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# Design of the natural ventilation system for the fishing vessel by the CFD methods

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**Key words:** fishing vessel, stern trawler, aerodynamics, ventilation, computational fluid dynamics

### Abstract

In this paper, application of the computational fluid dynamics has been presented in the process of design natural ventilation system for the fishing vessel. There are two main types of ventilation systems: natural ventilation which is used on small fishing vessels and sport craft boatsand, and forced ventilation. This type of ventilation is a common solution on all types of merchant ships. In this paper, solution of the velocity filed in the cargo hold space of the fishing vessel had been presented. Natural ventilation system has been validated using the CFD (Computational Fluid Dynamics). All calculations had been performed in the free CFD software called OpenFOAM.

## Introduction

Ventilation of merchant vessel is an important factor for the safety of navigation. Shipped cargo and good can emit harmful vapors and odors, danger for the crew, and possibly exploding gases can accumulate in the cargo hold space.

Cargo hold should be properly ventilated. There are two main types of ventilation systems [1]: natural ventilation and forced ventilation. Natural ventilation is the simplest way of providing fresh air to the given space. Air is exchanged by the difference in pressure and temperature. When the ventilated object moves, the relative motion of air gives the ventilation effect [2]. This type of ventilation is used on small fishing vessels and sport craft boats [2, 3]. Positions of the inlets and outlets, their shape and size should be determined during design of the natural ventilation system.

Forced ventilation is based on axial fans and air ducts. Fans are closed in so called fan room, from where, air is pushed through the air ducts to the rooms and holds [1]. Forced ventilation system is a common solution on all types of merchant ships, from medium fishing vessels to specialized reefers.

In this paper, solution of the velocity filed in the cargo hold space of the fishing vessel has been presented. Natural ventilation system has been validated using the CFD (Computational Fluid Dynamics).

All calculations has been performed in the free CFD software called OpenFOAM.

## Computational model of the cargo hold and superstructure

RANSE (Reynolds Averaged Navier Stokes Equations) method was used to obtain the velocity filed in the cargo hold and around superstructure. The $k$–$\varepsilon$ was used to model the turbulences, coefficients related to this model can be found in [4]. RANSE equation solved in the OpenFOAM system is shown below (1):

$$\frac{\partial V_i}{\partial t} + \frac{\partial V_i V_j}{\partial x_j} = F_i + \frac{1}{\rho}\frac{\partial \tau_{ij}}{\partial x_i} \tag{1}$$

where $\tau_{ij}$ is a tensor of mean stresses (2):

$$\tau_{ij} = -P\delta_{ij} + \mu\left(\frac{\partial V_i}{\partial x_j} + \frac{\partial V_j}{\partial x_i}\right) + \bar{\tau}_{ij} \tag{2}$$

where:
$\delta_{ij}$ – Kronecker delta;
$P$ – pressure;
$\mu$ – dynamic viscosity;
$\bar{\tau}_{ij}$ – turbulent stress tensor.

Table 1. Boundary conditions for the cargo hold computation

| Boundary name | Velocity | Pressure | Turbulent kinetic energy *k* | Dissipation rate *ε* |
|---|---|---|---|---|
| Inlet | fixedValue | zeroGradient | fixedValue | fixedValue |
| Outlet | zeroGradient | fixedValue | zeroGradient | zeroGradient |
| Walls | fixedValue | zeroGradient | kqrWallFunction | epsilonWallFunction |

Table 2. Boundary conditions for the superstructure computation

| Boundary name | Velocity | Pressure | Turbulent kinetic energy *k* | Dissipation rate *ε* |
|---|---|---|---|---|
| Inlet | fixedValue | zeroGradient | fixedValue | fixedValue |
| Outlet | zeroGradient | fixedValue | zeroGradient | zeroGradient |
| Base | slip | slip | slip | slip |
| Far field | | | | |
| Atmosphere | | | | |
| Symmetry plane | symmetryPlane | symmetryPlane | symmetryPlane | symmetryPlane |
| Hull | fixedValue | zeroGradient | kqRWallFuntion | epsilonWallFunction |

The simulation was set to steady state mode, fluid was incompressible and its kinematic viscosity and density were set to the air at the sea level. Newtonian model of the fluid was selected [5]. Velocity of the air around superstructure and on the inlets of ventilation ducts were set to the value of eleven knots. The scale of the simulation, lambda, was set to 25. Cargo hold during the simulation is empty, only air flows through. Boundary conditions linked to the variables of simulation are presented in tables 1 and 2. Definition of the implemented boundary condition can be found at [6].

