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Technical Note: A low cost Unmanned Aerial Vehicle for ship based science missions

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Abstract

A low-cost Unmanned Aerial Vehicle is compared with those already available and the motivation for its development is established. It is targeted at ship-based science missions and potential applications are described including a specific science case to measure white capping in the deep ocean. The current vehicle includes a range of more than 1000 km, carrying a payload of 2 kg and it can be launched and recovered from a coastal research vessel. The vehicle has flown successfully in Force 4 gusting Force 6–7 wind conditions, an important requirement for operation at sea. Data analysis is performed on images captured by the vehicle to provide a measurement of wave period and white capping fraction. The next stage of the project is to develop a suitable payload and perform a demonstration science mission.

1 Introduction

As part of a continuing programme to enhance measurement techniques the National Oceanography Centre Southampton (NOC) commissioned a study into the use of UAVs in oceanography (Pluck et al., 2003). There have also been studies by Lomax (Lomax et al., 2005) and Peterson (Peterson et al., 2003) among others. These studies indicate a gap between high-resolution direct measurements at the sea surface (by ships, gliders and buoys) and wide-area but low-resolution satellite measurements. They suggest this gap could best be filled with an airborne platform. This platform should carry a payload of instrumentation over distances that allow mesoscale ocean features to be examined. It should also be ship-based to allow it to operate in remote locations (Sect. 2) and travel quickly enough to survey a feature within one working day.

1.1 Existing commercial systems

The Aerosonde UAV has been developed commercially since 1993 (McGeer and Holland, 1993) and it is aimed at a variety of scientific missions. It can carry numerous

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types of sensor (Holland, 2001) including panchromatic imaging, infra-red and barometric. So far, it has only been applied in areas where the vehicle can be launched and recovered from land. This may partly be due to the high cost per vehicle and the difficulties involved in recovering it at sea. However, it does perform well in heavy wind as demonstrated by Lin and Lee (2008) who used an Aerosonde to measure the wind speed inside a typhoon.

The Insitu group SeaScan is a commercial UAV designed specifically for operation at sea (Insitugroup, 2007). It includes a catapult launch and a wire recovery system. The vehicle has very long endurance at over 22 h and only a 3-m wingspan. It can carry payloads of up to 6 kg and includes a stabilised camera turret. One vehicle, a control centre, launcher, capture system and training cost around $420 000 (Ramsey, 2004). The wire recovery system used is practical only in relatively good weather conditions where there is little ship motion and there is little gusting wind.

The Gull UAV is a small seaplane developed by Centaur Systems (Centaur Systems, 2007). It has demonstrated launching and landing on the sea in calm conditions but would likely not be able to operate in poor weather when working in the deep ocean. This would be necessary for some of the proposed science missions like the measurement of white capping (Sect. 2).

1.2 Technology gap

Consequently, although there are UAV systems available commercially, none of these can fulfil our requirements. They cannot operate from a ship in poor weather conditions and the individual vehicle cost is too high, making the impact of even a single loss significant to a science mission with limited funding. This leads to the requirement for a new UAV design that can be launched and recovered in poor weather, whose major components can be easily replaced and has a low cost per aircraft reducing the impact of any losses or damage.

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2 Motivating marine science applications

The motivating application for the development of this low cost Unmanned Aerial Vehicle is any science where there is a high probability of damage to the vehicle. This could be caused by poor weather in flight but it is most likely that any damage would occur during recovery. In heavy seas when there is a lot of ship motion, it is not deemed possible to recapture a UAV on deck for safety reasons. Existing systems typically only operate in light conditions. Landing the vehicle in the sea will damage many of its components but would allow it to be recovered as research vessel crews have a great deal of experience at retrieving equipment from the water.

As well as using the research vessel as a platform for deployment, one of the most useful modes of operation of a UAV could be in supplementing the work already being undertaken. This would involve flying ahead of the vessel to allow its research to be more accurately directed to areas of interest. Figure 1 shows a satellite image of remotely sensed chlorophyll, the dark areas are cloud cover showing that a UAV operating under the cloud could reveal more information as well as higher resolution images. Several mesoscale applications such as plankton bloom monitoring, where the area of interest is hundreds of square kilometres in size, could be enhanced by the ability to identify the edges and centre of the feature. Features as large as this require an aircraft with a range in excess of 1000 km as well as the ability to operate away from land.

