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Study on the Ventilation Fan System Onboard a Container Ship

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Abstract. In view of a number of recent global events in the field of transport and supply chain, including the catastrophic explosion at the Tianjin Chemical Factory (China), freight forwarders, contractors, shipping companies, warehousing companies, port terminals, handlers and all other parties involved in the transport of goods considered to be dangerous are under greater pressure when it comes to ensuring compliance with the rules and regulations on the transport of this type of goods, regardless of the route by sea, rail, land or air. Dangerous goods can be defined as materials or substances with dangerous properties which, if not properly controlled, pose a potential danger to human and animal health and safety, and last but not least to the environment and infrastructure. Dangerous goods can be delivered in solid, liquid or gaseous forms. They can be hot or cold, pungent or doorless, transparent or coloured, and their dangerous effects can occur in any form, from minimal to fatal, this making their proper ventilation a priority.

1. Introduction

The role of ventilation, heating and air conditioning systems is to process the air so that living conditions for crew and passengers are maintained in the ship's spaces, storage of goods and ammunition in the case of military ships and operation of equipment in optimal conditions. Heating is the process by which the temperature of the air in the compartments is raised from a heat source or by the introduction of hot air. The ventilation system circulates the air, eliminating heat, noxious substances, water vapor and smoke without processing the humid-thermal air.

The air conditioning system performs a complex air processing (heating, cooling, humidification, drying) to achieve comfort and working parameters. In the case of submarines and military ships with watertight compartments, the air conditioning system replenishes the oxygen consumed and retains the carbon dioxide retained on board. The basic design considerations for HVAC systems for marine applications are similar to those for onshore systems, except those marine systems must meet several requirements. Here are some of them:

- The space for equipment, pipes and components is smaller;
- A ship is mobile and solar heating can affect any external walled compartment above the water line;
- The ship can withstand extreme weather conditions during a day;
- HVAC systems must withstand the corrosive action of seawater and salt air;
- HVAC systems must be capable of normal and efficient operation in severe conditions of ship movement;
- HVAC systems must have a high degree of reliability as supply and intervention at sea are low and the ship must carry spare parts and tools with it;
- Enclosed spaces on the ship are small and noise and vibration transmitted through the ship structure and air must be minimized;
- The design of HVAC systems must prevent water from entering the ship in bad weather;
- The position of the openings through which the air intake and the evacuation from the ship are made are critical due to the small space available, the protection at the water entrance in the ship and the minimization of the air routes that cross the corridors for passengers and crew;
- An HVAC system must achieve satisfactory performance in compartments with a multitude of functions: living compartments, bathrooms, warehouses, compartments with propulsion equipment

and electric generators, compartments with electrical and electronic equipment, etc.;

- Smoke control and fire safety are critical due to the limited fire-fighting and rescue conditions.

It is the responsibility of the HVAC specialist engineer to develop systems that meet the required parameters. If the space is ventilated, the outside air must be heated or cooled separately and mixed with the recirculated air to reach the desired temperature. There are areas that need to be given more attention to fresh air supply and exhaust air. It is advisable to divide the spaces into smoking areas and non-smoking areas. Smoking areas are supplied with more fresh air than non-smoking areas to achieve the same result. The evacuation capacity at smoking areas will also be higher.

Sanitary, public or private spaces are provided with separate evacuation. Medical facilities such as hospitals, consulting rooms, etc. where sick people receive care, they have ventilation facilities separate from the facilities for the other spaces. Laundries have hot spots represented by boilers, washing machines, irons, etc. The amount of air supplied and the amount of air evacuated must remove heat and humidity in order for these parameters to be within certain limits. Cargo spaces are supplied with air to remove generated odors, water vapor, heat, etc. The amount of air supplied depends on the cargo carried by the ship.

It is important to create a depression in the ventilation of kitchens (the air pressure in the kitchen must be lower than in the surrounding spaces). This prevents the spread of kitchen odors in other compartments of the ship. If the kitchen has a separate space for preparing meat, a temperature below 16 ° C will be kept here.

Machinery spaces/compartments require special attention. Current engines are compact and generate a large amount of heat. Engine heat loss data is provided by the engine manufacturer. It is important that the temperature in the machinery spaces is controlled, values of 50 °C or more affect the health of the staff. In addition to the heat dissipation, the ventilation system in the engine compartment provides the necessary air for the operation of the main engine and auxiliary engines.

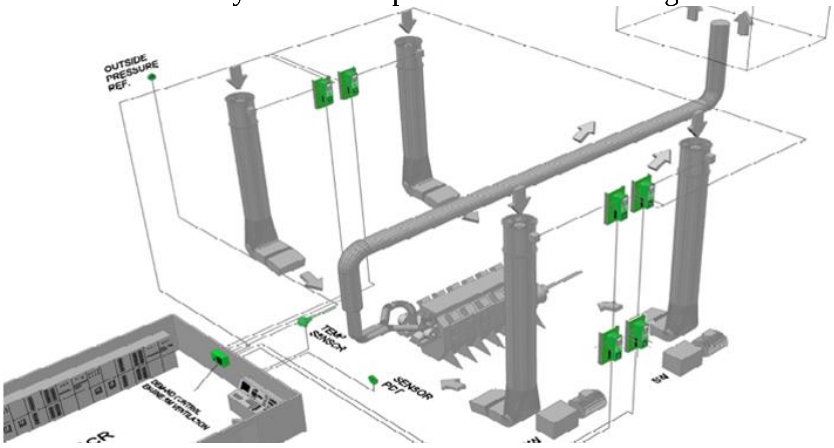

Figure 1: Typical configuration of a ventilation system fitted in a machinery compartment onboard a container ship [2]

