BERGEN - 30.08.2012
Ref. No.: CMR-12-A10266-RA-1
Rev.: 00

cmr Instrumentation

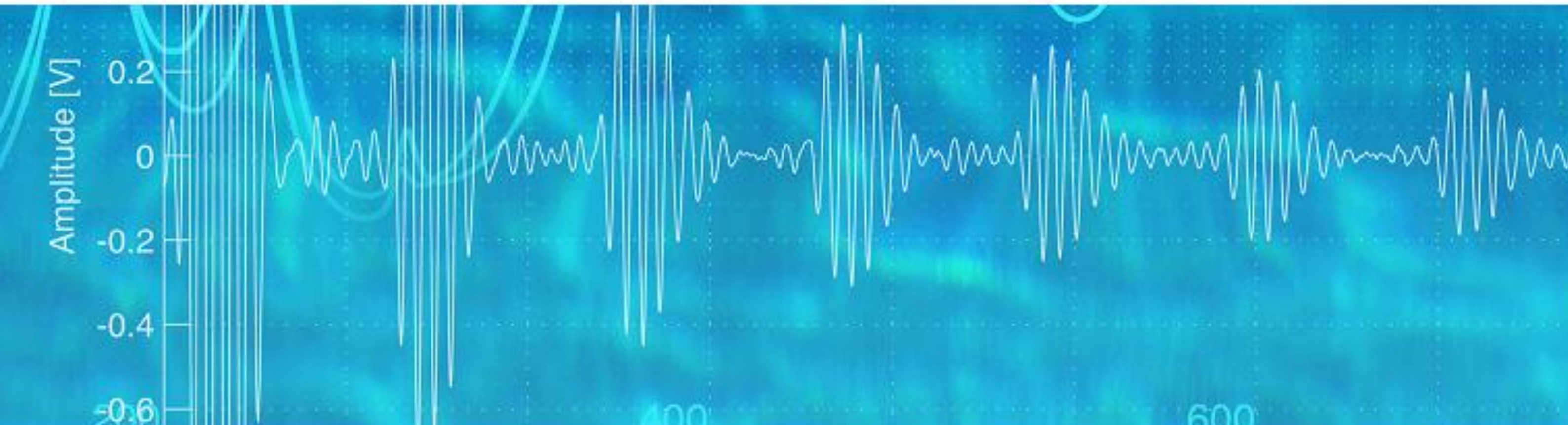
REPORT

Navigation performance of the SailBuoy

Bergen – Scotland mission

Client
N/A

Author(s)
Ilker Fer, David Peddie



Document Info

Author(s)

Ilker Fer, David Peddie

Classification (F=Confidential, SF=Strictly Confidential)

A

Title

Navigation performance of the SailBuoy

Extract

In this document, the navigation performance and characteristics are reported from a trial conducted in summer 2011 when the SailBuoy travelled a 1000-km-predefined course between Bergen (Norway) and Scotland in one month, from the 22nd of June to the 22nd of July 2011.

Project Info

Client

N/A

Client

N/A

CMR Project No.

10266

CMR Project No.

10266

Revision

Rev.	Date	Author	Project Manager	Dept. Manager	Reason for revision
00	30.08.2012	Ilker Fer		David Peddie	Created

Table of Contents

Disclaimer

CMR is not liable in any form or manner for the actual use of the documents, software or other results made available for or resulting from a project.

1 Introduction

The SailBuoy, developed by Christian Michelsen Research (CMR) Instrumentation, is an unmanned ocean vessel capable of travelling the oceans for extended periods of time (see http://www.sailbuoy.no and Section 2). It navigates autonomously, controlled by 2-way communication through the Iridium satellite system, transmitting data in real time underway. The SailBuoy can be fitted with various sensors to be used for a wide variety of ocean applications.

In this document, the navigation performance and characteristics are reported from a trial conducted in summer 2011 when the SailBuoy travelled a 1000-km-predefined course between Bergen (Norway) and Scotland in one month, from the 22nd of June to the 22nd of July 2011 (Figure 1).

