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Medusa II: A Quasi-Langrangian Autonomous Underwater Vehicle

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***Abstract* – This paper is a section of several preliminary studies of the Underwater Drones Group of the Università degli Studi "Roma Tre" Science Department. We describe the architecture and features of the Medusa as "quasi-Lagrangian" AUV and its "dual use": a simple emerging buoy or a sub glider.**

***Keywords* — Medusa, Underwater, Glider, AUV.**

I. INTRODUCTION

This paper is part of several preliminary studies of the Underwater Drones Group of the science department of the Università degli Studi "Roma Tre", which is developing an advanced AUV (Autonomous Underwater Vehicle) for the exploration of the sea at high depths. The final aim is to create a platform for underwater scientific research that can accommodate a wide range of different payloads [1]-[3].

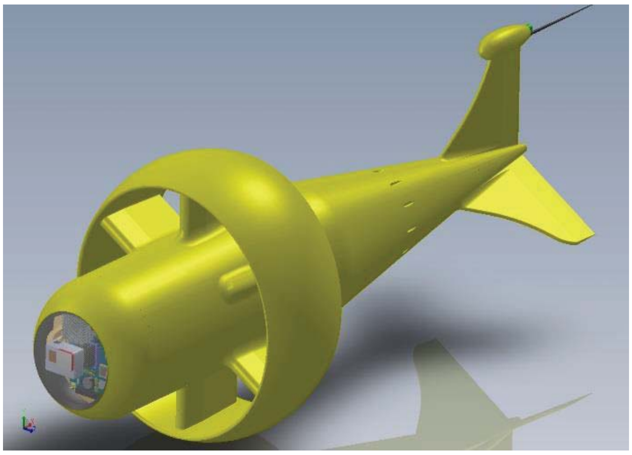

Fig. 1. Medusa II – Prospective view

Medusa Mk. II (Mediterranean Underwater Submersible Autonomous vehicle – see Fig.1) is a sub glider. The name Medusa comes from a figure from Greek mythology. Together with Steno and Euryale, she is one of the three Gorgons, daughters of the marine divinities Forco and Ceto. According to the myth the Gorgons had the power to petrify anyone who had met their gaze and, of the three, Medusa was the only one who was not immortal. in most versions it was beheaded by Perseus who brought with him the head of Medusa, who had not lost her power to petrify with her eyes, and used it as a weapon against numerous other adversaries and enemies [4]-[9].

The system can be considered as "quasi-Lagrangian" because, like the system ALACE (see), it is possible to use it as a simple emerging buoy and capable of a variable depth: it essentially includes the whole mission profile of the mentioned system. Furthermore, the innovation lies in the fact that, with very little expenditure in terms of energy, it can also be moved to the horizontal plane, compensating for currents and drifts, thus having the possibility of changing the mission and purpose until the end. Not least the possibility of being able to conduct an active "volumetric" exploration of a stretch of sea [10]-[16].

The fundamental element of the Medusa Mk. II is the profiling float, which controls buoyancy to surface periodically, transmits data and localizes via satellite, and returns to the sea depths [17].

A sub glider is essentially a float with wings to provide lift and allow it to move horizontally while profiling. Gliders are the natural next step in the development of autonomous float technology [18]-[21].

The wing has the task of transforming the descending motion into translational motion, allowing the vehicle to advance in a longitudinal direction. Its annular shape has the dual purpose of offering a low resistance to advancement and, at the moment, when it is lifted by the support vessel, a sort of "bumper" which prevents damage to the fuselage [22].

II. MEDUSA ARCHITECTURE

As Fig. 2 shows, the Medusa is a tailless sub glider: the cylindrical fuselage (hull) has a constant section (20 mm external diameter approx.), with an elliptical dome on the nose and a hydrodynamic fairing in the tail [23].

The fuselage (hull) is made out of Aluminium 6061-T6: it has excellent joining characteristics, good acceptance of applied coatings and combines relatively high strength, good workability and high resistance to corrosion [24]-[27].

The annular wings are made of Ultem 1000 (Polyetherimide high-density polymer) has a high dielectric strength, inherent flame resistance and extremely low smoke generation; furthermore, it has high mechanical properties and performs in continuous use to 170 °C [28]-[31].

