Modified Geometry of Mast to Reduce Smoke Ingress Problem in Naval Ship Using Flow Visualization Study of Exhaust Smoke

Prem Shanker Yadav [1], V. Seshadri [2], S.N. Singh [3]
[1]JSS ATE Noida, India, prem0jss@gmail.com
[2]IIT Delhi, India, vseshadri@am.iitd.ac.in
[3] IIT Delhi, India, prem0jss@yahoo.com

Abstract: One of the challenges in the ship building is to avoid the smoke ingress problem in gas turbine which is located at the base of tall mast and uses as a prime mover It is important to identify the possibilities of occurrence of ingress of smoke in to gas turbine at the at the design stage itself so that steps can be taken to avoid such an eventuality. Modern warships are prone to the problem of smoke nuisance because they tend to favor a full-beam superstructure with a tall mast and short funnels. This paper presents flow visualization studies undertaken in a wind tunnel over a simplified superstructure of a generic naval ship in order to understand the effect of opening in mast for plume trajectory by taking lowest velocity ratio to reduce smoke ingress problem in gas turbine and the exhaust plume path. These investigations have been carried out at three design of opening in mast for three frame of simplified superstructure. The result of these flow visualization studies provides insight into the process of plume dispersion in the vicinity of the funnel and other structures on the topside of naval ships. These results can also be used for validation of Computational Fluid Dynamics (CFD) simulations, including path lines of the exhaust smoke in the presence of superstructure interaction in a variety of vehicles like cruise vessels, ferries, yachts, naval ships, etc.

Key words: Plume trajectory, modified mast geometry, flow visualization, gas turbine.

Introduction

Stacks discharging the products of combustion to the atmosphere have long been the most common industrial method of disposing hot waste gases. The current practice in naval ship building is to favor short funnels and tall mast to house various electronics and antennas The smokestacks on ships are often referred as ‘FUNNEL’. This is located at the top side at the ship. The engineering function of the ship’s funnel is to discharge the products of combustion in such a manner that they will stay clear on the ship. The problem of smoke nuisance, where in hot exhaust gases from funnels tend to get trapped in the downwash of the funnel and superstructure and expose various topside operational areas, ventilation openings, electronics and weapon systems to high temperature and contamination. Gas turbines use as prime movers in warship, the problem of smoke nuisance has further aggravated with increase in mass flow and higher temperatures of exhaust compared to diesel and steam propelled driven ships. The downwash of exhaust causes funnel gases to disperse downward toward the deck more rapidly than upward. This has many adverse consequences like the sucking of hot exhaust into the Gas Turbine(GT) intake .The trapping of exhaust gases into the recirculation zones results in the exhaust gases being sucked in to GT intakes. The ingress of smoke in the GT intakes affect the performance of GT engine in two ways one by injection of oxygen depleted air and other by heat contamination. The inlet temperature of the air at GT inlet has a very pronounced effect on the gas turbine over all performances The impact of these hot gases has resulted in recurring problems with topside devices like antennas, electronic communication instruments, radar and weapon systems apart from increasing the Infrared signature of the vessel. That’s why all these things are positioned in the ship structure on the mast at appropriate height so as to have maximum arc of view. Hot air in the vicinity of antennas can interfere with the electromagnetic communication through ionization of air. Similarly the down wash can result in exposing the top deck weapons to high temperature.

