A Review and Inventory of Unmanned Aerial Systems for Detection and Monitoring of Key Biological Resources and Physical Parameters Affecting Marine Life during Offshore Exploration and Production Activities

Prepared for

Joint Industry Programme
on E&P Sound and Marine Life

by

LGL LIMITED
environmental research associates

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ABSTRACT

A literature review, internet searches, and communications with personnel working with unmanned aerial systems (UAS) were used to identify the capabilities of UAS throughout the world. We assessed their ability to replace manned aerial surveys for marine mammals and sea birds, monitor sea ice and other physical features and be platforms for search and rescue operations that are conducted by oil and gas exploration and production companies working in offshore Arctic and sub-Arctic waters. The vast majority of the systems identified were either too expensive or their capabilities did not meet minimum standards necessary to perform the tasks required of them. Eight systems were identified that might be able to perform some of the desired tasks. Several other systems had similar capabilities but had not been tested or would require upgrades. Installation of high-definition (HD) video and better stabilization systems would improve UAS performance. It is recommended that development of HD video with real-time data transmission and stabilization systems for UAS be pursued and that side-by-side comparisons of a few of the best systems be conducted.

KEYWORDS: INDEX OF ABUNDANCE; MONITORING; NOISE; SHORT-TERM CHANGE; SURVEY-AERIAL

INTRODUCTION

Dwindling oil and gas supplies and increased demand for existing reserves has prompted exploration and production (E&P) activities to expand into offshore areas that were considered inaccessible in the past. In many jurisdictions, concern about the potential impacts of these activities on marine resources, particularly marine mammals, sea turtles and seabirds, has created a requirement for E&P companies to monitor marine resources to help assess and minimize impacts of their activities on these resources. Because some species of marine mammals appear to react to the presence of E&P activities at distances that cannot be monitored from the platforms conducting the activities (Miller *et al*., 1999; Richardson *et al*., 1995), observations from other vessels or aircraft are sometimes required to document such behaviour. In these cases, accepted monitoring and mitigation methods cannot be used when vessels are too far offshore to safely conduct manned aerial flights, and some E&P activities face restrictions on the times and places where they can be conducted. Thus, new tools and methods are urgently needed to monitor marine resources in offshore areas so that E&P activities can be conducted there without having adverse impacts on species of concern.

Marine mammals have been the main marine resource of concern because they tend to be more sensitive to sounds produced by E&P activities than sea turtles or seabirds. Currently, visual vessel-based marine mammal monitoring programs are conducted from most seismic vessels (and some other E&P platforms) used for offshore oil and gas exploration (Johnson et al., 2007; Moulton et al., 2006; Patterson et al., 2007; Stone, 2003) and, more recently, academic geophysical research (Holst et al., 2005). Observations have also been conducted from artificial islands where production facilities are present (Richardson, 2006). The focus of these monitoring programs has been to detect marine mammals close to the activity so that mitigation measures can be implemented to avoid adverse effects on marine mammals by such measures as reducing or ceasing activities when marine mammals are observed within project-specific safety distances. When the zone of responsiveness has been too large to monitor from a vessel, aerial survey programs have been conducted at sufficient distances ahead of the vessel to allow companies to modify the timing and locations of activities so the activities do not impact those species, particularly sensitive components of the population such as mother-calf pairs (Yazvenko et al., 2007a; b). An alternative method of monitoring marine mammal presence in real time has been by the use of towed passive acoustic monitoring (PAM) to record or detect animal vocalizations. This method can be used at night and during periods of bad weather, but detection rates are often lower than with visual methods, locations of calling animals are often not precise enough to determine if animals are within defined safety radii of the activity and call detection range often is not sufficiently large to monitor safety radii around intense energy sources such as airguns. In addition, towed PAM arrays are not effective for species with low vocalization rates or near noisy activities that cause animals to cease or reduce calling. If the technology were verified, unmanned aerial systems (UAS) launched and recovered from a vessel may be able to provide unique platforms to monitor marine resources around offshore E&P activities. They may be able to survey a large enough area to monitor sound-based safety radii such as those required by the U.S. National Marine Fisheries Service (NMFS) for marine mammals around intense energy sources, and unlike manned aircraft, would not be restricted as to how far from land they could operate.

Selection of UAS that might be suitable for use in offshore areas is challenging because the technology is new and rapidly evolving, a very large number of systems are available and few systems have been tested specifically in offshore areas. Today, about 45 countries fly more than 600 different UAV models; in the USA alone, there are approximately 280 companies, academic institutions, and government groups developing more than 200 different UAS designs ranging in price from $1000 to $26 million (http://www.thirtythousandfeet.com/uav.htm).

Currently, surveys with manned aircraft are conducted in nearshore areas and offshore areas with ~200 km of land to obtain unbiased estimates of animals present because the aerial survey platform does not influence the distribution or behaviour of the animals that are being counted. In far offshore areas, where aerial surveys are not conducted due to safety concerns, ship-based surveys are used to survey animals, and it is known that many species of marine mammals and seabirds are either attracted to or avoid vessels (e.g., Barlow *et al*., 2006; Würsig *et al*., 1998), resulting in biased estimates of distribution and abundance. If UAS were found to be a suitable platform for conducting surveys of marine animals, then unbiased estimates of their distribution and abundance in offshore areas could be obtained. These data can be used to assess and manage potential impacts of various types of activities, on marine mammals and sea turtles.

