

Marianne Harbo Frederiksen & Mette Præst Knudsen

Drones for offshore and maritime missions: Opportunities and barriers

April 2018

Colophon

The FreeD offshore memo is the first of its kind springing from the research project Free the Drones funded by Innovation Fund Denmark. It provides an analysis and identification of barriers to commercialization of drone-based solutions in Denmark. In this way, the memo is aiming to identify barriers to unleashing some of the market opportunities for using drones for commercially-oriented missions. The project partners thank the participating companies and interviewees for their contributions. Nevertheless, all mistakes or misunderstandings are the sole responsibility of the authors. The authors thank Innovation Fund Denmark for the financial support for the research.



Authors

Marianne Harbo Frederiksen, Associate Professor at SDU Innovation and Design Engineering, Department of Technology and Innovation, University of Southern Denmark.

Contact: mha@iti.sdu.dk or website: <http://findresearcher.sdu.dk:8080/portal/da/person/mhf>

The research of Marianne Harbo Frederiksen revolves around innovation strategy and innovation process management, ranging from managing the fuzzy front end of new product development towards successful commercialization based on the actual adoption by users and customers of new offerings. Currently, she focuses attention mainly on opportunities and barriers to implementing drone technology for civil and commercial purposes. In doing so, the entire Danish drone innovation ecosystem is subjected to scrutiny. The research projects therefore include sparring with, among others, technology providers, potential customers, and representatives of the drone industry.

Mette Præst Knudsen, Professor and Head of Research at the Center for Integrative Innovation Management, Department of Marketing & Management, University of Southern Denmark.

Mette is work package leader in the project "Free the Drones".

Contact: mpk@sam.sdu.dk or website: <http://findresearcher.sdu.dk:8080/portal/da/person/mpk>

The research of Mette Præst Knudsen seeks to integrate market, management and technological perspectives on innovation processes. These perspectives are particularly relevant in relation to the creative development of new ideas searching for full commercialization to achieve competitive advantages. The focus on commercialization has proven particularly useful in relation to the development of new technologies with unknown market potential as for instance with innovative drone technologies and green technologies. The most recent projects are concerned with analyzing the effects of the latest transformative technologies and how they influence work and innovation – like industry 4.0, technological platforms, and additive manufacturing.

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1 General introduction

This is the first memo in a new series of publications that focus on the opportunities and challenges in using unmanned aerial vehicles, also known as drones, for civil and commercial applications in Denmark. The aim of the series is to inform existing and potential new businesses, inventors, investors, and policy makers about the opportunities for drones to develop into a new growth industry for Danish firms. The series of publications are (expected to be) concerned with the following fields of application:

- No 1: Drones for offshore and maritime missions: Opportunities and barriers (this publication)

Further publications are planned to focus on:

- Infrastructure inspection (harbors; airports; pipelines, etc.)
- Search and rescue
- Surveillance.

This memo originates as a part of the research project **Free the Drones** (FreeD)¹, which is funded by the Innovation Fund Denmark² and runs from 2016-2020. The prospects for drones are amazing, but currently the regulations for drone operations are limited to flying within visual line of sight (VLOS). However, the potential only becomes a reality if beyond visual line of sight (BVLOS) operations are permitted. This requires a number of research objectives to be completed before establishing drone air worthiness and successfully assessing the safety case. A specific research objective of FreeD is to deliver commercial value propositions. This project has primarily delivered input to publication no. 1: *Drones for offshore and maritime missions: Opportunities and barriers*.

¹ For more information about the project:

https://www.sdu.dk/en/om_sdu/institutter_centre/sduuascenter/researchprojects/freed

² <https://innovationsfonden.dk/en>

2 What is a drone?

The drone is characterized as a technology platform enabling a limited payload. Different types of drones are available on the market: Fixed-wing drones (similar to known airplanes); drones with several horizontal propellers (multirotor drones that are similar to helicopters); or a hybrid which is a fixed-wing drone that is capable of vertical take-off and landing. The payloads enabled include, e.g., electro-optical, infra-red, and multi/hyperspectral cameras; Radio/Light Detection and Ranging (RADAR/LiDAR); and particle/gas sensors to name a few. Drones are controlled remotely by an operator, but the longer-term perspective is autonomous flight. However, seen from a Danish perspective, this requires substantial development related to failsafe software, communications and control equipment, and sense and avoid technology. These are technology development tasks related to the FreeD project.



A drone equipped with a camera.

3 Why focus on drone applications?

Drones are fundamentally based on a well-established and mature technology that has earlier been associated with the military, but more recently drones have enjoyed popular usage in the toy market. There is a growing trend to adapt drones to applications relating to civil and commercial use and attempting to fully realize their market value. When assessing potential missions, the drone application typically replaces an existing solution that involves humans (e.g., helicopter inspection of powerlines or rope-based inspection of wind turbines). The drone is anticipated to do jobs considered dirty, dull, or dangerous – at a lower cost and with less risk. Since drones are capable of quickly reaching remote and difficult to access areas and then transmit, e.g., still photographs, thermal imaging, or video footage, they help provide the data for creating an overview of a given situation. Thus, drones serve as an extension of the operator assisting in the effective accomplishment of unique and varied missions. Time, personnel, and money are saved.