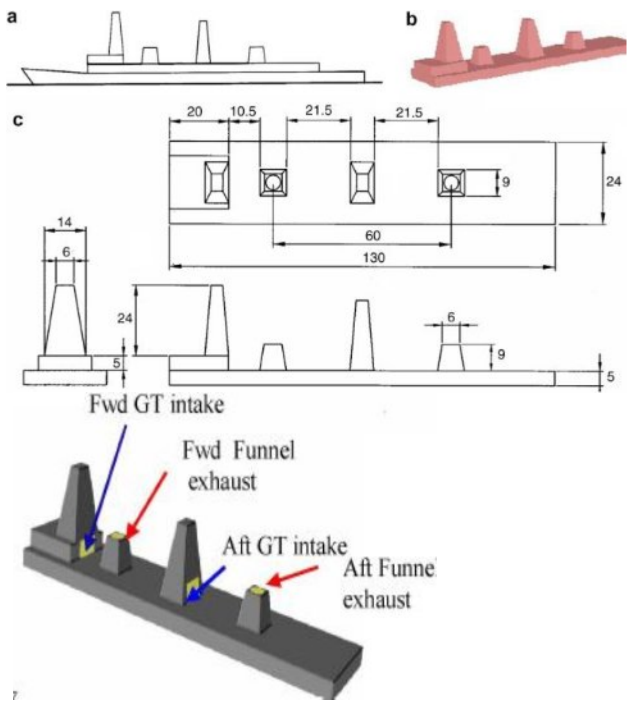


Fig1. Superstructure of generic frigate

Existing review:

The problem of smoke nuisance in the context of naval ships continues to be a subject of research. The famous passenger liner *RMS Queen Elizabeth 2 (QE2)* was designed and built in the year 1969 with all the latest technology the age had to offer. Protecting the two outdoor pools and sundecks from the stiff ocean breeze provided the exhaust fumes little place to escape. On *QE2* the problem of smoke nuisance would have been magnified because the entire area was to be enclosed with tall windscreens. Work on this problem has also been reported from the offshore industry. an investigation at I.I.T Delhi for directorate of novel design to solve the problem of smoke ingression in to GT intakes of the p-15 class of ship by simulating the phenomenon in a wind tunnel. A wooden 1:50 scale model was used .In order to visualize the flow condition at various locations on the model; the flow visualization techniques of smoke injection as well as tuff probes are used. On the basis of the result from the flow visualization studies, several modifications were suggesting the geometry of funnel outlets and GT intakes to overcome the problem by Seshadri et al [2006].

The studies by researcher Vijaykumar and et al [15] conducted the experimental study over the simplified superstructure provides an understanding of the near field behavior of hot flumes. It also identifies possible location of intakes and regions of hot spots in the superstructure.

Kulkarni et al. (2006) carried out flow visualization studies on a generic frigate model with two funnels, and progressively introduced topside-like structures fore and aft the mast superstructure. They presented these flow visualization studies in order to understand the interaction between bluff body air wake (of the funnel and superstructure/mast) and that of ship exhaust on naval ships. However, they did not study the problem of smoke nuisance for different velocity ratios, the effect of intake, and the various funnel-to-mast ratios

The experiments are carried on a 1:50 model of a typical topside configuration of a generic frigate similar to the model used by Vijayakumar et al. (2008). The naval ships with displacement of over 3,000 tons usually have two engine rooms spaced sufficiently apart in their general arrangement to necessitate two separate funnels and intakes. Furthermore, a survey of modern frigate-type ships indicates that they are fitted with two plated masts to accommodate various antennas/radars at different levels that are located close to funnels. Nowadays, the Funnels and masts are trapezoidal in shape rather than aerodynamic in order to reduce radar cross section of the vessel Hence for the investigation, the superstructure of the generic frigate with two masts (with the fwd mast located over the bridge) two funnels, and two intakes located near the base of the funnel was chosen. The typical dimensions of deck height and free board of a naval ship, and the dimensions of the representative superstructure of a generic frigate, as well as the dimensions of the 1:50 scaled model used in the wind tunnel study are shown Figure 1.

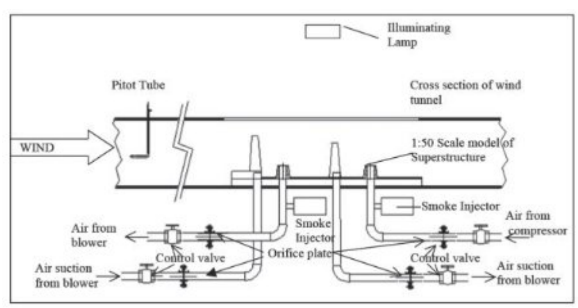


Fig: 2 (Experimental set up of 1:50 model)

Modification suggested in forward mast:

The problem of smoke nuisance, where in hot exhaust gases from funnels tend to get trapped in the downwash of the funnel and superstructure and expose various topside operational areas, ventilation openings, electronics and weapon systems to high temperature and contamination. Gas turbines use as prime movers in warship. This has many adverse consequences like the sucking of hot exhaust into the GT intake .The trapping of exhaust gases into the recirculation zones results in the exhaust gases being sucked in to GT intakes. To reduce the wake zone created between mast and funnel and due to gas turbine there are some modifications provided in mast

Case:1 It was suggested that if there is a straight opening provided in the mast from the deck of the ship to examine and analyze airflow disturbances created by the size and location of the fwd on the fwd exhaust plume paths. The studies are carried out for exhaust velocity ratios (defined as the ratio of exhaust velocity V_e to that of wind velocity V_w) of 0.5 with the gas turbine intake velocity 7.5 m/s. For this purpose, the exhaust velocity (V_e) is kept at 10 m/s, the wind velocity (V_w) is 5 m/s. the straight opening is 9 cm above from the deck.

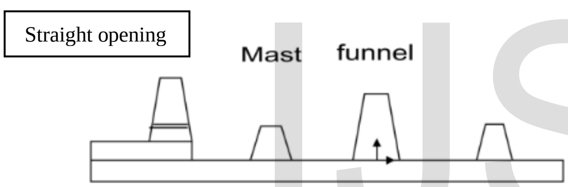
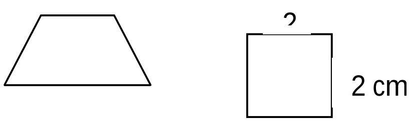


Fig3. Model of superstructure with straight opening



Front view **Side view**

Note: all the cross-section in cm^2

Case:2 In this modification in spite of straight opening 45 degree angle was provided at the end of the opening towards upward side with the same condition as in case1.

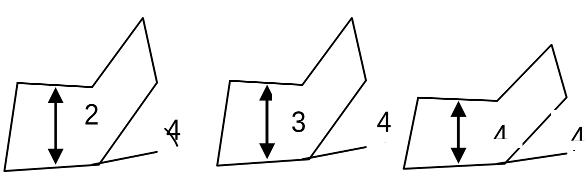


Fig4. Openings in mast with 45 degree bend with horizontal

Case:3 Modification in mast opening was done by taking case2(c) that maximum volume to be covered to reduce the low pressure zone to do that opening in the mast is done by providing 45 degree angle to the vertical and variation was provided in horizontal direction keeping all the velocities as in case 1

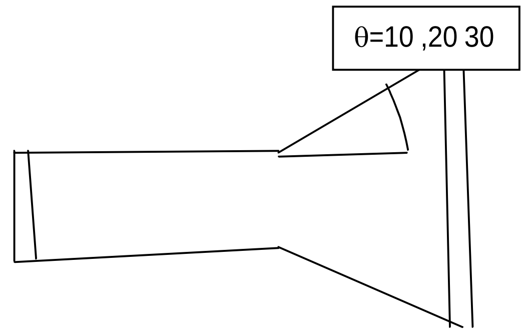


Fig5. Openings in mast with 45 degree bend with horizontal as well as vertical

Results and Discussion

Case:1

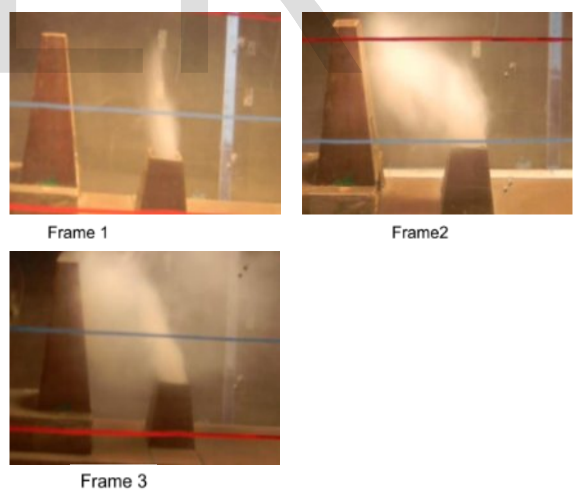


Fig6. Plume trajectory at k=0.5 with 2x2 cross-section throughout the mast straight opening 9cm above from the deck with gas turbine intake

