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Contributions to the optimization of air flow in machinery room ventilation systems for special ships

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Abstract. Numerical analyses can demonstrate the poor performance of obsolete ventilation systems and the need to replace or improve them. At the same time, given the destination of the ship that can operate in extreme climates, an efficient ventilation system for machinery rooms is vital. It has been shown in numerous scientific studies that the dispersion and accumulation of gases in the machinery room depends on multiple parameters and under the influence of the temperature gradient and its chemical characteristics, it tends to accumulate in the upper areas of the compartment. Therefore, the flow rate of the ventilation extraction system must be approximately 107 [%] of the flow rate of the air intake system according to the English standard NES 102 [1]. During the study, modelling and simulation were performed with the help of an Engineering Simulation Software to explore and predict how systems will behave in the real world.
Keywords: air, ventilation, heat, flow, machinery room

1. Introduction

This paper emphasizes the idea that computer programs that model physical processes can be used for scientific purposes to research different solutions with direct applications in the naval field. In the modelling process, certain variables/parameters are associated with the system components, some known (controllable), called input variables/parameters, others unknown (uncontrollable), called output variables/parameters.

Connections and interactions between system components with the exterior medium are translated into the model through functional relationships. Thus, the air flow inside the ventilation system related to the machinery room, where the ventilation requirement is very high, was studied using mathematical calculation techniques and a computer modelling program referring to a real ventilation system onboard a reference ship.[2][3]

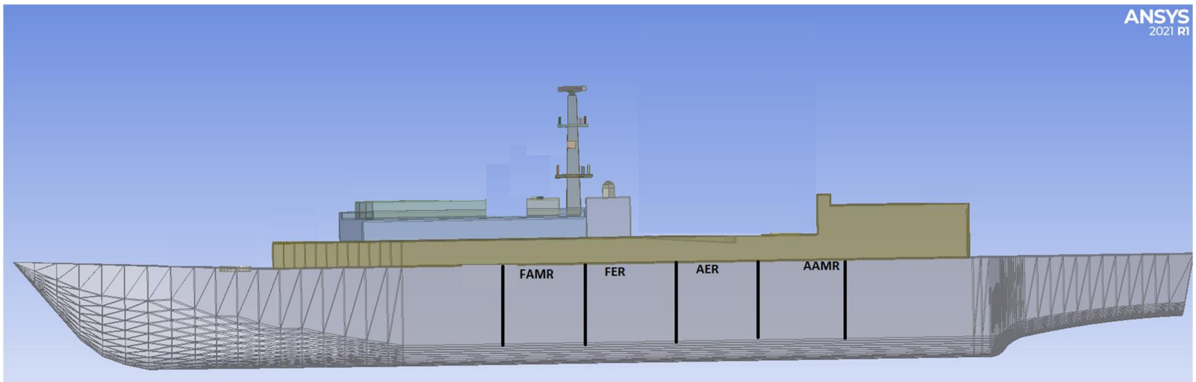

Figure 1. Special ship with machinery rooms [4]
AMRF –auxiliary machinery room forward, ERF –engine room forward, ERA –engine room aft, AMRA – auxiliary machinery room aft

2. General characteristics of the forward auxiliary machinery room

To accomplish this paper, It was taken as a reference a special ship with 4 machinery rooms. Each of the machinery compartments (auxiliary machinery room forward, auxiliary machinery room aft, engine room forward, engine room aft) are ventilated with 2 air intake fans and 2 exhaust fans.[5] When the ship sails in a contaminated atmosphere (special sea conditions), the air in the auxiliary engine room is recirculated through air coolers by inlet fans to cool all the inside volume. At the same time, air conditioning can be introduced into the engine rooms directly from inside the ship using removable flaps and ensuring the cooling of the compartments.[6] For the special ship, in accordance with classification societies, the flow rate of the exhaust fans must be higher than the flow rate of the intake fans to ensure the extraction of gas and smoke from the compartment and to ensure the cooling of the exhaust manifolds. It was taken as a study the forward auxiliary machinery room as displayed in figure no. 2. For this ship compartment there are 2 ventilation fans of 28746 $\left[\frac{m^3}{h}\right]$ intake air flow and 2 ventilation fans of 32716 $\left[\frac{m^3}{h}\right]$ exhaust air flow. As is shown in figure no. 2, the forward auxiliary machinery room has 2 ventilation systems for 2 Paxman Ventura diesel generators of 1000 [kW] power each which produces heat in operation.[7][13]

