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FORM DEVELOPMENT AND VALIDATION OF AN AUTONOMOUS UNDERWATER VEHICLE

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Abstract: *Engineering projects such as surveys for oil and natural gas resources, offshore structures, undersea pipelines, harbours, etc., require geomorphological, geological and geophysical as well oceanographic research both at the coastal and offshore areas. Such research is conducted by research vessels or by small craft equipped for the specific purposes, which require extensive labourship. This method of research causes high costs and may also involve threats to occupational safety and property due to the harsh weather conditions at sea. Furthermore, high precision measurements cannot always be performed during such seismic research. Thus, autonomous underwater vehicles (AUV) have been developed intensively in the last two decades.*

The objective of this study is to find the proper unmanned underwater surveying vehicle to conduct research on the geomorphological, geological and geophysical aspects of the structure of the sea bottom and on the Earth's mantle beneath the seas as well oceanographic opinions. Therefore, this article is aimed to provide a comprehensive understanding about computational fluid dynamics (CFD) analysis of a SWATH ship model and the validation of the results obtained in these analyses with those of the experiments of this ship model performed by Begovic et al, 2015. After successful conformity of the simulations carried out using the commercial software ANSYS/FLUENT, the developed models of an immature goose-beaked whale (ziphius cavirostris) and an immature sperm whale (physeter macrocephalus) as well three torpedo shaped AUV models with the same length of 6,0 m were analysed in the same manner and the results obtained were compared to each other.

Keywords: *Form development, autonomous underwater vehicle, CFD analysis, marine science.*

1 Introduction

Geomorphological, geological and geophysical as well oceanographic research, necessary for the engineering projects such as surveys for oil and natural gas resources, offshore structures, undersea pipelines, harbours, etc., at both the coastal and offshore areas are customarily conducted by research vessels or by small craft equipped for the specific purposes, which require extensive human labourship. Nevertheless, this method causes reducing the accuracy of measurements, increasing the costs of management and research, prolongation of the research periods and increasing the risks to human life and property by conducting the research by those vehicles due to the harsh weather conditions at sea. Thus in universities and research communities, autonomous underwater vehicles (AUV) have been developed intensively in the last two decades.

Autonomous Underwater Vehicles (AUVs) provide an important opportunity to collect detailed oceanographic and seismic data from the depths of the seas and oceans. The most important design factors for these AUVs are to reduce their body resistance force and to increase the thrust force, namely increasing the propulsive efficiency. Exact prediction of the body resistance of an AUV is the most fundamental factor in determining a specific range of power requirements and so operation route of the vehicle. Additionally, it is by now expected from AUVs to also possess the high manoeuvrability capacity of Remote Operated Vehicles (ROV) while maintaining the typical features of their types.

For estimating the body resistance of the AUV to be designed, first the study of Begovic et al [1] was examined elaborately. In their study, the different hydrodynamic aspects of the SWATH (Small Waterplane Area Twin Hull) concept are treated; their advantages and critical issues arising from this design are discussed. Furthermore, detailed numerical towing tank analyses were performed and the results obtained were validated by the physical towing tank tests carried out. Myring [2] used the data of the Royal Aviation Association in his study to confirm the numerical analysis results obtained for a series of

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body forms. In this case, a method has been developed to determine the resistance that affects the shape of the body in the axial symmetric flow [2]. Additionally, design of different AUVs in terms of body resistance, propulsion efficiency and other hydrodynamic properties are investigated using the CFD methods and/or tests or both in detail in [3-10].

The main objective of this study is to develop a proper unmanned underwater surveying vehicle to conduct research on the geomorphological, geological and geophysical aspects of the structure of the sea bottom up to the deep of 2,000 m and on the Earth's mantle beneath the seas as well oceanographic opinions, with the maximum und service speed in operation 8 kn and 2-3 kn, respectively. The AUV shall conduct more effective and less costly operations within a given time sequence with a high energy efficiency, and it shall be easily maintained as well repaired.

2 Materials and Method

In general, moving objects submerged in a fluid are exposed to the viscous drag that consists of two components, namely the viscous pressure and frictional resistance depending both upon the Reynolds number. If they are floating at the free fluid surface, these objects are additionally experienced wave resistance depending on the Froude number. Thus the small undersea craft as autonomous underwater vehicles must possess proper hydrodynamic form and surface characteristics regarding frictional and viscous pressure resistance, while they should also possess satisfactorily structural properties due to high hydrostatic pressure depending on the deep water.

Before of all, in order to approve the CFD method to be applied in all of the simulations in this study, an SWATH ship model equivalent to this published in [1] was modelled exactly and analysed (Fig. 1-5). The results obtained from the simulations were validated with those of the experiments of this ship model executed by Begovic et al [1] (Fig. 1,2,6). Since the SWATH ship model is floating at free sea surface, all of three components of the resistance, namely the frictional and viscous pressure as well wave resistance arise synchronously. Thus this type of analysis is more complicated than the simulation of the objects submerged in fluid. In this regard the SWATH ship form consisting of two torpedo shaped boundary elements and four struts was selected for validation of the CFD analyses carried out in this research (Fig. 1,2). Figure 3 indicates the model of the SWATH ship while Figure 4 and 5 show the domain of the system analysed and the meshed model, respectively. Figure 6 displays the good agreement of the results of the CFD analyses carried out in this study and the experiments performed by Begovic et al [1], each other.

