

1. SIMULATION OF SHIP HANDLING

1.1 Scaling down the ship's geometry

Model tests are widely used for solving problems of ship's manoeuvrability. The behaviour of a model and a full-scale vessel will be the same only when so called similitude criteria are satisfied.

First of all the geometric similitude criteria must be satisfied. It means that the ratio of all linear dimensions of the full-scale vessel to the corresponding dimensions of the model must be satisfied and equal to scale (fig. 1-1):

$$\frac{L_{\text{ship}}}{L_{\text{model}}} = \frac{B_{\text{ship}}}{B_{\text{model}}} = \frac{X_{\text{ship}}}{X_{\text{model}}} = \text{scale}$$

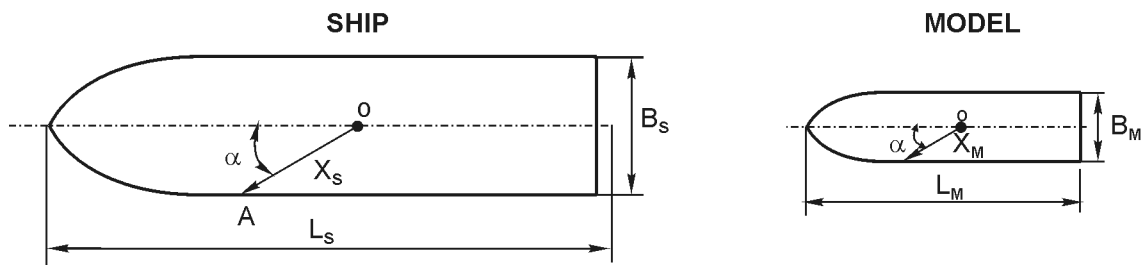


Fig. 1-1

It results from the above figure that corresponding angles for the model and the full-scale vessel have the same value.

Of interest will be also the knowledge of relationship between any surface for a model and a ship. For example, a full-scale vessel rudder area is: $A_{RS} = H_S \cdot C_S$ and a model rudder area is: $A_{RM} = H_M \cdot C_M$ (fig. 1-2).

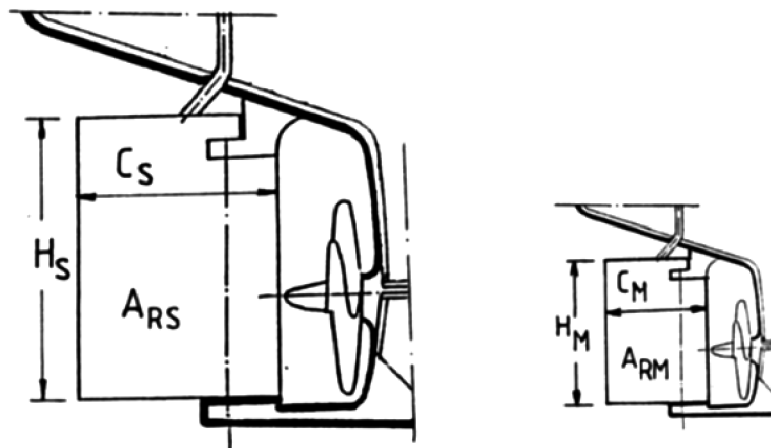


Fig. 1-2: Comparison of rudder areas for a ship and a model

From the geometric similitude criteria, we have: $\frac{H_S}{H_M} = scale$ and $\frac{C_S}{C_M} = scale$.

Hence the following ratio of ship and model rudder areas:

$$\frac{A_{RS}}{A_{RM}} = \frac{H_S \cdot C_S}{H_M \cdot C_M} = scale \cdot scale = scale^2$$

The same procedure can be extended over calculation of corresponding weight.

