2019 IMEKO TC-19 International Workshop on
Metrology for the Sea
Genoa, Italy, October 3-5, 2019

Slocum underwater glider acoustic capabilities improvement by wings re-design

Paolo Gemelli[1], Pierre-Marie Poulain[2], Mario Ivan Zignego[3], Daniele Cecchi[4]

[1] University of Genoa, DAD, Stradone S. Agostino, 37- 16123 Genova (GE) - Italy, gemelli@arch.unige.it
[2] NATO STO CMRE, Viale San Bartolomeo, 400- 19126 La Spezia (SP)- Italy, Pierre-Marie.Poulain@cmre.nato.int
[3] University of Genoa, DAD, Stradone S. Agostino, 37- 16123 Genova (GE) - Italy, zignego@arch.unige.it
[4] NATO STO CMRE, Viale San Bartolomeo, 400- 19126 La Spezia (SP) - Italy, Daniele.Cecchi@cmre.nato.int

***Abstract* – In order to improve persistence and acoustic capabilities of a Slocum underwater glider, the wings have been re-designed and a linear array of eight elements has been placed along their leading edges.**

In this configuration the lift/drag ratio has increased by about 15-20% with an angle of attack (AoA) of 4° with respect to the original wing configuration.

The best directivity performances have been obtained for a sound signals frequency around 2 kHz. According to the literature review, this may be useful for cetaceans passive acoustic monitoring (PAM).

I. INTRODUCTION

Underwater gliders are a class of Autonomous Underwater Vehicles (AUVs) that glide by controlling their buoyancy using internal tanks and pumps. Existing gliders have fixed external wings and tails and control their attitude by moving internal masses and using external control surfaces such as a rudder.

Gliders travel from place to place by concatenating a series of upwards and downwards glides. Characteristic glider motions include upwards and downwards straight glides in a sawtooth pattern, turning, and gliding in a vertical spiral.

Gliding flight is buoyancy driven and does not use thrusters or propellers. Thus, gliders must change depth to move horizontally. They glide downwards and upwards in the ocean by controlling their buoyancy to make themselves negatively and positively buoyant. Gliders may also hold their position by gliding against the current, making themselves neutrally buoyant and drift with the current, or resting on the bottom.

Through their use of buoyancy propulsion systems and low power designs, gliders are capable of long-range and high-endurance deployments. With careful design, buoyancy- driven gliders are quiet and use little power. Housing vehicle actuators within the hull shields them from the hostile ocean environment and makes gliders more durable [1].

Gliders report their position and measurements via wireless telemetry in near real time but they can't be efficiently directly controlled from remote locations.

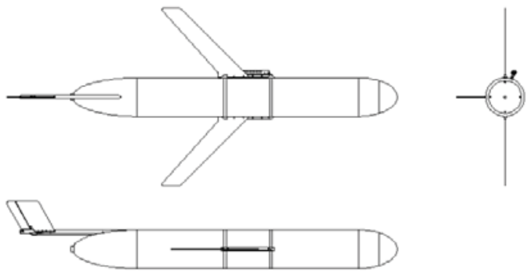

Fig. 1-Teledyne Slocum G2 glider layout

Table 1. Teledyne Slocum G3 glider general specifications

Power	Alkaline (A) / Rechargeable (Li) / Lithium (L)
Range	350-1200km/ 700-3000km/ 3000-13000km
Deployment Length	15-50 days/ 1-4 months/ 4-18 months
Depth Options	(4 to 150m) or (40 to 1000m) operating depth range*
Navigation	GPS, Pressure Sensor, Altimeter, Dead Reckoning
Communication	RF Modem, Iridium (RUDICS), ARGOS, Acoustic Modem
Horizontal Speed	Buoyancy Engine: 0.35 m/s (0.68 knot) Average, up to 0.5 m/s (1 knots) with full drive. Thruster: Up to 1 m/s (2 knots)
Mass	55 - 70kgs (dependent upon configuration)

The aim of this research, conducted with NATO STO CMRE (Center for Maritime Research and Experimentation) in La Spezia, is to improve the performances and its acoustic data gathering capabilities.

