MOTH –

an underwater glider design study carried out as part of the HGF Alliance ROBEX

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Abstract— **Underwater gliders have been conceived more than 20 years ago and as they are building up on concepts and technologies that were developed used for ARGO float systems have reached a maturity that give them a specific role in observing programs [Barker]. Why then starting a new design? It is exactly the success of the current glider systems that lead to revisiting the basic design and exploring alternative vehicle concepts. Current glider designs are suffering from limited scientific payload capacity which is a good motivation in its own right. Furthermore employing more energy efficient, low drag designs would vastly extend the application range.**

With the MOTH design study we were picking up a concept that is now extensively used in unmanned flight vehicles (drones), the blended wing design. Earlier attempts in that direction have proven to be quite successful [Jenkins]. In particular higher horizontal speeds could be reached and with the blended wing shape offering new payload capabilities other sensor types (sonar systems) will be integrated.

Making use of pre-existing knowledge and experience the project will be structured along the lines of a systems engineering approach. The scientific rationale is based on the needs of quantifying the particle flux in the upper part of the water column in regions of interest, like the Northwest African margin. Here MARUM has already a long term record of flux studies so that the anticipated glider missions can be validated against this data set. The scientific payload is defined based on this observation scenario which implies small flight angles and higher horizontal speeds (up to 1 kn). The endurance will lies in the range of days to a few weeks so that typical the glider system will be deployed and recovered during a single cruise. A particular emphasis will be given to assessing and enhancing the operational reliability of the system. This includes both the hardware and the software side of the system which implies that well defined testing procedures have to be described. During field tests it is planned to make use of the WAVEGLIDER (Liquid Robotics) that offers unique opportunities to track the trajectory of the glider and to set up a communication link.

In this presentation the basic system design will be presented to illustrate on how to make best use of the hull shape by employing new sensor integration concepts. Fabrication aspects together with a first sketch on the control architecture will be addressed as well.

Keywords—auv, glider, control system, composite materials, particle flux studies

I. INTRODUCTION

The HGF Alliance ROBEX is a project that aims to bring the space science and deep sea science communities together to work jointly on selected technical and scientific themes [HGF Alliance ROBEX].Spread over Germany 15 institutions from Space and marine research, the project partners are particularly developing technologies for the exploration of highly inaccessible terrain, such as the deep sea and Polar Regions, as well as the Moon and other planets.

The topic underwater glider evolved during the first discussions as a field of particular interest for both communities. The complementary expertise is helping to form a design team that is evaluating new concepts for an underwater glider design. The glider will be a technology development and technology carrier platform As far as the specification and development process goes, we are focusing on various advanced technological concepts that are going to push the envelope for underwater gliders opening up a new and/or larger operational envelope than the legacy gliders (Slocum [5], Seaglider [6], Spray [7]).

As the design is starting from scratch all components and system level designs have to be addressed. The following list shows the topics under discussion:

- Hull form based on scientific needs, hydrodynamic optimization, and fabrication options
- Hull material based on considerations in regard to weight, stiffness, and construction possibilities
- Control algorithms based on anticipated glider missions

- Hardware implementation in regard to electronic system, control members, buoyancy control, sensor systems
- Navigation and communication systems to be integrated into the glider

II. Scientific Mission

Although underwater gliders can carry out a number of different missions and the mission profile of today's glider has been extended significantly a specific application scenario has to be selected to focus the system design. In our case we specifically are interested in the quantification of particle fluxes through the water column where besides the standard physical parameters biochemical parameters like oxygen, fluorescence, and backscattering is of particular importance.

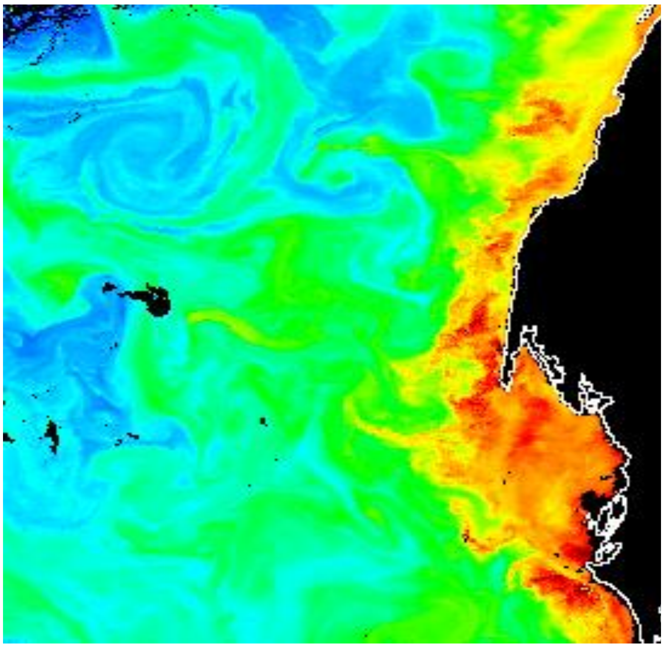

Figure 1: Satellite image showing large algae filaments off Cape Blanc, Western Africa

In figure 1 a typical measuring scenario is shown where large algae filaments can be detected on the satellite image. The scientific aim is to determine the magnitude of surface ocean primary producers by including the areal distribution at depth. To better relate surface processes with export flux it will be necessary to use the MOTH glider to measure the extent of these filaments at the depth of fluorescence maximum (below satellite penetration depth). Combinations of sediment traps, satellites, CTD profiles, and the MOTH glider will provide full horizontal and vertical measurements, relating surface ocean production to deep ocean export.