One motivating example is to improve understanding of wave breaking and white capping in the open ocean. These processes have a large influence on greenhouse gas exchange, sea-spray aerosol generation and air-sea fluxes of latent and sensible heat (Melville and Matusov, 2002). They are also currently poorly understood. Studying the same processes in coastal areas would also allow the influence of fetch and wave development to be examined. The critical measurement is area coverage of foam, which can be derived from optical imaging (an example analysis is shown in Sect. 5). The sensor package required would be a digital still/video camera with

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altimetry, attitude, speed and a measurement of the flux profile by the ship. As white capping only occurs where there are winds to create waves, this means it is really only useful to make measurements in conditions Force 4 and above.

3 Low cost design

Due to the almost inevitable damage to the vehicle when performing the types of missions described in Sect. 2, it is necessary for the vehicle itself to be low-cost relative to the value of the data that is collected. This does not mean that all the parts of the system will be low cost but that those most likely to be damaged should be. In addition, the value of the data generated by a single flight can be increased through good design leading to long range.

The damage caused by landing in the sea and the subsequent recovery by the research vessel will be to the large mechanical components, most likely to be damaged are the wing, tail and engine. This means that these must be commodity items, easy to replace and recondition with many of them taken as spares on each trip. The expensive items where replacement must be avoided (the flight control system and payload) are all contained within the fuselage. This needs to be buoyant, watertight and strong to withstand the recovery process.

More valuable than the physical hardware is the data collected during the mission. To reduce the impact of a total vehicle loss the data can be transmitted over a high bandwidth link prior to landing although this is very dependent on the mission profile. A 5 Megapixel image each file when compressed (JPEG100) results in typically 1.5 MB of data, if these are taken of a 200 square metre area at 30 m s^{-1} the resulting data rate is 220 KBps. If the vehicle stays in range of the high-bandwidth 2.4 GHz link for the entire mission (≈10 km with omni-directional antenna), it would be possible to transfer the data in real time. However, outside this range, the images could be stored; 6 h at this data rate creates 5 GB of data, which at close range could be transferred before landing at a rate of 11 Mbps taking 1.2 h. It may be possible to transfer just a subset

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of the data before landing, for example: every other image, highly compressed images or the processed result from each image (a single value indicating percentage of white capping or other parameter of interest).

The electronic hardware required to fly the aircraft is already a commodity item and can be manufactured for less than £1000. The valuable part of this system is the software component, which may take many years of development to reach a suitable level of sophistication. This makes it advantageous to develop a bespoke flight control system, as the loss of the hardware does not mean having to pay for the repeated software costs associated with buying from a commercial provider.

4 Overview of the current system

The UAV developed at the NOC has been designed to meet the requirements set out in Sect. 3. It is a pusher configuration with a 3.2-m wingspan, a payload capacity of 2 kg and a calculated range of more than 1000 km. This long range is enabled by good aerodynamics (lift to drag ratio is greater than 10) and a fuel-efficient propulsion system (2 kg for 1000 km). To aid landing at sea and reduce impact damage the wing deploys large split flaps, reducing flight speed to below 17 m s^{-1} from 30 m s^{-1} at cruise.

A flight control system has also been developed and tested along with bespoke software algorithms (Bennett, 2007). This allows fully autonomous flight between waypoints that can be updated in real time from the ground control station.

Launch of the vehicle is by elastic powered catapult (Fig. 2); this system has been successfully tested on land in winds gusting to Force 6–7 and at sea in constant Force 2. The launcher is an 8-m track with a scissor action release (Fig. 3) ensuring the vehicle gets away cleanly and that after release the arms lie flat to the track. The launcher can accelerate a mass of 15 kg to 25 m s^{-1} (peak 6 G), well above the minimum flight speed for the aircraft without needing to deploy the flaps, making it capable of launching even in heavy gusting conditions.

Recovery at sea is performed by grappling for the specially reinforced tail boom structure or using an extendable pole with a noose around the fuselage. For the first recovery test at sea, it was possible to collect the vehicle directly using a small launch. The vehicle landed heavily but still floated high with the fuselage sealed and was easy to retrieve. There was damage to the wing and tail as expected (Fig. 4) but it was possible to recondition both components and the engine has subsequently run successfully.

