Monitoring and Optimizing the Flight of the Atlantic Underwater Glider

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Abstract

This study is the result of the monitoring of Rutgers University's underwater Slocum series glider flying across the Atlantic from New Jersey to Spain and the optimization of its flight. Christened the "Scarlet Knight" but better known around the lab as ru17, It is the second but longest deployment by Rutgers of a long-duration, long-range glider. It has already set the record for the longest range of any autonomous underwater vehicle (AUV), and is the testbed for future gliders that will fly similar flights.

Background

Where they come from: Slocum gliders are a relatively new technology that were introduced by Rutgers University into the water in late 2003. Since then, the Coastal Ocean Observation Lab (COOL) group has deployed thousands of days worth of gliders along the eastern coast, collecting physical oceanographic data along the way.

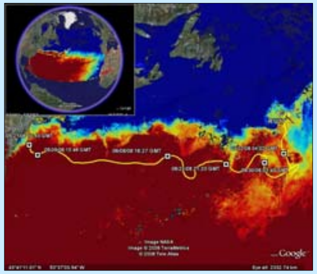
How they fly: Slocum gliders do not have any external propulsion device, such as a propeller. Instead, gliders are able to change their buoyancy by pulling in about a cup of water to make it dive. At the end of the dive, it pushes the water back out to become less buoyant than the water, and as a result climbs to the surface. This maneuver, in combination with swept wings to provide a glide angle, provides the glider with horizontal momentum that allows it to fly through the ocean in a characteristic saw tooth pattern (Fig. 1). This method of propulsion is incredibly efficient, allowing gliders to stay out in the water for months, while propeller driven AUVs can only stay out for hours at a time.

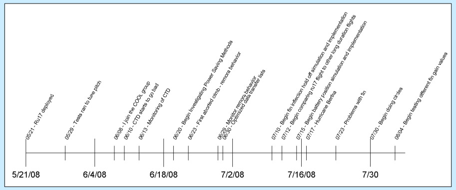
History of long-duration flights: There have been few long duration flights in the history of AUVs. The more well-known flights occurred in 2004 when the Scripps Institution of Oceanography flew a Spray series glider some 600 miles, in 2005 when the University of Washington sent a pair of Seagliders series gliders 1,800 miles towards Hawaii, and recently in June when Rutgers sent one if its gliders 1,600 miles to Halifax. Currently, ru17's crossing of the Atlantic has set the record of traveling 2,400 miles and counting.

Significance of long duration flights: Long-duration flights have two motivations:

• Scientific perspective: Allows gliders to stay out for longer periods, allowing the collection of more data over time. Also, they allow gliders to be able to fly into harsh environments or distant locations that scientists normally could not easily reach.

• Military perspective: The NAVY is interested in the penetrate and loiter capabilities of long duration gliders, as well as the potential that a network of continuous monitoring gliders can have.





Ru17's path and timeline of key events.

Methods

Monitoring ru17's flight

Data is sent from the glider to a server in the COOL lab through Iridium satellite. Using MATLAB, depth profiles (Figs. 1, 2) were created as often as possible and flight performance plots (Figs. 3, 5, 6) were compiled weekly based on data availability. These plots were then analyzed to make sure that ru17 was flying well by calculating vertical and horizontal velocities based on several variables, discovering any patterns with irregular behavior, and also by ensuring that the flight controllers were correctly interacting with each other.

Flight optimization

Glider code was studied in detail to aid in discovering useful commands that would optimize ru17's flight. Simulations were conducted in the lab (Fig. 4) implementing these new commands into ru17. Because current simulations do not appropriately represent reality, it was important to monitor the glider's behavior immediately following the new commands.

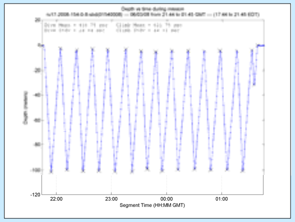


Figure 1. Typical depth profile

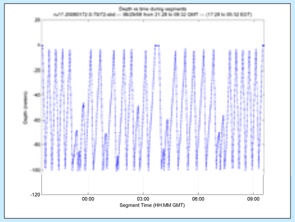


Figure 2. Depth profile during remora activity. This activity would only be seen at night.