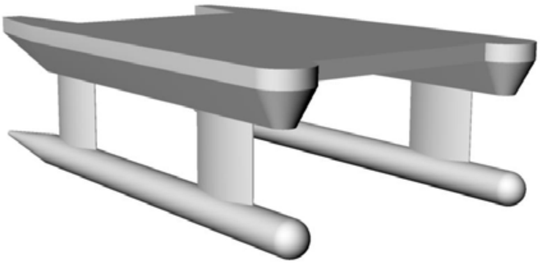

Figure 1. Designed SWATH ship hull [1]

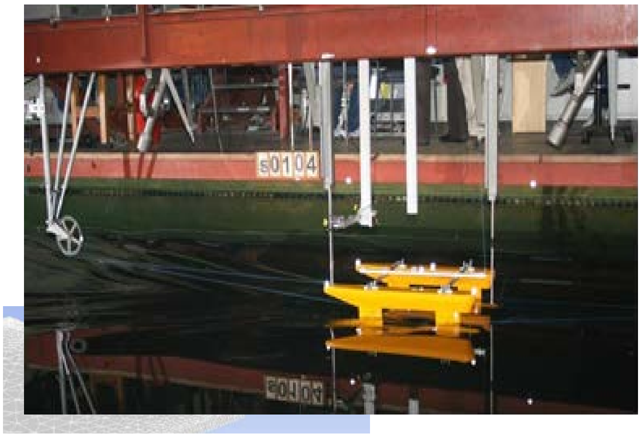

Figure 2. Resistance and seakeeping device [1]