Drones with mission specific cameras and payloads are already used for, e.g., inspecting wear and tear of powerlines³, searching for missing persons⁴, and getting an overview of a fire⁵. However, depending on the type of task, the drone is more than an “eye in the sky” or a “tattletale”. It is also an “errand boy” or an “enabler”, or even an “executer”, i.e., drones deliver goods, such as lab samples from medical clinics to hospitals⁶, or perform actual work, such as igniting an oil spill in the ocean⁷. Either way, each of these tasks require a specific combination of technologies and drone. This makes the full realization of the commercial market potential complex, as the many opportunities not only call for the development of the required drone platforms in various shapes and sizes; there is also a need for developing the payload, communication links, software programs, data analysis, training, and procedures to accomplish specific missions.

³ https://www.energy-supply.dk/article/view/309822/danske_firmaer_far_gront_lys_til_selvstyrende_drone# (in Danish)

⁴ <http://www.beredskabsstyrelsen.dk/viden/publikationer/Documents/trefoldet-drone-folder8.pdf> (in Danish)

⁵ <https://www.tvsyd.dk/artikel/brandvaesen-brugte-drone-faa-overblik-over-brand> (in Danish)

⁶ <https://www.theverge.com/2017/9/20/16325084/matternet-autonomous-drone-network-switzerland>

⁷ <https://blue-ocean-robotics.com/frontpage/bundles/offshore/oil-spill-handling/>

4 Over the open ocean or near harbors

This memo focuses on the potential use of drones for tasks in offshore and maritime contexts, either over the open ocean or near harbors. The memo is primarily based on a qualitative study involving a range of core actors within what can be regarded as the Danish drone innovation ecosystem.

A number of reports⁸ shed light on the overall use of and the demand for drones in offshore and maritime contexts. However, an important finding from the present study is that the majority of the identified fields of application are regarded, at best, as emerging markets for which the relevant actors find it difficult to estimate the potential need. Drones enable streamlining of existing processes, e.g., through automation hereof. Nonetheless, a common feature in relation to many of the anticipated applications is that the technology is under development and therefore the usefulness and pricing are yet unknown. This naturally makes it difficult to predict sales and profits, but also opportunities for job creation. The purpose of this memo is therefore not to offer estimations of market size for the different applications. Instead, the memo supplements existing reports by offering deeper insights into the opportunities and barriers for implementing drones for offshore and maritime missions.

The findings of the present study show drones already are or, are anticipated, to be useful for multiple purposes in those particular contexts. Nevertheless, several barriers are identified that, to some extent, prevent the offshore and maritime industries to fully benefit from drone-based technology. The biggest barriers to overcome are related to drone providers:

- **Context:** The harsh offshore environment places strong demands on the quality of the technology and the ability of the drone pilots. The drones and their payload must be designed to withstand harsh wind conditions, turbulence, and the influence of salty seawater. And the pilots must know how to navigate in such an environment, both weather-wise and regarding safety issues.
- **Market:** Both Business-to-Government (B2G) and Business-to-Business (B2B), the technology providers face substantial market entry barriers. Typically, at least in Denmark, there is a considerable power differential between small providers and large potential customers. Since the market is not yet developed, one way to market access is via large established customers in other industries. It is often challenging for the providers to gain the necessary access to such channels that will enable them to fully develop and prove the usefulness of their technology to specific market demands.
- **Financial:** The small drone technology providers experience that money often falls short. This delays technology development. A way to overcome this barrier is for customer firms to invest in small provider

⁸ E.g.: European Drones Outlook Study. Unlocking the value for Europe, SESAR, November 2016; Efterspørgsel og potentialer for brugen af droneteknologier i offshore-sektoren. Analyse udarbejdet for Region Syddanmark, Oxford Research, December 2017 (in Danish)

firms and thus help speed up the technology development while ensuring that the technology development is aligned with the needs of the customer⁹.

- **Legislative:** Denmark and the European Union regulations continue to develop in support of drone operations in the maritime domain, but barriers to BVLOS and autonomous flight currently prevent the full introduction of drones to the industry. A risk-based model accounting for ground and air hazards is in development for drones below 150 kg. The harmonization of the legislations across the European Union will open the market for maritime drone operations. Signed legislation is expected as early as December 2018. The legislation progress is closely linked to technological challenges still needing to be addressed to include unmanned airspace structure, drone safety and reliability equipment, and sense and avoid measures¹⁰.
- **Technological:** Battery lifetime, communications, fail-safe systems, reliability, sense-and-avoid technologies, low energy computing, on-board and off-board data processing and analysis are in development. Advancements in the drone system range, command and control, safety, automation, navigation, and airspace integration will bring the industry significantly closer to providing lower cost, flexible, more routine, and safer solutions to current manned helicopter and fixed-wing operations. Many of these technological solutions have been developed or are in development. The industry is now exploring how to combine the technology, drones, and existing airspace infrastructure via a series of demonstrations. It is anticipated within the next 2-5 years that many of the technological barriers will be solved with the focus on technologies aimed at integrating drones in more complex (and higher risk) urban areas such as cities.