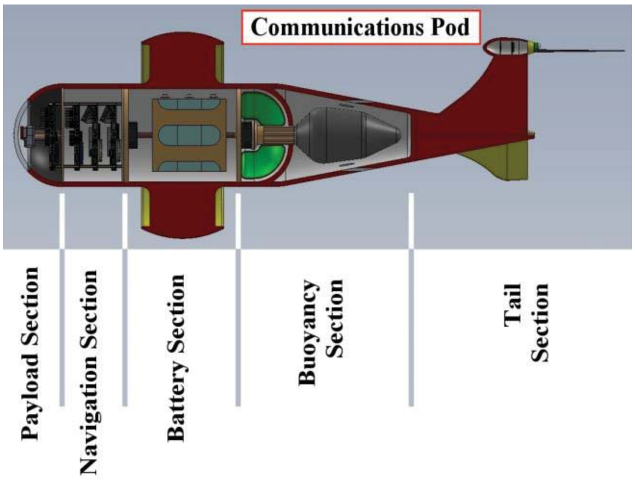

Fig. 2. Medusa II – Fuselage section (cutaway).

A. Payload Section

The nose cone is spherical and contains the (customizable) payload and the ancillary systems. The front section (up to the first bulkhead) is all an empty space that can be filled with all the instrumentation needed up to a diameter (see fig. 3). This peculiar radome allows accommodating many type of electromechanical sensor. If an active sonar is required, an appropriate version of the radome is available [32]-[37].

The second part of the section accommodates all the ancillary services such as payload power packs, thermal control, and other instrumentation recording and storage devices.

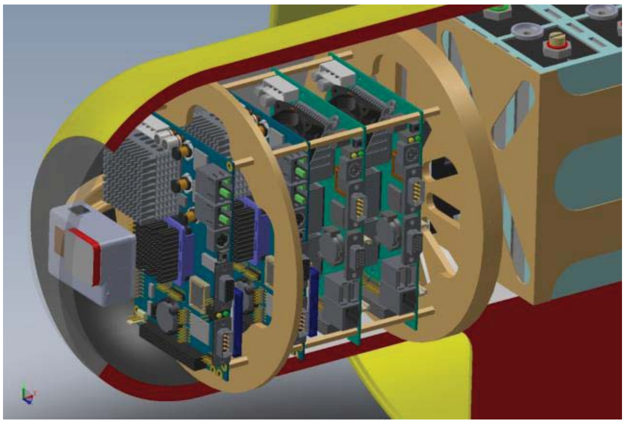

Fig. 3. Medusa II – cutaway of payload and navigation section.

B. Navigation Section:

contains the Glider Integrated Control System (GICS), the INS (Inertial Navigation System) platform). The GICS oversees all the functions of navigation, guidance and vehicle control [38]. In the run-up phase, the AUV receives its position via Global Navigation Satellite System-GNSS (which cannot be done if immersed), and connects itself to the Iridium communication satellite system, provides its own position to the user and downloads the navigation or payload. Then, if necessary, it gets new program parts and runs them [39].

C. Battery Section

It contains the battery pack (see fig. 4) and the servomotors to trim and regulate pitch and heading (yaw) of the AUV. The batteries are mounted on a special support (cradle) and actuated by servomotors (controlled by the OBC) that allow the forward/backward scrolling (for pitch control) but also the right/left tilt for intrinsic direction control [40].

D. Hydrodynamic Tail and Communication Pod

The hydrodynamic tail contains the oil bladder, is open to the water and provides a slender shape. The fairing has the task of not disturbing the hydrodynamic flow of the fuselage and closing the fuselage in closure [41]. In any case, it can withstand considerable loads: for this reason, there are several internal struts reinforcements. It also protects the bladder from the flow and its dynamic loads, which could deform it [42].

The communication pod contains the radio communication systems: Global Positioning System-GPS, Iridium RTx and HF emergency beacon.

In case of recovery from the support ship there is a flashing light beacon and a radio beacon in HF band to facilitate homing [43].

