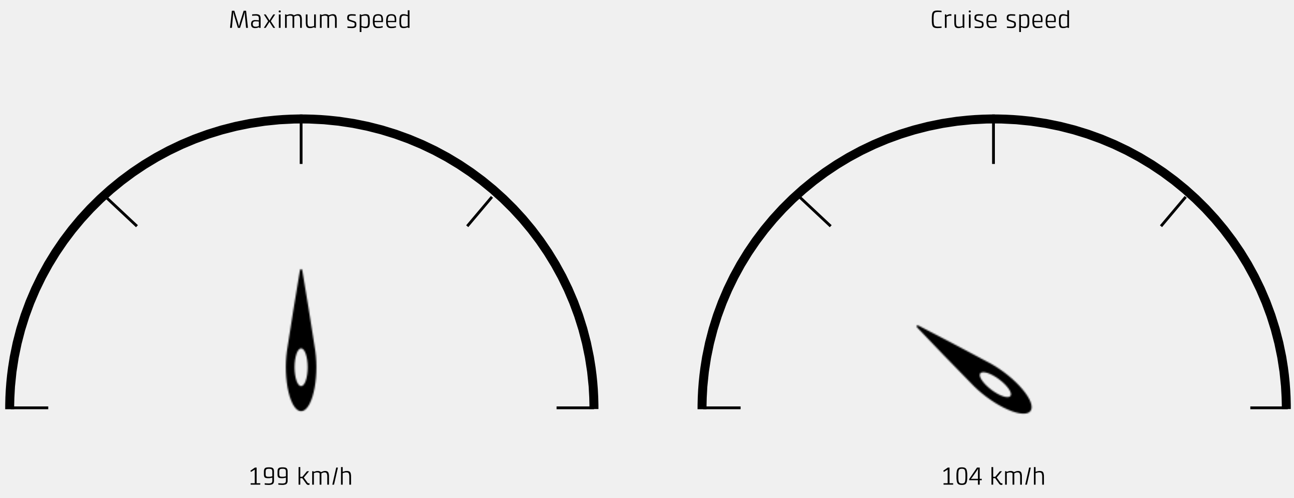
Speed is described by the maximum speed of UAS platforms, meaning the maximum air speed that they can reach. The picture to the left in Figure 3.1 shows the average maximum speed. Cruise speed is defined as the optimal speed for UAS platforms to gain maximum range or endurance, and the average value from the dataset is provided in the picture to the right in Figure 3.1.

Platforms for the military market are generally faster than all other UAS platforms. Their average maximum speed is 235 km/h and their average cruise speed is 130 km/h.

The second fastest UAS are used by the civil market with an average maximum speed of 147 km/h. They have an average cruise speed of 91 km/h, but they are much slower than the average military UAS.

The academic and commercial UAS markets are similar when it comes to speed with an average maximum speed reaching approx. 100 km/h. The average cruise speed for commercial UAS is 75 km/h and academic UAS are about 10 km/h faster. UAS platforms operating in the consumer market are the slowest UAS category with average maximum and cruise speeds near 70 km/h.

FIGURE 3.1. AVERAGE MAXIMUM AND CRUISE SPEED FOR ALL UAS PLATFORMS



N maximum speed: 1233. N cruise speed: 819. Graphics made by Danish Technological Institute.

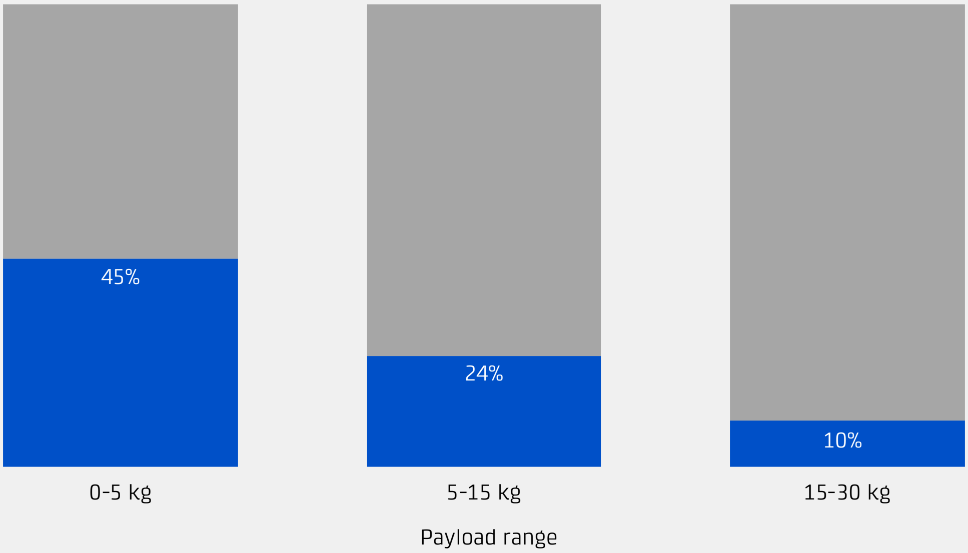
Payload

The average UAS payload, i.e., the load the UAS can carry in addition to its own weight, ranges between 0-5 kg. Equipment, such as different kinds of cameras, sensors, etc., typically weighs less than 5 kg, and therefore it is usually more than enough for the platform to be able to fly with this weight. However, UAS platforms for the military market are generally bigger and can usually carry a considerably heavier payload, such as weapons. Only approx. 30 percent of military UAS offer payload capacities of less than 5 kg and more than 20 percent of these platforms can carry more than 50 kg. In comparison, over half of the UAS from the other four markets fly with payloads of less than 5 kg.

The UAS on the consumer market are the least powerful with 80 percent of the UAS platforms lifting between 0-5 kg. UAS used by the academic market also tend to have lower payload capacities with 66 percent of the platforms carrying less than 5 kg.

Concerning the commercial and civil markets, approx. 50 percent of the platforms in each market area may lift payloads of less than 5 kg. Likewise, both markets have similar percentages of UAS that can lift more than 15 kg, 8..7% of commercial UAS and 8..5% of civil UAS respectively. While military UAS are the platforms with the highest payload capacity, UAS for commercial and civil markets are not lacking that far behind in this aspect.

3.2 THE PAYLOAD OF UAS PLATFORMS



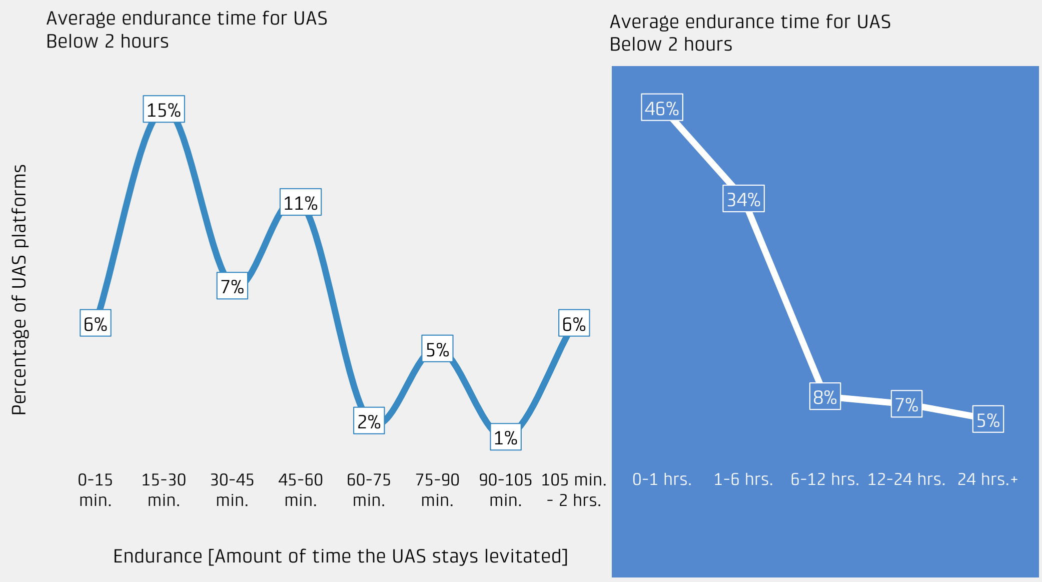
Note: Based on 1476 UAS platforms from AUVSI dataset.

Endurance

The time a UAS platform can stay airborne is referred to as its endurance. This is not to be confused with the range of a given UAS, as this specifically refers to how far in terms of distance the system can fly. Hence, for comparisons across different type and sizes of UAS, specifying the endurance is a better measure of the ability to stay airborne. Nonetheless, when different producers rate the endurance of their respective UAS platforms, this is done without the reference to a specific standard. Hence, few produces specifically state how, and under which conditions the endurance is assessed. One obvious way to state the endurance would be to report it for a given payload, barometric pressure and temperature. Obviously, the endurance reported for a given UAS can be increase if a larger fraction of its payload capacity is used to store energy. Also, the air temperature may have a significant impact on the endurance possible, with the general tendency that it decreases with falling temperature.

Therefore, when comparing endurances across the various UAS from the database, the above should be kept in mind, in particular because the endurance is key performance parameter used in the marketing of particularly commercial UAS systems.