2. Ventilation Systems Onboard Ships

Ventilation systems aim to circulate air from the ship's rooms in order to evacuate harmful heat, noxious substances and vapors, without heat or humidity processing. They consist of fans that ensure air circulation, main pipes coupled to the suction and discharge of the fan, branches to the ventilated spaces and distribution and capture elements.

The fans are axial or centrifugal. Axial fans are used on commercial vessels where high flow rates and low loads are required (fan piping to the distribution site is short), for example when ventilating the engine compartment or cargo bays.

Centrifugal fans have lower flow rates than axial ones but higher loads, which is why they are used to ventilate the ship's rooms. Axis fans are used in military ships due to their smaller size compared to centrifugal ones for similar parameters.

Depending on the processes that degrade the air in the room, ventilation is adopted by introduction, extraction or mixed. Ventilation by introduction is applied to the compartments without emission of noxious substances or harmful vapors. The introduced air is mixed with the indoor air and part of it is removed by means of exhaust vents with the blinds. Extraction ventilation is used in compartments with strong and foul odors (eg dirty laundry rooms, toilets, etc.), toxic gases or vapors (eg accumulator compartment). The stale air in the room is extracted with the fan and the completion is done by cutting with the blinds. The mixed variant, ventilation with introduction and extraction is applied to the compartments with releases of toxins and toxic vapors when the use of passive mouths (evacuation and introduction) is insufficient.

The figure below shows a typical scheme for an introductory ventilation system. The components of the system: 1 - blinds and filter, 2 - fan, 3 - bus, 4 - branch, 5 - air diffuser. The air drawn in by the fan is sent through the bus, branches and air diffusers to the ventilated spaces.

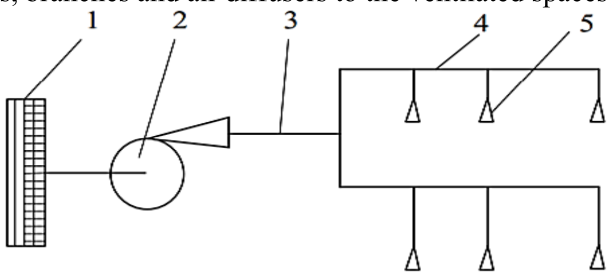

Figure 2: Schematic diagram of a ventilation system on board the ship [1]

3. Technical Data for the Fan Fitted in the Ventilation System Onboard the Container Ship

An axial fan from the MPV-D1 range, produced by the Norwegian company Nyborg, will be used for the route of the studied ventilation system, on board the container ship. The fans are delivered in sizes from ø 240 to ø 1640 with capacities up to 210,000 m^3/h and static pressures up to 1610 Pa. The fans in the MPV range are fans for marine applications, made of soft, hot-dip galvanized steel. The fans are made of stainless steel (AISI 304/316). The vast majority of fans are made of aluminum. MPV fans are manufactured in two versions with two different rotors:

- MPV-A1 - with a fan rotor without guide wings. They have a simple and robust design, which often makes it the most cost-effective alternative. The rotor is made of seawater-resistant aluminum and has a single cast unit with a high reversible capacity (approximately 60% of normal capacity). The model is best suited for large volumes of air and low to medium or moderate pressures. The fan with rotor A also has a small "stand" area. For sizes from ø 250 to ø 500 mm, the fan can be delivered with a reinforced polypropylene rotor. with variable pitch;
- MPV D1 with rotor D, being a fan with guide vanes: Axial fans with rotor D are equipped with guide vanes for higher efficiency and pressures. The rotor is made of seawater-resistant aluminum and has a variable pitch to more easily adapt to different capacities and pressures. Thanks to the guide vanes, the fan can reach pressures of up to 1600 Pa, being available in different construction versions.

The MPV fan is manufactured in four models:

- MPV A1K-D1K - piping fan for shipping routes, with installation in the pipe or at the end of the pipe, with inspection cover and gland in the housing;
- MPV A1E-D1E - for pipe connection/installation at the end of the pipe. The fan has a short housing and input cone for better performance. The motor is mounted outside the housing for easy accessibility. A protection network is fitted as standard for the fan;
- MPV A1B - for wall mounting. The fan is with inlet cone for lower pressure drops and better performance and comes with a protection network as standard;
- MPV A1M-D1M - for installation in the channel or the end of the channel. The fan is an oscillating construction in which the motor and rotor can be rotated for maintenance (and inspection).

The drive motors are inductive electric motors with cage and shortened rotor, TEFC standard, specially built-in marine execution. The motors are standard, with IP55 and insulation class F. The fans can be equipped with EXe EX class motors for an increased level of safety, or Exd or Exde (for explosion protection and fire protection) or EXN motors. Additional features of electric motors include:

- Protection in classes IP56, IP65 or IP66;
- Heating elements, anti-condensation;
- Anti-drip equipment;
- Vibration monitoring systems.