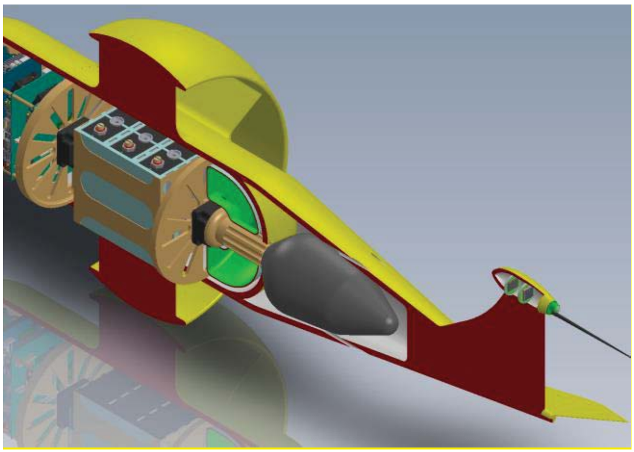

Fig. 4. Medusa II – cutaway of battery and buoyancy section and the communications pod.

E. Buoyancy Section

In order to reduce the force required to actuate the oil piston, which pushes the oil in the bladder at high depth, is necessary to reduce the piston surface (diameter) and increase the stroke. So, the buoyancy engine resembles to a “shotgun” [44] .

The evaluation of the buoyancy of the drone is made considering the buoyancy of the naked glider (as a rigid body) and the variable component due to the bladder and the buoyancy motor. So, the total buoyancy force on the glider is:

$$F_{TOT} = F_{DW} - F_{GB} - F_{BB} \qquad (1)$$

where:

F_{TOT} = Net total “weight” in the water

F_{DW} = *Dry* Weight of the vehicle

F_{BB} = Buoyancy of the oil bladder.

F_{GB} = Buoyancy of the naked vehicle.

For the balance of the forces on the Z axis we have:

$$\sum F_{TOTz} = F_{BP} + F_{OT} + F_{GB} + F_{GB} + F_{BB} = 0 \qquad (2)$$

where:

F_{BP}= weight of the battery pack.

F_{OT} = weight of the oil tank.

F_{GB} = weight of the naked glider.

So the expression of the buoyancy force is:

$$\sum F_{TOTz} = F_{BP} + F_{OT} + F_{GB} + F_{GB} + F_{BB} = 0 \qquad (3)$$

F. Wing Description

The aerofoil is type NACA 16-1013 (see Fig. 4): it was intended for use at high Reynolds’ numbers; the foil is optimized for use as a hydrofoil wing and at low speeds of the AUV expresses its best lift/drag rate.

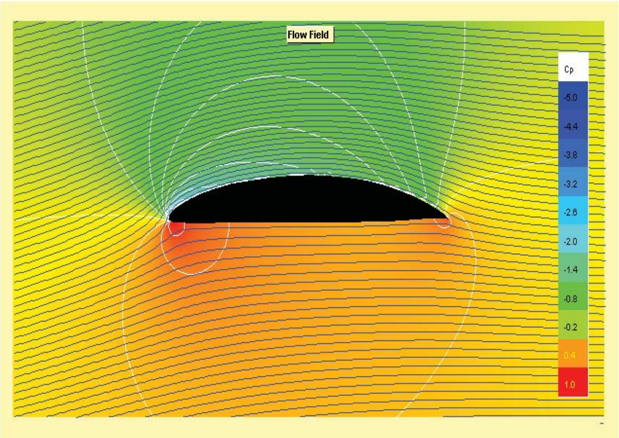

Fig. 5. NACA 16-1013 Flow field (Re=10^6, AoA=5°)

The choice of such a thick profile is due to two factors: first, the wing is subjected to considerable loads due to the peculiar annular geometry.

The second is that in such a thick section it is possible to accommodate a hollow tubular aluminium spar, which increases flexural rigidity. In fig. 5, the aerofoil flow field is shown.

In Fig. 6, the general arrangement of the annular wing is shown.

