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Evaluation of an Unmanned Airborne System for Monitoring Marine Mammals

William R. Koski,[1] Travis Allen,[2] Darren Ireland,[3] Greg Buck,[3]
Paul R. Smith,[4] A. Michael Macrander,[5] Melissa A. Halick,[4]
Chris Rushing,[6] David J. Sliwa,[7] and Trent L. McDonald[8]

[1]*LGL Limited, environmental research associates, P.O. Box 280, 22 Fisher Street,*
King City, ON L7B 1A6, Canada; E-mail: bkoski@lgl.com
[2]*Shell Exploration & Production, One Shell Square, P.O. Box 6933, New Orleans, LA 70161, USA*
[3]*LGL Alaska Research Associates, Inc., 1101 E. 76th Avenue, Suite B, Anchorage, AK 99518, USA*
[4]*Shell Exploration & Production, 16068 Pennzoil Building, 700 Milam Street, Houston, TX 77002, USA*
[5]*Shell Exploration & Production, 3601 C Street, Suite 1334, Anchorage, AK 99503, USA*
[6]*Evergreen Helicopters, Inc., 3850 Three Mile Lane, McMinnville, OR 97128, USA*
[7]*The Insitu Group, Inc., 118 E. Columbia River Way, Bingen, WA 98605, USA*
[8]*Western Ecosystems Technology, Inc., 2003 Central Avenue, Cheyenne, WY 82001, USA*

Abstract

Tests of an unmanned airborne system (UAS) for surveys of marine mammals were conducted near Port Townsend, Washington. Sixteen surveys were conducted over a 10-d period to find 128 simulated whale targets (4 to 9 per survey). Various weather conditions were encountered, and search-widths and altitudes were varied to establish optimal search parameters for future surveys. Logistic regression models were applied to estimate how detection rates were influenced by target color, degree of target inflation, shutter speed, search-width, and Beaufort wind force. Beaufort wind force was the strongest predictor of detection rates with color and degree of target inflation also included in the model that best fit these data. Overall detection rates of simulated large whale profiles using UASs were similar to published estimates of detection rates during manned aerial surveys for marine mammals, except the search area was much smaller (narrow strip width) when using the UAS. The best detection rates were obtained when Beaufort wind force was lowest (~ 2). The UAS tested showed promise for replacing manned aerial surveys for monitoring distribution and abundance of large marine mammals; however, improvements are required before the UAS would be an efficient tool for detection of all species. Side-by-side comparisons are needed between the UAS and manned aircraft to evaluate any differences in detection rates from the two platforms.

Key Words: aerial survey, altitude, cetacean abundance, cetacean distribution, color, search-width, video, wind, Beaufort wind force, unmanned airborne system, UAS

Introduction

With increasing need for information on marine mammals and birds in Arctic offshore areas, the concern for the safety of people conducting marine mammal surveys, as well as the concern for marine mammal populations that occur in those areas, has prompted the investigation of using unmanned airborne systems (UASs) as a new method of detecting marine mammals. For many years, aircraft (e.g., Koski & Davis, 1994; Harwood et al., 1996; Forney & Barlow, 1998; Bengtson et al., 2005) and ships (e.g., Cattanach et al., 1993; Barlow, 1995; Swartz et al., 2003; Barlow & Forney, 2007) have been the primary platforms for documenting the distribution and abundance of marine mammals over broad geographic areas. Vessels are commonly used for collecting census data, but vessels can influence the distribution of some marine mammal species. Secretive species, such as beaked whales (*Ziphiidae*), avoid vessels, while other species, such as Dall's porpoise (*Phocoenoides dalli*), are attracted to vessels and bow-ride (Würsig et al., 1998; Barlow et al., 2006). When vessels are conducting noisy activities, such as seismic surveys, marine mammals may avoid areas near the vessels by distances well beyond observation by personnel on the vessel. In those situations, aircraft have been used to investigate the distribution of marine mammals around the operations and have been the only method of covering large geographic areas in a short period of time.

The use of small, hand-launched UASs has been tested for wildlife surveys in terrestrial and near-shore areas (Jones et al., 2006), but the UAS they investigated had very limited flight, range, and payload capabilities. Alternatively, UASs that were initially developed for military operations can be launched and recovered from vessels or offshore structures and have much larger operational ranges than the UAS tested by Jones et al. The flight patterns of advanced UASs can be manually controlled up to ~70 to 150 km from the ground control station (GCS), and predetermined routes can be flown at greater distances without direct control of the aircraft. Therefore, these more advanced UASs have the potential to replace manned aerial flights in some situations and to eliminate the risk to human life that is associated with using marine mammal observers aboard aircraft during aerial monitoring. As UAS technology has improved, so has the ability to detect and identify targets. Current systems have been identified as being potentially useful for detection and identification of marine mammals, but no systematic tests have been conducted. In this paper, the results of tests of a UAS to detect simulated whale targets in Puget Sound, Washington, are summarized. The combination of an unmanned aircraft (UAV), a launch and recovery system, and a GCS is referred to as an unmanned airborne system (UAS).