A ship weight is: $\Delta_S = \rho_S \cdot C_{BS} \cdot L_S \cdot B_S \cdot T_S$

A model weight is: $\Delta_M = \rho_M \cdot C_{BM} \cdot L_M \cdot B_M \cdot T_M$

Then we can write: $\frac{\Delta_S}{\Delta_M} = \frac{\rho_S \cdot C_{BS} \cdot L_S \cdot B_S \cdot T_S}{\rho_M \cdot C_{BM} \cdot L_M \cdot B_M \cdot T_M}$

Where: ρ_S, ρ_M - salt and fresh water densities;
 C_{BS}, C_{BM} - block coefficients for a ship and a vessel

Assuming that $C_{BS} = C_{BM}$ (geometric criteria- the same form of hulls for a full-scale ship and a model) and neglecting differences in salt water and fresh water densities we obtain:

$$\frac{\Delta_S}{\Delta_M} = \frac{L_S \cdot B_S \cdot T_S}{L_M \cdot B_M \cdot T_M} = scale \cdot scale \cdot scale = scale^3$$

1.2 Scaling down forces acting on the ship

When a ship is moving through the water, a characteristic flow pattern is creating. This flow pattern can be observed as a system of waves generating by moving hull, and so called boundary layer along the hull.

It is obvious that for a good reproducing of ship's behaviour, flow patterns for a model and a full-scale vessel must be similar (fig. 1-3). The above requirement is called kinematic criteria and is satisfied when forces acting on a ship are similar.

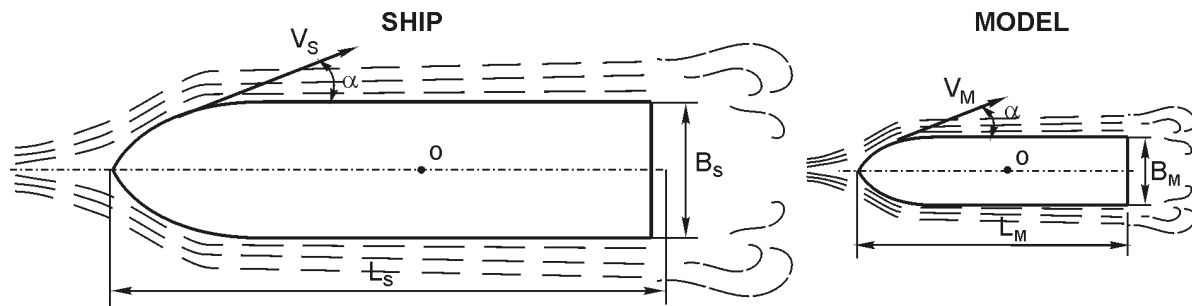


Fig. 1-3

When analysing manoeuvrability of ships, two kinds of forces have to be taken into account:

- **Frictional forces**
- **Gravity forces**

Frictional forces are proportional to velocity-squared, wetted surface and friction coefficient.

Governing law: *REYNOLD'S law*

REYNOLD'S law: Reynolds numbers for the ship and its model have to be equal:

$$\frac{V_S \cdot L_S}{\nu_S} = \frac{V_M \cdot L_M}{\nu_M}$$

where ν is kinematic viscosity coefficient.

$$Re_{SHIP} = Re_{MODEL}$$

Gravity forces are proportional to mass of the ship and velocity-squared.

Governing law: *FROUDE'S law*

FROUDE'S law: Froude's numbers for the ship and its model must be equal:

$$\frac{V_S}{\sqrt{g \cdot L_S}} = \frac{V_M}{\sqrt{g \cdot L_M}}$$

where g is the acceleration due to gravity.

$$Fn_{SHIP} = Fn_{MODEL}$$

Neglecting differences between viscosity for sea and fresh water (for ship and model), we get for HAWA models:

$$V_M = V_S \cdot Scale = V_S \cdot 24 \quad \text{according to Reynolds identity}$$