FIGURE 3.3. UAS PLATFORM ENDURANCE TIME

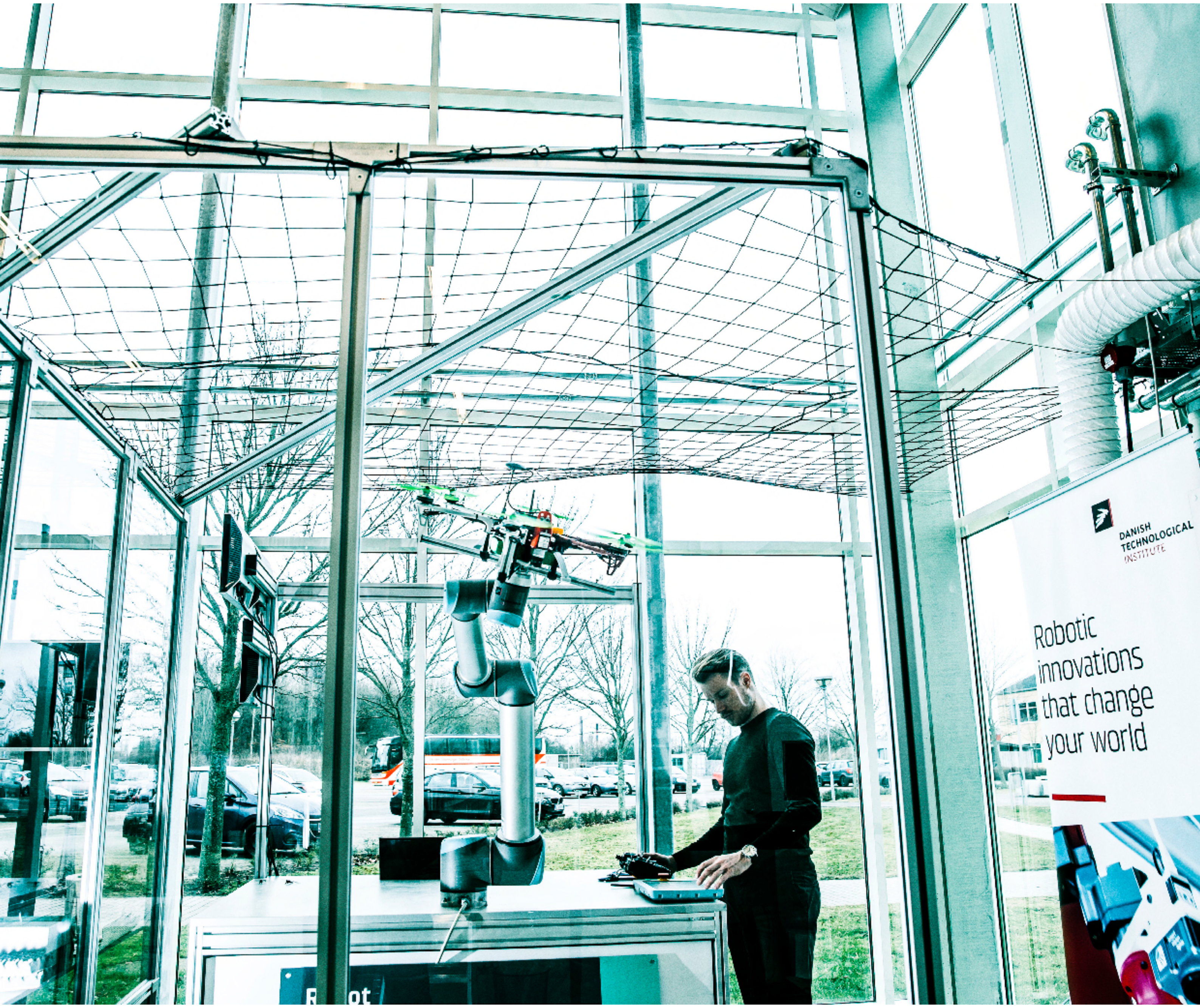


Note: Based on 1855 UAS platforms from the AUVSI dataset. Calculations by Danish Technological Institute.

94 percent of the consumer market platforms have an endurance of 1 hour or less, which means that the UAS in this market offer the shortest endurance. In comparison, the UAS for the military market offer the longest endurance with nearly 20 percent being able to stay airborne for more than 12 hours.

The civil, commercial, and academic markets all have in common that approx. 80 percent of the platforms can fly for 6 hours or less. Nearly 12 percent of UAS platforms for the civil market are powerful enough to fly for more than 12 hours. In comparison less than 9 percent of the UAS for the academic and commercial markets can fly for that long (12 hrs.+).

As a final note on the endurance it should be noted that the scaling of the endurance with the size (system weight) of the UAS is very different for multi-rotor and fixed-wing systems.



Wind resistance

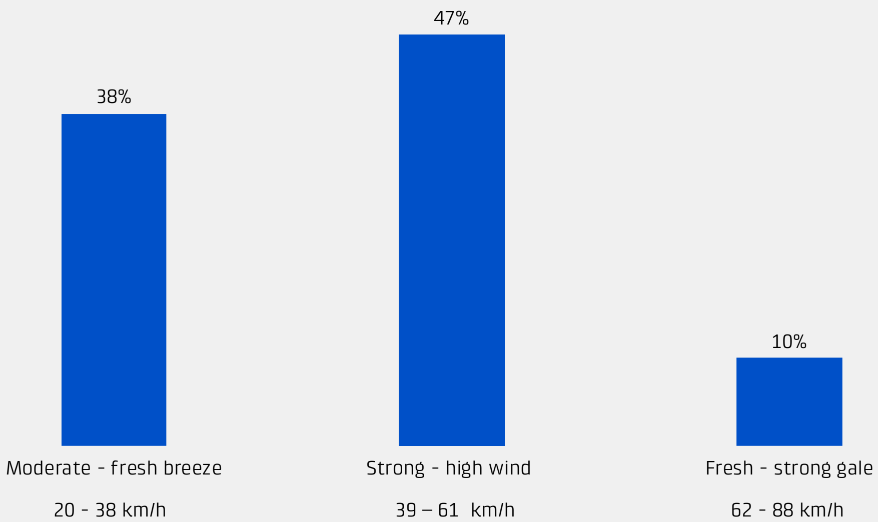
The wind resistance (or recilience) of the UAS included in this analysis is distributed according to the Beaufort wind force scale which defines the strength of the wind force from 0-12, with 0 being no wind and 12 a hurricane. In the dataset used for this analysis, wind resistance is accounted for in 25 percent of the UAS platforms. Still, it provides a good idea of the overall development in this aspect.

Recilience to wind is important because it can impact the functionality of the UAS significantly. When using UAS for missions such as building inspection, target acquisition, livestock surveys, etc., it is important that it can stabilize under the given weather conditions, since it may otherwise collect biased data or even fly astray and crash.

Academic UAS platforms are the most sensitive to wind with 15 percent of these platforms only stabilizing if the wind is no more than a gentle breeze (maximum 19 km/h). Even so, nearly eight percent of them can fly in a storm, which is more than can be said of the consumer market UAS. Most consumer market UAS (90 percent) are not usable in high wind, i.e., wind speed of +61 km/h.

In this specification category, the military UAS only take the lead slightly. 17 percent of military market platforms can fly in more than a fresh gale. This exceeds the civil and commercial market platforms by approximately 5 percent.

FIGURE 3.4: WIND RESISTANCE



Note: Based on all UAS in the dataset. N: 569

Size

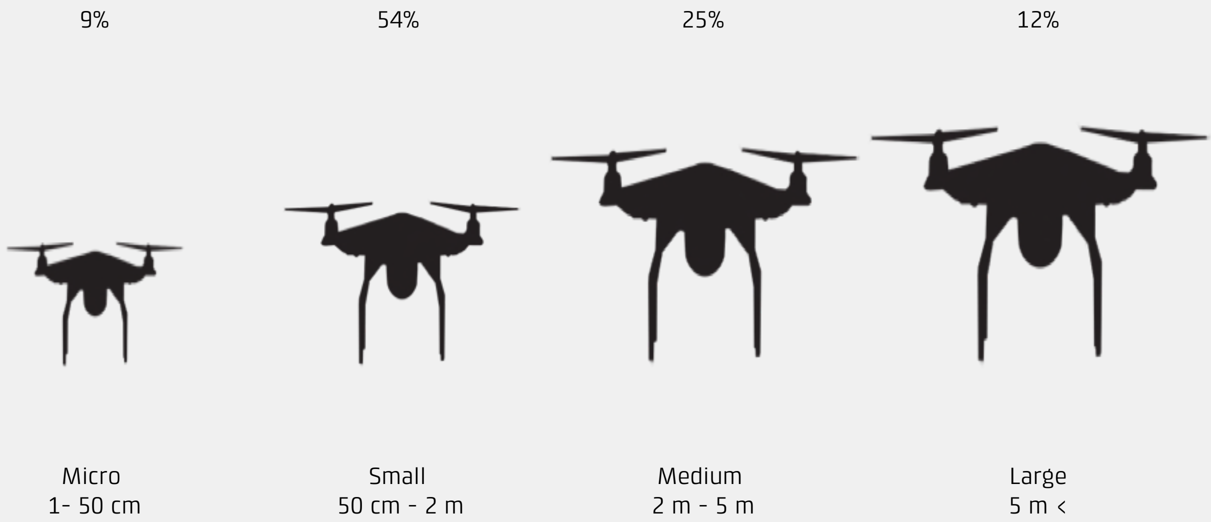
The platform size usually depends on the intended application of a given UAS with pros and cons for every size. UAS sizes in this report are the length of the platforms, where they are categorized as micro (1-50 cm), small (50 cm – 2 m), medium (2 – 5 m), and large (more than five meters). In general, more than 60 percent of UAS platforms are less than two meters (Figure 3.5).

