International Journal of Mechanical and Thermal Engineering

E-ISSN: 2707-8051
P-ISSN: 2707-8043
IJMTE 2022; 3(1): 26-34
Received: 23-11-2021
Accepted: 30-12-2021

Mahendra Petale
Engineering Research Centre, Tata Motors Ltd., Pune, Maharashtra, India

Avinash Nikam
Engineering Research Centre, Tata Motors Ltd., Pune, Maharashtra, India

Indranil Dey
Engineering Research Centre, Tata Motors Ltd., Pune, Maharashtra, India

Corresponding Author:
Mahendra Petale
Engineering Research Centre, Tata Motors Ltd., Pune, Maharashtra, India

Heat ingress mitigation in driver cabin and driving comfort enhancement using CFD for off-road vehicles

Mahendra Petale, Avinash Nikam and Indranil Dey

Abstract
The Indian Tipper truck market was 1.65 $ billion in 2020 and it is projected to grow 11% in coming 5 years due to increasing numbers of infrastructure projects and also due to governments new financing policies to support business endeavors and ease of business. Looking to this opportunity every manufacture is eying on market share and by this customer centric market share is always need of hour. As tippers are used for transporting materials and are involved in intense mining & construction operations in off-road which demands good amount of ground clearance due to this all important parts should be above chassis level height like Exhaust system to avoid damages due to off-road conditions, acting to this problem Engineers attempted and succeed to package Exhaust system vertically behind cabin & looking at application requirements also its operational intensity. We faced challenges to maintain balance between Engineering requirements and customer comfort, as customer dis-comfort Can be of any type related handling, atmosphere inside cabin etc. while vehicle operating.
Above scenario of discomfort was faced by customer i.e. cabin inside temperature increasing due to exhaust system packaging behind driver cabin.
This problem was resolved with an Engineering technology to perform analysis of different illustrations on virtual interface i.e. Computational Fluid Dynamics (CFD) analysis.
The design with most favorable CFD results further taken for physical validation and the thermal results inside cabin found within acceptable limits.

Keywords: Exhaust system, CFD analysis

1. Introduction
In today's scenario customer demand is prime focus for manufactures to maintain leadership position in market. For this manufactures are always trying to minimize gap between customer comfort requirements and Engineering requirements.
We have successfully attempted & packaged exhaust system vertically and it is novel design in MHCV vehicles as compare to competition. In attempt to have novelty in design i.e. vertical layout in heavy duty vehicles we phased certain challenges like cabin heat ingress which is resolved with continues CFD digital simulations.
To solve problem of "Heat Ingress inside cabin" few Design level steps were taken and vigorous virtual analysis with field analysis conducted. This resulted in significant reduction in "heat ingress" inside cabin and improved Driver and Co-driver comfort.
To understand level of discomfort and quantifying customer voice, thermal mapping was carried out at all potential areas i.e. inside cabin, outside Co-driver side, between exhaust & cabin side, load body surfaces with the base design of open box type diffuser.

Fig 1: Surface Source temperature of Engine and Peripherals

Table 1: Shows Max. Power and Highway Trials

SN	Description	Max. Power	Highway Trials
1	Oil Sump	87.8	87.8
2	Crank case	90	90
3	Cylinder head	95.1	95.1
4	Cylinder head cover	95.1	95.1
5	Exhaust Manifold	520	520
6	Turbo charger-Turbine	520	520
7	Turbo charger-Compressor	170	170
8	Pipe after turbo	265.2	265.2
g	Flange after turbo	480.2	480.2
10	First pipe after flange	141.1	130
11	Flex pipe-1	201.5	201.5
12	Pipe after flex pipe 1	141.2	141.2
13	Flex pipe-2	201.5	201.5
14	Pipe before EGP	219.2	194.7
15	EGP surface (DOC Side)	219.2	194.7
16	EGP surface (DPF Side)	162.7	162.7
17	EGP surface (Urea injector)	202.6	202.6
18	EGP surface (SCR side)	182.1	181.3
19	Pipe after EGP (Tail pipe)	390	390
20	Diffuser	365	365
21	Flywheel housing	80	80
22	Clutch housing	80	80
23	Gear box housing	91.2	91.2

Above Fig 1 is representing point where surface temperature of components measured at Max Power condition during Highway trial and Table 1 showing its measurements Max Power during Highway trial run. This help us to understand vehicle operating temperature & to take appropriate measures in mitigating temperature rise of cabin.

