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A BRIEF REVIEW ON EXAMINATION OF EXHAUST GAS DISPERSION ON MARINE SHIPS

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Abstract

The dispersion of exhaust smoke is affected by a large number of parameters such as efflux velocity and temperature of smoke, level of turbulence, wind velocity and direction, geometry of the structures on ship's deck etc. For this reason, Analyzing of the dispersion of exhaust smoke from ship stack is really complex. Traditionally, the behavior of the exhaust gases by using scale models in wind tunnels can be investigated. In nowadays, however, as a result of technological advances in numerical computational methods and computers, dispersion of the exhaust gases from Marine ship's stack can be calculated and high performance funnels of the ship can be designed during pre-design phase. While cruising, ship has a boundary layer. In the sailing ships, these harmful emissions from funnel and high exhaust temperature affects the electronic devices in the ship's deck and also the health of the crew in the deck. In this study, as a result of this literature review of this topic, a short summary of these studies will be presented.

GEMİLERDE BACA GAZI DAĞILIMI ÜZERİNE İNCELEME

Özetçe

Egzoz gazlarının bacadan dağılımına etki eden bir çok faktör vardır. Bu faktörlerden başlıcaları; egzoz gazlarının bacadan çıkış hızı ve sıcaklığı, türbülans, rüzgarın hızı ve yönü gibi atmosferik şartlar, güvertedeki yapıların geometrisi ve yerleşimi şeklinde sıralanabilir. Bu neden ile egzoz *gazlarının dağılımının hesabı karmaşıktır. Geleneksel olarak egzoz gazların davranışı ölçekli modeller kullanılarak rüzgâr tünellerinde incelenebilir. Günümüzde ise sayısal hesaplama metotlarındaki ve bilgisayarlardaki teknolojik gelişmeler sonucunda egzoz gazlarının dağılımı daha kolay bir şekilde hesaplanabilmekte ve yüksek performansa sahip gemi bacaları dizayn edilebilmektedir. Gemiler seyir halinde iken bir sınır tabakaya sahiptir. Egzoz gazları üst binada bulunan sistemlere zarar verebilmekte ve aynı zamanda güvertede çalışan personelin sağlığını da etkilemektedir. Bu çalışmada; konu üzerinde yapılan çalışmaların incelenmesi sonucunda kısa bir literatur özeti sunulacaktır.*

Keywords: Exhaust Gas Dispersion, Exhaust Emission, Ship.
Anahtar Sözcükler: Egzoz Gaz Yayılımı, Egzoz Emisyonu, Gemi.

1. INTRODUCTION

With the advancement of technology over the years, the marine ship as a platform has become increasingly sophisticated. Accordingly, the superstructure of a marine ship has undergone profound and far-reaching changes from the iron clads of the late 1800's to the present day modern machines. The sophistication of the sensors of present day marine ships requires that more than one radar and a number of electronic sensors/equipment be mounted on the mast – as high as possible. In addition, the large number of electronics required topside lead to their electromagnetic interference and electromagnetic compatibility problems that require them to be separated from each other.

As a result, modern ships have at least two masts on the superstructure to house the associated electronic equipment. A study of the evolution of superstructures on ships over the last hundred years shows that the need to locate the topside electronics at as high a location as possible has resulted in hemming in the funnel. Therefore, it is not possible to have the funnel height even as high as is found in modern passenger ships. In the process, the thumb rules of good design practices for a funnel in order to avoid smoke nuisance (like increasing funnel height and avoiding the bluff bodies in the vicinity of the funnels) are violated on marine ships [5].

The downwash of exhaust causes funnel gases to dissipate downward toward the deck more rapidly than upward. This has many adverse consequences like the sucking of hot exhaust into the main engine intake and the ships ventilation system in additional to high temperature contamination of topside electronic equipment (Please see Figure 1) and interference of the smoke with helicopter operations.

Figure 1: Electronic equipments damaged by exhaust gases.