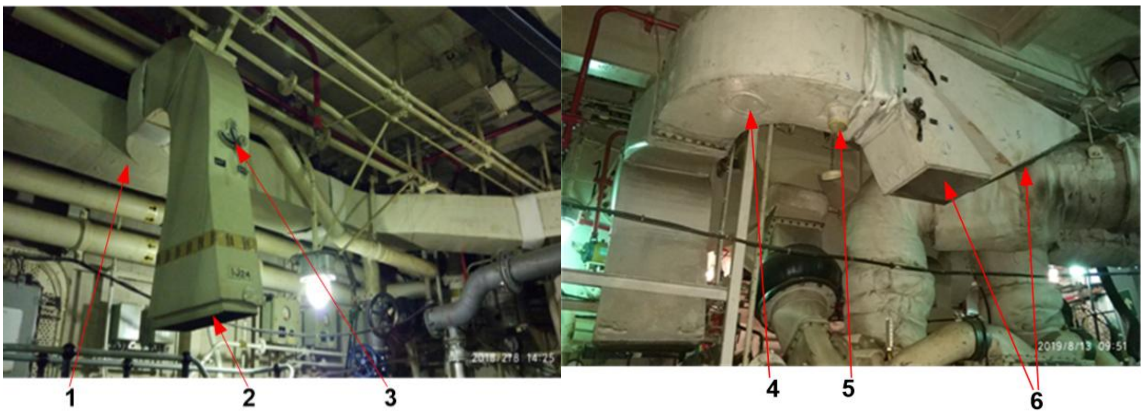

Figure 2. Forward auxiliary machinery rooms ventilation system layout [real images onboard particular ship]
1 – split in ventilation system, 2 – exhaust area, 3 – open/closed lever, 4 – removable cover, 5 – drain pipe, 6 – exhaust area

3. Calculation of the air flow required to evacuate the heat flow from the forward auxiliary machinery room

The air flow required to take out the heat from the machinery space $\left[\frac{m^3}{s}\right]$ has the formula:

$$\dot{V}_{air} = \frac{\dot{Q}_{dp}+\dot{Q}_{dg}+\dot{Q}_{b}+\dot{Q}_{p}+\dot{Q}_{g}+\dot{Q}_{el}+\dot{Q}_{ep}+\dot{Q}_{t}+\dot{Q}_{o}}{\rho \cdot c \cdot \Delta T} - 0.4 \cdot (V_{dp} + V_{dg}) - V_b \left[\frac{m^3}{s}\right] \quad (1)$$

[5]

where:

- $\dot{Q}_{dp}$- is the energy flow for main propulsion engines [kW];
- $\dot{Q}_{dg}$- is the energy flow for diesel generators [kW];
- $\dot{Q}_{b}$- is the energy flow for boilers and heat exchangers [kW];
- $\dot{Q}_{p}$- is the energy flow from steam and condense pipes [kW];
- $\dot{Q}_{g}$- is the energy flow for air-cooled electric generator [kW];
- $\dot{Q}_{el}$- is the energy flow from electric systems [kW];
- $\dot{Q}_{ep}$- is the energy flow from exhaust pipes [kW];
- $\dot{Q}_{t}$- is the energy flow from heated tanks [kW];
- $\dot{Q}_{o}$- is the energy flow from other systems [kW];
- $\dot{V}_{dp}$- is air flow for main engines combustion process $\left[\frac{m^3}{s}\right]$;
- $\dot{V}_{dg}$- is air flow for auxiliary engines combustion process $\left[\frac{m^3}{s}\right]$;
- $\dot{V}_{b}$- is air flow for auxiliary boiler combustion process $\left[\frac{m^3}{s}\right]$;
- ρ =1.16 $\left[\frac{Kg}{m^3}\right]$ – is air density at temperature of +35 [ºC], 70 [%] relative humidity and 101.3 [kPa] pressure;
- $c = 1.01 \left[\frac{kJ}{KgK}\right]$- air specific heat;
- $\Delta T = 12.5\, K$- is the raise of machinery room temperature or difference between inlet and outlet temperature measured on exhaust pipes.[5]

In formula no. 1 we will not consider the last part of the formula for the air flow used for combustion because for the reference ship there are separate pipes for combustion that communicate with the atmosphere. In the forward auxiliary machinery room, there are no propulsion engines, auxiliary boilers, steam pipes and heated fuel tanks. In the machinery room there are other electrical equipment such as 2 sea water pumps and 2 air conditioning plants. The heat emitted represents 20% of the electrical power of the equipment when the ship is on the sea. The heat flux emitted by the exhaust pipes of diesel engines is extracted from the graph in figure no. 3 according to ISO 8861 and depending of the exhaust manifolds diameter and length. For 4-stroke engines, we take Δt = 350 [K].

Table 1. Calculation of air flow required for heat exhaust from machinery room [8] [12]

Current no.	Parameter	Calculation relation	Numerical value	unit
1.	Standard service power of diesel generator at maximum continuous power	P_{dg}	1000	[kW]
2.	Thermal flow from diesel generator	$\dot{Q}_{dg} = 0.396 \cdot P_{dg}^{0,7}$	49.85	[kW]
3.	Installed power of air cooled generator	P_g	1000	[kW]