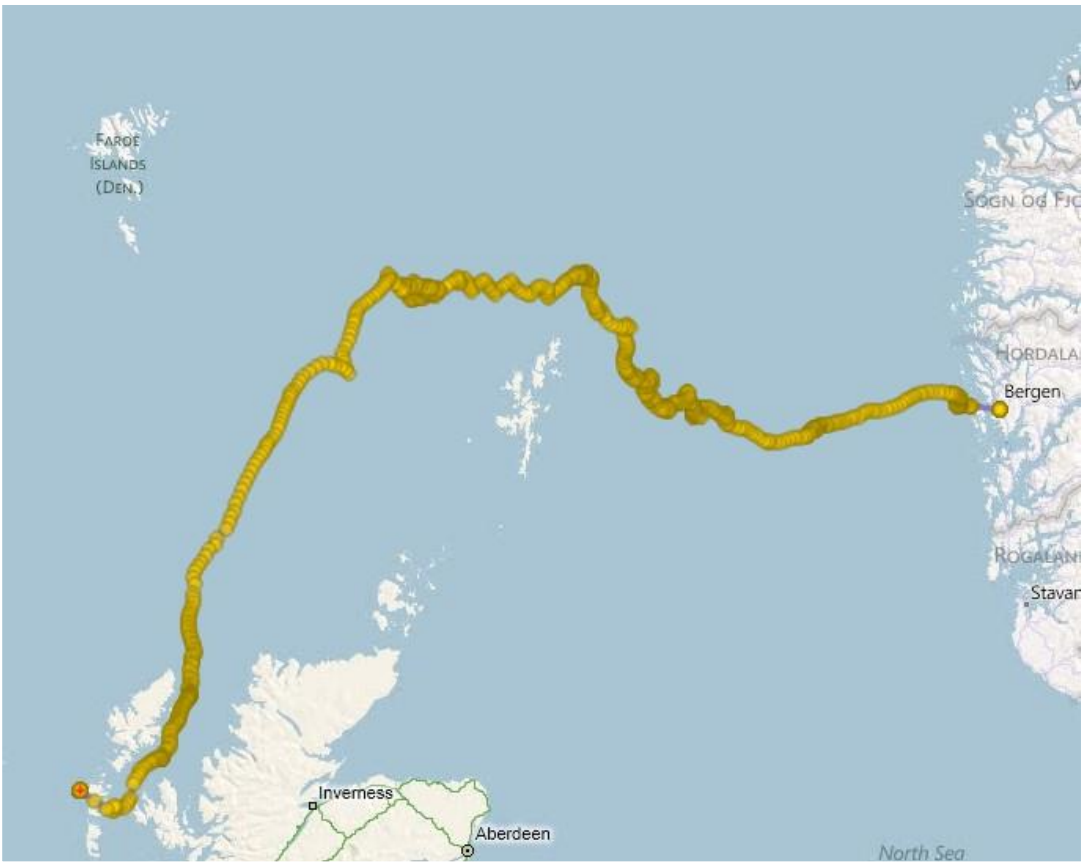


Figure 1. The track of the SailBuoy during the mission from Bergen to Scotland in summer 2011.

2 SailBuoy

The SailBuoy (Figure 2) is a small unmanned vessel which can be equipped with oceanographic and/or atmospheric sensors. It navigates autonomously and can be controlled by the 2-way communication system through the Iridium satellite system. Data is transmitted in real time, at regular intervals via satellite.

The SailBuoy has a length of 2 m, displacement of 60 kg and a payload of 10 kg (60 l). It is proven to navigate under control up to wind speeds of 20 m s^{-1} at a speed of up to 1 m s^{-1}.

The SailBuoy can be equipped with conductivity and temperature sensors to measure the upper ocean temperature and salinity characteristics, heave sensor to measure the wave statistics, and wind and air pressure sensors to measure the atmospheric forcing. Other sensors to measure fluorescence, chlorophyll, blue green algae, crude oil and ocean current can also be installed allowing for a variety of applications, both scientific and industrial.