Despite these challenges, the application fields in offshore and maritime contexts for drone-based technology are numerous. And the implementation of drone technology will continue.

⁹ As an example, Siemens has invested in SkySpecs: <https://www.prnewswire.com/news-releases/skyspecs-collaborates-with-siemens-wind-power-for-use-of-automated-drone-technology-in-offshore-turbine-inspections-300414202.html>

¹⁰ European Aviation Safety Agency Opinion, No. 01/2018, December 2017

5 Examples of drone missions at sea

The usefulness of drones for, e.g., public authorities' offshore missions is apparent; it could be for border security tasks, such as detection of illegal border crossings¹¹, or for the protection of endangered species such as turtles¹². The commercial actors, who participated in our study emphasize, however, that taking advantage of the numerous opportunities related to drones more or less is impeded by the above-mentioned barriers. Nonetheless, the interviewees point to a number of applications that are already or could be implemented in offshore and maritime contexts. These opportunities for drone technology implementation fall into four main categories:

Inspection: The drone as an eye in the sky

- *Inspecting tanks and other confined spaces on ships*¹³; for instance, when changing from dirty to clean cargo (e.g., from bunker oil to vegetable oil), there is a need for inspecting the tank. Maersk Tankers has experimented with using drones for this task. The tests were quite successful and showed potential for removing a somewhat uncomfortable task that is normally carried out by an inspector. However, the drone that was found to be able to do the job is not ATEX-approved (in accordance with the explosive atmospheres directive). This limits the window of opportunity for tank inspections, as it can only be done the few days a year when the tank is completely clean. Moreover, a flue gas is used when changing cargo. The gas creates a fog inside the tank. Thus, the tank environment places certain demands on the drone and its payload.
- *Inspecting wear and tear*, such as corrosion or other deteriorations on oil rigs and bridges¹⁴ or delamination and cracks on wind turbine blades¹⁵. Such missions today require scaffolding or rope inspectors, but are also carried out by means of drones. In fact, this is by far the most talked about application for drones among the interviewees. The expected next step is that the drone can measure, e.g., the degree of corrosion. Thus, it is expected to become more than an eye in the sky taking pictures.

Surveillance and detection (of incidents): The drone as an eye in the sky and a "tattletale"

- *Coastal/offshore monitoring*, e.g., to create maritime situational awareness (relating to search and rescue missions) or to prevent illegal immigration. The latter could be at port, where a drone equipped with a thermographic camera is used for detecting whether anyone is hiding inside or under the trucks that are parked there, before they board the ship. If a shipping company detects a refugee on its ship, it can cost up to a seven-digit number to handle the situation, including ensuring that the refugee returns to the place of origin. Drones can help to lower these costs.

¹¹ <https://www.information.dk/udland/2013/03/eus-graenseagentur-promoverer-brug-droner> (in Danish)

¹² <http://nordeainvestmagasinet.dk/artikler/droner-redder-truede-skildpadder> (in Danish)

¹³ <https://www.akzonobel.com/for-media/media-releases-and-features/akzonobel-and-partners-developing-drone-technology-make-marine>

¹⁴ <https://blue-ocean-robotics.com/blue-ocean-robotics-identify-robotic-potentials-on-the-great-belt-bridge/>

¹⁵ <http://www.creativesight.eu/inspektion/>

- Drones may also be used to *monitor harbor areas*, e.g., if people fall into the water.
- *Detection of incidents over the open ocean* such as illegal fishing¹⁶, poisonous gas leaks from oil rigs, or sulfur emission from ships' plume of smoke¹⁷. Compared to the use of helicopters for such detective work, drones can make these missions more cost and time effective.

Communication: The drone as an “enabler”

- *Testing and calibrating ships' antennas*. Today, such calibrations entail many working hours and timewise inconvenience for those on-board as well as those owning a vessel. By having a drone act as an artificial satellite, the job is performed faster and perhaps more accurately¹⁸.

Delivery: The drone as an “errand boy”

- *Delivering goods from harbor to ship* and vice versa. Maersk has successfully tested the delivery of a cookie tin from port to a vessel¹⁹. However, finding a drone that complies with ATEX-legislation (the explosive atmospheres directive) has been a challenge. Moreover, even though last mile delivery is a substantial part of transportation costs, a solid business case for using drones has yet to be established.
- *Delivering vital equipment at sea*. Drones are already used for assisting maritime search and rescue missions²⁰ – or even detecting if anyone is in distress. It can be used for delivering a life jacket or a life raft and thereby help save lives. Drones can also be used for delivering spare parts for, e.g., wind turbines or the equipment for igniting oil spill from ships²¹. In general, the expectation is that drones are useful for offshore delivery of high-value cargo.