4.	Generator efficiency	η	94	[%]
5.	Thermal flow from the electric generator	$\dot{Q}_g = P_g \cdot \left(1 - \frac{\eta}{100}\right)$	60	[kW]
6.	Power of electrical plants from the machinery room	P_{el}	50	[kW]
7.	Thermal flow from electrical plants in the machinery room	$\dot{Q}_{el} = 0.2 \cdot P_{el}$	10	[kW]
8.	Length of exhaust pipes	$l_{tubev} = 10\ [m]$	10	[m]
9.	Dissipated heat from exhaust pipes	$q_{tubev} = 0.4 \left[\frac{kW}{m}\right]$	0.4	$\left[\frac{kW}{m}\right]$
10.	Thermal flow from exhaust pipes	$\dot{Q}_{tev} = l_{tubev} \cdot q_{tubev}$	4	[kW]
11.	Air flow required for removing the heat from the machinery room	$\dot{V}_{aer} = \frac{2\dot{Q}_{dg} + 2\dot{Q}_g + \dot{Q}_{el} + 2\dot{Q}_{tev}}{\rho \cdot c \cdot \Delta T}$	16.91	$\left[\frac{m^3}{s}\right]$

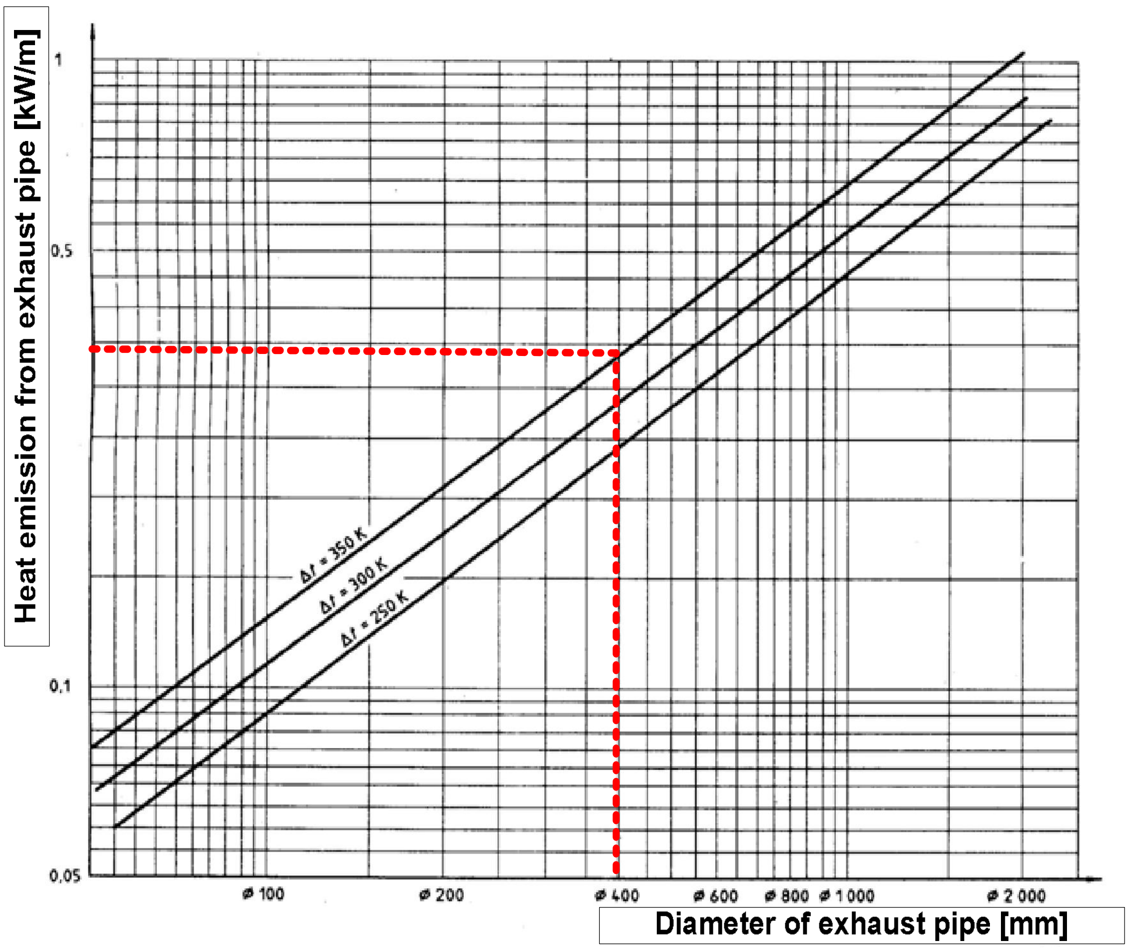

Figure 3. Graph for calculation of exhaust pipes heat flow [8]

4. Simulation and optimization of machinery room ventilation

The model, an isomorphic representation of reality, provides an intuitive, rigorous image in the sense of the logical structure of the phenomenon being studied, and enables the discovery of links and legacies that are difficult to establish in other ways.

The results provided by the calculation and verification algorithm of the ventilation system were achieved numerically with the help of the Fluent program developed by Ansys. CFD is a numerical technique for solving problems involving fluid flow. This involves flow algorithms, turbulence modelling, time integration schemes, stability algorithms and more. In short, CFD refers to solving Navier-Stokes equations. The Fluent program is used for a wide variety of engineering applications such as modelling heat transfer and phase mixing through or around bodies with different geometries, modelling fluid flow, etc.