## Numerical grid

Calculation of the general velocity field around the superstructure of the B410 vessel was the first step to obtain the velocity filed inside the cargo hold. This general velocity field provided some hints about the positions, of the future ventilation inlets. Hull presented in figure 1 was used to generate mesh for the external aerodynamic simulation.

Fig. 1. B410 hull used in computations

OpenFOAM is based on hexahedron shaped cells [7], so this type of mesh was created around model of the hull B410. Lower boundary of the domain was set to the draught level of the vessel, and in this type of simulation it was a rigid wall. Symmetry plane was used to save computational cells. Appropriate refinement of the cells around superstructure was used to obtain better results of computations. Dimensions of the domain can be found in table 3.

Table 3. External aerodynamics domain dimensions

| Length of domain along X axis [m] | Length of domain along Y axis [m] | Length of domain along Z axis [m] | Number of cells |
|---|---|---|---|
| 5 | 2 | 1 | 1 212 824 |

Mesh for the external air flow simulation is presented in figures 2 and 3.

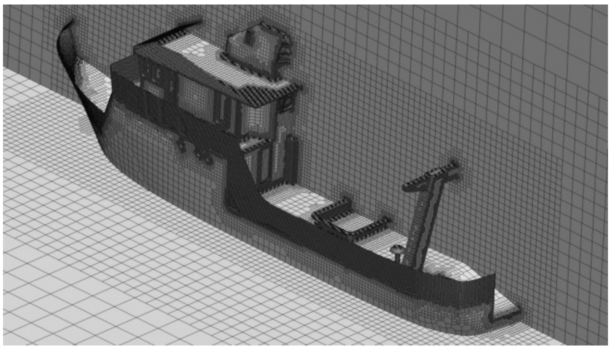

Fig. 2. Superstructure mesh used in external aerodynamics computations

Grids used in internal flow simulation inside cargo hold were made from hexahedron cells. Three variants of the inlet position were considered. All meshes were built from around 250,000 elements. Outlets of the ventilation ducts were fixed in the same position for three variants. Hatch and inside construction of the hold has been omitted.

Table 4. Characteristics of the cargo hold variants. Model scale

| Variant | Crosssectional area of inlet channel [m$^2$] | Crosssectional area of outlet channel [m$^2$] | Crosssectional area of inlet [m$^2$] | Crosssectional area of outlet [m$^2$] | Volume of fish cargo hold [m$^3$] |
|---|---|---|---|---|---|
| A | 0.00005008 | 0.00005008 | 0.00014174 | 0.00015024 | 0.00512 |
| B |  |  | 0.00042193 |  |  |
| C | 0.000128 |  | 0.00080128 |  |  |

Variants were named: A, B and C. In table 4, their characteristics can be found. Drafts of variants are shown in figures 4, 5 and 6, computational mesh of the variant C is shown in figure 7.

Inlet of the ventilation system of the variant A was set in the chimney of the vessel. One channel with a diameter of 200 mm was used at the inlet to hold.

Inlet in the variant B was moved to the front wall of the superstructure. In the last variant, two independent inlets were mounted with the rectangular cross section shape.

