A STUDY ON THE INTERACTION OF EXHAUST SMOKE WITH THE SUPERSTRUCTURE AND GAS TURBINE INTAKES OF NAVAL SHIPS.

by

R.Vijayakumar

DEPARTMENT OF APPLIED MECHANICS

INDIAN INSTITUTE OF TECHNOLOGY DELHI

Jun 2009

A STUDY ON THE INTERACTION OF EXHAUST SMOKE WITH THE SUPERSTRUCTURE AND GAS TURBINE INTAKES OF NAVAL SHIPS.

by

R.VIJAYAKUMAR

DEPARTMENT OF APPLIED MECHANICS

SUBMITTED

in fulfillment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

TO THE

INDIAN INSTITUTE OF TECHNOLOGY DELHI

Jun 2009

Dedicated to

My daughters Suvetha and Priyadharshini
and my nieces Parabanjini and Sivasakthi

ACKNOWLEDGEMENTS

I wish to express my deepest sense of gratitude to Prof. V Seshadri, Prof. S. N. Singh and Cdr (DR) PR Kulkarni the thesis supervisors, for their keen interest, invaluable guidance, support and encouragement, which manifested in so many different ways.

I am deeply indebted to Prof. V Seshadri, through his knowledge, practicality, foresight and uncompromising standards has constantly guided me through out the work. During the entire course of this work, apart from the educative discussions, Prof. SN Singh inspired and motivated me with his leadership and guidance in crucial and critical matters. I would like to express special thanks to Cdr (DR) PR Kulkarni for motivating me in taking up the task of pursuing this doctoral thesis work.

I am indebted to Captain. VK Satyam Officer-in-Charge, Naval Construction Wing for encouraging my efforts in this research. I would like to place on record my appreciation to Shri Gaurav Nigam, whose assistance in the preparation and conduct of experiments has been of great help.

My sincere thanks to all the staff of Gas Dynamics Laboratory of the Department of Applied Mechanics, especially Shri. RP Bhogal, Shri. Rameshwar and Shri. Jugtiram for their skillful work during the fabrication of the experimental setup. I would also like thank Shri. Ramsarup, Shri. Onkar Singh and Shri. Diwan Singh from the Fluid Mechanics Laboratory and Shri. Rawat of the Computational Lab for their help and assistance. I would like to acknowledge the contribution from Shri. DC Sharma from the Department workshop for his valuable suggestions during fabrication of the experimental set up.

I would like to reserve special thanks for Shri. Dharam Singh, from Naval Construction Wing, for his valuable support and generous help. I would also like to thank Shri Dipin Rana for his assistance in numerous miscellaneous jobs throughout this study.

I have no words to express my gratitude to my parents, brother R Rajkumar and my sister R Dhanalakshmi for their continuous encouragement, and last but not the least, to my wife Jaipriya and daughters Suvetha and Priyadharshini for the unlimited freedom provided to me to carry out this Doctoral Research. Their patience and understanding in dealing with me have been phenomenal. This work has been made possible only by their loving support, unstinting patience and understanding.

(R.Vijayakumar)

Date : Jun 2009

Place : N. Delhi - 110 016.

ABSTRACT

Smoke nuisance is encountered on ships due to the interaction between the exhaust gases from the ship funnel and the ship's superstructure. This problem is encountered in both passenger as well as naval ships. However, the problem is more acute in the case of modern naval ships were the height of the funnel is restricted on the basis of operational and strategic consideration. It is important to identify the possibilities of occurrence of downwash of exhaust smoke on ship's deck at the design stage itself so that steps can be taken to avoid such an eventuality. The smoke nuisance causes several undesirable effects like ingress of smoke into the ventilation system, adverse effect on electronic system, suction of smoke into GT intakes, interference with helo/aircraft operations, increase in IR signature etc.

Even though the "problem of smoke nuisance" has been a subject of research since 1940's, the publications regarding the exhaust smoke-superstructure interaction on naval ships are very few in the public domain. At present, the path of the exhaust smoke from the funnel is predicted by the designers on the basis of either semi empirical formulae or wind tunnel tests. The evaluation of funnel performance using scale models in wind tunnel are done at a relatively advanced stage of design, where in the superstructure, mast and intake locations and size are already fixed with very little room for modifications. In order to account for the smoke nuisance problem in ship design, the ship designer needs to be able to have a means of visualising the path of the exhaust under different conditions very early during the design phase. This experimental and numerical study of the exhaust smoke-superstructure interaction is envisaged to fulfill such a need.