To do this, a wing re-design process has been performed in order to obtain both an augmented lift/drag ratio and the space suitable for an eight elements linear array along the leading edges of the wings themselves.

II. WINGS RE-DESIGN

Persistence is one of the parameters that characterize the performance of an underwater glider, which is the ability to operate as long as possible without human intervention. As first step the dynamic model developed by Graver [1],[2] has been implemented in MATLAB from Singh [3]. Simulation provides values of depth [m], pitch angle [deg], angular velocity [deg/s], linear velocity [m/s], angle of attack [deg] in function of the simulation time (1500 s).

During common operations, the typical values for the angle of attack are in a range between zero (>0) and 5 degrees.

The original Slocum wings are flat with a sweep angle around 45°, and, for the purpose of MATLAB simulation, they have been modelled with NACA profile 0006. Instead for the purpose of the CFD simulation a 3D model has been realized.

In order to improve it, the lift/drag ratio has been calculated for three different NACA profiles: 0006, 0012 and 0015, in function of the angle of attack.

The design variables considered has been:

- NACA profile: (0006, 0012, 0015);
- Wing span (1.62 m, 1.82 m, 2.12m);
- Sweep angle, set to 0° for the purpose of hydrophones installation.

They have been combined in order to identify the combination that optimizes the theorical Lift/Drag ratio. Simulation has been performed in MATLAB modifying the *Wing designer* [4] code as to consider the underwater environment.

After that a CFD simulation has been performed in OpenFOAM using SimpleFoam: a steady-state solver for incompressible flow using the SIMPLE (Semi-Implicit Method for Pressure Linked Equations) algorithm.

In order to verify the theorical values, the most common Angles of Attack for SLOCUM, between 4° and 6°, has been used to evaluate Cl and Cd.

It must be underlined that the values presented here needs further verifications. This is due to the nonlinear behavior of NACA 0012 profiles with low Reynolds Number (45,948 in this case) as assessed by Pranesh et al. [5]

Oceanographic parameters were obtained from Thermodynamic Equation of Seawater - 2010 (TEOS-10) [6].

New wings have NACA 0012 profile and sweep angle equal to zero (Fig. 2a-2b) in order to have better performances of the hydrophone array.

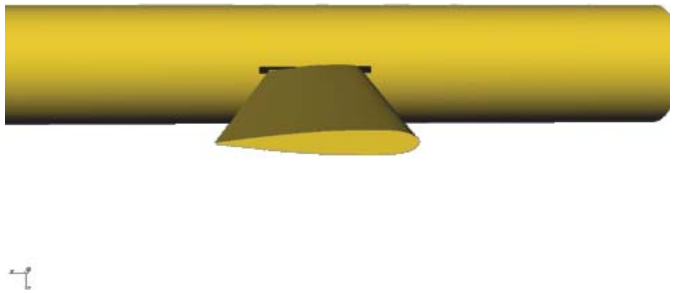

Fig. 2a – 3D model of the re-designed wing: NACA 0012 profile has been chosen.

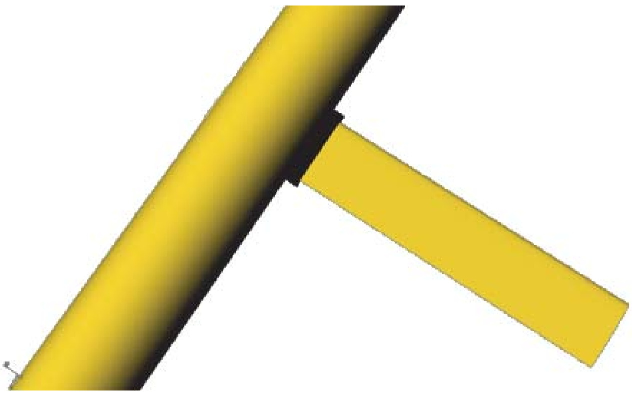

Fig. 2b – 3D model of the optimized wing: the sweep angle is set to 0°.