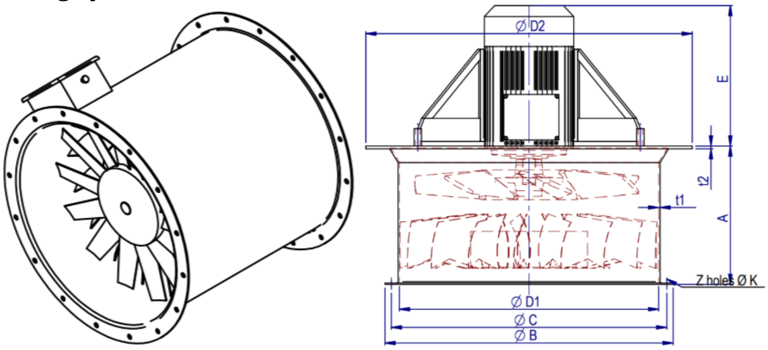

Figure 3: Nyborg MPV-D1E axial fan used in the container ship ventilation system [3]

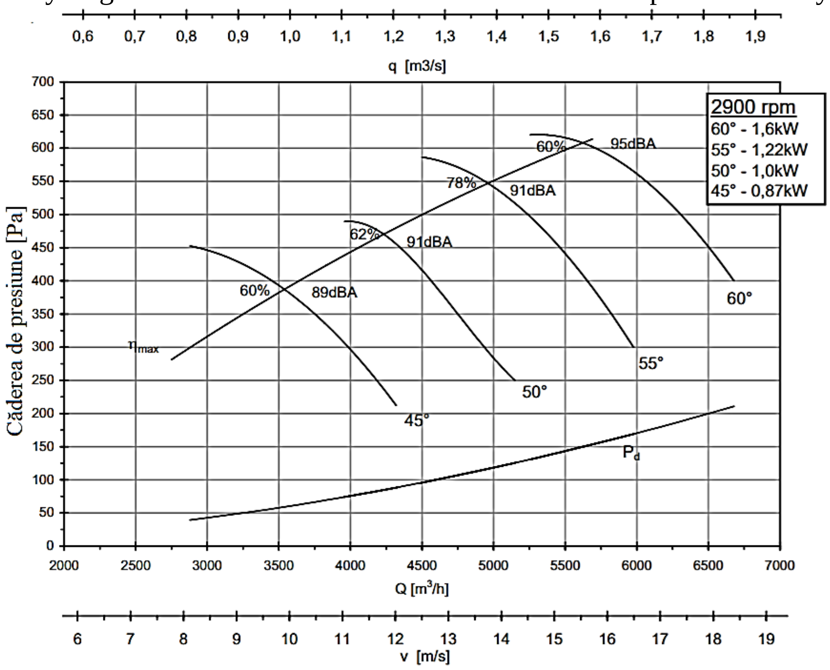

Figure 4: Diagram of the functional characteristics of the Nyborg MPV-D1E fan [3]

The figure above shows the operation diagram of the Nyborg MPV-D1E fan, showing the operating parameters as follows:

- Flow rate (Q) - in [m^3/h];
- Flow rate (q) - in [m^3/s];
- Rotation speed - in [m/s];
- Electric motor speed - in [rpm];
- Pressure - [Pa];
- Electric motor power - in [kW];
- Noise level - in [dB].

4. Operational Analysis for the Nyborg MPV-D1E Axial Fan

Finite Elements Method (FEM) is a numerical technical analysis developed for continuous structures, for two and three dimensions (2D and 3D), with mainly technical applications (for the study of deformation phenomena, heat transfer, fluid flow, etc.).

MEF starts from the idea that for a continuous, real structure (with geometric geometries and complex boundary conditions) the exact solution cannot be found, and if it can be found, the effort is just that. In the case where an approximate solution can be found more easily reached and the degree of approximate reasonably engineered, this becomes the solution for the initial structure. In other words, the analysis with MEF of one structure consists in replacing it with another one for which the solution is easier to find, the results of this being close to the approximate point.

In principle, the analysis of a structure with MEF follows the same steps from the calculation known from the method of classical matrix statics. Steps to solve a problem with the help of finite element methods:

- Step 1. Divide the domain of the analysis into finite elements - In this stage the analyst chooses his type and the types of elements that are finely structured. This operation, which is also called discretization, can be done with the help of a computer. The type of finite element is defined by many characteristics, such as the number of dimensions (one-, two-, three-dimensional), the number of nodes of the element, the functions of the approximate and the other. The choice of the type of finite element is of great importance for the need for internal memory, for the effort of the calculation imposed on the computer and for the quality of the results. The starting point for the mathematical construction of the different finite element methods is the respect of the following principles: a use of an approach based on the use of the simplest elements, for which we have a solution at our disposal; an increase in the accuracy of the calculation by refining the discretization.

- Step 2. The constitution of the equations of the finite elements (the equations of the elements) - The behaviour of the material of its medium in the content of a finite element is described by it. They form a system of equations of the element. The elementary equations can be deduced directly, by variation, by the residual or residue method (Galerkin) or by the method of the energy balance.

