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TMMOB GEMİ MÜHENDİSLERİ ODASI
The Turkish Chamber of Naval Architects and Marine Engineers

GMO

1 TEMMUZ
DENİZCİLİK VE KABOTAJ BAYRAMIMIZ KUTLU OLSUN

Denizciliği Türk'ün büyük milli ülküsü olarak düşünmeli ve onu az zamanda başarmalıyız.

K. Atatürk

TMMOB Gemi Mühendisleri Odası

EDİTÖRDEN / EDITORIAL

Değerli Meslektaşlar ve Okurlar,

Gemi ve Deniz Teknolojisi dergimizin 212. sayısında, İstanbul'da Yıldız Teknik Üniversitesi Gemi İnşaatı ve Denizcilik Fakültesi'nin organize ettiği 3. Uluslararası Gemi İnşaatı ve Denizcilik Sempozyumu'nda (INT-NAM 2018) sunulmuş olan çalışmalardan seçilen dört makale yer almaktadır. "Sürtünme Direncini Azaltmak İçin Geminin Çift Dip Tabanına Monte Edilmiş Hava Sirkülasyon Tankının Geliştirilmesi" başlıklı ilk makalede, bir geminin çift dip kısmına monte edilen tankta biriken hava ile sürtünme direncini büyük ölçüde azaltan bir sistem olan Hava Sirkülasyon Tankı incelenmektedir. "Denizcilik ve Havacılıkta Çarpışma Önleme Sistemlerinin Karşılaştırmalı Olarak İncelenmesi" başlıklı ikinci makale, havacılık ve denizcilik endüstrileri arasında hem uçaklar hem de gemiler için yönetmelikler, operasyonel uygulamalar, teknikler ve prosedürler açısından bir karşılaştırma sağlamaktadır. Üçüncü makale "Çekme Tankı Deneyleri ve Hesaplamalı Akışkanlar Dinamiği Yöntemleri Kullanılarak Bir Sekiz Tek Yarış Teknesinin Trim Optimizasyonu" başlığı ile yer almaktadır. Bu çalışmanın amacı, 2000m'lik yarış boyunca sekiz kişilik bir yarış teknesinin optimal trimini incelemek için deneysel ve Hesaplamalı Akışkanlar Dinamiği (HAD) yöntemlerini kullanmaktır. "FLNG ve Buzdağı Çarpışma Modellemesi Üzerine Bir Çalışma" başlıklı son çalışma, kutup bölgelerindeki denizcilik faaliyetlerine dikkat çekmektedir. Çalışma kapsmında, gemilerin buz dağlarıyla yüksek çarpışma riski ve gemi yapılarının tasarımı için çarpışma hasarının doğru bir şekilde tahmin edilmesi üzerine çalışılmıştır. Makalede KOSORI modeli kullanılarak gerçekleştirilen gemi – buzdağı çarpışması senaryoları uygulamaları ve sonuçların katı buz modeli ile karşılaştırılması incelenmiştir. Gelecek sayılarda ise INT-NAM 2018'de yer alan diğer ilginç konuların başında gelen tekne kirlenmesi konulu çalışmalara yer verilmesi planlanmaktadır.

Saygılarımızla.

Prof. Dr. Ahmet Dursun ALKAN
Baş Editör

Distinguished Colleagues and Readers,

In the issue 212 we present four selected papers submitted to 3rd International Naval Architecture and Maritime Symposium (INT-NAM 2018) held and organized by Naval Architeture and Maritime Faculty, Yıldız Technical University, Istanbul. The firs paper entitled "Development of an Air Circulating Tank Installed in the Double Bottom of a Ship to Reduce Frictional Resistance" proposed an Air Circulating Tank which is a system to drastically reduce the frictional resistance by air accumulated in the tank installed in a ship's double bottom. "Comparative Review of Collision Avoidance Systems in Maritime and Aviation" is the title of the second paper which provides a comparison between aviation and maritime industries in the context of collision avoidance for both aeroplanes and ships focusing on the regulations, operational practices, techniques and procedures. The title of the third paper is "A Trim Optimisation of an Eights Racing Shell using Towing Tank and Computational Fluid Dynamics Methods". The aim of this paper is to use experimental and Computational Fluid Dynamics (CFD) methods to investigate the optimal trim for an eights racing shell over a 2000m race. The last paper entitled "A Study on FLNG and Iceberg Collision Modelling" draws attentions to marine operations increase in the arctic regions. In the paper high collision risk of ships with ice bergs and accurate assessment of collision damage in estimating loads for the design of ship structures are studied. The paper focuses on applications of ship – iceberg collision scenarios by using the KOSORI ice model which takes into account ice mechanic in terms of influencing parameters and, comparing results with rigid ice model. In the following issues we wish to give place to other interesting papers submitted to INT-NAM 2018 where hull fouling was one of the topics came to the forefront.

Best regards,

Prof. Ahmet Dursun Alkan PhD
Editor-in-Chief

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MEZUNİYET HATIRASI

Mesleğine Hoşgeldin

Sürtünme Direncini Azaltmak İçin Geminin Çift Dip Tabanına Monte Edilmiş Hava Sirkülasyon Tankının Geliştirilmesi

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Özet

Hava Sirkülasyon Tankı (ACT), geminin çift dip kısmına monte edilen tankta biriken hava ile sürtünme direncini büyük ölçüde azaltan bir sistemdir. Sistemin mikro kabarcıklar kullanan hava yağlama sisteminden farkı, daimi hava beslemesini enjekte etmek için ek enerjiye ihtiyaç duyulmamasıdır. Tank, geminin alt su akışının sürtünme kuvveti ile, tankta dolaşan havanın akışını oluşturarak hava kaçışını en aza indirecek şekilde tasarlanmalıdır. Bu çalışmada, ACT ile büyük bir sürtünme azaltma etkisi elde etmek için çok geniş ve draftı küçük bir gemi seçilmiştir. Mevcut araştırma projesinde, ACT, 200m'lik bir geminin ölçekli modelinin çift dip tabanına kurulmuştur. CFD hesaplamalarında, ACT'de oluşan hava sirkülasyonunun özelliklerini ve hava ile su arasındaki sınırdaki oluşturulan dalgaların fiziksel özelliklerinin anlaşılması hedeflenmiştir. CFD sonuçlarına dayanarak bir ACT geliştirilmiştir ve gemiye etkiyen direncin ölçülebilmesi için model deneyleri gerçekleştirilmiştir. Sonuç olarak, ACT'nin ölçek etkisi CFD kullanılarak incelenmiştir.

Anahtar kelimeler: Sürtünme direnci azalması, hava sirkülasyon tankı, tekne dibi

Development of an Air Circulating Tank Installed in the Double Bottom of a Ship to Reduce Frictional Resistance

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Abstract

Air Circulating Tank (ACT) is a system to drastically reduce the frictional resistance by air accumulated in the tank installed in a ship's double bottom. The difference of the system from the air lubrication system using micro bubbles is no need of additional energy for injecting continuous air supply. The tank must be designed to make the air-escape minimum by generating a circulating flow of the air in the tank by the frictional force of the bottom water flow of the ship. In the present study, a very wide and shallow-draft ship is selected to get a large drag reduction effect by the ACT. In the present research project, the ACT is installed in the double bottom of the scale model of a 200m ship. CFD calculations are carried out to understand the characteristics of the generated air-circulation in the ACT and the generated waves on the boundary between air and water. On the basis of the CFD results, an ACT has been developed, and model experiments to measure the resistance acting on the ship are carried out to know the effects. Finaly the scale effect of the ACT is investigated by using CFD.

Keywords: Frictional resistance reduction, air circulating tank, hull bottom

1. Introduction

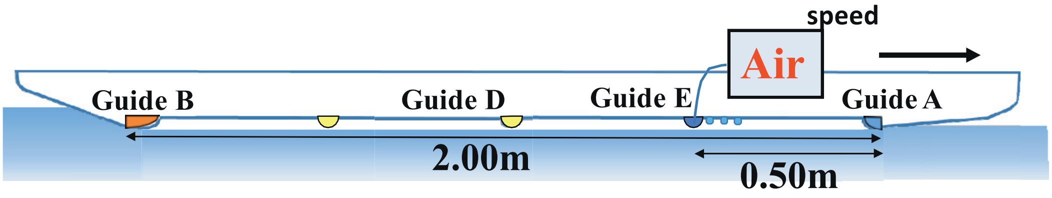
As the frictional resistance is dominant in the resistance of a large and slow ship, it is effective for energy saving of such a ship to reduce the frictional resistance. Usage of air may be one of the methods to reduce the frictional resistance, and nowadays some methods have been already applied to ships in practice. For example, it is said that a heavy cargo carrier "YAMATAI" could be saved about 12% of energy by Air Lubrication Method developed by Mitsubishi Heavy Industries (Mizokami et. al., 2010).

In some methods using air, the authors have focused on Air Circulating Tank (ACT), or Air Cavity Method. In the authors' previous study (Sugawa et. Al., 2015), the very wide breadth and shallow draft model of a 400m ship was selected to investigate the effects of an ACT. The ACT was installed in the double bottom of the parallel part of the model and resistance tests were carried out in a circulating water channel and a towing tank. As the result, a 25% drag reduction was obtained at Fn=0.10. It was found, however, that as ship speed increases, the effect of the drag reduction rapidly decreases, and disappears at Fn=0.13 because the almost all the air escapes from the ACT. This might be because the ACT is very shallow.

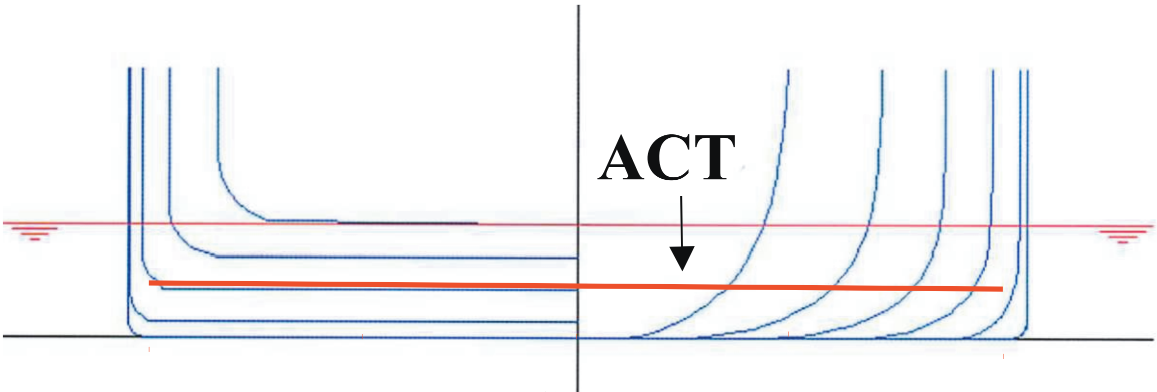
Then, the depth of ACT is increased to be twice of the previous one. The air escape, however, does not stop, and continuous air injection into the ACT is needed to keep the effect of the reduction of the frictional resistance. To understand the reason why the air escape occurs from the ACT, water flows passed the model with the ACT and airflow in it are calculated by a commercial CFD code, Fluent. The results show the resistance reduction, the circulating air and the generated waves in the ACT, the boundary layers changed by the ACT and the local frictional force acting around the ACT. On the basis of the CFD results, the ACT are modified. To confirm the effect of the improved ACT, experiments to measure the resistance acting on the model running in still water are carried out in a circulating water channel and a towing tank. Finally, the scale effects of the ACT are also investigated by using CFD.

2. Ship and ACT

The body plan and the principal particulars of the model ship used in the present study are shown in Fig. 1 and Table 1. The model ship corresponds to a 200m ship with a 2m-depth double bottom in full scale. The ACT is installed in the double bottom. The ACT is transversely divided into four compartments by three longitudinal walls, and the plates of the both outside-walls of the ACT are deeper by 10mm than the depth of the ACT to keep the air in the ACT for heeling or roll motions. The four compartments also avoid the stability loss due to shift of air in it (Watanabe, et. al., 2015). The ACT is longitudinally divided into four compartments by three banks or guides. At the front and the rear ends, guides are installed to make outside water flow smooth. The ACT is covered on the flat bottom of the parallel body of the ship, and reduces the wetted surface of the underwater hull by 39%.



(a)



(b)

Fig. 1. Profile (a) and body plan (b) of model ship with ACT

Table 1. Principal particulars of model ship and ACT

Length : L[m]	2.67
Breath : B[m]	0.500
Draft : d[m]	0.063
Length of Air Circulation Tank : L_{ACT}[m]	2.00
Breadth of Air Circulation Tank : B_{ACT}[m]	0.476
Depth of Air Circulation Tank : D_{ACT}[mm]	25.0
Wetted Surface Area of Model without ACT : $WSA_{without\ ACT}[m^2]$	1.549
Wetted Surface Area of Model with ACT : $WSA_{withACT}[m^2]$	0.597

2.1. Resistance tests in still water

To show the efficiency of the ACT, following coefficients are used in this paper.

- Wetted area reduction coefficient:

$$_{s} = \frac{\varnothing S}{WSA} \tag{1}$$

- Resistance reduction coefficient:

$$_{R} = 1 \quad \frac{R_{tACT}}{R_{t0}} \tag{2}$$

- ACT efficiency:

$$= \frac{_{R}}{_{s}} \tag{3}$$

where ΔS denotes the area of the ACT, WSA the wetted surface area of the ship without ACT, R_{tACT} the resistance acting on the ship with the ACT, R_{to} the resistance acting on the ship without the ACT, respectively.

Experimental results are shown in Figs. 2 and 3. The effect of the resistance reduction by the ACT disappeares at Fn=0.16 if no air injection. This is because the air escapes from the ACT due to the bottom water flow. By air injection during the measurements, the resistance reduction becomes larger. In the model with air injection, a 28% of resistance reduction and a 45% of ACT efficiency are got at Fn=0.12. Furthermore, in this model, the resistance reduction effect of the ACT can be kept up to Fn=0.19, although in the authors' previous study (Sugawa et. al., 2015) on a shallower ACT, the drag reduction effect was lost at Fn=0.13. It may be considered that the drag reduction effect can be gotten at larger Froude number because the depth of the ACT is deep and some air is injected into the ACT during the measurements, and they can keep enough air in the ACT to reduce the frictional resistance.

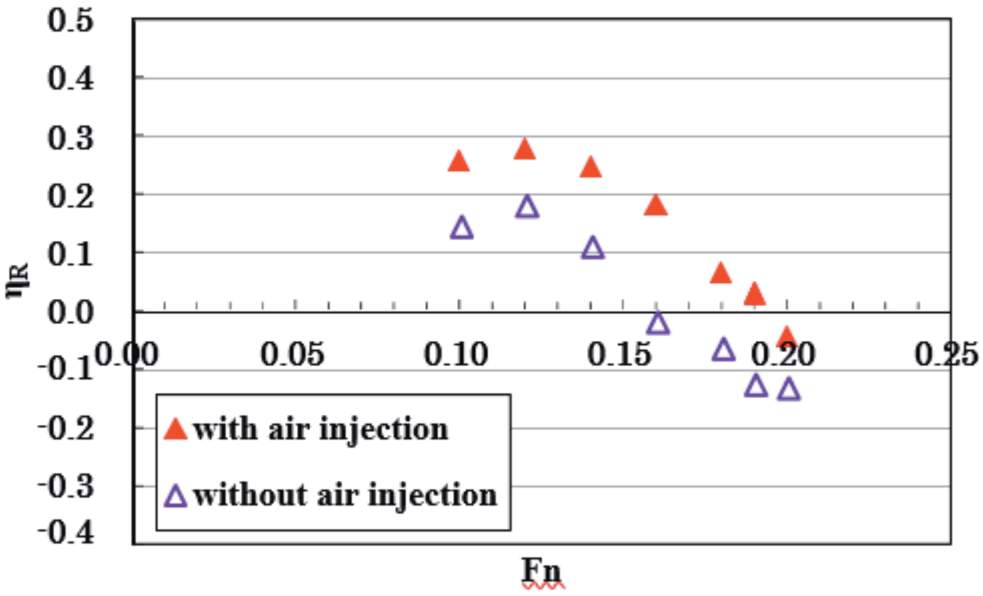


Fig. 2. Experimental results of resistance reduction ratio with and without air injection

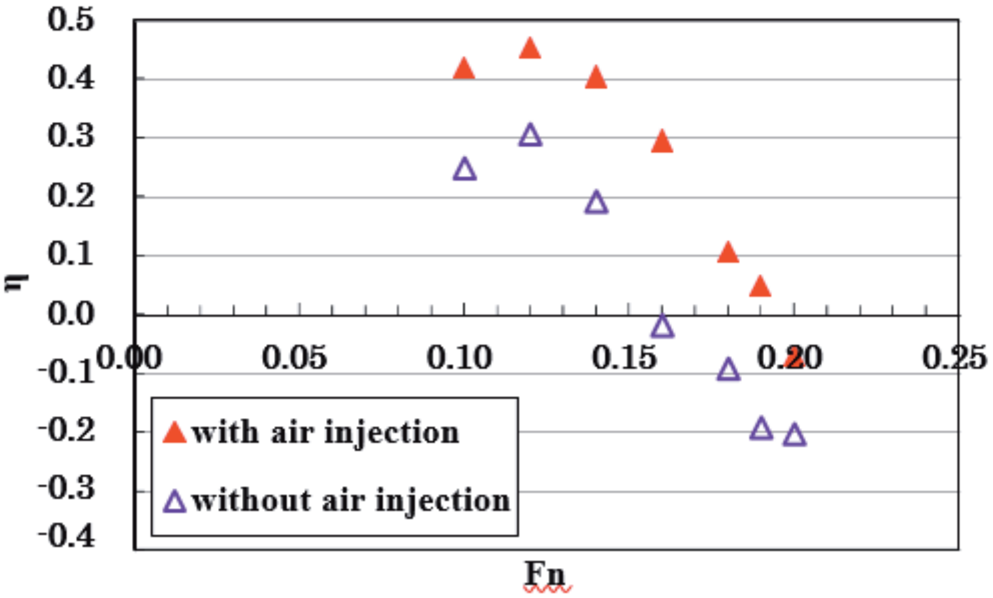


Fig. 3. Experimental results of ACT efficiency with and without air injection

2.2. CFD calculation

To clarify the reason why air escape occurs, CFD calculations of flows around the ship with and without the ACT are carried out. A commercial CFD code, Fluent 14.5, is used for the calculation. Computational domain of the 3D-model and calculation conditions are shown in Fig. 4 and Table 2. To save the computational time, the plane of symmetry is made and only one-half of the model is made.