Materials and Methods

Study Area

The study area was in Admiralty Bay, which is on the west side of Whidbey Island east of Port Townsend, Washington. Evergreen Helicopters, Inc., and Insitu have obtained permission from the military authorities to conduct flights, on a not-to-interfere basis, of a UAS within the restricted airspace boundaries shown in Figure 1. Tests were further restricted because deployment of "whale-like targets" in a shipping lane could have created a hazard to vessels transiting through the area.

Unmanned Airborne System

The UAS consists of an unmanned aerial vehicle, a launch system, a recovery system, a video camera payload carried aboard the UAV, and a ground control system. The UAV used during tests was the Insight A-20 with an Alticam 400 or Alticam 600 payload turret for stabilizing the video camera (see the Insitu website: www.insitu.com).

Insight A-20—The Insitu Insight A-20 (see Figure 2) is in the same family of UAVs as the Boeing

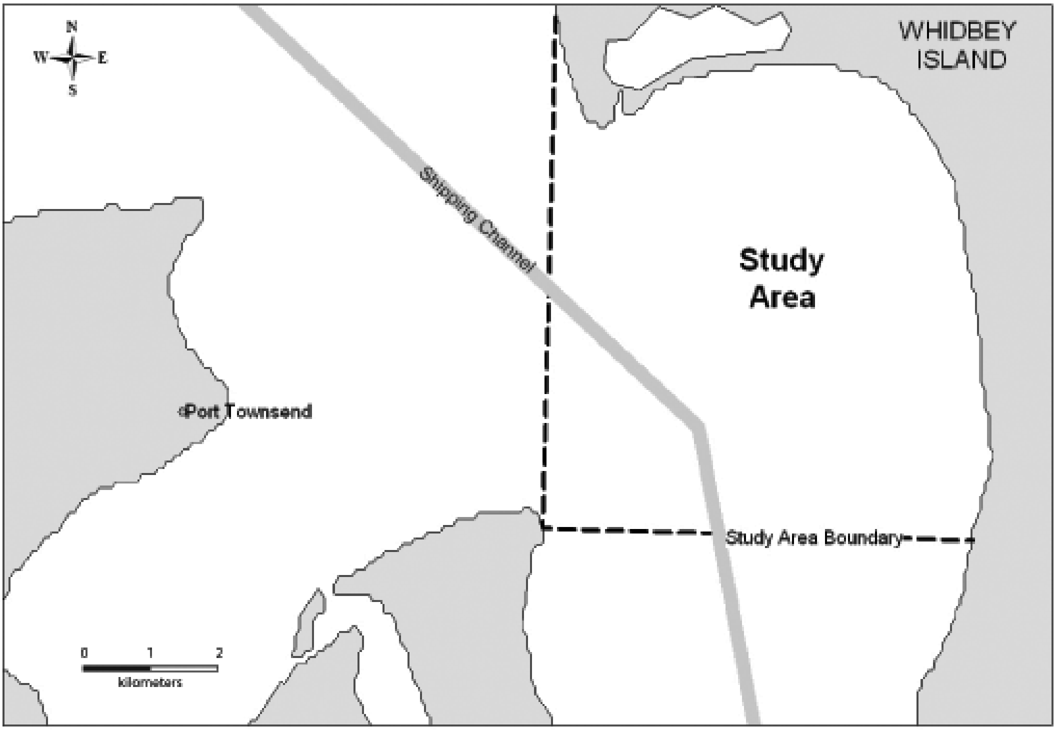

Figure 1. The study area in Admiralty Bay near Port Townsend, Washington, used to test the detection of whale-like targets by an unmanned airborne system (UAS)

ScanEagle that has been used during U.S. military operations in Iraq. It was developed to be launched and retrieved autonomously from a relatively small vessel (18 m) typical of those used in off-shore tuna fisheries (McGeer et al., 2002). It navigates using an onboard global positioning system (GPS). Position and other data are relayed to the GCS and monitored by an operator. This small (3.1-m wing span, 1.2-m long, 18-kg max. gross weight) UAV can operate for 20+ h at an average speed of 25 m/s (maximum speed is 40 m/s), has a service ceiling of 6,000 m, and can be controlled out to ~150 km from a GCS. The Insight A-20 is able to fly preprogrammed routes farther from the GCS. The aircraft is launched via a catapult and retrieved by hooking a suspended wire with locking clips located on the wingtips. Flight (including launch and recovery) is preprogrammed and entirely autonomous, but direct control of the aircraft can be assumed by the operator to investigate sightings of interest when within ~150 km of the GCS. The Insight A-20 can be fitted with a variety of payloads, including infrared (IR) cameras, video cameras, and in the near future, Synthetic Aperture Radar (SAR). Data are streamed to a GCS in real time.

UAV Launch and Recovery System—Launch and recovery of the UAV was from the *USRV Shackleton*, a 17.7-m research vessel converted from a tuna seiner. It was outfitted with an Insitu Super Wedge Catapult for launching the UAV in marine areas and an Insitu Skyhook Recovery System to recover the UAV.