To understand the effect of bluff body interaction on the plume path, the simplified superstructure as shown in Figure 6 has been studied in the wind tunnel. The location of the fwd funnel, with respect to the fwd mast, are shown the trajectory of smoke at various frames from the fwd funnel at K=0.5. At this this velocity ratio, the path of the smoke is seen that the plume bends towards the fwd mast. The wake generated from the upstream obstacle of the fwd funnel (bridge deck and mast) and gas turbine intake velocity generates a strong, negative pressure. But due to less cross-sectional opening and the plume does not have adequate momentum to overcome the wake. The plume path indicates that the complete smoke from the fwd funnel bends towards the mast and gets entrapped in the low-pressure region (wake region) between the mast and the funnel.

Case: 2 (a)

FRAME1

FRAME2

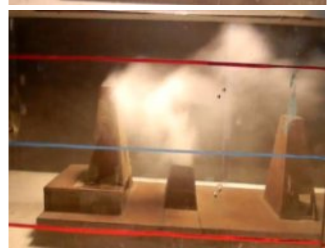
FRAME3

Fig7. Plume trajectory at k=0.5 with 2x2 cross-section throughout the mast with 45 degree opening and 9cm above from the deck with gas turbine intake

2(b)

FRAME1

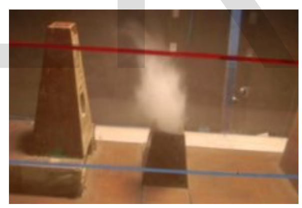
FRAME2



FRAME3

Fig8. Plume trajectory at k=0.5 with 3x2 cross-section throughout the mast with 45 degree opening and 9cm above from the deck with gas turbine intake

2(C)



FRAME1

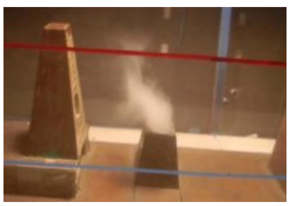
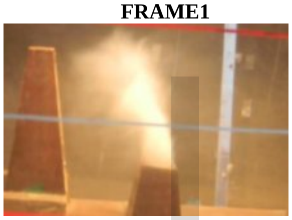
FRAME2

FRAME3

Fig7. Plume trajectory at k=0.5 with 4x2 cross-section throughout the mast with 45 degree opening and 9cm above

The trajectory of smoke for three openings in mast values at K=0.5 are shown in Figure. it is seen that as the opening provides an angle at the end with varying cross-sections the tendency of plume to bend towards the mast is different and less as compared to straight opening The wake generated from the upstream obstacle of the fwd funnel (bridge deck and mast) and gas turbine intake velocity reduce, negative pressure. An increase in opening and angle effect show the effective momentum of air is able to resist the plume to bend towards gas turbine but it is not effective for throughout the mast area because of cross flow and size of mast.

Case:3 (a)


FRAME1

FRAME2

FRAME3

Fig8. Plume trajectory at k=0.5 with 4x2 cross-section throughout the mast with 45 degree opening in horizontal and 10 degree vertical direction and 9cm above from the deck with gas turbine intake

3(b):

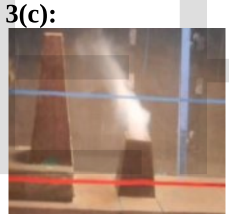

FRAME1

FRAME2

FRAME3

Fig9. Plume trajectory at k=0.5 with 4x2 cross-section throughout the mast with 45 degree opening in horizontal and 20 degree vertical direction and 9cm above from the deck with gas turbine intake

3(c):


FRAME1

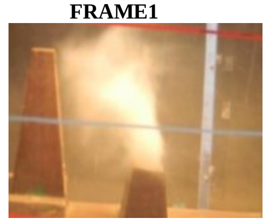
FRAME2

FRAME3

Fig10. Plume trajectory at k=0.5 with 4x2 cross-section throughout the mast with 45 degree opening in horizontal and 30 degree vertical direction and 9cm above from the deck with gas turbine intake