Table 2. Re-designed wings specifications

Wing profile	NACA 0012
Sweep angle	0°
Wing span	2.12 m
Theorical Lift/Drag ratio improvement respect to the original configuration	15-20%
Lift/Drag ratio using RANS CFD simulation	See *Table 3*
Construction	3D printing
Material for prototype	Acrylonitrile Butadiene Styrene (ABS)

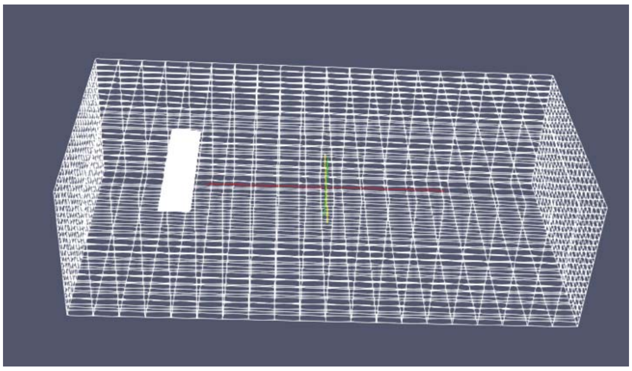

Fig.3 – 3D computational domain for CFD

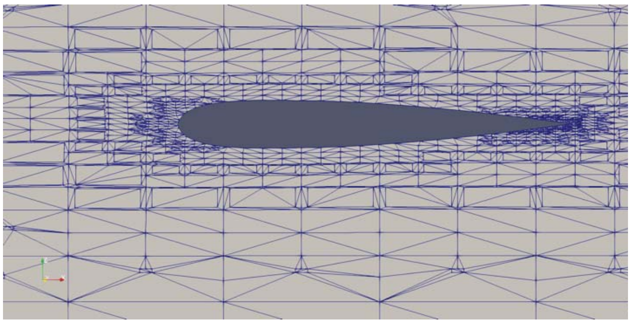

Fig.4 – NACA 0012 profile meshing with openFoam snappyHexMesh function

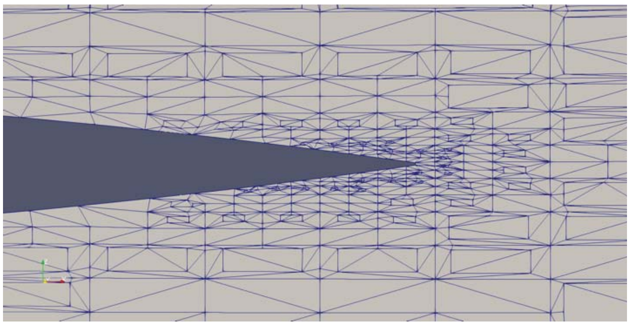

Fig.5 – Detail of NACA 0012 trailing edge meshing

Table 3. RANS CFD simulation results

	Original wing			*New wing*		
AoA	**Cl**	**Cd**	**Cl/Cd**	**Cl**	**Cd**	**Cl/Cd**
4°	0.0064	0.0068	0.9505	0.5283	0.0262	20.1720
5°	0.0105	0.0071	1.4901	0.7641	0.0076	100.000
6°	0.1526	0.0063	24.3010	0.0849	0.0308	2.7528

III. PASSIVE ACOUSTIC MONITORING OF CETACEAN

Passive Acoustic Monitoring (PAM) of cetaceans is a technique for surveying and studying cetaceans, not only because they frequently use sound for their day-to-day activities, but also because acoustics is so far the only tool that allows the study of submerged animals that are not visible to human observers and does not interfere with the animals' behavior if properly implemented [7]. PAM is becoming increasingly important due to the socio-political requisite to mitigate the impact of anthropogenic sound on these species [8],[9].