Video Camera—The video camera used during this test was a standard National Television Standards Committee (NTSC) video camera with 640 × 480 pixel resolution (see Table 1). The resolution spot size (RSS) of the camera at the 1.6 zoom used was ~32 cm at the edge of the search area, which provided a 9 by 2 pixel image on the video screen. As a guide, an object is deemed to be detectable if it is five or more pixels in size. The camera was mounted in a turret which balanced and stabilized the camera to minimize effects of engine vibration. The camera was mounted under the nose of the aircraft in a Plexiglas housing that allowed the camera the widest possible field of view (see Figure 2). The camera can be manually manipulated by the pilot to confirm targets as well as to assess their characteristics (e.g., size/color). The zoom function of the camera revealed

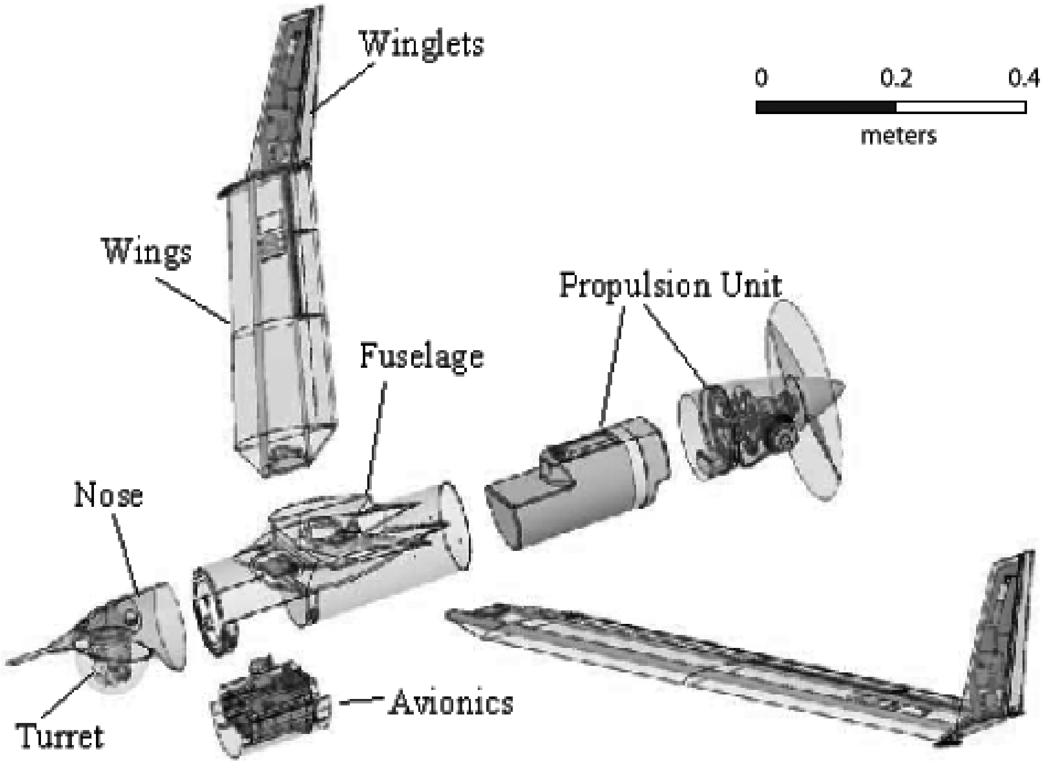

Figure 2. The Insight A-20, the unmanned aerial vehicle (UAV) used during the detection tests on whale-like targets near Port Townsend, Washington, on 4 to 16 December 2006

significantly finer detail and allowed for confirmation of whale-like targets or for rejection of false positives (e.g., logs, kelp, gulls, etc.).

The usual turret in the Insight at the time of the tests was the Alticam 400, but for the tests reported here, Insitu provided two Insight A-20 aircraft with a beta-test version of the Alticam 600 turret for evaluation.

Ground Control Station—The GCS consisted of two operator stations: one was a flight control station and the other a video data exploitation system. Three people operated the GCS during the tests. One operator controlled the UAV and input flight parameters, while two marine mammal observers (MMOs) spotted and recorded the whale-like targets during the survey; saved video and still clips of each sighting; and recorded environmental variables such as glare, wind speed, rain, fog, and other information which could be used to confirm sighting of a whale-like target. Each operator station had three, high-resolution flat-screen displays that could be configured in a number of ways. Examples of data that could be displayed on one or both stations are preprogrammed flight tracks with the current UAV location, which were overlaid on detailed maps of the region; video imagery relayed from the UAV in real time; enhanced video imagery delayed by 4 s (for review of objects of interest); imagery from successive frames that was stitched together to form a mosaic of the search area in real time; video clips (30-s segments of the video that could be saved upon request and could be reviewed in near real time); and a list of the 120 flight parameters downloaded from the UAV at up to 20 Hz. Flight parameters were monitored in tables and rolling graphs monitored by the GCS. Based on these, the pilot was notified of potential issues or malfunctions.

Survey Patterns

Parallel transects were flown along the long axis of the study area with different distances between center lines, depending on the search-width during the flight (Figure 3). We designed the grids to test different search-widths based on different UAV altitudes and environmental conditions. Based on 2 d of pretest flights, a survey altitude of 305-m with 600 m and 400 m between survey lines was identified as the best candidates for tests. When time permitted, additional surveys with alternate parameters were conducted at 457-m altitude or at 305-m altitude using other search-widths. Cetacean surveys in the Canadian and Alaskan Arctic are typically flown at 305- to 457-m altitude (Davis et al., 1982; McLaren & Davis, 1985; Harwood et al., 1996). Table 2 gives the altitude, search-width, survey speed, and whale target information for each test flight. The average time to complete a survey was 55 min (range 43 to 90 min).