The location of the funnel, with respect to the mast, are shown the trajectory of smoke at various frames from the funnel at K=0.5 and cross section 4x2 with outlet angles(10,20.30) at opening. At this velocity ratio and design in opening, it is observed that by varying cross section in opening and variation in angle at the outlet of opening provides better arc of plume trajectory as compared to other cases. In frames it is seen that the clearance of plume from the deck is more that show the reduction of negative pressure due to the mast and gas turbine.As the cross sectional area at outlet will increase momentum of air will be less but the cross flow volume will be more to resist the bending of plume towards the mast

Conclusion:

Case:1 straight opening in mast

The plume trajectory from the funnel at k=0.5 with cross section 2x2 is found to be unacceptable wherein the effluent from the opening is found to have insufficient momentum to reduce the negative pressure the vortices and eddies behind superstructure, as well as into the GT intakes. Cross section increase is necessary to clear the plume from the wake of a funnel or superstructure and prevent ingress into GT intakes.

Case:2 (a,b,c) Opening in mast throughout cross section with angle at outlet

At k=0.5 with cross section (2x2, 3x2, 4x2) an outlet angle 45 degree , as the opening cross section increases the tendency of bending of plume trajectory is less due to increase in volume flow. The mast is still able to draw the vortices and eddies behind the structure due to narrow volume flow. Outlet angle increase in trapezoidal is acceptable to give more volume flow of air in cross flow to reduce the bend of plume.

Case:3 (a, b, c) Opening in mast throughout cross section with trapezoidal outlet

The plume trajectory from the funnel at k=0.5 with cross section 4x2 , 45degree bend angle, increasing vertical angle(10,20, 30 degree) is found to be acceptable wherein the effluent from the opening is found to have sufficient momentum and volume flow of air to clear the deck. Presence of intake at the base of the mast in a pressure deficit region induces the exhaust gases to be sucked into the GT intakes. The exhaust descends low enough that the exhaust smoke can get sucked into the GT intake.

REFERENCES:

1.Sherlock RH, Stalker EA. A study of flow phenomenon in the wake of smoke stacks. Eng Res Bull, Univ Michigan 1941:44

2. Nolan RW. Design of stacks to minimise smoke nuisance. Trans SNAME 1946;54:42–82.

3. Acker, H.G., "Stack Design to Avoid Smoke Nuisance", Trans SNAME, Vol. 60, 1952, pp. 566-594

4. Ower E. and Third A.D, "Superstructure Design in Relation to the Descent of Funnel Smoke", Trans. Institute of Marine Engineers (London), Vol. 1, 1959, pp. 109-138..

5. Third AD and Ower E., "Funnel Design and Smoke Plume", Trans. Institute of Marine Engineers (London). Vol. 72, 1962, pp. 245-272

6.Baham Gary J. and D. McCullum, "Stack Design Technology for Naval and Merchant Ships", trans SNAME, Vol. 85, 1977, pp. 324-349

7. Seshadri V, Singh SN. Wind tunnel studies to obviate the problem of unwarranted rise in air intake temperatures of gas turbines in naval ship. Technical Report, Applied Mechanics Department, IIT Delhi 2000.

8.Kulkarni P.R., Singh S.N., Seshadri V., Nagababu G., "Study of Exhaust Smoke Ingress into GT Intake in Naval Ships", International Conference in Maritime Hydrodynamics 2006, Visakhaptnam, 5-7 Jan. 2006, pp, 847-858

9. Seshadri V, Singh SN, Kulkarni PR. A study of the problem of ingress of exhaust smoke into the GT intakes in naval ships. J Ship Technol 2006; 2(1):22–35

10. Vijayakumar R., Seshadri V., Singh S.N., Kulkarni P.R., "A Wind Tunnel Study on the Interaction of Hot Exhaust from the Funnel with the Superstructure of a Naval Ship", Oceans 2008, Kobe, Japan 18-21,April 2008