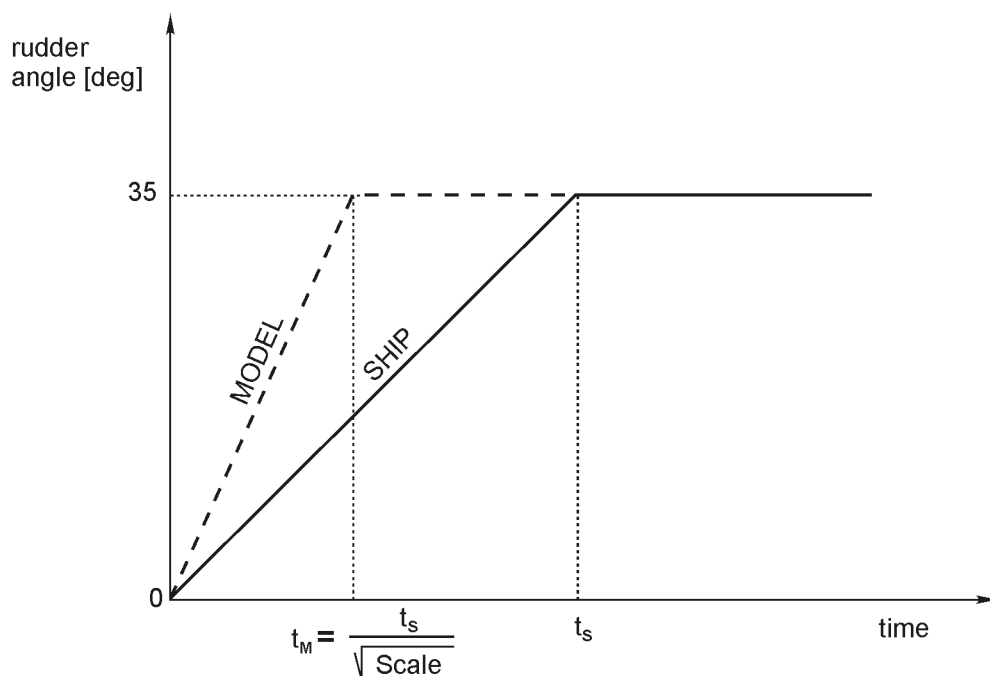
and

$$V_M = \frac{V_S}{\sqrt{scale}} = \frac{V_S}{24} \quad \text{according to Froude identity}$$

From the above formulas results that only modelling of dynamic similitude according to Froude's law is possible. Reynolds law cannot be satisfied. This results in "scale effect", which is very small and can be neglected or very easily compensated if models are large.

Table 1: relationship between geometric and kinematic parameters for Froude identity

<i>Item</i>	<i>Value of ship / model ratio</i>
Length, Beam, Draft, Turning, Diameter, Stopping, Distance, and other linear dimensions	scale
Windage, Rudder area, etc	scale ²
Volume, Displacement, Force	scale ³
Speed	scale ^{1/2}
Angle	1
Rate of Turn	1/scale ^{1/2}
Time	scale ^{1/2}