The spacing between transect lines was planned to allow ~5% overlap of the searched area with neighboring transects, but errors in the original design specifications sometimes resulted in gaps in coverage between adjacent transects because the camera did not scan as far to the side as specified by the manufacturer. Although the error was discovered near the beginning of the tests, it was not confirmed until approximately halfway through the study, and, thus, operations continued under the same parameters to keep data collection consistent. Post-season analyses of the imagery obtained during the study found some additional gaps in coverage within the reduced survey width. These gaps were later confirmed to be related to an error in the camera turret programming that has since been corrected by the manufacturer of the camera turret. Because of these two problems, we were not able

Table 1. Specifications of the video camera used during the test of a UAS to detect whale-like targets in Admiralty Bay, Washington, on 4 to 16 December 2006

Parameter	Specification
Sensor type	EO daylight
Sensor sensitivity	400 to 900 nanometers
Sensor pixels	640 × 480
Video	NTSC[1] analog
Lens	Remote control motorized zoom and auto focus
Lens focal length at zoom 1.6×	80 mm
Resolution spot size (RSS) at the center (edge) of search area	25 (32) cm
Zoom factor	1 to 25 optical
Field of view (optical)	45 degrees (1×) to less than 2 degrees (25×)
Weight (camera and lens)	About 230 g
Sensitivity	3 lux

[1] NTSC = National Television Standards Committee (= North American analog video format)

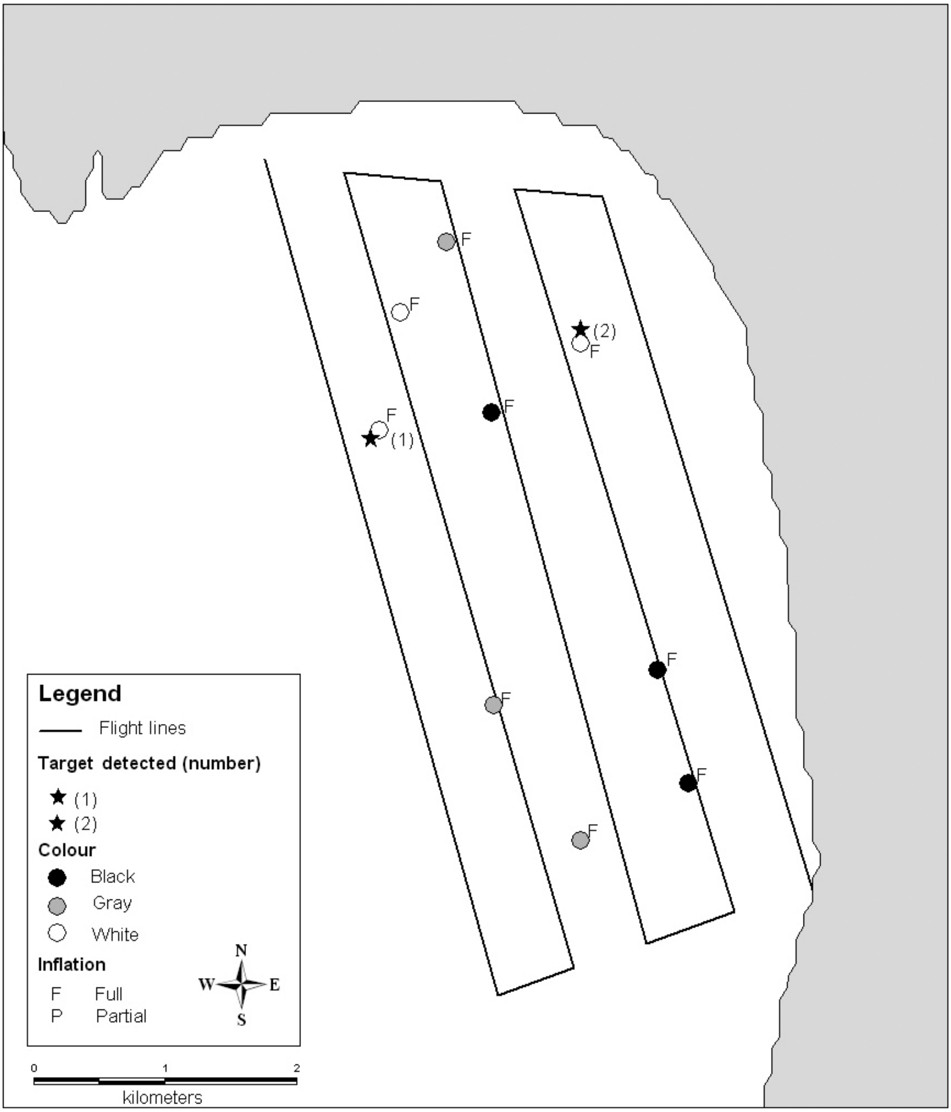

Figure 3. Transects flown during the first UAS detection trial on 9 December 2006; symbols show whale-like target locations and types, and stars show detected whale-like targets. Search parameters were 305-m altitude, 1.6× zoom, and 600-m nominal search-width. Environmental factors included slight haze, intermittent light rain, and Beaufort wind force of 2 to 4.

to determine which whale-like targets were available for detection during flights with zoom settings of 1.0 and 2.5, and, therefore, only flights with a zoom of 1.6× were included in the analyses.