In general, the missions mentioned by the interviewees require a drone pilot today. The technology and service providers generally seek to develop semi- or fully autonomous solutions for the jobs-to-be-done. However, the successful implementation of some drone applications depends on the possibility for flying BVLOS.

In the following, three case descriptions highlight opportunities and point to the general expediency of using drones for the jobs to be done in offshore and maritime contexts. However, the cases also provide a more detailed picture of the barriers to doing so.

¹⁶ <http://fst.dk/nyheder-og-presse/nyheder/nyhed/nyhed/naturerhvervstyrelsen-tester-flyvende-kontrol/>

¹⁷ <http://explicit.dk>

¹⁸ http://quadsat.com/?page_id=17

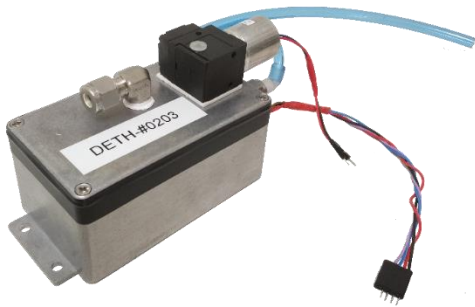
¹⁹ <http://www.maersk.com/en/hardware/2016/03/flown-out-by-drone;>
<http://www.unmannedsystemstechnology.com/2016/03/maersk-tankers-successfully-completes-drone-delivery-to-vessel-at-sea/>

²⁰ <https://www.youtube.com/watch?v=Knnff9WZAmY>

²¹ <https://blue-ocean-robotics.com/frontpage/bundles/offshore/oil-spill-handling/>

5.1 Sulfur emissions compliance: Monitoring exhaust plumes from ships

Drones are expected to replace helicopters on a number of missions – also offshore. However, as described below, the Danish firm Explicit knows using drones poses certain challenges.



Explicit's mini sniffer system.

Explicit has developed a miniaturized gas analyzer – a mini sniffer system – that reliably measures whether the sulfur content in a ship's exhaust plume complies with international environmental legislations restricting air pollution from ships. The sulfur emission legislation has led the European Maritime Safety Agency (EMSA)

to include ship source emissions surveillance (SO_x detection) into their mission statement²².

Legislation prescribes that ships must sail on low-sulfur fuel when operating in designated Emission Control Areas (ECAs), such as the one covering all main waters in Northern Europe. However, the shipping industry presumably is not automatically interested in doing so, since low-sulfur fuel is almost twice as expensive as high-sulfur fuel leading to an incentive for non-compliance.

Fact box

To combat the effects of air pollution caused by shipping, the International Maritime Organization has set certain standards and requirements (as described in MARPOL Annex VI) for measuring, evaluating, and documenting the emission of sulfur from ships. The overall goal is to reduce the environmental and health impacts stemming from air pollution caused by shipping by restricting the amount of sulfur allowed in the bunker fuel being burned. The rules apply to the so-called Emission Control Areas (ECAs) which currently include most waters in Northern Europe and North America. These areas are characterized by a huge amount of ship traffic (close to densely populated areas) and, thus, account for over 30% of air pollution. Therefore, within these zones vessels are only allowed to burn fuel with a sulfur content of maximum 0.10%. Explicit's Mini Sniffer System for measuring sulfur emission from ships has so far been used to monitor more than 800 ships in European waters. The firm is currently responsible for conducting airborne sulfur monitoring in Danish waters on behalf of the Danish Environmental Protection Agency and has previously done similar airborne campaigns in collaboration with the Dutch authorities.

²² <http://www.emsa.europa.eu/>

In response, the relevant national authorities (e.g., environmental protection agencies and maritime authorities) have recently begun deploying remote monitoring technologies to survey exhaust plumes from ships passing through the environmental zones. This enforcement strategy is designed to have a preventive effect as well as document cases of non-compliance warranting an authority response. The strategy is also intended to support fuel sampling efforts in port by applying smart targeting using air sampling to qualify port inspections.

The current solutions for remote monitoring of sulfur emissions include fixed measuring stations analyzing drifting plumes from ships passing the monitoring point (such as the one installed on the Great Belt Bridge in Denmark and at entry ways to key European ports) or airborne surveillance using gas analyzer equipment like the solution developed by Explicit mounted on either a manned helicopter, plane or drone. The advantage of airborne surveillance over fixed stations is the ability to navigate the aircraft close to each exhaust plume and obtain a better quality air sample. Additionally, airborne surveillance covers larger geographical areas and allows for surprise inspections to better enforce compliance. In the following, we focus on the comparison of mounting a gas analyzer on a helicopter vis-à-vis a drone.



Explicit's mini sniffer system mounted on a drone.