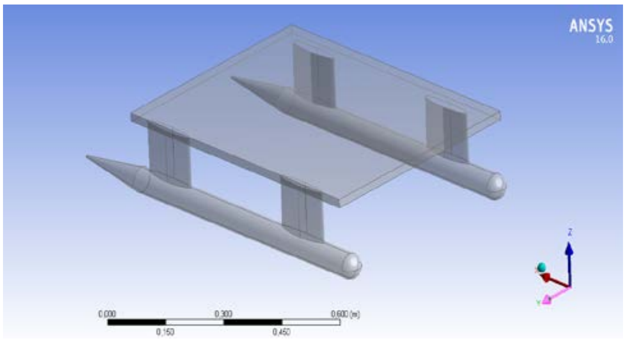

Figure 3. Modelled SWATH ship hull

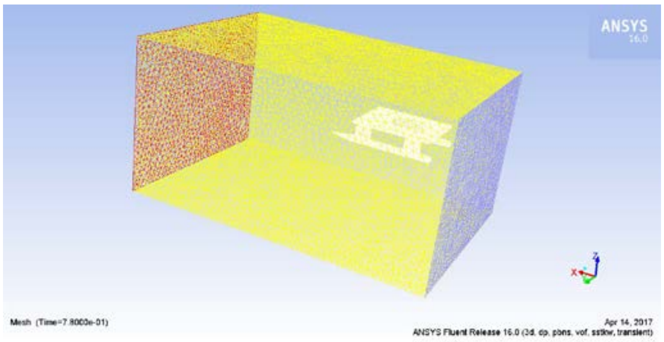

Figure 4. Domain of the SWATH ship

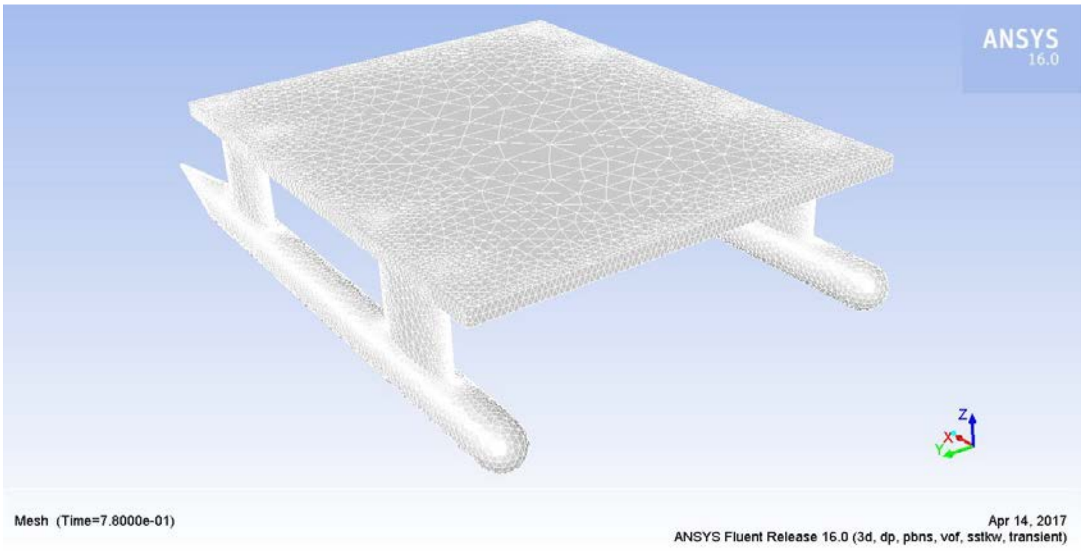

Figure 5. Meshed SWATH ship hull of the model

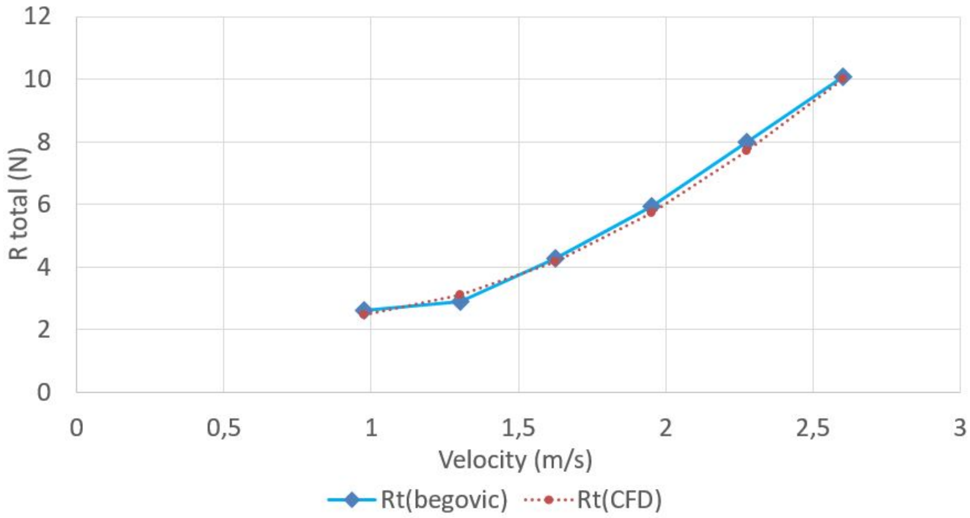

Figure 6. Total resistance results of the test and CFD analysis of the SWATH ship

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Further, the models of an immature goose-beaked whale (*ziphius cavirostris*) and an immature sperm whale (*physeter macrocephalus*) developed in this study should be exploited because these whales can dive up to the deep of 3,000 m (Fig. 7-10). In this regard within this research, after developing three torpedo shaped AUV models and the models of the whales above mentioned (Fig. 11-15), detailed CFD analyses of these models with the same length of 6,0 m were carried out using the commercial software ANSYS/FLUENT and the results obtained were discussed comparatively .

Fig 7-16 show the developed and meshed models of the immature sperm and beaked whale, different AUVs as well their domains in which they were analysed. So it became possible to hydrodynamically compare the two whale forms evolved after millions of years and the AUV forms shaped according to torpedos each other.

Beaked whales have a top speed of 11-12 km/h while sperm whales can reach the maximum speed of 35-45 km/h. In order to compare all models each other, all AUVs and the both whales shall have an optimum speed of 5 m/s [11,12].

