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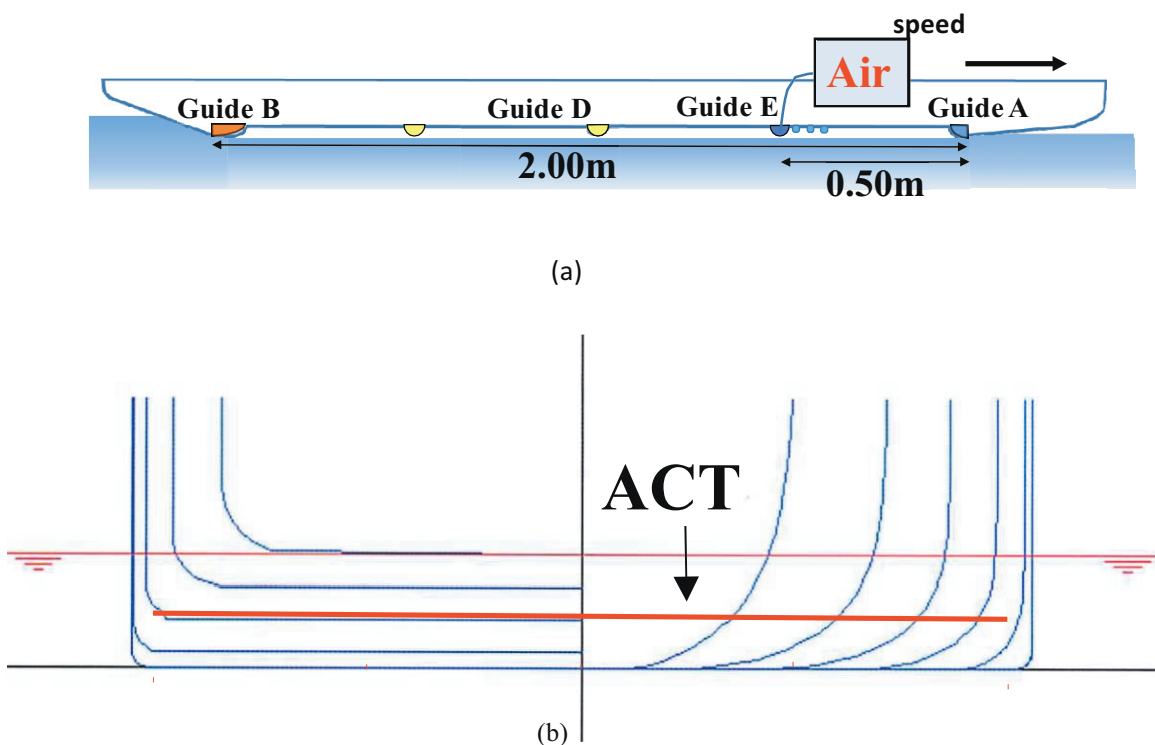
Fig. 1. Profile (a) and body plan (b) of model ship with ACT