Not surprisingly, the UAS for the military market are by far the biggest with 20 percent of them having a size longer than 5 meters, and they are categorized as large in this report. Large UAS often carry heavier payloads and have a longer endurance since they also allow for large (and thus more energy efficient) engines and fuel storage. For a military UAS this is very useful, since they loiter in the air for extended periods of time while conducting surveillance and patrolling missions.

UAS intended for the civil market have a similar distribution as shown in Figure 3.5 for the full dataset. Consumer market platforms are the smallest with 97 percent being less than 2 meters. More than 40 percent of consumer UAS are less than 50 cm (categorized as "micro" in this report), meaning that they pose a minimal threat to humans on the ground in case of a crash, and they can often be used indoors. Many of these micro UAS can be stowed in configurations no larger than a cell phone making them even more attractive to the consumer market.

As for UAS used by the commercial and academic markets, the two markets are similar in that no more than five percent of these platforms fall into the large category. Micro UAS account for 10 percent of the platforms from the commercial market – approx. 10 percent less than the distribution of micro UAS in the academic market. Micro UAS offer the advantage of being able to access narrow spaces. For academic purposes, this means that the UAS can collect data in locations that would otherwise be difficult to reach by humans.

FIGURE 3.5. SIZES OF UAS PLATFORMS



Note: Based on 2073 UAS in the AUVSI dataset. N: 2073. Infographic by Danish Technological Institute.

BLOS capabilities

BLOS is the acronym for Beyond Line of Sight, which is the ability of a UAS to operate safely beyond human line of sight. When discussing BLOS it is important to distinguish between the ability to fly out of sight and the actual BLOS capability. In practice any UAS platform can fly out of human sight even though they are not built for that purpose. To let a UAS fly out of sight when not designed for it is unsafe, as well as illegal in many places. When speaking of BLOS platforms we refer to UAS which have been installed with the proper navigation systems as well as communication links which extend over long distances.

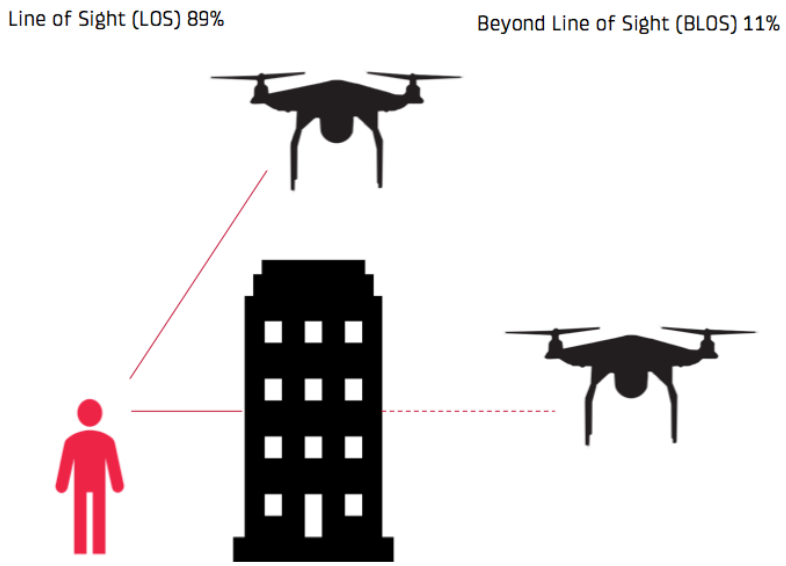
Even though there are restrictions on this capability in most countries, the technology is available and represents expanding possibilities. With UAS being able to fly BLOS safely, information can be collected over vast distances that can greatly assist in missions like linear infrastructure inspections. Moreover, there is a growing potential for UAS delivering food, medicine or other goods into remote and not readily accessible areas.

The leading market for this technology is the military market, where nearly 16 percent of the UAS platforms can fly BLOS. Considering what military UAS are used for, it makes sense that the technology is more widely integrated among these platforms.

On the consumer market, only a half percent of the platforms can fly BLOS. This capability is not necessary for the consumer market since most UAS are used for hobbies or basic photography tasks. Also, in this market, the price tag of the UAS is the dominant competition parameter, and adding the BLOS capability would significantly increase the cost.

For the civil, academic, and commercial markets, approximately 10 percent of UAS in each market can fly BLOS. As mentioned above price might be a reason for the small numbers, but also air traffic regulations on BLOS play a role. However, the interest and potential is growing, and we are likely see more platforms capable of flying BLOS in the future.

FIGURE 4.1. ILLUSTRATION OF THE BLOS CAPABILITIES OF UAS



Note: Based on 2185 UAS in the AUVSI dataset. Infographic by Danish Technological Institute.

Types of propulsion systems

With the advent of high energy density lithium batteries, electrical propulsion for UAS systems became possible. In fact, measured on the number of systems sold, electric propulsion revolutionized the UAS technology and created a completely new market, namely the consumer market. Before electrical propulsion became viable for UAS system, the dominant means of propulsion was internal combustion engines (ICE), and the UAS systems used by professionals only.

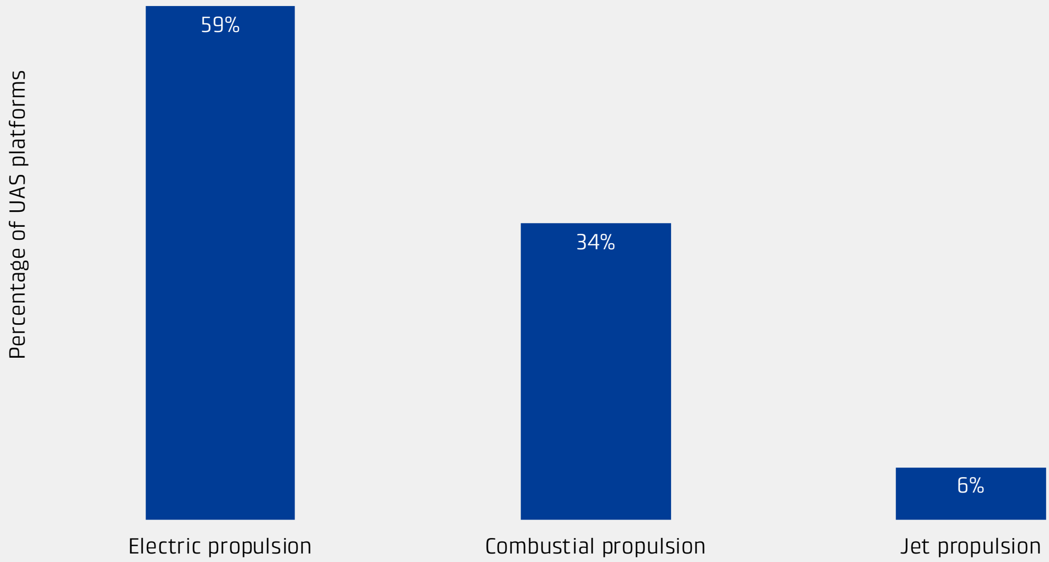
Generally speaking, electric propulsion offers all the things UAS designers and operators would want to ask for, but for one namely limited range. The limited range links directly to an energy storage capacity of lithium batteries, at least an order of magnitude smaller than the gasoline used in ICE propulsion systems. The upsides of electric propulsion are low noise, heat and vibrational signature, mechanical simplicity and low maintenance costs, as well as an energy efficiency up to 80-90%.

Electric propulsion combined with modern speed controller electronics made multi-rotor UAS systems without pitch control possible. This is a significant mechanical simplification, which effectively opened the consumer market for small, easy-to-use and low cost multi-rotor UAS systems.

When comparing different types of propulsion system one should keep in mind that the overall energy efficiency of the system (and thus endurance) scales very differently with size. Generally, small ICE propulsion systems have very low energy efficiency for which reason electric propulsion is the preferred means of propulsion for systems under 5 kg. As the UAS size increases, the efficiency of ICE propulsion increases and the fuel contributes a relatively smaller fraction of the total weight. For this reason, ICE propulsion is the preferred means of propulsion for larger UAS system, where long endurance most often is required.
Jet propulsion systems also use a combustible high energy density fuel, but these systems only becomes energy efficient at high speeds in high altitude missions, and for this reason are exclusively used in long endurance professional missions.

The consumer market is the market with the highest percentage of UAS using an electric propulsion system. Based on the overall percentages, it is assumed that there is a general tendency for vehicles to be powered by an electric system when it fits the required mission capabilities. The energy density offered by batteries and the efficiency of electric motors have continued to increase over the years. Approximately 75 percent of the UAS from both the academic and commercial markets are equipped with electric propulsion systems. Meanwhile, the civil market accounts for a larger portion of combustion and jet systems, amounting to 33 percent and 2 percent respectively.