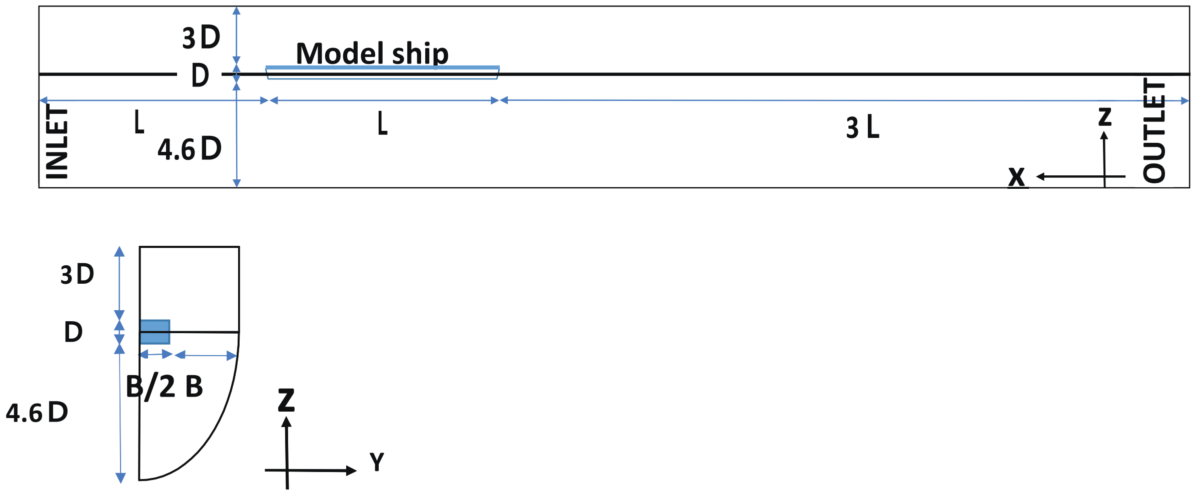


Fig. 4. Computational domain of 3D model

Table 2. Calculation conditions for CFD calculation

Mode	3D transient
Viscous	k-ωSST model
Multiphase	VOF(Volume of Fluid)
inlet water velocity	0.614 m/s (Fn=0.12)
air density	1.125kg/m^3
water density	998.2kg/m^3
air viscosity	1.7894×10^{-5}kg/m.s
water viscosity	1.003×10^{-3}kg/m.s
gravitational acceleration	9.81m/s^2
surface tension	7.17×10^{-2}N/m

The calculated result of the resistance acting on the model is shown in Fig. 5. By the ACT, the total resistance, Rt, is reduced by 19%, and the frictional resistance, Rf, is reduced by 37%. The residual resistance, Rr, however, increases by 37%. Although a 62% of the wetted surface area is reduced by the ACT, the reduction of frictional resistance by the ACT seems to be too small. The authors pointed out that one of the reason why the frictional is not reduced as expected is because that the frictional force acting on the stern hull surface behind the ACT increases (Sugawa et. al., 2015).

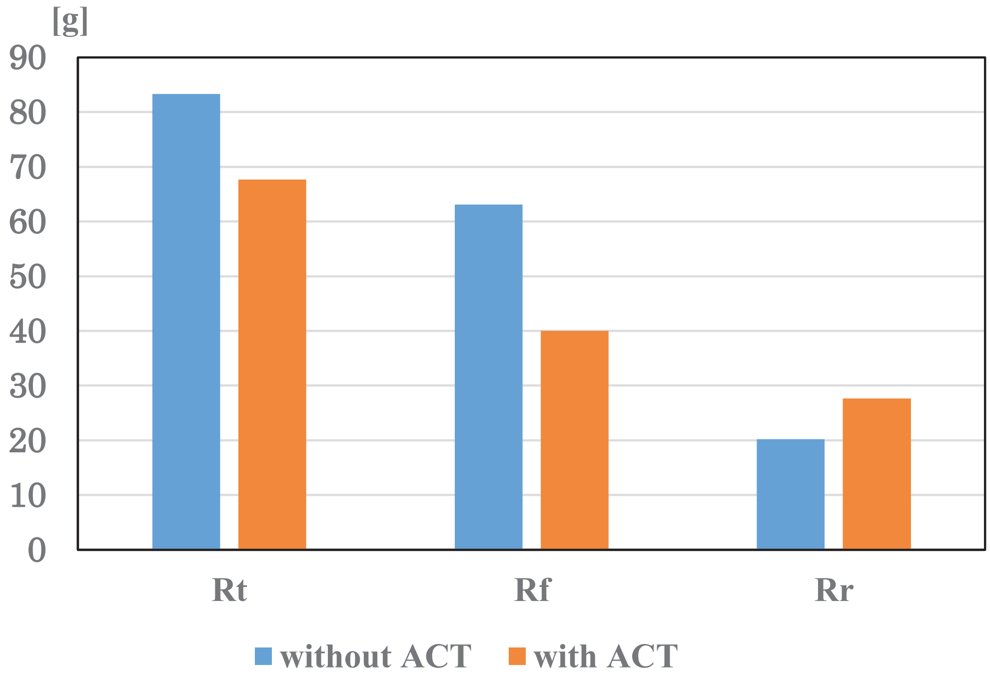


Fig. 5. Comparison of calculated resistance components of the ship with and without ACT by CFD.

Calculated velocity distributions in the boundary layer of the outer water flow at the front, middle and end locations of the ACT are shown in Figs. 7~9. The locations are shown in Fig.6. In Fig. 7, similar distributions can be seen for the flows with and without ACT. In Fig.8, however, the velocity distributions of them are completely different, and flow near the water-air boundary of the ACT becomes fast because of no frictional force acting on the boundary between outside water and inside air. At the end of the ACT, the water flow near the boundary becomes very fast as shown in Fig.9. The fast flow may increase the frictional force acting on the stern hull surface behind the ACT, and reduce the efficiency of the frictional resistance reduction of the ship with the ACT.

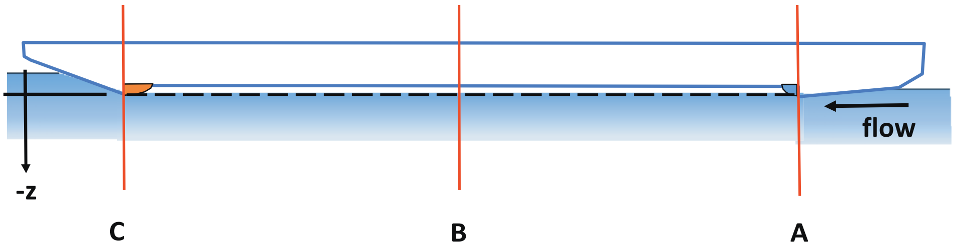


Fig. 6. Locations for calculating velocity distributions in boundary layer of outside water flow for Figs. 7-9

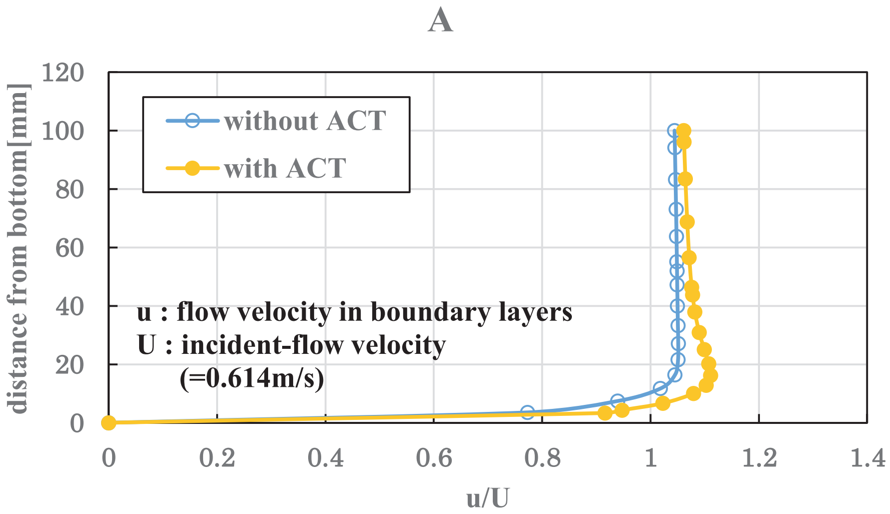


Fig. 7. Calculated velocity distributions in boundary layer for with and without ACT at location A

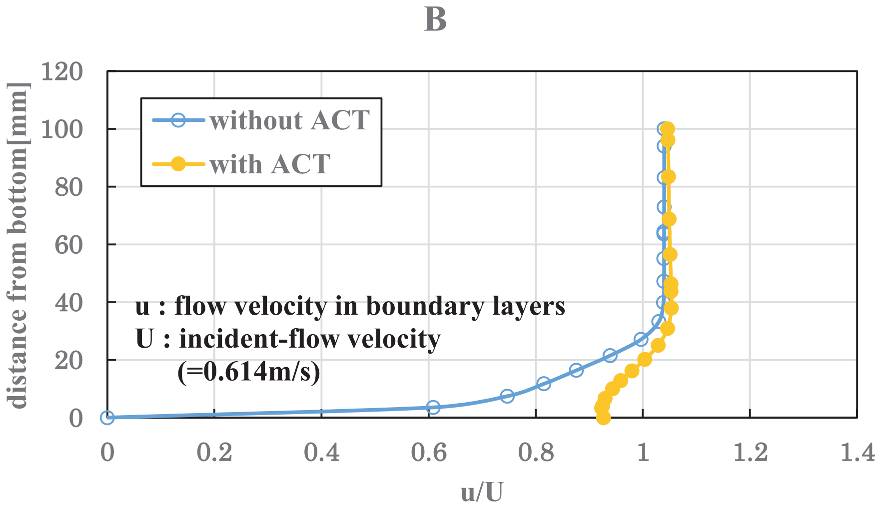


Fig. 8. Calculated velocity distributions in boundary layer for with and without ACT at location B

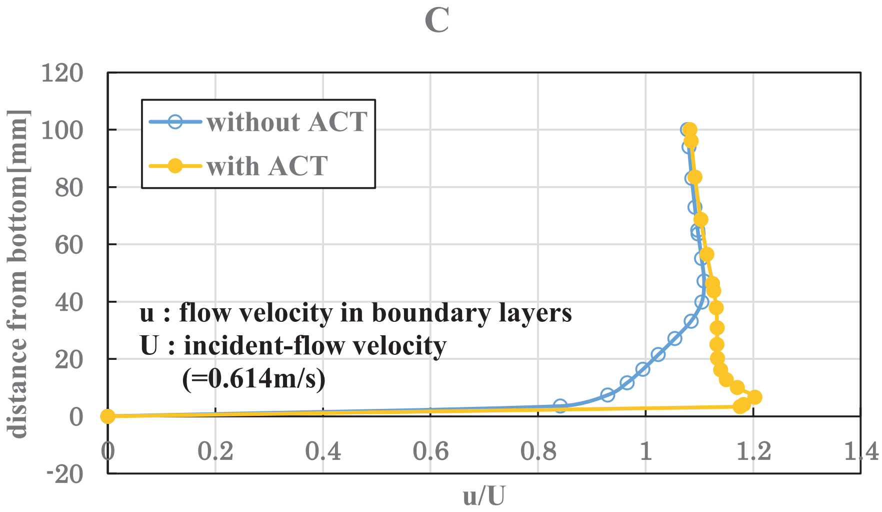


Fig. 9. Calculated velocity distributions in boundary layer for with and without ACT at location C

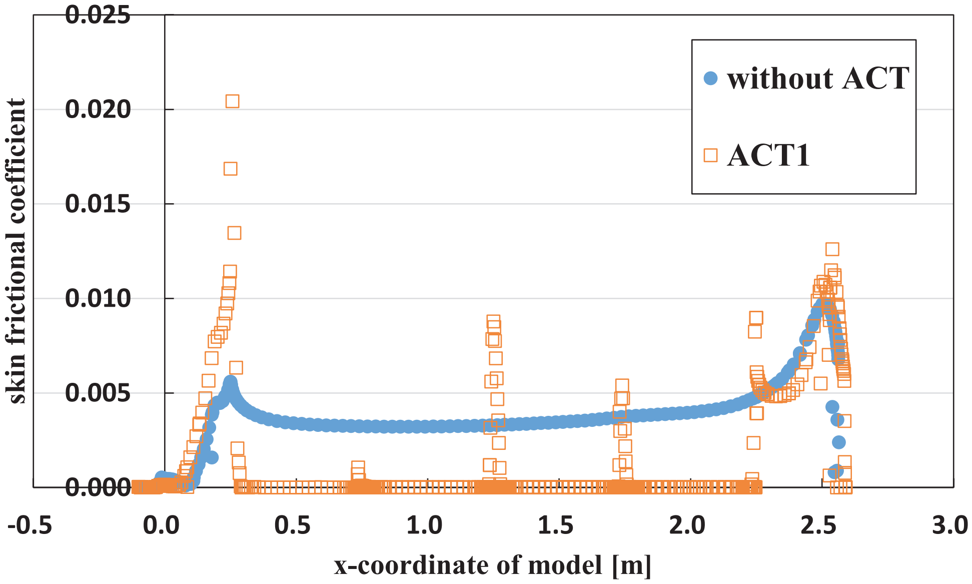


Fig. 10. Calculated local skin frictional coefficient of models with and without ACT (ACT1)

In Fig.10, calculated local skin friction coefficients of the bottom surface of the model with and without ACT are shown. In the ACT, no frictional force act on the bottom surface but large forces act on the guides. The most important point may be that high frictional force acts on the bottom surface just behind the end of the ACT. The force may pull the air from the ACT and cause the air escape from it.

2.3. Development of ACT with no air escape

On the basis of the knowledge obtained by the CFD calculations mentioned in previous section, new ACTs are developed as shown in Fig. 11. To make the pressure graudient smooth, some aft compartments of the ACT are closed. The areas of ACT of the ACT0.75 and the ACT0.5 are reduced by 25% and 50%, respectively.

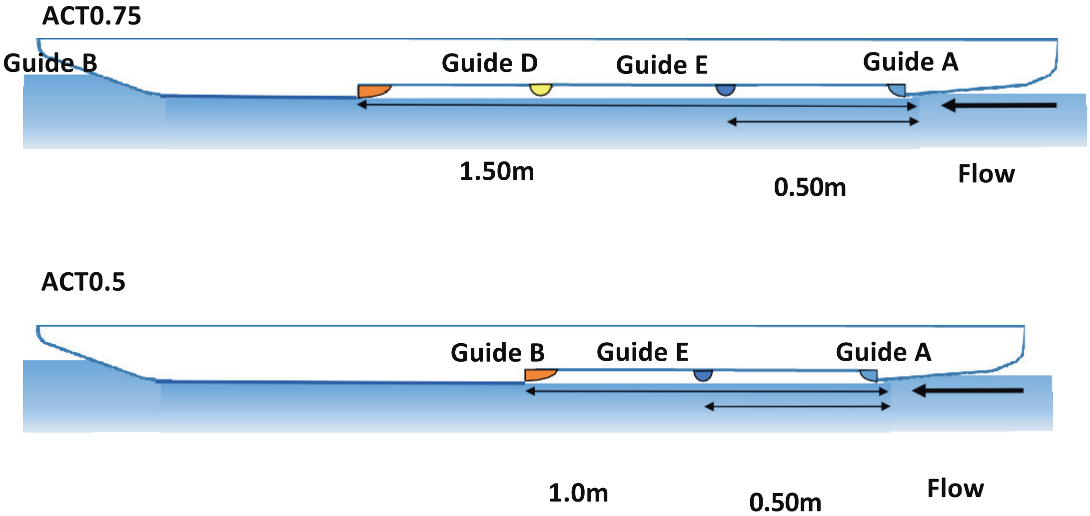


Fig. 11. Side views of model with ACT0.75 and ACT0.5

The calculated local skin friction coefficients of ACT0.75 and ACT0.5 by CFD are shown in Fig.12. The large frictional force acting on the hull surface behind the end of the ACT1 (original one) become smaller and sharper for the modified ACTs. It is also found by the CFD results that air escape from the ACTs drastically reduces. The calculated results of the resistance acting on the model with the ACT0.75 and ACT0.5 are shown in Figs. 13 and 14. Even though the reduction ratios of the wetted surface are reduced by 25% and 50%, respectively, the resistance reduction ratios η_R of the modified ACTs are much larger than the original ACT1 as shown in Fig.13. The ACT efficiency η of the modified ACTs become much larger than that of the original one as shown in Fig.14. It should be noted that at very low speed the ACT efficiency reaches 0.6.