2. Thermal Mapping of Heat Prone Region

Tipper are prone to exhaust gas recirculation due to packaging of Exhaust system between load body/tipper body and cabin with this scenario Engineers prudently package Exhaust open box type diffuser to avoid direct exposure exhaust gases to load body and to clear CMVR norms (Central Motor Vehicle Rules).

To understand the system hot regions thermal mapping was carried out and by this process recirculation areas were identified. The results helped in taking key measures in diffuser design change from Open box type to Cobra type fluidic design and by finalizing its position to direct exhaust gas directly to atmosphere without any vehicle object interference.

Fig 2(a): Base configuration with box type diffuser

Fig 2(b): Open diffuser

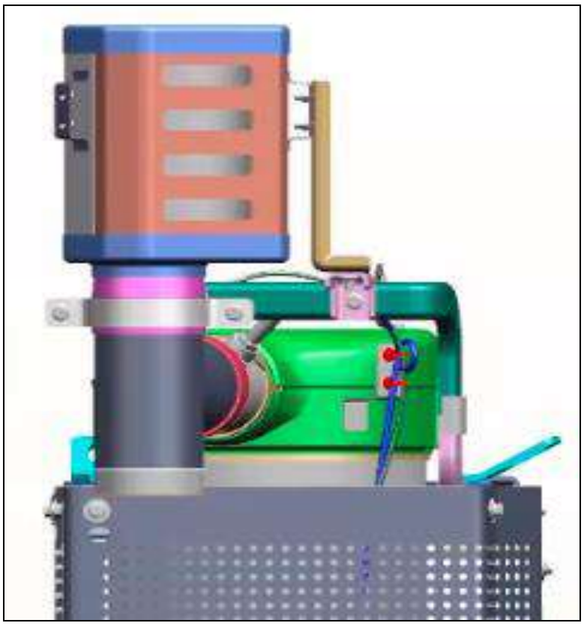


Fig 3(a): Box Type Diffuser

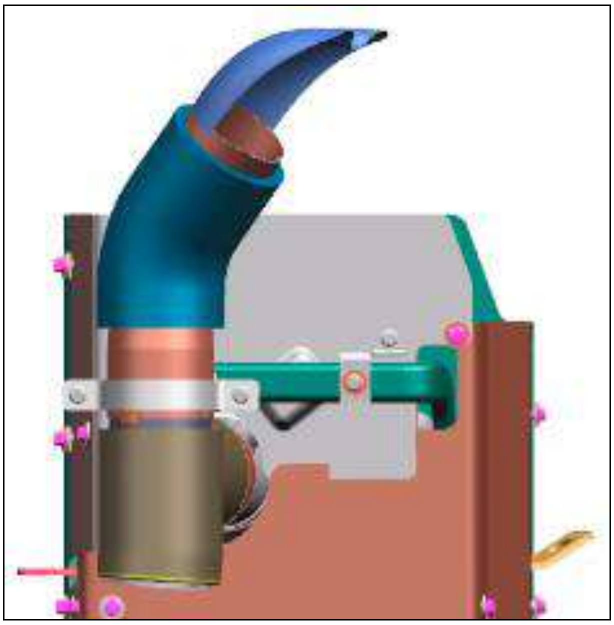


Fig 3(b): Open type Diffuser

Change of Diffuser design is key step towards resolving exhaust gases ingress in Driver cabin.

Previous design (box type diffuser) refer fig 2(a) was attempted to clear CMVR norms and as per norms packaging to be done within vehicle width and still exhaust gas to be directed to atmosphere. This was the initial Engineering prudent call taken, followed by new cobra type/open diffuser packaging with other key measures such as providing full length heat shield to EGP & air deflectors.

In addition, to above changes, air deflector were used at two locations to deflect hot gases coming from Engine & EGP.

