Stability and Roll Motion of a Ship with an Air Circulating Tank in Its Bottom

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ABSTRACT

A ship with an air circulating tank in its bottom has been developed in Osaka Prefecture University with several Japanese shipyards to reduce the frictional resistance drastically and to save fuel consumption of the ship. It was pointed out that the moving air in the tank due to heel and roll motions may reduce the stability, and changes the roll motion characteristics of the ship.

In the present paper, at first, the effects of the moving air on the stability of a ship with an air circulating tank which has a single compartment are theoretically and experimentally investigated to confirm the loss of stability. To resolve the stability loss, the air circulating tank is divided into some transverse compartments. The stability calculation suggests that four compartments can keep enough stability in small roll angle. For the new tank, the stability, roll damping and roll motions are experimentally investigated.

Keywords: *air circulating tank, frictional resistance, stability, roll motions, roll damping*

1. INTRODUCTION

Reduction of the frictional resistance acting on a ship by using air has been studied in more than hundred years. In Russia (Soviet Union), Europe and Japan, research and development of ship drag reduction by using air were carried out from 1960's to 2000's. Comprehensive reviews were published (Gorbachev, Y, 2012 and Makiharju, S, 2012). For a large ship which runs in lower Froude number, drag reduction devices by using air-micro-bubbles were successively installed to module carriers, bulk carriers and a Ro-Ro ferry in Japan, and revealed that the devices gave a 3-12% reduction of fuel consumptions.

To get more effective drag reduction tools, the authors have been developing an air circulating tank (ACT) which is installed in the bottom of a ship and in which air is kept and circulates. Reduction of the frictional resistance can be more than the air micro-bubble method mentioned above. The experiments carried out by the authors showed that a 25-30% reduction of frictional resistance can be achieved in lower Froude numbers (Furuo, A, 2015). There are some problems to keep the drag reduction, for examples, how to keep the air in trim, heel and ship motions, how to reduce generated waves on the free surface between inside air and outside bottom water flow, how to keep the stability of the ship with the air circulating tank.

In the present study, fundamental characteristics of the stability of a ship with ACT are theoretically and experimentally studied, and an ACT to avoid the stability reduction due to the bottom air is developed. Roll damping and roll motions in beam waves are also experimentally investigated.

2. STABILITY OF A SINGLE-COMPARTMENT ACT

Stability characteristics of a box shape model with a single-compartment ACT in the bottom are investigated. The cross section of the model are shown in Fig. 1. Air is accumulated in the ACT or the well.

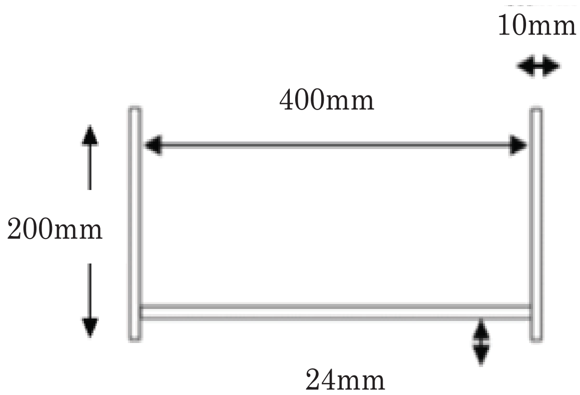

Figure 1 Cross section of the box shape model with a single-compartment ACT .

With increasing heel angle, the inside air shifts and generates a negative restoring moment as shown in Fig. 2. The inside air escapes from the tank in larger heel angle and the draft increases due to reduction of buoyancy as shown in the fourth figure in Fig. 2.

The stability reduction due to the air shift and escape in the ACT can be easily calculated. The results are shown in Fig. 3 with experimental results obtained by the authors. We can see that the air in ACT significantly reduces the stability of the model. It should be noted that the stability in small heel angle becomes very small as shown in Fig. 3. This means that the ship may be unstable in some degree, and needs appropriate GM to compensate the reduction of the stability due to the air. In larger heel angle, however, the inside air escapes from the ACT, and the stability may recover to the safety side.