Understanding of the exhaust smoke behavior is so important aspect of ship design that falls under the category of ship aerodynamics. However, this application of aerodynamics is not recognised a priori in the design of ships. Consequently, the smoke nuisance problem gets detected at a very late stage, often post construction, during the sea trials or even post delivery. Modifications to the topside configuration and the imperative and costly troubleshooting between the launch and delivery of such a vessel become inevitable.

The dispersion of exhaust smoke is affected by a large number of parameters such as efflux velocity and temperature of smoke, level of turbulence, wind velocity and direction, geometry of the structures on ship's deck etc. Traditionally, the funnel performance has been investigated using scale models in wind tunnel at a relatively advanced stage of design, when many aspects of the design are frozen. Making changes at that stage may involve redesigning many aspects of the ship [6]. Wind tunnel studies are very lengthy, time consuming and expensive but it is really beneficial to validate the computational results (Please see Figure 2).

Flow visualization techniques to determine the exhaust plume path using a scale model in the wind tunnel has been in use since the earliest study of the problem. Solutions to funnel problems are often found by flow visualization from the ship funnel using smoke, which is exhausted at the correct flow rate and velocity and is an ideal tool for the marine architect to ensure that the funnel will not cause a problem during operation. A number of flow visualization techniques to study the problem have been reported in literature.

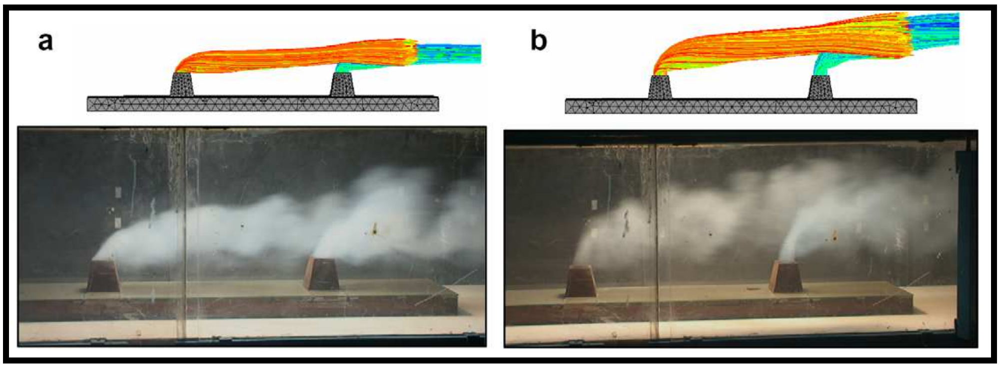

Figure 2: Validation of Computational Study with Wind Tunnel Study

Consequently, understanding of the exhaust smoke behavior is so important aspect of ship design that falls under the category of ship aerodynamics in order not to encounter high costs after the delivery of the ships.

2. LITERATURE REVIEW

Stack design of a ship has been investigated since the 1970s. However, the exhaust gas dispersion of the marine ships with helicopter platform, the effects of the exhaust gases and exhaust gas temperature to the infrared signature (IR) and the helicopter operation has not been investigated deeply as of today in the literature. Although G.J.Baham and his friend investigated the stack design technology in 1977, it was not enough [1]. The following studies have been given regarding these studies by publication date.

G.J. Baham and his friend discussed design techniques for surface ship stack casing and exhaust duct terminals. The discussion treats both marine ship and auxiliary vessel stack designs , as well as commercial stack configurations. The traditional engineering problems unique to stack design are described. These include marine architectural problems with topside arrangements and superstructure design as well as safety and esthetic considerations associated with entrainment of the smoke plume in downwash passing over ship’s decks. Examples of unique contributions to the state-of-the-art are presented. Analytical theory and procedures are described in detail. These include design guidance for selecting the height, shape, location of the stack, and techniques for estimating the downwind plume gas temperatures and trajectories [1].