**Fig. 1-4 History of rudder deflection for a ship and a model**

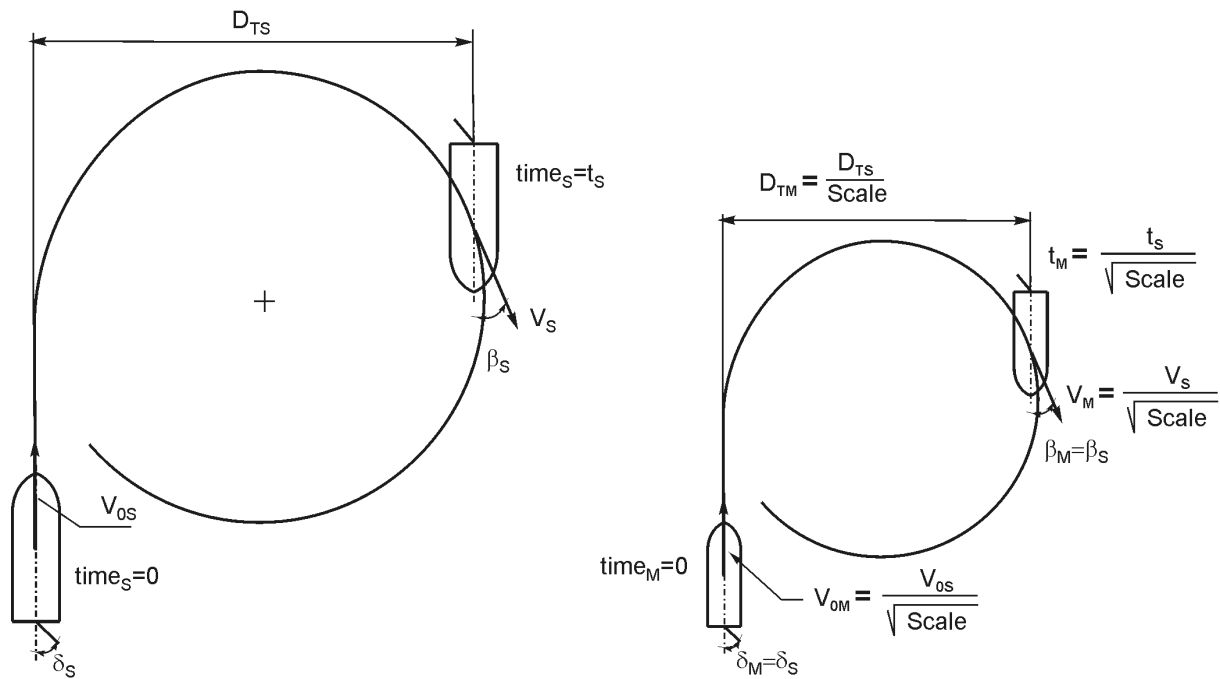


Fig. 1-5 Comparison of a turning manoeuvre for a model and a ship it reproducing

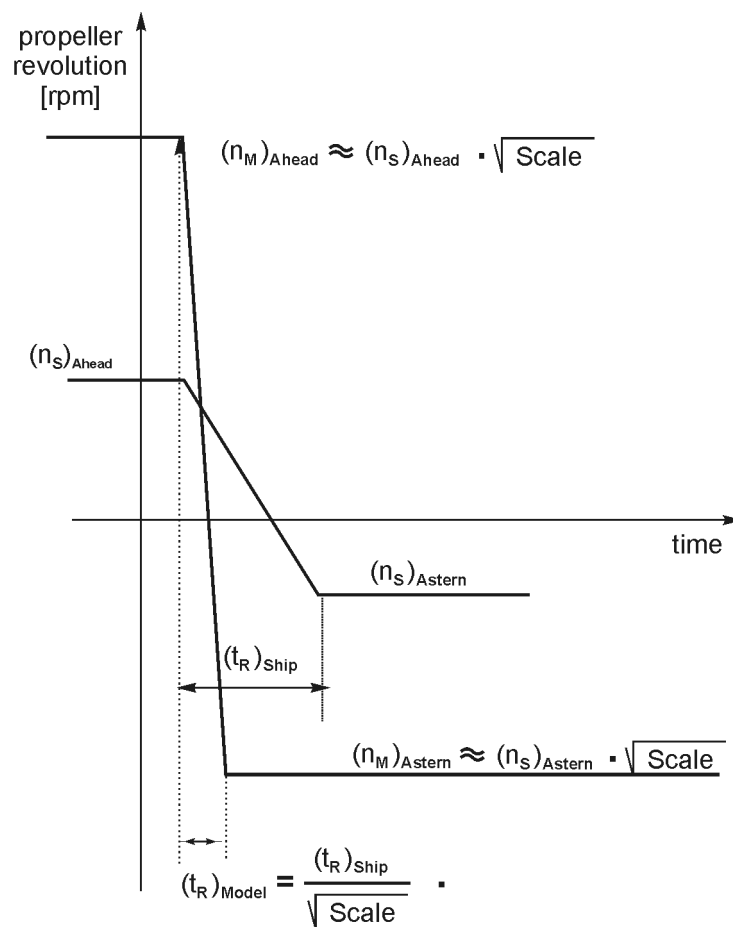


Fig. 1-6 Reversing of engine for a ship and a model