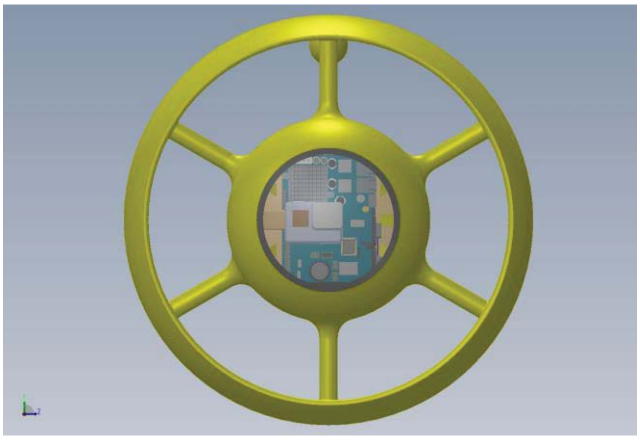

Fig. 6. Medusa II – Front view

III. CONCLUSIONS

This paper is part of several preliminary studies of the Underwater Drones Group of the science department of the Università degli Studi “Roma Tre”, which is developing an advanced AUV (Autonomous Underwater Vehicle) for the exploration of the sea that is a high depths platform for underwater scientific research that can accommodate a wide range of different payloads. We have highlighted the general architecture of the UAV and the internal arrangement in order to optimize the space dedicated to the payload (which can be appropriately customized). In addition, we have illustrated the main parameters of the forces at play inherent to navigation and buoyancy, choosing an appropriate hydrofoil (NACA 16-1013).

REFERENCES

[1] Davis, R. E., D. C. Webb, L. A. Regier and J. Dufour. 1992. “The Autonomous Lagrangian Circulation Explorer (ALACE).” Journal of Atmospheric and Oceanic Technology. 9:264-285.

[2] Davis, R. E., C. C. Eriksen and C. P. Jones. 2003. Autonomous buoyancy-driven underwater gliders. In: Technology and Applications of Autonomous Underwater Vehicles, ed. G. Griffiths, pp. 37-58. Taylor and Francis.

[3] S.Wood – “State of Technology in Autonomous Underwater Gliders” Marine Technology Society Journal, Volume 47, Number 5, September/October 2013.

[4] R.W. Beard, T.W. McLain “Small Unmanned Aircraft - Theory and Practice” Princeton University Press (2012).

[5] H. Stommel “The Slocum Mission” Oceanography, pp. 22 - 25, April 1989.

[6] S.Wood “Autonomous underwater gliders” In: Underwater Vehicles, Chapter 26, edited by A. V. Inzartsev, 499-524, In-Tech, 2009 Vienna, Austria.

[7] Jenkins, S.A. et al., “Underwater Glider System Study” Scripps

Institution of Oceanography, Technical Report No. 53, May 2003.

[8] N. A. A. Hussain, M. R. Arshad and R. Mohd-Mokhtar “Modeling and Identification of An Underwater Glider” Proceedings of the 2010 International Symposium on Robotics and Intelligent Sensors (IRIS2010) Nagoya University, Nagoya, Japan, March 8-11, 2010. ISBN: 987-4-9905048-0-9, ISSN: 1884-1023

[9] D. Titterton, J. Weston “Strapdown Inertial Navigation Technology”, 2nd Edition – The Institution of Electrical Engineers and The American Institute of Aeronautics and Astronautics.

[10] Byrel Mitchell, Eric Wilkening, Nina Mahmoudian, "Low cost underwater gliders for littoral marine research", American Control Conference (ACC) 2013, pp. 1412-1417, 2013, ISSN 0743-1619.

[11] D. Meyer “Glider Technology for Ocean Observations: A Review” Ocean Sci. Discuss., doi: 10.5194/os-2016-40, 2016.

[12] Eriksen, C. C., T. J. Osse, R. D. Light, T.Wen, T. W. Lehman, P. L. Sabin, J. W. Ballard and A. M. Chiodi. 2001. Seaglider: A longrange autonomous underwater vehicle for oceanographic research. IEEE J Oceanic Eng. 26:424-436.

[13] D.L. Rudnick et al. “Underwater Gliders for Ocean Research” Marine Technology Society Journal, Spring 2004 Volume 38, Number 1.

[14] J. G. Graver, J. Liu, C. Woolsey et al., “Design and Analysis of an Underwater Vehicle for Controlled Gliding,” in Conference on Information Sciences and Systems (CISS), Princeton, 1998.