M.P.Fitzgerald studied and described in his paper that a method to predict stack gas dispersion performance that was developed during the design of a recent surface combatant. This method was presented in the form of a step-by-step procedure. This method includes a two-sided procedure for the analysis of model test results. This two-sided approach combines a quantitative approach and a qualitative approach to evaluate model test results. An introduction to stack design considerations and the problems associated with low-profile stack design are presented. The major points of stack design technology are highlighted. Future directions in stack design technology are discussed [2].

In the study of Eunseok Jin and his friends, a CFD based parametric study was introduced, which was intended to investigate the smoke behavior depending on the funnel and accommodation arrangement. Corresponding calculation results were analyzed systematically and a simple measure was obtained, which hopefully could be applied to the preliminary design of funnel and accommodation arrangement. In modeling the geometry, elements having minor effects on the flow field were excluded and its reasonableness was proved by some precalculations. But, the remaining elements that have considerable effects were modeled and the analyses were performed in pretty realistic conditions. Properties that have significant effects on the behavior were chosen as parameters to be investigated. Each parameter was varied in a given range. Calculations were performed for all models resulting from the parameter variations. Analyzing all the calculation results, influences of the parameters on the smoke behavior and a simple measure to predict the smoke exhaust performance was obtained [3].

In the G.F.syms paper, the air wake surrounding the flight deck of a ship was analyzed to better understand the flow field that a helicopter pilot wolud encounter when operating from this maritime platform. This was a first step in studying the fully coupled helicopter/ship air wake environment. The flow around a simplified scale model of a Canadian ship was measured experimentally and simulated numerically. The computations were carried out using the structured multi-block flow solver CFD-ACE employing the k-ε turbulence model with wall functions. Comparison of experimental and computed velocity and turbulent kinetic energy profiles showed that the simulation captures the flow structures but contained higher spatial gradients. This difference colud be partially attributed to the unsteadiness of the flow in the airwake with which a steady-state Navier–Stokes solver will have trouble [4].

P.R.Kulkarni and his friens investigated the flow visualization studies undertaken to understand the interaction between a bluff body air wake (of the funnel and superstructure/mast) and the ship's exhaust on ships. As a first step, the analysis of the exhaust smoke-superstructure interaction was carried out in a wind tunnel for a generic ship shape. Four variants of the superstructure configuration with progressive introduction of the structures on the topside (i.e. the superstructure/mast upstream and downstream of the funnel) were investigated in the wind tunnel at two velocity ratios through flow visualization studies to understand their effect on the exhaust plume path. Apart from providing an insight into the process of plume dispersion in the vicinity of the funnel and other structures on topside of marine ships, the results of the flow visualization studies presented can also be used for validation of the computational fluid dynamics (CFD) simulations (including particle tracing) of the exhaust smoke-superstructure interaction for cruise vessels, ferries, yachts, as well as marine ships [5].

P.R.Kulkarni and his friends investigated and presented a parametric study on representative topside configurations of a generic ship using computational fluid dynamics (CFD). The results presented had been analyzed for a total of 112 different cases by varying velocity ratios and onset wind direction for four superstructure configurations. Use of both experimental and computational approaches had been made so that they became complementary to each other. The CFD simulation had been done using the computational code FLUENT. Closure was achieved by using the standard k–e turbulence model. The parametric study has demonstrated that CFD is a powerful tool to study the problem of exhaust smoke–superstructure interaction on ships and is capable of providing a means of visualizing the path of the exhaust under different operating conditions very early in the design spiral of a ship [6].