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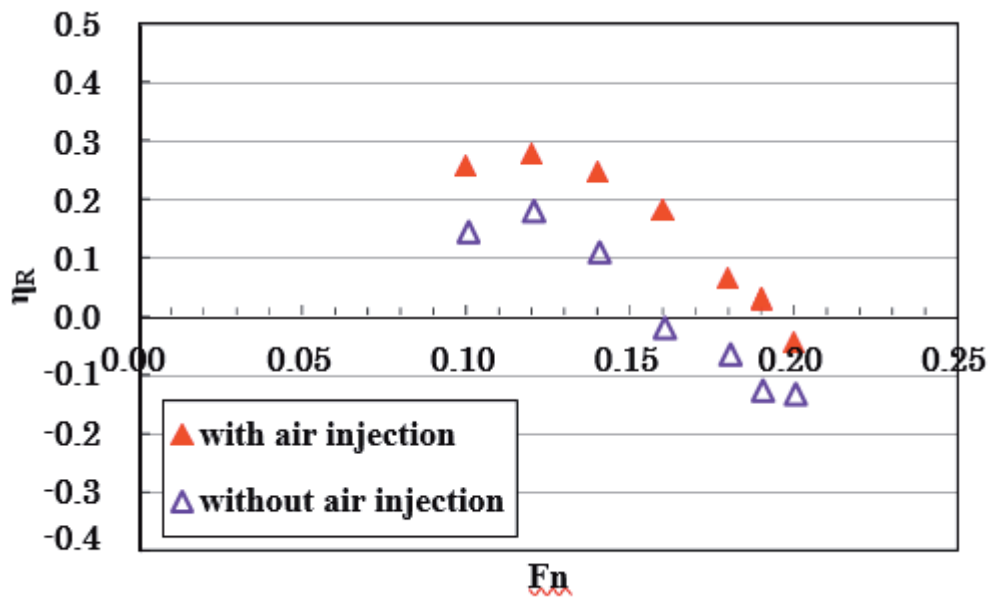
Fig. 2. Experimental results of resistance reduction ratio η_R with and without air injection
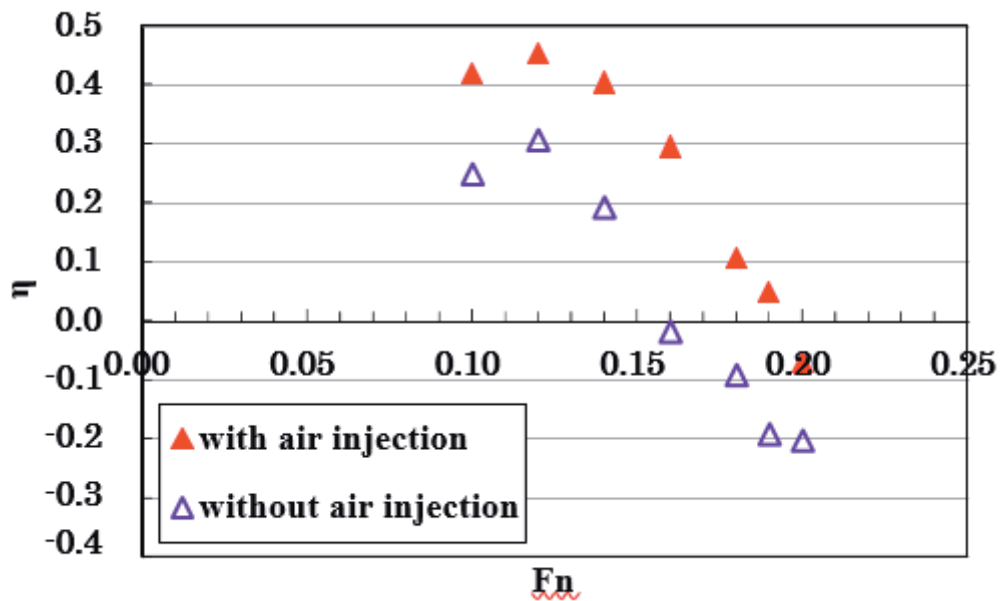

Fig. 3. Experimental results of ACT efficiency η with and without air injection

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.
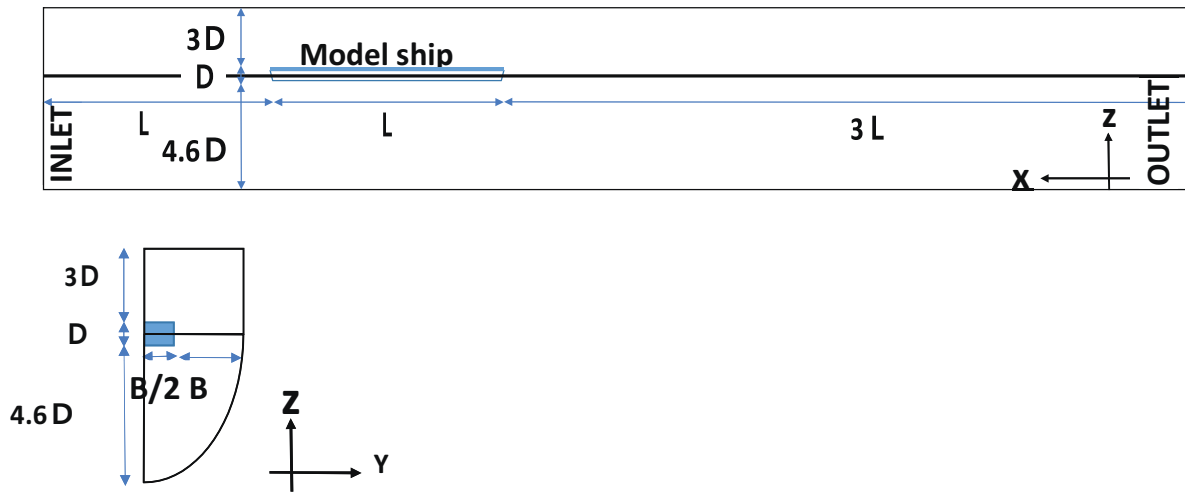
Fig. 4. Computational domain of 3D model

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	$1.125 kg/m^3$
water density	$998.2 kg/m^3$
air viscosity	$1.7894 \times 10^{-5} kg/m.s$
water viscosity	$1.003 \times 10^{-3} kg/m.s$
gravitational acceleration	$9.81 m/s^2$
surface tension	$7.17 \times 10^{-2} N/m$