Figure 2. The SailBuoy SB01

3 Navigation characteristics during the Bergen-Scotland mission

The complete track of the mission from Bergen to Scotland is shown in Figure 1. For this mission SailBuoy SB01 was deployed. For the analysis of the navigation performance, the hourly GPS fixes between 22 June 2011 09:00 and 18 July 2011 and 18-Jul-2011 12:00 are used, i.e., excluding the portions near Bergen and Scotland where SB01 was manually navigated. Once offshore, SB01 was left to navigate autonomously and was given four waypoints underway. Figure 3 shows the portion of the track chosen for analysis together with the four assigned waypoints and the bottom topography.

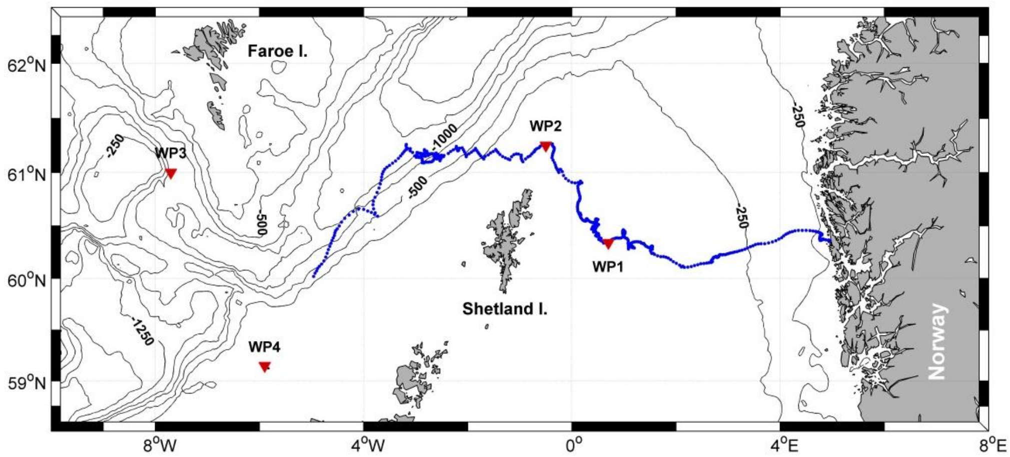


Figure 3. Map showing the track covered by SB01 (blue dots) in summer 2011. Isobaths (black) are drawn at 250 m intervals. Four waypoints (WP1 to WP4) are marked by the red triangles.

Together with the hourly position data, information on the course of the vessel relative to the wind was relayed. During the mission, SB01 sailed 75% of the time against and 25% of the time downwind. Out of a total of 590 hourly data points, 57 points were removed in the vicinity of the waypoints when SB01 kept position upon reaching a given waypoint, waiting for the next waypoint.

In order to calculate horizontal excursions and speed through water, the longitude/latitude positions are converted to distance referenced to the first point as the origin, using the SSM/I polar stereographic projection based on the Hughes Ellipsoid (exact at 70° latitude). The resulting vessel track with distance toward east and north is shown in Figure 4. During the period chosen for the analysis, SB01 covered a total range of 570 km in the east-west direction and 160 km in the north-south direction while sailing a cumulative total distance of 1145 km.