R.Vijayakumar and his friends studied and presented the mapping of the temperature field around a simplified topside configuration of a generic ship model. The configuration comprises of two funnels (forward and aft) a superstructure block consisting of bridge, mast and two intakes (fwd and aft) ahead of respective funnels along with piping network with blowers to achieve the desired air flow through funnels and intakes. A set of electrical heaters has been fitted in the funnel inlet pipe to provide hot gases. The exhaust temperature from the funnel has been maintained at 50^0C above the ambient temperature through out the experiment. The mapping of temperature profile was conducted by measuring temperature using RTD. Six measurement planes were chosen so as to cover the most critical region around the superstructure with a total of 1344 discreet measurements. The study provides an understanding of the near field behavior of hot flumes and also suggests possible location of intakes and regions of hot spots in the superstructure. These results can serve as reference data for marine architects for their use in the validation of the numerical simulation using CFD [7].

J.H. Kim andhis friends studied and provided guidelines for the funnel design to prevent the thermal damage of the electronic devices from the exhaust gases and to block them re-circulating near accommodation and inflowing into fan room intakes. From CFD analyses, it is certain that the major factors affecting the exhaust gas dispersion are the large scale mixing by separation vortices and the sluggish flow in the recirculation region. And also the standards of the funnel design to minimize the exhaust gas dispersion have been established by adjusting the funnel shape, the position of the exhaust pipe, the shape of bulwark, the exhaust direction of air ventilated an engine room and the angle of the exhaust pipe [8].

In the study of Sunho Park and his friends, the exhaust-gas flow was computationally investigated and the results were applied to improve the antenna location of a ship. To verify the computational method, the turbulent shear-layer flow was simulated and validated against existing experimental data. Various engine loads, wind speeds, and directions were considered for the exhaust-gas flow analysis, providing valuable information for more suitable locations for the antenna. A better antenna location determined computationally was confirmed by temperature measurements from actual exhaust-gas flows during sea trials [9].

In the S.Ergin and his friend’s paper, the exhaust smoke-superstructure interaction for a generic ship model was investigated numerically. The ship was driven by a CODOG system. The k-ε model is adopted for turbulent closure, and the governing equations in three dimensions are solved using a finite volume technique. The computations were performed for different yaw angles, efflux velocities and temperatures of the exhaust smoke. The cases with diesel engines and gas turbines are considered. The calculated streamlines, temperature contours and smoke concentrations are presented and discussed. Furthermore, the detailed predictions are compared with the available experimental measurements. A good agreement between the predictions and experiments is obtained. The study has demonstrated that computational fluid dynamics is a powerful tool to study the problem of exhaust smoke–superstructure interaction on ships [10].

3. CONCLUSION

The prediction of flow path of exhaust plume from the ship funnels is extremely complicated since the phenomenon is affected by a large number of parameters like wind velocity and direction, level of turbulence, geometry of the structures on ship's deck, efflux velocity of smoke etc. To complicate the matters, the entire turbulent flow field is subject to abrupt changes as the yaw angle changes. In order to understand how the smoke is brought down to ship's deck, it is necessary to have a knowledge of the funnel exhaust behavior very early in the design spiral of the ship by undertaking parametric investigation of the interaction effect between exhaust smoke and the ship superstructure. Some studies have been performed and presented as of today and these studies have been investigated summarized in this paper. But, in addition, there are some investigations and papers regarding the simulation and modeling of the air wake created by the ship's superstructure in the literature [11-13, 15-16].

As can be seen in the literature review, studies which examining the dispersion of the exhaust gases from the ship's funnel is limited for marine ships. Understanding of dispersion of exhaust smoke is therefore an important aspect of ship design that falls under the category of ship aerodynamics. However, very often, this application of aerodynamics is not recognized a priori in the design of ships.

As a result, the smoke nuisance problem gets detected at a very late stage, often post construction, during the sea trials or even post delivery. Modifications to the topside configuration and the imperative and costly troubleshooting between the launch and delivery of such a vessel become inevitable. In order to take the smoke nuisance problem into account, the ship designer needs to be able to have a means of visualizing the path of the exhaust under different conditions during the design phase, which will enable detection of shortfalls very early in the design spiral. This requires the ship designer to have knowledge of the funnel exhaust behavior, which shall enable him to find efficient means to eliminate the problem and also to avoid the costly post construction additions and alterations.

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