Fig 4(a): Horizontal deflector

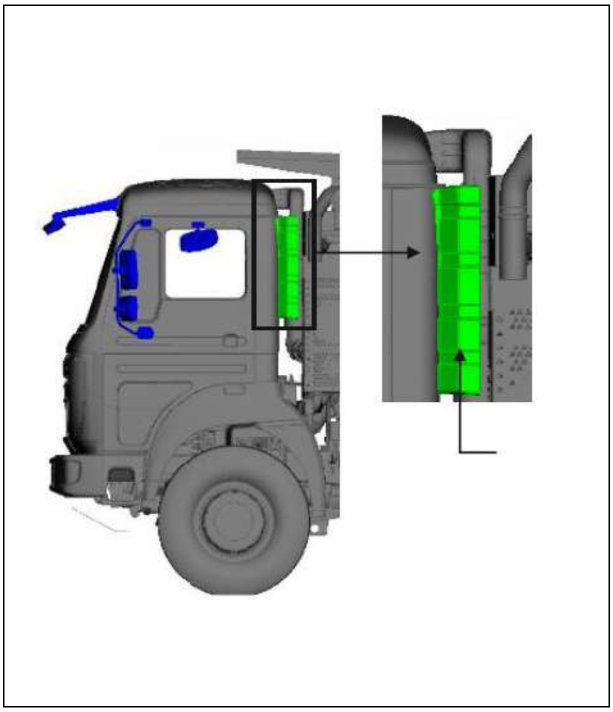


Fig 4(b): Vertical deflector

Fig 4. demonstrating deflector installation between engine & cabin refer fig 4(a) and deflector installed between cabin and EGP fig 4(b)

2.1 Digital Simulations in Running Condition

While driving the vehicle, there was challenge to establish hot regions mapping due to atmospheric conditions (temperature and vehicle speed etc.). To counter this challenge CFD (computational fluid dynamics) analysis has played a key role.

Temperature & velocity mapping at different sections of cabin were recorded with different running conditions and design iterations.