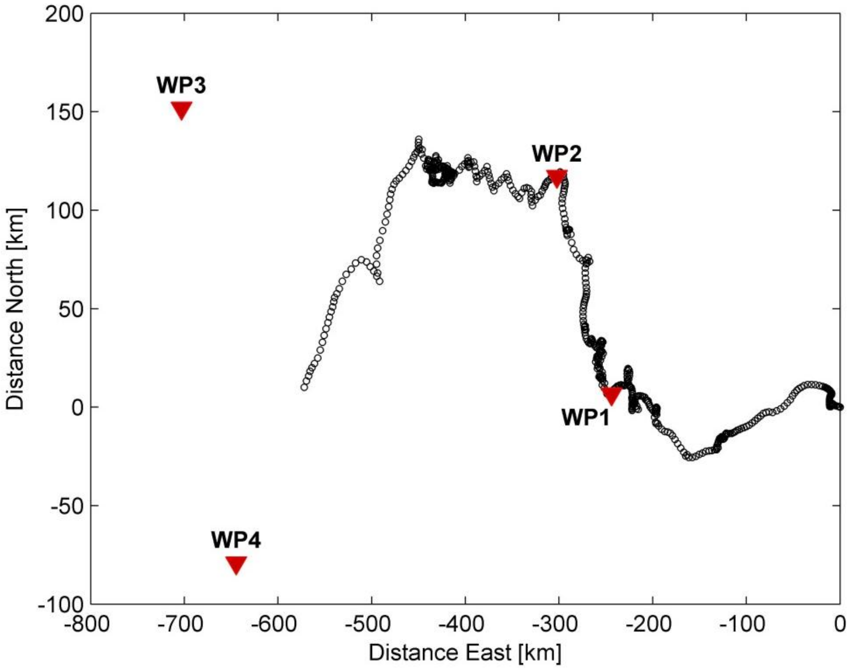


Figure 4. Horizontal distance relative to the start position inferred from the hourly longitude/latitude data. The waypoints (WP1 to WP4) are marked by the red triangles.

Segments are picked between the times when consecutive waypoints were commanded. Note that, e.g., WP3 is commanded after reaching WP2, and as the SailBuoy progresses toward WP3, a new waypoint (WP4) is assigned before WP3 is reached. The four segments thus picked include the one from the initial point to WP1, between WP1 and WP2; from WP2 to about x = -450 km when the next waypoint was commanded, and from this turn point to the end of the track. Hourly complex position vectors are constructed as eastward and northward distance (x, y) relative to the first point of each segment (x_0, y_0):

$$\vec{r} = \left(x - x_0\right) + i\left(y - y_0\right) \tag{3.1}$$

The distance vector between adjacent hourly positions is obtained by taking the difference of subsequent position vectors, and its magnitude is integrated to yield the total distance, D, covered for the given segment:

$$D = \sum_{k=1}^{N-1} \left| \vec{r}\left(k+1\right) - \vec{r}\left(k\right) \right| \tag{3.2}$$

where N is the total number of data points in the segment. For an efficient navigation this integrated distance approaches the distance along the line between the end points of the segment; however, D will be much longer for an eddying path with significant excursions from the straight line between the two points. The velocity vector between hourly points is calculated as $\vec{v} = \Delta\vec{r} / \Delta t$, by taking the first difference of $\vec{r}$ and dividing by the time difference between subsequent points. This velocity vector is then projected onto toward-waypoint (u_{WP}) and across-waypoint components (v_{WP}). The toward-waypoint direction is obtained as the orientation of the line between the start and end points of the segment. An efficiency index, e, is then constructed as the ratio of the velocity toward the waypoint to the speed:

$$e = \frac{u_{WP}}{|\vec{v}|} \tag{3.3}$$

The maximum efficiency is thus unity (or 100%), and is obtained when the vessel sails toward the waypoint. On the other hand, negative efficiencies can occur when the vessel transits away from and in a direction opposing the waypoint when caught into strong currents or eddies.

The time series of the vessel speed, the component of the velocity toward the waypoint and the efficiency are shown in Figure 5. The SailBuoy reaches speeds up to 1.5 m s^{-1} (approximately 3 knots) and has a mean of 0.55 m s^{-1} (about 1 knot). When inferred from instantaneous hourly values, about 70% of the time, the SailBuoy maintained speed toward the waypoint, u_{WP}, greater than 0.1 m s^{-1}; 28% of the time u_{WP} was greater than 0.5 m s^{-1}. About 18% of the time, the SailBuoy sailed directly opposite to the WP ($u_{WP} < 0$).

Hourly-derived efficiency is noisy due to short term response to wind and ocean currents. Smoothing by a 12 hour window shows a pattern where the SailBuoy performed with efficiency greater than 50% for extended periods of time but disrupted by presumably mean ocean currents and mesoscale eddies. When inferred from smoothed values, 53% of the time the efficiency was greater than 50% and 10% of the time the efficiency was negative.