- Step 3. Assembly system for equations of structural elements – for the entire structure a modelling process is being performed by assembling the equations systems in the structure specific equation system, thus meaning that the balance of the system depends on balance between finite elements. By assembling it is imposed that, in the common nodes of the elements, its function or functions unknown to have the same values.

- Step 4. Boundary conditions implementation and solving the equation system of the entire system - the equation system obtained at the corresponding limit is being solved by usual methods, for an example the Gauss elimination or the Choleski devise, using these methods in order to calculate de functions in the structural nodes. These are also called unknown or first-order primaries.

- Step 5. Performing additional calculations to determine secondary unknowns - In one problem, after appearing in the primary unknowns, analyse. This is usually the cause of thermal conduction problems, in which the primary unknowns are nodal temperatures. In other problems, however, the knowledge of only the primary unknowns is not sufficient, the analysis having to continue with the determination of the secondary or second-order unknowns. These are derived from a higher order than the unknown primary ones. Thus, for example, in the mechanical problems of elasticity, the primary unknowns are nodal displacements. With their help, at this stage, the unknown secondary determinations of specific deformations and tensions are determined. And in case of thermal problems the analysis can continue with the determination of the unknown secondary ones which are the intensities of the thermal fluxes (thermal gradients).

In this context, the operation of the Nyborg MPV-D1E axial fan will be analysed, which is installed in the ventilation section on board the container ship, present in the previous chapter. Axial flow fans, although unable to develop high pressures, are suitable for handling large volumes of air at relatively low pressures, which makes them perfect for use on board ships. In general, they have a low cost and a good efficiency and have a distinct aerodynamic shape. Axial flow fans have good efficiency and can operate at high static pressures if such operations are necessary.

The aim is to model and analyse the flow through the Nyborg MPV-D1E axial fan, using the ANSYS CFD software and to deduce the results obtained, in order to obtain maximum efficiency. In this sense, the performance of an axial fan can be simulated using CFD analysis, and the effect of the variation of different parameters, such as the number of blades, the noise level, the speed, the temperature and the distribution, can be studied in detail.

The main aim is to present a final model, developed by 3D CAD, of the Nyborg MPV-D1E axial flow fan. By adapting this model to the components available on the market, the first form of optimization was made. After this step, the CFX flow solution is used to perform the necessary numerical analyses on the aerodynamic performance of this fan model. This analysis will result in a final optimization of the proposed 3D model.

The axial fan is widely used in many engineering applications, including the shipbuilding industry. At the same time, this type of fan is used in a wide variety of construction forms, ranging from small cooling fans for cooling electronic boards to giant fans used in tunnels. Axial flow fans are used for air conditioning applications and various industrial processes. Its adaptability has led to its implementation in large-scale systems, from industrial dryers to car engine cooling and air recirculation systems in the cabin on board the ship.

Extensive use of axial flow fans for fluid movement and heat transfer has led to detailed research on the performance attributes of many models. Numerous surveys were performed in these studies to quantify the performance of the axial fans and the characteristics of their air flow. Axial fans blow or circulate air along the axis of the fan, linearly, where they took their names.

Axial flow fans have blades or blades that force the air to move parallel to the shaft around which the blades rotate. With the expressive capacity of the computer and the extensive development in the field of simulation, CFD has attracted attention in recent years. With the help of CFDs, the complex 3-D geometries of the equipment can now be modelled only with minor simplifications in computing matters. CFD models, if created correctly, can explain the complex flows of this type of equipment. CFD models for axial fans were used to evaluate the behaviour and flow characteristics.

Figure 5: Real model of the Nyborg MPV-D1E fan

Models offer sufficiently accurate predictions for a series of operating conditions, which are not possible using other methods of analysis. In this sense, CFD was used to model the flow passing through a Nyborg MPV-D1E axial fan. The objective was to determine ways to increase efficiency, in order to optimize its operation. Although they are unable to develop high pressures, they are well suited for handling large volumes of air at relatively low pressures. In general, they have a low cost and have a good efficiency and can have aerodynamic shapes. The principle of operation of axial flow fans is simply defined by the physical process of air deflection. The flow rate can be broken down into two components, axial velocity - tangential or circumferential velocity. Axial velocity is the desired velocity, because is displaces the air from/to the cabin/cargo spaces on board the ship, and tangential velocity is a loss in these kinds of fans which can convert it statical pressure. The first step in the simulation process of the Nyborg MPV-D1E fan is to identify a typical fan with axial flow that can be reproduced as a model designed in a 3D technical framework using specialized CAD software.

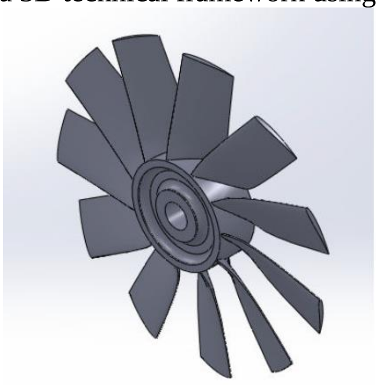

Figure 6: The Nyborg MPV-D1E fan blade model in Solidworks CAD [5]

The 3-D models are then imported into ANSYS CFD software, remodelled in different sections and refined to generate a finished volume network. This is a crucial step, in which the details of the geometric shape must be precisely defined. The flow domain is generated through this program, and the final network of all components is accurate. Any errors in the design and flow area are corrected before proceeding.