[15] D. L. Rudnick, R. E. Davis, C.C. Eriksen et al., “Underwater Gliders for Ocean Research,” Marine Technology Society Journal, vol. 38, no. 1, Spring, 2004.

[16] Teledyne Webb Research. 2013. Slocum electric glider. Available at: http://www.webbresearch.com/.

[17] Leccese, F., Cagnetti, M., Giarnetti, S., (...), Bozzi, L., Formisano, C. “A simple Takagi-Sugeno fuzzy modelling case study for an underwater glider control system” 2018 IEEE International Workshop on Metrology for the Sea; Learning to Measure Sea Health Parameters, MetroSea 2018 – Proceedings 8657877, pp. 262-267

[18] C.Waldmann, A.Kausche, M.Iversen – “MOTH an underwater glider design study carried out as part of the HGF Alliance ROBEX”

[19] B.J. Bohenek “The Enhanced Performance Of An Integrate Navigation System In A Highly Dynamic Environment” Air Force Institute Of Technology – ref.: AFIT/GE/ENG/94D-01

[20] Petritoli, E., Leccese, F., Ciani, L. Reliability assessment of UAV systems (2017) 4th IEEE International Workshop on Metrology for AeroSpace, MetroAeroSpace 2017 - Proceedings, art. no. 7999577, pp. 266-270. DOI: 10.1109/MetroAeroSpace.2017.7999577.

[21] A.C. Watts, V.G. Ambrosia, E.A. Hinkley “Unmanned Aircraft Systems in Remote Sensing and Scientific Research: Classification and Considerations of Use” Remote Sens. 2012, 4, 1671-1692.

[22] Daniel L. Rudnick, Russ E. Davis, David M. Fratantoni, Mary Jane Perry, “Underwater Gliders for Ocean Research,” Marine Technology Society Journal, v 38, n 2, pp 73-84, Summer 2004.

[23] Petritoli, E., Leccese, F. Improvement of altitude precision in indoor and urban canyon navigation for small flying vehicles (2015) second IEEE International Workshop on Metrology for Aerospace, MetroAeroSpace 2015 - Proceedings, art. no. 7180626, pp. 56-60. DOI: 10.1109/MetroAeroSpace.2015.7180626.

[24] A. Pereira, H. Heidarsson, D.A. Caron, B.H. Jones, and G.S. Sukhatme. An implementation of a communication framework for the cost-effective operation of Slocum gliders in coastal regions. In Proceedings of the 7th International Conference on Field and Service Robotics, Cambridge, MA, July, 2009.

[25] H. C. Woithe, Ulrich Kremer, "A programming architecture for smart autonomous underwater vehicles", Intelligent Robots and Systems 2009. IROS 2009. IEEE/RSJ International Conference on, pp. 4433-4438, 2009.

[26] G.Parthasarathy, Degala Shravya Sree, B.Lakshmi Manasa – “Design Mathematical Modeling and Analysis of Underwater Glider” International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064.

[27] R.N.Smith, M.Schwager, S.L.Smith, D.Rus, G.S.Sukhatme “Persistent Ocean Monitoring with Underwater Gliders Towards Accurate Reconstruction of Dynamic Ocean Processes” Robotics and Automation (ICRA), 2011 IEEE International Conference.

[28] Wilcox, J. S., J. G. Bellingham, Y. Zhang and A. B. Baggeroer. 2001. Performance metrics for oceanographic surveys with autonomous underwater vehicles. IEEE J Oceanic Eng. 26:711-725.

[29] Petritoli, E., Giagnacovo, T., Leccese, F. Lightweight GNSS/IRS integrated navigation system for UAV vehicles (2014) 2014 IEEE International Workshop on Metrology for Aerospace, MetroAeroSpace 2014 - Proceedings, art. no. 6865894, pp. 56-61. DOI: 10.1109/MetroAeroSpace.2014.6865894.

[30] Webb, D. C., P. J. Simonetti and C. P. Jones. 2001. SLOCUM: An underwater glider propelled by environmental energy. IEEE J Oceanic Eng. 26:447-452.