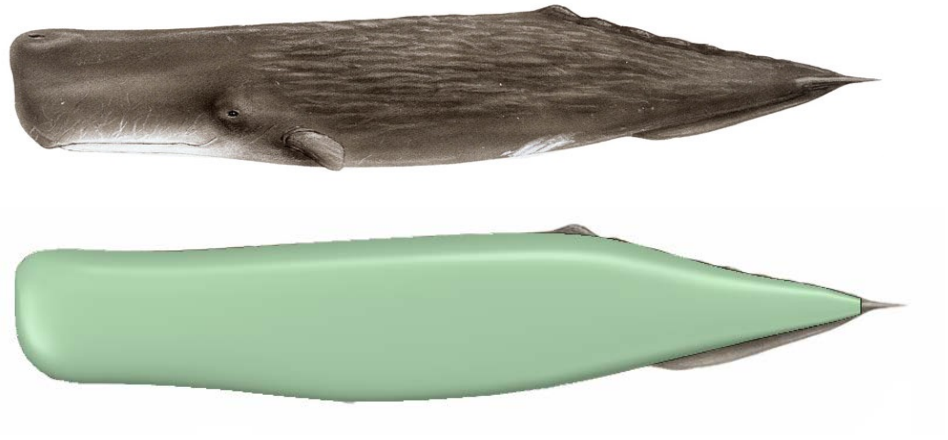

Figure 7. Sperm whale (*Physeter Macrocephalus)*

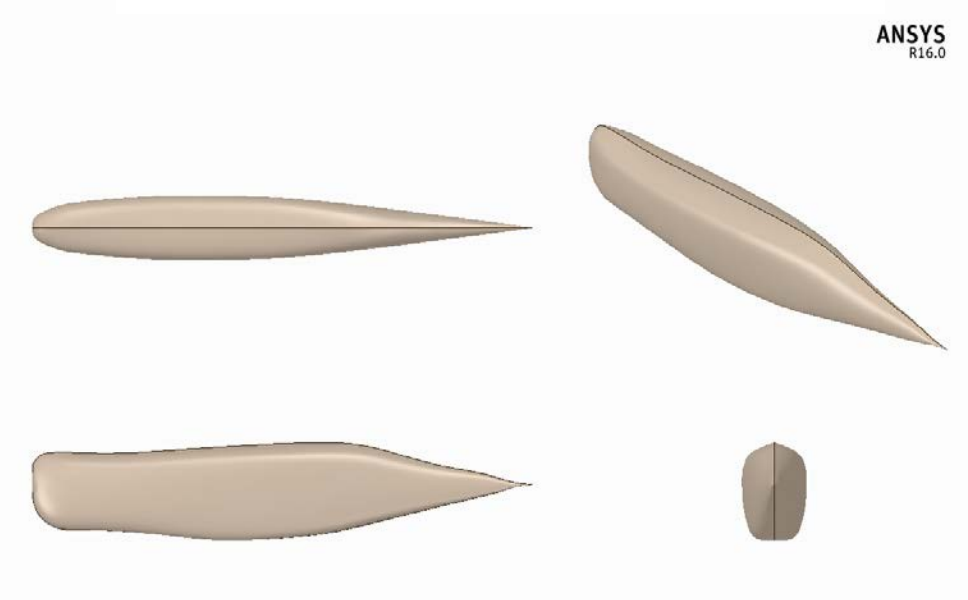

Figure 8. Modeling of an immature sperm whale

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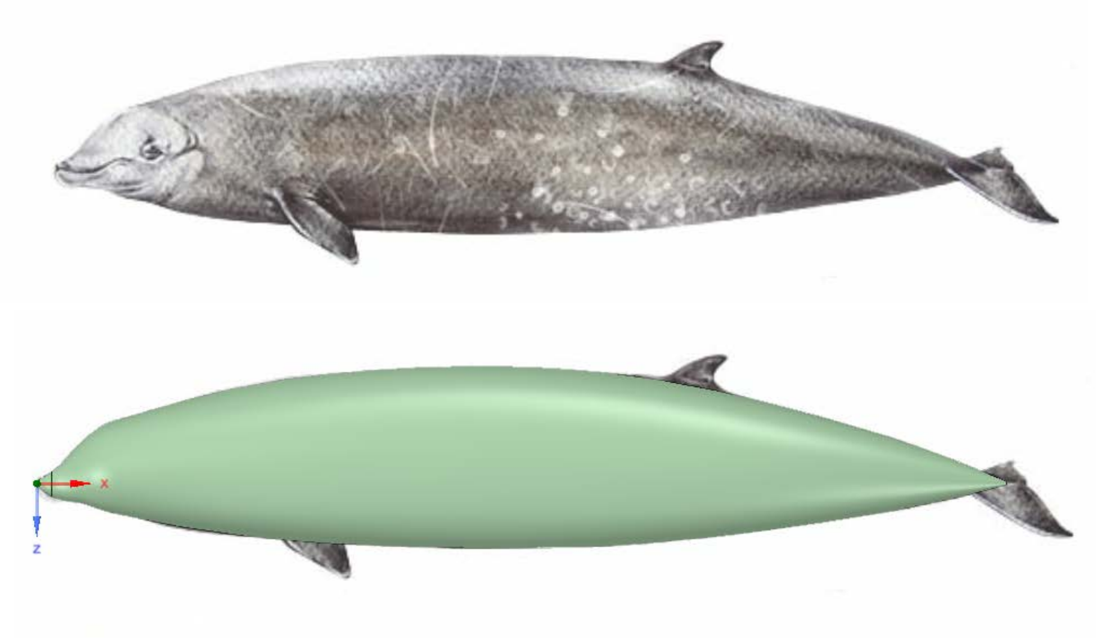

Figure 9. Beaked whale (*Ziphius Cavirostris*)

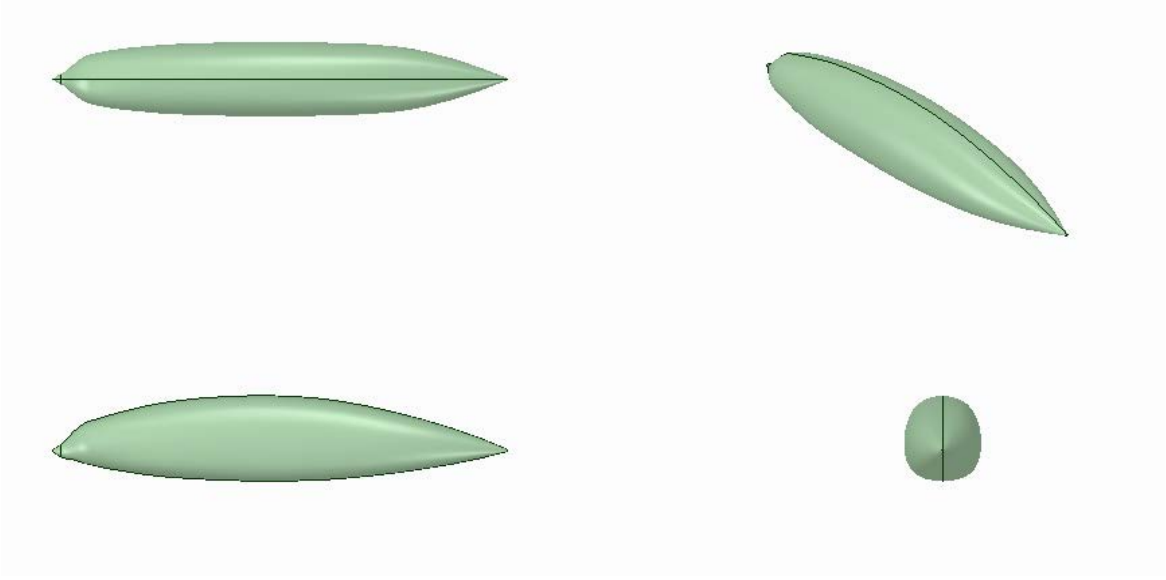

Figure 10. Modeling of an immature beaked whale

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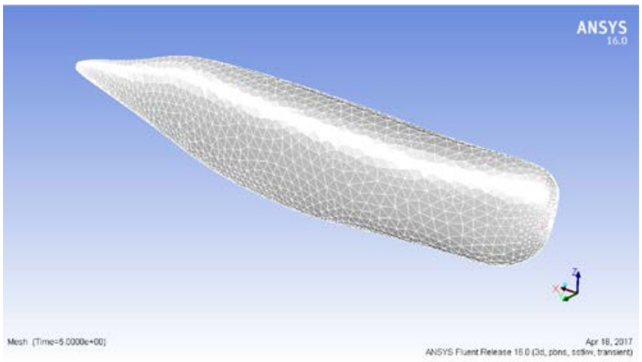

