# Air Pressure Scale Effects during Damage Model Tests

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**Abstract:** The Stability in Waves committee of the 27th ITTC has investigated the significance of scale effects in air pressure on flooding model tests under atmospheric conditions. For this purpose, the committee classified the flooding cases into the trapped air case and vented air cases, and investigated the flooding process for a simple geometry using the state equation of air and the orifice equation. As a result, the committee concluded that the scale effect is large for the case of trapped air and small vent area. For the other cases, the effect is small and can therefore be neglected in the model test of a damaged ship. The committee further proposed some guidelines that can be used to reduce the scale effect of air pressure.

**Key words:** Scale effect of air, damage model test, depressurised wave basin

## 1. Introduction

One of the tasks of the committee on Stability in Waves of the 27th ITTC is to investigate the scale effect due to air pressure on damage model test and to update the ITTC Recommended Procedure 7.5-02-07-04.2 “Model Tests on Damage Stability in Waves”. The procedure provides guidelines for carrying out model tests on a damaged ship in irregular waves to determine the probability of capsizing or the significant wave height that will cause the model to capsize in a fixed time period. If there is a compartment of the model which is not vented, and this compartment has a large effect on damage stability, scale effects due air pressure may be important. However, most damage model tests are carried out in atmospheric conditions. Model testing under scaled air pressure is not customary; there is one facility suited for such tests among the ITTC member facilities. Ypma (2010) reported a comparison of the model test in atmospheric and reduced air pressure conditions and the difficulties of model testing in such conditions.

The Stability in Waves committee has investigated the significance of scale effects in air pressure on flooding model tests under atmospheric condition. For this purpose, the committee classified the flooding cases into the trapped air case and the vented air case, and investigated the flooding process for a simple geometry using the state equation of air and the orifice equation.

In the case of trapped air, the scale effect due to air pressure is significant regardless of the damage opening size. In the case of vented air, the scale effect is dependent of the size of the vent area. The ratio of the vent area to the damage area plays an important role in the flooding process. When this ratio is large, i.e. a large vent area, the scale effect turns out to be small. For the small vent area, the scale effect is large

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during the initial stage, and as time passes the scale effect becomes small. In order to reflect the damage model test procedure, in which the model is initially set in equilibrium condition, the effects of assuming the air compression process to be isothermal or adiabatic were investigated after setting the inner air pressure to be equal to the outside water pressure at the position of damage opening. The scale effect is small in this case for both isothermal and adiabatic processes.

As a result, the committee concluded that the scale effect is large for the case of trapped air and a small vent area. For the other cases, the effect is small and can therefore be neglected during model tests. Furthermore the committee proposed some guidelines that can be used to reduce the scale effect of air pressure.

## 2. Model Test and Scale Factor

Damage model testing is carried out under the Froude hypothesis. If the Froude number is set to be the same in full scale and model test, there is a dynamic similitude. The Froude number,

$$F_n = \frac{V}{\sqrt{gL}} \tag{1}$$

is the ratio of inertia force and gravitational force. Let the scale factor $\lambda$ be the ratio of ship length to model length. Then the physical quantities follow the scale laws below.

$$\frac{L_s}{L_m} = \lambda, \quad \frac{V_s}{V_m} = \sqrt{\lambda}, \quad \frac{t_s}{t_m} = \sqrt{\lambda}$$
$$\frac{\omega_s}{\omega_m} = \frac{1}{\sqrt{\lambda}}, \quad \frac{p_s}{p_m} = \lambda \tag{2}$$

where $L$ is length, $V$ velocity, $t$ time, $\omega$ frequency, $p$ pressure, and the subscript 's' means the full scale ship and 'm' means the model. In order to follow the scale rule, the pressure head of the model should be reduced by 1/λ, and the atmospheric pressure should reduce accordingly.

The water flow through an opening is usually represented by the orifice equation

$$q = C_D \rho_w A \sqrt{2(g\Delta h + \Delta p_a / \rho_w)}, \tag{3}$$

where $C_D$ is the discharge coefficient of the opening, $\rho_w$ the density of water, $A$ the area of opening, $\Delta h$ the difference of water pressure head, $\Delta p_a$ the difference of air pressure in and out. Using water with the same density under the same gravity, the flow rate obeys the scale rule provided that the air pressure follows the scale rule of 1/λ.

