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Modeling of Performance of a AUV Vehicle Towards Limiting the Hydro-acoustic Field

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ABSTRACT: Some results of research devoted to the modeling of a AUV-Stealth vehicle performance towards limiting its hydro-acoustic field are presented in the paper. At the beginning the AUV-Stealth autonomous underwater vehicle concept is described. Then the method of research is introduced. Next the key design drivers of the AUV-Stealth vehicle are presented. Between them are the AUV-Stealth hull form, arrangement of internal spaces, materials, hull covers, energy supply and propulsion system, etc. Some results of the hydrodynamic and stealth characteristics of the AUV-Stealth vehicle are briefly described. It is presented in the paper that the hull form, construction materials including the covers may affect the AUV-Stealth vehicle boundary layer and wake. This may create some problems of identification of the AUV-Stealth vehicle using a sonar or hydrophone. The final conclusions are presented.

1 INTRODUCTION

The last decade has brought a rapid development of the maritime unmanned surface (USV - Unmanned Surface Vehicle) and underwater (UUV - Unmanned Underwater Vehicle) vehicles for the different missions to perform. Some of these vehicles are purely unmanned vehicles with the different solutions regarding the steering and energy supply. Some of them seem to be a partially autonomous (AUV - Autonomous Underwater Vehicle). Between them first fully autonomous may appear.

Concerning the USV, UUV and AUV vehicles they may perform the typical patrol, reconnaissance or combat missions. From the navy point of view the vehicles may be equipped with the sophisticated reconnaissance electromagnetic, hydro-acoustic and IT-based equipment or conventional arms. The most advanced vehicles may be equipped with the small fast underwater missiles (Gerigk, 2014).

The aim of the is to work out a AUV-Stealth vehicle model which may possess a few features enabling to obtain a stealth-type performance of the AUV-Stealth vehicle. Between them are as follows:

- limited boundary layer and wake,
- limited emission of the noise and vibration,
- others.

Although there is a lot of investigations in front of the research teams it may be anticipated that the future AUV-Stealth vehicles will have more advanced hull forms, will be equipped with the innovative energy supply sources and propulsion systems, will have the advanced navigation, communication and steering systems, may be covered using the innovative covers guarantying some kind of invisibility in the water.

Silent, invisible, intelligent and autonomous AUV-Stealth. Despite the above mentioned features the most important for the AUV-Stealth vehicles is to design and manufacture them using the most advanced stealth technologies. "Stealth" does not only mean to avoid and/or absorb the data radiation by the unique hull form and/or hull skin cover. "Stealth" concerns the propulsion system as well. The AUV-Stealth vehicles should be equipped with the silent electric engines and jet propellers. The noise and vibrations generated by a AUV-Stealth vehicle should on the lowest possible level. The construction of the AUV-Stealth vehicle should protect the emission of heat from the systems installed onboard. Moving under the water surface the AUV-Stealth vehicle should generate a small value of boundary layer and wake to limit its own acoustic signal. This is why the innovative hull skin covers are of great importance. Despite of the mission the AUV-Stealth vehicles should be equipped with the coded navigation, communication and steering subsystems to operate the vehicles above the water surface (wing in ground vehicles), on the water surface and under the water surface. The vehicles should be equipped with the energy supply subsystem (batteries) to perform up to several hours missions with the possibility to upload the batters using the submerged energy loading stands. According to the tasks some AUV-Stealth vehicles should be equipped with the autonomous intelligent (AI - Artificial Intelligence) steering and vehicle positioning subsystems enabling to use the data obtained from the vehicle sensor subsystems. The most advanced AUV-Stealth vehicles would be those which could independently communicate with the other vehicles (USV, UUV, ASV, AUV) and make decisions on their own.

The presented concept of the AUV-Stealth vehicle is a future vision of an advanced AUV vehicle for the ocean engineering missions as well.

2 AUV-STEALTH VEHICLE CONCEPT

The primary aim of the research is to work out a functional model of the stealth AUV vehicle moving in the data operational conditions.

The novel solutions have been applied regarding the hull form, arrangement of internal spaces, materials, hull covers, energy supply and propulsion system. The hull form is a hybrid stealth hull form. The arrangement of internal spaces is designed according to the functional requirements and is very much affected by the sub-systems installed onboard.