4.1. Numerical model and limit conditions

The air flow and temperature distribution on the ventilation system of the machinery compartment are leaded by the laws of conservation of mass, momentum and energy. The finite element method was used to discretize the geometry system. The flow is considered constant, turbulent, incompressible and three-dimensional (3D). The standard k-ε model is used to model turbulent flow to highlight direction lines, velocity, pressure, and temperature fields. The purpose of the paper is to determine the distribution of air velocity and pressure on the ventilation system to optimize the operation of the entire system. The standard model k-ε is based on the model of the equation of motion for kinetic energy (k) and its dissipation (ε). In the equations below we have mass conservation or continuity equation (2), moment equation (3), turbulent kinetic energy equation (4) and energy distribution (5). [9][11]

$$\frac{d\rho}{dt} + \nabla x(\rho\vec{u}) = 0 \tag{2}$$

where ρ $\left[\frac{Kg}{m^3}\right]$– density, t $[s]$– time, u $\left[\frac{m}{s}\right]$– fluid velocity vector;

$$\frac{d\rho}{dt} + \nabla x(\rho uu) = -\nabla p + \rho g + \nabla x(\mu \nabla u) - \nabla x \tau_t \tag{3}$$

where p $[Pa]$– pressure, g $\left[\frac{m}{s^2}\right]$– gravitational acceleration, μ $[Pa \cdot s]$– dynamic fluid viscosity, τ_t- turbulence loading divergence;

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho uk)}{\partial x} = \frac{\partial}{\partial x}\left[\mu + \frac{\mu_t}{Pr_k}\right]\frac{\partial k}{\partial x} + \mu_t G - \rho\varepsilon + S_{k,p} \tag{4}$$

$$\frac{\partial(\rho \epsilon)}{\partial t} + \frac{\partial(\rho u\varepsilon)}{\partial x} = \frac{\partial}{\partial x}\left[\mu + \frac{\mu_t}{Pr_\varepsilon}\right]\frac{\partial \varepsilon}{\partial x} + \frac{\varepsilon}{k}\left[C_1\mu_t G - C_2\rho\varepsilon\right] + S_{k,p} \tag{5}$$

In equations 4 and 5 we have: C_1 and C_2 - empirical constants, P_r - Prandtl number for kinetic energy, S - user-defined source term, G - kinetic energy turbulence calculated in equation 6.

$$G = \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\frac{\partial u_i}{\partial x_j} - \frac{1}{\rho^2}\frac{\partial \rho}{\partial x_j}\frac{\partial \rho}{\partial x_J} - \frac{2}{3}\left(\frac{\rho k}{\mu_t} + \frac{\partial u_i}{\partial x_J}\right)\frac{\partial u_J}{\partial x_j} \tag{6}$$

4.2. Model geometry

The results provided by the calculation and verification algorithm of the ventilation system were achieved numerically with the help of the Fluent program. With the help of the Design Modeler option offered by the Ansys Fluent program, was made the geometric construction of the ventilation section. For this simulation, we built the configuration of the ventilation system corresponding to the forward auxiliary machinery compartment for the special ship taken as reference according to figures 4 and 5.