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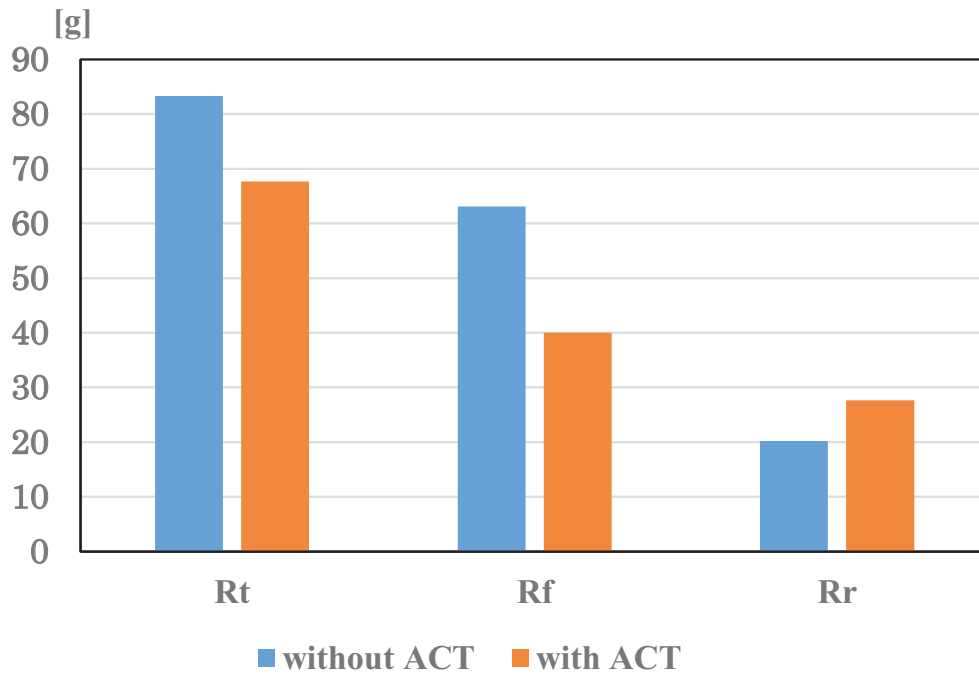
Fig. 5. Comparison of calculated resistance components of the ship with and without ACT by CFD.

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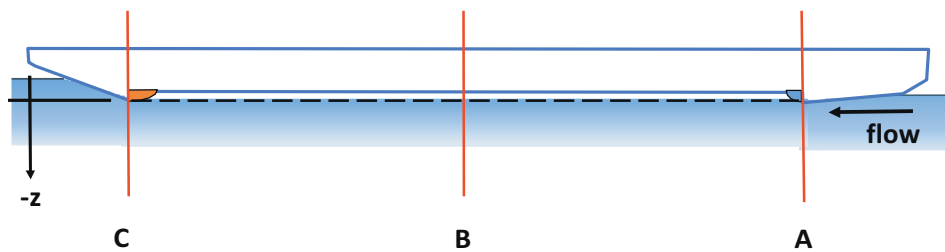
Fig. 6. Locations for calculating velocity distributions in boundary layer of outside water flow for Figs. 7-9

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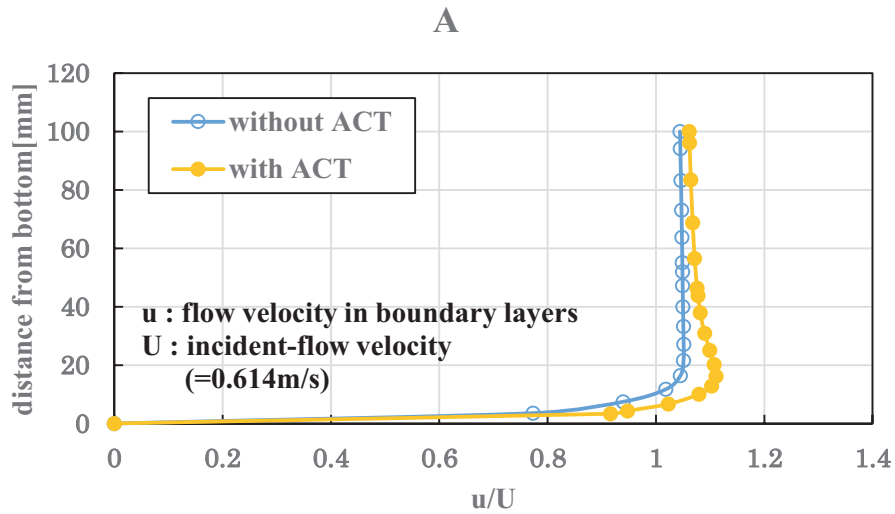
Fig. 7. Calculated velocity distributions in boundary layer for with and without ACT at location A
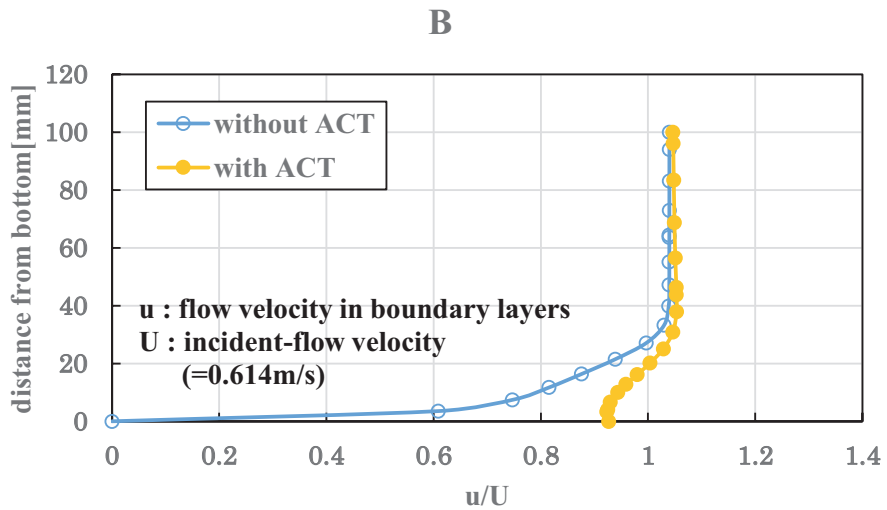
B