Today, Explicit attaches its mini sniffer system to a carrying arm mounted on a manned helicopter. When inspecting a ship, the helicopter including the mini sniffers is navigated into position within the exhaust plume of a moving vessel to sample the gasses. The full measurement process (approach, sample, and departure) takes approximately 90 seconds per vessel. The use of a manned helicopter makes this an expensive mission. However, since Explicit's mini sniffer system weighs less than 500 g per sniffer unit, the equipment could be

mounted on a drone instead. Thus, the mission is accomplished by means of a light-weight “sniffer drone”, which could lower the costs per mission. Nonetheless, some challenges are observed:

- **BVLOS flight.** The ships are sailing in dedicated “shipping lanes” far off the coastline. Therefore, the drone is unable to easily reach the ships for analyzing the plume. Accordingly, a full implementation of sulfur emission monitoring requires that the drone must fly autonomously or at least be remotely controlled from the mainland. The current legislation concerning flights that are beyond visual line of sight (BVLOS) does not allow for such missions and accordingly poses a challenge. In most countries, there is a requirement for the pilot to maintain unaided visual line of sight of the drone while in operation. With this current legislation, the pilot would be required to operate the drone from a chase ship to get close enough to analyze the exhaust plume and still comply with the drone operating laws. Hence, to fully implement the drone solution the firm must await a relaxation of the European BVLOS legislation.



A drone positioned behind a ship's exhaust plume.

Explicit would like to start flying drones in Danish territory. Normally, this should not pose a problem as long as the drone stays under 150 meters above sea level. To measure the sulfur emission behind ships, the drone would only have to fly between 25-50 meters above sea level. However, e.g., the Great Belt is a low-flying zone available to the Danish Defence, and it is occasionally used for reconnaissance missions where fighter planes fly low to, e.g., take pictures with the purpose of spotting what is onboard ships. The Defence does not have to inform anyone before flying. This makes it difficult to plan drone missions over

the open ocean in that area, and the Danish Transport, Construction and Housing Authority would have to make an agreement with the Defence Command.

- **Speed and maneuverability.** Sniffer drones must be able to combine the ability to maneuver and at the same time cover the distance between vessels efficiently. Thus, the drone must be able to fly slowly, 5-10 meters second, and stay behind the ship's exhaust plume for 30-45 seconds while collecting the sulfur emission data. At the same time, the drone must be able to speed up between vessel targets to produce an efficient output. The need for different velocities and good maneuverability may be met by using a powerful multi rotor drone or by using a hybrid drone platform, i.e., a fixed-wing drone capable of vertical take-off and landing. Such drones are currently being developed.
- **Flight range and altitudes.** Sniffer drones must be able to reasonably reach/cover the main shipping lanes and maritime traffic hotspots. In Northern Europe this means from 5-100 km off the coast. A main challenge for achieving this range is radio communications for control/command over long distances. In addition, the low flight altitude combined with the BVLOS distance required for this type of mission poses a challenge on how to maintain robust radio links despite the Earth's curvature.
- **Operational capacity: A combination of endurance and speed.** When using a helicopter for the missions, Explicit averages seven to eight measurements per flight hour in Danish waters. In other waters with more dense shipping traffic, this easily increases to 10-14 measurements. Thus, in order for a drone to replace the helicopter, the drone must be able to stay airborne for a sufficient amount of time to cover the distance to shipping lanes. Ensuring sufficient power supply is a challenge in this respect. At the same time, the drone must be able to deliver a competitive number of measurements per flight hour in order to outperform other airborne options, such as helicopters which may be expensive but also produce a consistently high output. This requires a sufficient operational speed between plumes.
- **The technical challenge of flying BVLOS:** When flying within visual line of sight, the operator is able to see and avoid people, obstacles or aircrafts and take the necessary actions to prevent a collision with the drone. This is all accomplished at relatively small distances and low altitudes providing an additional degree of safety from collision with other drones or aircraft. BVLOS operations therefore must ensure the same operational performance but at a longer range. The main technical challenge becomes the extension of the operator's eyes, ears, and situational awareness to make the appropriate command decisions. The electronic command and control link, video telemetry, navigation, communications, and overall mission feedback must support the operator to safely conduct the flight. This is complicated by the fact that as the range increases, the altitude of the aircraft (or the operator antennae) must increase to maintain electronic line of sight. Alternatively, satellite communications may be used, but will add additional weight and equipment cost to the air vehicle. Finally, the risk of colliding with low-flying manned aviation aircraft increases because current on-board systems are unable to detect the conflict in enough time to mitigate the risk. The very low altitude environment and the small drone size prevent air surveillance radar to detect the air to air conflict and timely warn the manned pilot or unmanned operator.
- **Legislative challenges.** Given the above operational and technical difficulties, legislation is focused on mitigating fatal injuries to people on the ground, fatal injuries to manned aircraft in the air, and damage to critical infrastructure²³. In the case of sniffer drones, the concern then becomes assessing the drone operating risk relative to people in the maritime environment, ships, and low-flying manned aircraft. The low population density in the maritime environment compared to urban areas significantly reduces the likelihood of injury to a person on the ground (sea). It is possible to avoid ships visually and electronically

²³ Joint Authorities for Rulemaking of Unmanned Systems (JARUS). Guidelines on Specific Operations Risk Assessment, June 2017

provided information is timely received by the drone operator and the command and control link allows for re-routing the drone. Therefore, the major risk remains detecting and avoiding low-flying aircraft. Legislation is focusing on regulating drone equipment to identify the drone location, altitude, and course; regulating the airspace and location for drone operations, e.g., designating special use segregated airspace for drone operations; and develop safe drone transit corridors to separate manned and unmanned traffic.