[31] Sherman, J., R. E. Davis, W. B. Owens, and J. Valdes, 2001: The autonomous underwater glider “Spray”. IEEE J Oceanic Eng. 26:437-446.

[32] Petritoli, E., Leccese, F. “A high accuracy navigation system for a tailless underwater glider” IMEKO TC19 Workshop on Metrology for the Sea, MetroSea 2017: Learning to Measure Sea Health Parameters 2017-October, pp. 127-132

[33] Bong-Huat Jun, Jin-Yeong Park, Fill-Youb Lee, Pan-Mook Lee, Chong-Moo Lee, Kihun Kim, Young-Kon Lim, Jun-Ho Oh. “Development of the AUV ‘ISiMI’ and free running test in an ocean engineering basin,” Ocean Engineering, v 36, n 1, pp. 2-14, January 2009.

[34] Petritoli, E., Leccese, F. “A high accuracy attitude system for a tailless underwater glider” IMEKO TC19 Workshop on Metrology for the Sea, MetroSea 2017: Learning to Measure Sea Health Parameters 2017-October, pp. 7-12

[35] Petritoli, E., Leccese, F., Cagnetti, M. “High accuracy buoyancy for underwater gliders: The uncertainty in the depth control” (2019) Sensors (Switzerland), 19 (8), art. no. 1831, DOI: 10.3390/s19081831

[36] N. E. Leonard and Joshua G. Graver,”Model-Based feedback control of autonomous underwater gliders,” IEEE Journal of Ocean Engineering, Vol. 26, No. 4, 2001.

[37] M. Arima, N. Ichihashi, T. Ikebuchi, “Motion characteristics of an underwater glider with independently controllable main wings,”OCEAN ’08 MTS/IEEE Kobe-Techno-Ocean’08-Voyage toward Future, OTO’08, 2008.

[38] Paggi, A., Mariotti, G.L., Paggi, R., Ghizzoni, E.F., Leccese, F., Calogero, A. “Radome reliability” (2018) 5th IEEE International Workshop on Metrology for AeroSpace, MetroAeroSpace 2018 - Proceedings, art. no. 8453519, pp. 571-575.DOI: 10.1109/MetroAeroSpace.2018.845351

[39] Roger E.O, Genderson JG, Smith W.S, Denny G.F, Farley P.J., “Underwater acoustic glider,” Geoscience and Remote Sensing Symposium, IGARSS ’04. Proceedings. IEEE International Vol. 3, pp. 2241-2244, 2004.

[40] Leonard and Graver, “Model based feedback control of autonomous underwater glider,” IEEE Journal of Oceanic Engineering, Vol. 26, No 4, pp.633-644, 2001.

[41] Caciotta, M., Cerqua, V., Leccese, F., Giarnetti, S., De Francesco, E., De Francesco, E., Scaldarella, N. “A first study on prognostic system for electric engines based on Envelope Analysis” (2014) 2014 IEEE International Workshop on Metrology for Aerospace, MetroAeroSpace 2014 - Proceedings, art. no. 6865950, pp. 362-366. DOI: 10.1109/MetroAeroSpace.2014.6865950

[42] Petritoli, E., Leccese, F., Cagnetti, M. “A high accuracy buoyancy system control for an underwater glider” 2018 IEEE International Workshop on Metrology for the Sea; Learning to Measure Sea Health Parameters, MetroSea 2018 – Proceedings 8657831, pp. 257-261

[43] Xiaobo Tan, Drew Kim, Nathan Usher, Dan Laboy, Joel Jackson, Azra Kapetanovic, Jason Rapai, Beniamin Sabadus, Xin Zhou, "An Autonomous Robotic Fish for Mobile Sensing", Intelligent Robots and Systems 2006 IEEE/RSJ International Conference on, pp. 5424-5429, 2006.

[44] Ryan N. Smith, Arvind Pereira, Yi Chao, Peggy P. Li, David A. Caron, Burton H. Jones, Gaurav S. Sukhatme, "Autonomous

Underwater Vehicle trajectory design coupled with predictive ocean models: A case study", Robotics and Automation (ICRA) 2010 IEEE International Conference on, pp. 4770-4777, 2010, ISSN 1050-4729.