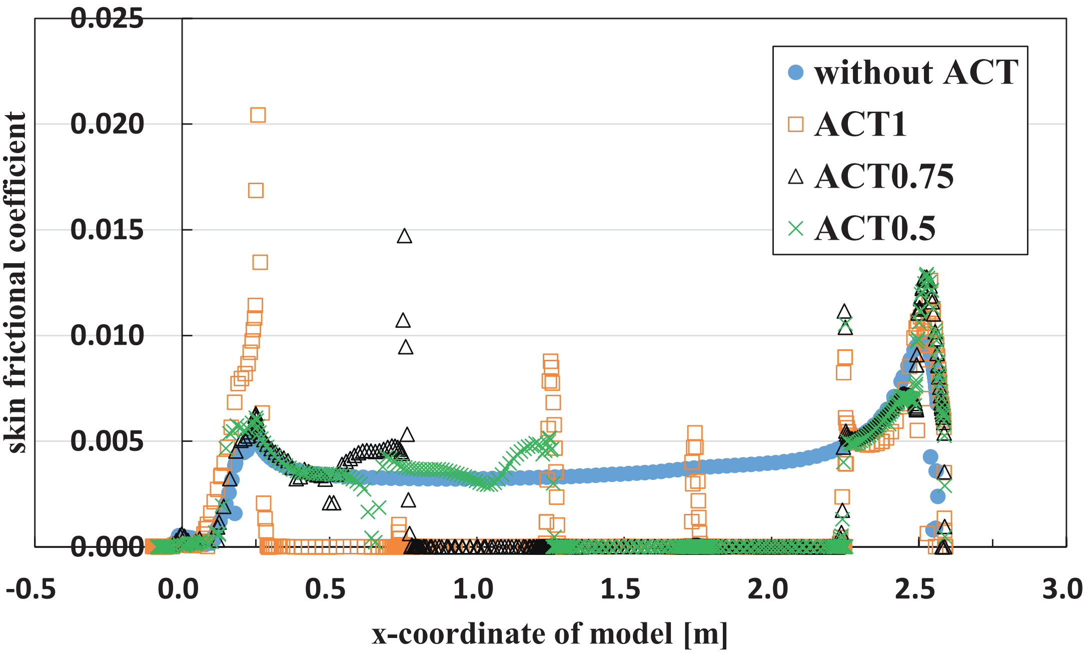


Fig. 12. Calculated local skin frictional coefficient of models with ACT1, ACT0.75 and ACT0.5

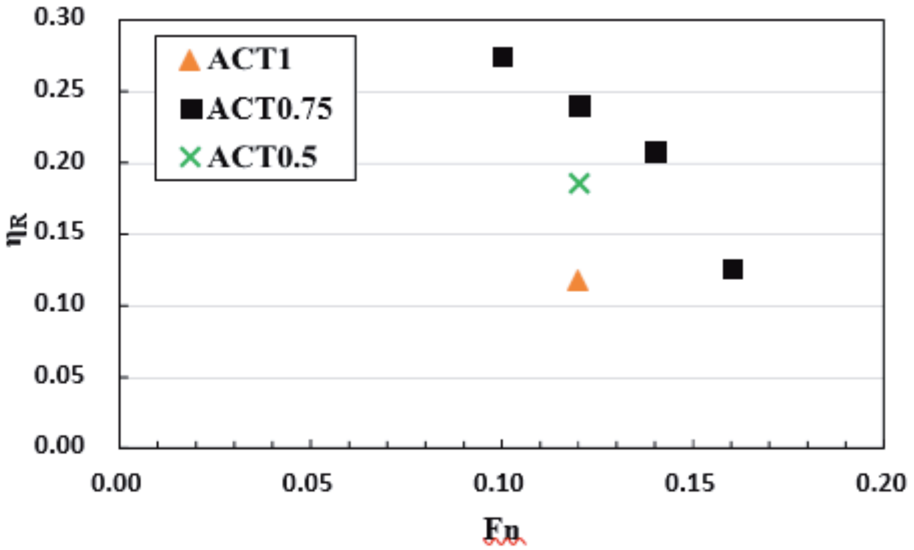


Fig. 13. Calculated resistance reduction efficiency, η_R of modified ACTs to compare with that original ACT

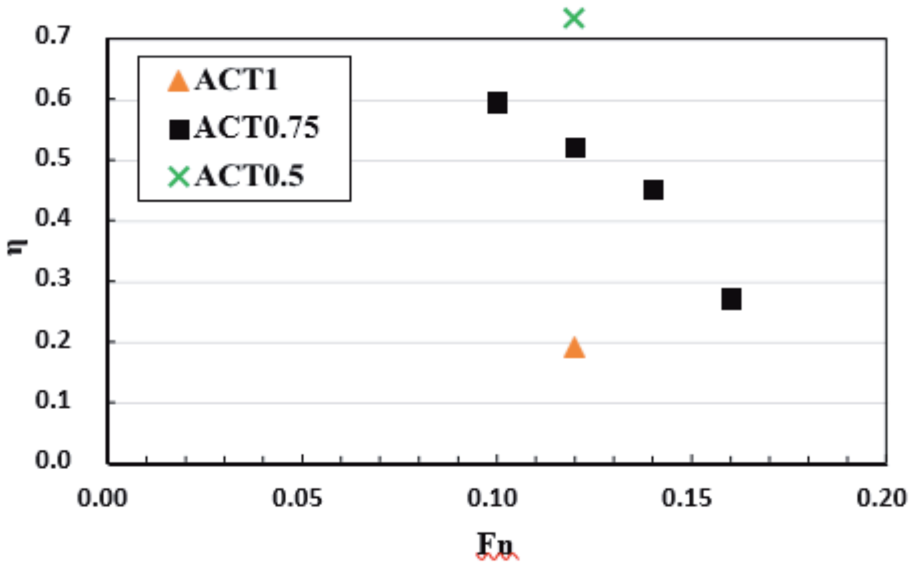


Fig. 14. Comparison of ACT efficiencies, η of modified ACTs to compare with that of original ACT

2.4. Measurement of resistance of modified ACT

Measurements of the resistance acting on the model with the modified ACT0.75 are carried out. Several kinds of tests as shown in Fig. 15 are done. In Test 7, the ACT is divided into six compartments because increase of walls in the ACT may contribute to the structural strength of the ship. Obtained results are shown in Figs.16 and 17. The results of Test 3 show similar tendency but slightly lower resistance reduction and lower ACT efficiency than calculated ones shown in Figs.13 and 14. The results of Test 7 suggest the ACT efficiency decreases with forward speed but some air injection can recover the decrease of the ACT efficiency in higher forward speed.

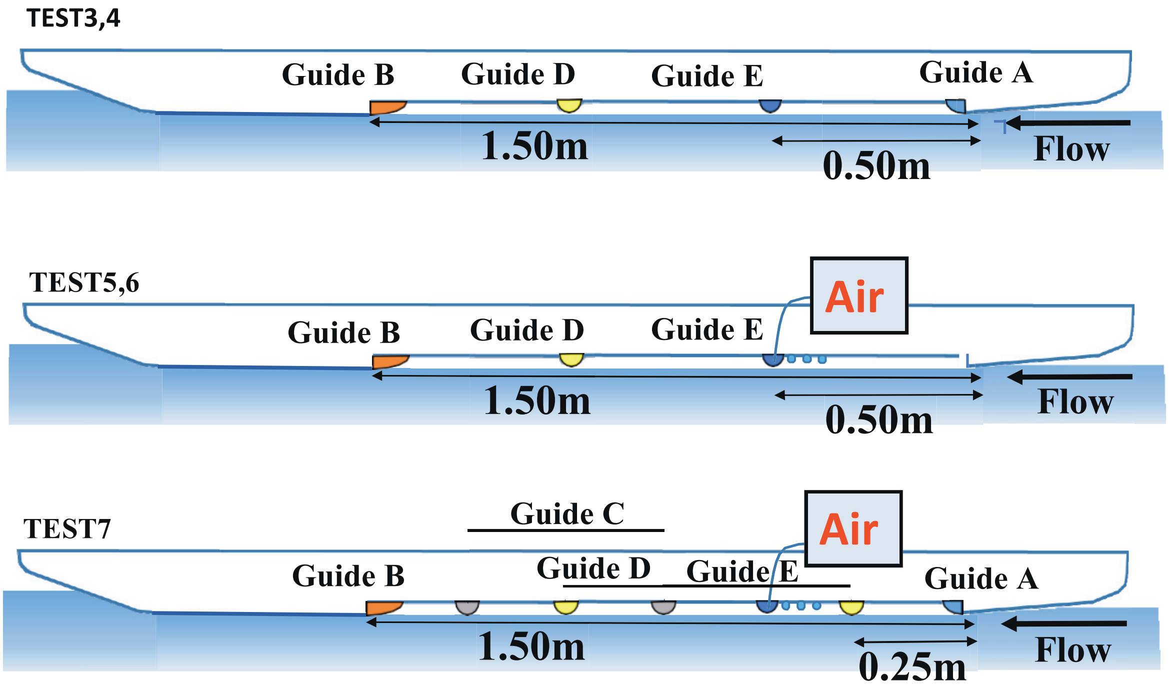


Fig. 15. Side views of models used experiments

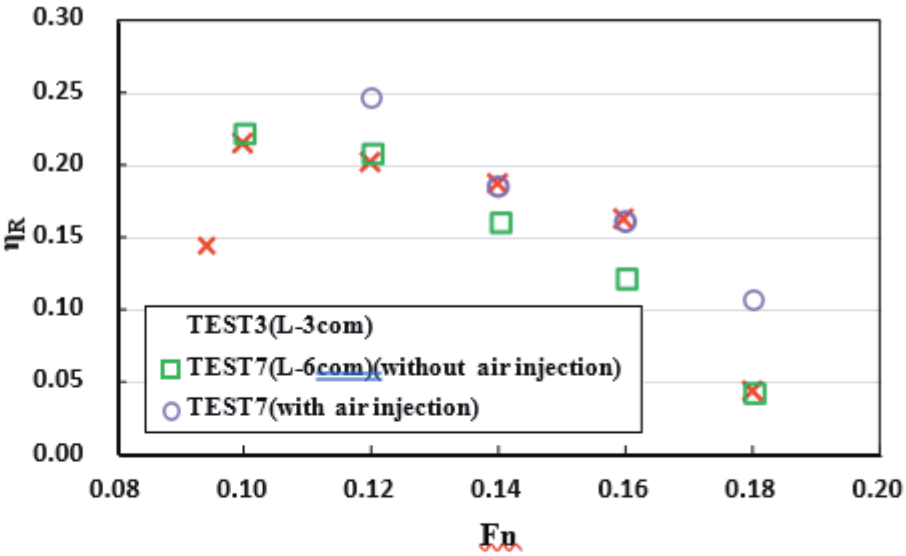


Fig. 16. Experimental results of resistance reduction ratio η_R of ACT0.75

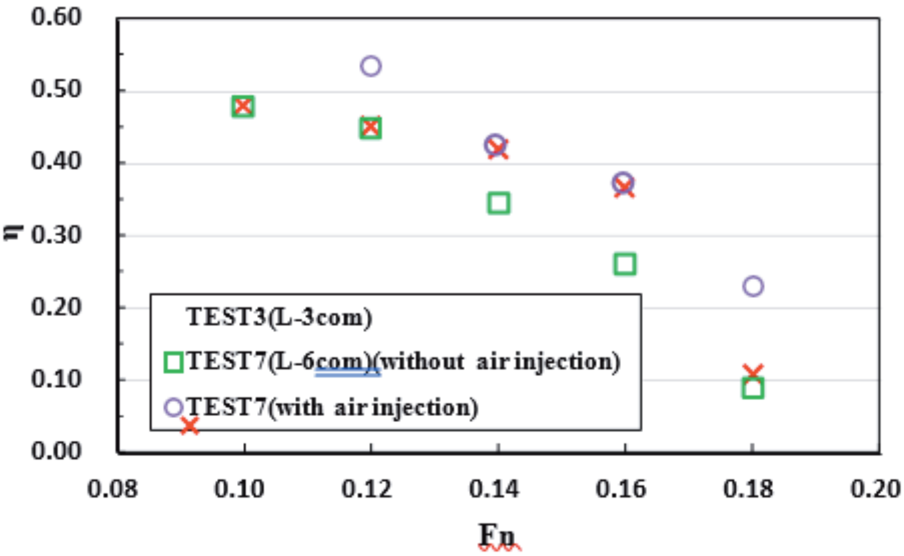


Fig. 17. Experimental results of ACT efficiency ηof ACT0.75

2.5. Scale Effect of ACT

Finally, scale effects of the ACT are investigated by using CFD. For the full scale calculation, the mesh in the full scale boundary layer are made small enough to represent the boundary layer. The comparison of local frictional resistance coefficients of the model and full scale is presented in Fig.18. It can be seen that at the full scale, the ACT is also effective to reduce the frictional force (c_f). At the bow and the stern bottom surfaces, the frictional stress acting on the ship is much smaller than that on the model because of the difference of Reynolds numbers. The difference of the local frictional coefficient c_f on the surfaces is similar to that of a flat plate.

The difference of the boundary layer flows in model scale and full scale at the just front entrance of the ACT are shown in Fig. 19. As expected, the flow near the hull surface of the full scale is much faster than that of the model scale. The faster water flow in full scale changes the shape of the air in the front compartment of the ACT and creates larger waves as shown in Fig.20.

The reduction of resistance and ACT efficiency of the model and the full scale ship are presented in Table 3. It can be seen that at the full scale, a 36% reduction of resistance can be archived which is larger than that at model scale. The ACT efficiency, η, significantly increases by up to 79% at full scale comparing 46% at model scale. The results demonstrate that the efficiency of resistance reduction of the ACT at full scale is much larger than that at model scale.

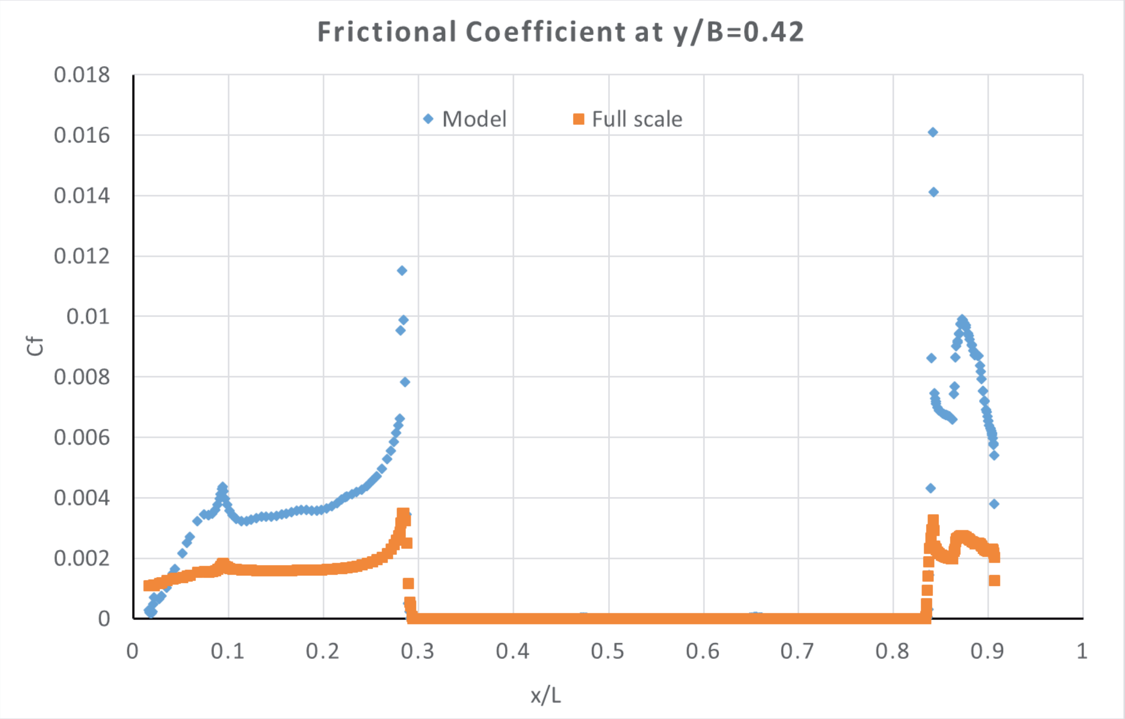


Fig. 18. Calculated local frictional coefficients of model and ship.

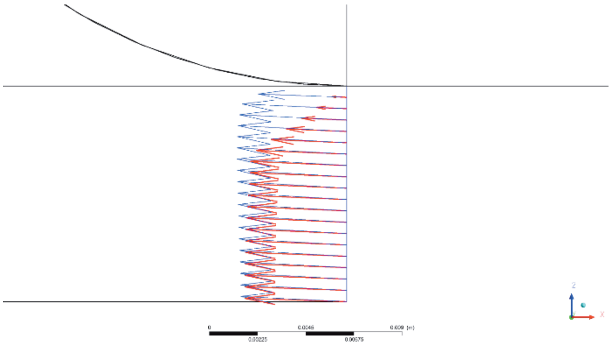
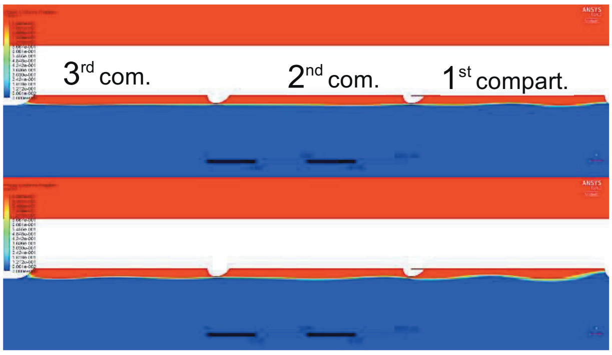


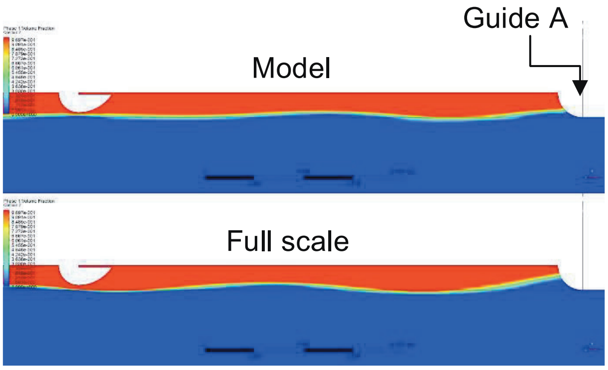
Fig. 19. Comparison of velocity profile in boundary layer at the entrance of ACT (Blue: full scale, red: model scale).