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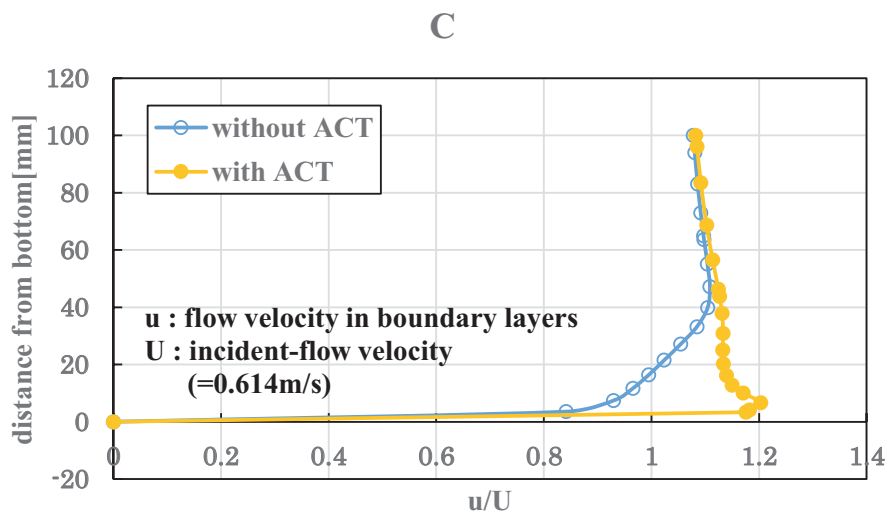
C

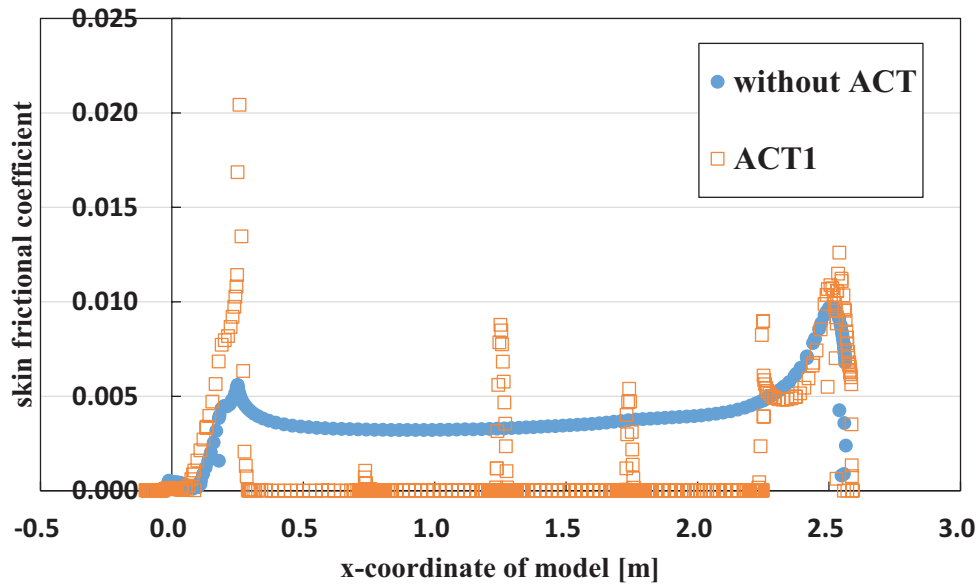**Fig. 9.** Calculated velocity distributions in boundary layer for with and without ACT at location C