Whale-Like Targets

Three-meter long inflatable kayaks were used to simulate whale profiles during the test flights. Canvas tarps were painted one of three colors with flat paint and draped over the kayaks to simulate whale profiles and colors. The kayaks with canvas tarps provided an above-water surface area equal to medium-sized bowhead whales (*Balaena mysticetus*) and gray whales (*Eschrictius robustus*) based on measurements from aerial photographs. The 3-m long kayaks substantially under-represented the size of fully mature whales, which are 10 to 18 m. Colors that were used included black, to simulate the color of bowhead whales; gray mottled, to simulate the patterns of gray whales; and white, to simulate an over-sized beluga whale (*Delphinapterus leucas*) and to provide a target

Table 2. Test parameters during each of the UAS detection trials on whale-like targets conducted near Port Townsend, Washington, 4 to 16 December 2006

Date – Test	Altitude (m)	Zoom	Search-width (m)	Survey speed (km/h)	Sea conditions[1]	Targets available
6 Dec – 2	305	1.6	600	102	1-2	9
7 Dec – 1	305	1.6	600	83	3-4	5
7 Dec – 2	305	1.6	600	83	3-4	5
7 Dec – 3	305	1.6	400	83	3-4	4
8 Dec – 1	305	1.6	600	83	1-2	9
8 Dec – 2	305	1.6	400	83	1-2	9
9 Dec – 1	305	1.6	600	93	3-5	9
9 Dec – 2	305	1.6	400	102	4-6	9
12 Dec – 1	305	1.6	600	83	2	9
12 Dec – 2	305	1.6	400	83	1-2	9
13 Dec – 1	305	1.6	600	83	2-3	9
14 Dec – 1	305	1.6	600	83	2	8
14 Dec – 2	305	1.6	400	83	1-2	7
16 Dec – 1	305	1.6	600	83	2-3	9
16 Dec – 2	305	1.6	400	83	1-3	9
16 Dec – 5	305	1.6	600	83	2	9
Total						128

[1] Beaufort wind force scale

with maximum contrast against the dark water. To provide two different simulated whale profiles, some of the kayaks were fully inflated to provide "large" whale-like targets and others were partially inflated to provide "medium" sized whale-like targets. The sample sizes of the three colors and two levels of inflation during each flight used in the analysis are shown in Table 3.

The locations of kayaks within the survey area were randomly chosen before tests each day. If more than two test flights were conducted per day, the kayaks were repositioned after both pairs of observers had conducted a test flight so the kayak positions were unknown to observers during each flight. Kayaks were anchored with ropes that were approximately six times longer than the water depth, which allowed the whale-like targets to move around the anchor, depending on wind and current direction and speed. These long anchor ropes were required to prevent the kayaks from drifting because of strong currents in the study area. Whale-like target locations were recorded both during deployment and recovery but were not revealed to the MMOs, UAS operators, or pilots until after flights were completed by both pairs of MMOs.

Search Methods

Prior to the start of each survey, the operator uploaded a flight plan with survey patterns (see Figure 3) to the Insight UAV from the flight control station. The flight plan defined the parameters of the search, including the position of the track lines, altitude, and speed. The Insight camera system had a built-in scan function that panned the camera back and forth across the vehicle's flight-path. Prior to each flight, variables controlling the search area (i.e., left/right limits, forward distance, and scan period) and camera operation (i.e., shutter speed and zoom) were uploaded from the flight control station to the UAV. The left and right limit settings of the pan mode defined the perpendicular distance from the aircraft's flight-path that the center of the camera's field of view was allowed to travel as it panned. The forward distance defined how far in front of the aircraft's position the video frame was centered as it panned back and forth. The period setting determined the over-ground distance traveled by the aircraft during one complete scan cycle (left-right-left pan).

The operator and one MMO watched the real-time video feed from the UAV to the GCS to locate whale-like targets. When an object of interest was observed, the information would be passed orally to the second MMO who was watching an enhanced video produced by a custom software program (*Terrasight Player*™). The enhanced video was displayed with a 4-s delay. *Terrasight Player*™ software allowed capture of the video stream for a period up to 30 s (the period is operator selected) before the save command was issued. This gave the second MMO a brief warning before the object of interest appeared on their screen and allowed them to take a real-time video clip, which

Table 3. Sizes and colors of kayaks deployed as simulated whale targets during UAS detection trials conducted near Port Townsend, Washington, 4 to 16 December 2006; large targets were fully inflated kayaks and medium targets were partially inflated kayaks.