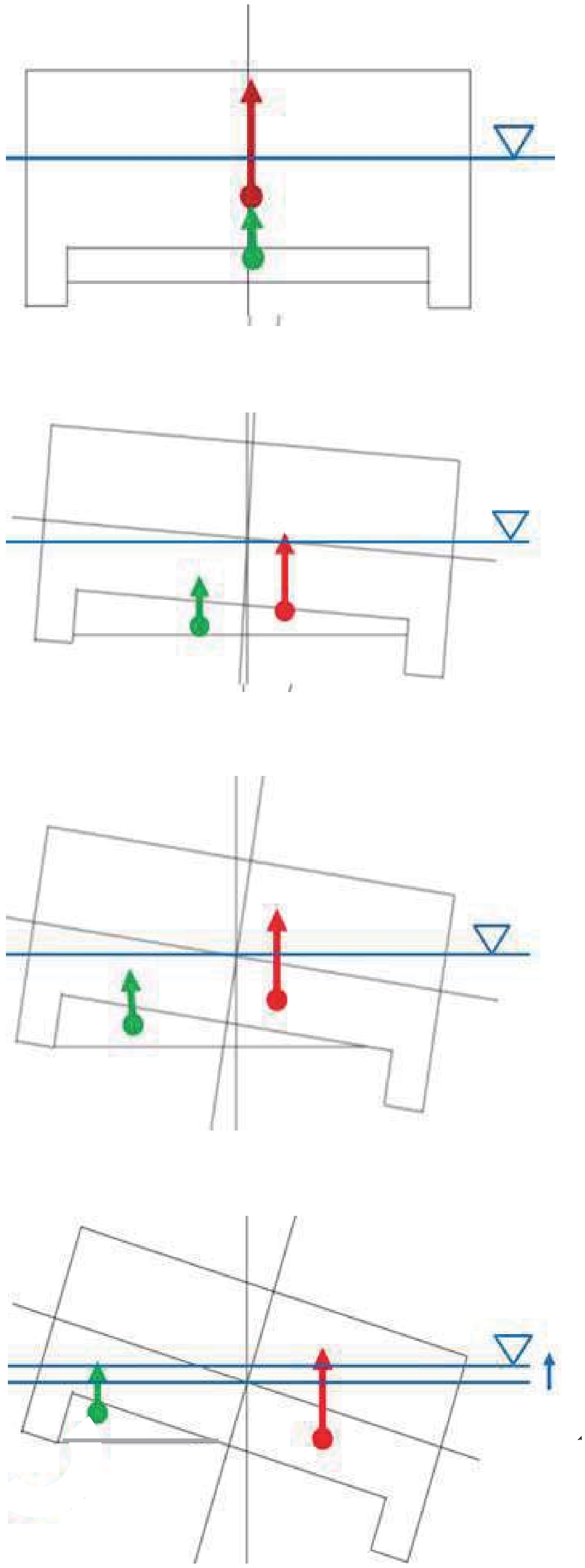

Figure 2 Inclining of a ship and air in ACT (red arrow: buoyancy acting on the body, green arrow: buoyancy by trapped air).

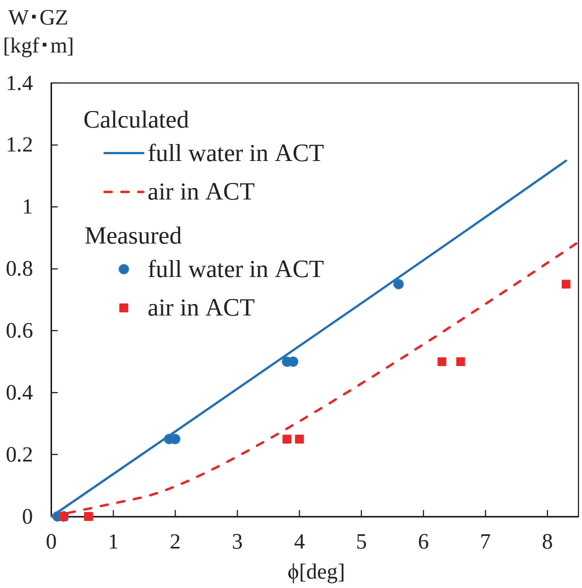

Figure 3 Reduction of stability of a box model due to air in a single-compartment ACT (lines: calculated, marks: measured)

3. IMPROVED ACT

The easiest way to resolve the reduction of the stability of a ship with ACT may be to transversely divide the tank into some compartments. Fig. 4 shows air shift in each compartments of the box model with a four-compartments ACT. Stability calculations for various numbers of the compartments are carried out, and the results are shown in Fig. 5. The results demonstrate that the transverse compartments drastically improve the stability, and the stability of a model with four compartments are almost same as that of the case of no air in the ACT. We can safely said that the four compartments can resolve the stability problem of a ship with an air circulating tank.