UAS can also be used to collect other data that are required to support E&P activities. Sea ice imposes restrictions on locations where activities can be conducted and also can affect offshore exploration, drilling and offshore production activities. UAS can provide real-time information on ice and ice movements and physical features of the offshore environment. In many situations, these data could not be collected using other methods, such as satellite imagery, because of cloud cover over the survey area. UAS with infrared sensors could be used to more effectively detect some marine mammals such as polar bears and walrus than manned visual surveys and assist with search and rescue operations or the detection and monitoring of unplanned discharges.

With all of the above uses in mind, the objectives of this study were to

- prepare a compilation of UAS characteristics deemed important for monitoring marine animals and physical features such as ice, and compile a review of research on UAS that might be applicable to offshore oil and gas industry activities;
- review and assess each UAS with respect to its cost, availability and technical details;
- evaluate the applicability of existing UAS and sensors for use in offshore areas by the oil and gas E&P industry and review studies that have tested this technology;
- identify areas of further technological development that would improve the ability of UAS to accurately detect, classify and track marine mammals, turtles and seabirds; and
- identify political or regulatory barriers (including patents) to advancing the state of knowledge and acceptance of the technology.

METHODS

Initially, a list of the range of capabilities of UAS and sensors was developed. Capabilities of UAS vary from model airplanes that are controlled by a joystick within a range of a few kilometres to high-altitude UAS used for military applications that have ranges of 1000s of km and can fly at 15,000m above sea level. The information on the low-tech UAS, in particular, is voluminous, and setting boundaries on the information that would be integrated into the evaluation was necessary. Based on prior experience with using UAS in marine mammal monitoring (Koski *et al*., 2007a; b; Lyonns *et al*., 2009), a set of criteria for evaluation of UAS was developed (Table 1). The most important criteria included the ability to launch and recover the aircraft from a mid-size vessel; flight endurance of at least 4 hours; payload capacity of 1.5-2kg to accommodate high-quality sensors; a broadband datalink which allows National Television System Committee (NTSC), Phase Alternating Line (PAL) or Advanced Television Systems (ATSC or HD) video to be streamed back to a control station; and reasonable cost.

Based on the criteria in Table 1, a list of UAS and sensors was prepared using various data sources, i.e., technical reports, internet searches, UAS newsletters and contacts with UAS suppliers or people who have conducted research on UAS and various types of sensors that could be put in them. Personal contacts with companies' representatives provided a lot of useful information. In some cases, a system that was best suited for offshore surveys was in development or only recently available, and therefore was not present on the company's website or included in their technical descriptions. Alternatively, some systems that seemed highly suitable for our purposes were rejected based on the information obtained during conversations with company's technical staff or because they were no longer in production.

Studies were identified that have evaluated UAS and potentially useful sensors for use in marine resource surveys. Because of the relative scarcity of the published and gray literature that is directly relevant to the use of UAS in marine mammal surveys, internet and personal communications turned out to be the main sources of information on the present status in this area. A variety of web sites were browsed, including manufacturer's sites, the sites of various UAS associations, meetings and exhibitions; various blogs were included in the subsequent analysis and forums related to UAS.

Technical parameters for each UAS and sensor that met the criteria in Table 1 were tabulated. These parameters included cost, availability for civilian use, flight duration, deployment and retrieval systems, operating altitude, payload capabilities, image stabilization properties, data storage and transfer capabilities, user control systems, ways in which the UAS and sensors could be used during E& P activities, contact names and numbers, and other useful details. Research and testing that has been done on UAS and sensors were also reviewed (see Discussion).

We evaluated and assigned ranks to all UAS and sensors that were tabulated with respect to their applicability for monitoring marine mammals, sea turtles and sea bird distributions; marine mammal movements; marine environments around E&P activities such as sea ice and surface temperature; the E&P activities themselves; oil spills or other unplanned discharges; and any other activity that would be of interest to E&P operators. Their usefulness during search and rescue operations was also considered. The criteria for evaluation were the same as those in Table 1, with the emphasis on cost, control (remote or autonomous), the temporal and geographic scale of monitoring, the requirements for real-time vs. delayed data collection and analysis, the efficiency and accuracy of monitoring and the potential to train biologists and local stakeholders to operate such a system. In the evaluation and ranking, we considered two markets separately because of political and military boundaries: North America, Europe, Israel and Asia vs Eastern block countries, which included Russia and the countries of the former Soviet Union.

Finally, areas were identified where further technological development would improve the ability of UAS to provide the data required for E&P operations, including the ability to detect, identify and track marine animals accurately. Attention was paid to limitations in existing UAS such as video and camera resolution, ability for real-time data transfer, ability to operate multiple sensors, launch and recovery capabilities and the ability to operate in harsh environments.

The political, regulatory and patent barriers to advancing UAS technology were identified. Most often, they related to military confidentiality and security; operation of UAS in civil airspace; and patent barriers.

UAS information collected

A matrix was constructed with a row for each UAS or sensor. Data required for evaluation of each system were recorded in columns. The data recorded included: name, manufacturer or vendor and contact information, web address, cost, current availability, operator and training requirements, fuel or power source, size, weight, maximum payload, maximum speed, distance under control, maximum operational altitude, maximum flight duration, sensors with current system, resolution of sensors, data captured, data capture methods and whether data are available in real time, methods of launch, methods of recovery, other operational notes, sound levels, other issues such as health, safety and environment (HSE) concerns and other general notes. When the cells were completed, each system was evaluated as being good, fair-good, fair or poor based on the criteria in Table 1. Some systems could not be evaluated because information in brochures or on websites was insufficient and manufacturers or vendors did not respond to our queries. To be considered good, a system had to exceed the minimum criteria listed in Table 1. The criteria were intentionally set low so that marginal systems would be included with the hope that future upgrades would improve performance so that they might be useful. Also, for some applications, UAS with lower capabilities might be used for activities with lower performance criteria if there is a cost advantage.