Co-owner of Explicit, Jon Knudsen, taking part in an EMSA test of sulfur emission.

All these challenges considered, Explicit is reserving judgement on the precise commercial value of applying drones as airborne platforms in replacement of the manned helicopters for sulfur emissions monitoring at sea. In particular, the firm stresses further tests and studies need to be made in order to properly address the above-mentioned challenges and credibly assess when and where drones might prove useful in sulfur enforcement going forward. To this end, Explicit is collaborating with a number of partners, in particular drone operators, manufacturers, and authorities, on various efforts to explore the true potential in maritime sniffer drones. Among other things, the firm is conducting tests with smaller multi-rotor sniffer drones for near-harbor deployments in parallel to their helicopter operations and is contributing their system payload to several maritime BVLOS drone trials, such as those currently conducted by EMSA targeting sulfur enforcement.

The fact that many of the barriers that Explicit and their partners are facing strike at the core of what makes BVLOS flight challenging overall and makes the case of sulfur monitoring at sea equally relevant to a broader discussion of BVLOS, including how and where to enable it.

About Explicit

Explicit focuses on environmental data collection in settings that are difficult to access. The owners of the firm describe themselves as 'innovative integrators'. They combine off-the-shelf components such as micro gas sensors with innovative advanced software in order to deliver high-quality data that sheds new light on environmental impacts.

<http://explicit.dk/>

5.2 Smarter testing of antennas on ships

Sailing ships are highly dependent on the functioning of their satellite communication system for good and fast internet connection. However, testing and calibrating such systems often entail many working hours and timewise inconvenience.

The start-up QuadSAT plans to use drones for stress testing and calibrating satellite communication antennas on ships and other large vessels. One of the owners is used to test and calibrate ships' antennas the traditional way, which is however not efficient for establishing the functioning of a system. After a repair, a preventative maintenance, or a new installation it is often necessary to verify the functionality of the antenna. This brings up the need for performing a sea trial by sailing the ship around and, thus, assessing the real environment antenna operation. This can take up to 12 hours and, due to high costs and considerable downtime, the procedure is often skipped. This can further lead to potential system malfunctions and improper operations that are likely to cause interference on adjacent satellites and, thus, to other users.

QuadSAT works on a solution to lower both time and costs for testing ships' satellite communication systems. A drone basically acts as a satellite simulator and can be used for testing stabilized directional antennas, i.e., antennas that move freely on a platform. So, when the drone moves around, the antenna will always point towards the drone, because it gets the signal that the drone is an actual satellite. Thus, the drone acts as an orbital satellite allowing for worldwide simulation of the ship's movements – even when the ship is stationary at port.



Illustration of QuadSAT's drone solution for testing ships' satellite communication systems.

The aim is to have a 100% first time fix rate, and QuadSAT has estimated the flight time to be around 15 minutes per mission. Battery lifetime is therefore not a barrier to the implementation of a drone solution, since a multirotor type of drone can easily do the job. However, there are still some obstacles to overcome before QuadSAT can implement their drone solution:

- **Autonomous flight.** QuadSAT aims at programming the flight path in order to have the drone flying autonomously. This will make it easier for one person to perform the tests and calibration, since this person will not have to both control the drone and keep an eye on the performance of the satellite communication system. However, QuadSAT still needs to do the flight path programming.
- **BVLOS flight and high altitudes.** It is sometimes useful, when testing antennas, to have the system located farther away. Thus, there could be a need for having the drone flying BVLOS distances. Moreover, to test an antenna, it must have a minimum elevation (the recommendation is 30 degrees), which could imply a need for having the drone flying at higher altitudes than what is legally allowed. Therefore, the legal limitations with regard to BVLOS and altitudes might impede the testing of antennas in some cases.
- **Flying over people's heads.** Whether at port or at sea, the drone will be flying over people's heads. QuadSAT would need permission to do so – from those onboard the ship and perhaps also from the port authority. Luckily, the best way to perform the tests is to fly close to the antenna. Proximity generates good speed on the antenna's movements, which means that it is possible to check the maximum capacity of the antenna's tracking capabilities, etc. Nonetheless, it always poses a risk to fly a drone close to people. And

since ships sail and call at ports all over the world, applying for flight permissions may become a never-ending job. Therefore, QuadSAT would benefit from a harmonization of legislations.