FIGURE 4.2. PROPULSION SYSTEMS FOR UAS PLATFORMS



Note: Based on 2185 UAS in the AUVSI dataset. Calculations by Danish Technological Institute.

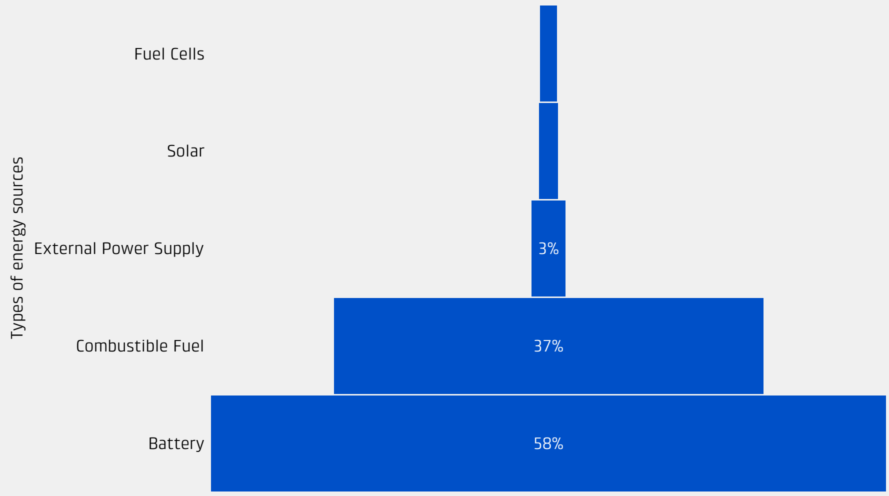
Energy sources

The type energy carrier used by a particular UAS obviously relates to the installed propulsion system. All ICE and jet based propulsion systems rely on a range of gasoline mixtures. Common to these is that they are highly flammable liquids and their combustion in the UAS propulsion systems not subject to any environmental regulation. Consequently, the emission of un-combusted fuel, NOx, Carbon monoxide and soot particles may be significant, as catalytic converters are not used. Especially, for small ICE systems the air pollution per released energy equivalent may become very large.

On the upside, gasoline and jet fuel both are globally readily available, low cost, easy to handle and has unbeaten energy density per weight and volume.

UAS system with electric propulsion all rely on rechargeable lithium batteries. Despite the limited range possible with batteries (low energy density), such batteries offer a very convenient, emission free and user-friendly way of carrying energy along. The high power density (not energy density) of lithium batteries is the key enabling parameter, which made electric UAS systems possible for the consumer market. For many smaller electric UAS

FIGURE 4.3. ENERGY SOURCES FOR UAS PLATFORMS



Note: Based on all 2185 in the AUVSI dataset. CalculationsCalculations by Danish Technological Institute.

systems, "refueling" is simply a matter of swapping a battery pack, which effectively make the technology tractable for the hobbyist segment. Despite a continuous advancement of the lithium battery technology, long charging times, the limited number of charging cycles, their cost and the regulations on transporting larger battery packs by air, all pose practical problems for users of electric UAS systems.
Another way of powering electric UAS systems is through an external power supply. For example, the UAS can be tethered to a power supply on the ground through a power cord, and hence they can stay airborne for longer – infinitely in theory. The military market has the highest percentage of the five markets with four percent of the platforms using an external power supply.

Electric UAS systems may have their range extended if equipped with either solar and fuel cells, and have a similar distribution when looking at the overall dataset. Solar cells are most popular in the academic market where approx. 7 percent of the platforms are powered by solar energy. Solar cells are generally mounted on the wings of the UAS, and some models have even used them as the structure for their airframe.

Most commonly, fuel cells use pressurized hydrogen as the fuel. This technology is very new in the field of UAS, but if the necessary balance between size and power is reached, the potential for more sustainably powered high-endurance UAS will be possible. Ultimately, there are not many UAS powered by fuel cells, and the leading market for this is the civil market, where 1..8 percent of the platforms use fuel cells.

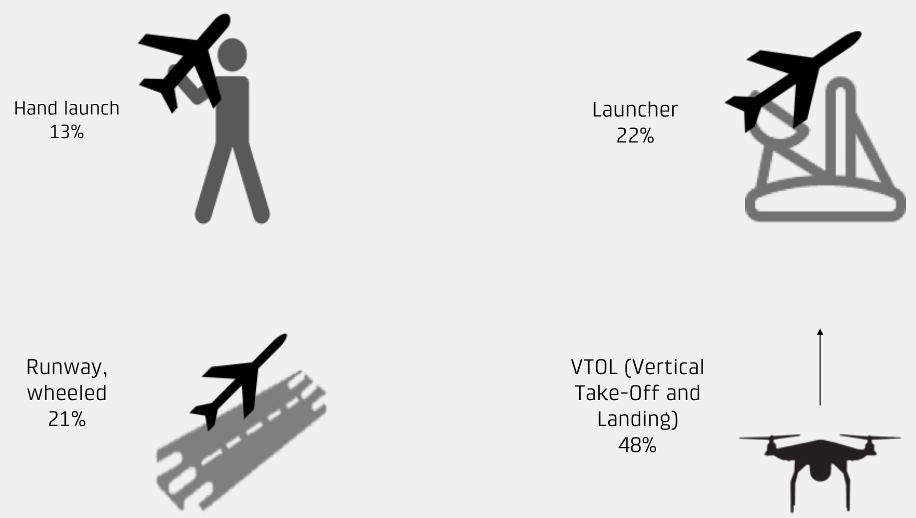
It should also be noted that there is a growing tendency towards hybrid power systems, in which the electric propulsion systems is supplemented with an ICE and generator, to provide the electrical power. Hybrid systems should embody the upsides of electrical propulsion and the range possible with a combustible fuel. Hybrid systems in terms of efficiency scales positively with the size of the UAS system, and thus for small UAS systems (<5kg) they are not meaningful yet.

Launching and landing methods for UAS platforms

The most common launching method for all markets is Vertical Take-Off and Landing (VTOL). UAS equipped with a rotary wing airframe are capable of VTOL. These rotary wing airframes have been developed in a range of different configurations from a single helicopter-style rotor to multi-rotor platforms that use multiple propellers for vertical thrust. The key advantage offered by VTOL UAS is the limited footprint required for this launch and landing,. Unlike wheeled, fixed-winged vehicles that require a linear strip of land or pavement to become airborne, and land, VTOL UAS simply need a small circular clearing. Therefore, it makes sense that in the consumer market more than 80 percent of the platforms use VTOL to launch and land their UAS.

The next most common launching method in the consumer market is hand launching, where one simply throws the UAS into the wind. More than 10 percent of UAS from the other four markets utilize hand launch. However, the academic market is the leading market when it comes to hand launch where more than 20 percent use this method. One issue of hand launched UAS platforms is the landing. When a UAS is small enough to be thrown into the air by arm power it will not necessarily be easy to land it safely under all conditions. Mostly

FIGURE 4.4. LAUNCHING METHODS FOR UAS PLATFORMS



Note: Based on 2185 UAS in the AUVSI dataset. Infographics and calculations by Danish Technological Institute.

belly landing in soft grass field or on snow is preferred, but capture in mid air by suspended nets is also used.

UAS that utilize a launcher device have some type of ground-based structure to assist with take-off whether by means of a catapult, bungee, etc. 30 percent of platforms intended for the military market use some type of launcher, while less than 20 percent of the other four markets make use of this launching method.

Runways take up a lot of space and are therefore not a very common launching method in the consumer market. For the academic and civil markets, approx. 20 percent of the platforms require this launching method. However, the military market is where you find the highest amount with 30 percent of the UAS using a runway to launch. It should be noted that some vehicles can be launched by multiple methods depending on the mission requirements.

Plenty of different designs meet issues of balancing effective take-off and landing in the same platform. One of the more promising ones would be the hybrid (or transitional) airframe, where propeller for take-off- and landing is combined with fixed wings for energy efficient flying.

Airframe

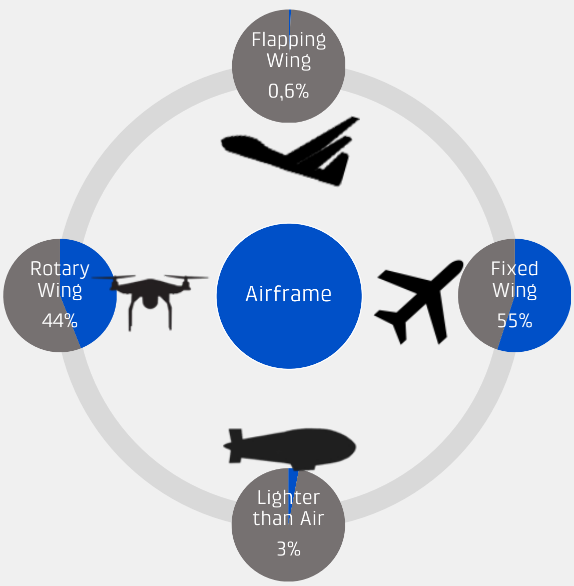
UAS use two main airframe types, i.e., fixed wing and rotary wing. Fixed wing aircraft requires a certain speed to gain lift and can only travel in a forward direction. In comparison, rotary wing aircraft utilize the rotation of propellers or rotor blades to gain lift, can operate from hover to cruise speeds of more than 100 km/h, and are capable of omnidirectional motion. Some recent technology developments include airframes that combine a fixed wing with a rotary wing. These hybrid (transitional) designs provide the extended endurance of a fixed-wing aircraft with the flexibility of limited footprint required for take-off and landing of a rotary wing aircraft.