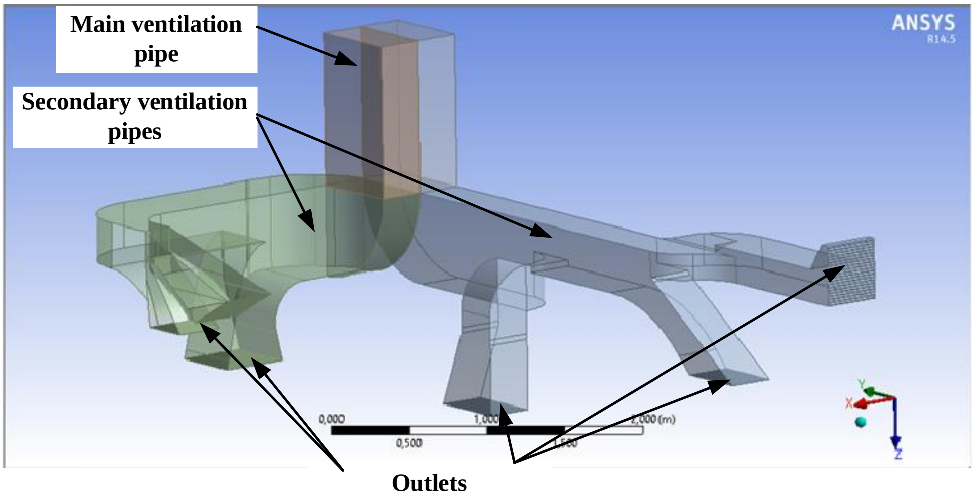

Figure 4. Ventilation system geometry

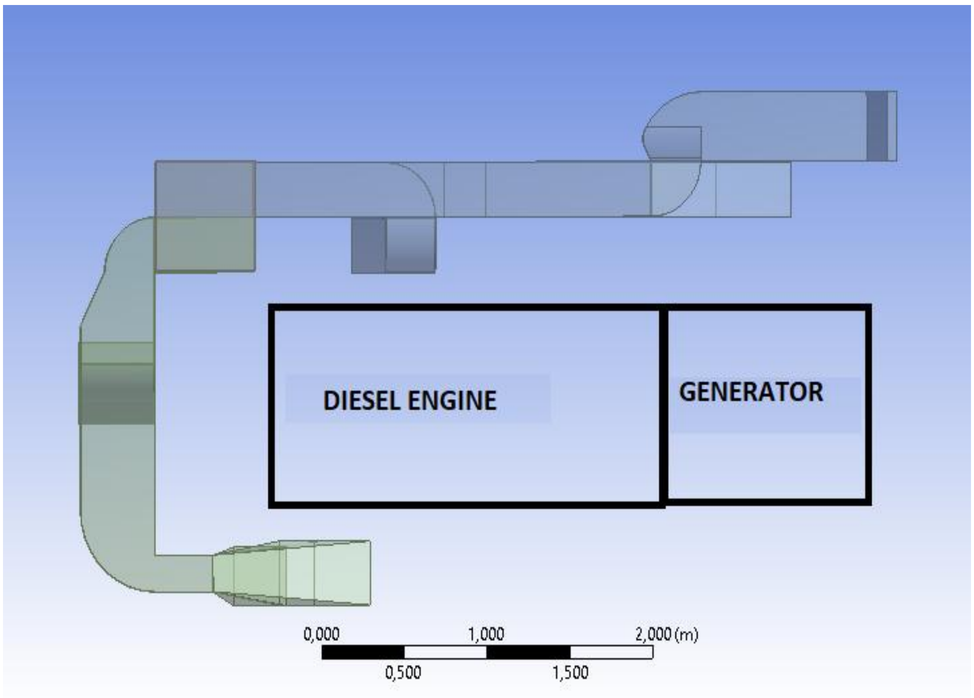

Figure 5. Ventilation system geometry around diesel generator

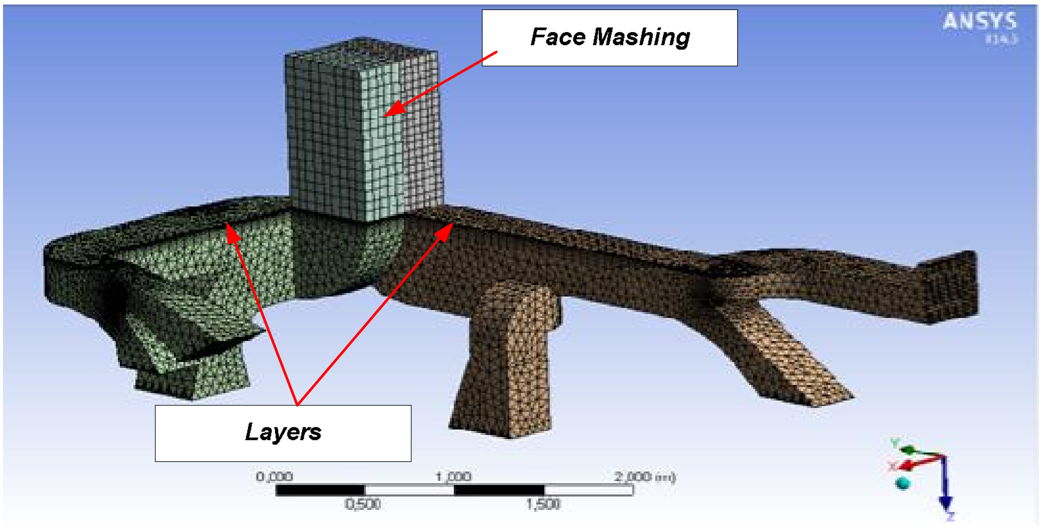

Figure 6. Geometry discretization

Table 2. Limit conditions for the simulation

Nr.crt.	Limit condition	Value
	Inlet	
1.	Velocity inlet	$9\left[\frac{m}{s}\right]$
2.	Temperature inlet	296.45 [K]
3.	Specification method	Intensity and viscosity ratio
4.	Turbulent intensity	5 [%]
5.	Turbulent viscosity ratio	10
	Outlet	
6.	Pressure outlet	-
7.	Temperature outlet	-
8.	Specification method	Intensity and viscosity ratio
9.	Turbulent intensity	5 [%]
10.	Turbulent viscosity ratio	10
	Wall	
11.	Wall	

4.3. Simulation and optimization

The variation of the air speed on the ventilation system of the machinery room can be seen in figure 7. The results obtained have global values of speed in the range 0 – 19.49 $\left[\frac{m}{s}\right]$. Figure 7 shows quite explicitly how the air velocity is distributed on the ventilation system. Ansys-Fluent offers a fine variation of the working parameters of the air. Thus we can conclude that the Ansys-Fluent numerical program provides a better diagram of turbulent air flow. This is due to the use of a structured discretionary network. In addition, the program also allows the visualization of other important elements for visualizing turbulence. It is observed that on the discharge sections the air speed has a value mainly in the range 0...9.747 $\left[\frac{m}{s}\right]$.