The second step is to import the files in the pre-processing stage, which will solve the air flow equations. Here are also set the limiting conditions of the flow fields. These include essential parameters such as: the mass flow rate of the inlet air, the outlet pressure, the properties of the fluid and the characterization of the flow domain, such as the internal area in motion and the ground. The next step is to simulate the process as a constant and turbulent 3-D problem.

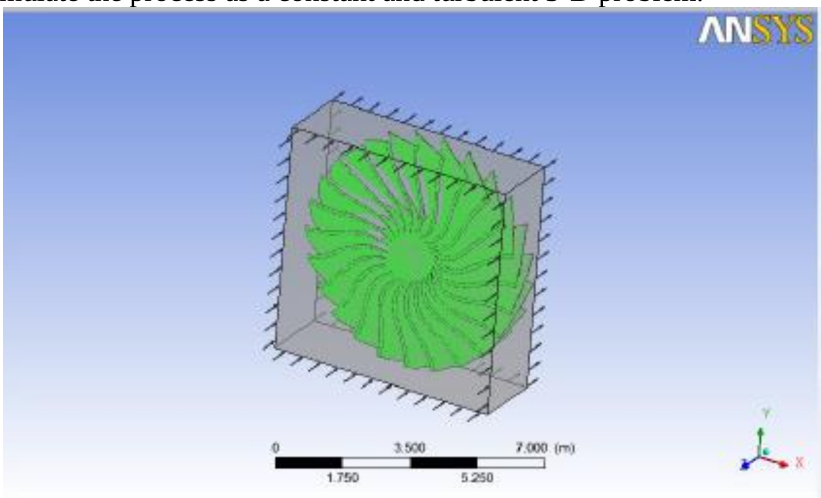

Figure 7: Establishing the fan simulation domain [5]

The simulation is preceded by the CFD code that processes the data, applying the basic theory of fluid mechanics by balancing the continuity of the mass and the impulse equations in numerical form and then producing numerical predictions of the variable fluxes. The configuration process of the problem is completed by defining the limit conditions, the solvent parameters and the convergence monitors. Assuming that the flow is ideal and the air is dry at standard atmospheric pressure, the boundary conditions include the characteristics of the fixed wall, the moving internal area, the zero pressure at the outlet and the mass. The residual values of all the resolved variables are monitored during the iteration process. This iteration process should be monitored for convergence and repeated if the numerical error conditions are not met. The last step is to analyse the output data and present them in the form of simplified speed. Thus, the simulation parameters are set as follows:

- turbulence model - k - ε - which is the turbulence model with standard wall functions;
- temperature - 298 0K;
- pressure - 1 bar (atmospheric pressure);
- flow domain - air;
- 3D pressure - default, stable;
- the driver's solution - SIMPLE;
- convergence criterion - 1-4;
- meshing - the method of volumetric extraction, with tetrahedral elements.

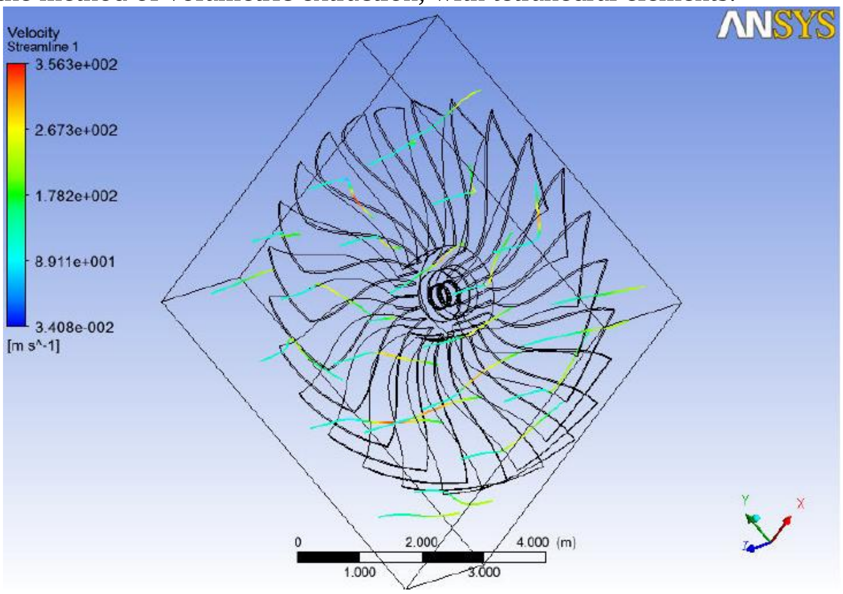

Figure 8: Simulation of fan flow lines [5]

At the postprocessing of the CFD numerical results, the observations are presented in the form of velocity flow lines, temperature contour diagrams and static pressure contour diagrams. The results are compiled separately for initial and optimized projects.