Figure 11. Meshed model of the sperm whale

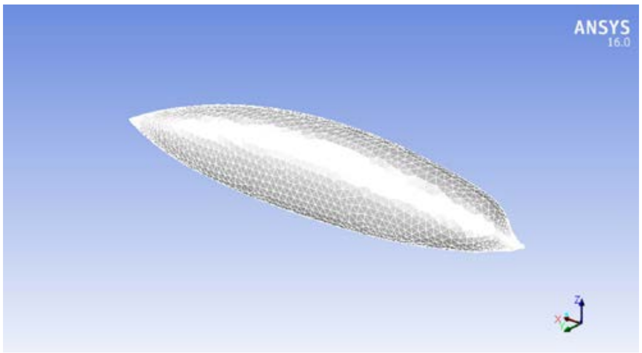

Figure 12. Meshed model of the beaked whale

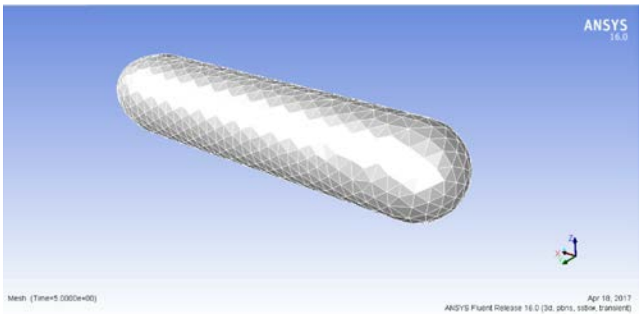

Figure 13. Meshed model of the AUV-1

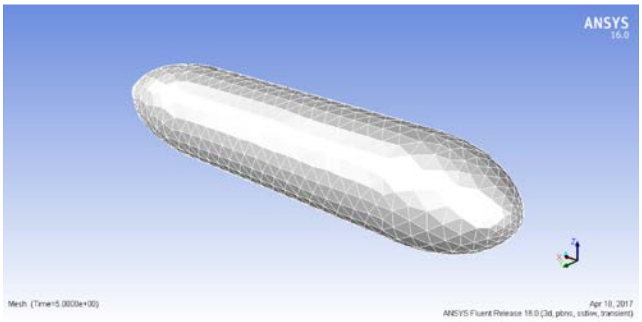

Figure 14. Meshed model of the AUV-2

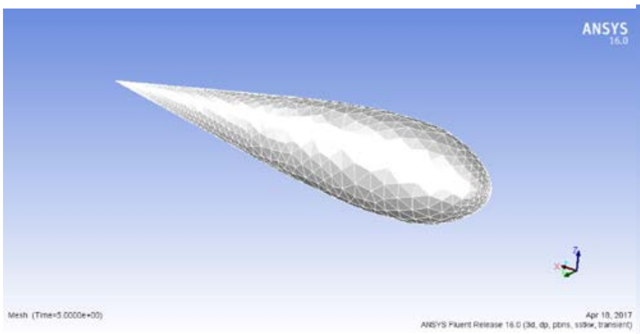

Figure 15. Meshed model of the AUV-3

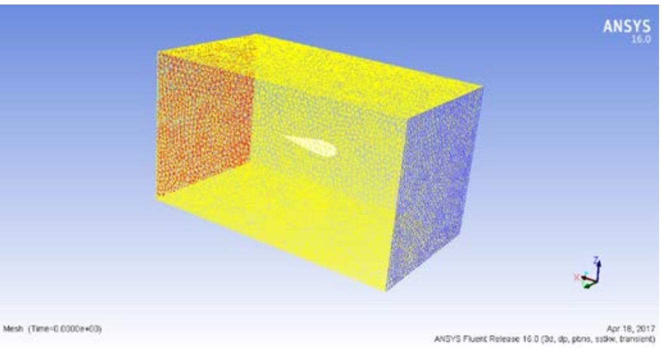

Figure 16. Domain of meshed model of the AUV-3

3 Analysis of the Models and Results

After successful confirming of the CFD method applied using the SWATH ship concept of Begovich et al [1], all of the five models treated in the section above were analysed numerically in which the turbulence modelling of ANSYS/FLUENT "Shear Stress Transport k–ω model (SSTKW-Menter) was applied (Fig. 17-26). The reason for this that this modelling type generally gives accurate prediction of the onset and the size of separation under adverse pressure gradient since SSTKW-Menter contains a modified turbulent viscosity formulation to calculate for the transport effects of the principal turbulent shear stress [13,14]. Certain separations at the sterns of these models were expected.

The results of total viscous resistance of the whales obtained from the CFD analyses performed by the software ANSYS/FLUENT shows that the both whales experience nearly the same viscous forces from the water in full dived condition although their forms are not identical (Fig. 7-10). Nevertheless, they have relatively identical pressure and turbulent kinetic energy distribution fields at their bodies (Fig. 11,12,17, 18,22,23).