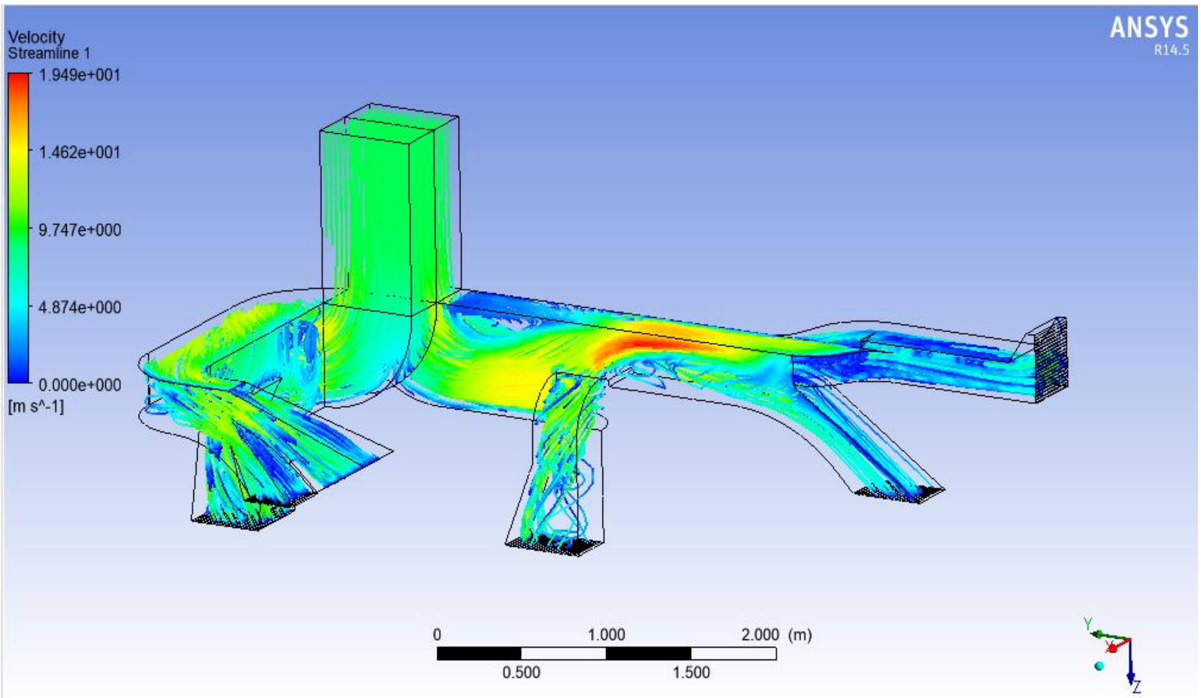

Figure 7. Velocity simulation

Figure 8 shows the variations in the working pressure of the air along the flow direction through the ventilation system. We can easily see the drop in air pressure in the air deflection areas, respectively the bends on the installation. We also have areas of negative pressure or depression. This requires correction with the help of air deflector blades, which was discussed at the end of subsection 4.3 where the flow optimization was performed.