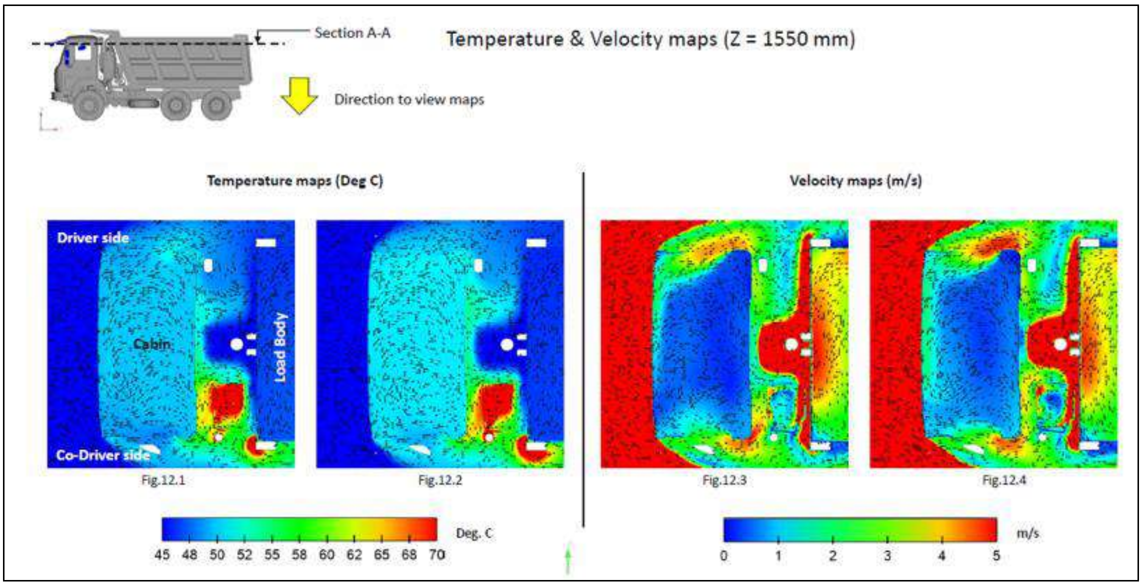


Fig 5: Temperature Vs velocity mapping at 1550mm from ground

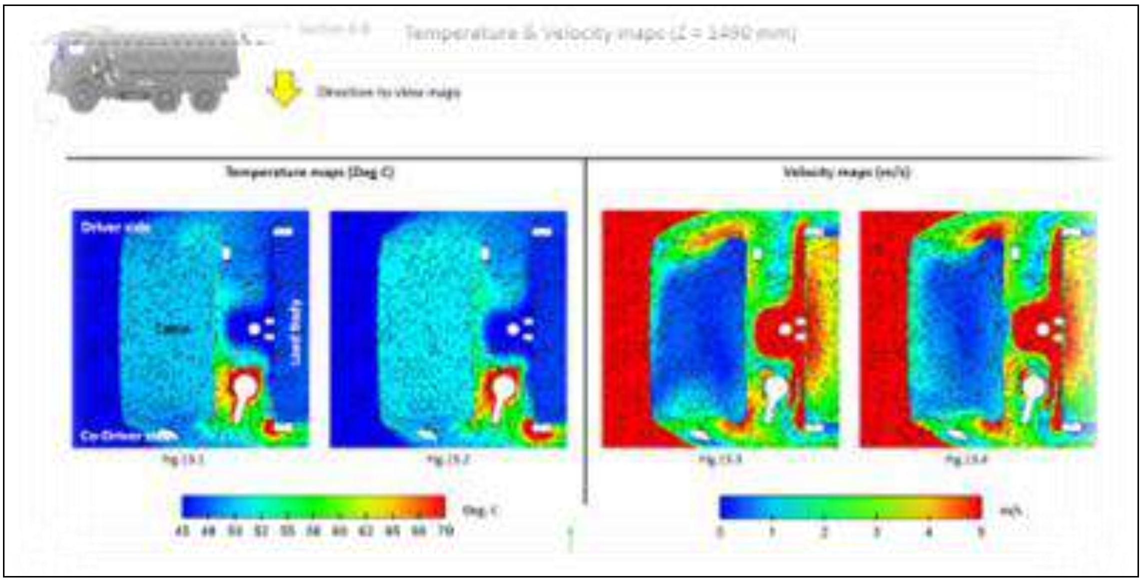


Fig 6: Temperature Vs velocity mapping at 1490 mm from ground

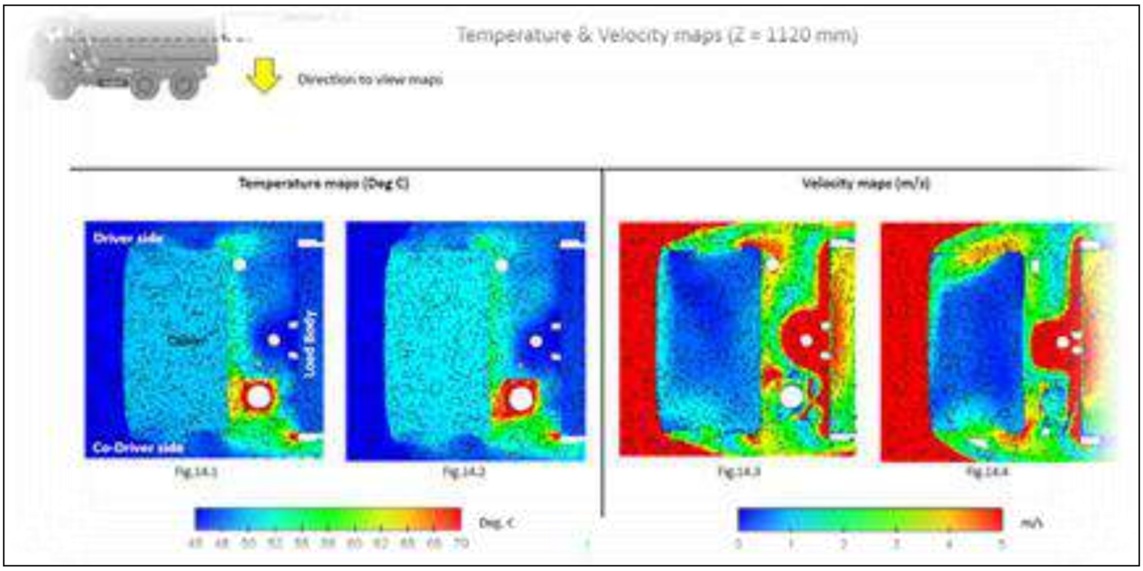


Fig 7: Temperature Vs velocity mapping at 1120 mm from ground

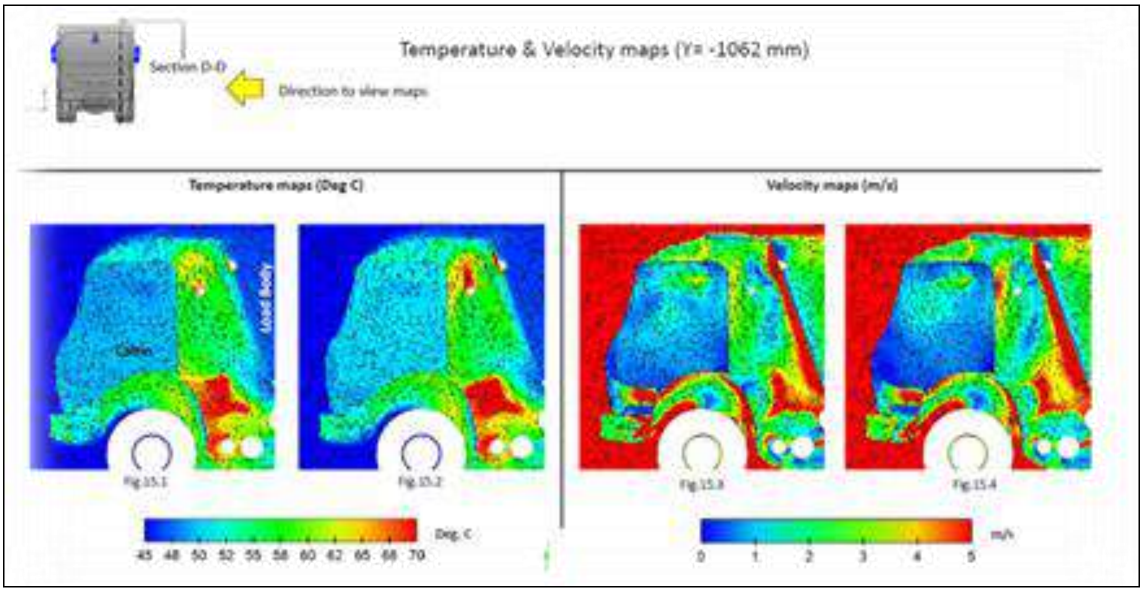


Fig 8: Temperature Vs velocity mapping at 1062 mm from vehicle center

Fig 5, 6, 7 & 8 CFD analysis showing measurement at different height zone of cabin to map temperature with different vehicle velocity.

3. Effect of Design Change

After all necessary decisions made such as diffuser type selection, heat shield at bare EGP area & air deflectors, it was still a challenge to package cobra type diffuser within vehicle width.

Certain iterations were performed to finalize diffuser angle which will direct exhaust gas away from load body and cabin.

Based on the CFD analysis further physical vehicle test was performed to verify design. Significant decrease in temperature observed.

Below Fig 9 & Fig 10 are analysis carried out on vehicle and measurement observed.