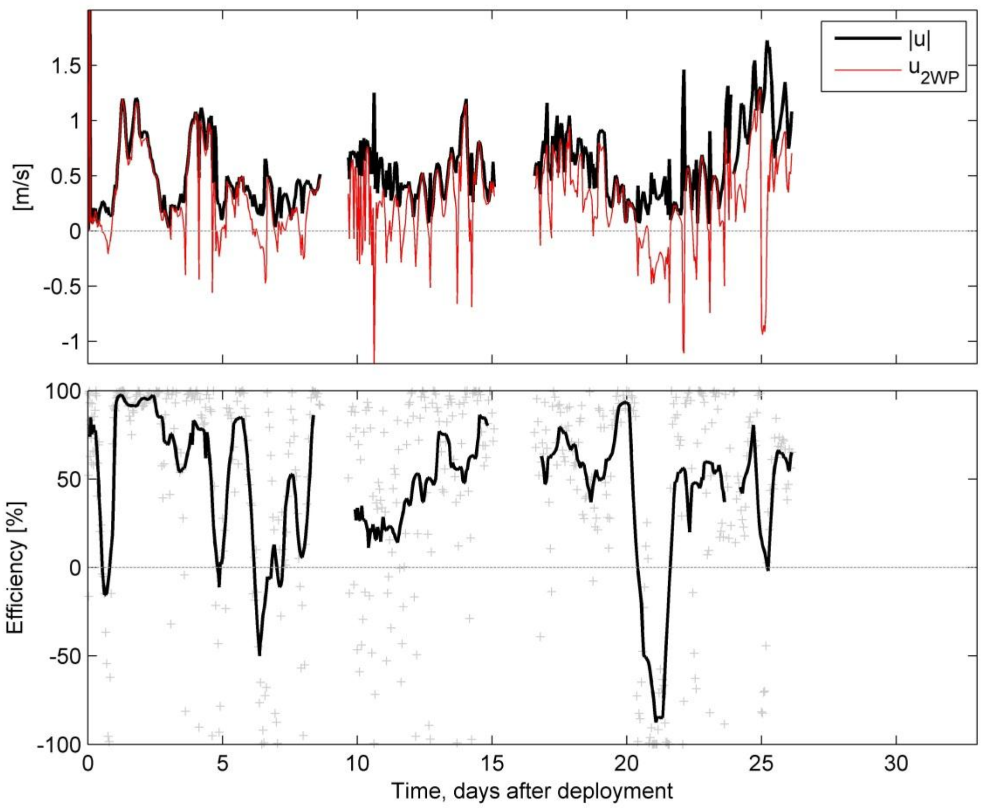


Figure 5. Time series of (top) the vessel speed (black) and the component of the velocity toward the waypoint (red) and (bottom) the efficiency index, e. The maximum efficiency is 100%, and is obtained when the vessel sails toward the waypoint. Hourly derived efficiency is noisy (crosses) and is further smoothed by a 12 hour window (black).

The corresponding histograms and statistics are given in Figure 6 and Table 1, respectively. The average speed toward the waypoint was 0.3 m s^{-1}. When derived over instantaneous values, the efficiency of the SailBuoy is 47%. The SailBuoy speed more than doubles, approaching 1 m s^{-1} when sailing downwind relative to a mean against wind speed of 0.43 m s^{-1}; however this happens typically 25% of the time. For this particular deployment the SailBuoy sailed against the wind 75% of the time.