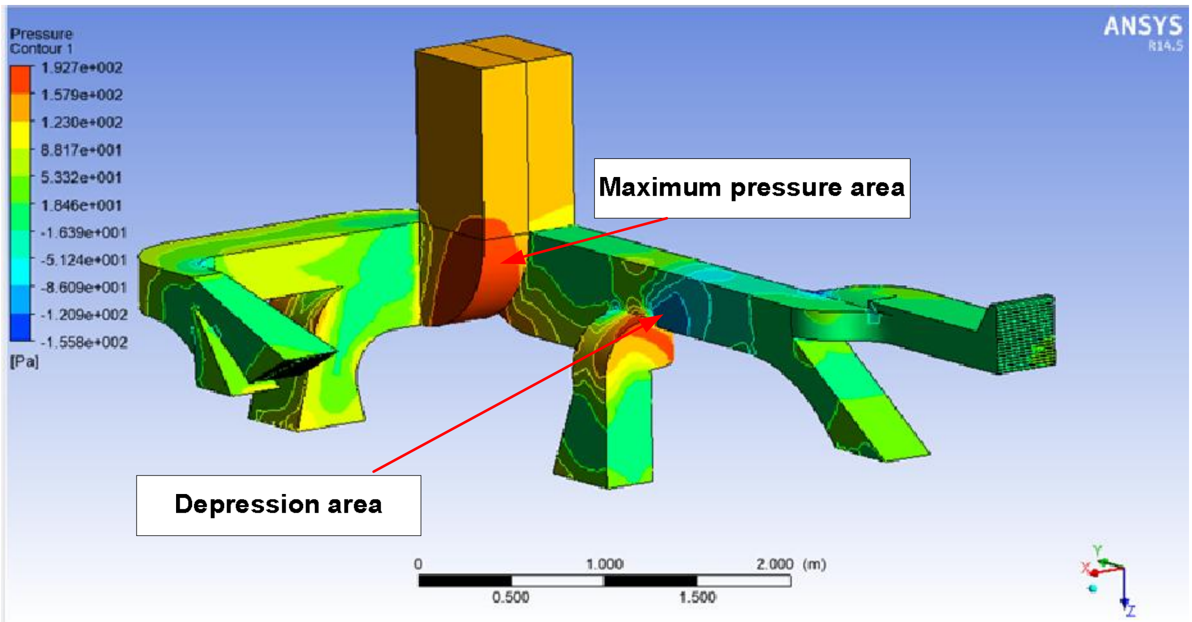

Figure 8. Pressure simulation

With the assistance of the Ansys Fluent program, was performed the optimization of the ventilation system by upgrading its configuration. Thus, was configured the system with air deflection blades (guides blades) in areas with high turbulence and extreme pressure fluctuations. Were added to geometry a number of 17 guides blades according to figure 9, as follows:

- 14 air flow deflection blades with an angle of 90º;
- 2 straight blades for air homogenization;
- 1 curved blade to homogenize the air flow in the same direction.

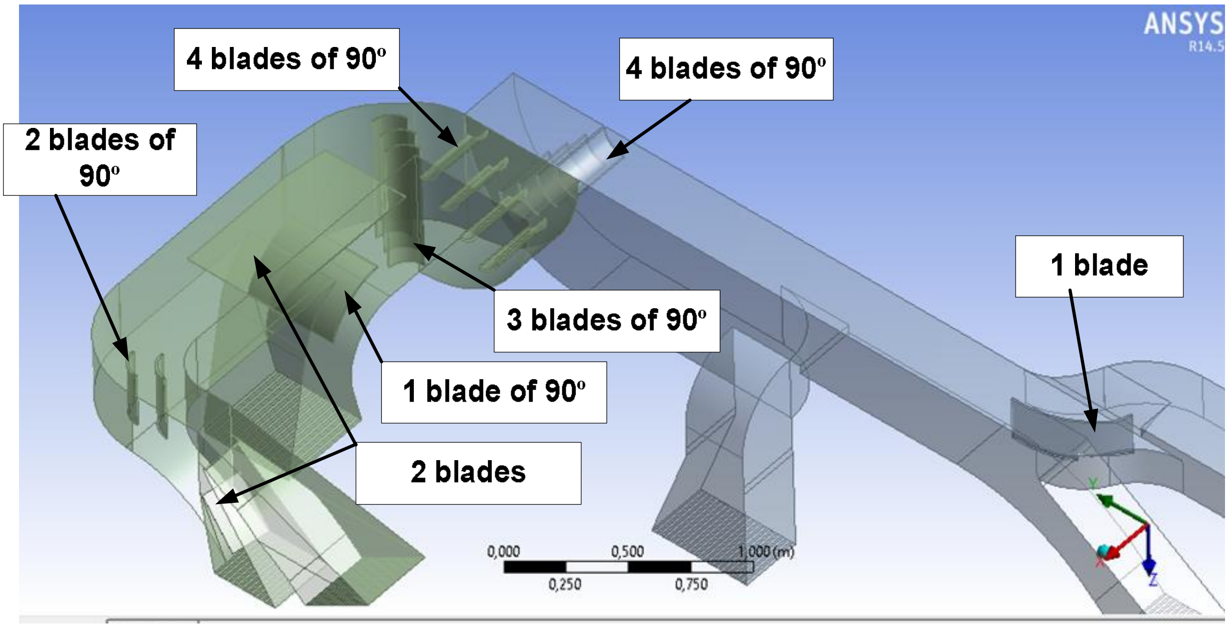

Figure 9. Ventilation system optimization

In Figure 10 we have highlighted the difference between the homogeneity of the air pressure on the ventilation system. If in figure 10a there is a red area with high pressure, we notice that the blades in figure 10b take the air flow and distribute it further on the installation lowering the pressure.