Also included in the dataset are flapping wing UAS and lighter-than-air platforms like aerostats or blimps. Flapping wing UAS use a biomimetic design where the aircraft imitates the motion used by birds, bats or insects to generate forward propulsion. Most flapping wing UAS have been developed as a proof-of-concept and only a handful of designs have been intended for commercial production. Lighter-than-air platforms use the buoyant nature of gases lower in density than air (like helium) to remain airborne for long-duration missions.

Fixed wings are the most common airframe for UAS across the entire dataset with 55 percent of vehicles using this design. Rotary wings are the next most popular at 44 percent. Lighter-than-air platforms account for over 3 percent. Almost all the lighter-than-air platforms are used by the civil market for applications like border patrol, and 80 percent can be used for military applications (often for extended observation and surveillance). Less than 1 percent of UAS utilizes a flapping wing design with over half of these vehicles designed for research purposes by academics.

When looking at specific markets we find that over 58 percent of the UAS for commercial applications use a rotary wing design while less than 44 percent use a fixed wing. For the consumer market, the difference between wing designs is substantial with almost 84 percent using rotary wings and only 18 percent using fixed wings. For the military, the distribution flips in the opposite direction as 27 percent of vehicles used in this market integrate a rotary wing and 70 percent integrate a fixed wing. These distributions reflect the different requirements for each market. Military missions can require UAS with extended endurance and this is most efficiently accomplished with a fixed wing. Whereas commercial operations can involve more precise inspections at close range which is easier to execute with a rotary wing. While still growing in popularity, hybrid wing designs only account for just over 4 percent of the total dataset. The distribution of these vehicles by intended market are 87 percent civil, 82 percent commercial, 53 percent military, 5 percent consumer, and 4 percent academic.

FIGURE 4.5. AIRFRAME TYPES



Note: Based on 2185 UAS in the AUVSI dataset. InfographicInfographic and calculations by Danish Technological Institute.

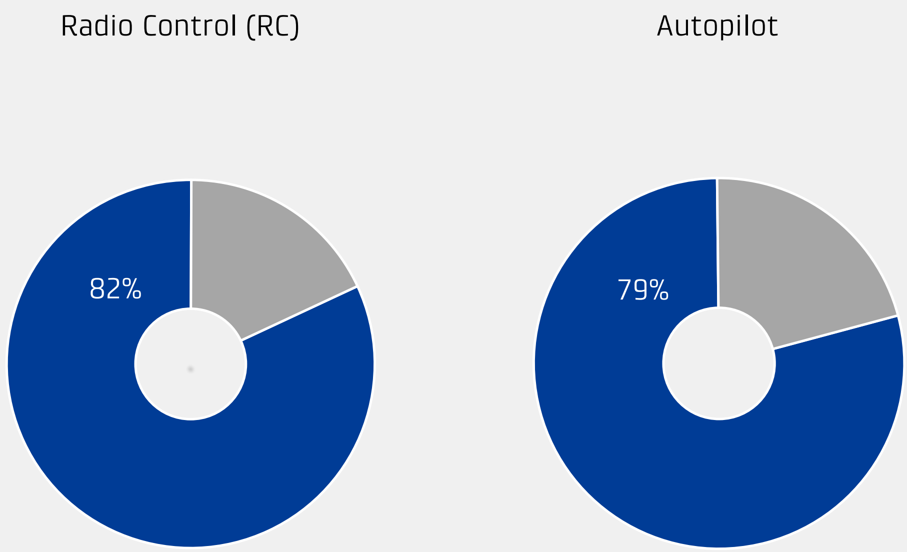
Navigation systems

UAS can be equipped with both autopilot navigation systems and radio control and similar percentages of vehicles from the dataset are equipped with these two technologies. Radio-controlled UAS are operated wirelessly through radio waves sent out by the pilot through a transmitter and to a receiver installed in the platform. The transmitter and receiver are tuned into the same frequency and this allows the pilot to remotely control the UAS. In other terms these platforms are manually controlled. Remote controls often come in the form of small joystick-based hand control units, tablet- or phone-based applications, or large ground control units.

UAS integrated with autopilot systems can navigate without the intervention of the pilot. Autopilots often follow preprogrammed routes, or flight plans, using GPS waypoints and can also incorporate range sensors for obstacle avoidance or to maintain precise cruising altitudes. These platforms are in other terms autonomous systems and are most appropriate for BLOS.

A platform can be equipped with more than one navigation system, making it possible to select the most appropriate for the different tasks. The consumer market is different from the other markets

FIGURE 4.6. PERCENTAGE OF UAS PLATFORMS WITH RADIO CONTROL AND AUTOPILOT NAVIGATION SYSTEM.



Note: Based on 2185 UAS in the AUVSI dataset. Calculations and graphics by Danish Technological Institute.

with only 66 percent of the platforms equipped with an autopilot where autopilots are integrated in most of the UAS from the other four markets and 95 percent of the platforms on the consumer market offer radio control.

There are several pros and cons of each navigation method. Autopilot systems reduce the burden on pilots allowing them to focus on other aspects of the flight such as monitoring weather conditions or conducting data sampling on route. UAS integrated with autopilots can execute precise missions which is essential for surveying applications, etc.

Autopilots also offer the possibility to control multiple UAS at the same time, further increasing the efficiency of operators. Most vehicles are equipped with an autopilot system with the option to transition to remote control if needed. One of the known weaknesses of UAS is that the radio frequency may be hacked, allowing other actors to take control of a vehicle. Also, some transmitters might not be powerful enough for the UAS to fly very far, limiting their potential uses. Even so, they are highly popular and with a strong frequency transmitter it allows the pilot to operate the vehicle remotely from a distance. This is important in military situations, where the UAS might be in danger of becoming a target while the pilot remains safe.

Precision agriculture

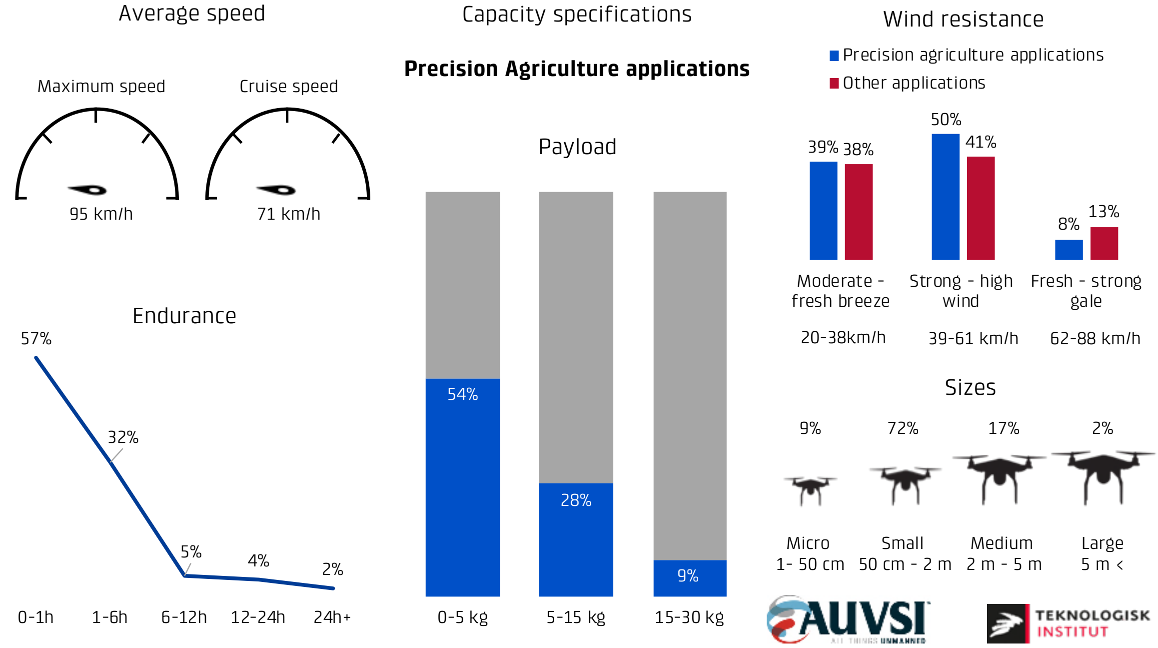
Out of the 2185 UAS platforms accounted for in the dataset behind this report, 1,070 of them can be used for precision agriculture. In accordance with DTI's overview at the end of the report, DTI has been working with UAS technologies, which can support the work of farmers. For example, UAS can be used to monitor crops and give the farmer an idea of potential diseases or rodents and thus prevent them from spreading. In addition, experiments have been conducted with nano-sized UAS (smaller than micro) used for plant nurseries. The dataset shows that a concentration of UAS for precision agriculture is available in Europe.

Capacity specifications

Platforms for precision agriculture applications are rather small and slow. Focus of these platforms obviously is stability and precision. For instance, the small platforms can carry the necessary equipment used to monitor fields. Also, they have a fair wind resilience as is illustrated in Figure 5.1, where 50 percent of the UAS can operate in strong to high winds. This is important given the outdoor operating environment of agriculture where strong winds are always a risk.