RESULTS AND DISCUSSION

Of the 600 or so UAS that are advertised, in production or in development, about 400 were briefly evaluated. Of these, 162 UAS (aircraft or aircraft plus sensors) and 15 sensors were entered into an evaluation matrix and information on their capabilities was summarised from the various sources mentioned above. Only 12 UAS (7.4% of those evaluated in detail) were considered "good" prospects for use by the oil and gas E&P industry in offshore areas. Eight additional systems (4.9%) were considered "fair to good". The majority of the systems were considered fair or poor and would require significant improvements before they could be used (Table 2).

There is a wide variety of UAS available, but only a few of the 162 systems evaluated might be useful to the oil and gas industry to support offshore E&P activities. The most promising systems are discussed here, and a general discussion of capabilities and deficiencies in other systems is included in the next section.

Top-rated UAS

Eight UAS were considered to be potentially appropriate for use by the oil and gas industry in offshore areas, two from eastern block countries and six from other regions of the world. None of these systems has been fully tested to establish their efficacy for detection of marine mammals or other tasks for which UAS might be used. Because most of these systems have not been tested, it is likely that some of these UAS would need improvements before they could be used for many applications. Further, some systems have not been tested in the Arctic, where cold and icing pose problems not encountered in other regions. The strengths and limitations of each of these systems are discussed below.

The **Insight A-20** (also called the ScanEagle; Insitu Group, Bingen, WA and Evergreen Helicopters, McMinnville, OR) is one of the top-rated UAS in the size and cost range considered useful to oil and gas E&P industry and is one of only three UAS that have undergone or are undergoing systematic testing of their capabilities as a platform for surveying and observing marine mammals. The other systems tested for use with marine mammals, the Warrigal 2 and the systems tested by the University of Rostock, did not make the list of top-rated UAS (see below). The Insight A-20 was included among the top rated systems because of the testing that

Table 1.
Criteria used to evaluate whether UAS are suitable for use as survey platforms during offshore exploration and production activities by the oil and gas industry.

Vehicle characteristic	Requirements
Size	UAS of all sizes were considered, but if range (<200km) or flight duration (<4h) would not permit launch and recovery from land, then vehicles needed to be small enough to be handled by 1-2 people aboard a vessel.
Cost	Aircraft suitable for supporting E&P activities needed to be <$250,000 because of risk of loss and the need for mutiple aircraft for back-up or to house different sensors for different applications.
Payload capacity	A payload capacity of 2kg or more was deemed necessary to carry sensors and fuel.
Vehicle control	Both real-time flight control and pre-programmed flight control were considered, but real-time flight control to 50km is necessary for some functions such as marine mammal mitigation.
Distance of operation from base	UAS needed to be able to fly >20km from launch location if launched and recoverd from a vessel and >200km if launched and recovered from land. See also vehicle control requirements.
Flight duration	Minimum flight duration was 1h if operated from a vessel or 4h if operated from land. For most applications, flight duration in the survey area needed to be >4-6h.
Speed	UAS need to be able to operate during moderate wind conditions and so must have a minimum airspeed of 46km h^{-1}.
Fuel	Fuel or power for the UAS had to be readily available and non-hazardous. Gasoline was considered acceptable.
Launch and recovery requirements	The aircraft could be launched and recovered either from land or from a vessel, depending on flight duration (see Flight duration).
Sensor capabilities	A wide variety of sensors was considered to meet a wide variety of E&P industry needs. These included, but were not limited to, sensors to detect marine mammals (visual, infrared, UV, night vision); measure water temperature; map ice conditions; measure ocean currents and chlorophyll; and measure weather variables including wind speed and direction, air temperature, humidity and cloud cover.
Sensor size	Sensors as large as 20kg were evaluated but to be useable on current UAS sensors needed to be no heavier than 2-5kg.
Video resolution	Video resolution needed to be 640×480 pixels or better.
Image stabilization	Imagery needed to be stabilized to reduce motion/vibration and to allow clear imagery when scanning a large area.

has been done during 2006–2008 and because it appears to meet or exceed the capabilities of the other top-rated systems. In particular, the Insight A-20 can be manually controlled and sensor data can be obtained in real time out to 150km from the control station (depending on flight altitude and antenna height at the base station). If efficacy was established for detection of marine mammals, that range would make it suitable for marine mammal monitoring and mitigation to support large-array seismic programs, which may have required monitoring radii as large as 80km. Pre-programmed routes can be flown beyond 150km. The long endurance of the Insight A-20 (24h) facilitates efficient surveying of large areas and minimizes the number of launches and recoveries. It is small enough to be easily handled on a vessel (3.1-m wingspan) and has an efficient launch and recovery system that can be deployed from an offshore platform or a vessel. It has a sophisticated ground control station (GCS) that provides real-time display and processing of imagery and storage of all data collected. The current video system (NTSC) appears to cover an area approximately the same as a single observer in a manned aircraft and with similar detection probabilities (Koski *et al*., in prep). If a high definition (HD) video system was installed, it would allow coverage of a larger survey area than was possible during the tests conducted by Koski *et al*. (2007a; b). It is likely that a HD video system would make the Insight, and other systems listed below, suitable for surveying birds and most species of marine mammals (see Discussion on HD video below).