Table 3. Reduction of resistance and ACT efficiency.

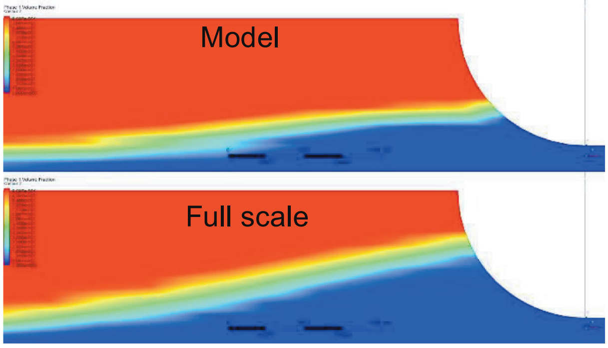
	R_t [N]		R	S	
	Without ACT	ACT0.75			
Model	2.34	1.84	0.21	0.46	0.46
Full scale	953.34	606.95	0.36	0.46	0.79



a) Side view of whole ACT



b) Side view at 1^{st} compartment



c) Side view near Guide A

Fig. 20. Difference of boundary between air and water of ACT due to scale

3. Conclusions

An air circulating tank for installing in the double bottom of a 200m ship with very wide breadth and shallow draft was developed, and its performances have been investigated in the present study. Following conclusions have been obtained.

1) Avoiding air-escape is the most important key factor to get large reduction of the resistance by an air circulating tank. By decreasing the frictional stress at the rear end of an air circulating tank, an air circulating tank has been developed in the present work.
2) Up to 22% reduction of the resistance of a ship are experimentally confirmed by measurements of the resistance in a circulating water channel at low Froude nuber (0.1-0.12).
3) The reduction of the resistance decreases with increasing advanced speed because some air-escape occurs. Some amount of air injection improve the resistance reduction performance at higher advanced speed.
4) Scale effect increases the resistance reduction efficiency of the ACT. It was confirmed by CFD that a 36% reduction of the resistance of the ship and a 79% efficiency of ACT are achieved.

Acknowledgements

The present study have carried out in a Research Project, D-ACT, with nine Japanese shipyards; Imabari Shipbuilding Co., Ltd. , Oshima Shipbuilding Co., Ltd. , Onomichi Dockyard Co., Ltd., Kawasaki Heavy Industries, Ltd. , Sanoyas Holdings Corporation , Japan Marine United Corporation , Shin Kurushima Dockyard Co., Ltd. , Namura Shipbuilding Co., Ltd. , Shipbuilding Research Centre of Japan. The authors would like to appreciate their cooperation for developing an Air Circulating Tank.

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Denizcilik ve Havacılıkta Çarpışma Önleme Sistemlerinin Karşılaştırmalı Olarak İncelenmesi

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Özet

Bu çalışma, çarpışmadan kaçınma kapsamında havacılık ve denizcilik endüstrileri arasında bir karşılaştırma sunmaktadır. Böylece bu çalışmada, hem uçaklarda hem de gemilerde çarpışmadan kaçınma için düzenlemeler, operasyonel uygulamalar, teknikler ve prosedürler anlatılmaktadır. Havacılık endüstrisindeki güvenlik ve teknolojideki gelişmelerden faydalanılarak, gemilerde çarpışmadan kaçınmayı önlemek için daha iyi durum farkındalığı oluşturulması ve daha gelişmiş bir seyir takibi yapılabilmesi için havacılıktaki gelişmeler uygulanabilir. Genel olarak, sefer köprüsünde alınması gereken tüm kararlardan, Gemideki Görevli (Officer of the Watch, OOW) sorumludur. Sonuç olarak, bu durum muazzam miktarda veri analizi gerektirmektedir ve ayrıca; bu veri köprünün çeşitli lokasyonlarında bulunmaktadır. Yine de bu, OOW için, insan hatalarına ve durumsal farkındalık eksikliğine yol açabilecek bir iş yüküne neden olabilmektedir. Bu çalışma, havacılık endüstrisinden esinlenilerek, denizde çarpışma riskini azaltmak için güvenlikle ilgili en son geliştirmeleri ve teknolojileri benimsememize yardımcı olarak, denizcilik sektöründeki eksiklikleri ortaya koymaktadır.

Anahtar kelimeler: : Otomatik çarpışmadan kaçınma, Navigasyon, COLREG, Havacılık, TCAS sistem, İnsan hataları, Durumsal farkındalık, İnsan makina arayüzü, Bilgi akışı

Comparative Review of Collision Avoidance Systems in Maritime and Aviation

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Abstract

This study provides a comparison between aviation and maritime industries in the context of collision avoidance. Thus, it focuses on the regulations, operational practices, techniques and procedures in both aeroplanes and ships for collision avoidance. Due to safety and technology advancements in the aviation industry, advancements in aviation to prevent collision avoidance can be implemented in ships, developing a better situational awareness and improved navigational watch. Generally, the Officer of the Watch (OOW) on board ships is responsible for all the decisions that need to be taken on the navigational bridge. Consequently, this requires an immense amount of data analysis; moreover, this data is located in various locations on the bridge. Yet this can cause a work overload for the OOW, potentially leading to human errors and lack of situational awareness. This study reveals the shortages in maritime industry, helping us to adopt new safety-related enhancements and technologies to reduce the risk of collision at sea, which is inspired by the aviation industry.

Keywords: Automatic collision avoidance, Navigation, COLREG, Aviation, TCAS system, Human errors, Situational awareness, Man-machine interface, Information flow

1. Introduction

Just after the expansion in the use of radar in commercial shipping, around 1960s, and the increases in traffic density, the need arose for technological support, in order to help the OOW avoid collision at sea (Szlapczynski and Szlapczynska, 2015; Tam et al., 2009) . Moreover, that led to faster ships in less sea room for manoeuvring, making the navigation tasks harder and requiring more concentration (Tam et al., 2009). Nevertheless, the OOW maintains a good level of safety when navigating the ship, but errors are still being made, contributing to accidents occurring (Statheros et al., 2008). In addition, the varying cognitive abilities of the OOW, dependent on factors such as lack of good sleep and food, workload, stress, noise levels, experience, mental health, missing home and the ergonomics of bridges, can all affect the OOW's decisions. Wrong decisions made under these conditions can cause accidents (May, 1999). However, in order to improve the OOW's situational awareness and to reduce the human error, it is advantageous to have a decision-making support system, as a navigational aid on bridges (Perera and Soares, 2012). The decision-making support system will ensure objective decisions rather than subjective ones (Statheros et al., 2008). Moreover, that will also ensure a system fully compliant with the Role of the Road (COLREGs) (Statheros et al., 2008). The benefits of introducing the new technologies on board ships as navigational aids and decision-making support systems or automatic collision avoidance systems are reducing the workload on the OOW, reducing human error and increasing the situational awareness of the OOW (Statheros et al., 2008).

The organisation of the paper as follows; section two presents the aviation collision avoidance system and its working principles. Then, section three highlights the collision regulation (GOLREG) in marine navigation and its shortages. Section four illustrates the navigational aids and equipment. After that in section five, a comparison between the aviation and maritime industries with regard to collision avoidance is performed. Finally, the discussion is presented in section six.

2. Collision Avoidance in Aviation

In aviation, where they do not have manoeuvring regulations, the decision is left to the pilot to avoid collisions. In addition, they have the Air Traffic Control (ATC) role to allocate every aeroplane with a specific level (altitude) of flying and to ensure the separation of aeroplanes in general (Kuchar and Drumm, 2007; Williams, 2004). Also the Traffic Alert and Collision Avoidance System (TCAS) comes as last measure of collision avoidance, by alerting the pilot of any intruders in the vicinity, which could be a potential conflicting aeroplane (Burgess et al., 1994; Kuchar and Drumm, 2007). If that intruder comes in a collision course, the TCAS provide the pilot with the best avoidance action. The TCAS system has proven its reliability as collision avoidance system (Harman, 1989). However, that makes it mandatory to obey the system's decisions immediately, even if the pilot does not acquire the intruder visually, as mentioned in the International Civil Aviation Organisation ICAO (Honeywell, 2006). It could be the case that the pilot is unaware of the intruder or cannot see it visually and the TCAS system detects it and issue the avoidance decision (EUROCONTROL, 2016).

2.1. TCAS principle

The principle of the TCAS is based on sending an interrogation to other TCAS equipped intruders and waiting for reply in order to measure the range and altitude of the intruder (EUROCONTROL, 2016; FAA, 2011; Harman, 1989; Kuchar and Drumm, 2007). As a result, the TCAS system starts communication with the intruder's system, to coordinate the avoidance manoeuvre (Honeywell, 2004). The intruder must have its altitude in its reply message, so the TCAS System can locate it accurately before issuing the avoidance manoeuvre, otherwise no avoidance manoeuvre will be issued (EUROCONTROL, 2016).

TCAS system has two types of alerts: Traffic Advisories (TA) and Resolution Advisories (RA) (Murugan and Oblah, 2010). The TA is a visual alert to the pilot, and to prepare him if needed, to avoid any risk of collision (Harman, 1989). The RA is an avoidance manoeuvre for intruders that are on the same track where the pilot must take action to avoid the collision (Honeywell, 2006). Usually the TA alert comes first and then the RA as an avoidance action. The TCAS's RAs are in vertical dimension only (climb or descend); it does not issue RA to change course (FAA, 2011). Figure 1 is an illustration of the TA and RA areas and times. Figure 2 is an example of the RA avoidance manoeuvre; with reversal RA (both airplanes are equipped with TCAS system).

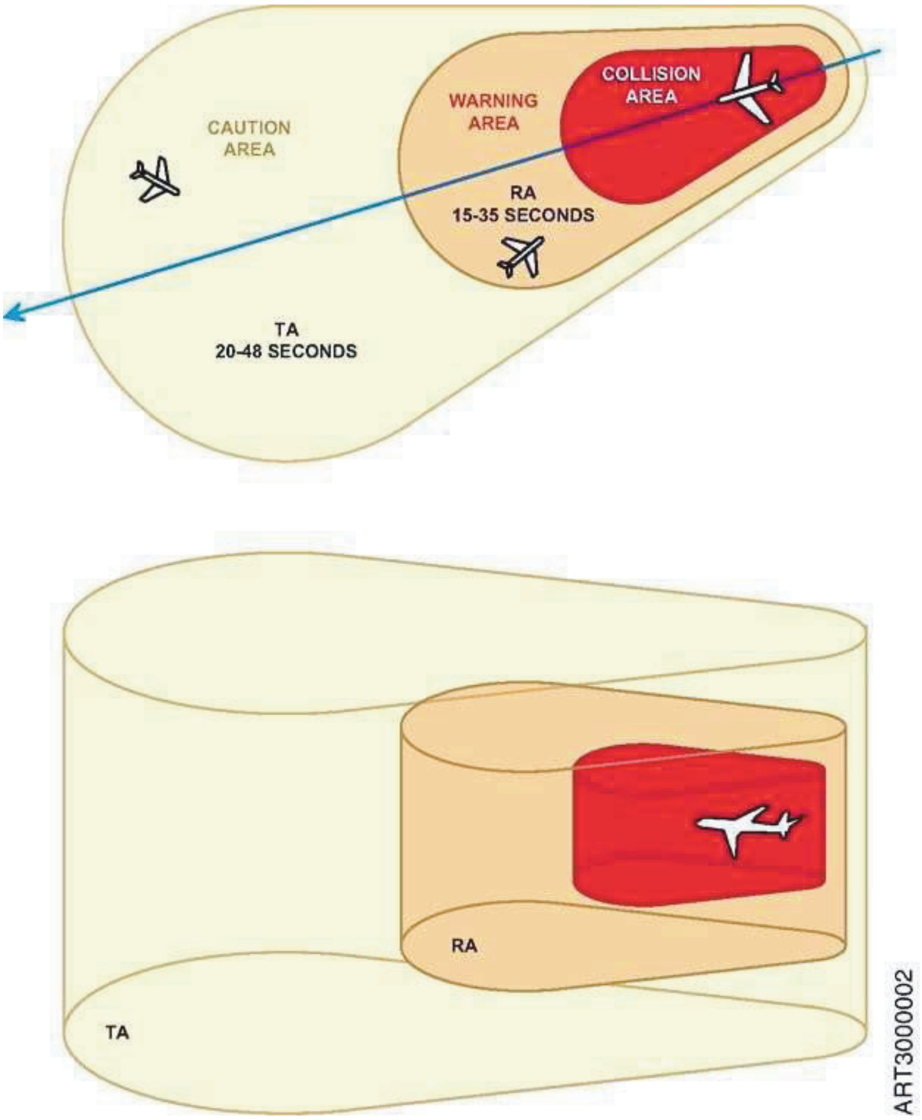

Fig. 1. TA and RA Zones (FAA, 2011)

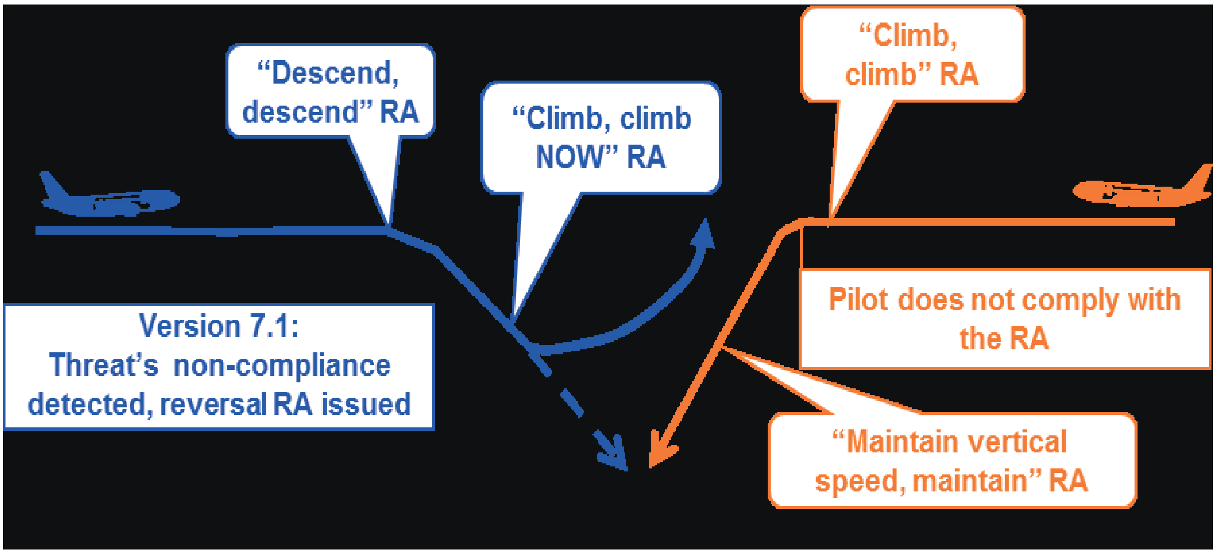

Fig. 2. TCAS RA to avoid collision (EUROCONTROL, 2016)

2.2. Collision avoidance logic in TCAS

The principle logic of the collision avoidance is based on the concept of Time to Closest Point of Approach (TCPA) (FAA, 2011). This means it is dependent on the time of CPA rather than the distance, to issue the TA and RA alerts (Munoz et al., 2013). The time to issue a TA is 48-20 second, and for RA is 35-15 second, before the time to CPA (EUROCONTROL, 2016).

2.3. Coordination between two TCAS equipped airplanes

When two airplanes are in an encounter situation and both of them are equipped with TCAS, the TCAS systems in both airplanes coordinates the avoidance manoeuvre, in order to avoid the airplanes from selecting the same RA manoeuvre (both of them climbing or descending) (Murugan and Oblah, 2010). This coordination is known as Resolution Advisory Complement (RAC). The coordination procedure is as follows: the first airplane sees the other as a threat, selects the RA, and sends its selection to the threating airplane to restrict its selection to the opposite direction only (if the first airplane selects a climbing RA, then the other airplane must select a descending RA) (EUROCONTROL, 2016). The TCAS system keeps monitoring the execution of the avoidance manoeuvre every one second, and in case the threating intruder is not following the RA issued by his TCAS, the RA will be reversed in the obeying plane. This is known as Reversal RA (FAA, 2011). The TCAS system always selects the RA which provides the largest separation between the airplanes.