5 Demonstration deployment

As part of the sea trials, where the launch and recovery aspects of the vehicle were demonstrated, images were taken from the aircraft of the sea surface. Wave period and white capping were measured from the images as a demonstration that the vehicle could meet the requirements of the motivating science applications.

Wave period can be estimated from the images as light from the sun illuminates one side of the wave. This creates a repeating pattern with a period equal to the spatial period of the waves. The dimensions of the image are calculated using the optical properties of the camera and the altitude of the aircraft. The processed image in Fig. 5 was taken at an altitude of 130 m; the wide-angle lens used during the flight gives a resolution of 0.2296 m per pixel.

To calculate the period, first the DC component was removed from the image and then a 2-D FFT was performed. The FFT was filtered to remove random noise and then a circular dilation filter was applied to enhance the peaks (Fig. 6). The dark areas indicate the most significant frequencies present in the image and their direction. Two distinct sets can be identified even in the very calm conditions, one at 19.5 m, 29.8°, which represents the wind driven sea, and one at 5.8 m, 73.8°, which is the most dominant chop period and direction. This data has been overlaid onto Fig. 5 where the green indicator lines show the wind driven waves and the blue indicator lines, the dominant chop.

The second type of data measured from the recorded images is percentage white capping fraction. A standard automated process developed by Moat et al. (2009) was applied to images taken during the flight. The result of this processing is shown Fig. 7, giving a calculated white capping fraction of 0.0432%. Given the very light conditions on the day of the test flight (Force 2), a very small fraction would be expected.

This data processing could be performed after recovery of the vehicle (as in these examples), although it is also possible that this data could be generated in real-time by the payload management system, providing a low rate subset for transmission to the ship.

6 Conclusions

The UAV developed at the NOC has made significant progress in the last four years. A prototype vehicle has been test flown from a NERC research vessel and the autonomous functions demonstrated using a test platform. The vehicle has a low cost of £5000 excluding payload, software and development. This meets the disposable requirement as part of science mission. It has also launched and flown successfully in winds gusting to Force 6–7 (over land), which would be considered the minimum conditions for the white capping survey used as an example.

There is some work remaining before the system can be regularly used for scientific measurement. Certification or regulatory requirements require further development with the Civil Aviation Authority. A typical payload package and associated electronics needs to be developed, as well as more testing of recovery techniques. The vehicle is currently not equipped to operate in very cold conditions although this is a possibility that has already been demonstrated by Aerosonde (Curry et al., 2004).

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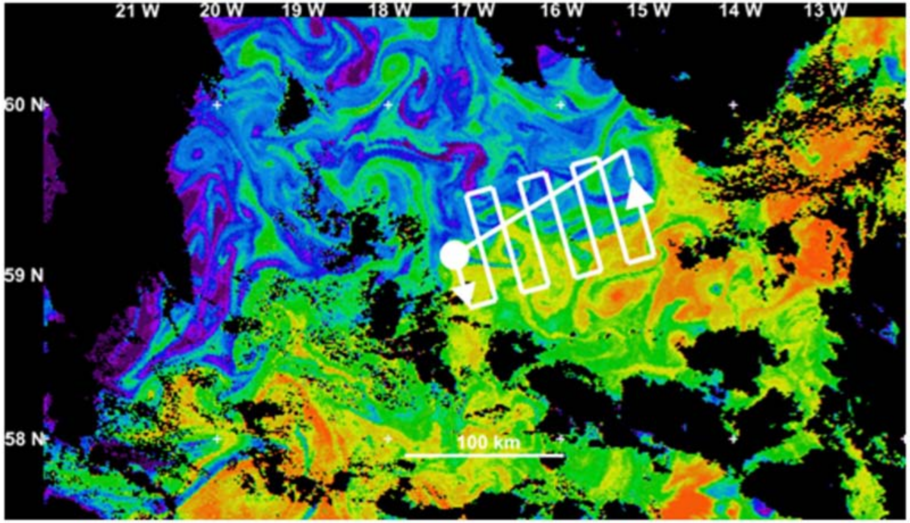

Fig. 1. This example shows chlorophyll concentration in a snapshot image of 11 June 2009 south of Iceland. Here the chlorophyll acts as a tracer of physical structures, mesoscale eddies and "hammerhead" structures, showing stirring of the ocean on scales of 1–50 km. The UAV survey (taking nine hours) would result in less smearing (be more synoptic) than a ship survey that would take more than thirty hours. Image produced by the NERC Earth Observation Data Acquisition and Analysis Service, Plymouth.

