Rebuttal to the Indian Reviewer

We thank the reviewer for giving his valuable time to evaluate the thesis, and suggest constructive comments in order to improve the thesis.

Question #1: Page 2: "Depictedin" is used as one word. There are many mistakes like this. These mistakes should be corrected. I will point out few of them. (i) Page 8: "Outon" and "orderto" are used as single word. (ii) Page 13: "Inferred emission" should be corrected. (iii)Page 18: "employednear" and "diameter" need to be corrected (iv) Page 22: Correct "beenused" and " ε model".

Answer: These typing errors have been corrected and the corrections are incorporated in revised thesis. (Pages: 2, 7, 8, 13, 17, 22)

Question #2: Section 1.2.1, Page 3: How is drag reduction study by Bruneau et al. (2010) related to jet entrainment?

<u>Answer:</u> It was wrongly written in the thesis. However, they used flow methods such as the use of porous layer to control the flow over the Ahmed body. Here, we mean to say that by the use of passive techniques the flow can be controlled. The drag reduction is not at all related to jet entrainment. The author means to say that both the flow past the Ahmed shaped body and IRS device use passive techniques. Corrections are inserted in **Page 3**.

Question #3: Page 16: There is a mistake in equation 2.2.

Answer: In Eqn. 2.2 (i.e., $m_{out} = \int_{0}^{r_{tf}} 2\pi r \rho(T) V(r) dr$) the integrand "dr" was missing. Now it is corrected. (Page: 17)

Question #4: Fig 2.3, Page 17: There is no mention about the justification in using four funnels. What are the lengths of the funnels used?

Answer: We varied the number of funnels from 1 to 5 in a real life IRS device. Then we carried out the computational investigation for the mass suction into the IRS device, and we found that the maximum mass entrainment is achieved when the IRS device contains four funnels. We used

this inference to construct the laboratory scale IRS device. Therefore, in the laboratory scale IRS device we used only four funnels.

For the laboratory scale IRS device, the length of funnels is called the height of funnel. The non dimensional funnel heights are $H_f / D_{nz} = 14,20,16$, and 12, respectively from bottom to top of the device. These values have been mentioned in revised thesis in **Page No: 14.**

Question #5: The role played by another cylindrical computational domain on the numerical simulation is not clear. It should be clarified.

Answer: Since the air entrainment takes place from the ambient through the peripheral openings of the IRS device, another cylindrical computational domain has been placed around the IRS device. This bigger computational domain acts as the ambient from where the cold air is sucked when the combustion products (here, either cold or hot air) is ejected into the IRS device.

Question #6: The justification for using constant conductivity and viscosity for hot fluid should be mentioned.

<u>Answer</u>: The entrainment study carried out by Mishra and Dash (2010 a, b) reported that the thermal conductivity and viscosity of the fluid was weakly dependent on the temperature. In their study, the air entrainment into a louvered funnel has been investigated using both cold as well as hot (Tnz= 300-700 K) nozzle fluid. Therefore, we derived the confidence from their study to use the constant thermal conductivity and viscosity in our present study.

Question #7: Section 2.3.2, Page 20: The adiabatic wall assumption for thin wall is difficult to justify. There should be relook at the adiabatic assumption with appropriate clarification.

Answer: Since in our experiment Perspex funnels have been used and a negligible amount of heat transfer takes place through the Perspex funnels, so the adiabatic boundary condition at the funnel walls may be appropriate. Moreover, the radial temperature variation through the walls of the Perspex funnels is negligible as the wall-thickness is very small. Therefore, the adiabatic boundary condition may be suitable for the present numerical simulations.

Question #8: Page 21: (i) what is Re? (ii) Correct the typing error" imperical".

Answer: E is wrongly written as Re. The correction has been incorporated in the revised thesis. The typing error is also corrected. (Page: 21)

Question #9: Section 2.3.2, Page 21: The implementation details of equation 2.17 and 2.19 are not clear.

Answer: The semi-empirical formulas called the wall functions are used to bridge the viscosity affected regions between the wall and fully turbulent region. Due to the wall function the necessity for modification in the turbulence model is obviated. Equations 2.17 and 2.19 represents the standards wall functions as has been suggested by Launder and Spalding. The equation 2.17 represents the non-dimensional velocity (U*) which relates the non-dimensional (y*) with the average velocity at a point 'P' in the flow field in terms of the turbulent kinetic energy (k_p) and wall shear stress. Similarly, the y* in Eqn. 2.19 represents the non-dimensional distance of the first grid distance from the wall.

Usually, the standard wall functions are suitable for high Reynolds number flows to model the highly viscous region near the wall where the solution variables change most rapidly because of the presence of wall. The viscosity affected regions are not required to resolve when the wall function approach is implemented.

Question #10: Figure 2.5 (i) The inset is not visible (ii) There is an error as "Pressure out inlet" (iii) There is no reference year of Hinze et al.