The major sub-systems of the stealth AUV vehicle are as follows (Gerigk, 2015; Gerigk, 2016):
- ballast sub-system,
- energy supply sub-system (batteries),
- water-jet propulsion sub-system,
- T-foil stabilizing sub-system,
- steering, navigation and communication sub-system,
- dedicated sub-system.

The main parameters of the AUV-Stealth vehicle are as follows (Gerigk, 2015; Gerigk, 2016):
- overall length L - is equal to 2.2 meters,
- operational breadth B - is equal to 1.1 meters without the appendages,
- height H - is equal to 0.35 meters appendages,
- mass is equal to from 0.16 to 0.32 tons, depending on the mass of equipment installed onboard,
- averaged speed during the underwater mission for the submerged conditions (3 meters) v_{uw} - is equal to 1.0-2.0 meters per second.

The general visualizations of the hull form and arrangement of external spaces of the AUV-Stealth vehicle are presented in Figure 1.

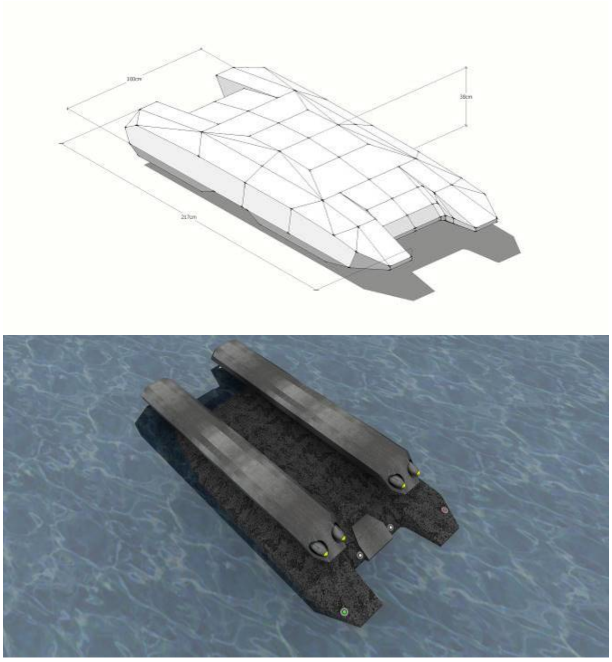

Figure 1. The general visualizations of the hull form and arrangement of external spaces of the stealth AUV vehicle (Gerigk, 2014-2018).

3 THE RESEARCH METHOD

The aim of the is to work out a AUV-Stealth vehicle model which may possess a few features enabling to obtain a stealth-type performance of the AUV-Stealth vehicle. Between them are as follows:
- limited boundary layer and wake,
- limited emission of the noise and vibration,
- others.

"Stealth" means to limit the probability to detect the AUV-Stealth vehicle to the lowest possible level using the well and hardly known (advanced, innovative) methods and means of reconnaissance.

The current investigations on the stealth technologies towards their application onboard the AUV-Stealth vehicles are associated with the following problems:
- size and hull form of the AUV-Stealth vehicle,
- skin covers of the AUV-Stealth hull,
- minimizing the noise and vibrations generated by the onboard sub-systems and AUV-Stealth vehicle itself (flow: boundary layer, wake),
- minimizing the heat emissions,
- minimizing the emission of electromagnetic and hydro-acoustic signals,
- avoiding and/or absorbing the outside (electromagnetic, hydro-acoustic) radiation,

– maximizing the invisibility of the AUV-Stealth vehicle.

The research method for modeling the hydrodynamic and stealth both the features and characteristics of the AUV-Stealth vehicle is a kind of performance-oriented risk-based method which enables to assess the above mentioned at the design stage and in operation (Gerigk, 2010). The method takes into account the influence of design and operational factors following from different sources. The holistic approach and system approach to performance and risk assessment have been applied.

The physical models and computer simulation techniques have been applied to obtain the AUV-Stealth vehicle hydrodynamic and stealth characteristics and features. At the research and design stage, the assessment of AUV-Stealth vehicle performance enables to identify the sequence of events for the operational conditions very close to reality (Gerigk, 2015; Gerigk, 2016: Gerigk, Wójtowicz, Zawistowski, 2015; Gerigk, Wójtowicz, 2015).