- **The technical challenge of flying over people's heads.** To decrease the risk of flying over people's heads, the drone must have redundant systems to prevent single points of failure. This is often accomplished by using drones with multiple GPS sensors, redundant communication links, additional rotors above and beyond the lift required, and software logic to safely land the aircraft in various failure modes. There are commercially available drones on the market today that meet the Danish regulatory requirement for operation in a populated area.

About QuadSAT

QuadSAT is a Danish firm owned by a Norwegian and a Moldavian. The firm focuses on drones to fulfill its aim to radically change the satellite communication industry within the maritime, aerospace and military sectors.

<http://quadsat.com/>

5.3 Inspection of offshore wind turbines

Inspection of wind turbine blades is one of the most-talked about application fields for drones offshore. Several firms seek to become technology and service providers for this task, but there are still substantial barriers to realizing the full potential.

Harsh weather wears out the offshore wind turbine blades, as the coating of the blades only has a limited ability to withstand the extreme conditions. In particular, the blade leading edge and tip have a tendency to delaminate and crack. Therefore, the wind turbine manufacturers (such as Siemens Gamesa Renewable Energy and MHI Vestas Offshore Wind) and owners (such as Ørsted Wind Power and Vattenfall) occasionally need to inspect the current state of the blades. In that connection, it is all about costs and closely related to the number of man-hours it takes to do anything, any process – and inspection costs in an offshore context easily accelerate.

Typically, inspections are made by a tripod zoom lens camera, e.g., placed on the transition piece of the offshore wind turbine, or they are made by rope inspectors. The former procedure requires that someone accesses the transition piece from a boat and then positions the camera. However, it does not necessarily result in a satisfactory data material for assessing the state of the blades. The advantage of rope access inspection is that the technician hanging there is very close to the blades and can both visually and physically inspect their current state and do repair work if needed. However, this is basically a both risky and time-consuming job.



A drone on a wind turbine blade inspection mission.

Both providers (e.g., Creative Sight and Drone Solutions Denmark) and the customer side believe there is an immediate business case in applying drone technology for blade inspection. The use of drones enables better picture quality and lowers the downtime of the wind turbines. Moreover, less man hours are needed to do the inspections. However, it is particularly a more intelligent use of data including picture recognition and damage categorization that allows better design and financial decisions that the customers are looking for.

The customers find it difficult to make accurate forecasts on the number of inspections needed, since this depends on blade warranty issues but also on the value that can be created by having the data which has not been fully demonstrated yet. Drones are already used for piloted inspections of the blades. The general ambition is to have a fully autonomous solution, i.e., to be able to do regular inspections without a pilot being present. It could be by having a drone hangar as part of the wind turbine farm where the drones can be recharged between flights. Either way, in a Danish context at least, there are considerable obstacles to the implementation of drone technology for wind turbine blade inspection:

- **Extensive market entry barriers.** The industry is characterized by a number of very small technology and service providers addressing very large customers. Thus, there is potentially a power differential between the industry actors. At a recent meeting in the “Forum for offshore drones” hosted by the industry clusters Offshore Energy and UAS Denmark, the providers and the potential customers discussed the opportunities and barriers for using drones for inspecting offshore wind turbines. According to the providers, the customers put high demands on the providers. As an example, they must live up to HSE (health; safety; environment) standards and therefore need to attend a course to understand how to behave around the wind turbines and potentially also how to stop and start them.
- **Financial challenges.** Since the providers, at least in a Danish context, are generally very small firms with limited resources, it is a huge challenge to finance the technology development that is needed to fulfill the ambition of having fully autonomous inspections. The wind turbine manufacturers support and invest in small(er) drone technology providers to speed up the process and ensure that the technology is developed in the desired direction. However, getting through the eye of the needle is a challenge and, not surprisingly, requires that a provider has to some extent already demonstrated the ability to develop and

deliver what is needed. Overall, the market entry barriers are extensive, and the customer side urges the small providers to pull together and gain bigger “muscles” by teaming up with other providers.

- **Technical challenges.** The piloted version is no longer a problem. Neither is semi-autonomous inspection where a pilot is positioned on a boat and handles both takeoff and landing but lets the drone do the inspection according to a pre-defined flight route. However, a fully autonomous solution, i.e., made without a pilot to assist the inspection, is still a difficult task to solve. Another challenge within the wind turbine industry is to define the data format to include image resolution, meta-data, geo-referencing, quality standard, etc. Important to the imagery analysis is the ability to automatically detect and classify the observed defects, correlate and compare the information with previous data, and produce predictive analysis to determine when a defect needs repair.
- **Legislative challenges.** Legislative challenges vary depending on the operational design of the offshore inspections. Local inspections performed from a maintenance vessel or from a platform pose little risk to people or aviation as long as the inspection is limited to the specific wind turbine/structure. However, if the operator desires to transit from the mainland to the offshore wind farm or transit within the wind farm itself, the risk to manned aviation, especially service and transportation helicopters also operating in the wind farm, increases. Development of standard scenarios defining airspace and operational procedures as well as a detailed risk assessment would need to be developed to allow for BVLOS operations.
- **Time challenge.** Generally, the customer side takes small steps and tests the opportunities. At the same time, the customers have an innovation horizon beyond autonomous inspection. They expect drones to be developed to a stage where they can deliver, e.g., spare parts or even carry out actual work. However, most of the firms on the provider side are busy merely developing the drone technology for inspection purposes to be able to comply with the request for a semi- or fully autonomous solution.