Table 2.
Summary of numbers of UAS and payloads evaluated in detail.

	Aircraft	Aircraft plus payloads	Payloads	Total
Good	7	5	3	15
Fair to Good	4	4		8
Fair	30	12	7	49
Poor	36	21	1	58
Could not be evaluated	12	1	4	17
Not available	10	4		14
Too Expensive*	13	3		16
Total	112	50	15	177

* These systems would be clasiffied as good if they were affordable.

The **Manta B**, which is a larger version of the Silver Fox (Advanced Ceramics Research, Inc., Tucson, AZ), is slightly smaller (2.7-m wingspan) and less expensive than the Insight A-20, but has fewer capabilities. Its ability to operate in the Arctic has been proven during research in Greenland (Table 3). However, currently it cannot meet the "distance under control" requirements for marine mammal mitigation (control to only 37km), its endurance of >6h is marginal for mitigation and it can be launched but not recovered from a vessel. A marine recovery system (in a net) is currently being developed and tested, which would improve its usefulness. The Manta B or Silver Fox might be useful in nearshore areas or for some tasks in offshore areas once the marine recovery system is verified.

The **Arcturus T-16** XL (Arcturus UAC, Rohnert Park, CA) meets most of the performance criteria for use in offshore areas. It has a 24-h flight duration and it can be launched and recovered (in a net) from a vessel. It is slightly larger (3.9-m wingspan) than the Insight and Manta B, which would make it slightly more difficult to handle on a vessel. It is less expensive than either the Insight or the Manta B. The major flaws of the Arcturus T-16 XL are the small range under control (16-24km) and the fact that it has not been tested in Arctic conditions. In particular, extending the range under control would markedly increase the value of this system.

The **CryoWing** (Norut Northern Research Institute, Tromsø, Norway) is one of the UAS that could be used to support many offshore activities. It is relatively inexpensive (€30,000 for the aircraft) but among the larger UAS (3.8-m wingspan) that could be deployed from a vessel. CryoWing has been specifically designed by a Norwegian team of scientists to operate in the Arctic and has been tested there. It has flight endurance of up to 20h at speeds of up to 160km hr^{-1} and it can be manually controlled out to >70km from the control station. Pre-programmed routes can be flown beyond 300km. The current video system is PAL, which has slightly higher resolution than NTSC but is of similar clarity because of a slower refresh rate. Datalink options include 3G GSM (up to 1Mbit), and up to 7Mbit dedicated radiolink, which might permit use of HD video, but HD video has not been investigated or tested. The main weakness of the CryoWing is that it is not recoverable on a vessel (it is launched by a catapult that could be used on a vessel but it lands on its belly), so it would need to be recovered from land. Its long flight duration and the ability to pass control from one control station to another or pre-program the landing at the end of the flight makes this feasible. In this situation, the UAS would become separated from the vessel after the first flight. As an alternative, it could be launched and recovered from land, but this is not practical if operations are far from shore. It

Table 3.
Deficiencies in UAS and whether they can be addressed.

Limitation	Description of Problem	Can This be Improved?
Video resolution	The resolution of current systems does not permit monitoring of large areas because the pixel size or resolution is not high enough.	Yes, higher resolution cameras are available and being tested by some providers. A study with HD video showed it to be as good as manned surveys for estimating densities and identification of birds (Mellor and Maher 2008).
Image quality	Movement and vibration degrade image quality.	Yes, in three ways. The more sophisticated UAS have built in image stablization systems and some high end cameras have image stabilization built into the lens or camera body. In addition, post processing of the imagery can produce a clearer image. That is available in real time for some systems.
Real-time data transition rates	Real-time data transmission rates are limited which prevents use of higher resolution sensors in real time.	Yes, the technology exists for the military.
Limited range with real-time control of UAS	Some applications, such as mitigation for marine mammal issues, require real-time acquisition of data and implementation of mitigation measures.	Better and higher antennas on offshore structures will increase range of control. Satellite linked data transmission is possible at increased cost to operations.
Simultenous use of multiple sensors	Smaller UAS can only support one sensor at a time because of payload limitations.	Sensors continuously get smaller and some of the larger models might be able to hold multiple sensors simultanously. This can also be solved by flying two aircraft, each with a different sensor, at the same time.
Weather-proofing of systems	The ditching of a UAS into sea-water would damage the electronics and, in some cases, possibly the aircraft itself.	Yes, a few systems are designed for offshore operations. Water-proof casings can be designed for almost any system (or system components) and make them operational in offshore environments.
Icing	Systems can be prone to icing in certain arctic conditions.	Systems can be designed to better monitor this risk and reduce the likelyhood of icing. Heat can be provided to key locations on the aircraft to reduce or prevent icing.
Launch and recovery limitations	Some systems that are otherwise suitable cannot be launched and recovered at sea	Yes, the smaller aircraft could be captured in nets or on a wire like the Insight™.
Cost	Many systems are too expensive.	Costs will come down substantially when these systems are used for commercial purposes. Current use is by the military and few units have been sold in comparison to the potential civilian market.

is a light system (30kg) but has a relatively large wingspan (3.8m), which would make it slightly more difficult to handle than some of the smaller aircraft if vessel launch and recovery were implemented.