The risk assessment is based on application of the matrix type risk model which is prepared in such a way that it enables to consider almost all the possible scenarios of events which may occur in operation. The criteria is to achieve an adequate level of risk using the risk acceptance criteria, risk matrix, (Gerigk, 2010). Providing a sufficient level of safety based on the risk assessment is the main objective. Safety is the design objective between the other objectives. The measure of safety of the AUV-Stealth vehicle is the risk or the risk level.

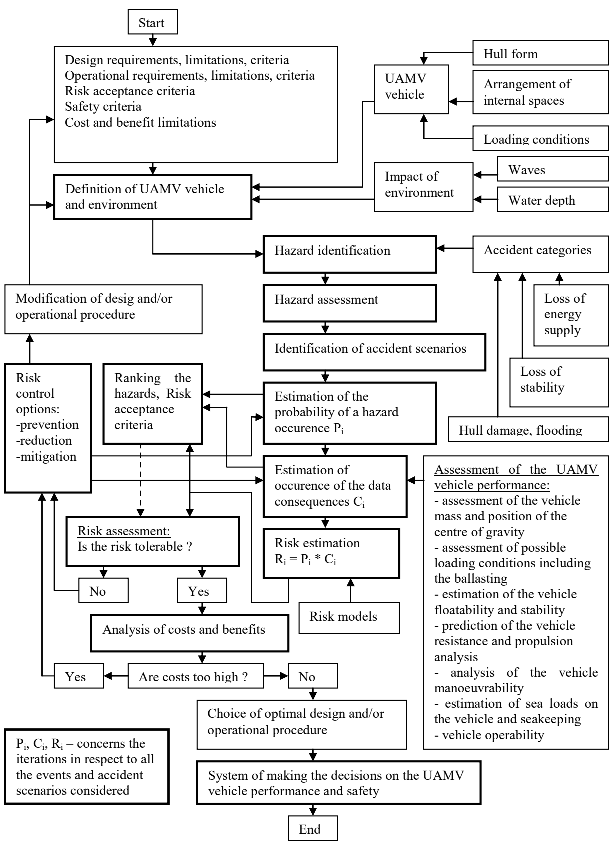

Figure 3. A Structure of the method for assessment of the UAMV vehicle performance and risk assessment (Gerigk, 2014-2016).

The method itself is based on the following main steps presented in the papers by Gerigk (Gerigk, 2016; Gerigk, 2017): setting the requirements (criteria, limitations, safety objectives), defining the AUV-Stealth vehicle, defining the operational conditions, identifying the hazards and event scenarios, assessing the AUV-Stealth vehicle performance, estimating the risk, assessing the risk, managing the risk, selecting the design that meet the requirements, optimizing the design, making the final decisions on design and on safety.

The structure of the method which combines the typical design/operational procedures with the risk assessment techniques is presented in Figure 3 (AUVSI/ONR, 2007; Abramowicz-Gerigk, Burciu, 2014; Cwojdziński, Gerigk, 2014; Dudziak, 2008; Faltinsen, 1990; Faltinsen, 2005; Gerigk, 2010; Gerigk, 2015; Lamb, 2003; Szulist, Gerigk, 2015).

4 DESIGN DRIVERS

The research and design methodology is based on the following approach: application of key (advanced) technologies may give an innovative solution concerning the AUV-Stealth vehicle.

The key technologies which play the main role during the research and design of the AUV-Stealth vehicle are as follows:

– technology of autonomous systems;
– technology of sensors and effectors;
– technology of materials including the AI materials, nano-materials;
– technology of energy supply sources;
– technology of innovative propulsion systems;
– IT technologies including the communication, navigation and steering;
– stealth technologies;
– cosmic and satelite technologies and others.

The innovative solutions may be as follows: innovative platforms and single-, double- and triple-mode vehicles. Between them are the AUV-Stealth vehicles which are the double-mode vehicles.