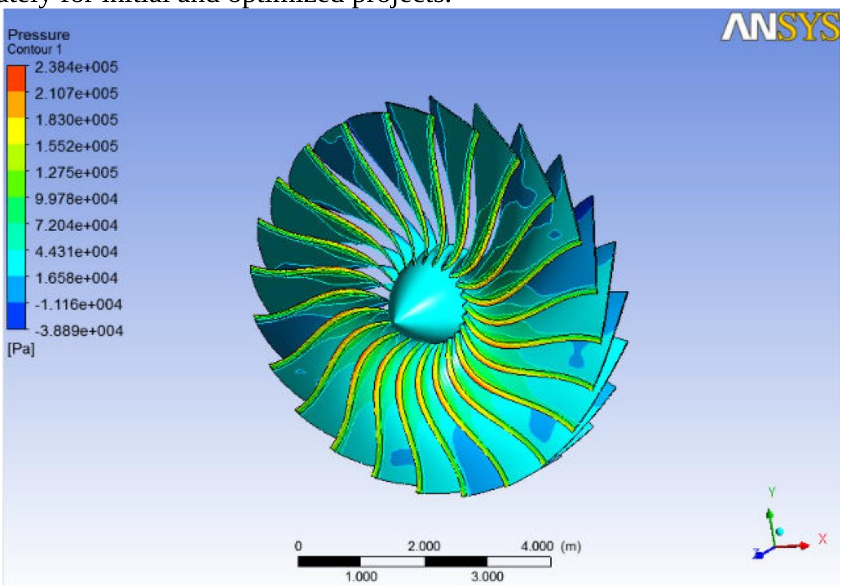

Figure 9: Pressure contour of the simulated fan [5]

Initial design - the Nyborg MPV-D1E fan initially analyzed is 7 blades. For the fan projected initially, the results were compiled for air flow at a rate of 22 m/s and with an outlet pressure equal to atmospheric pressure. Figure 10 shows the diagram of the turbulence kinetic energy contour of the initially projected fan.

Figure 11 shows the pressure contour of the initially projected axial fan. By observing the contour of the pressure, the pressure varies from a negative scale to a positive scale; as a result, there is room for the creation of a pressure area at the exit.

Figure 12 shows the contour of the temperature of the initially projected axial fan. The temperature variation is due to the room temperature of the air and the heating by cooling. The temperature variation is not uniform on the surface of the blade, as can be seen in the figure. The color (which shows the contour of the temperature) changes drastically. The sudden change in temperature on the surface of the blade will lead to the formation of thermal cracks that can damage the blade.

Moreover, the aerodynamic design of the blade is distorted due to high melting temperatures. The lifespan of the blade is very short. The air temperature of the outlet is, as well as, increased. Fan efficiency gradually decreases.

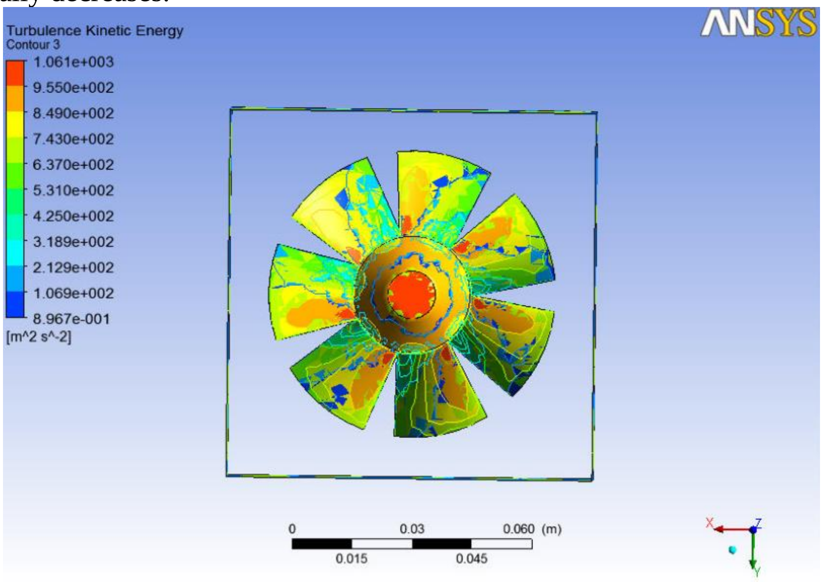

Figure 10: Kinetic energy contour of the initial fan model [5]

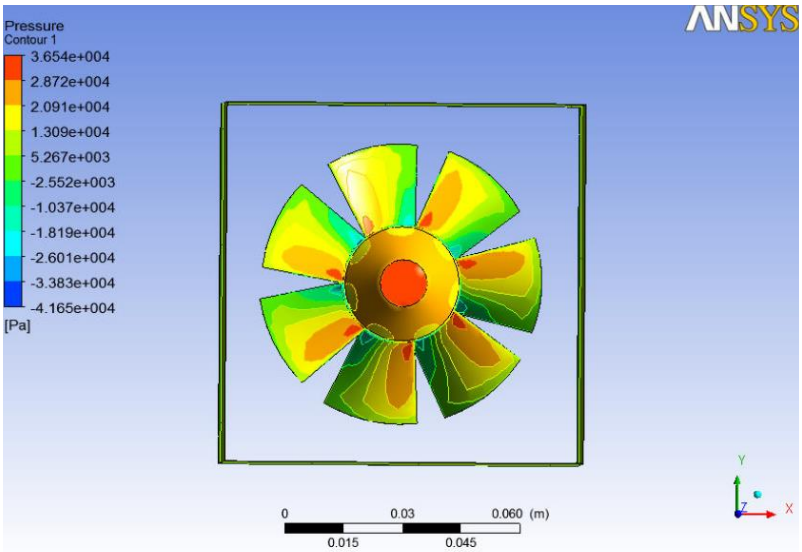

Figure 11: Pressure contour of the initial fan model [5]