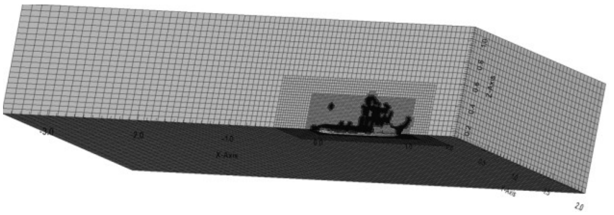

Fig. 3. Overall view of external aerodynamics mesh

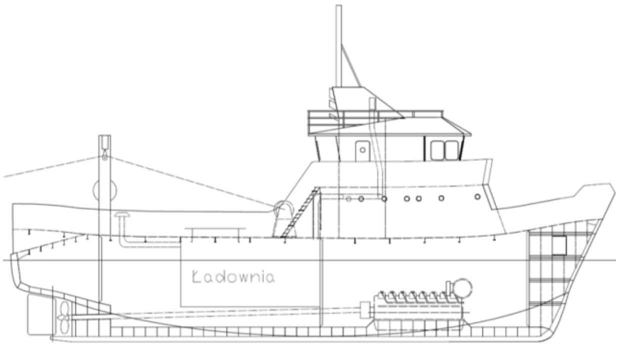

Fig. 4. Variant A of cargo hold

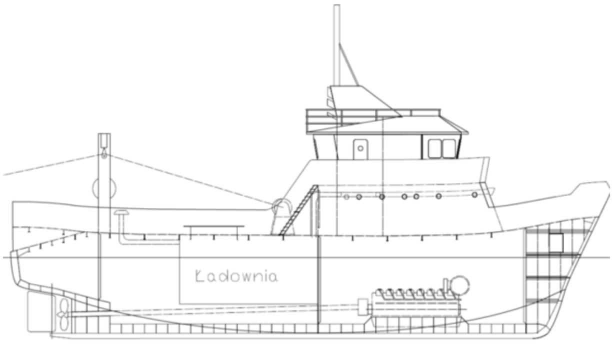

Fig. 5. Variant B of cargo hold

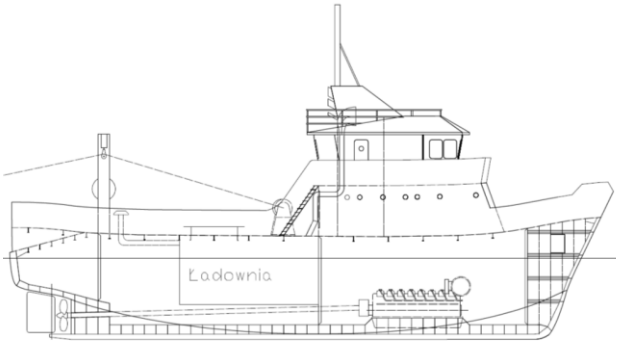

Fig. 6. Variant C of cargo hold

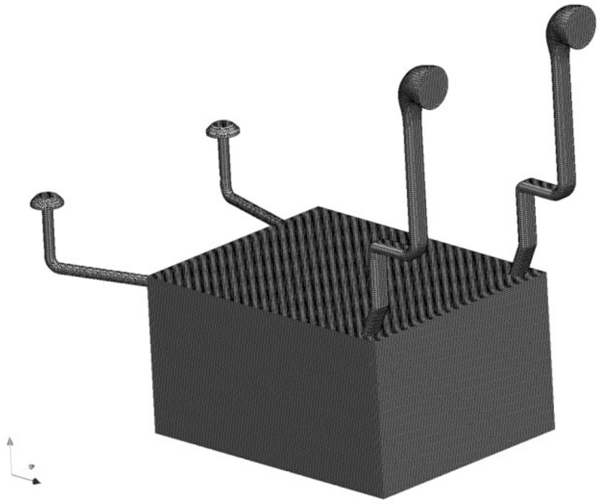

Fig. 7. Computational grid of the cargo hold, variant C

## Results of the numerical computations

General velocity field is shown in figure 8. Streamlines are shown in figure 9. After this simulation, positions of the inlets were determined. Position located on the main deck was excluded from the further analyses.

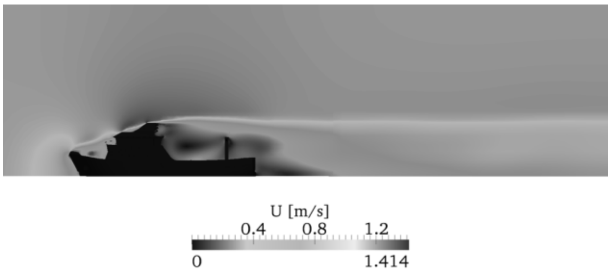

Fig. 8. Velocity field around superstructure. Model scale

In the cargo hold, air should change five times per hour. In the model scale this value is equal to 0.0256 [m$^3$/h]. This condition can be checked by calculating the flow rate in the inlet duct. Streamlines can be helpful in determining the good solution of the natural ventilation system. The streamlines inside the cargo hold for the three variants are shown in figures 10, 11 and 12. Flow rate in the inlet ducts can be found in table 5.