3. The International Regulation for Preventing Collision at Sea (COLREG) 1972

COLREGs are basically a set of rules that provided to the OOWs in order to help them assisting the encounter situation, such as; crossing, head-on or overtaking (Wang et al., 2010). Nevertheless, this requires full understanding and interpretation of the whole situation around the ship (Mohovic et al., 2016). However, the OOW will be able to appoint the responsibilities between vessels in encounter situation and how to avoid collision situation (Wylie, 1962). The rules guide the OOW about the suggested course of actions to avoid collision with other vessels, and give some prohibited actions that shall not be taken under any circumstances. However, these rules and its interpretation need to be well understood by the OOW to avoid any conflict situations at seas. With consideration to COLREG, three conditions of vessels conflict has been identified that covers all possible collision situation at sea (IMO, 2005). The collision situations are; Overtaking, Head-on and Crossing, however, it is important to correctly interpret the conflict situation in order to take the correct actions (Mohovic et al., 2016).

Overtaking situation / Rule 13

Any vessel approaching the other from stern is an overtaking vessel, and she shall keep clear of the vessel being overtaken (COLREG, 2017; IMO, 2005).

Head-on situation / Rule 14

Any vessel meeting the other on a reciprocal or near reciprocal course in a head-on situation, where both vessels shall alter course to starboard side so they pass port to port (COLREG, 2017; IMO, 2005)..

Crossing situation / Rule 15

Any vessel on a crossing course with another, where risk of collision exists, is in crossing situation (COLREG, 2017; IMO, 2005). The vessel seeing the other on her starboard side shall keep clear, as well as avoiding passing ahead of the other vessel if the circumstances admit it (Cockcroft and Lameijer, 2012b; IMO, 2005).

Give-way vessel / Rule 16

The vessel that is required to keep clear of another by this regulation is the Give-way vessel (COLREG, 2017; IMO, 2005).

Stand-on vessel / Rule 17

The vessel that is not the Give-way is the Stand-on one, and she shall maintain her course and speed (COLREG, 2017; IMO, 2005).

3.1. Subjectivity and uncertainty of COLREG regulation

In maritime navigation, all collision avoidance manoeuvres are made based on the Collision Regulations (the Rules of the Road) COLREG. Although these rules have helped in managing the maritime traffic and also advised every vessel about the collision avoidance manoeuvres that need to be taken in every situation, they have not stopped accidents from happening (Demirel and Bayer, 2015; Lušić and Erceg, 2008). After a deep study of the COLREG a number of issues that can cause a hassle and confusion for the OOW were identified (Belcher, 2002; Demirel and Bayer, 2015; Szlapczynski and Szlapczynska, 2015; Wylie, 1962). First of all, the subjective nature of the rules, where it does not inform the OOW about the exact action to take, instead it leaves the decision to OOW to decide (Belcher, 2002; Szlapczynski and Szlapczynska, 2015). This is clear in some phrases such as; "*If the circumstances of the case admit*" "*In ample time*" and "*If there is sufficient sea room*" all these cases are subject to the interpretation of the situation (Cockcroft and Lameijer, 2012b; Wylie, 1962). Moreover, COLREG does not inform the OOW with the magnitude, nor the time to take actions (Belcher, 2002; Wang et al., 2010). However, the judgement is left to the experience of the OOW and the good seamanship practices, which causes dangerously subjective decisions to be made (Belcher, 2002; Cockcroft and Lameijer, 2012a; Wang et al., 2010). Nevertheless, if we look at rule 15 Crossing Situation, it is clear that the ship sees the other one on her starboard side is the Give-way vessel and she should avoid the Stand-on vessel (Cockcroft and Lameijer, 2012b). whereas in rule 17 it says *"the Stand-on vessel may take action to avoid collision by her manoeuvre alone as soon as it became apparent to her that the vessel required to keep out of the way is not taking appropriate action"* (Cockcroft and Lameijer, 2012b). Again it is left to the OOW on the Stand-on vessel to decide when to take action, which are again subjective decisions (Belcher, 2002; Kunieda et al., 2015; Wang et al., 2010).

4. Navigational Aids and Equipment on Ships' bridge

Sailing started long time ago, where there were no electronic communicational methods, nor navigational systems. However, sailors depend heavily on traditional methods and experiences inherited from previous navigators and sailors. Moreover, the toughness of a sailor's life on board and the long times they used to spend in seas generated a pride and glory in themselves, which over time turned out to be an arrogance where it became the most-known trend about sailors to date. Indeed, this created a resistance from a large number of navigators to the development of new navigational technologies and techniques, claiming that they are inefficient and it is impossible to dispense with traditional techniques. In addition, the long processes and time required for adopting new technologies and systems in maritime industry by the International Maritime Organisation (IMO) lead to individual equipment introduction over long periods (Bole et al., 2014). This develops a poor bridge layout and systems' integration (Bole et al., 2014; Brigham, 1972). Consequently, the OOW is exposed to a high information flow from navigational equipment located in different areas in bridge (Pietrzykowski et al., 2016). All these navigational aids are information systems only, yet no decision support system has been developed to help the OOW in decision making (Pietrzykowski et al., 2016). Upcoming is the navigational aids and equipment on ships' bridge, which are used to assist the OOW in understanding the situation around the ship and conducting the navigational watch:

- Ship's conning display unit
- Weather monitoring unit
- Automatic Identification System (AIS)
- Radar, X and S bands / Automatic Radar Plotting Aid (ARPA)
- Electronic Chart Display and Information System (ECDIS)
- Global Positioning System (GPS)
- VHF for external communication
- Echo sounder

For collision avoidance, ARPA and ECDIS are the most utilised aids for detection, assessment and monitoring of targets, with the integration of AIS system for ships' information. Although, these systems provide the most needed information for collision assessment, but they are still information systems only. This means, the OOW must collect the information, analyse it and provide the most appropriate decision for the safety of the ship. Moreover, these systems do not warn the OOW about dangers or collision situations. However, the OOW is responsible for monitoring all these systems to detect dangerous situations and decide the best course of action to avoid them.

5. Similarity and Differences between Aviation and Maritime Collision Avoidance

Collision Avoidance Systems; Operation and Techniques

Aviation industry has succeeded in developing an automatic collision avoidance system which helped to enhance the flight safety significantly by reducing the risk of mid-air collision. The TCAS system is the last barrier of mitigating the risk of mid-air collision and it works independently without interference from ATC (Honeywell, 2004). In essence, the TCAS system alerts the pilot of any potential mid-air collision in two consequence steps: firstly, the TA alerts the pilot about any intruder in the vicinity and prepares him for avoidance manoeuvres. Secondly, the TCAS generates the RA to provide pilots with the best avoidance actions.

In maritime industry, there are no such systems which support the OOW in collision avoidance decision making. Hence it is all information systems, which means the OOW needs to collect all the navigational information, from various sources, to build up an adequate level of situational awareness (Pietrzykowski et al., 2016). As a result, the OOW should monitor various systems on different screens and locations. For collision risk assessment, the OOW extracts information from ARPA and ECDIS (two separate screens) (Hadnett, 2008; Pietrzykowski, 2010). However, he still needs to be fully aware about other important aspects, such as: Anemometer for weather conditions, Echo sounder for depth, Paper charts, GPS and GMDSS (Communication system). Constant monitoring of all this equipment is an exhausting task, especially when the devices are located away from each other (Hetherington et al., 2006). On the top of that, he still needs to assess the situation and decide the best avoidance manoeuvre, based on the COLREG rules (Belcher, 2002).

Collision Avoidance Procedures, Actions and Responses

The most significant benefit of the TCAS system is the enhancement in situational awareness by alerting about conflict traffic in vicinity and collision avoidance manoeuvres (ICAO, 2006). Hereunder are scenarios of collision situations in air and sea to make comparison between safety levels of navigation in both industries.

Scenario 1, Air collision Situation

Looking at the principle rules of separation in aviation, firstly the ATC is responsible for aeroplane control on the ground and in the controlled airspaces and as advice in non-controlled areas (EUROCONTROL, 2016). Its responsibility is to prevent collision and ensure separation between aeroplanes (EUROCONTROL, 2016). Then is the “See and Avoid” principle, where the pilot sees the other as threat, must avoid it in the best manoeuvre to avoid collision. Finally, as a last resource of collision avoidance is the TCAS system (EUROCONTROL, 2016).

The basic operation of the TCAS system starts when the TCAS issues the TA to alert the pilot about an intruder (CÎRCIU and Luchian, 2014). The TA helps the pilot in the visual acquisition of intruders, preparing him to respond to RA if risk of collision exists (FAA, 2011). Once the RA is issued, the pilot needs to respond immediately, if the given manoeuvre does not endanger the safety of the aeroplane (EUROCONTROL, 2016).

Scenario 2, Marine collision situation

In Maritime, the basic and first method of collision risk assessment is by taking a frequent visual compass bearing; if the bearing does not change that means the target ship is on a collision course. The next method is the radar, helping especially in the restricted visibility. Finally, the Automatic Radar Plotting Aid ARPA, the ARPA system makes it much easier to assess the collision situation by assessing the Closest Point of Approach (CPA) and the Time to CPA (TCPA).

In normal operation, the OOW needs to monitor the ARPA system to detect any target in the vicinity, in addition to the constant visual look out (with the support of the Look Out watch man if needed). When a target is detected, the OOW sees the target’s information and parameters on ARPA (which is integrated with the AIS system), and based on the CPA he decides if a risk of collision exist. If the target ship is on a collision course, the OOW needs to evaluate the situation, based on the COLREG rules, to know which ship is the one to give way. If it is his own ship, then he/she needs to keep clear of the Stand-on vessel. On the other hand, if the other ship is to give way, the Stand-on vessel should keep her course and speed. Additionally, the water depth is an important factor in marine accidents, causing grounding. In general, the passage planning is created before the departure, and all the routes are checked to ensure a safe passage for the ship, with ship’s draught in consideration all the way to the arrival point. However, in case of avoidance manoeuvres which need an alteration from the original route, the OOW must check the availability of sea room around the ship to avoid shallow water and grounding accidents.

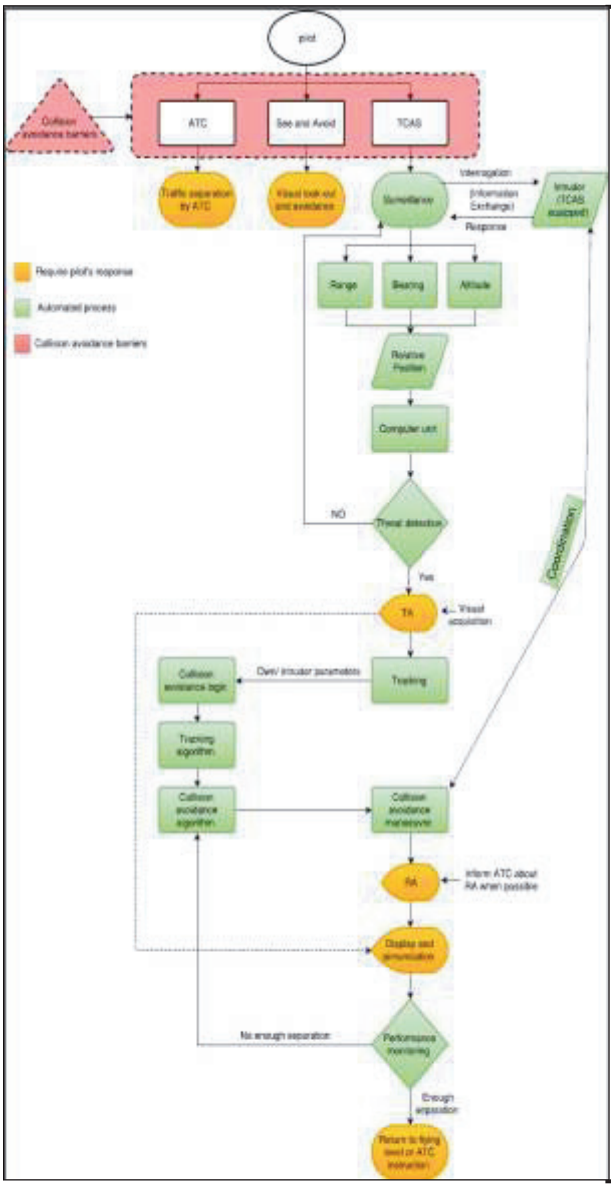

Fig. 3. Collision avoidance procedures in aviation

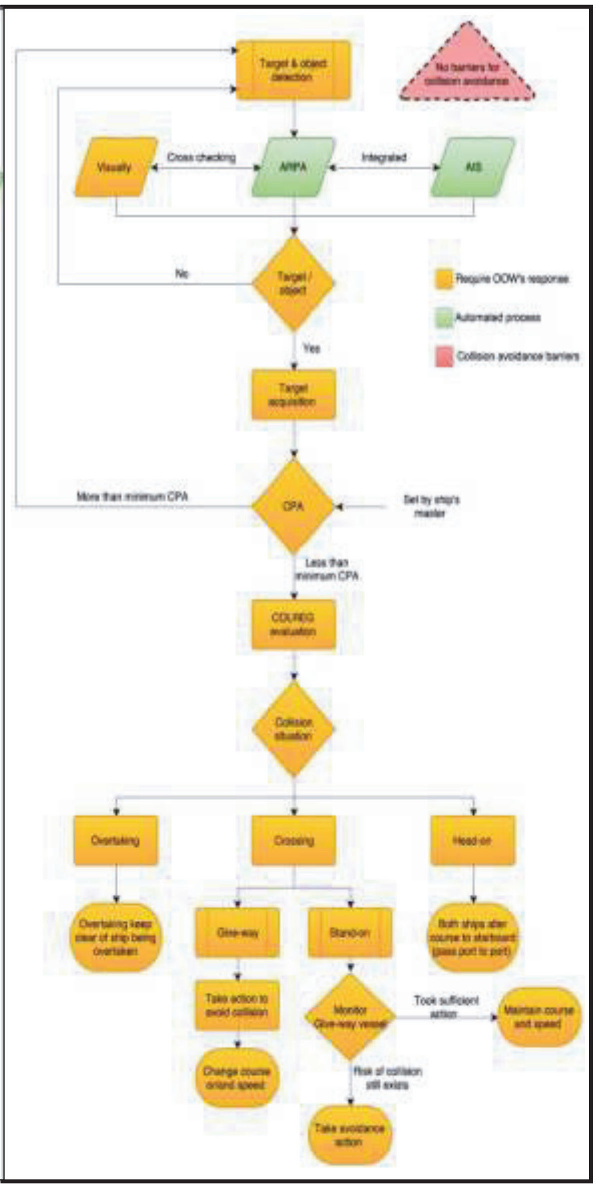

Fig. 4. Maritime collision avoidance procedures

5.1. Procedural diagrams for collision avoidance in aviation and maritime sectors

The comparison between the collision avoidance procedures in aviation and maritime has revealed a number of concerns in maritime sector. Still the diagrams help to spot the most important issues in the maritime procedures. However, by comparing it with the aviation procedures, a significant improvement can be achieved to enhance the situational awareness and navigational safety as well.

Starting with the aviation diagram, a three independent collision avoidance measures are available to stop mid-air collision from happening. The ATC is to control the overall aerospace and to provide separation between aeroplanes. Then the "See and Avoid" technique by the pilots to monitor the traffic in vicinity and to avoid any intruder by best actions. If these two barriers failed to prevent the collisions, then the TCAS system is in place, which is independent system that acts as the last mean of mid-air collision avoidance. On the other hand, in ships, there are no barriers for collision avoidance, it is all depend on the OOW to conduct an efficient look-out to maintain a safe navigational watch with the support of the navigational aids. Also careful monitoring of all the equipment on bridge is required as well as interaction with the ARPA system, which is used for target detection and to extract targets' information. Nevertheless, all the navigational aids, including the ARPA, provide the OOW with information that need farther process to build a decent situational awareness level. Consequently, the OOW utilise these information to realise the encounter situation, based on COLREG, then to decide the avoidance manoeuvre and responsibilities. Yet, the navigational aids do not either; warn the OOW about threats in vicinity, nor the best avoidance actions. Another important different is the automation level, in aviation the TCAS system work automatically, without any human interference, to alert the pilot about intruders in vicinity and the best action to avoid them. On the other hand, navigational aids only provide the OOW with information, and left all the analysis and decisions to him. This leads to subjective decisions based on the understanding and interpretation of the OOW to the situations around him.

6. Discussion

The above comparison has shown that the technological advancement, the collision avoidance procedures and the safety level are superior in the aviation industry.

- Information flow
- Man-machine interaction
- Automatic Coordination and Connection
- Subjectivity and objectivity of the decisions and the uncertainty of the COLREG

Hereafter are the key elements found in the aviation industry, which can be adopted by the maritime to enhance the navigational safety, especially in critical collision situations.

First, the amount of information flow in ships' bridge is immense. In such critical situations, the OOW becomes distracted by all equipment that needs to be monitored and the manoeuvrability of his ship. In order to enhance the OOW's performance, it would be better if a standardised display on one screen, presenting all the important information for critical collision decision-making procedure is available on bridge. In this case the OOW will be able to focus on decision-making without missing any other important information or tasks.

Second, the man-machine interaction: this technique will enhance the level of situational awareness on the bridge. The ordinary navigational systems are informational systems only, which present all the information and the OOW utilises what he needs. In this case, the chances of missing a key element are high and there is no method of ensuring that the OOW is fully aware about the situation. By applying the man-machine interaction technique, the system will automatically ensure the awareness of the OOW and the full utilisation of the information. Also, in order to ensure the awareness of the OWW, an alert must be issued when he is not utilising the important information on the system.