During the research the following research and design key-drivers have been adopted:

1 hull form - arrangement of internal spaces, distribution of masses, payload;
2 energy supply system;
3 propulsion system;
4 steering, communication, navigation system;
5 sensors and effectors;
6 dedicated system.

5 AUV-STEALTH HYDRODYNAMIC AND STEALTH CHARACTERISTICS

The main aim of research is to work out a AUV-Stealth vehicle model which may possess a few features enabling to obtain a stealth-type performance of the AUV-Stealth vehicle. Between these features are:

– limited boundary layer and wake,
– limited emission of the noise and vibration,

– others.

The stealth technology (def.): minimizing the probability of detection of the S-AUV vehicle using the well known and „unknown" means (technologies, devices, etc.

The "stelth" function is anticipated as follows:

$$E = E\,[p_1, p_2,\ldots, p_n, f_1(x_1, x_2,\ldots, x_{m1}),$$
$$f_2(x_1, x_2,\ldots, x_{m2}), \qquad (1)$$
$$\ldots\ldots$$
$$f_k(x_1, x_2,\ldots, x_{mt})]$$

where:
k – No. of a stealth technology applied;
$m_1, m_2, m_3, m_4, m_5, m_6, m_t$ – No. of independent (dependent) characteristics for the data stealth technology;
p – parameters;
x - variables;
f – a stealth characteristics (function, polynomial, etc).

The physical fields for the research have been anticipated as follows:
– F 1- main particulars, hull form (gemetry);
– F 2- skin covers (nano-surface) – materials;
– F 3- noise and vibrations;
– F 4- elektromagnetic, magnetic;
– F 5- temperature (heating);
– F 6- boundary layer + wake;
– F 7- visibilty.

The first step during the research was to check how much a hull skin cover may affect the AUV-Stealth vehicle flow including the boundary layer and wake. During the computer simulation of the flow the mesh consisted of 3 275 000 elements was used. The numerical domain had the size (Kardaś, Tiutiurski, Gerigk, 2016):

5 meters x 1.5 meters x 1.2 meters (2)

and it is presented in Figure 4.

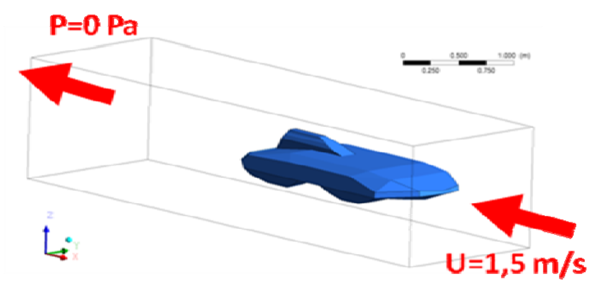

Figure 4. A visualization of the numerical domain for the computer simulation of the impact of different hull skin covers on the flow (boundary layer and wake) of the AUV-Stealth vehicle.

The water flow velocity was anticipated to be from 0.5 up to 2.5 meters per second with the step 0.5 meters per second.

During the simulation the hull skin cover was generated by the skin roughness as follows:
– Ra 80 - as a normal steel plate surface,
– Ra 1.25 - as a slightly polished steel plate surface,
– Ra 0.01 - as a polished steel plate surface,
– Ra 0.0025 - extremely polished steel plate surface (called during the research as a nano-surface).

The flow was estimated for the distance 0.5 meters, 1.0 meters, 1.5 meters and 2.0 meters behind the AUV-Stealth vehicle. An example of results of the flow estimation for the data skin roughness and velocity anticipated are presented in Figure 5 (Kardaś, Tiutiurski, Gerigk, 2016).

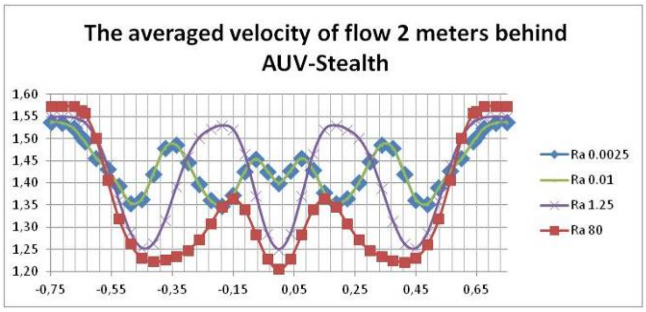

Figure 5. The example results of the impact of different hull skin covers on the flow 2 meters behind the AUV-Stealth vehicle for the data skin roughness and flow velocity anticipated.