The model scale pressure should be 1/λ of the atmospheric pressure in order to maintain dynamic similitude. This is possible only in a depressurised tank facility. Most model basins can only test in atmospheric air conditions, not under scaled air pressure. Figure 1 reveals conceptually the difference in pressure head between the scaled air pressure model test and atmospheric model test.

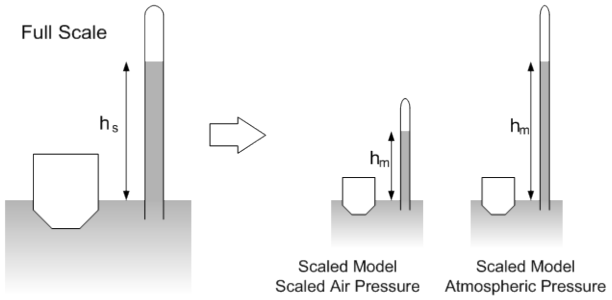


**Figure 1 Concept of scaled model test**

## 3. Scale Effects in Air Pressure

There are some cases in which the flooding of a ship is affected by the air pressure inside the vessel. The main contribution of air pressure takes place in the trapped air case and the vented air case with small vent area. In a model test with a damaged ship, if the air pressure is maintained at atmospheric pressure, then scale effects in air pressure occur.

For the trapped air case, the pressure of the model in atmospheric conditions is higher than in scaled pressure. Therefore, the flooding to that compartment is restricted as shown in the Figure 2.

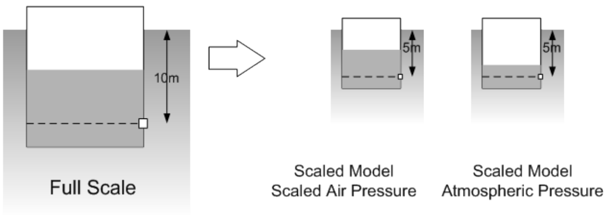


**Figure 2 Flooding in trapped air case**

For the vented air case, the air will be compressed and the internal pressure increases. The pressure in atmospheric conditions is higher than in scaled air pressure, so the flooding speed will be slower than in scaled air pressure. Therefore the following situation will occur, Figure 3.

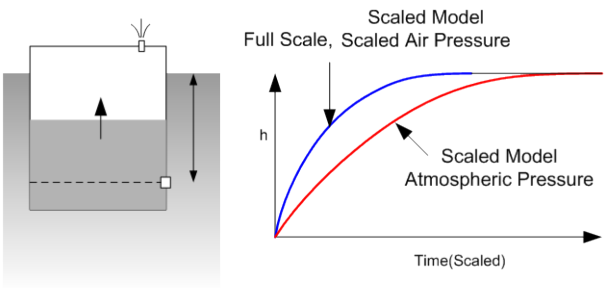


**Figure 3 Flooding in vented air case**

We can simulate the above situation by using the state equation of air.

$$PV^{\gamma} = const. \qquad (4)$$

where $P$ is absolute pressure of the air, $V$ is the volume under consideration, and $\gamma$ is the ratio of specific heat, in the case of air it is 1.0 for an isothermal process and 7/5 for an adiabatic process. The flow through an opening can be estimated by the orifice equation.

Figures 4, 5 and 6 show the water height as a function of the scaled time in the case of trapped air case for a small opening and a large opening in the compartment bottom.