From this scenario some fundamental characteristic for the anticipated system can be derived. In a first phase it would be enough to have the glider crossing the filaments where distances of 10-100 km have to be covered. For this application small flying path angles (1°-10°) would be advantageous. The following list gives an overview over additional specifications:

- Max. horizontal speed 1 kn
- Depth rating up to 2000 m
- Duration 48 h
- Satellite communication link also to transfer GPS signals when surfacing
- Navigation and determination while underwater by using a low power INS system
- Use of a WAVEGLIDER as a communication hub to the glider and to track the maneuvers of the glider

First field tests with a basic sensor suite are planned for 2015 where besides the pure technical tests an evaluation of the glider in regard to the performance of the scientific tasks will be carried. This may lead to some redesign of particular components.

III. Technical Implementation

We started out with a prototype glider system based on a flying wing design as this hull design is offering advantages in regard to payload integration and payload capacity. The blended wing concept is offering a lot of space at the wing front which is a prominent position for sensors to be integrated as the disturbance on the sensor volume flushing from the hull is minimal. Furthermore, blended wing designs allow for small a gliding angle which is sought for with the selected scientific mission. Disadvantages of this concept are related to the shape of the payload volume which calls for flat housings or small diameters. Currently, it is considered to use pressure compensated components (batteries, controller systems) but for the sensors it seems to be not necessary as newer designs are already built accordingly small.

After carrying out a number of tests with the first prototype that was based on a HORTEN IX design [9] we came up with a number of conclusions:

To achieve small gliding angles the blended wing design is ideal

The blended wing design needs additional efforts for balancing the weight perpendicular to the flight direction

A hull form approaching a delta wing is advantageous for distributing floatation elements

More weight has to be moved to the wing fronts to compensate for the wing lift

With these assumptions a revised hull form has been developed which is shown in figure 2.

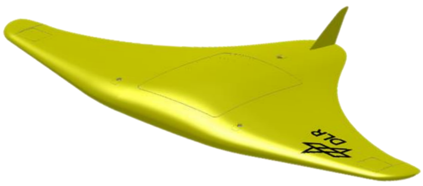

Figure 2: A revised hull design for the MOTH glider

One can see the basic design approach which also considers a payload concept where three standard payload volume sizes are considered.

At this point a quantitative estimate for the system to be integrated into the has to be carried out:

- Assessment of system and payload mass
    - Control electronics
    - Buoyancy engine
    - Payload sensors
    - Navigation unit, IMU, DVL etc.
    - Communication unit
- Energy requirements

Based on that the hull dimensions are derived and a simulation of the hydrodynamic behavior will be carried out. To be able to optimize the hull design the shape is parameterized.

IV. FIRST IDEAS ON THE MISSION AND CONTROL SYSTEM

Due to the involvement of space sciences in the ROBEX project cocnepts that have been used during space missions are explored in regard to their utility in the underwater context. For instance DLR and AIRBUS have been involved in glider designs for re-entry from space into the earth atmosphere with X38 Parafoil for NASA [10], the Phoenix RLV demonstrator [11], RIMRES [12] and other systems.In those systems particular attention is given to fault detection, identification and recovery (FDIR) concepts where the system operator is able to intervene into the mission sequence to recover from an incorrect mission state. The simulation of different operational statesand sequences is therefore an essential part of the development process.

The software development process will structured in different phases starting with the the system support and mission analysis process. This design steps consists of:

a) Mission and GNC system layout

b) Preparation for hydrodynamic tests

c) Trajectory planning

Furthermore an establish flight validated data base has to be developed to be able to work on:

d) Hydrodynamic characteristics

e) Inertia & wing loading, ‘flying qualities’

f) Static stability margin

In the next step the guidance, navigation, and control (GNC) design will be intiated where the following tasks have to be addressed:

g) GNC control algorithm design; implementation and verification

h) Navigation algorithm design, implementation and verification

i) GNC software implementation and non real time functional verification

j) Statistic analysis (Monte Carlo Simulation)

k) Software integration in real time test bed and demonstrator

The work on these topics has been started already by using flight data from the first MOTH glider prototype and from existing, commercially available glider systems.

V. SUMMARY

In this paper the steps towards the development of a new underwater glider system are described. The main driver for this development is that with new components like new, pressure compensated battery systems it may be possible to come up with completely new hull shapes that allow for a better integration of payload modules. Furthermore, synergies between ocean and space sciences are explored to identify new concepts for enhancing the reliability and the operational capabilities of underwater gliders.

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