The **Elbit Skylark II LE** (Elbit Systems Ltd, Haifa, Israel) is a system recently developed by one of the world leaders in the UAS industry. The cost of the system was not given by the supplier who did not respond to our request for information. It appears to be one of the more advanced systems, but has not been tested either in the Arctic or in offshore areas. It can carry a 9kg payload, has flight endurance of up to 17h at speeds of up to 74km hr^{-1}, and can be manually controlled out to 50km from the GCS. The payloads of Skylark II are among the most sophisticated in its class; a gimballed and stabilized triple-sensor payload (Micro-CoMPASS) includes a colour CCD daylight camera, 3rd generation thermal-imaging night camera and a laser illuminator. Skylark II LE is not currently recoverable on a vessel, but a vessel-based launch and recovery system is undergoing sea trials. Considering the pace of its evolution, Skylark II LE is one of the systems to watch in the next 1-2 years.

The **Fulmar** (Aerovision VehÍculos Aeros, S.L. San Sebastian, Spain) is one of the top rated UAS in the size and cost range (€20,000 for one fully equipped UAV) considered for use by the E&P industry. Fulmar has been specifically designed by a Spanish team of scientists to operate at sea, and its capabilities appear to meet most requirements for offshore use. In particular, it can be launched and recovered from a vessel into a net or by descending and sea-landing on a pneumatic skate. It is waterproof, and a satellite radio beacon is incorporated into the aircraft for recovery. Fulmar has flight endurance of up to 8h at speeds of up to 150km h^{-1}, it can be manually controlled out to 100km from the GCS and.pre-programmed routes can be flown farther. The data link with the control station at 900 Mhz is out to 100km at 128kbps but the real-time video link at 2.4 Ghz has a maximum range of 50km. It is a light system (19kg) with a medium wingspan (3.1m) and can carry 8kg of payload including fuel.

The **ZALA 421-16** (A Level Aerosystems, Izhevsk, Russia) is the top rated UAS for the Russia/FSU market. It has a 1.6-m wingspan and the cost is €200,000 for two aircraft and a GCS. It is a newly released system (2009) and so it is untested. A pilot project involving ZALA 421-16 funded by Rosneft, a Russian oil company, will be conducted in offshore Arctic waters during summer 2009. Its capabilities appear to meet most requirements for use in offshore cold-water environments. In particular, the ZALA 421-16 has flight endurance of 5-7h at speeds of 80-100km h^{-1} (marginal for some needs), can be deployed and retrieved from the vessel, and can be manually controlled out to >70km from the GCS. Pre-programmed routes can be flown beyond 200km. As with the

CryoWing, the communications bandwith can be increased to 7 Mbits, which might make transmission of HD video possible.

The **R-100 Marine** (UAVia Pte Ltd, Kiev, Ukraine) can be launched and recovered from a vessel, is small (1.8-m wingspan) and can be controlled up to 100km from the GCS. The current version has only 4h endurance (battery powered) but a 10-h version (gasoline powered) is being developed. As with most eastern block systems, the R-100 Marine appears to be costly ($1.0M for 3 aircraft and GCS) and it has not been tested for surveys of marine mammal.

Other UAS

Several other systems are available or under development that might become suitable for use by the oil and gas E&P industry as systems are upgraded. These include the Aerosonde MK-4 and Shadow (Aerosonde Pty Ltd, Notting Hill, VIC, Australia and AAI Corp, Hunt Valley, MD), V-Bat (MLB Co., Mountain View, CA), Warrigal 2 (V-TOL Aerospace Pty Ltd, Brisbane, Queensland, Australia), Resolution (Airborne Technologies, Inc, Wasilla, AK), Skyblade IV (Singapore Technologies Aerospace, Paya Lebar, Singapore), Aerostar and Orbiter 3 (Aeronautics Defence Systems Ltd, Yavne, Isreal) and the S4 Ehécatl (Hydra Technologies, Zapopan, Mexico).

There are several large and very sophisticated UAS used for military applications that exceeded the requirements of a system for use by the oil and gas industry. However, the cost of operating these systems would be prohibitive, which eliminated them from consideration. In addition, many of these systems are classified and are available only for military use. As the technology advances, and more research and development are done, some of the features in these large, sophisticated systems may become available to the smaller, more practical systems.

A potentially large benefit to users of UAS over manned aerial surveys or observers on vessels is that data streams from UAS can be transmitted in real time from the GCS where data are received from the UAS to all parts of the world through the internet. Some systems like the Insight A-20 and CryoWing have used this capability for some studies, and although not demonstrated for many systems, it is a relatively simple process to implement, provided that high speed internet access is available at the GCS. By using this capability, the oil and gas industry could minimize the numbers of people on vessels in offshore areas and do some data processing in the office in real time. Because bunk space is usually limited during offshore activities, and it is safer and more cost-effective to have personnel working in the office rather than the field, this would provide significant cost and safety benefits to the industry.

A review such as this one relies on information provided by vendors and manufacturers. Thus, no actual tests or side by side comparisons of systems were made. Based on our experience working with UAS, the most common deficiencies among the systems have been poor image quality (primarily due to lack of image stabilization), low or marginal flight duration and the lack of the ability to launch and recover the UAS from a vessel or offshore platform (Table 3). Because these deficiencies have been overcome in some systems, future generations of many of the UAS examined may address these deficiencies. In many cases, systems have not addressed these deficiencies because the market for such systems had not been identified before we contacted the system marketers.