The second step during the research was to check the influence of the parameters (modelled roughness, nano-surface) of the hull skin cover on the flow including mainly the boundary layer. During the computer simulation three types of nano-surface has been modelled. Some results of the computer simulation of the flow estimation in the boundary layer (for the data skin roughness, for the nano-surface modelled) are presented in Figure 6 (Ciba, Dymarski, Gerigk, 2018).

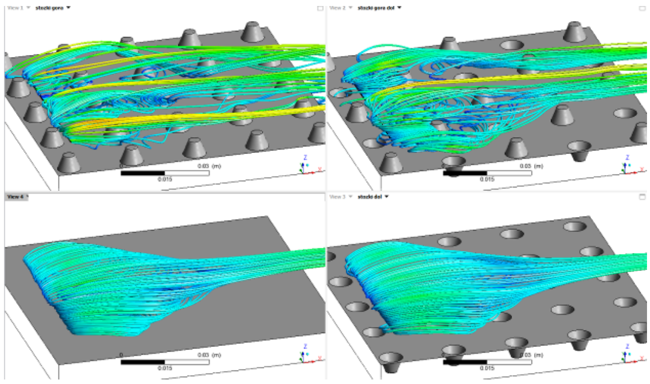

Figure 6. The example results of the impact of different hull skin covers on the flow in the boundary layer of the AUV-Stealth vehicle for the data skin roughness (nano-surface modelled) and flow velocity anticipated.

The third step was to check the influence of the hull skin cover on the sonar system signal. During the towing tank investigations three types of AUV-Stealth hull skin covers were tested. Some results of these investigations are presented in Figure 7 (Barański, Gerigk, 2018).

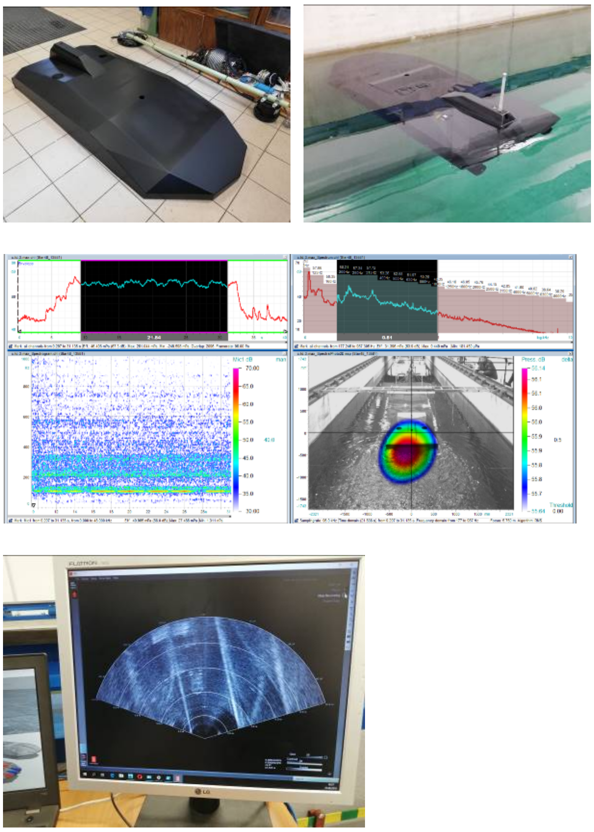

Figure 7. Some results of the hydro-acoustic investigations of the AUV-Stealth vehicle.

6 CONCLUSIONS

In the paper some results connected with development of the AUV-Stealth vehicle model are presented.

Some data on the AUV-Stealth vehicle concept, research method, hydrodynamic and stealth characteristics of the AUV-Stealth vehicle are described in the paper.

As the examples some results concerning the impact of the different hull skin covers (skin roughness, nano-surface) on the boundary layer, wake and sonar signal were investigated.

At the current stage of research an influence of combined stealth characteristics on the AUV-Stealth vehicle performance is investigated.

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