The endurance of these platforms is much like the average from the overall dataset, and most of them can stay airborne for less than 6 hours. This amount of time could be enough for the vehicle to cover a field and then get back for refuelling or reloading.

FIGURE 5.1 CAPACITY SPECIFICATIONS FOR PRECISION AGRICULTURE UAS



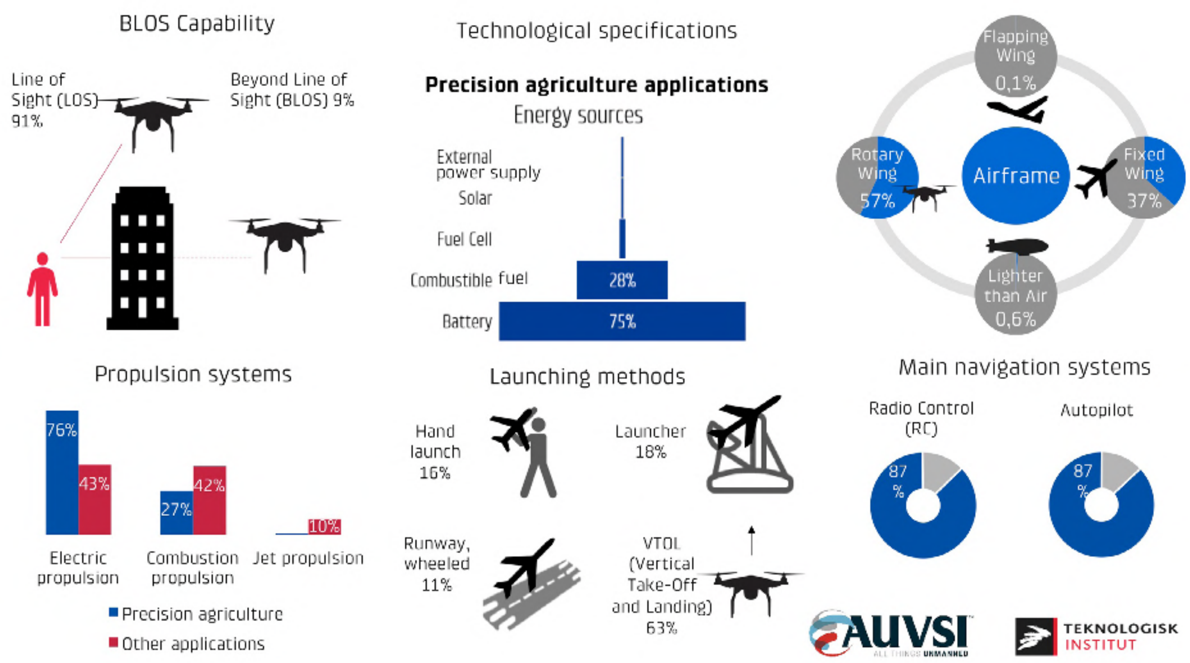
Note: Based on 1070 UAS in the AUVSI dataset. Calculations and infographics by Danish Technological Institute.

Technological specifications

From Figure 5.2 it is clear that electrically powered vehicles make up the majority of UAS intended for precision agriculture, and in fact correlates with the short duration time mentioned in section 5.1. These platforms are primarily rotary wing vehicles offering VTOL capabilities for simple launch/recovery from fields. Rotary wing vehicles also offer the ability to fly at low speeds or even hover.

Ability to fly beyond line of sight is not widespread even though this would probably be of high value to a farmer. However, the limited market penetration of BLOS might be due to current legal restrictions.

FIGURE 5.2 TECHNOLOGICAL SPECIFICATIONS FOR PRECISION AGRICULTURE UAS



Note: Based on 1070 UAS in the AUVSI dataset. Calculations and infographics by Danish Technological Institute.

Search & rescue

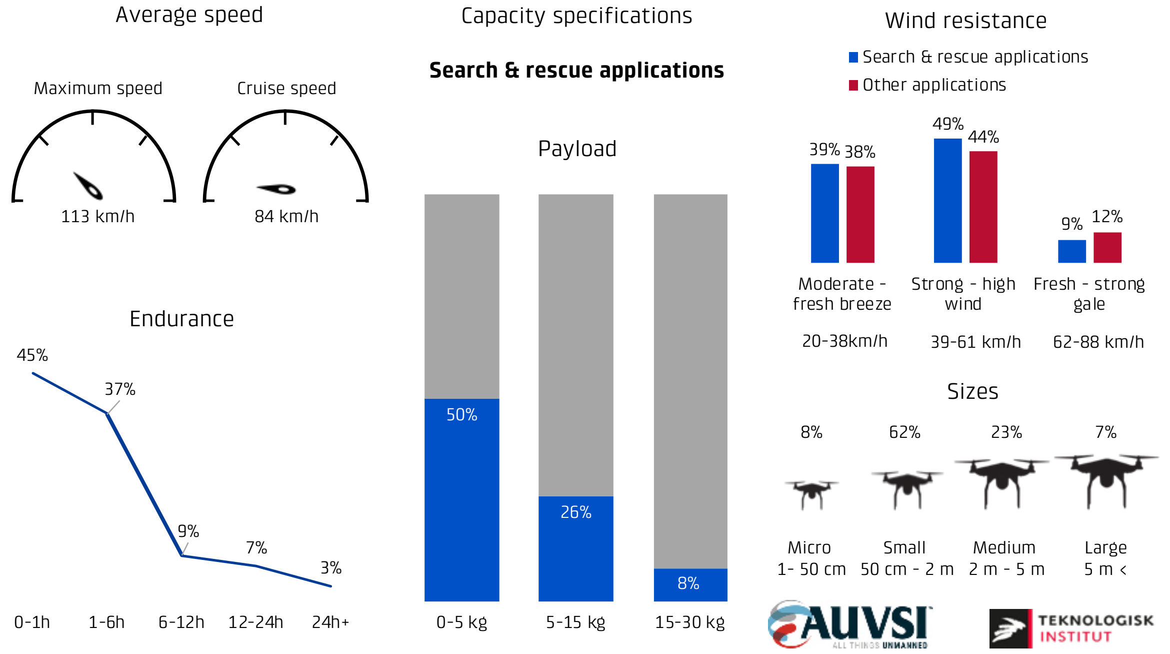
1,347 UAS platforms in the dataset have been developed to conduct search and rescue operations. These platforms integrate electro optical and/or infrared sensors to locate, for example, lost hikers and survivors of a natural disaster. It can be dangerous for first responders to try and reach other humans following a disaster, and therefore UAS can be a very useful tool in this matter.

Capacity specifications

Platforms developed for search and rescue purposes are generally larger than those used for precision agriculture. When comparing the specifications from Figure 6.1 and Figure 7.1, we see that this in turn brings an increase in average endurance, speed and payload capacity for search & rescue UAS. The extended endurance and increased speed allow these UAS to fly further and faster in their search for survivors. The larger payload capacity also allows for integration of more advanced sensors to improve the success of operations or deliver medical supplies to survivors.

Search & rescue UAS generally offer a good wind resistance with approx. 50 percent being able to fly in strong to high winds.

FIGURE 6.1: CAPACITY SPECIFICATIONS FOR SEARCH & RESCUE UAS

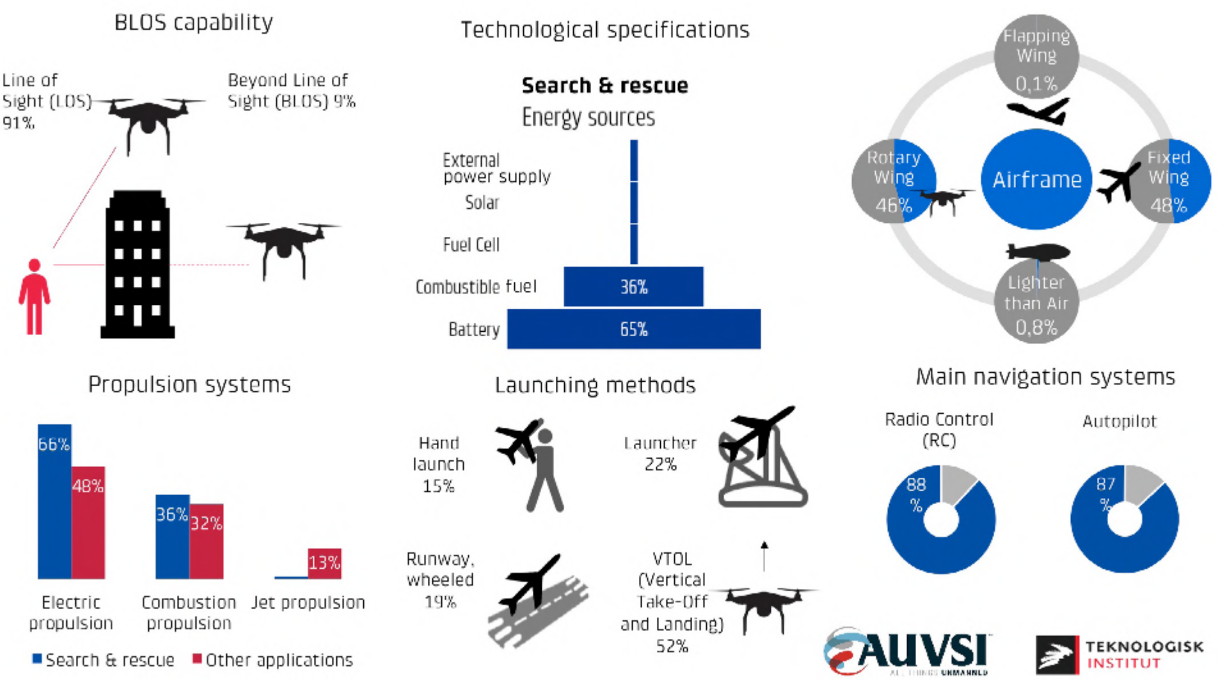


Note: Based on 1070 UAS in the AUVSI dataset. Calculations and infographics by Danish Technological Institute.