In Cab temperature comparison: Highway

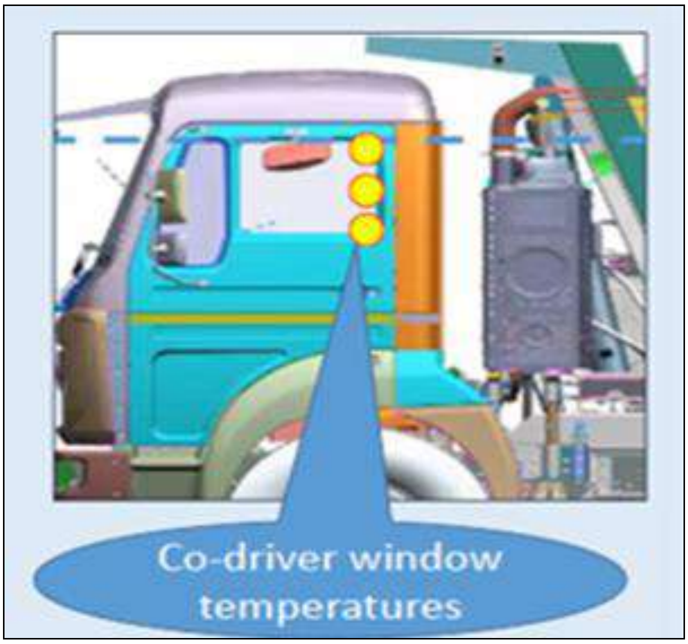
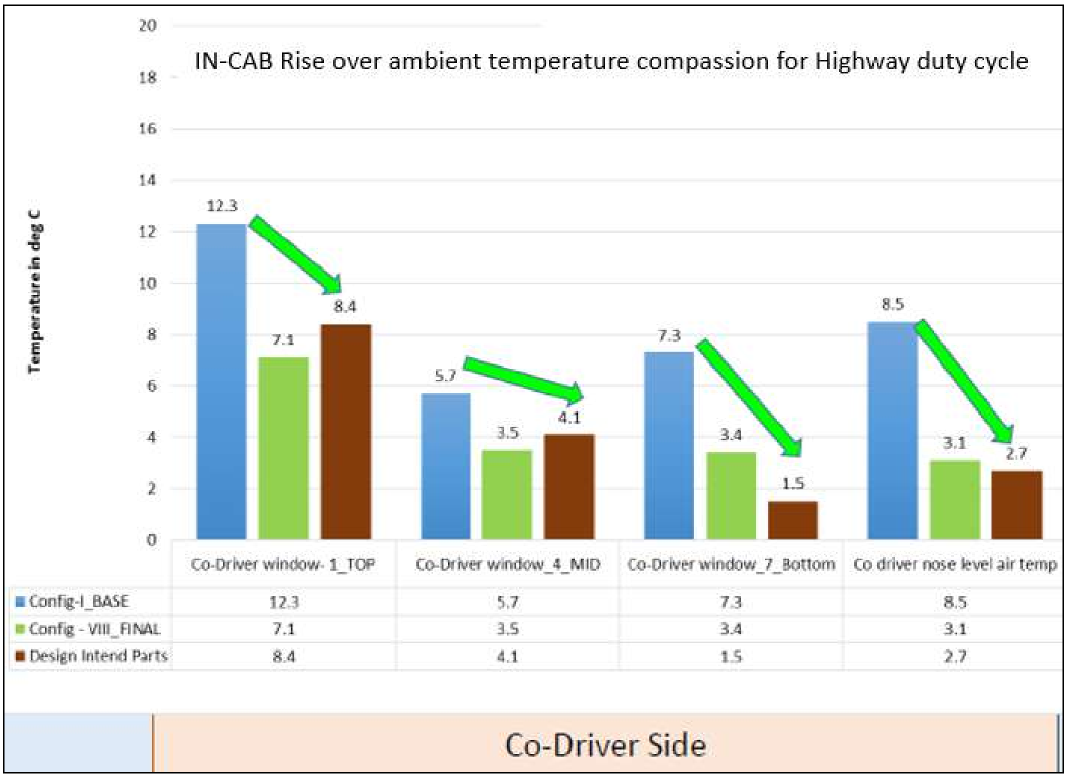
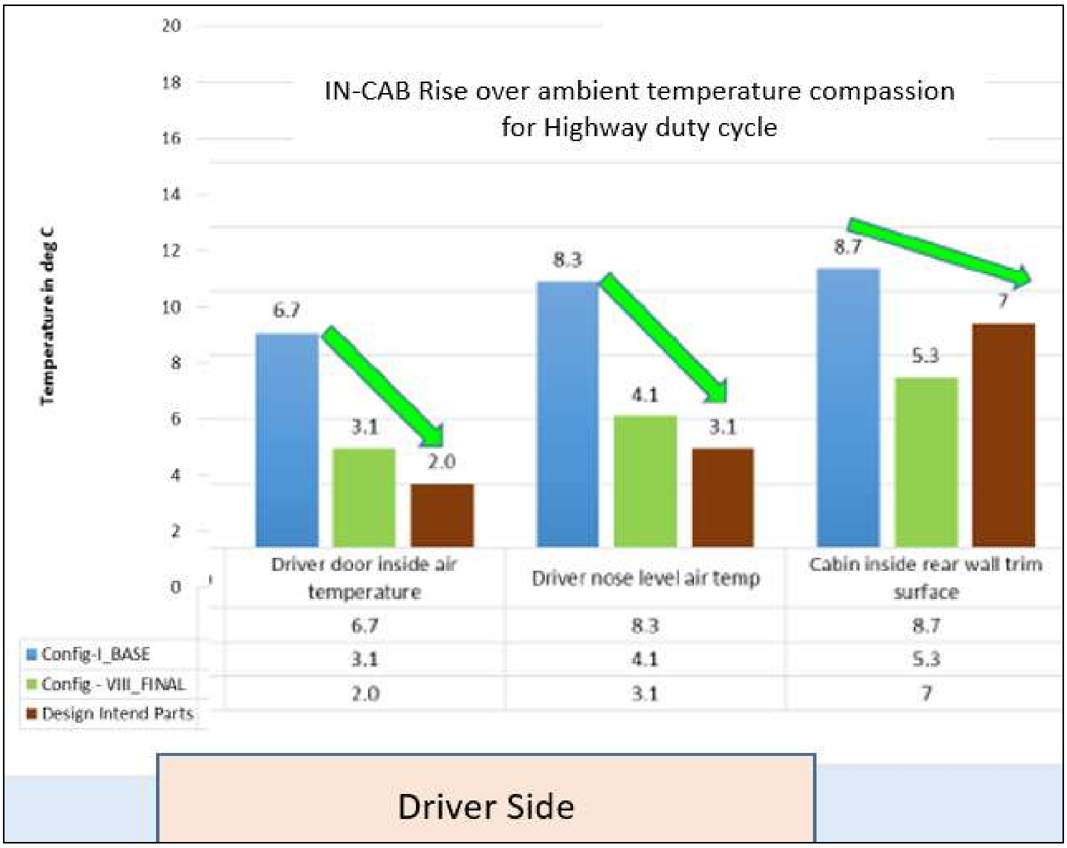