	Large			Medium			
Date – Test	White	Gray	Black	White	Gray	Black	Total
6 Dec – 2	2	2	2	1	1	1	9
7 Dec – 1	1	2	1	0	0	1	5
7 Dec – 2	1	2	1	0	0	1	5
7 Dec – 3	1	1	1	0	0	1	4
8 Dec – 1	2	2	2	1	1	1	9
8 Dec – 2	2	2	2	1	1	1	9
9 Dec – 1	3	3	3	0	0	0	9
9 Dec – 2	3	3	3	0	0	0	9
12 Dec – 1	3	3	3	0	0	0	9
12 Dec – 2	3	3	3	0	0	0	9
13 Dec – 1	2	2	2	1	1	1	9
14 Dec – 1	2	2	2	1	0	1	8
14 Dec – 2	2	2	1	1	0	1	7
16 Dec – 1	2	2	2	1	1	1	9
16 Dec – 2	2	2	2	1	1	1	9
16 Dec – 5	2	2	2	1	1	1	9
Total	33	35	32	9	7	12	128

could immediately be reviewed to decide whether the UAV track should be paused to get a better look at the object of interest.

During periods with light to moderate winds, it was difficult to return to an object of interest after detection if the aircraft was allowed to continue. Consequently, the operator marked the object of interest immediately when it was detected, and the UAV circled that GPS coordinate while one MMO reviewed the video and the second MMO and the operator attempted to zoom in on the object. This procedure permitted immediate location of the object and quick classification of possible whale-like targets.

The MMO data recorded during flights were reconciled with the saved video clips from *Terrasight Player*™ after the survey was completed. The video allowed us to compare the positions of objects that were identified as whale-like targets during the survey with the positions of actual targets deployed during that survey (e.g., Figure 3). As noted above, because of the long anchor ropes, the positions of kayaks could vary by up to 150 m around the anchor point, depending on wind and current conditions.

Analysis Methods

In total, data were available from 16 test flights on 8 d from the period 6 to 16 December 2006 (see Table 3). During these flights, a total of 128 whale-like targets were placed in the study area and were available for detection. Following inspection of the video records and matching locations to remove multiple detections of the same target and false detections at locations where no targets were present, all whale-like targets in the study area were recorded as either "detected" or "undetected" during each trial. Characteristics of the targets (i.e., color and degree of inflation), flight parameters (i.e., search-width and shutter speed), and environmental conditions (i.e., Beaufort wind force [Bf]) were recorded during the flight or for individual targets. The objective of the analysis was to identify the combination of whale-like target characteristics, flight parameters, and environmental conditions that were associated with high (and low) probability of target detection. The five primary covariates included in the analyses were target color, degree of target inflation, camera shutter speed, search-width, and Bf (an indication of sea conditions).

To achieve the analysis objectives and to relate detection probabilities to target, flight, and environmental conditions, an exploratory logistic regression model (McCullagh & Nelder, 1989, Chapter 4) was estimated using stepwise Akaike's Information Criterion (AIC) variable selection. Responses in the logistic regression models fit during stepwise selection recorded detections to be "successes" (coded as 1) and nondetections as "failures" (coded as 0). Detections of individual whale-like targets were treated as independent of one another because targets were randomly placed within the study area prior to each trial, and MMOs conducting the trials were unaware of target locations. Following stepwise model selection, all subsequent inference and detection probabilities were estimated using this final model. All analysis was carried out using the R statistical programming language (see *The R Project for Statistical Computing*, www.r-project.org) and the functions *glm* and *step*.

Stepwise AIC variable selection proceeded as follows. The initial model at step one contained an intercept term only. A list of potential effects, including interactions, were added one at a time to an initial model, and AIC statistics were recorded. If AIC was reduced when at least one effect was added, the effect that reduced AIC the most was added to the initial model that, in turn, became the initial model for the next step. If AIC was not reduced by the addition of any effects, the stepwise process stopped. If removal of any effect already in the initial model resulted in a lower AIC, the effect that reduced AIC the most was removed.

The set of effects considered for inclusion in the logistic regression model consisted of the five primary covariates (listed above) and six interactions among the five primary covariates that were deemed estimable. An interaction between two primary covariates was deemed estimable if an adequate number of whale-like targets (~5) existed in every combination of the two variables. When ~5 or more targets existed in every combination of variables, coefficients for the interaction effects were stable with reasonable SE. This was not surprising because, as a general rule of thumb, the normal approximation to the distribution of a binomial proportion is adequate when n = ~5 or more, indicating that the mean can usually be adequately estimated. For example, to estimate the interaction between target color × the degree of target inflation, adequate numbers of partially inflated black, partially inflated gray, partially inflated white, fully inflated black, fully inflated gray, and fully inflated white targets were required. Of the five primary covariates, all were considered to be discrete. The six interactions deemed estimable were search-width × color, search-width × degree of target inflation, shutter speed × color, color × degree of target inflation, and color × Bf.