Technological specifications

Surprisingly, these platforms do not have a high percentage of BLOS capabilities. This might be due to a difference in how search and rescue is defined by the manufacturers. Some platforms could be defined as search and rescue applicable platforms from their ability to hover over a fire for instance and survey it. Meanwhile other UAS platforms have BLOS capabilities and are used for monitoring greater disasters and looking for survivors.
Like the precision agriculture UAS, most of the search & rescue UAS are battery powered. However, a relative increase in the use of combustible fuels could explain the observed increase in endurance as well.

FIGURE 6.2 TECHNOLOGICAL SPECIFICATIONS FOR SEARCH & RESCUE UAS



Note: Based on 1347 UAS in the AUVSI dataset. Calculations and infographics by Danish Technological Institute.

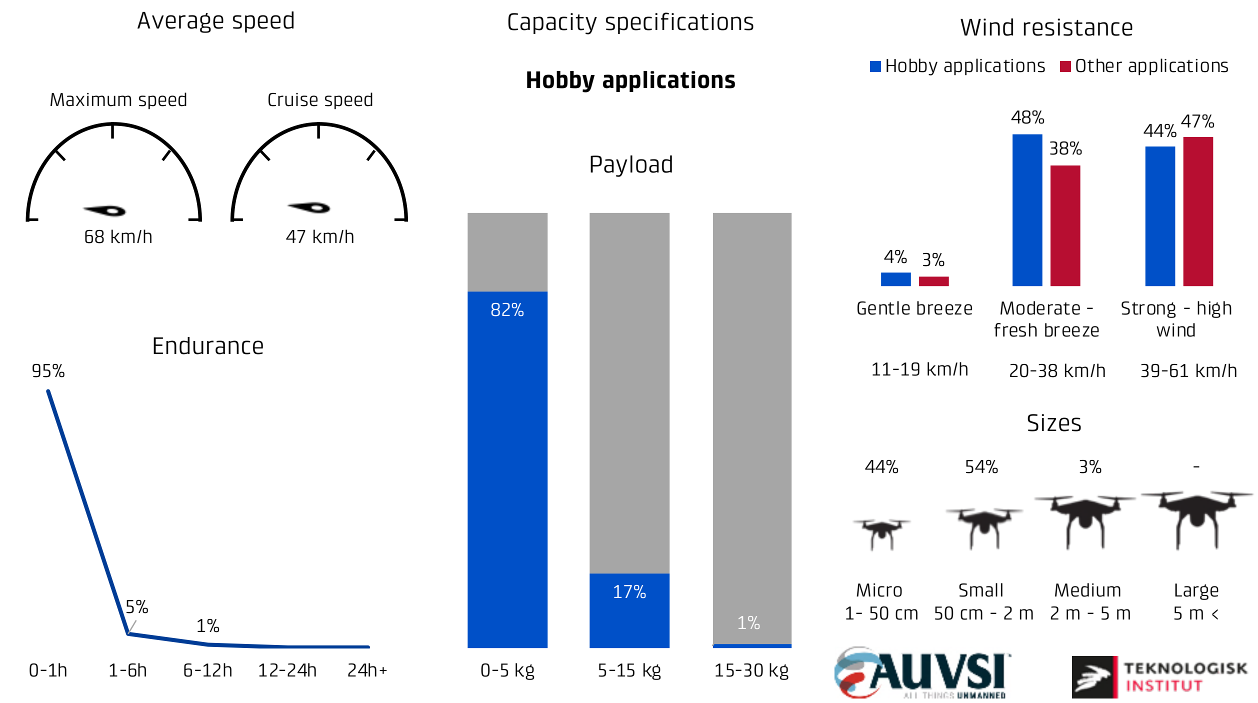
Hobby

Though it is not within the scope of AUVSI's database to capture toys, the dataset does include some UAS that are used by the consumer market for hobby applications. Generally, these consumer UAS have been included in the database as they are also capable of basic commercial applications such as aerial imagery for advertising or real estate. While the dataset of hobby UAS is limited to less than 200 platforms, some of these vehicles account for the highest production volume due to their low cost. We anticipate that the adoption of this technology by consumers will continue to grow as the cost decreases with the increased production volumes. Some examples of hobby uses for these vehicles include filming when travelling or practicing extreme sports. Instead of filming by hand, the UAS can track its target using a transmitter – located in a watch for instance – and can film activities dynamically even though the user is moving.

Capacity specifications

Hobby UAS are by far the least powerful category of vehicles in the dataset. On average, they are the slowest, with shorter flight times and smaller loads than vehicles used for other applications. They primarily fall into the small or micro-category with no vehicles in the large size range. Moreover, they are generally more sensitive to wind. These specifications reflect the cheaper production costs of these types of platforms relative to the other UAS categories.

FIGURE 7.1: CAPACITY SPECIFICATIONS FOR HOBBY UAS



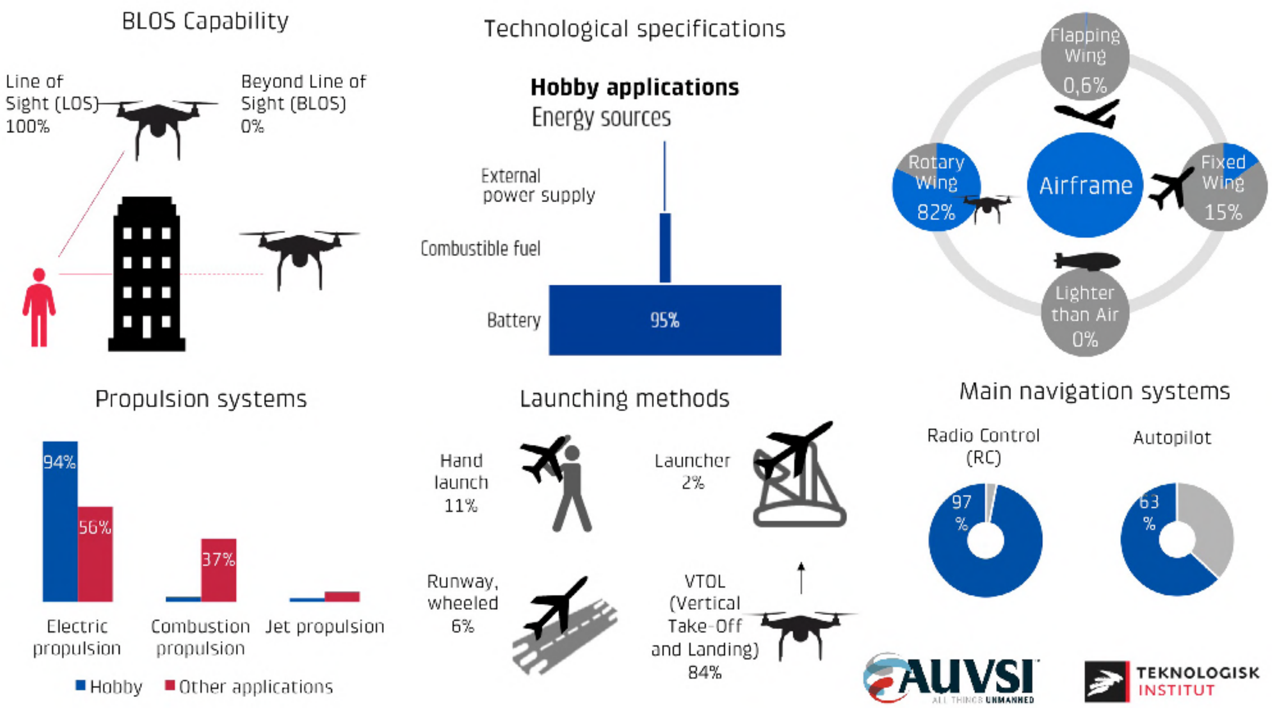
Note: Based on 177 UAS in the AUVSI dataset. Calculations and infographics by Danish Technological Institute.

Technological specifications

Nearly all the hobby platforms are battery powered. They cannot fly safely out of the sight of the pilot, and their primary launching method is VTOL. They are generally operated via radio control from a hand control unit or tablet-/phone-based application.

UAS for hobby applications tend to be more simple platforms compared to their commercial and military counterparts. However, they have opened a whole new realm of air photography and it is expected that the features and capabilities of this technology will continue to advance at an exponential rate.

FIGURE 7.2: TECHNOLOGICAL SPECIFICATIONS FOR HOBBY UAS



Note: Based on 177 UAS in the AUVSI dataset. Calculations and infographics by Danish Technological Institute.