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 graduent 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.
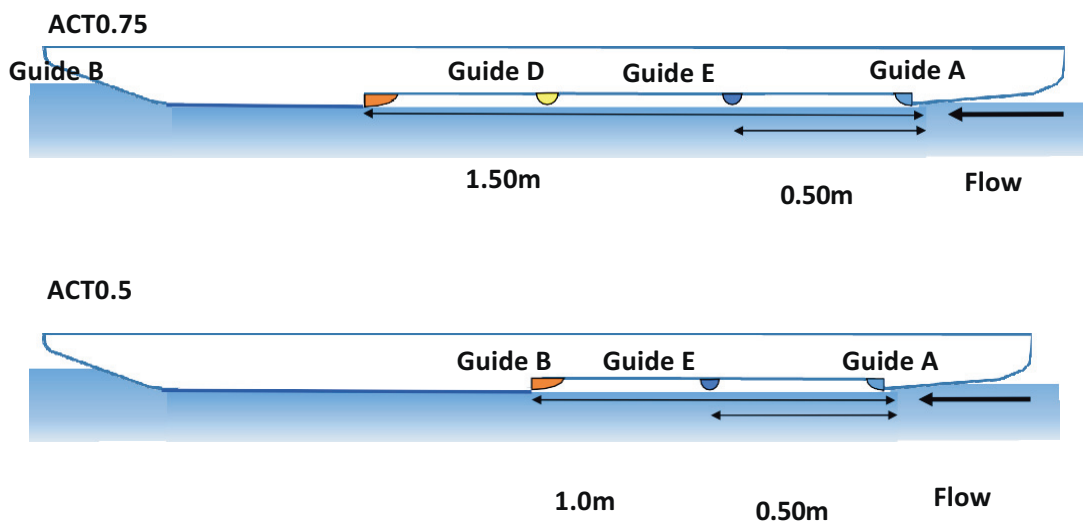

Fig. 11. Side views of model with ACT0.75 and ACT0.5

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.
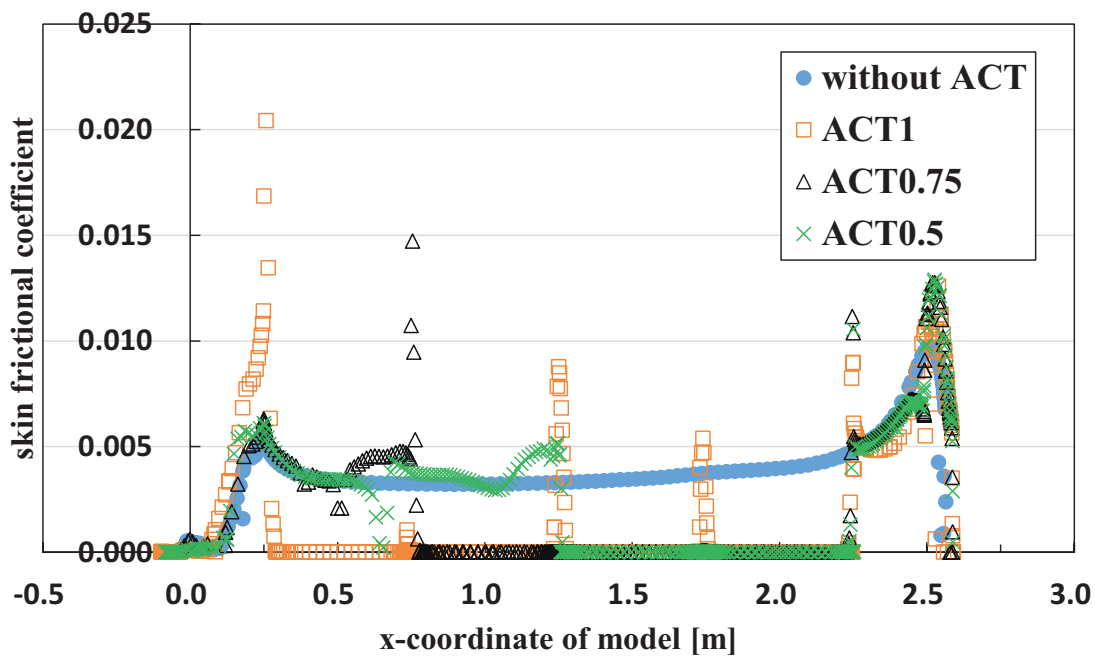

Fig. 12. Calculated local skin frictional coefficient of models with ACT1, ACT0.75 and ACT0.5
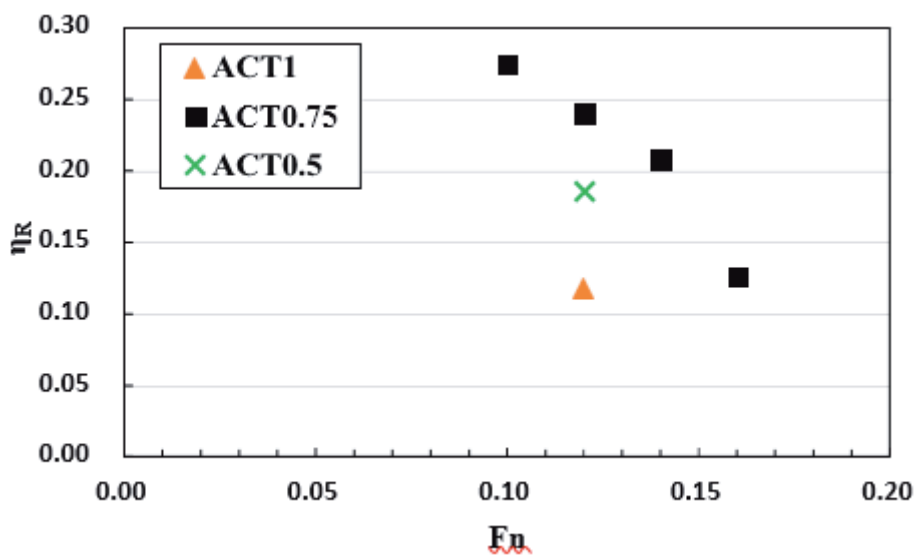