In addition to the identified barriers, drone technology and service providers also must take into the account what can potentially disrupt the need for regular inspections. As an example, the durability of the blades can be significantly improved²⁴.

²⁴ <http://renews.biz/102051/siemens-tackles-blade-erosion/>

6 Overall potential and outlook

Whilst Danish governmental documents and others suggest that new jobs will emerge from drone-based solutions to tasks, our findings indicate that drones and associated technology will in the short-term be mainly resources for existing roles. For instance, as long as the drone cannot carry out actual repair work, but merely inspects the state of the blades on wind turbines, there is still a need for gaining rope access to the wind turbine. Moreover, actual job creation will be hindered by the development of autonomous solutions, since the need for drone pilots will decrease. Nonetheless, drones can replace dangerous jobs as for instance ignition of oil spill from ships and, in any case, potentially lower the costs associated with a task remarkably.

At this point in time, drones are already used for offshore and maritime missions and will, no doubt, be implemented for other types of jobs to be done in this particular context. If especially market, legislative, and technological barriers are overcome, Danish firms have the potential to succeed with the further development and implementation of drone-based technology; be it for inspection purposes, delivery of goods, or execution of physical tasks. Importantly though, the interviewees in our study as well as market reports point to data processing as where the maximum growth will be. And maybe this is a suited focus for Danish providers while also keeping an eye on the global development and where interesting opportunities occur. Legislation-wise, there are examples of a high degree of risk appetite in other parts of the world. As hinted at earlier, the logistics firm, Matternet²⁵, has already started flying lab samples, autonomously, from medical clinics to hospitals in Zurich – a densely populated area. And in the next few years, one of China's biggest online retailers, JD.com, will establish almost 200 drone airports in Sichuan which will allow delivery of agricultural products from the province to anywhere in China within 24 hours at up to 70% lower cost than today²⁶.

²⁵ <https://www.theverge.com/2017/9/20/16325084/matternet-autonomous-drone-network-switzerland>

²⁶ <https://amp-businessinsider-com.cdn.ampproject.org/c/s/amp.businessinsider.com/chinese-online-retailer-is-building-200-drone-airports-rural-china-2017-12>

7 Method

This memo draws on a combination of desk research and primary interview data. The interviews (Table 1; next page) were conducted with a range of stakeholders in Denmark between May 2016 and June 2017 by researchers from University of Southern Denmark (SDU). The interview data was transcribed and, together with the secondary data, it was coded to enable categorization and analysis of the most important aspects in relation to the use of drones in offshore and maritime contexts.

Role	Organization	Interviewee	Position in the organization
Technology provider	Blue Ocean Robotics	John Erland Østergaard	Co-owner, Partner, and Director
		Creative Sight	Henrik Beck
	Sebastian Duus		Co-owner and Partner
	Benjamin Mejnertz		Co-owner and Partner
	Drone Solutions	Michael Smedegaard	CEO and Partner
		Jan Bønnelykke	Co-owner and Partner
	Explicit	Jon Knudsen	CEO
		Bettina Knudsen	CMO and COO
	Lorenz Technology	Lars Lorenzen Jensen	Chairman and Partner
		Helge Munk	Member of Advisory Board
	QuadSAT	Joakim Espeland	CEO and Co-founder
		Andrian Buchi	Co-founder
Viacooper	Jussi Hermansen	Owner, UAV Special Consultant	
(Potential) customer	Maersk	Peter Lystrup Christensen	Project Manager, Fleet Management and Technologies
		Steen Sander Jacobsen	Head of Technology and Innovation, Tankers
	Vattenfall	Rikke Juul Balle	Senior Blade Engineer
		Morten Saldern	Blade Specialist
	Ørsted Wind Power	David Lee-Jones	Senior Technical Project Lead
Transport regulation	Danish Transport, Construction and Housing Authority	Klavs Andersen	Chief Flight Inspector
Accredited technological institute	DELTA Force	Ole Steensen	Manager of Technology & Innovation
		Anders Mynster	Specialist in EMC, IoT, and wireless
		Rune Yding Brogaard	Business Manager, Drone Operations
Navigation service and traffic control of the Danish airspace	Naviair	Ronni Winkler Østergaard	Drone Programme Manager
		Jens Christian Skinneholm	Master of Engineering
		Steen Myhre Erichsen	Head of Division, International Development
Danish offshore industry cluster	Offshore Energy	Glenda Napier	CEO
		Henrik Böhmer	Project Manager

Overview of the interviewees.