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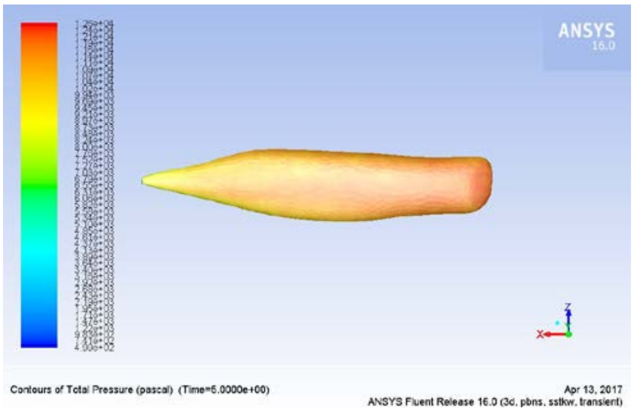

Figure 17. Total pressure distribution of the sperm whale

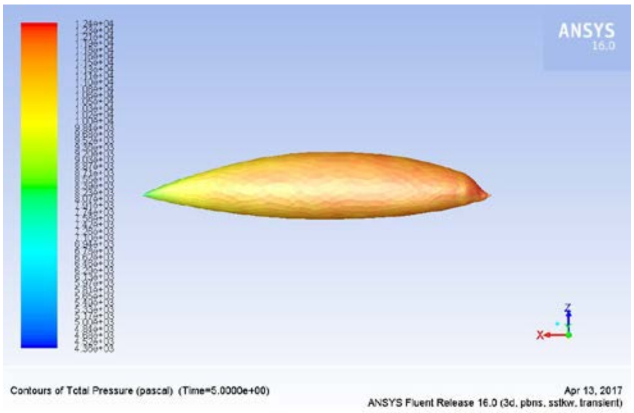

Figure 18.Total pressure distribution of the beaked whale

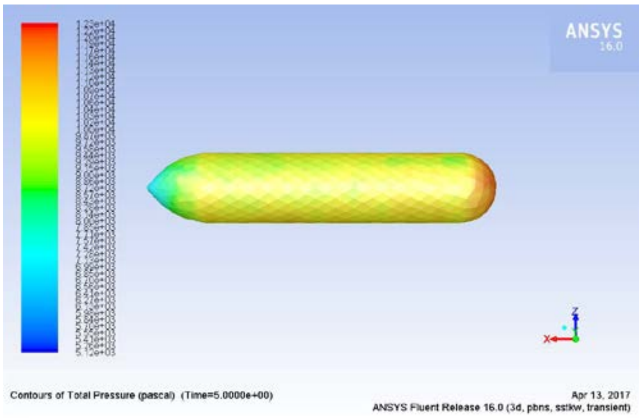

Figure 19.Total pressure distribution of the AUV-1

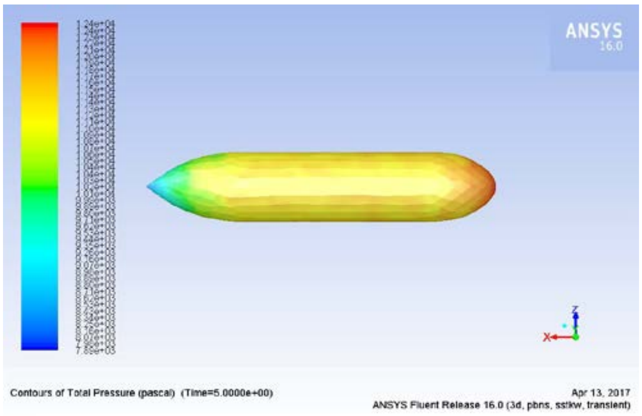

Figure 20.Total pressure distribution of the AUV-2

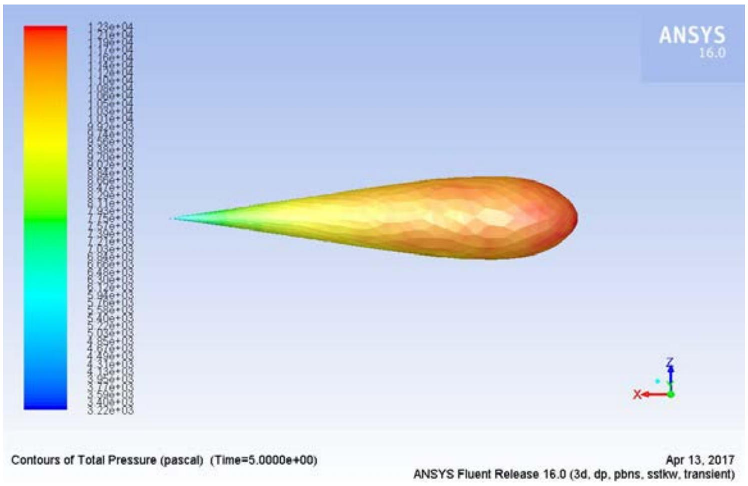

Figure 21.Total pressure distribution of the AUV-3

Partially similar to the both bodies of the sperm and beaked whales, two AUV forms were modelled and analysed under the same conditions (Fig. 13,14,19,20,24,25). However, the results of the viscous forces arose at the AUVs were astonishingly higher than those of the whales (Fig. 27). The AUV form with ellipsoid head (AUV-2) possesses less friction and viscous pressure forces about 37.5 % than the one with sphere head (AUV-1). Pressure and turbulent kinetic energy distribution fields of these models appears variously at the sterns due to different grads of turbulences, but more uniform at the AUV-2 than at AUV-1 (Fig. 19,20,24,25).