Fig. 13. Calculated resistance reduction efficiency, η_R of modified ACTs to compare with that original ACT
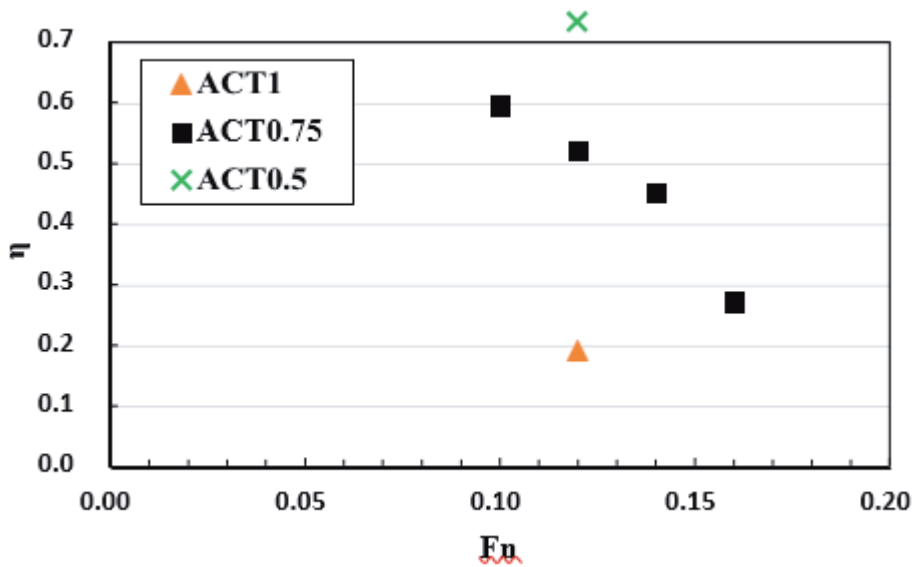
Fig. 14. Comparison of ACT efficiencies, η of modified ACTs to compare with that of original ACT

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.
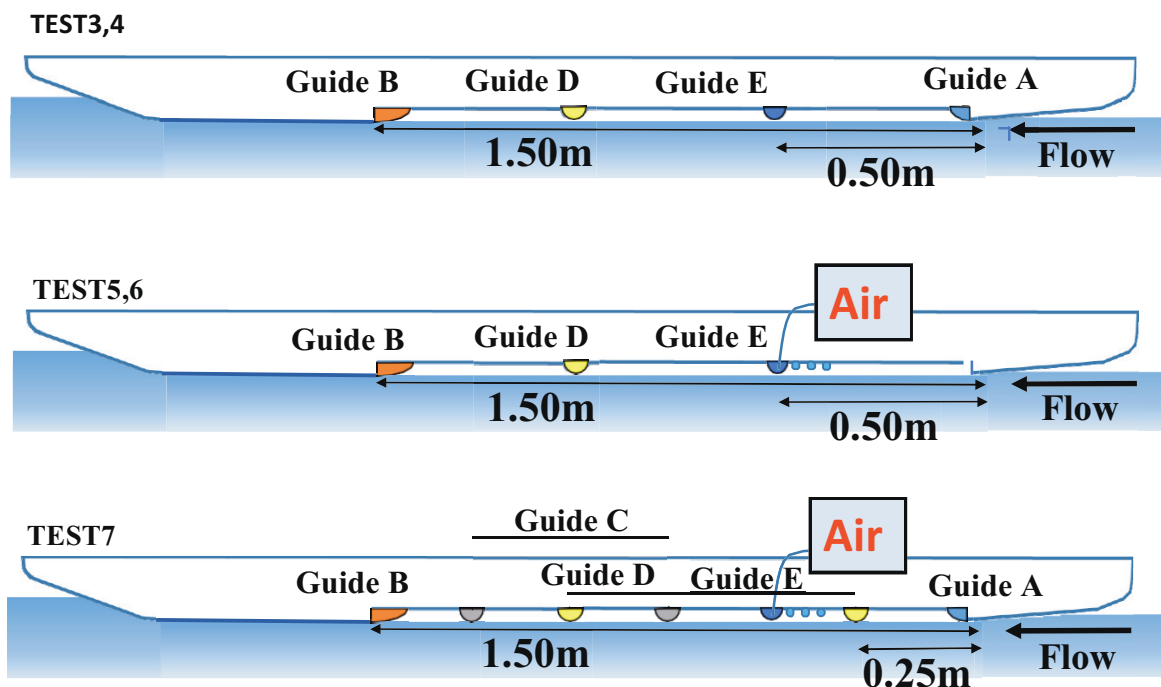