Results

Logistic Regression Modeling

During stepwise model selection, Beaufort wind force (Bf) entered first, followed by degree of target inflation (full or partial) and color. Addition of camera shutter speed, search-width, or any of the six interaction terms did not reduce AIC further and, therefore, did not enter the best-fit model. The final exploratory logistic regression model selected by stepwise minimum AIC was

$$\ln(\Pr(detection) / (1 - \Pr(detection))) = 0.1339 + 0.2154(\text{targetcolor=gray}) + 1.4840(\text{targetcolor = white}) + 1.9479(\text{degree of target inflation = partial}) - 1.1968(\text{Bf=3}) - 3.0177(\text{Bf=4}) - 3.2503(\text{Bf = 5})$$

Predicted probabilities of detection for all combinations of variables in the final model appear in Figure 4. In the final model, average probability of detection declined dramatically as Bf increased from 2 to 3 to 4 or 5 (2 vs 3, $p = 0.034$; 2 vs 4, $p = 0.007$; 2 vs 5, $p = 0.005$). For example, average detection probabilities for white, fully inflated targets, declined from 83% for Bf = 2 to less than 20% when Bf was 5. Black targets were detected less often than gray targets but not significantly so ($p = 0.67$). Black targets were detected significantly less often than white targets ($p = 0.009$). Partially inflated targets of all colors were detected more often than fully inflated targets ($p = 0.005$).

Discussion

Several factors influenced the detection rates of whale-like targets by the UAS. Wind, target color, and degree of target inflation all had strong influences and were included in the model that provided the best fit to the test data. All factors except degree of target inflation had the expected effect on detection rate. Surprisingly, partially inflated targets were detected more frequently than fully inflated targets. We speculate that the partially inflated targets created more surface disturbance than fully inflated targets, thus creating more white froth and wave action on the surface of the water, which increased visibility of the partially filled targets. If true, the partially filled targets more accurately reflect the wave action created by a surfacing whale than do the fully inflated targets. Additional tests with larger sample size should be conducted to confirm this.

Logistic regression identified Beaufort wind force (Bf) as the strongest predictor of target detection rate. Previous studies of marine mammals have identified Bf as strongly influencing the detection rates of marine mammals during ship and aerial surveys (Gunnlaugsson, 1991; Palka, 1996; Barlow et al., 2001, 2006; DeMaster et al., 2001; Teilmann, 2003). As a consequence, past studies have used upper limits of Bf = 4 or 5 for including effort and sightings in analyses of survey data for large cetaceans and dolphin groups, and Bf = 2 for including secretive species such as beaked whales, pygmy sperm whales (*Kogia breviceps*), and dwarf sperm whales (*K. sima*). Even at Bf = 5 (wind speed = ~31 to 39 km/h), the detection rates for gray and black whale-like targets were 25 to 29% when the search-width was 400 m. These detection rates are similar to expected rates based on the above studies (Table 4).

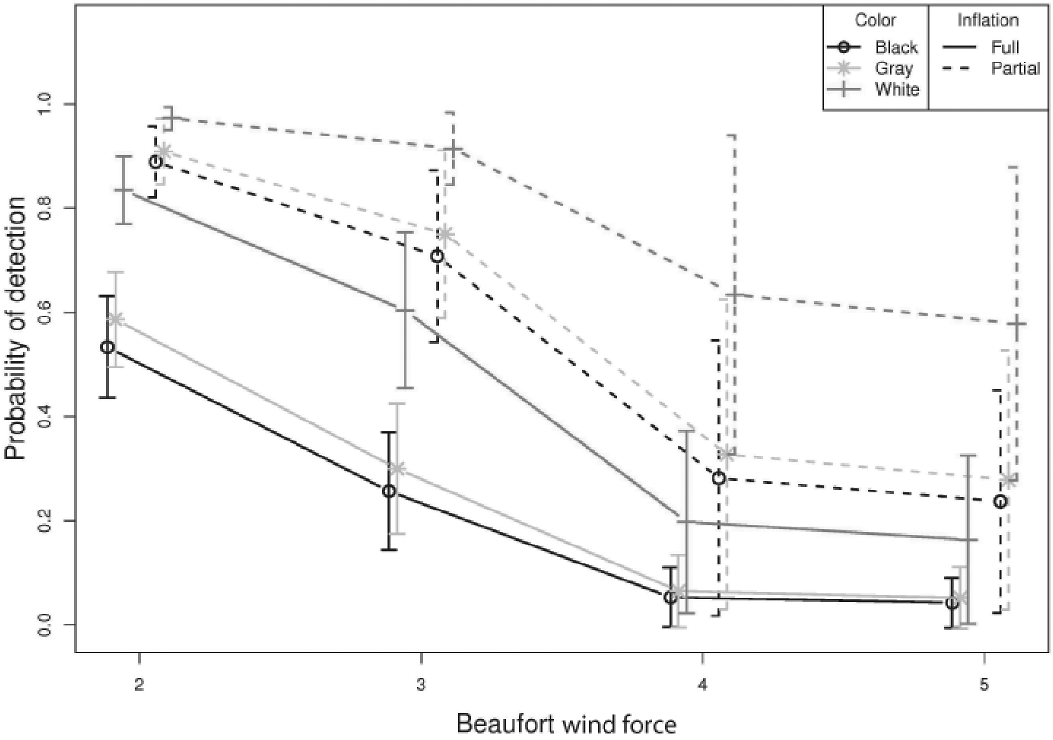

Figure 4. Predicted probabilities of detection of whale-like targets by a UAS from the final logistic regression model that included Beaufort wind force, degree of inflation, and color; vertical bars are ± 1 SE of the prediction.