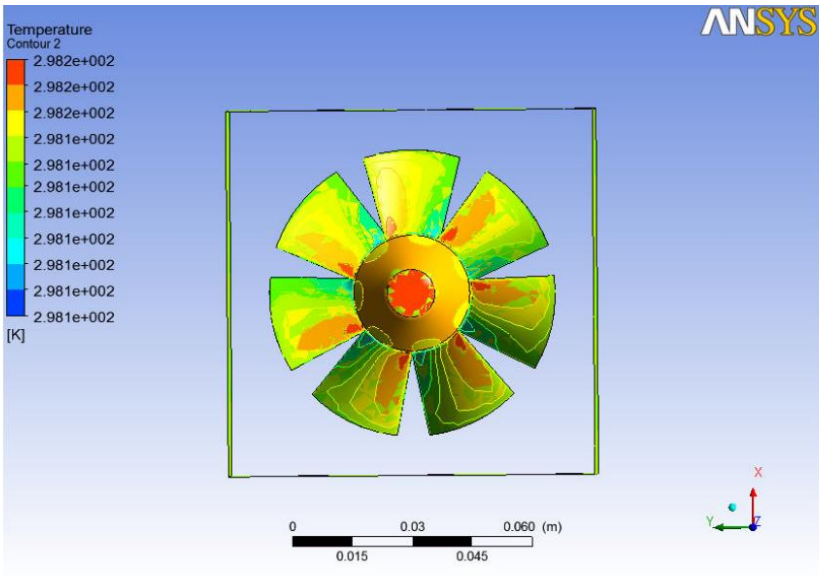

Figure 12: Temperature contour of the initial fan model [5]

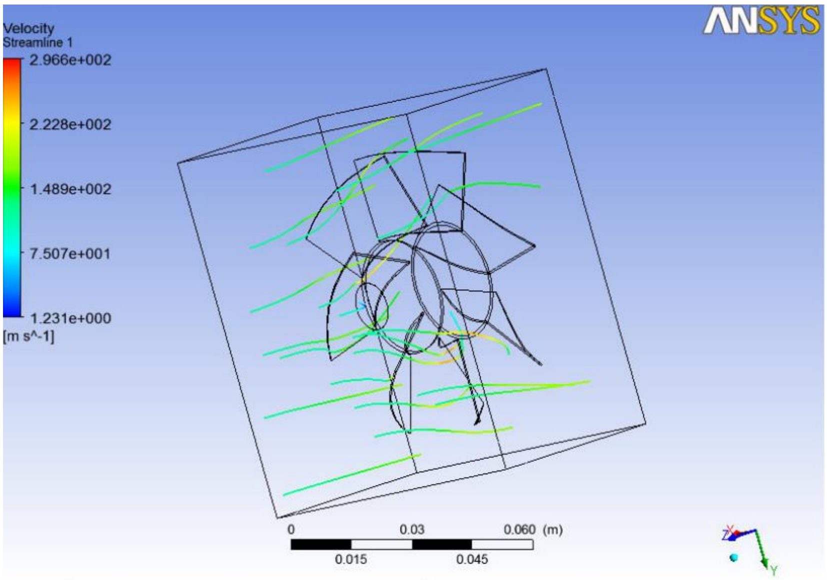

Figure 13: Speed contour of the initial fan model [5]

The last figure shows the velocity flows of the fan projected initially. Observing the graphics, one can observe how the speed currents are not uniform across the fan blade, which means that the flow is not uniform. The large variation in speed can be seen on the surface of the blade. As we can see in in Figure 13 the colour of the aerodynamic line changes drastically as the air moves on the blade. Moreover, there is a reduction in exit speed. This uneven flow will lead to huge noise and acoustic problems and will reduce the overall efficiency.

Optimized design - The Nyborg MPV-D1E fan in the optimized version has 11 blades. For the fan projected in the optimized variant, the results were compiled for the same working conditions on board the ship as for the fan model initially projected at 22 m/s and having an output pressure of 1.

Figure 14 illustrates the contour of the fan temperature projected in the optimized version. The temperature variation takes place due to the temperature of the air in the cabin and the phenomenon of cooling by cooling. The temperature variation is almost uniform on the surface of the blade or is almost the same on the whole blade. This is evident from the same color pattern of the temperature contour of the blade.

Within this optimized design there is less chance of crack formation due to thermal stresses. The design of the fan blade remains unchanged throughout the life of the fan. The lifespan of the blade is increased. The temperature of the outlet air is the same or almost the same as that of the inlet air. Thus, the efficiency increases.