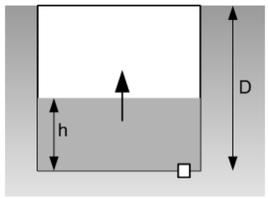


**Figure 4 Schematic drawing for flooding in non-vented air case**

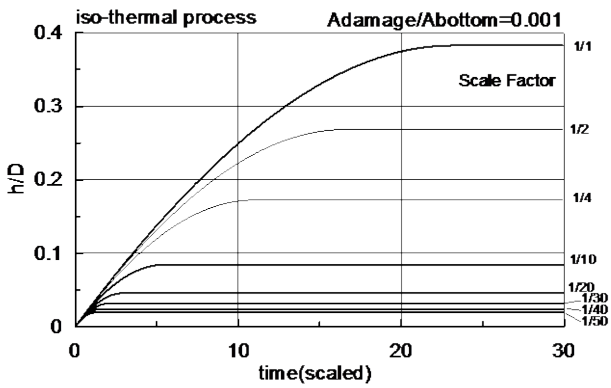


**Figure 5 Flooding in non-vented air case for a small opening**

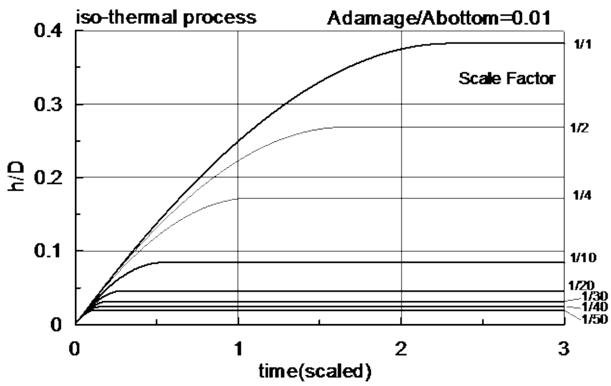


**Figure 6 Flooding in non-vented air case for a large opening**

The above two figures are exactly same except for the time scale. This time scale difference comes from the opening area ratio. As one over the scale ratio becomes small, the final water height reduces also. In this case, the scale effect of air pressure is significant regardless of the damage size.

For the vented case, Figures 7 to 10 show the density ratio of the air and the water height during the flooding process.

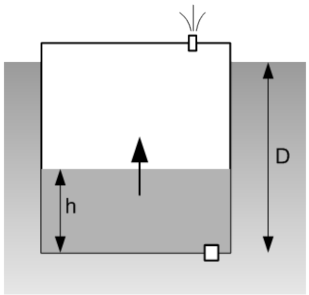


**Figure 7 Schematic drawing for flooding in vented air case**

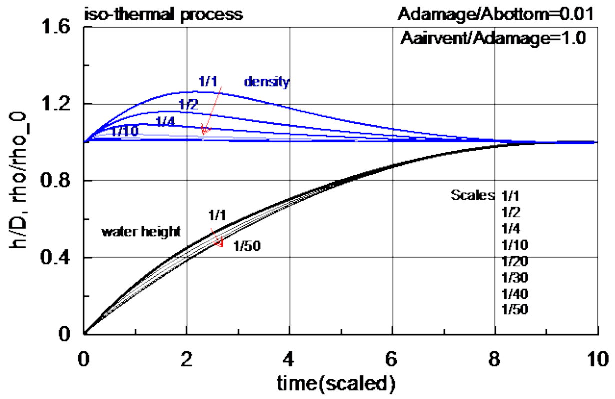


**Figure 8 Flooding in vented air case for a large vent area**

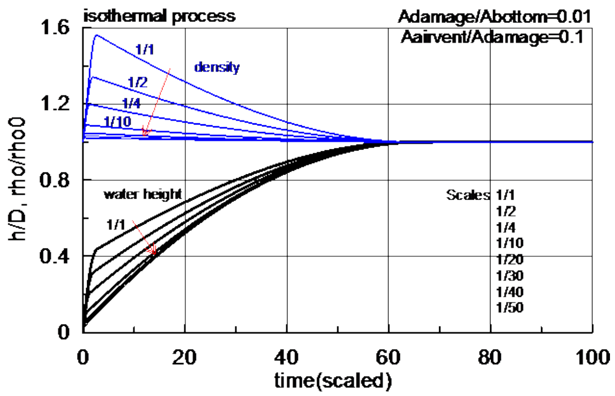


**Figure 9 Flooding in vented air case for a medium vent area**

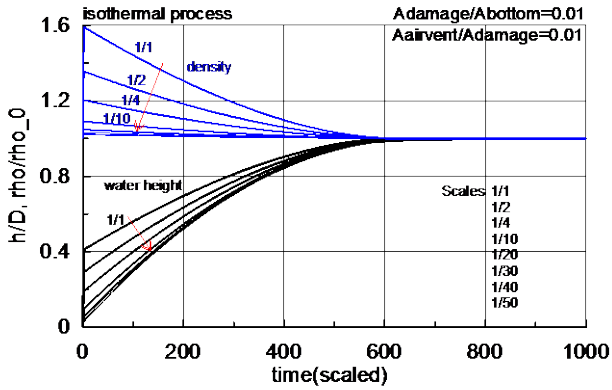


**Figure 10 Flooding in vented air case for a small air vent area**

The ratio of the vent area to the damage area plays an important role in the flooding process. When this ratio is large, i.e. a large vent area, the scale effect turns out to be small. For the small vent area, the scale effect is large during the initial stage, and as time passes the scale effect becomes small.