Third, the technique of automatic coordination and connection between maritime collision avoidance systems to remove the uncertainty. By adding such a technique, the OOW will be able to monitor the target ship more accurately. Moreover, it will allow the OOW and the systems to deal with the changeable parameters of target ships as well. Additionally, the feature of acknowledging the manoeuvres of both target and own ships will enhance the level of situational awareness significantly. For example, the OOW is able to monitor the target ship's changes in course and/or speed in real time. Plus if the target ship can show a means of acknowledgment to indicate its awareness of the situation, this will remove the uncertainty of the whole situation and it will indicate both ships' recognition of the situation. In such cases the Stand-on vessel in rule 17 will be sure about the Give- way vessel's action and she can act accordingly. Whether the Give-way is aware about the situation and taking the avoidance action or she needs to avoid the collision by her own actions.

Finally, the approach proposed here aims to remove the subjectivity nature of the OOW's decisions, which are based on his own perception and interpretation of the situation. This can be done by developing automatic process of information flow from different navigational systems and presenting the processed information as a warning and decision support. By enhancing his level of situational awareness through the proposed decision support based on real time information OOW should be able to make objective decisions in good time and enhance navigational safety dramatically.

In conclusion, to improve the maritime navigational safety, it is important to introduce an Automatic Collision Avoidance System, which mimics the TCAS system. The new system will enhance the collision avoidance procedures and utilisation of information on the bridge. Consequently, the navigational safety will improve by using better interpretation and perception of the OOW. In addition, this will remove the uncertainty in the COLREG and the decision-making, as well as the subjectivity of the OOW decisions.

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Çekme Tankı Deneyleri ve Hesaplamalı Akışkanlar Dinamiği Yöntemleri Kullanılarak Bir Sekiz Tek Yarış Teknesinin Trim Optimizasyonu

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Özet

Uluslararası ve Olimpik kürek yarışmalarında kullanılan yüksek performanslı yarış teknelerinin uzunluğu ve genişliği yıllar içerisinde biraz değişmiş olsa da gövde formları büyük ölçüde aynı kalmıştır. Bu konudaki çalışmaların çoğunluğu kürek tekniğinin biyomekaniğini ve küreklerin sudaki etkinliğini araştırmıştır. Bununla birlikte tekne formuna ve tekne hızına bağlı olarak ağırlık dağılımı açısından optimal araştırma eksikliği vardır. Birçok kürek yarışı bir saniyeden daha az farkla kazanılmaktadir. Bu sebepten dolayi, bu çalışmada deneysel ve Hesaplamalı Akışkanlar Dinamiği (HAD) yöntemlerini kullanarak bir sekiz tek yarış teknesinin 2000 m'lik yarışa en uygun trimini araştırmayı hedeflemiştir. Sayısal bir model üretilirek doğruluğunu değerlendirmek için model testlerle karşılaştırılmıştır. Model teknenin trim optimizasyonu ortalama bir yarış hızda gerçekleştirilmiş ve gerçek olan, kürek çekme hareketine bağlı değişen tekne hızları hariç tutulmuştur. Sonuçlar, referans ağırlık dağılımı ile (sıfır trim durumu) karşılaştırıldığında direncin azalmasını ortaya koymakla birlikte sporcuların aynı hızı korumak için yapması gereken çabadaki değişikliği de göstermektedir.

Anahtar kelimeler: Kurek yaris teknesi, trim optimizasyonu, çekme tankı, hesaplamalı akışkanlar dinamiği

A Trim Optimisation of an Eights Racing Shell using Towing Tank and Computational Fluid Dynamics Methods

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Abstract

High performance racing shells for international and Olympic rowing competitions over the years have varied slightly in length and breadth but have largely remained a very similar hull shape. Majority of studies have explored the biomechanics of rowing technique and the effectiveness of the oars through the water. There is still a lack of research into the optimal shell form and operation condition in terms of weight distribution. Given that many rowing races are won by less than a second. Therefore, the aim of this paper is to use experimental and Computational Fluid Dynamics (CFD) methods to investigate the optimal trim for an eights racing shell over a 2000m race. A computational model is produced and compared with model tests to assess its accuracy. Trim optimization of the model shell was performed at an average speed and the varying velocities of realistic rowing motion were excluded. Comparing the results with the reference result (zero trim condition) reveals the reduction in resistance obtained and hence demonstrate the difference in the effort the crew would have to make to maintain the same speed.

Keywords: Rowing shell, trim optimization, towing tank, computational fluid dynamics

1. Introduction

Rowing has been on the Olympic programme from the beginning in 1896. It is such a competitive sport even the difference between winners and runner-up can be split second. To improve the boat speed researchers have been focused on rowers' performance, biomechanics, displacement, weight distribution (sitting position), rigging, foot-stretcher set-up and shell form (Barrett and Manning, 2004, Buckeridge, Weinert-Aplin et al., 2016). The surrounding domain of the racing shell, such as water depth, is also important of factor effects the boat dynamics (Day et al., 2011).

Performance of rowers may be variable from race to race. However, studies showed that elite athletes, i.e. international and Olympic rowers, have quite a consistency and similar performance. This variability for the rowers is only ~1% in finish times (Smith and Hopkins, 2012).

An eights racing shell is a boat for eight rowers who propel the boat and a coxswain who steers. The boat is installed with outriggers and a small fin to improve course keeping. Eights racing shells for a competition have a long sleek shape with a length to beam ration of around 30 and U form midbody (Empacher 2018, Filippi 2018, Hudson 2018). To protect fairness and equality of opportunity Fédération Internationale des Sociétés d'Aviron's (FISA, 2015) imposed appropriate requirements which restricted the boat design (FISA, 2015).

Having similar athlete performance, limited design parameter of the racing boat shell and other equipment lead this study to investigate the effect of the trim on the boat speed. It is a simple variant to alter by changing the sitting order of rowers who have different weights (Hodge, 2016). The main objective of this paper is to optimize the trim to maximize speed. In order to identify optimal trim in still water with confidence experimental and numerical approach were used. The boat displacement is primarily depended on the crew weight category. Heaving light or heavyweight crew might differ the effect of trim on boat speed (Weitao et al., 2007). In the study, the Newcastle University's Rowing Club heavyweight crew was chosen. Finally, the relationship between trim and boat performance is presented.

2. Methodology

2.1. Problem definition and the geometry

The target crew was chosen as the Newcastle University eights racing team. Table 1 shows the weight distribution of the crew. The position 1 is the bow rower and 8 is stern rower. In an eights racing shell coxswain sits at the stern facing onto the rowers.

Table 1. Rower's position and weights

Position	**Weight (kg)**
1 (Bow)	80
2	85
3	95
4	95
5	95
6	95
7	85
8 (Stroke)	90
Cox	55

Scaled model test in a towing tank and computational fluid dynamic methods were used to optimize the trim of the boat. A scale factor of 5.69 model eights racing shell was chosen as the target boat. Main properties of the model are given in Table 2. The 3D view of the model and the sections are given in Figure 1.

Fig. 1. The 3D view and the sections of the model.

Table 2. Main properties of model eights racing shell

Parameter	Model
Length m	3.207
Breadth m	0.107
Draught m	0.038
Displacement kg	6.183

The trim angle was varied between -0.5 and 2.0 º. Negative trim angles indicate the trim by bow and the positive angles indicate trim by stern. The change in trim is then calculated using Equation 1.

$$\Delta \text{Trim} = \frac{\text{mass x 9.81 x distance moved}}{\text{MCT}_{1\text{cm}}} \tag{1}$$

2.1. Experimental setup

The model testing was carried out in the towing tank of School of Marine Sciences and Technology Newcastle University. 3.2 m model had a turbulence simulator at station 9.5. Figure 2 shows the model shell in the Newcastle University's towing tank. The tank is 37 m long, 3.75m wide with water depth 1.2m. The system can operate with a maximum speed of 3 m/s. A dynamometer is attached to the monorail. Gifford dynamometer consists of 4 strain gauges 2 of them for port and starboard resistance components; 2 of them for measuring fore and aft side of the forces. Pitch and heave motions are measured from potentiometers and connected to data acquisition system on the carriage. Data was recorded for 10 seconds at 100 Hz.

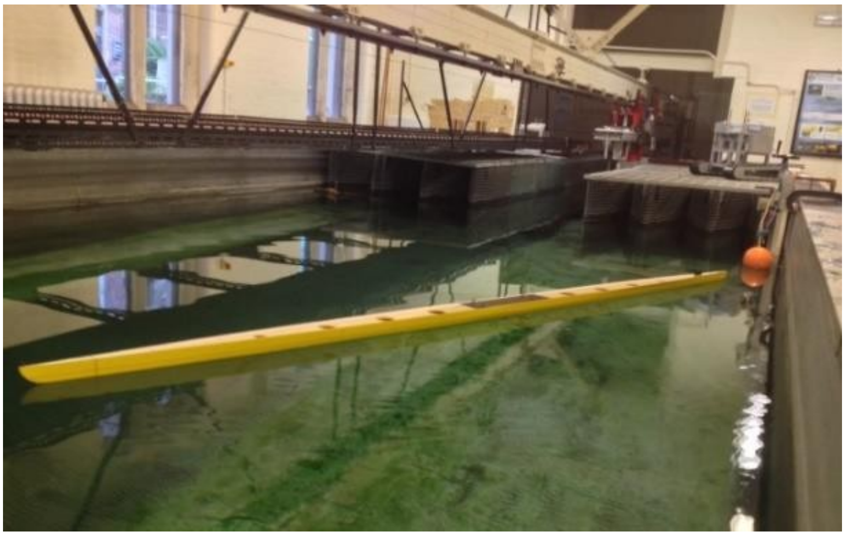

Fig. 2. The model in the Newcastle University Towing Tank.

The operation speeds are given in Table 3. The model was towed without simulating any motion (i.e. surge, pitch, and heave) which occurs due to the rowing action. Such a test rig would be realistic (Day et al., 2011). Having limited towing length and data collecting time would not allow capturing enough stroke. The average stroke for an eight in a race is around 41 (1/min). There was also a risk to bring uncertainty into the force measurements due to oscillation.

Table 3. The model and the full scale speeds

Model speed (m/s)	Full scale speed (m/s)
1.72	4.1
1.94	4.63
2.15	5.14
2.37	5.66
2.59	6.17
2.8	6.69

2.2. Numerical setup

The RANS solver was used to define the flow. κ-▸ turbulence model is chosen for the effect of turbulence on the fluid. The number of the phases was chosen as multiphase flow (water and air). Trimmer mesh, prismatic boundary layers are created for two regions. The numerical mesh created for this study is given in Figure 3. In general, grid points are grouped around the hull and calm water plane to provide adequate resolution at the free surface interface. The total number of cells was approximately 2.2 million. The numerical model of the shell was simulated for fix trim and sinkage to reduce the converging time.

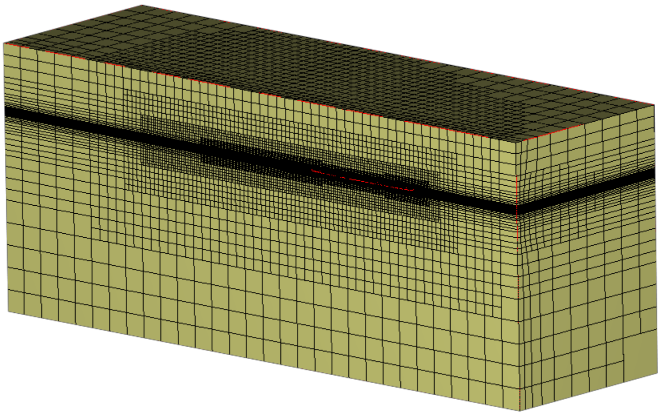

Fig. 3. The general view of the domain and the mesh structure.

3. Results and discussion

Figure 4 shows the towing resistance at the zero-trim condition which is accepted as a reference point to be able to compare with the other trim conditions (Hodge, 2016).

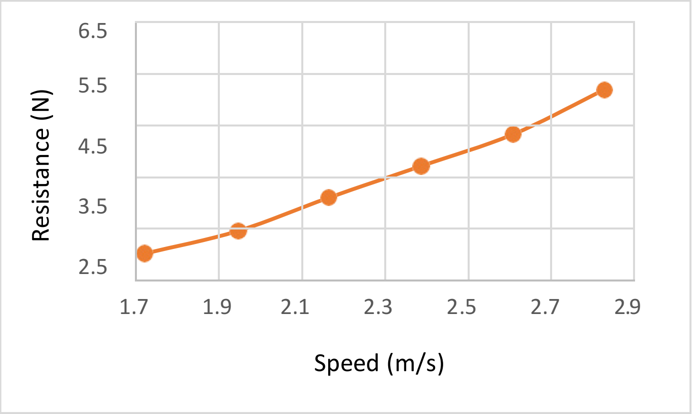

Fig. 4. Model speed vs. resistance.

Figure 5 shows the towing resistance of the model at different trim and speed. In full scale, 5.65 m/s is likely the average speed most of the crew reaches along the 2000m race course. Thus, the model was towed for extra trim to look at the detailed results. The resistance is decreasing at 0.5 º trim for the speeds from 2.15 to 2.8 m/s. Curves are a fitted second-degree polynomial for 2.37, 2.59 and 2.8 m/s.

The hydrodynamic performance of the boat starting to show a different trend at 2.15 m/s. The resistance could be better described by a linear curve at those low speeds 1.72 and 1.94.

The cylinder thin form of the shell generated very low drag. Therefore, a bias was caused by low drag due to towing a boat at the low end of the dynamometer’s range. An electrical background noise on the data acquisition system contributed to around 10% of the overall resistance (Adam, 2016).

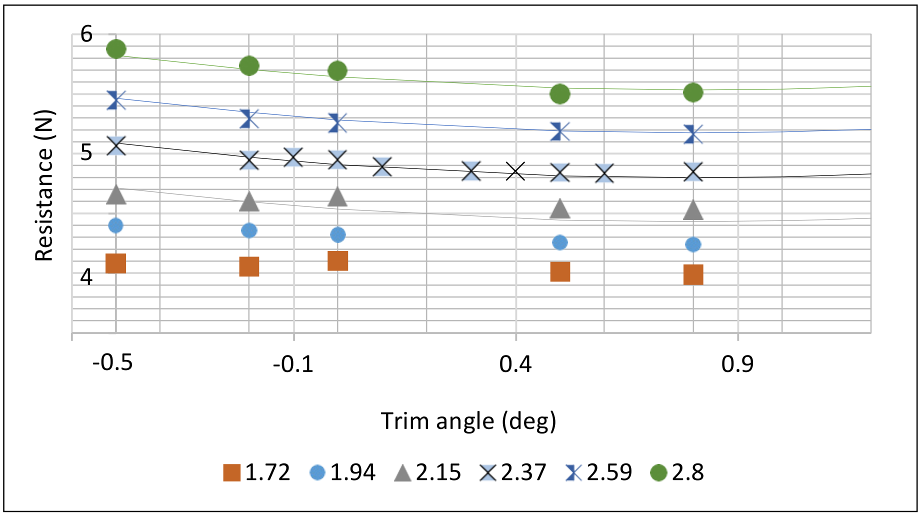

Fig. 5. Results from the towing tank: Resistance of the rowing eight's shell at various speed and trim.

The CFD results are plotted in Figure 6. As it can be seen from the figure, the resistance from the CFD simulation is lower the towing tank results. Nevertheless, there is a resistance reduction around zero trim.

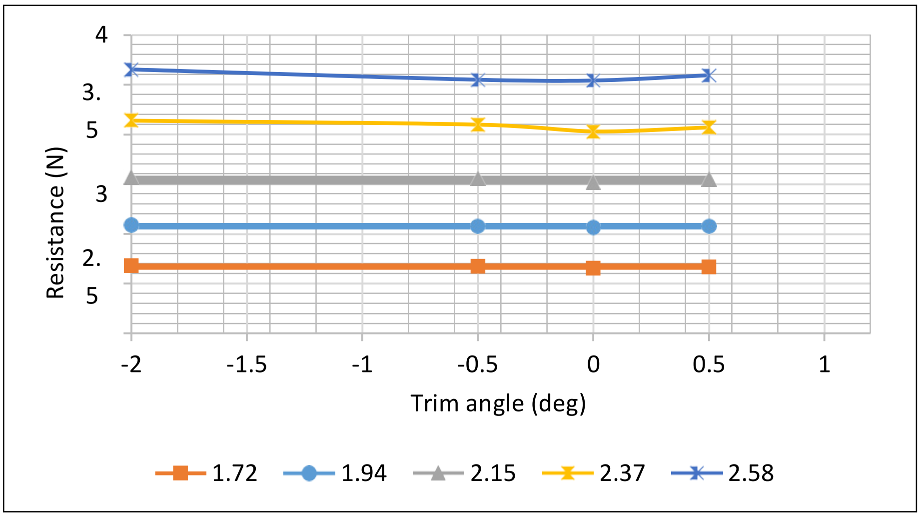

Fig. 6. Results from the CFD: Resistance of the rowing eight's shell at various speed and trim.

The mass fraction and global wave pattern around the hull were given in Figure 7 and 8, respectively. Looking at Figure 8, it is apparent low the wave height (m) is generated by the boat. That means the frictional forces dominating, as expected, at speeds lower than 2.15m/s. It is also apparent from Figure 5 and 6 that trim has almost no contribution to the boat performance below 2.15 m/s.

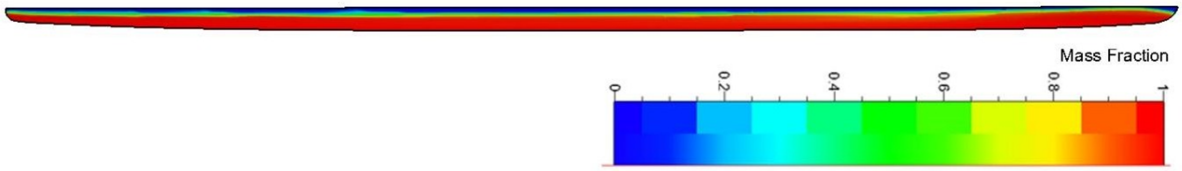

Fig. 7. Mass fraction on the hull surface @ 2.37 m/s model speed.