A study on the interaction of Exhaust Smoke with the superstructure and Gas turbine intakes of naval ships is carried out for a simplified superstructure of a generic frigate shape. As a first step, scale model experimentation in wind tunnel with wind conditions scaled accordingly without considering the thermal gradients to measure and study the behavior of the interaction between masts, deck structures, funnels and intakes is undertaken. This has been done by simulation of the flow over a model ship superstructure in a wind tunnel with injection of iso-thermal (unheated) exhaust flow from the funnels and suction through intakes of the model superstructure. This study includes the mapping of the flow structure around simplified representative superstructures of a generic frigate using the 5-hole probe as well as the flow visualisation studies (by smoke technique) for some practical ship situations and configurations. Next, as a part of thermal effect experimental studies, the air fed to the funnels was heated (maintained at 50^{o}c higher than ambient) and temperature distribution over the simplified superstructure of generic frigate has been mapped experimentally in the wind tunnel.

The mapping of the velocity flow field for two different operating conditions and temperature contours for one operating condition in the wind tunnel has resulted in generation of experimental data that can directly be correlated to the results of the numerical simulations. The flow visualisation studies undertaken on three configurations at different flow conditions have provided high quality photographs of the plume trajectories. Apart from providing an insight into the interaction of exhaust smoke, intake and the superstructure on naval ships, these photographs enable a qualitative comparison of the plume trajectory predicted by CFD.

The methodology adopted in the present study involves comparing the flow parameters predicted by CFD simulation using the CFD code FLUENT version 6.2.1

with experimental results obtained from the wind tunnel study. The comparison of the experimental data (from flow visualisation studies as well as mapping of the flow structure in the wind tunnel) with the results from CFD simulation show a reasonably good agreement which leads to the conclusion that the numerical scheme, wherein the closure is achieved by using the standard k-ε turbulence model along with grid refinement and grid adaptation techniques, predicts the flow and performance characteristics for the simplified model reasonably well.

After having established the capability of the CFD code with standard k-ε turbulence model, the same has been used for undertaking parametric investigation of the flow characteristics of the exhaust smoke superstructure interaction on the ship's topside. The prediction of flow path of the 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 the ship deck, efflux velocity of smoke etc. To complicate the matters, the entire turbulent flow pattern is subject to abrupt changes as the yaw angle changes. The parametric investigation using CFD is carried out by varying the velocity ratio (K), yaw angle (ψ) and the superstructure configuration for a total of 210 cases which has been investigated.

The salient conclusions that have been drawn from the experimental and computational investigations are as follows

(a) The flow around the superstructure of a warship is highly complex, unsteady, incompressible and three-dimensional. The air wake of the superstructure (bluff body) contains significant gradients, resulting in vortex structure whose form, dimension and persistence are function of the size and location of bluff bodies.

(b) The low pressure region caused by the interaction of wind with bluff body superstructure and presence of GT intakes was found to cause the problem of downwash and ingress of smoke in the intake.

(c) Momentum increase, high enough funnel to mast height ratio and proper GT intake locations is necessary to clear the plume from the wake of a funnel or superstructure and prevent the downwash and ingress of smoke in GT Intakes. it is concluded from the experimental and CFD studies that a minimum velocity ratio of 2, funnel to mast height ratio of 0.46 and location of GT intakes at the sides of the mast are desirable to avoid the problem of down wash and smoke ingress in GT intakes for the geometry considered.

(d) The experimental results of temperature contours compare reasonably well with the CFD predictions using constant turbulent Schmidt number of 0.2 in the standard k - ε turbulence model. The parametric investigation using higher temperature and velocity ratios were able to identify the hot spots in the superstructure to help in the proper location of electronics like radars and antennas on the superstructure.

(e) This study also presents CFD results in the form of polar plots for various funnel heights and different ratios of cross wind to exhaust wind velocity and direction for two different funnel locations for generic naval frigate, which can be used by ship designer to fix the initial height of the funnel either for symmetrical or off centered funnel locations during the earlier phases of design to avoid smoke nuisance problem onboard naval vessels. Further optimization of funnel height can be carried out by improving the local arrangement of the funnel so as to increase the momentum of the exhaust plume.

(f) The study has also demonstrated that CFD is a powerful tool capable of accurately predicting the larger scale features of the exhaust smoke superstructure interaction on naval ships as long as sufficient care is taken to ensure proper discritization and appropriate turbulence model are used.

CONTENTS