In order to reflect the damage model test procedure in which the model is initially set in equilibrium condition, the effects of assuming the air compression process to be isothermal or adiabatic can be simulated after setting the inner air pressure to be equal to the outside water pressure at the position of damage opening. For this purpose, the pressure of the compartment is set to the outside water pressure initially for the vented case. Figures 11 and 12 show the flooding process of the isothermal and adiabatic processes, respectively.

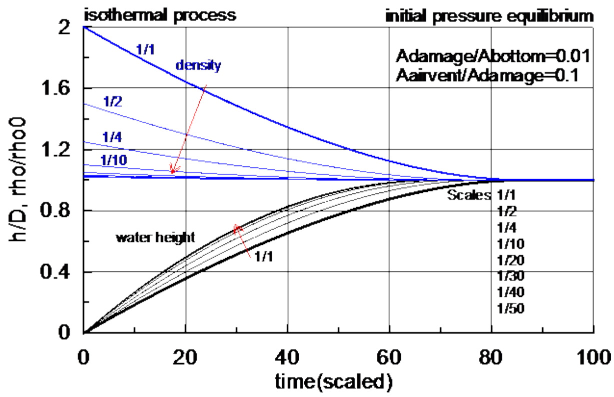

**Figure 11 Flooding for the isothermal process; when the air pressure was initially balanced.**

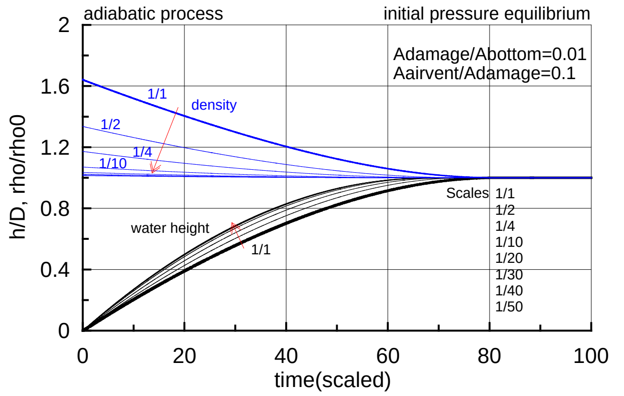


**Figure 12 Flooding for the adiabatic process; when the air pressure was initially balanced.**

If the flooding speed is low, the air compression process will be isothermal, and if the speed is high the adiabatic process can be applied. When a damaged ship with a large damage opening floats in waves, the flooding due to wave and ship motion is relatively fast, so an adiabatic process takes place in the air compression process. The Figures 11 and 12 show that then the scale effect is not large.

In line with the above discussion, it can be concluded that the scale effect is large for the case of trapped air and a small vent area. For the other cases, the effect is small and can therefore be neglected in the model test of a damaged ship.

In atmospheric conditions, it is possible to use alternative methods to reduce the scale effect due to the air pressure. For the case of a small vent area, the vent opening can be enlarged to an appropriate size in order to reflect the inflow and outflow of the full scale situation. For the case of trapped air, a simple solution would be to attach a balloon or a flexible membrane to the compartment in order to reduce the scale effect of air pressure, and to obtain realistic flooding results in the test condition.

## 4. Conclusions

In summary, if the damage opening is large and the compartment is well vented the scale effect of air pressure will be small, and model tests in atmospheric conditions are suitable. The scale effect will be large in the trapped air case and small vent area case. In that situation, if precise and accurate test results are required, the use of pressure regulation values on the compartments to control the internal pressure or model tests in a depressurised model basin are solutions. As a minimum, in the case of model tests under atmospheric conditions modifications are recommended to reduce the scale effects.

The ITTC model test procedure for damage stability experiments was updated to reflect the above discussion.

## Acknowledgments

The aim of this paper is to introduce the work of ITTC Stability in Waves committee on the damage model test. The present paper is based on the SiW report to the 27th ITTC.

## References

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