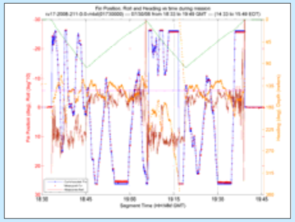


Figure 3. Cohesive flight characteristics. Plots like this one were used to ensure that each flight controller was interacting with one another properly.

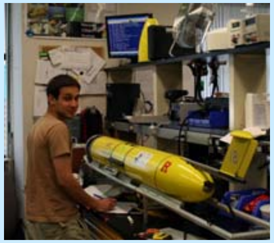


Figure 4. Lab where simulations were done. The information we obtained from these would tell us if new settings would be accepted on the glider or not.

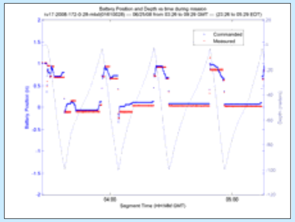


Figure 5. Pitch battery movement before new command to throw it to one position and then hold it there.

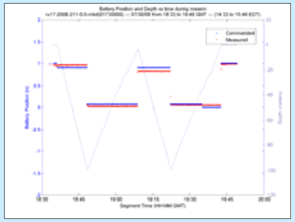


Figure 6. Pitch battery movement after new command. The result was no movement during yos and resulted in saving power.

Results

Biology: Ru17's flight has been heavily influenced by biology. A severe example can be seen in Figure 2. Here, the glider had aborted climbs which is an indication that the glider suddenly became too heavy. By determining that the irregular flight behavior happened only at night (between 23:00 and 7:30 GMT), the suspect became biology, specifically of the fish Remora remora which are well known to attach themselves to sharks. Further analysis shows that biology has been persistent only during the night (Fig. 7) by observing that glider's vertical climb rates increase dramatically during only the night, but affect glider speed as a whole. Further evidence of biological interactions can be seen in the number of yos completed between surfaces (Fig. 8), which suddenly decrease at the start of the remora interactions.

Flight: Because of biological interference, flight optimization took a back seat. While several optimizations should have been successful, such as:

• Holding the fin at inflections points, where the glider's speed becomes slow and the effect of the fin on steering becomes negligible, and

• Moving and keeping the pitch battery to one position and holding it there to prevent overall unnecessary movement and power drain (Figs. 5,6),

uncertainties from biological interactions prevented these new optimizations from remaining implemented on such an important glider. However, these new settings can be used on gliders that remain close to the eastern coast, where the COOL group does most of its ocean monitoring.

Instruments: Towards the beginning of the Atlantic mission, the pressure sensor on the CTD sensor stopped working due to speculative reasons. Currently, the glider may also be seeing signs that the internal compass is broken as hypothesized due to the fact that recently the glider has been doing circles on downcasts (Fig. 3 in orange), however the observed behavior could once again be due to biology.

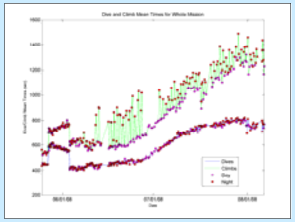


Figure 7. Dive and Climb behaviors were seen to increase only during the night, giving evidence that many of the problems we had were due to biology.

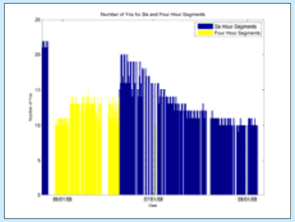


Figure 8. The number of yos between surfaces started to decrease at the beginning of the remora interactions.

Conclusions

With ru17 experiencing so much trouble from biology in the Atlantic that has not been seen on any other glider to date, it is important to consider two things:

• A new design specific for long duration gliders that will aid in deterring biology from interfering with a glider that will be anywhere in the ocean that is not near the coast.

• Redundant instruments in case one of the sensor failure.

With these considerations, as well as others that will come as the Atlantic mission continues on, the future where fleets of gliders constantly flying through and monitoring the ocean is one step closer to becoming a reality.

Acknowledgements

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