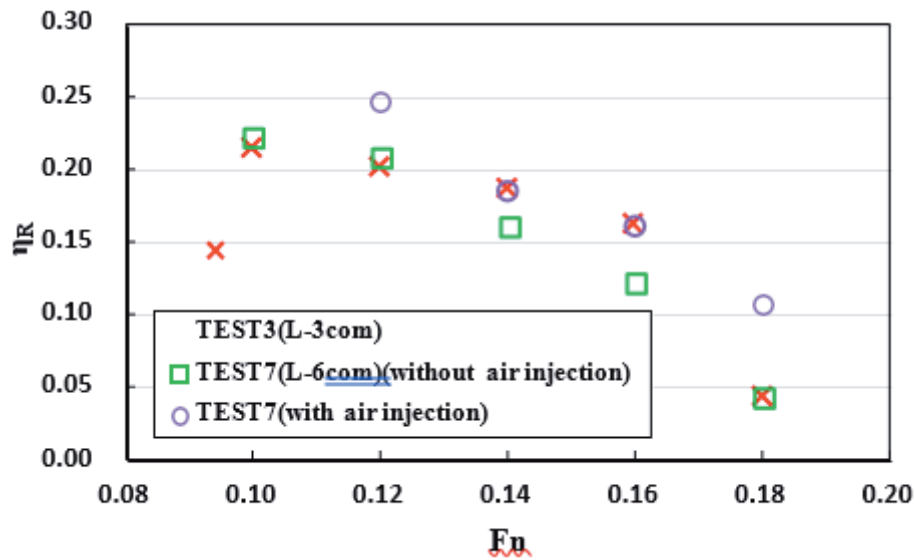**Fig. 15.** Side views of models used experiments

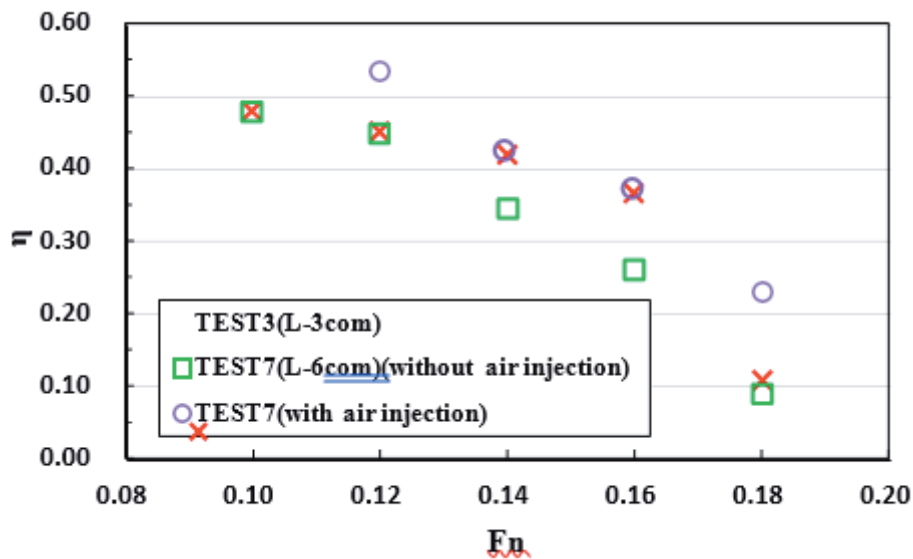**Fig. 16.** Experimental results of resistance reduction ratio η_R of ACT0.75