Answer: (i) Two separate figures (Fig. 2.5(a) and (b)) have been incorporated and the enlarged inset has been shown in Fig. 2.5(b). (**Page: 23**)

(ii) This error has been corrected in Fig. 2.5(b). (Page: 23)

(iii) The reference year of Hinz et al. is corrected in the revised thesis. (Page: 23)

Question #11: Figure 2.4 and 2.5: The author compares his simulation with experiment in literature. It is not clear, why the author has not used his own experimental data for validation.

Answer: The author has tried to compare the numerical simulation with experiment in literature so as to gain a confidence that the present numerical methods are working correct. Since there is

a dearth of literature in the field of air entrainment into an IRS device, the validations shown in Figs. 2.4 and 2.5 have been done for a free jet.

The present computational as well as the numerical results have been shown in the results and discussion section (Chapter-2) which may be considered as one way of validation for the appropriateness of the computational schemes.

Question #12: Fig. 2.6, Page 24: (i) What is the inset in Fig. 2.6? (ii) The reference Ricou and Spalding is not [28]. It should be corrected.

Answer: (i) In Fig. 2.6, the left hand inset shows the grid arrangement and the right hand inset shows the velocity vectors for the evolution of the jet (i.e., free jet) in the ambient air as well as the entrainment of air into it. (**Page: 25**)

(ii) The reference for Ricou and Spalding is corrected. (Page: 24)

Question #13: Fig. 2.8, Page 27: The lines used in legend of Fig. 2.8 are not clear. It should be corrected.

Answer: In Fig. 2.8, the continuous lines represent CFD results and the symbols represent the results obtained from the present experiment. The legends are now more clear by incorporating "Continuous Lines: present CFD" and "Symbols: present expt." in Fig. 2.8. (**Page: 27**)

Question #14: Page 28: The author discusses the role played by turbulent eddies on the entrainment. However, no data on the turbulent fluctuation are presented in the thesis.

Answer: The entrainment of air into a jet body is strongly dependent on the appearance of eddies at the outer edge of the jet which is called the free shear layer. Although the author has discussed the importance these eddied in the entrainment process, the data related to the formation of eddies are not discussed in the thesis as the RANS equations are used to compute the entrainment of air. In RANS equations, it is not possible to capture the turbulent fluctuations because it averages (i.e., time averaging) the fluctuation quantities.

Question #15: Fig. 2.9 (a) what is the unit of entrainment color scale? (b) What is the unit of pressure scale?

Answer: In Fig. 2.9 (a) the unit of entrainment color scale is m/s, since this figure represents the velocity vector during the entrainment. (**Page: 29**)

Fig. 2.9 (c) the unit of entrainment color scale is Pascal. (Page: 29)

Question #16: Fig. 2.10, Page 31: It is difficult to distinguish the lines used for CFD simulation in the graph.

Answer: The legends in the figure have been changed to distinguish the lines used for CFD simulation. (Page: 31)

Question #17: Fig. 2.11, Page 33: (i) Correct "overalp", (ii) The lines used for CFD simulation is not possible to distinguish.

Answer: (i) The spelling mistake is corrected; (ii) The legends for CFD simulation are changed. (Page: 32)

Question #18: Chapter 2: If the objective is to suppress IR signal, it is not clear why the author does not report the temperature data at all.

Answer: The objective of the present thesis is to investigate the air entrainment rate in terms of different pertinent parameters (i.e., nozzle Reynolds number, funnel overlap height, distance of the nozzle from bottom funnel and outlet temperature etc.) for a real life IRS device so that the developed correlations equations will be used for designing the real IRS device. The correlation equations are given in Chapter-3. The decrease in the funnel outlet temperature has been shown in Fig. 3.7, (Page-50, 51 in Chapter 3) for a real life IRS device. Since the present experimental set up is only a laboratory scale IRS device, all the variables in wide ranges have not been considered.

Question #19: Section 3.2, Page 39: Author mentions that the real life scale is much higher than their laboratory scale. The scale ratio should be mentioned.

Answer: The laboratory scale IRS device has been designed using four funnels of different diameters (Df= 8 cm, 11 cm, 14 cm, 18 cm, respectively from bottom to top). These particular values of the diameters have been selected because of the availability of Perspex funnels in the market. Similarly, the heights are: 30 cm, 25 cm, 20 cm and 15 cm, respectively from the bottom

to top. The computations as well as experiment have been carried out with this laboratory scale IRS device to obtain the air the entrainment.

In real life situations, the diameters of the funnels are very larger than that of the laboratory scale IRS device. For example, the diameters of the funnels in Series-5 are: 108.32 cm, 120.56 cm, 130.35 cm and 138.3 cm, respectively. Moreover, five different diameter series (S1-S5) have been used for the real life IRS device. Therefore, we have not used any scale for the present work.

Question #20: Section 3.2, Page 39: There should be discussion on dynamic stability to justify the conditions used by the author.

Answer: The gravity force acting at the center of the gravity and the buoyancy force balances with each other on the center line of the vessel when the vessel is upright. An extra weight has been added on the vessel when the IRS device is installed. This extra weight shifts the center of gravity to up thereby the upper portion of the ship becomes heavier. Also, the ship rolls at a higher angle due to a higher external force. An IRS device causes a higher external force to act on the ship when wind flows past it. The external force as well as shifting of center of gravity affects the stability of the ship.