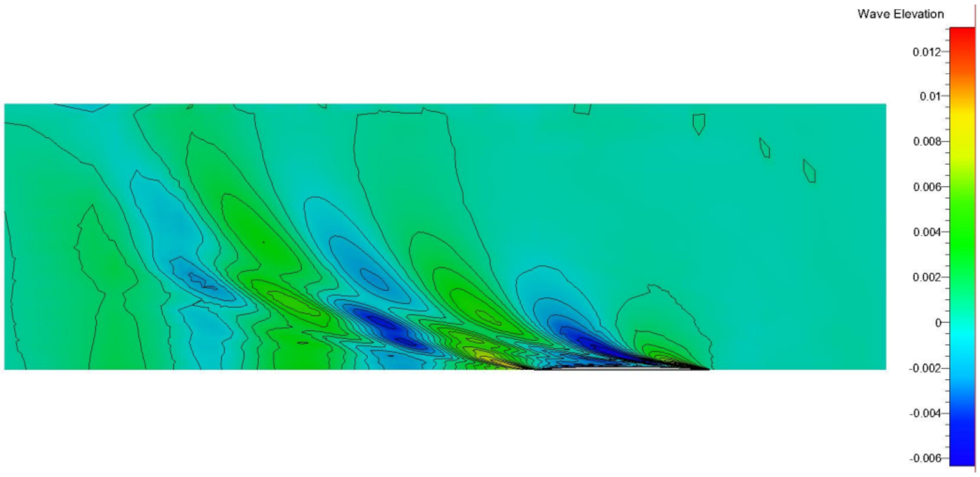

Fig. 8. Global wave pattern (in meter) around the hull @ 2.37 m/s model speed.

4. Conclusions

By employing scaled model experiment and RANS based computational fluid dynamic methods, this study aimed to improve an eights racing shell performance. Results from towing tank test demonstrate a consistent association between trim and resistance at speeds higher than 2.15m/s. Nevertheless, both methods showed trim optimization can be beneficial for the boat performance. According to towing tank results, 0.5 -0.6 º trim by stern decreased the resistance. That means the crew would be able to save 5% of their power. This condition can be set by changing the rower number 3 with number 7, and rower number 4 with number 8. The CFD simulation showed low resistance at zero degree trim condition. The result differences between two methods might be caused by assuming fix trim and sinkage. Therefore, further study needs to be done for computational part of this study.

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FLNG ve Buzdağı Çarpışma Modellemesi Üzerine Bir Çalışma

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Özet

Kutup bölgelerinde deniz seferlerilerinin artmasıyla bu bölgelerdeki buz dağları ile gemilerin çarpışma riski de artmaktadır. Bu nedenle, deniz yapılarına etki edecek dizayn yüklerini belirlemek için çarpışma hasarının doğru değerlendirilmesi bir zorunluluk haline gelmiştir. Bu çalışmada, buz mekaniğini etkileyen parametreleri içeren KOSORI buz modeli kullanılarak gemi - buzdağı çarpışma senaryolarının uygulamalarına odaklanılmıştır ve elde edilen sonuçlar rijit buz modeli ile kıyaslanmıştır. KOSORI ve rijit buz modelleri kullanılarak oluşturulan buzdağı modeli ile FLNG gemisinin çarpışma durumu incelenmiştir.

Anahtar kelimeler: Buz malzemesi, Malzeme modellemesi, FLNG çatışması, Çatışma simülasyonu

A Study on FLNG and Iceberg Collision Modelling

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Abstract

Marine operations increase in the arctic, therefore collision risk of ships with ice bergs in the regions is higher and so the accurate assessment of the collision damage has become a necessity to estimate loads for the design of ship structures. This paper focuses on applications of ship – iceberg collision scenarios by using the KOSORI ice model which takes into account ice mechanic in terms of influencing parameters and, comparing results with rigid ice model. A case of collision of an iceberg with FLNG structure is studied by using the KOSORI ice model as well as the rigid body model for iceberg.

Keywords: Ice Material, Material Modelling, FLNG Collision, Collision Simulation

1. Introduction

Due to the global warming, the last few decades have seen the accelerated melting of huge icebergs and glaciers. This situation gets new opportunities such as the exploration of oil and natural gas industry in the arctic regions and shorter routes for transportations. Accordingly, with continuing increase in the marine operations, the risk of collision of floating structures such as offshore platforms or ships with icebergs is high and so the accurate assessment of the collision damage has become a necessity to estimate loads for the design of floating structures.

The iceberg - ship collision event has two major parts which are external and internal mechanics as shown at Figure 1. External mechanics of the collision include added mass effect, wave damping restoring forces, etc. Although the external mechanics of the collision between ship and iceberg are really important, there is not enough study of them. Therefore, in this study those are neglected. The internal mechanic is examined. Ice and steel materials behaviours change extremely under low temperature or other environmental conditions such as the highly random nature associated with the iceberg. There are usually three different approaches used for numerical simulation of ice and steel interaction, strength design, ductile design and shared energy design (Liu et al., 2011; Norsok, 2013). Major part of collision energy is absorbed by iceberg in the strength design. In some studies ice is assumed as a rigid material for the collision (Sato et al., 2013). Thus, all collision energy is absorbed by steel structure that is the ductile design. In reality, steel is much stronger than ice and the collision energy is shared by both colliding bodies. This approximation is named as shared energy method. The material models of both steels and ice materials should be characterised for numerical computations as the collision impact energy is dissipated for the two colliding as deformation in the bodies.

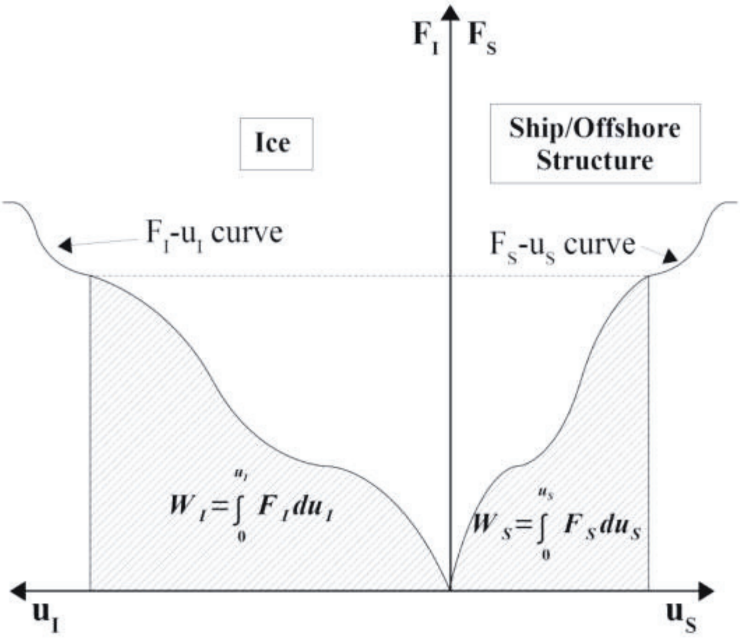


Fig. 1. Energy components absorbed by ice and marine structure.

Even though steel is the main material for ship structure design, ice material responses are important for shared energy design. Ince et al. (2017 a) developed the KOSORI ice model which includes a constitutive equation and a fracture model for ice structural mechanic (Ince et al., 2017 a).Then the model is implemented as a finite element subroutine and validated by ice drop experiment on steel plate (Ince et al., 2017 b). It is the comprehensive model which considers effect of influencing parameters such as strain rate, temperature and salinity based on experimental results. The ice strength and fracture behaviour in the KOSORI model are combined with the traditional metal strength model to implement as a user defined material model (UMAT) into nonlinear finite element program to solve ice-steel interaction problem. An experiment is conducted on interaction of steel plate and ice to validate the developed methods. Additionally, a rigid body drop test is performed for similar conditions with ice drop test to show difference between considering ice as rigid and as deformable. The motivation of this paper is coming from need of application of the model to the realistic collision scenarios. Thus, two examples of marine structure – iceberg collision scenarios are performed in this study.

2. Site-Specific Metocean Effects

The term metocean comes from the abbreviation of the words meteorology and oceanography. It is used in the offshore industry to describe the environment near the offshore structure. Metocean data are essential for the design of ships and offshore structures destined for ice-infested seas. The design of these structures requires practical knowledge of the physical changes occurring in the properties of ice throughout the year and depending on the temperature and salinity. Due to the environmental conditions, the properties of ice in different seas differ from each another. Same way, ice formation in Arctic area is very different from the ice, which freezing in inland seas (Pashin et al., 2011). Thus, ice types are as diverse as region itself. The cold regions are home to huge variations in their geography, resources and environmental conditions, creating a variety of highly complex ice structure. It is necessary that simplify the complexity and to put more reasonable solution for ice behaviour in terms of impact engineering.

Each sea has different metocean properties at different times of the year. For example, Leppäranta et al., (1992) studied the structural behaviour of first-year ice in the Baltic sea and found that the ice salinity rate was 0.05% and the density of the ice was 0.9 g/cm3 in that region, while Urabe et al., (1988) studied the Antarctic sea ice, finding the salinity of ice to be between 0.01–0.025%, the density to be between 0.75–0.9 g/cm3 and the root brine volume to be between 0.025–0.05% (Leppäranta et al., 1992). The salinity of ice also changes with time. Sammonds et al., (1998) gathered data on first- year sea ice from Tuktoyaktuk and Prudhoe Bay and multi-year sea ice from Buckingham Island (Sammonds et al., 1998)The salinity of ice from Tuktoyaktuk and Buckingham Island was between 1– 3 ppm, while that of Prudhoe Bay was between 4–7 ppm. Although Tuktoyaktuk ice was first-year ice, its salinity was the same as Buckingham Island multi-year ice. Therefore, instead of first-year and old ice separation, site-specific ice examination can give better idea about ice strength. Salinity and temperature parameters were used in the KOSORI model to define the ice mechanics for specific location.

2.1. Weather changes over year

As known, temperature in the Arctic region changes strongly in a day from daytime to night as well as yearly. Temperature changing over years from 1979 is shown in the Figure 2 for 70°N and 70°S obtained by satellite. Especially after 1993, average temperature is increasing in the Arctic regions as a result of global warming. Because of that, instead of big massive ice bergs, the amount of icebergs increases in some regions. On the other hand, in a year sharply temperature change is seen in the graph, therefore it affects ice making process highly. Unfortunately, this change effect is unpredictable.

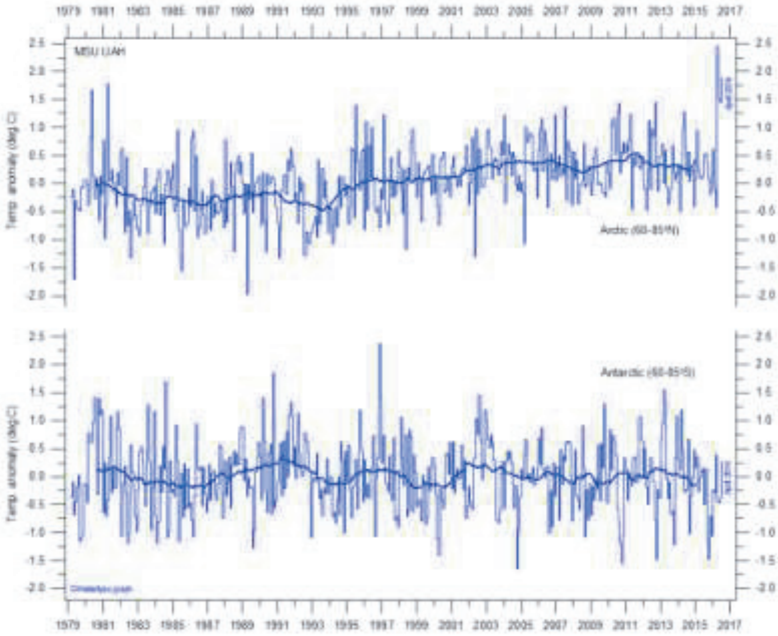


Fig. 2. Temperature changes over years from 1979 to April 2016 for Arctic and Antarctic (Spencer et al., 2016).

Temperature is really effective material properties of steel and ice. Even though, sea water temperature cannot go less than –1.9 °C, air temperature is going –40 °C at night time in some regions. Therefore, both ship and icebergs parts which is under water will be around –2 °C but superstructures will be in – 40 °C, because of this temperature difference both materials have pre-stress. Outer layer temperature of the icebergs which also contact with marine structures is highly effecting water or weather temperature changes. But the inside temperature of icebergs is isolated by an outer layer. The KOSORI model has temperature parameters. Thus, Ice can be model for different temperatures by the model.

2.2. Ocean properties changes over year

Not only temperature, but also winds, currents and waves are important to ice making process and ice crushing itself process. But the effects of them are hard to predict.

The icebergs and icebergs are also moved by the ocean condition. It can cause the collision between the offshore platforms and icebergs or ridges. As an example, Table 1 shows the iceberg velocities for Bransfied Strait (Madejski et al., 1990). Possible collision risks should calculate for specification of the location.

Table 1. Bransfied Strait iceberg velocities

Term	Mean Range (m/s)	Absolute Range (m/s)
February–April	0.6–0.8	0.2–0.9
May–July	0.1–0.2	0.0–0.3
August–October	0.4–0.6	0.1–1.0
November–December	0.4–0.5	0.1–0.5

3. Applied Example

The KOSORI ice model which is implemented in a finite element computer program as a subroutine is used for an example of FLNG – iceberg collision. The KOSORI ice model and rigid model of iceberg cases are compared.

The model helps us to put all of these parameters together into one governing equation. The constitutive material model can adequately represent a wide range of strain rates, temperatures and salinity levels. Equation 1 is constitutive equation of the KOSORI model.

$$\sigma = A\underbrace{\left[1+B\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_o}\right)\right]}_{\substack{\text{Strain rate}\\ \text{Parameter}}}\underbrace{\left[C\left(\frac{T}{T_o}\right)\right]}_{\substack{\text{Temperature}\\ \text{parameter}}}\underbrace{\left[D\ln(\sqrt{\frac{v_b}{v_{bo}}})\right]}_{\substack{\text{Salinity}\\ \text{Parameter}}} \quad [\text{MPa}] \qquad (1)$$

where $\dot{\varepsilon}$ is strain rate, $\dot{\varepsilon_O}$is reference strain rate, T is temperature, T_o is reference temperature, is the brine volume and is the reference brine volume and *A, B, C,* and *D* are the test coefficients of material. Additionally, the model has fracture model which base cohesive zone model. Unlike classical cohesive zone model, it is fracture opening speed depended cohesive model. Equation 2 shows the relation between dynamic strain energy release rate and fracture opening speed of the model.

$$= G_0[5 - \alpha \, ln(\delta_m)] \quad [\mathrm{N/mm}] \qquad (2)$$

Where G_d is the dynamic strain energy release rate, G_0 is the reference energy release rate, α is the coefficient, δ_m is $\dot{\delta}/\dot{\delta}_0$, $\dot{\delta}$ is the fracture opening speed and δ_0 is the reference fracture opening speed.

For numerical simulations first step is meshing process. Finite element programs run on the mesh model of the design. Therefore, high quality mesh is required to take good results from computer simulations. In the literature a lot of studies are focused mesh qualities and mesh size. It is not the target of this thesis, but simply will explain the mesh technic and will study mesh size to get better results.

In the explicit finite element analysis, time step size is calculated by using minimum mesh size. Therefore, mesh size should be uniform to get faster simulation. After creating a mesh model of the structure, mesh qualities should check and impact area and critical areas (intersection of the two or more bodies, around holes or edges etc.) should model out of triangular element. Because linear triangular element shape function is not allowed to show stress changes in element and it gives the mean stress everywhere in the element.

3.1. Iceberg – FLNG collision

Floating liquefied natural gas (FLNG) ship has the facility which produces, liquefies, stores and transfers LNG. It is useful due to the operational capability and processing, LNG on the ship. Additionally, they have some challenges due to the huge LNG storing tanks. Possible colissions can be catastrophic.

3.1.1. Numerical modelling

In this collision scenario,2500 tonnes iceberg collides with middle of the FLNG tank at 0.5 m/s speed under effect of wind and current. FLNG main dimensions and other details of the scenario are given in the Table 2. Figure 3 shows the CAD geometry of the collision. Iceberg is defined as a rigid body and the KOSORI ice model for two cases.