Fig. 17. Experimental results of ACT efficiency η of 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.
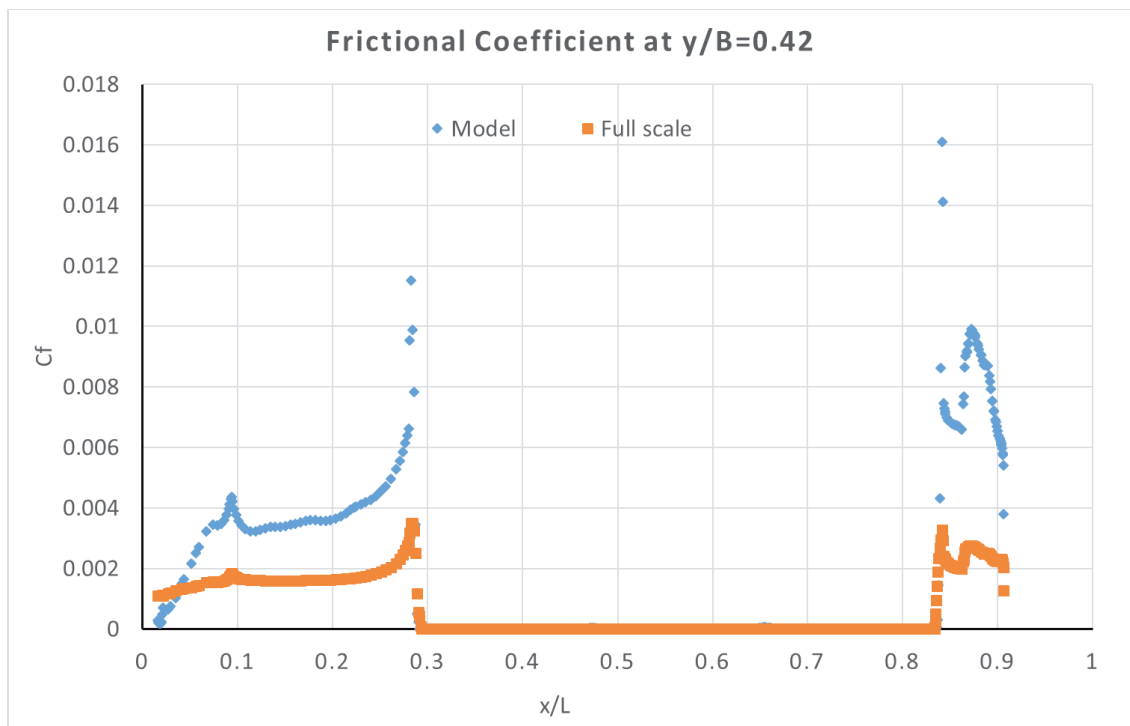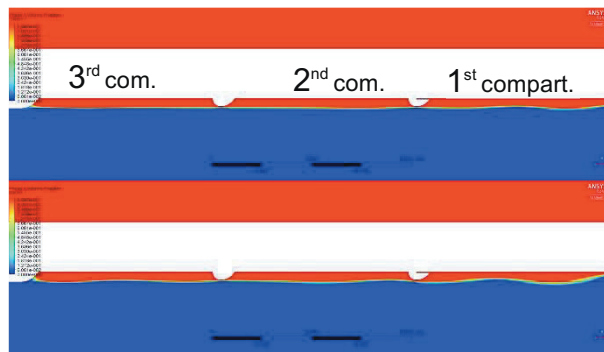

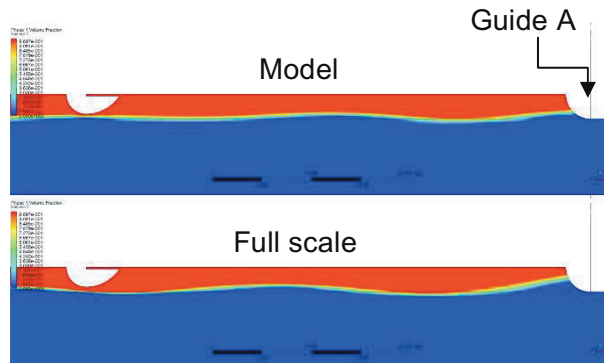**Fig. 18.** Calculated local frictional coefficients of model and ship.
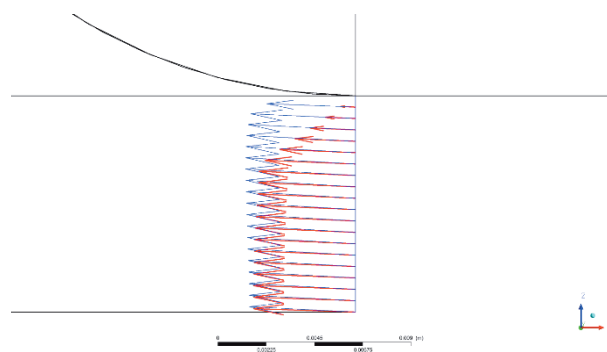
Fig. 19. Comparison of velocity profile in boundary layer at the entrance of ACT (Blue: full scale, red: model scale).

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 1st compartment
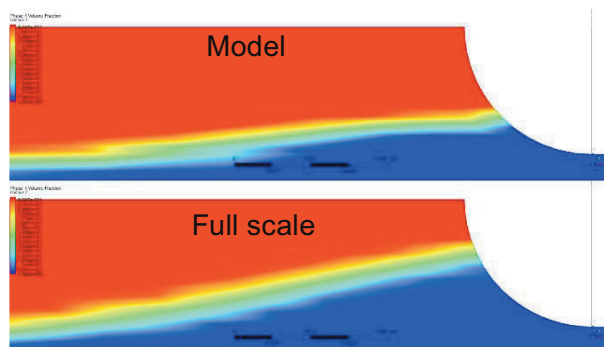
c) Side view near Guide A

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.

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