This explanation has been added in the revised thesis (Page: 39& 40).

Question #21: Fig. 3.2, Page 41: The author does not mention about the correlation eqn. 3.1 and 3.3 used in the figure inside the text.

Answer: The descriptions for the above equations have been incorporated in the revised thesis. (Page: 41)

Question #22: Page 42: The author mentions that they have used temperature ratio between1-2. Check if it is 1-1.66?

Answer: Yes, we have used the temperature ratio between1-2. The reviewer may be confused as the temperature ratio shown in Fig. 3.3 (**Page- 43**) lies in between 1-1.66. Since it is a representative plot, we have shown the temperature ration in between 1-1.66.

Question #23: Fig. 3.3, Page 43: Cannot differentiate between the lines used as the temperature scale.

Answer: The continuous lines represent the present CFD results and the dashed lines represent correlations developed from CFD data. Fig. 3.3 is changed in the revised thesis. (**Page: 43**)

Question #24: equations 3.1, 3.2, 3.3, 3.4, 3.4, 3.5, 3.6: Author should add the conditions for validity of each equation below these equations. At present, the conditions are specified in paragraph mode below it and it is difficult to read and understand.

Answer: The conditions for validity have been given below each equation as suggested by the reviewer. (Pages: 44, 46 and 50)

Question #25:Fig. 3.4, Page 45: (i) what is the equation no 16? (ii) It is not clear what experimental conditions were used for correlation development.

Answer: The Eqn. 3.2 was wrongly written as Eqn. 16. Eqn. 3.1 was wrongly written as Eqn. 15. These are corrected in the revised thesis and incorporated in Page: 45. The correlation equations (Eqns. 3.1 and 3.2) are developed from the CFD data obtained from the numerical simulation of real life IRS device. (Page: 45)

Question #26: Fig. 3.5, Page 46: (i) What are equations no 17 and 18? (ii) It is not clear what experimental conditions were used for correlation development.

Answer: The Eqn. 3.4 was wrongly written as Eqn. 17. Eqn. 3.4 was wrongly written as Eqn. 18. The correction is incorporated in **Page: 46**. For these equations, CFD data have been used to develop the correlations.

Question #27: Fig. 3.6, Page 47: The lines used in plots cannot be distinguished from each other.

Answer: Fig. 3.6 (**Page 47**) has been modified by thickening the legend lines in order to have a clear visibility. The continuous lines represent the CFD results and the dashed lines are the correlation results.

Question #28: Fig. 3.9, Page 50: What is the meaning of color scheme used?

Answer: In Fig. 3.9, **Page 51:** the color schemes are means of visualization for fluid particle path lines during its suction into the IRS device.

Question #29: Section 4.2.1, Page 55: Is it not a repeat of section 2.3.1?

Answer: We agree with the reviewer that this section is a repeat of the section 2.3.1. Therefore, the equations are not rewritten in section 4.2.1 in the revised thesis (**i.e., Page 56**). However, the present computations in Chapter 4 have been carried out for a three-dimensional computational domain using isothermal nozzle fluid. Thus, the energy equation is not required to solve, and the buoyancy term in the momentum equation disappears.

Question #30: Section 4.2.2, Page 56: How is this section different from Section 2.3.2?

Answer: In Section 4.2.2 (**Page: 56**), the conditions are imposed on the computational surfaces since the geometry is a three dimensional computational domain. But the boundary conditions in section 2.3.2 are imposed on the computational edges, since the numerical analysis has been carried out for a two-dimensional axisymmetric geometric. Therefore, we felt to retain this section in Chapter 4.

Question #31: Section 4.2.3, Page 57: How does it compare with section 2.3.3?

Answer: In section 4.2.3 (**Pages: 57-58**) the computation was done for a three dimensional computational domain, and in section 2.3.2 the computation was carried out for two-dimensional axi-symmetric domain. So we retain this section in this chapter.

Question #32: Fig. 4.10, Page 66: (i) Change the caption "effect...." To "Effect of.....", (ii) What is the unit of the color scale used?

Answer: This error is corrected and is incorporated in **Page 66**. The color scale has been used to show the static pressure variation. Its unit is Pascal.

Question #33: Fig. 4.11, Page 67: (i) What does the color scheme represent? (ii) The corresponding temperature distribution needs to be mentioned for better clarity.

Answer: (i) In Fig. 4.11 (**Page 68**) the color scheme represents the velocity contours and its unit is m/s.

(ii) In Chapter 4, the nozzle fluid is isothermal, so the temperature contours can't be shown. This chapter has been done to see the effect of multiple circular and non-circular nozzles on isothermal air entrainment.

<u>Question</u> #34: Fig. 4.12, Page 68: (i) What does the color scheme represent? (ii) The corresponding temperature distribution needs to be mentioned for better clarity.

Answer: The present answer is same as that of the previous answer. (Page: 68)

Question #35: Chapter 5: Overall conclusion from the thesis should be mentioned in addition to "Scope of future work".

Answer: Sections 5.1-5.3 (**Page: 70-72**) are incorporated in the revised thesis for the overall conclusion of the thesis.