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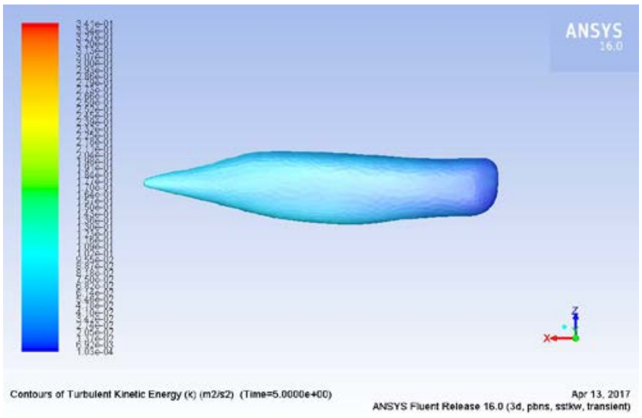

Figure 22.Turbulent kinetic energy distribution of sperm whale

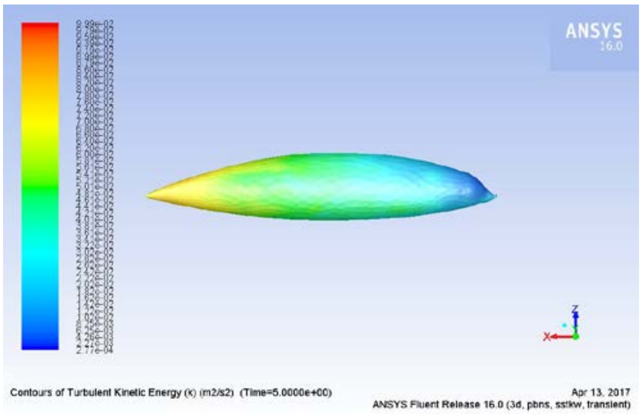

Figure 23. Turbulent kinetic energy distribution of sperm whale

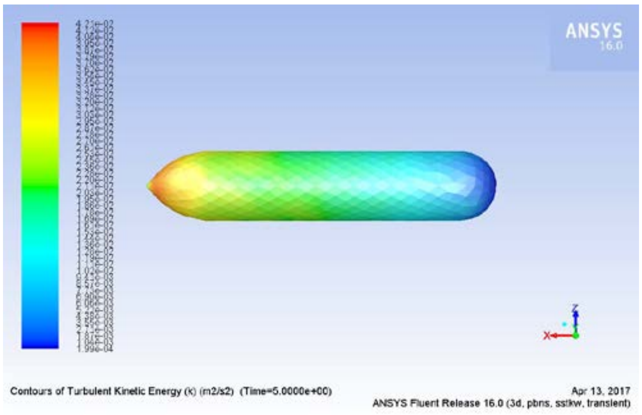

Figure 24. Turbulent kinetic energy distribution of the AUV-1

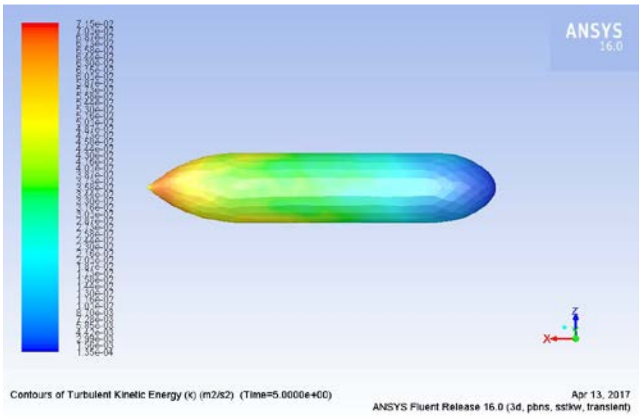

Figure 25. Turbulent kinetic energy distribution of the AUV-2

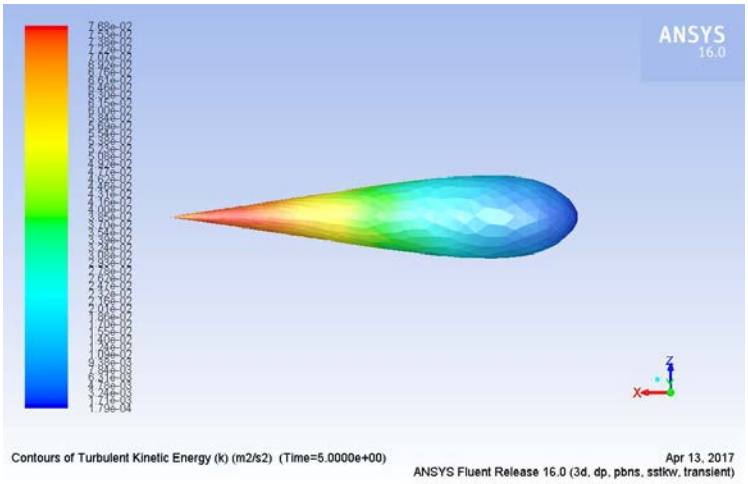

Figure 26. Turbulent kinetic energy distribution of the AUV-3

Thereupon the AUV form with ellipsoid head (AUV-2) was developed further that mainly its parallel body was changed as the form of the immature beaked whale and renamed as AUV-3 (Fig. 15). As can be seen in Fig. 21,26,27, the viscous forces (total resistance) of this new form decreased about 29 % compared to the former form, and the distribution of the pressure and turbulent kinetic energy distribution fields at this AUV form improved considerably. The water plane section area of this form appears as those of a ship rudder (Fig. 26) and causes considerably less turbulences in the stern of the model than those in the aft body of the other models whereat this level of the turbulences lies still higher than those at the both whales (Fig. 22-27).