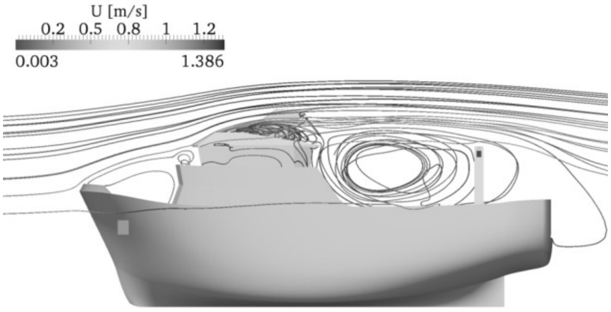

Fig. 9. Streamlines around superstructure. Model scale

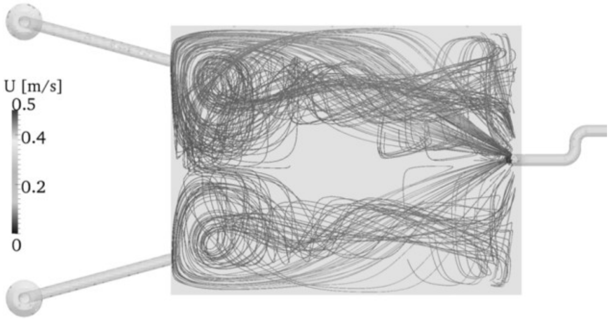

Fig. 10. Streamlines in cargo hold. Variant A

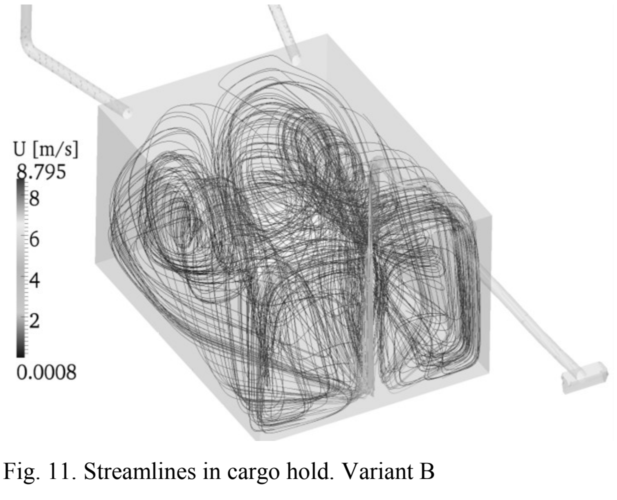

Fig. 11. Streamlines in cargo hold. Variant B

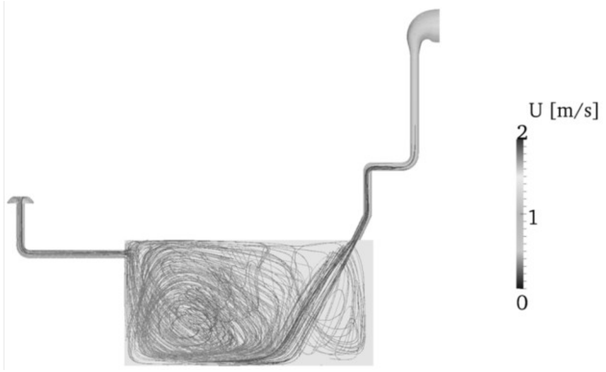

Fig. 12. Streamlines in cargo hold. Variant C

Table 5. The flow of cargo hold through the inlet channels. Model scale

| Variant | Inlet flowrate [m$^3$/h] |
|---|---|
| A | 0.576 |
| B | 1.26 |
| C | 6.516 |

As shown in figure 12, when the duct is not perpendicular to the upper side of the cargo hold, the flow is better distributed than in other variants.

## Conclusions

CFD method can be very helpful in choosing the best option during design process of the ventilation system. Natural ventilation system has no power demands, so saved energy and may be used for other vessels purpose.

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