Figure 15 shows the specific speed currents of the fan projected in the optimized variant. By observing the contours of the velocity, it is possible to determine that the velocity fluxes are uniform, which implies that the flux is almost uniform. The necessary variation of the blade speed is realized. The color of the aerodynamic line is almost the same on the blade, ie at the entrance and exit. The desired exit speed will be obtained, depending on the given parameters. As a result of the uniform flow, less or even negligible noise is obtained and all the acoustic problems are solved and, as a result, the efficiency is increased, which is important for a ship.

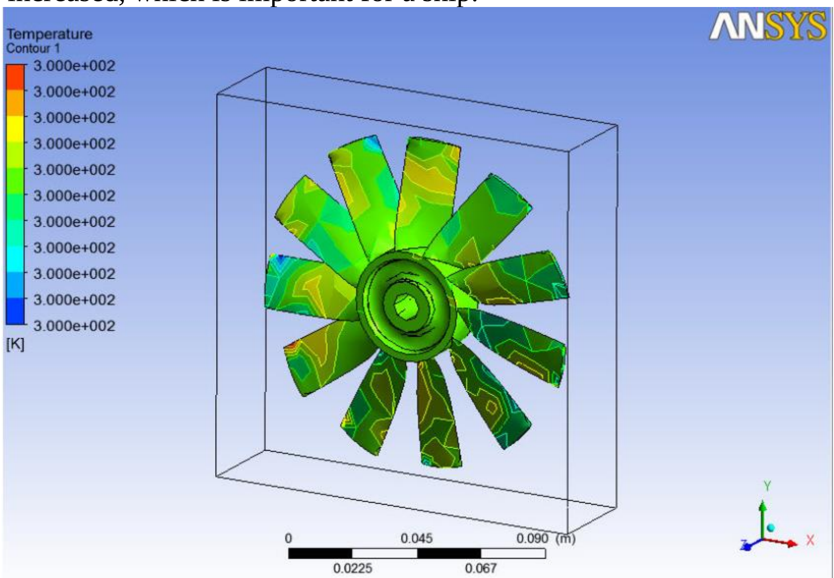

Figure 14: The temperature contour of the optimized model of the Nyborg MPV-D1E fan [5]

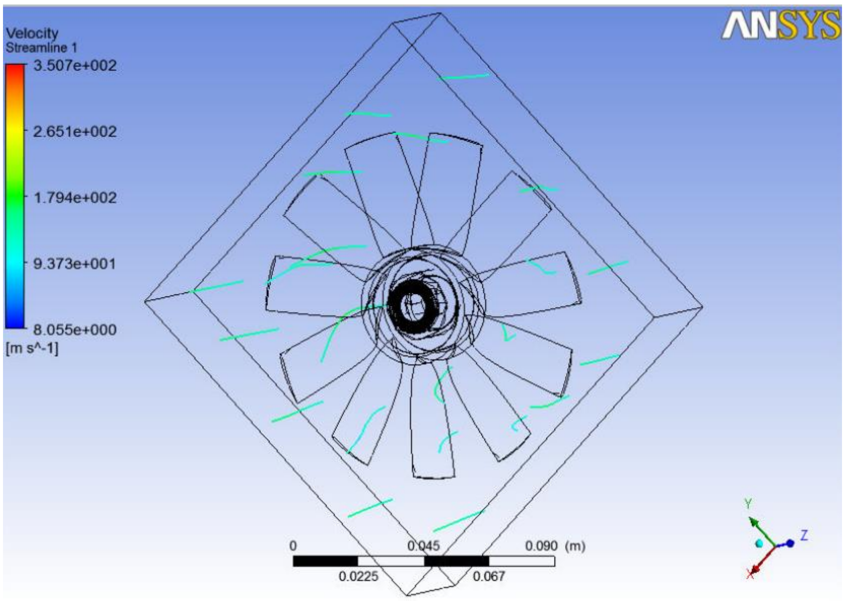

Figure 15: The speed contour of the optimized model of the Nyborg MPV-D1E fan [5]

5. Conclusions

In the last part of the study the results of numerical simulations provided an in-depth understanding of the fluid flow behaviour around an axial fan with a different number of fan blades, which is used in the ventilation system of the container ship. The CFD numerical analysis was performed both for the initially designed axial fan (the one already existing on board the ship) and for the optimized one.

The results of the CFD numerical simulations for the optimized fan model were then compared with the results obtained in the case of the initially designed axial fan. The key and important results of this study are the following:

- The CFD modelling presented in this study proved to be very helpful in initiating an additional and more comprehensive numerical study of the axial fan used on board the container ship;
- The CFD results were presented in the form of speed flow lines, which provided comprehensive details on the actual characteristics of the air flow flowing around the fan, for a different number of fan blades;
- Various variable parameters (such as temperature, pressure, fan noise and turbulence) were taken into account during the CFD analysis. The study showed that the fan with an optimal number of blades worked well compared to the fan with a smaller number of blades.

In general, as a trade-off between efficiency and cost specific to the naval field, five to twelve blades are very good practical solutions. The optimized design of the fan on board the containere ships must have a number of 11 blades.

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