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Fig. 2. The NOCS UAV launching from the RRS Discovery, October 2008.

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Fig. 3. Image sequence showing the operation of the UAV release.

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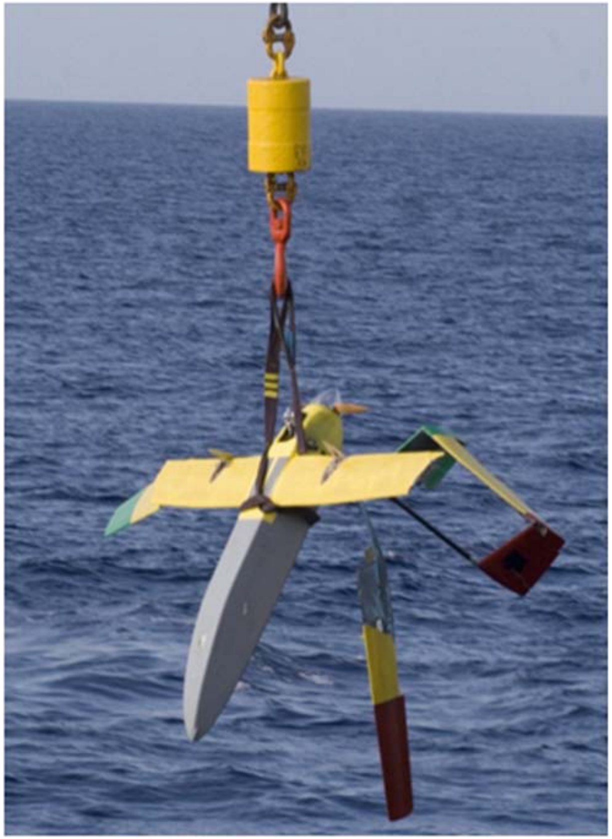

Fig. 4. The NOCS UAV being recovered onto the RRS Discovery in Force 2 conditions, October 2008.

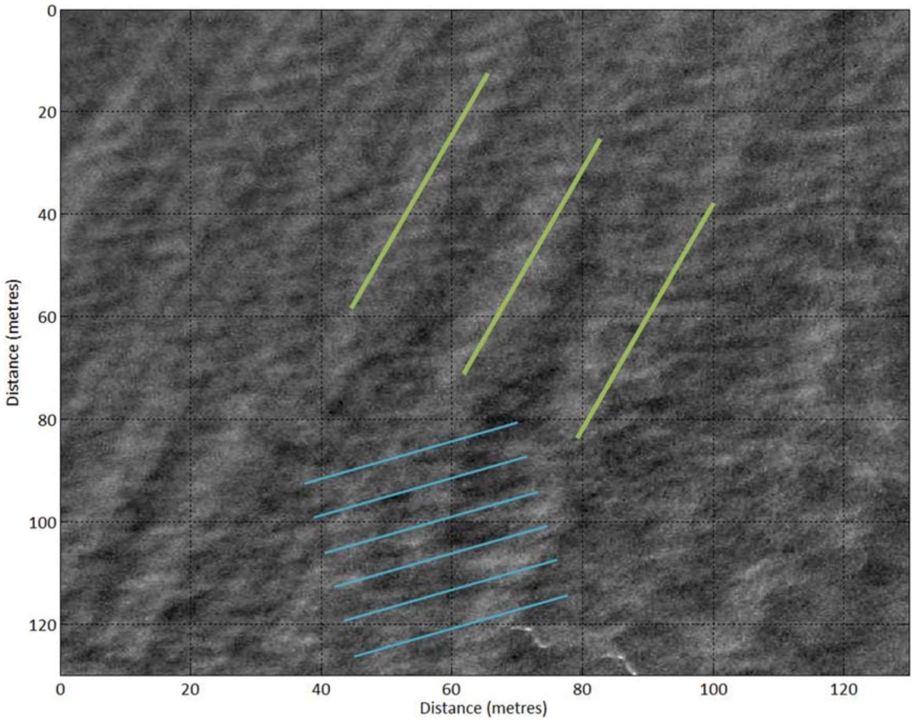

Fig. 5. Filter wave image with indicators to show the dominant measured wave periods.