4. STABILITY AND ROLL MOTIONS OF ULCC

The authors developed a 20,000TEU ultra-large container carrier with shallow draft and wide beam. To reduce the frictional resistance of the ship, an ACT was developed for the ship as shown in Fig. 6.

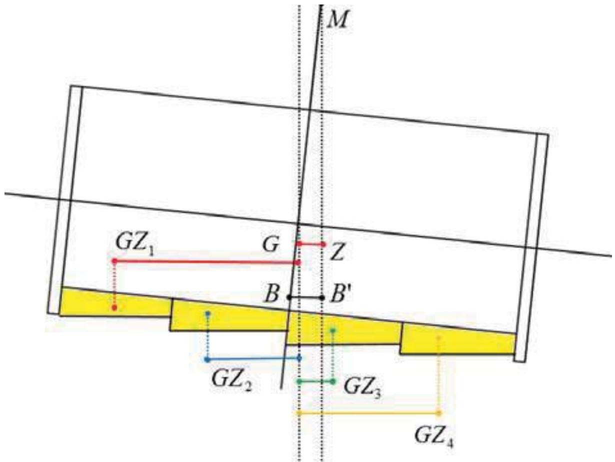

Figure 4 Schematic view of an inclining box model with an ACT with four-compartments.

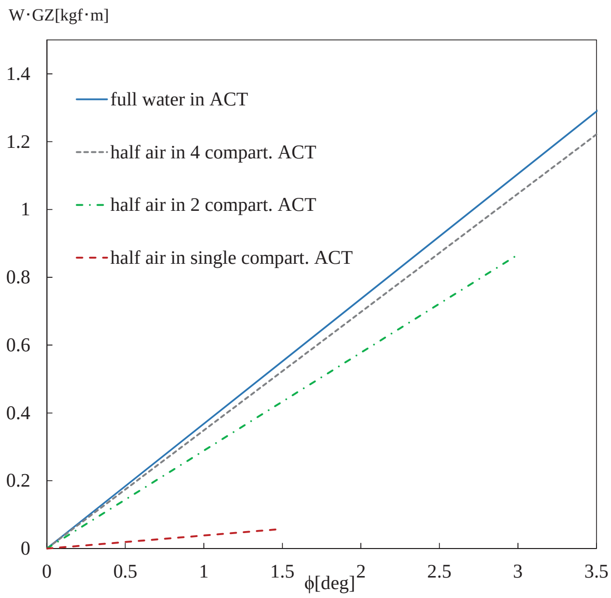

Figure 5 Calculated stability reduction of ACTs with single, two and four compartments.

Model experiments to measure the resistance acting on the model were carried out in a circulating water channel and a towing tank to find a 26% reduction of the frictional resistance in low Froude number (Furuo, A, 2015).

In the present study, roll motions in beam waves are experimentally investigated. The body plan and the principal particulars of the model are shown in Fig. 7 and Table 1. The experimental results are shown in Figs. 8 and 9. The roll damping shown in Fig. 8 demonstrates that the air decreases the damping drastically. It can be seen that the damping for the case of no air in the ACT is much larger than those for the cases of air in the ACT and normal bottom. The increase of the roll damping may be because that the longitudinal walls which divide compartments in ACT works as the same as bilge keels of a ship. Roll amplitudes of the ship in beam waves shown in Fig. 9, however, suggest that the air in the ACT has only slight effects on the roll motions. The peak value at resonance of the case of air in the ACT is slightly larger than that full water in the ACT.

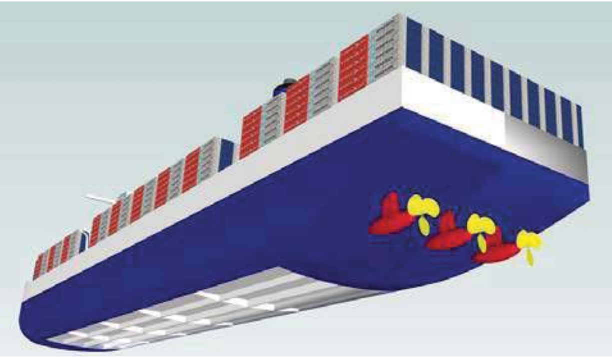

Figure 6 Artist impression of a 20,000TEU container ship with ACT.