Currently, there are three commonly used approaches for the surveys of cetaceans: towed hydrophone arrays, autonomous recorders on undersea gliders and seafloor hydrophones. As underlined by Griffiths et al. [10] each approach has some advantages, but also some drawbacks. Whereas towed hydrophone surveys allow broad geographic coverage, on the other hand, hard-wired hydrophones allow long time recordings and may be used as permanent listening stations [11], nevertheless gliders can also cover broad geographic area.

In the past years, acoustic payloads for gliders have been developed at NATO STO CMRE (former NURC) in order to detect and classify marine mammals [12].

During the SIRENA '08 sea trial conducted from 17 May to 18 June 2008 in the Alboran Sea, two autonomous oceanographic Slocum gliders were deployed off the coast of Almerimar. The 1.5 m, 52 kg vehicles operated in a saw-tooth pattern at an approximate speed of 0.3 m/s down to a maximum depth of 200 m. On board sensors included a conductivity, temperature, depth (CTD) sensor, GPS, and passive acoustics.

The problem of the features identification for the signals emitted by cetaceans has been addressed by several authors.

Oswald et al. [13] provides an acoustical identification of nine delphinid species (spinner dolphins *Stenella longirostris*, striped dolphins *S. coeruleoalba*, pantropical spotted dolphins *S. attenuata*, long- beaked common dolphins *Delphinus capensis*, short-beaked common dolphins *D. delphis*, rough-toothed dolphins *Steno bredanensis*, bottlenose dolphins *Tursiops truncatus*, short-finned pilot whales *Globicephala macrorhynchus*, and false killer whales *Pseudorca crassidens*) in the eastern tropical Pacific Ocean by whistles recordings and the spectrographic analysis.

Rendell et al. [14] analyzed the vocalizations of five odontocete cetaceans: the false killer whale *P. crassidens*, short-finned pilot whale *G. macrorhynchus*, long-finned pilot whale *G. melas*, white-beaked dolphin *L. albirostris* and Risso's dolphin *G. griseus*.

IV. ARRAY DESIGN

PAM systems are based on hardware (hydrophones and acquisition board) and software in order to detect and classify sounds.

In literature another project exists which aims to deploy acoustic arrays as underwater gliders payload. D'Spain et al. [15] developed an underwater glider based on a flying wing design with 6.1m span and an acoustic payload of 32 elements array placed along the leading edge of the wing.

In this configuration the best performance in terms of directivity is achieved at the sound frequency around 3 kHz.

In this paper a linear array of eight equispaced elements is proposed. The array elements are omnidirectional Cetacean Research™ CR2 hydrophones (see Table 3 for specifications) placed on the leading edges of the glider wings and embedded into the structure in order to maximize the hydrodynamic performances of the vehicle. An eight elements linear array has been placed along le leading edges of the wings.

The resulting directivity plot is shown in Fig.6

Table 4. CR2 hydrophone specifications

Linear Frequency Range (±3dB) [kHz]	0.0019 to 28
Usable Frequency Range (+3/-12dB) [kHz]	0.0005 to 60
Transducer Sensitivity [dB, re 1V/µPa]	-214
SPL Equiv. Self-Noise at 1kHz [dB, re 1µPa/√Hz]	68
Maximum Operating Depth [m]	370
Operating Temperature Range [°C]	-40 to 70
Capacitance [nF]	0.82
Dimensions [mm]	56 L x 14 (diameter)
Directionality	omnidirectional below 10kHz