Studies on UAS

To date, few studies have been conducted with UAS either in offshore Arctic regions or for surveys of marine mammals. The first six studies in Table 4 are studies on marine mammals. The first was conducted in 2002 and the technology has advanced substantially since that test, so the findings are outdated. Even at that time, the researchers were able to detect and identify humpback whales (NOAA, 2006).

The 2006 study by Shell was the first systematic test of the ability of a UAS to detect objects of interest in a marine environment (Buck *et al*., 2007; Ireland *et al*., 2007; Koski *et al*., 2007a; b; in prep.). The surveys were flown in winter conditions in Washington State (they included freezing rain, fog and high winds), which are very similar to conditions that would be encountered in the Arctic during the late summer and autumn. Kayaks were used to simulate the dorsal surfaces of whales at the surface that would be available to be seen by marine mammal observers (MMOs) during manned aerial surveys. The kayaks were placed randomly in the search area and the MMOs, who were blind to kayak locations, used a systematic grid to search for them using an Insight A-20. Detection rates varied with sea conditions (greatest influence), kayak colour and kayak inflation, but detection rates with search swaths up to 600m were similar to those reported in the published literature for manned aerial or vessel-based surveys (Koski *et al*., in prep). The authors concluded that the system tested (Insight A-20) was suitable for surveys of large cetaceans or large groups of small cetaceans, but noted that the search swath was narrower than that covered by a manned aircraft. The smaller search area could be compensated for by the longer flight duration of the UAS and by flying during periods with ceilings <300m when manned aircraft are not permitted to fly because they could disturb marine mammals.

The 2008 study by Shell and ConocoPhilips (Lyons *et al*., 2009) showed that the Insight A-20 could be operated successfully in the Arctic where oil and gas activities were being conducted. It was flown for 32h over a 10-day period, and several cetaceans and pinnipeds were sighted and captured on video. The 2008 study was

Table 4.
UAS studies conducted on marine mammals or used to evaluate performance in the offshore Arctic.

Organisation	System	Objective	Key Contacts	Study Period	Conclusions from Tests (References)	Strengths/weaknesses
Office of Naval Research	Silver Fox	Marine mammal (MM) monitoring	Dr. Patterson Advanced Ceramics Research, Inc. Tel: 703-650-6347	2002	Whales were seen during trials (NOAA 2006).	No quantitative assessment of detectability but systems have improved substantially since this test.
Shell E&P Co., RTD Arctic Technology Division	Insight A-20	Test system for detection of simulated MMs.	Michael Macrander, Jerod Kendrick, William Koski	December 2006	Potential for detecting large cetaceans or large groups of small cetaceans (Koski *et al* ., 2007a; b; 2009; Buck *et al* ., 2007; Ireland *et al* ., 2007).	Detection of simulated MMs with UAS appeared similar to people in manned aircraft (but search width smaller). Few MMs in survey area; only 1 cetacean encountered during tests.
Shell E&P Co., Conoco-Phillips	Insight A-20	Actic deployment of vehicle and detection of MMs.	Michael Macrander, Jerod Kendrick, William Koski	September 2008	Gray whales, unidentified large cetaceans, seals and walruses were detected (Lyons *et al* ., 2009).	Permits limited scope of work
University of Queensland	Warrigal 2	Aerial surveys of humpback whales and dugongs.	Michael Noad, Amanda Hodgson	Australian fall and winter	Data are currently being analyzed but (1) range limits use, (2) launch and recovery are limiting, (3) video is not stabilized which reduces video quality.	Major strength is low cost. Weaknesses include imagery not stabilized, system has limited range, the aircraft is difficult to operate without substantial experience, and launch and recovery requires large open flat areas.
University of Rostock, Germany		Surveys of harbour porpoise, other MMs and birds.	Thomas Wegner, Torsten Foy, Gorres Grenzdörffer	Ongoing	In progress (Grenzdörffer, 2008).	
NOAA/NMFS/NMML	Insight A-20	Census of ice seals in the Bering and Chukchi seas.	Robyn Angliss	Spring 2009 and ongoing	UAS tested in Bering Sea in spring 2009. Results pending, but promising.	Imagry currently not stabilize, which reduces capability for species identification
University of Colorado	Aerosonde MK-3	Sea ice monitoring near Barrow, AK. To develop, test, and deploy a low-cost laser profiling system that can be operated onboard small unpiloted aerial vehicles.	Jim Maslanik	1998-2004	Adaptations made for cold polar work were successful. Sensors were succesful in measuring sea-ice temperature and surface imaging. Icing-detection device designed (Curry *et al* ., 2005).	Electronics bays insulated. Cables teflon-sheathed to mitigate cold-induced brittleness. Heated tube installed to prevent icing and failure of pilot-static system. Engine converted to fuel-injection to reduce carburator icing. Redesigned lubrication system to reduce problems with cold engine oil and condensation on oil lines.
NOAA and Airborne Technologies Inc.	Resolution	Operating the Resolution from vessels of various lengths.	Tim Veenstra, Airborne Techologies Inc. www.highseasghost.net	March 2008 (ship-based test in November-December 2007)	Successfully operated from vessels of various lengths. Future work will focus on develpment of sensors and automatic detection of objects such as drift nets and marine debris (Churnside *et al* ., 2009).	Not specifically tested for detection of marine debris (or marine life) at this point.
NOAA and Uiversity of Colorada	Manta	Monitor ice cap melting over Greenland.	Jim Maslanik	2008	Data currently being analyzed. Builds on similar earlier study.	In progress
Memorial University of Newfoundland (MUN) and Provincial Aerospace Limited (PAL)	Aerosonde MK-4	Offshore surveillance (illegal fishing, pollution).	Dr. Siu O'Young Principal Investigator, Project Raven Faculty of Engineering, Memorial U. Email: oyoung@mun.ca Tel: 709-737-8345	First flight: 23 Novermber 2006	Current work will investigate and develop Sense and Avoid (SAA) technology and the resulting innovations will be commercialized around a proprietary Autonomous Collision Avoidance System (ACAS) for small UAS.	In progress.
National Institute of Polar Research, Itabashi, Japan	Ant-Plane	Meterological data and aeromagnetic data collection	Minoru Funaki National Institute of Polar Research, 9-10 Kaga 1, Itabashi, 173-8515 Japan	2003-2006	Work involved building and testing small UAS for use from vessels in Antarctic. Development is ongoing (Funaki *et al* ., 2008).	In progress.
USDA-ARS Hydrology and Remote Sensing Laboratory	Vector P	Assessment of agricultural crop biomass and nitrogen status.	E.R. Hunt, Jr. Tel: 301-504-5278 Email: erhunt@hydrolab.arsusda.gov	2002-2003	Mixed results. Model aircraft and digital cameras overcame many problems associated with comercial satellite and airborne imagery, but limitations due to model aircraft used and consumer-oriented digital camera remained (Hunt *et al* ., 2006).	Constaints with take-off and landing areas. Limitations related to flying skills of operator. Inspection of digital imagery ensured complete coverage. Low-cost sensors resulted in correspondingly low-quality data. There have been advances in sensor quality since this study.
COWRIE	HD video	Evaluate high-definition (HD) video to replace manned aerial surveys for birds in offshore waters near wind farms.	M. Mellor and M. Maher HiDef Aerial Surveying Ltd	13-14 March 2008	Video survey provided unambiguous identification and detection of birds within a 30-40m swath covered by 1 HD video camera. The HD system can replace manned survey but >1 camera necessary to cover equivalent survey areas (Mellor and Maher, 2008).	Higher degree of identification from video than manned surveys. Can survey sensitive species without flushing them, as has occurred during manned surveys. Simplified analysis because search swath is fully covered.