Table 2. Iceberg – FLNG collision details

LOA	396 meters
LWL	387 meters
B	45 meters
T	25.3 meters
D	16 meters
DWT	260 000 tonnes
Iceberg Mass	2 500 tonnes
Iceberg Velocity	0.5 m/s

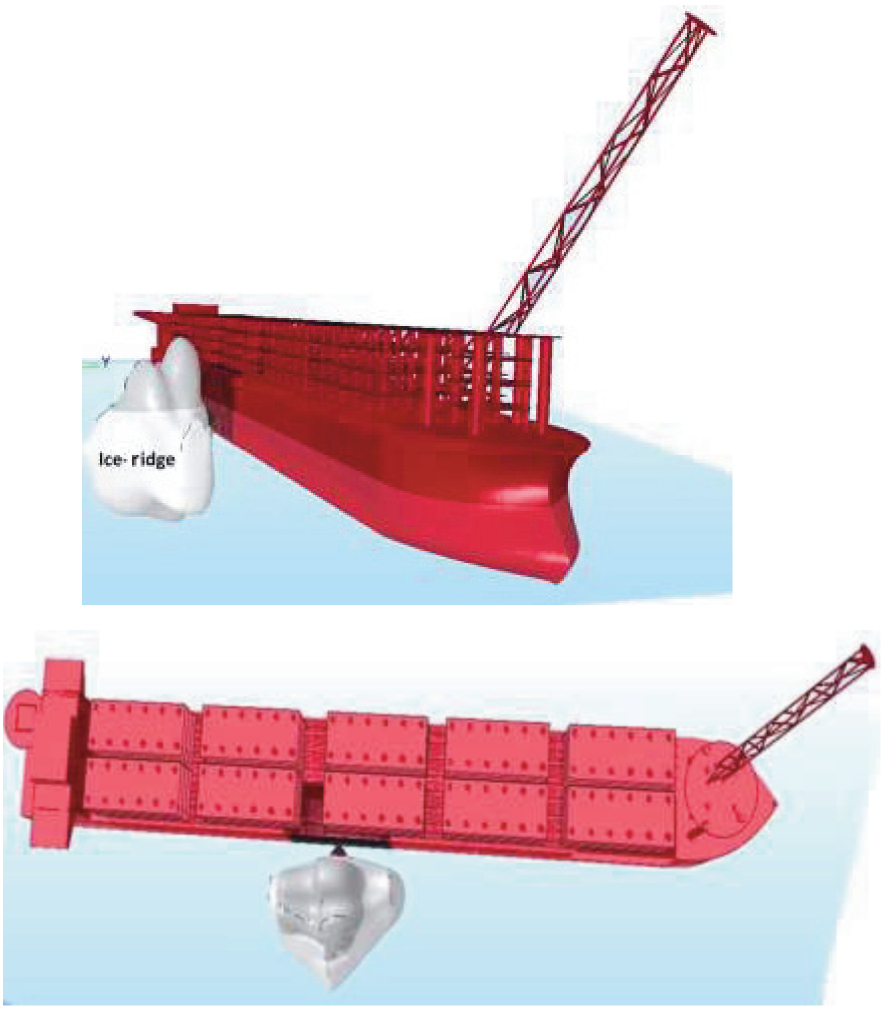


Fig. 3. CAD geometry of the FLNG – iceberg collision.

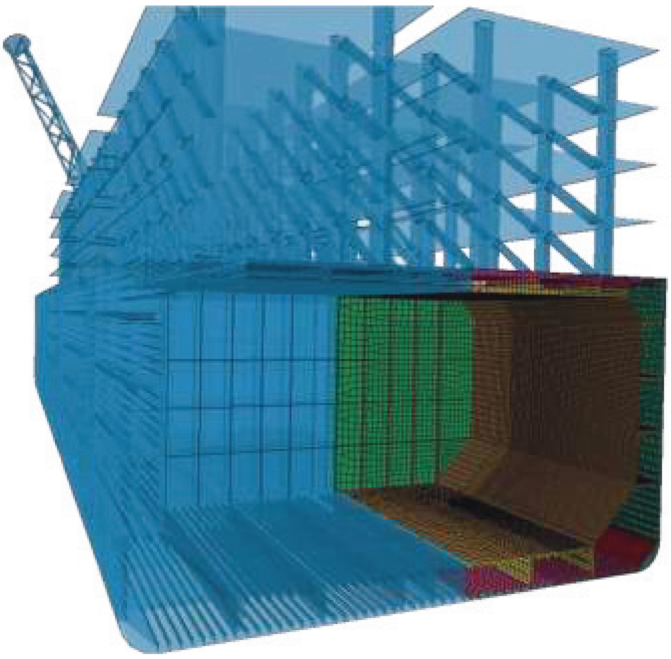


Fig. 4. Mesh model of the FLNG.

In the Figure 4, FE meshes of the FLNG are shown. Thicknesses and other important local dimensions are given in the Table 3.

Table 3. Details of the collision area structure

Outer hull thickness	18 mm
Inner hull thickness	14 mm
Longitudinal frame thickness	14 mm
Transverse girder thickness	14 mm
Longitudinal girder thickness	14 mm
Distance between hulls	2.85

3.1.2. Results and discussion

FLNG – iceberg collision simulations are performed by using KOSORI ice model and rigid body ice model. Figure 5 illustrates the FLNG side structure deformation after collision. Ice elements are separated during collision, therefore the impact contact area is enlarged. Thus, the pressure is decreasing on the contrary the rigid assumption as seen in Figure 6.

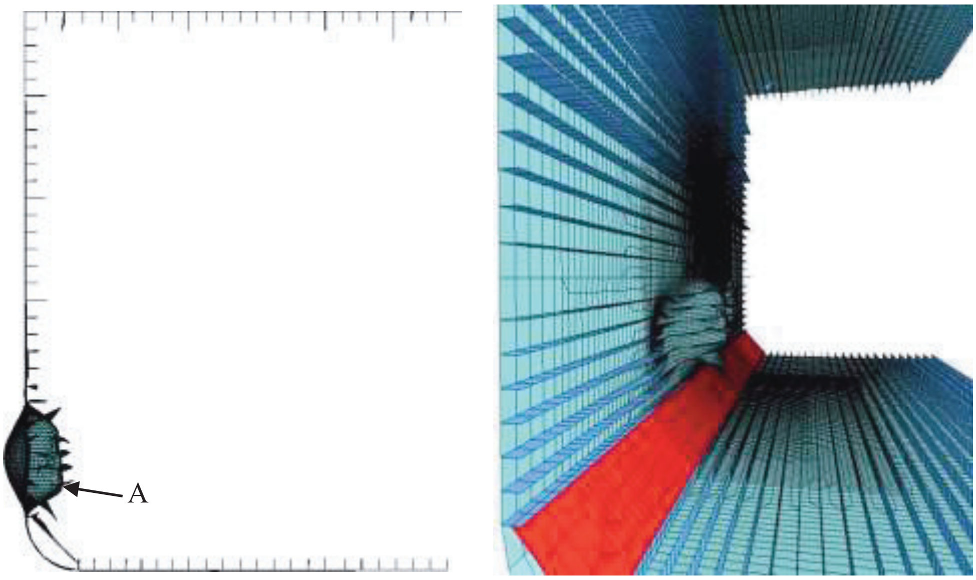
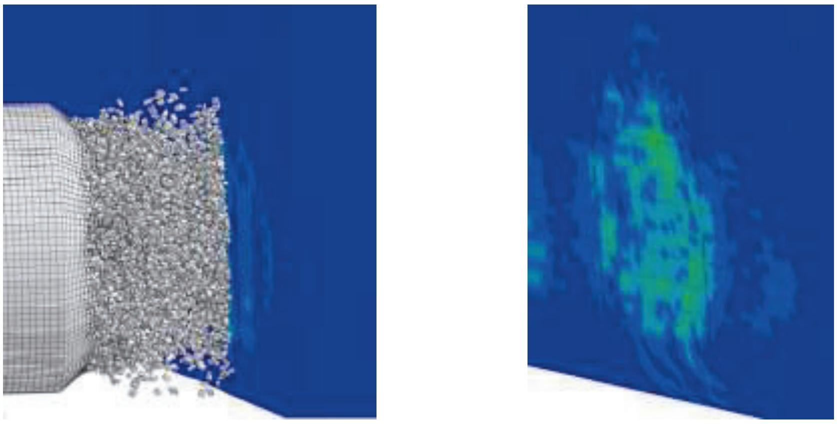
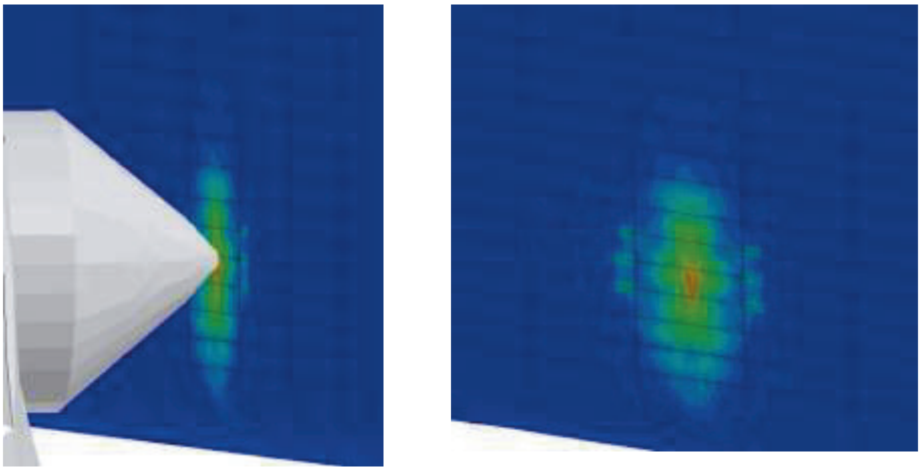


Fig. 5. FLNG side structure deformation after collision by magnification of 50.

Figure 7 shows force and penetration relationships for the KOSORI and rigid model. For both cases, similar maximum force is founded and the maximum deflections are 39 mm for KOSORI model used case and 131 mm for the rigid case.



(a) The KOSORI model



(b) Rigid model

Fig. 6. FLNG side structure deformation after collision.

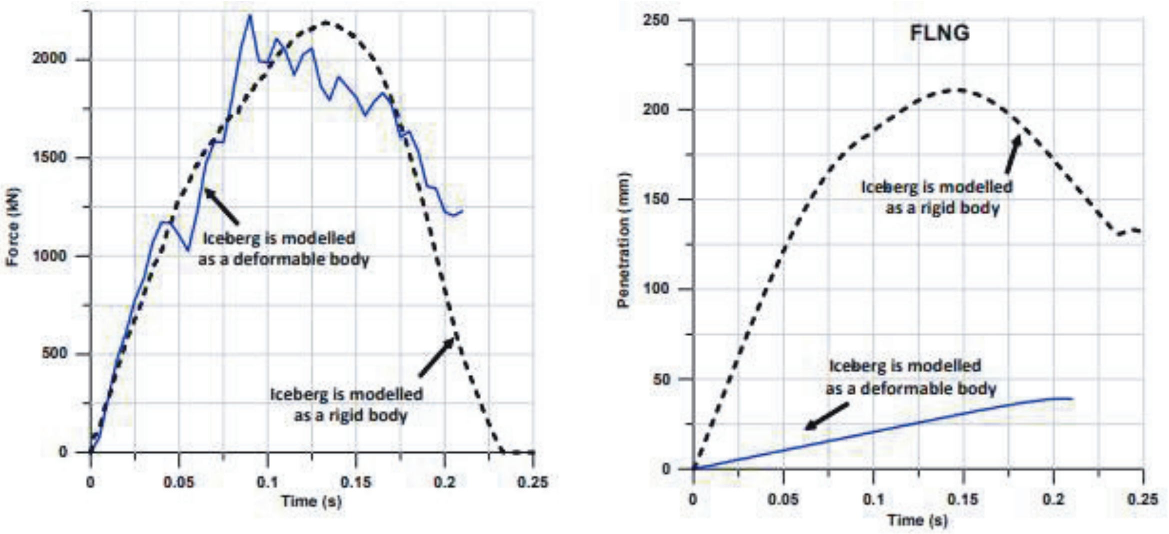


Fig. 7. Force and penetration responses of the collision between FLNG and iceberg for point A.

Force and penetration alteration for both, ice and FLNG side structure is shown Figure 8. In the KOSORI model case, the energy dissipated for deforming ice and FLNG on the contrary rigid model. It is clearly seen that, the energy mostly absorbed by ice structure.

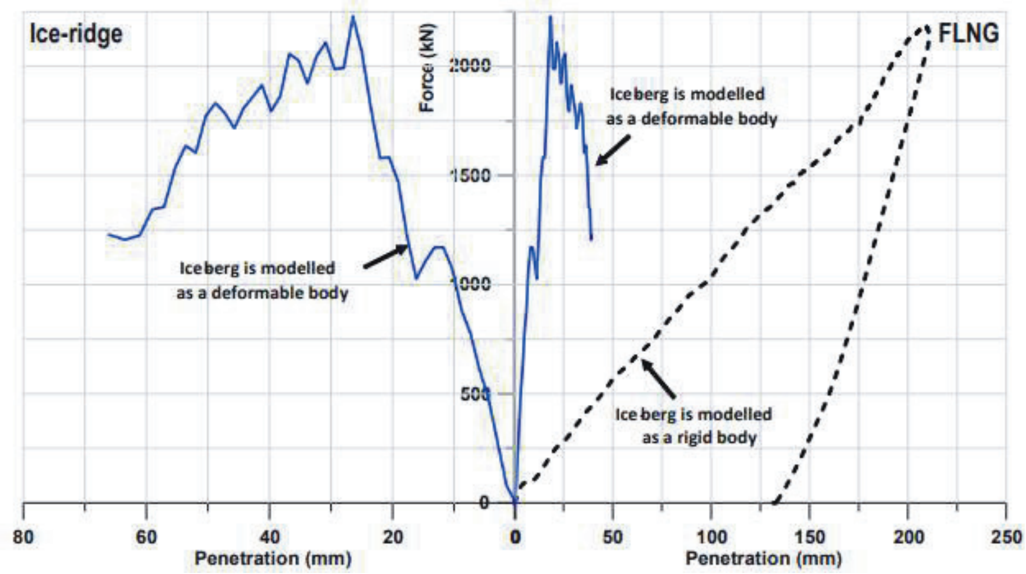


Fig. 8. Force and penetration relation of point A for both models.

Figure 9 shows absorbed energy comparison of the both model. At the end of the simulation, 7.42 kJ energy absorbed by the hull plate for using KOSORI ice model and 115 kJ energy absorbed in the rigid model case. All impact energy dissipated for deforming FLNG in the rigid model case. Therefore, it shows higher absorbed energy than the KOSORI model. The differences of the energy between rigid model and the KOSORI model case absorbed by iceberg.

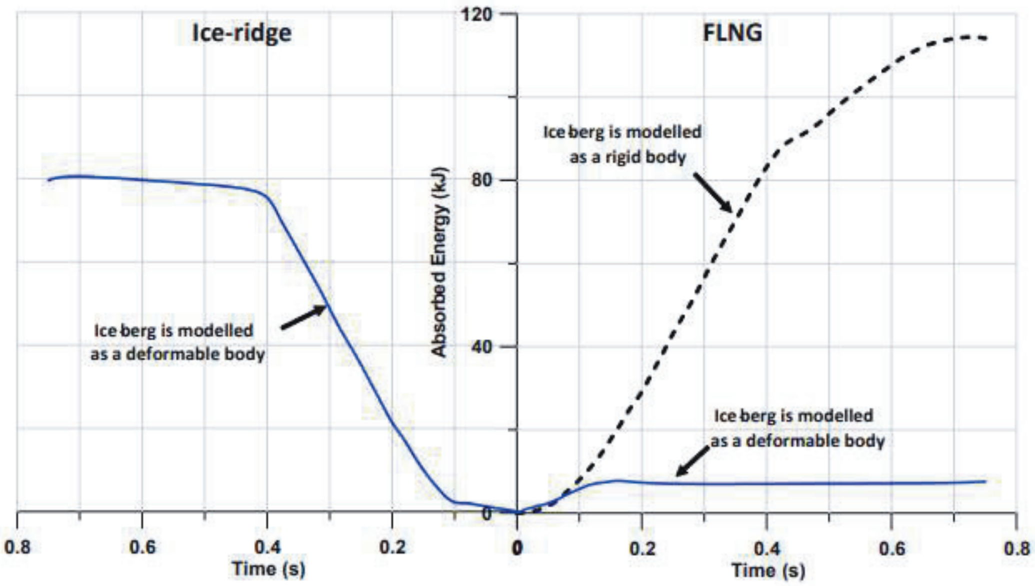


Fig. 9. Absorbed energy of the collision between FLNG and iceberg.

As a result, the penetration decreased more than four times by using realistic ice material model. Even though implementation of the rigid assumption is easy and simulation takes shorter time, it is quite pessimistic scenario for the collision between iceberg and marine structure.

4. Conclusion

The collision scenario is applied between a FLNG with iceberg for different ice model cases. Classical ice material as a rigid body assumption is compared with KOSORI ice model. In the simulation, following points are seen:

- Impact area is highly changing in the ship and iceberg collisions. Therefore, the discrete fracture capability of the KOSORI ice model was compensate impact area changes successfully. Rigid model case, the tip of the ice has been always sharp and it causes more damage.
- Even though force transfer from ice to ship structure during collision is similar in the KOSORI ice and rigid model cases, deflections are quite different.
- In the rigid model case, all impact energy absorbed by the marine structure. In the KOSORI ice model cases, the energy shared between ice and structure. The energy absorbed by structure in rigid ice model was really high comparatively the KOSORI ice model cases.
- The rigid ice model case, analysis is quite faster than the KOSORI ice model.

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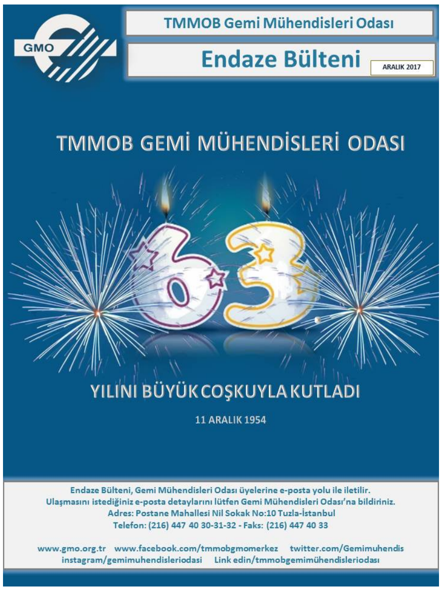
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