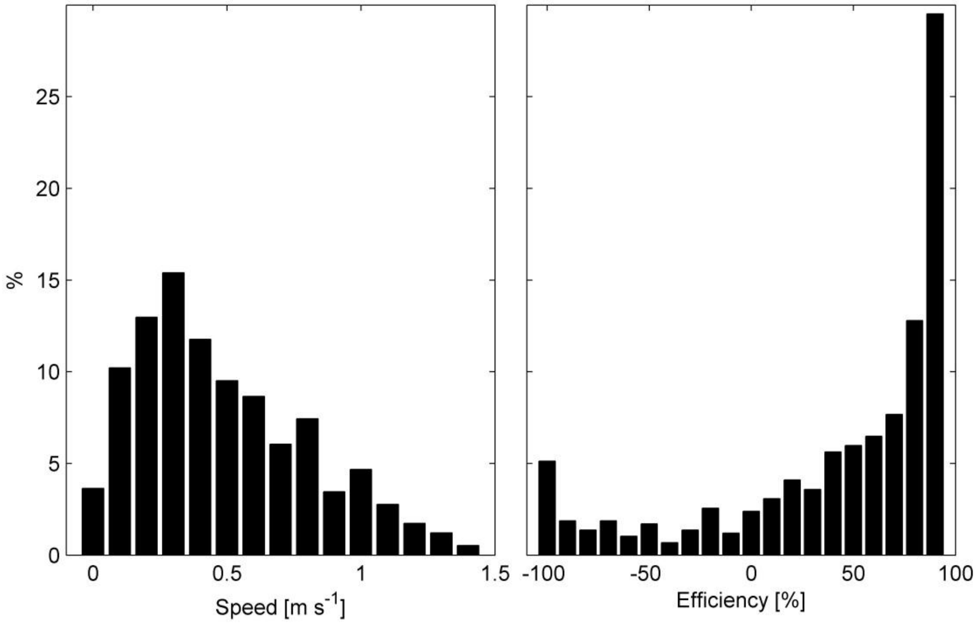


Figure 6. Histograms of (left) speed and (right) efficiency of the SailBuoy during the mission from Bergen to Scotland

Table 1. Statistics of SailBuoy speed and efficiency during the mission. The arithmetic mean, one standard deviation, median, and the minimum and maximum values are listed. Vessel speed statistics are given for the entire data set and also, separately, for the times sailing with the wind and against the wind. Speed toward the waypoint (WP) is the component of the vessel velocity projected in the direction toward the WP.

	mean	*std*	*median*	*min*	*max*
Speed [m s^{-1}]	0.55	0.35	0.47	0.01	2.61
against wind	0.43	0.28	0.39	0.03	2.61
with wind	0.91	0.31	0.90	0.01	1.73
Speed toward WP [m s^{-1}]	0.30	0.42	0.28	-1.24	2.59
Efficiency [%]	47	59	70	-100	100

4 Summary

The navigation performance and characteristics of the SailBuoy are reported. The SailBuoy is a small unmanned, un-propelled vessel which navigates autonomously and can be controlled by a 2-way communication through the Iridium satellite system. Hourly position data from a one-month trial conducted in summer 2011 between Bergen (Norway) and Scotland are analyzed. In the bulk of the about 1000 km long track, the vessel navigated autonomously and received four waypoints underway.

The vessel speed, the component of velocity toward the waypoint, and an inferred efficiency index are reported and discussed. The SailBuoy reaches speeds up to 1.5 m s^{-1} (approximately 3 knots) and has a mean of 0.55 m s^{-1} (about 1 knot). The average speed toward the waypoint is 0.3 m s^{-1}. Significantly larger values are obtained, however; for 28% of the time the vessel sailed toward the way point with velocity faster than 0.5 m s^{-1}. Typical efficiency of the SailBuoy is 50%. More than half of the deployment period the efficiency was greater than 50% whereas 10% of the time the efficiency was negative (vessel sailing in a direction opposite to the waypoint). The typical SailBuoy speed doubles when sailing downwind. For this particular deployment, the SailBuoy sailed against the wind 75% of the time, during which the average speed is comparable to (80% of) the entire deployment average.

5 Conclusion

The SailBuoy successfully completed a one-month mission between Bergen (Norway) and Scotland, receiving waypoints and navigating autonomously. The track of the mission passes across challenging ocean currents and a significant mesoscale activity. It is found that the vessel fulfills the expectations and sails with a typical efficiency of 50% despite harsh weather, strong current and ocean conditions. In this test, the average speed of the SailBuoy was about 0.5 m s^{-1} and with an effective average speed toward the waypoint of 0.3 m s^{-1}. The results of this test suggest that the SailBuoy has great potential as a platform for near-surface measurements of the ocean and atmosphere properties for extended periods of time with reliable navigation performance.