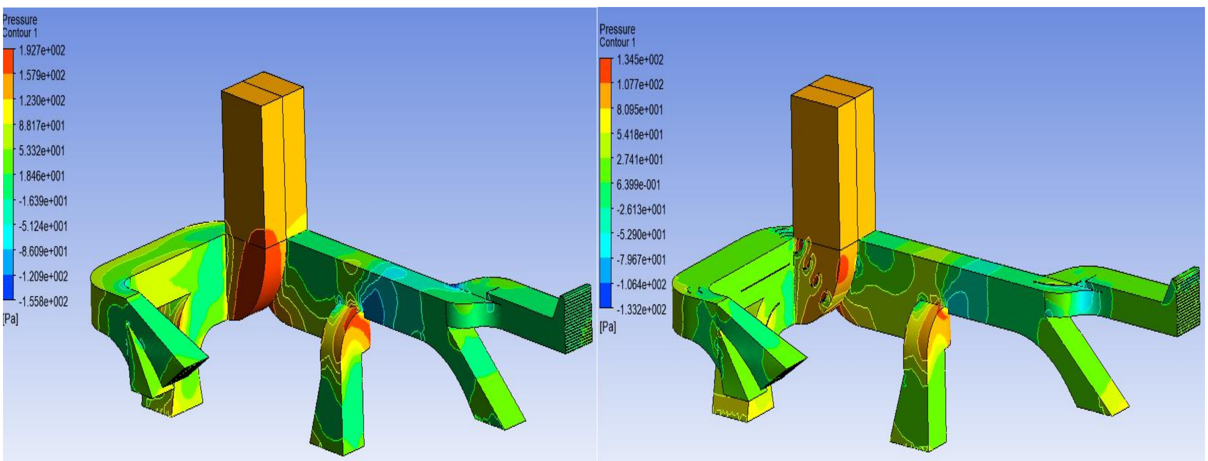

Figure 10. Comparison between the air pressure in the system
a- simulation without blades, b – simulation with blades

In figure 11 we have a visible difference between the values of the speed at the outlets to the vents for the system equipped with guides blades. We also have a larger vortex area in Figure 11a.

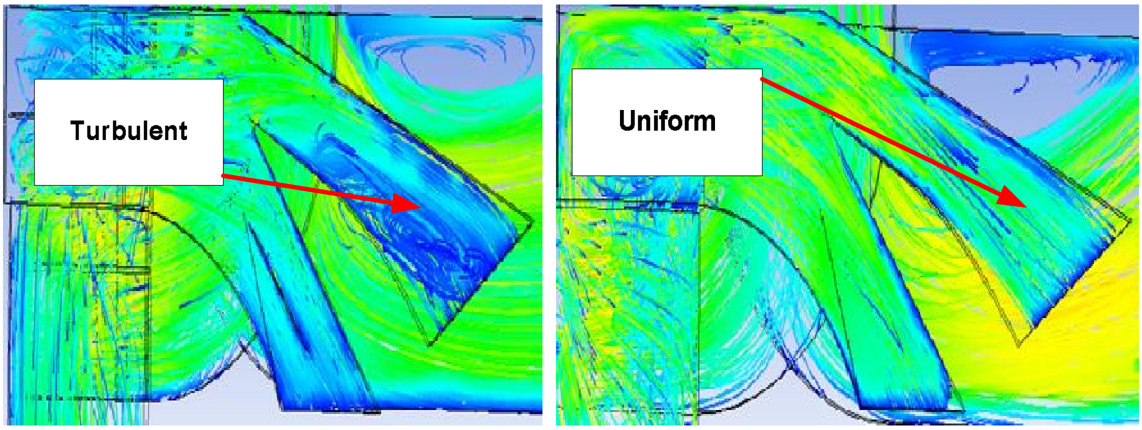

Figure 11. Comparison between air speeds in the system
a- simulation without blades, b – simulation with blades

5. Conclusions

Simulation of air flow in the ventilation system takes into account both the atmospheric conditions and the operating conditions of the plants in the machinery compartment. The standard k-ε model was used to demonstrate the effect of operating conditions on the ventilation system in the machinery compartment. The standard model k-ε demonstrated the conformity of the chosen turbulence model. Also, the Ansys CFD program showed speed and pressure fields.

As noted, the geometry of the ventilation system for the machinery compartment corresponds to the actual system and the arrangement of the ventilation sections must respect the following conditions:

- to ensure effective air circulation inside the machinery compartment;
- to ensure effective supply of air consumers;
- do not blow air directly into radiant areas such as exhaust manifolds.

Flow and temperature distribution are governed by the laws of conservation of mass, momentum and energy. The finite element method was used in the discretization scheme. The objective of the simulation was to determine the distribution of air in the ventilation pipes to improve the air circulation in the machinery room. As limit conditions were used the inlet speed for the suctions and the outlet pressure for the exhausts of the ventilation system. It is observed that due to the complexity of the ventilation ducts, but also to the rather high roughness due to the deposits, we have successive acceleration and deceleration of the air flow. Simulating under the same conditions for the 2 configurations of ventilation sections (optimized and initial system), we noticed that the optimized ventilation system is more efficient than the simple system without directional in terms of homogeneity, continuity and turbulence of air flow. At the same time, the depression on the optimized system is much less widespread than in the case of the simple system. The values of the speeds calculated by the Ansys program was a maximum of 19.49 $\left[\frac{m}{s}\right]$ for the simple system and a maximum of 18.45 $\left[\frac{m}{s}\right]$ for the optimized system. The air intake velocity in the ducts is equivalent to the fan discharge speed and was calculated to be 9 $\left[\frac{m}{s}\right]$. The optimization of the ventilation system was carried out with the help of angular blades located inside the ventilation ducts.

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