Detection rates of white targets were higher than for gray and black targets. In this test, black, gray, and white targets represented marine mammals that would be encountered during Arctic surveys (i.e., bowhead, gray, and beluga whales, respectively). The white targets were larger (and therefore more obvious) representatives of beluga whales, while the black and gray targets were designed to be close in size to the surface expression of the species that they represented. White targets were included in this study because they were expected to be detected during circumstances when gray and black targets would not be detected. Although detection rates of the white targets were higher, their detection rates declined similarly to gray and black targets when Bf increased.

Since these tests were conducted, the UAV's manufacturer has made improvements to the turret control system to provide more consistent search patterns. These improvements provide autonomous changes to video coverage to provide consistent water surface coverage when ground speed and search parameters are modified. They have also made specific modifications to their interface which are designed to enhance the ability of a pilot/MMO team to quickly mark and re-acquire a mammal's position. Although these improvements were not tested during this study, it is likely that they will have a positive effect upon system performance.

Based on the above-reported experiment, it appears that a UAS has the potential to replace manned aircraft during surveys for large cetaceans or large groups of small cetaceans if the search area is small. However, higher video resolution is needed before the UAS would be effective for surveys of large areas or for detection of smaller cetaceans and pinnipeds.

There are also safety and regulatory issues associated with operating a UAS in civil airspace which need to be addressed by the Federal Aviation Administration (FAA) in the U.S. and by local agencies in other countries.

The tests reported above used covered kayaks, which are at the surface 100% of the time, as simulated whale profiles, and it is not known whether a UAS could detect real marine mammals as well as it can detect the kayaks. Therefore, side-by-side comparisons between the UAS and a manned aircraft are needed to evaluate any differences in detection rates from the two platforms. Marine mammals are at or above the surface, where they

Table 4. Proportions of cetaceans detected during aerial and vessel-based surveys conducted during different Beaufort wind force conditions compared to detection of whale-like targets by the UAS in this study; values in bold typeface account for animals that were at the surface but were missed and values in regular typeface assume that all animals at the surface were seen when Bf was 0.

		Beaufort wind force					
Study	Species/platform	0	1	2	3	4	5
This study (see Figure 4)	Fully inflated black kayaks/aerial	**NA**	**0.53**[a]		**0.26**	**0.05**	**0.04**
This study (see Figure 4)	Fully inflated white kayaks/aerial	**NA**	**0.83**[a]		**0.61**	**0.21**	**0.16**
This study (see Figure 4)	Partially inflated white kayaks/aerial	**NA**	**0.97**[a]		**0.92**	**0.63**	**0.57**
Gunnlaugsson (1991) combined Tables 1 & 2	Minke whale/vessel	1.00	1.07	0.47	0.30	0.14	0.22
Davis et al. (1982); McLaren & Davis (1985)	Bowhead whale/aerial	**0.69**[b]		**0.64**	**0.63**	**0.27**	**0.42**
Palka (1996)	Harbour porpoise/aerial	1.00	0.94	0.49	0.25	NA	NA
Barlow et al. (2004)	All species/vessel	1.00	0.85	0.36	0.19	0.08	0.04
Barlow et al. (2006) – SEFSC 1991-2003	Beaked whales/vessel	1.00	1.03	0.50	0.24[c]	0.15[c]	0.09[c]
Barlow et al. (2006) – SWFSC 1986-2202	Beaked whales/vessel	1.00	0.43	0.08	0.07[c]	0.01[c]	0.03[c]
Barlow et al. (2006) – NEFSC 1998	Beaked whales/vessel	NA	1.00	0.16	0.05[c]	NA	NA
Jackson et al. (2008)	All species/vessel	1.00	0.63	0.39	0.25	0.11	0.09
DeMaster et al. (2001)	Beluga whale/aerial	**1.00**[b]		0.34	0.33	0.26	NA

[a] Calculated from sightings and effort with Beaufort wind force 1 or 2

[b] Calculated from sightings and effort with Beaufort wind force 0 or 1

[c] Beaked whales are not expected to be reliably detected during these sea conditions.

can be seen, for only a fraction of the time. During manned surveys, observers can detect the presence of surfacing animals over a wider area than a UAS because observers have a wider field of view than the video camera. Also, observers may be able to detect other sighting cues, such as hanging blows and surface disturbances, that might not be detected by the UAS.

These tests provide some anecdotal information concerning these points. During one of the test flights, two surface disturbances were noted. While circling the location, a single minke whale (*Balaenoptera acutorostrata*) was observed to surface. Sea conditions were calm (Bf = 1), and under those favorable conditions, the surface disturbances were detectable by the UAS for about 1 to 2 min after the whale dove. We do not know if other medium or large cetaceans might have been present in the survey area and not detected by the UAS, but none were seen by personnel aboard the *USRV Shackleton* or the *M/V Cascade*, which deployed, moved, and recovered the kayaks during the study. Secondly, the video system seems to enhance contrast between some objects and the water surface. For example, floating kelp appears to have been more readily detected on the video system than it would have been by human observers in an aircraft. A third point worth noting is that harbor seals (*Phoca vitulina*) and California sea lions (*Zalophus californianus*) were present in the area and were seen by observers on the *USRV Shackleton* on several occasions; however, no pinnipeds were detected by the UAS, even during calm seas.

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