constrained by US Federal Aviation Administration requirements to remain within one nautical mile of the vessel and requirements for a cloud ceiling of at least 300m before the UAS could be flown. This prevented useful evaluation of the efficiency of the UAS in comparison to surveys by manned aircraft.

Two additional studies are underway to investigate the use of UAS for surveying marine mammals. One is at the University of Queensland, Australia, and the other is at the University of Rostock, Germany (Table 3). Both studies are incomplete and results are pending.

Memorial University, Canada, and Provincial Aerospace Limited are using an Aerosonde MK-4 for monitoring illegal fishing and pollution in the North Atlantic off Newfoundland. This study is ongoing and results are not available yet. Of more importance to the present review, this group is also working on the development of an autonomous collision avoidance system for small UAS. As noted in the next section, development of such a device is important to permitting considerations for use of UAS in many areas.

NOAA and Airborne Technologies are testing the Resolution (one of the UAS listed in the "Other UAS" section) for detection of abandoned fishing gear. An interesting finding by Churnside *et al*. (2009) during these tests was that an infrared sensor could detect whale tracks in temperate areas by thermal disturbance at the water surface. During earlier tests in the Arctic, however, biologists were unable to locate bowhead whales or their tracks with infrared sensors even though the whales could be seen in imagery collected using low resolution colour video (W. Koski, unpubl. data).

University of Colorado scientists used the Aerosonde MK-3 to study ice roughness and surface temperatures and they identified and implemented modifications to the UAS to permit flying in the Arctic (Curry *et al*., 2005). The modifications suggested during these early UAS studies have resulted in increased safety and efficiency of UAS operations in the Arctic.

A study of the test of a Cineplex gyroscopically stabilised high-definition (HD) (1080×1920) colour video has been included in the review because HD video is being modified for use in some of the UAS reviewed. Mellor and Maher (2008) tested this system in a small fixed-wing aircraft flying at 600m above sea level with a 30-40m surface coverage. The objective of the test was to determine if the HD video in a fixed-wing aircraft was suitable for obtaining information on species, distribution and abundance of seabirds near offshore wind farms. The target species included alcids (Alcidae), common scoters (*Melanitta nigra*) and cormorants (*Phalacrocorax* spp.), which are dark-coloured birds that are difficult to detect and identify during manned aerial surveys. The smaller of these species are approximately 35cm long when swimming on the water. The study concluded that the target species could be detected and identified easily in the imagery that was obtained, and that birds were less likely to be disturbed than during lower-level manned surveys.

Problems with UAS Use

There are many problems involved in using UAS to replace manned aerial surveys and support other offshore oil and gas industry activities. These include acceptance of the technology by regulatory bodies that issue permits, responsiveness by UAS providers and aviation-related restrictions on flying UAS. The problems and solutions to these problems are listed in Table 5.

Regulatory agencies in some jurisdictions such as the USA will not permit the oil industry to replace current monitoring and mitigation studies by observers on vessels or in manned aircraft with UAS surveys until they are confident that the data from the UAS surveys are similar to or better than those that are currently being collected. Because UAS studies are ongoing in several countries outside of the USA, including Canada, Germany, Norway (Spitsbergen) and Australia (Table 4), the comparison studies could be conducted in these jurisdictions. Moving forward with the use of UAS in jurisdictions where they can currently be flown is likely to facilitate implementation of UAS in the more restrictive jurisdictions, because one of the main concerns is whether they can be flown safely.