Danish Technological Institute

Danish Technological Institute (DTI is a self-owned not-for-profit institute with six divisions and 35 specialist centers. DTI has more than 1,000 employees in Denmark, Sweden, Norway, Poland, and Spain. As part of DTI, we always have access to the best experts in technology, business and competence development and innovation. This enables us to set a team that can solve our clients' technological problems

DTI develops, applies, and disseminates research- and technology-based knowledge to Danish trade and industry and the public sector and participates in development projects, which are of use to society in close collaboration with leading research and educational institutions both in Denmark and abroad. Thus, DTI is one of the leading and strongest technology and social science consultancy environments in Denmark. DTI was founded in 1906.

DTI is approved by the Danish Ministry of Higher Education and Science as an Advanced Technology Group Institute (GTS). Thus, DTI is one of the seven GTS Institutes in Denmark. As a GTS institute, DTI navigates independently of political and financial interests and any profits are invested back into new research and development and innovation.

DTI has a broad international client base in all industry sectors and public institutions and ministries, and we participate in global research and consultancy networks. This way we are always at the cutting edge of technological and societal changes to the benefit of our clients and partners.

During the past three years, Danish Technological Institute has developed new advancements for UAS technologies to solve some of the challenges that might hinder the spreading of UAS technology more generally. For example:

- DTI researches and develops fuel cell technologies powered by propane that has the potential to allow UAS to fly for more than 24 hours. The research includes research in new materials, energy technology and vision and sensor technologies.
  For more information contact Head of Section, Ph.D., Jan H. Hales, jhhs@teknologisk.dk

- Developing technology to improve the usefulness of UAS for building inspections. DTI has worked with specialists at Centre for Concrete to combine the UAS technology that gathers data with machine learning so that the processing of data does not necessarily have to be done manually.
  For more information contact Consultant Morten H. Petersen, mhop@teknologisk.dk

- Also, the potentials for use of UAS in agriculture are expanding fast. Farmers would benefit highly from having their fields and crops surveyed automatically. With the right software, UAS can easily lift this task and autonomously fly to the assigned fields, whenever weather conditions allow, and gather information about crop sickness or pests. For this project UAS and agricultural specialists from Danish Technological Institute have worked together to

DANISH TECHNOLOGICAL INSTITUTE

develop technology for this purpose.
For more information contact Senior Specialist Thomas Nitschke, tnit@teknologisk.dk

- Much of the value UAS can provide for civil purposes depends on whether they can operate autonomously. DTI has developed software, which will allow the UAS to do this.
For more information, contact: Consultant and leader of UAS Denmark Mathias Flindt, mfl@teknologisk.dk. Mathias Flindt is also chairman of the Drone Denmark Association (https://www.dronedanmark.eu/).

AUVSI

The Association for Unmanned Vehicle Systems International (AUVSI), the world's largest nonprofit organization dedicated to the advancement of unmanned systems and robotics, represents corporations and professionals from more than 60 countries involved in industry, government and academia. AUVSI members work in the defense, civil and commercial markets.

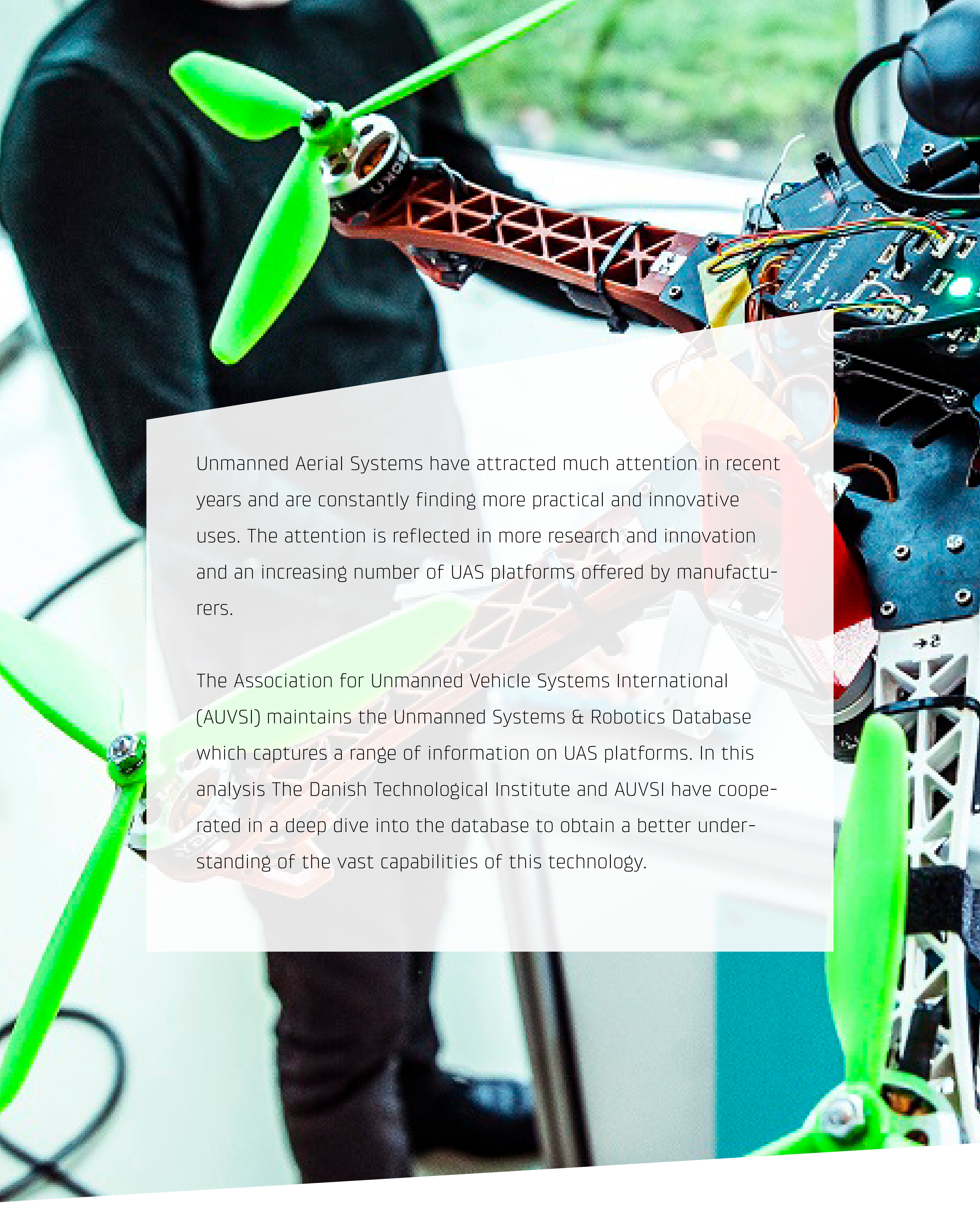
Become an AUVSI member and gain access to the world's largest unmanned systems community. From exclusive networking events to exciting business development opportunities, our experts can help you navigate the ever-evolving world of unmanned systems. AUVSI membership is open to all types of unmanned systems and robotics companies and professionals serving the industry. If you want to have access to the innovative resources that will help you gain the competitive edge in this fast-paced and continually evolving industry, then AUVSI membership is a must. Our members take advantage of numerous opportunities to get connected, get informed and get involved all year long.

AUVSI's Unmanned Systems and Robotics Database is the largest comprehensive and searchable database of all unmanned vehicles operating in the air, ground and maritime domains. This database offers up-to-date, detailed information on unmanned vehicles spanning the civil, commercial and military markets.
Since 2010, the AUVSI research team has been collecting information on every robotic platform we could find. This has culminated in a huge database of platforms from around the world. To achieve this, information has been captured from:
More than 100 conferences attended worldwide;
Over 10 man-years' worth of web searches from several search engines and more than 10 languages.

All information collected is from open sources. Each platform and company is evaluated by researchers for specific traits:

- Platform Applications – applications where the product may be used (imaging, search and rescue, etc.);
- Platform Markets (Commercial, Civil, Military, etc.) – markets for which the platform is either being promoted by the company or being applied by a user;
- Platform Status – flagged active if the platform is either currently being marketed by the company or has been noted in use by public sources in the last 12 months;
- Company Status – flagged active if the company is actively in operation.
- Detailed information is available for each platform based on publicly available specifications released by the manufacturer:
- Platform Size – the full range of parameters (length, width, height, diameter, wing span, weight, payload, etc.);
- Platform Performance – the full range of parameters (endurance, max/cruise speeds, range, etc.);
- Subsystem Descriptions – all detailed descriptions of integrated subsystems (navigation, communication, payloads, etc.) are captured and provided for each platform.

For more information on the database or to receive a demo please contact David Klein, Research Analyst, dklein@auvsi.org.



Unmanned Aerial Systems have attracted much attention in recent years and are constantly finding more practical and innovative uses. The attention is reflected in more research and innovation and an increasing number of UAS platforms offered by manufacturers.

The Association for Unmanned Vehicle Systems International (AUVSI) maintains the Unmanned Systems & Robotics Database which captures a range of information on UAS platforms. In this analysis The Danish Technological Institute and AUVSI have cooperated in a deep dive into the database to obtain a better understanding of the vast capabilities of this technology.