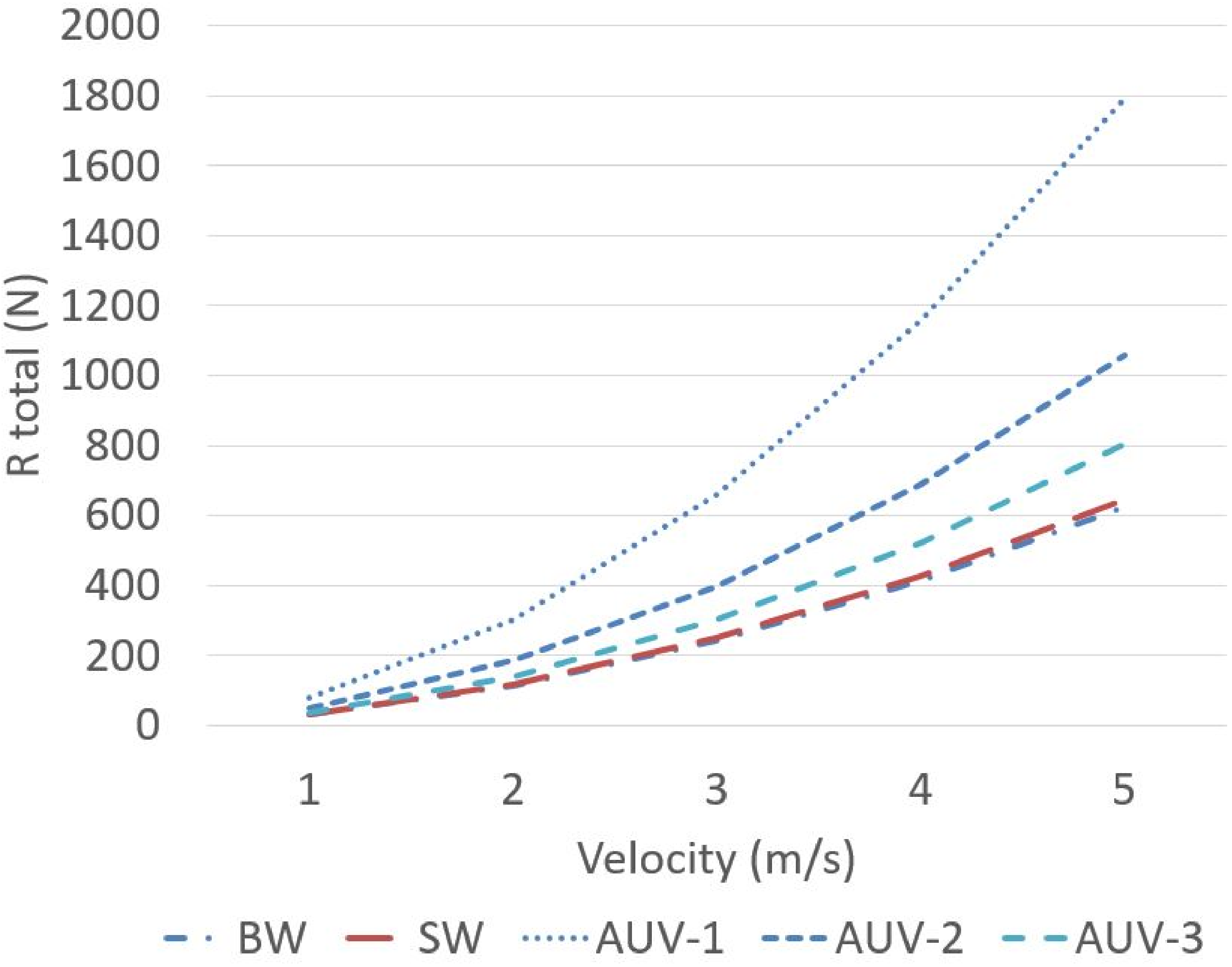

Figure 27. Total resistance results of the CFD analyses of all models

Conclusions

This study is aimed to develop a proper autonomous underwater surveying vehicle form to conduct research on the geomorphological, geological and geophysical aspects of the structure of the sea bottom and on the Earth's mantle beneath the seas as well oceanographic opinions. Therefore, in order to apply exactly the CFD method to the analyses, a SWATH ship model was modelled and analysed. After the successful validation of the results obtained in these CFD analyses through those of the experiments of this ship model performed by Begovic et al, 2015, the simulations carried out on the developed models of an immature goose-beaked whale (*ziphius cavirostris*) and an immature sperm whale (*physeter macrocephalus*) as well three torpedo shaped AUV models with the same length of 6,0 m, were analysed in the same manner using the commercial software ANSYS/FLUENT, and the results obtained were compared to each other.

The new form appears to possess better characteristics than the AUV-1 and AUV-2. However, the forms of the both whales evolved after millions of years indicate to have still better shapes and characteristics than one of the last model AUV-3. Nevertheless, in this case an important issue arises that the new AUV includes considerable less volume than the former forms. Thus this new form should be improved and/or optimised further in terms of its volume for batteries and equipment.

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