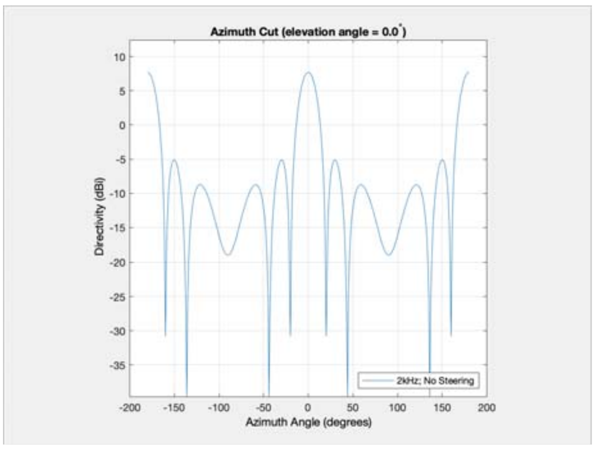

Fig.6 – MATLAB simulation of the directivity of the eight elements array at 2kHz (element spacing=0.28 m); propagation speed=1550 m/s).

V. AUTHORS CONTRIBUTION

Within the work here presented P.Gemelli has contributed to sections II and IV, P.Poulain and D.Cecchi to section I and III, M.I. Zignego to section II.

REFERENCES

[1] J. G. Graver, "Underwater gliders: Dynamics, control and design," Princeton University USA, 2005.

[2] J. G. Graver, R. Bachmayer, N. E. Leonard, and D. M. Fratantoni, "Underwater glider model parameter identification," in Proc. 13th Int. Symp. on Unmanned Untethered Submersible Technology (UUST), 2003, vol. 1, pp. 12–13.

[3] S. Yogang, *Solution-to-Equations-of-Motion-for-Underwater-Glider*.

[4] J. Rogers, *Wing Designer*. 2007.

[5] C. Pranesh, M. Sivapragasam, M. D. Deshpande, and H. K. Narahari, "Negative lift characteristics of NACA 0012 aerofoil at low Reynolds numbers," *Sādhanā*, vol. 44, no. 1, p. 21, Jan. 2019.

[6] "Thermodynamic Equation of SeaWater 2010 (TEOS-10)." [Online]. Available: http://www.teos-10.org/. [Accessed: 27-Jul-2018].

[7] W. Zimmer, *Passive Acoustic Monitoring of Cetaceans*. Cambridge: Cambridge University Press, 2011.

[8] "Understanding the impacts of anthropogenic sound on beaked whales," *J. Cetacean Res. Manage*, vol. 7, no. 3, p. 11, 2006.

[9] W. M. X. Zimmer and G. Pavan, "Context driven detection/classification of Cuvier's beaked whale (Ziphius cavirostris)," in *2008 New Trends for Environmental Monitoring Using Passive Systems*, Hyeres, France, 2008, pp. 1–6.

[10] E. T. Griffiths and J. Barlow, "Cetacean acoustic detections from free-floating vertical hydrophone arrays in the southern California Current," *The Journal of the Acoustical Society of America*, vol. 140, no. 5, pp. EL399–EL404, Nov. 2016.

[11] M. A. McDonald, J. A. Hildebrand, and S. C. Webb, "Blue and fin whales observed on a seafloor array in the Northeast Pacific," *The Journal of the Acoustical Society of America*, vol. 98, no. 2, pp. 712–721, Aug. 1995.

[12] A. Dassatti et al., "On-board underwater glider real-time acoustic environment sensing," in OCEANS 2011 IEEE - Spain, Santander, Spain, 2011, pp. 1–8.

[13] J. N. Oswald, J. Barlow, and T. F. Norris, "Acoustic identification of nine delphinid species in the eastern tropical Pacific Ocean," *Marine Mammal Science* vol. 19, no. 1, p. 18, 2003.

[14] L. E. Rendell, J. N. Matthews, A. Gill, J. C. D. Gordon, and D. W. Macdonald, "Quantitative analysis of tonal calls from five odontocete species,

examining interspecific and intraspecific variation," *J Zoology*, vol. 249, no. 4, pp. 403–410, Dec. 1999.
[15] G. L. D'Spain, R. Zimmerman, S. A. Jenkins, J. C. Luby, and P. Brodsky, "Underwater acoustic measurements with a flying wing glider," The Journal of the Acoustical Society of America, vol. 121, no. 5, pp. 3107–3107, May 2007.