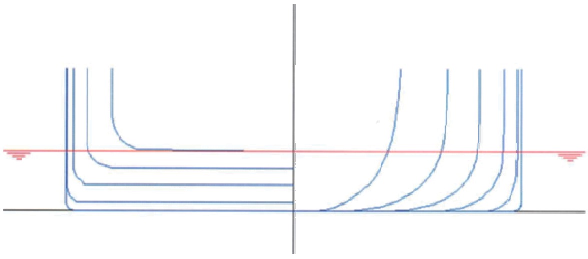

Figure 7 Body plan of the model without ACT

Table 1 Principal particulars of the model of ULCC

Model ship	Loa(m)	2.770
	Lwl(m)	2.670
	B(m)	0.500
	D(m)	0.150
	d(full load)(m)	0.063
	Wetted Surface Area (full load)(m^2)	1.549
	Cb	0.955
Air Circulating Tank	L(m)	2.000
	B'(m)	0.476
	H(m)	0.0125
	Surface Area (m^2)	0.952

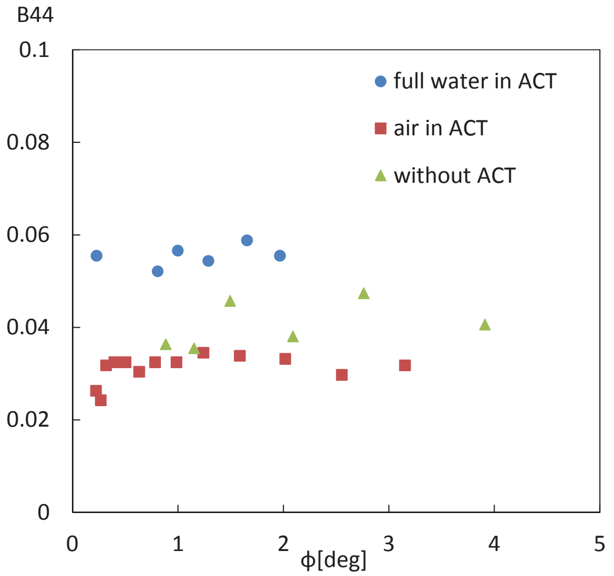

Figure 8 Measured roll damping coefficients by free decay tests

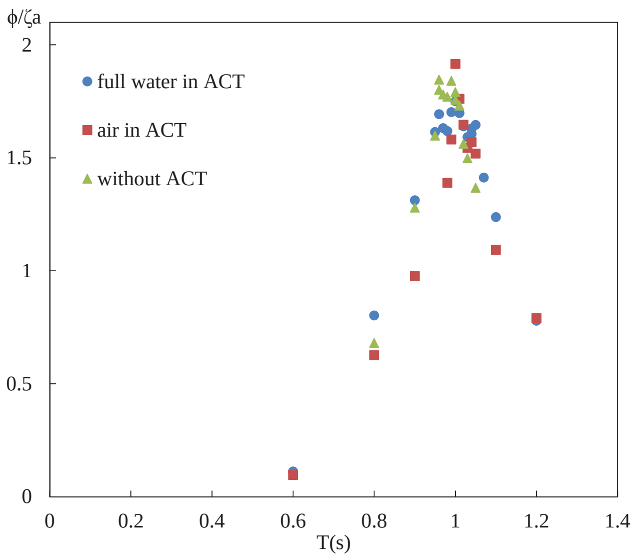

Figure 9 Measured roll amplitudes in beam waves of ULCC model with and without ACT

5. CONCLUSIONS

Effects of air in an air circulating tank (ACT) on the stability and the roll characteristics of a ship are theoretically and experimentally investigated, and following conclusions have been obtained.

1) Air in an air circulating tank of a single compartment reduces the transvers stability, particularly in small heel angle.
2) By dividing the ACT into some transverse compartments, the reduction of the stability decreases. The reduction disappears for four compartments.
3) Effects of the air in ACT on roll motions in beam waves are slight.

6. REFERENCES

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