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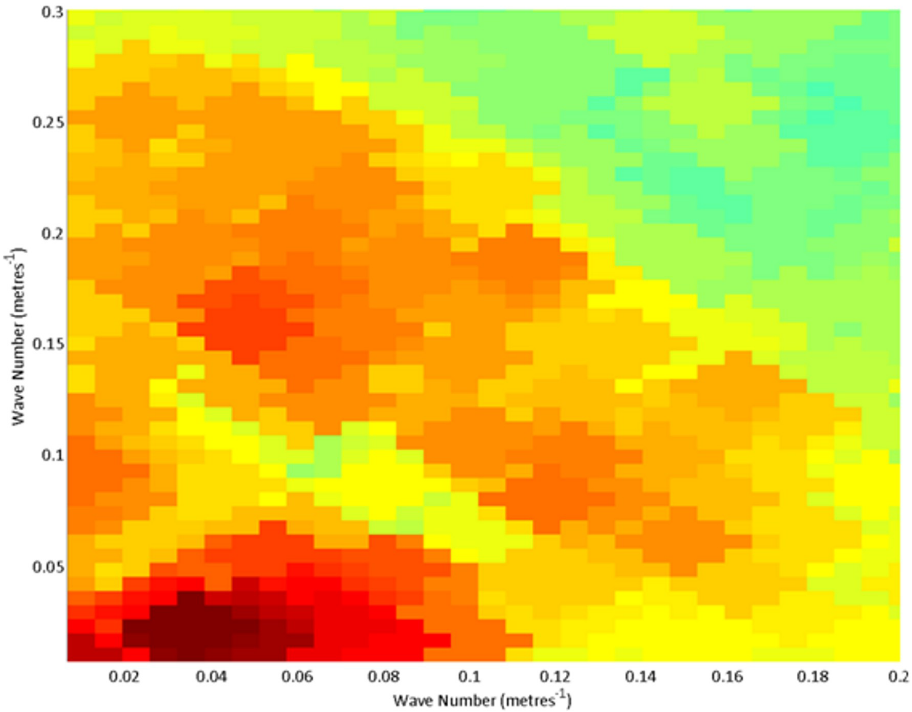

Fig. 6. Post filtered two-dimensional FFT of wave image.

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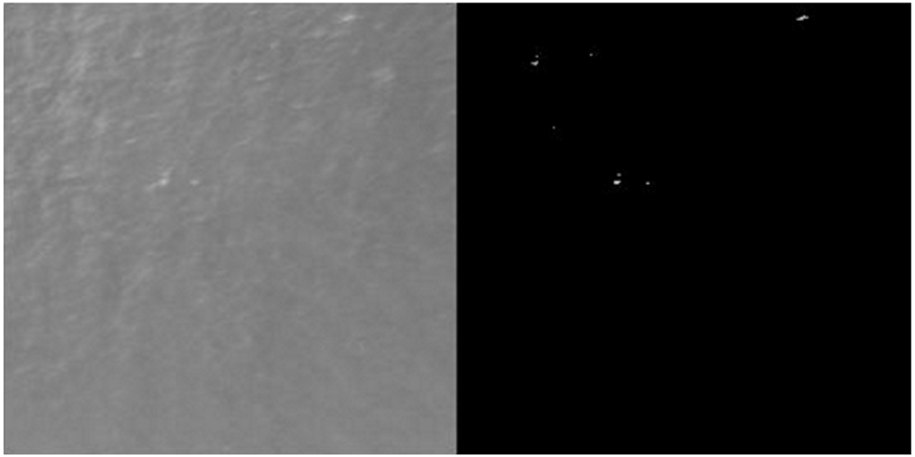

Fig. 7. Image processed for white capping measurement (0.0432%).

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