CONCLUSIONS

Many of the UAS investigated during this study would be suitable for ice reconnaissance and marine search and rescue operations, but only a small fraction of them might be useful for replacing aerial surveys currently conducted using manned aircraft. Those UAS that might be suitable have sensors with sufficient resolution to conduct surveys of large cetaceans or of large groups of small cetaceans, but the search area is smaller than that covered by a manned aircraft and the survey speed is slower. A typical survey speed is 200km h^{-1} for a manned aircraft and 83km h^{-1}.for a UAS such as the Insight A-20 tested by Koski *et al*. (2007a; b). A Twin Otter with wing-tip tanks can fly for ~4.5h and could conduct two flights a day; it could survey for about 3.0h per flight, depending on the distance from the airport to the survey area. Thus, observers in a Twin Otter could survey ~1,200km in one day. A single UAS could cover the same 1,200km in about 14.5h at a typical speed of 83 km h^{-1}. However, the manned aircraft would have two observers, each with an effective strip widths (ESW) of ~600m and a UAS searches an area about 600m wide. Thus, two UAS would be needed to obtain similar coverage to a 9-h survey by two MMOs in a single manned aircraft. Given that some UAS can survey for up to 24h without refuelling and that UAS can fly at lower altitudes without disturbing animals, a UAS may be able to obtain the coverage needed to replace manned

Table 5.
Problems or concerns involved in using UAS.

Concern	How Concerns Can be Addressed	Possible Mitigation
UAS may not provide comparable data to manned aerial surveys.	Conduct parallel studies using UAS and manned aerial surveys and compare results.	Studies have not been conducted in USA because of Federal Aviation Administration (FAA) restrictions on UAS flights. Conduct studies in other countries if restrictions in the USA are not relaxed.
Many suppliers have not been responsive to requests for information.	More contacts with suppliers by industry. Funding studies is likely to attract their attention.	Use responsive suppliers. Responsiveness and attitudes will probably change when the market is verified.
Industry-specific modifications to UAS have not been made.	Funding for modifications will increase likelihood of them being pursued. Once market is established, others will make the changes.	Use responsive suppliers. Responsiveness and attitudes will probably change when the market is verified.
Fear of a collision between UAS and aircraft.	UAS can be outfitted with transponders so that they can be detected by manned aircraft.	Civilian aircraft could be required to have instuments to detect transponders.
Fear of a collision between UAS and aircraft.	Development of anticollision devices.	Anticollision devices (detect and avoid capabilities) for UAS are still in experimental stage but can be given a higher priority.
Fear of a collision between UAS and aircraft.	Fewer concerns when working in remote areas where low-level aircraft are not present.	Agencies are cautious and in some jurisdictions, like the USA, the FAA has applied the same rules to all areas. This is gradually changing.
Fear of a collision between UAS and aircraft.	Use radar for detection of aircraft in research area.	Small portable radars are available that can detect aircraft to a few tens of km.
Export restrictions for some UAS	Use different UAS in different jurisdictions.	None possible at this time. Technology is likely to become more open in the future.
Licensing/capabilities of operators	Need for regulators to identify minimum requirements for UAS operators.	This is not currently an issue, but might become one in the future.
Lack of an established flight approval process in most juridictions	Governments are in the process of establishing rules for UAS to avoid conflicts with manned aircraft.	Some agencies worry about the above concerns and the possibility of a collision between a UAS and poorly-equipped manned aircraft. To date progress has been slow.
Lack of a consistent flight approval process among different juridictions	Rules for UAS are different among different jurisdictions.	So are rules for manned aircraft, and parallel rules for UAS and manned aircraft would simplify flight control issues.

aerial surveys; however, this has not been tested. In some situations, UAS might obtain coverage when a manned aircraft could not survey because of low cloud in the survey area or at the aircraft base.

HD video provides 6.75 times the number of pixels in a frame as does NTSC video; as a result, it could cover an area three times wider than NTSC video with the same resolution. Implementation of stabilized HD video into a UAS likely would provide imagery that would be as good, or better, than data collected during manned aerial surveys. As demonstrated during the Mellor and Maher (2008) study, in some cases HD video could provide better data than manned surveys because species identification from the video may be better than that possible during manned aerial surveys. In part, this is because of the ability to review characteristics of a sighting, which can't be done during real-time manned aerial surveys. Thus, it is recommended that development of HD-video capture and transmission be encouraged. HD video may be the break through that would permit use of UAS for surveys of birds and small marine mammals in offshore areas.

Image stabilization is another limiting factor to the use of UAS for wildlife surveys. UAS are small and unstable platforms for capturing visual data. Development of better stabilization systems for sensors would increase the quality of imagery and permit more efficient searching for animals.

See-and-avoid systems should be developed for UAS. One of the major roadblocks to using UAS in most jurisdictions is the lack of a see-and-avoid system that would prevent a UAS from colliding with an aircraft.

In summary, several UAS are available that would be suitable for monitoring offshore ice conditions, wave height and some other physical features of the offshore environment, but more testing is needed before UAS can be used as replacements for manned aerial surveys of marine mammals and birds. Side-by-side testing should be conducted using the most promising systems. Development of better image stabilization systems and implementation of higher-resolution video is recommended to improve the capabilities of current UAS.

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