Fig 9: ROA-Rise Over Ambeint Measurement





	Driver door inside air temperature	Driver nose level air temp	Cabin inside rear wall trim surface
Config-I_BASE	6.7	8.3	8.7
Config - VIII_FINAL	3.1	4.1	5.3
Design Intend Parts	2.0	3.1	7

Fig 10: Cabin temperature comparison at highway for Co-driver and driver.

All the Engineering efforts in finalizing diffuser angle resulted in decrease of 3.9 deg c temperature at co driver window top and inside cabin temperature. Refer comparison Chart 1 & 2.

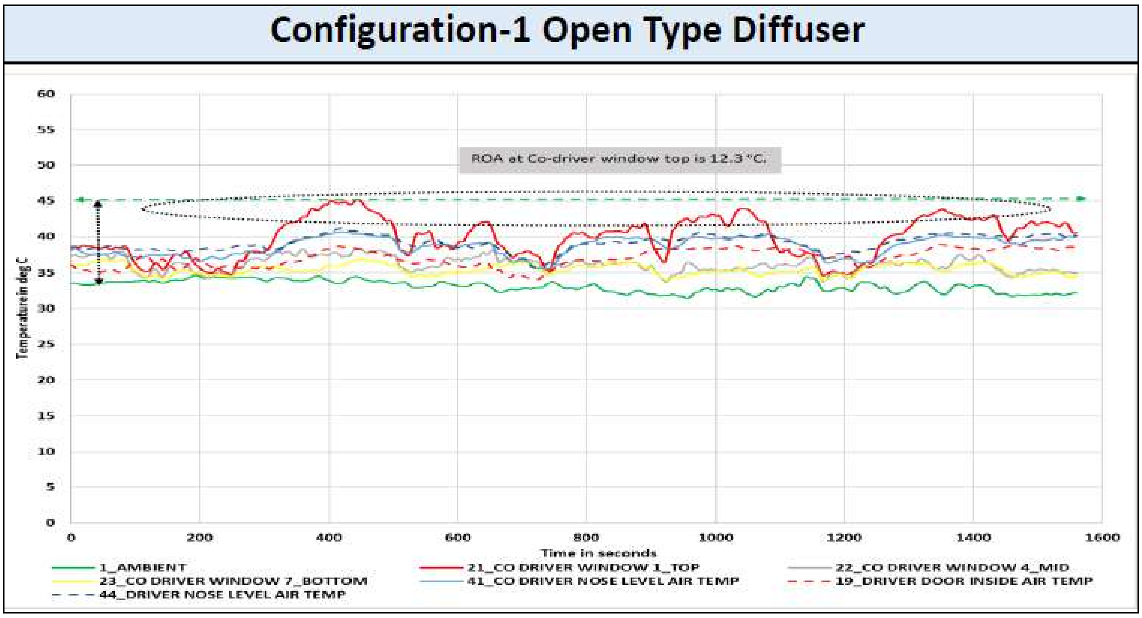


Chart 1: Configuration-1 Open Type Diffuser

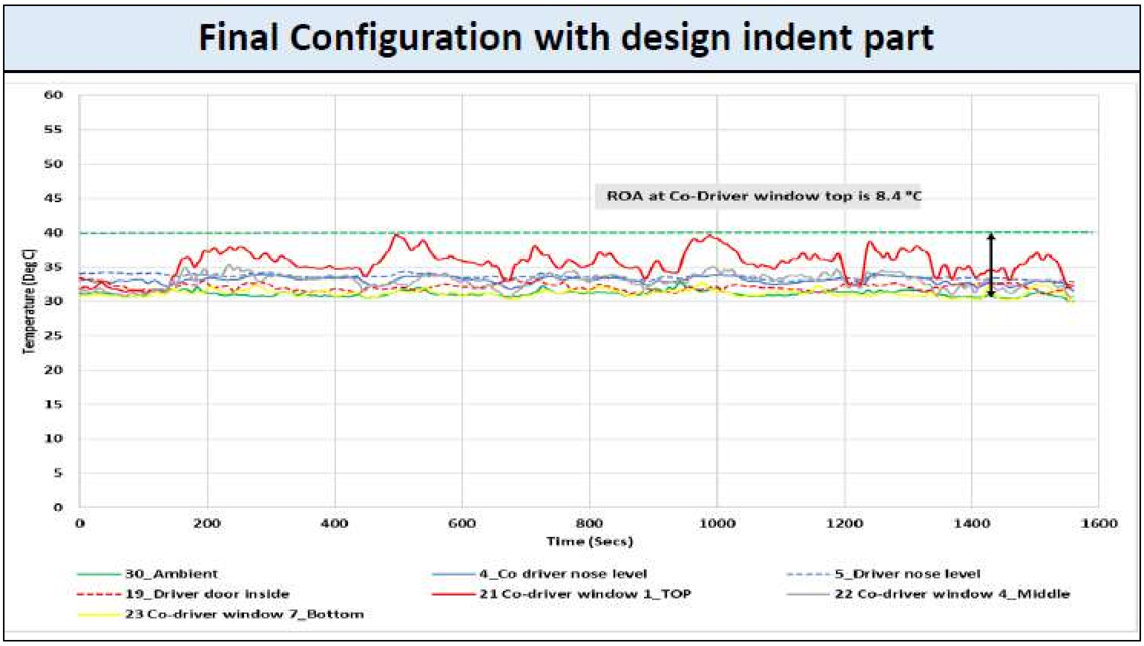
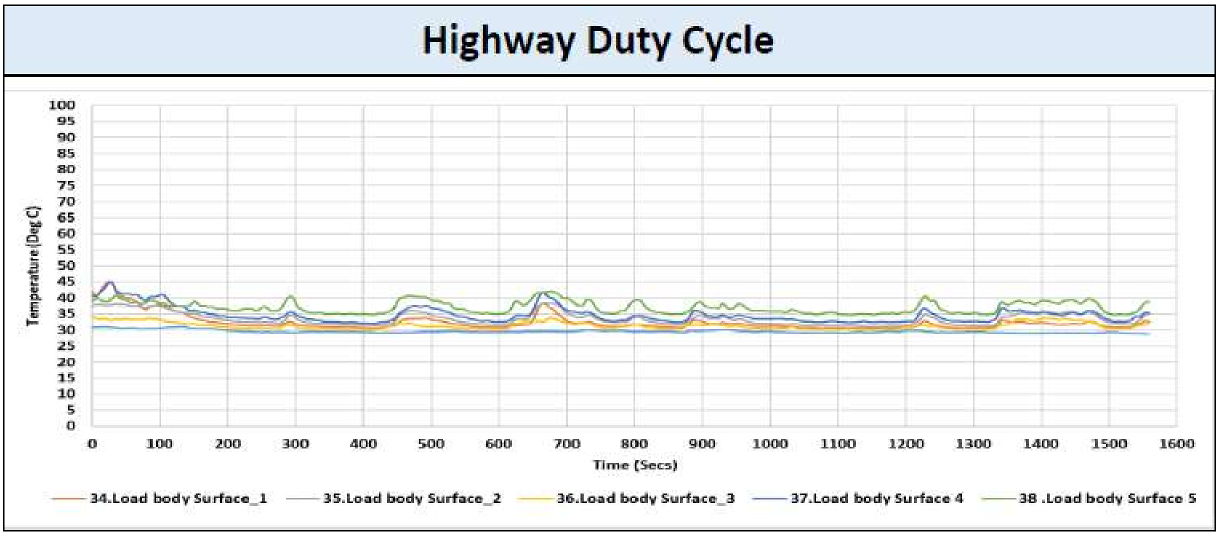


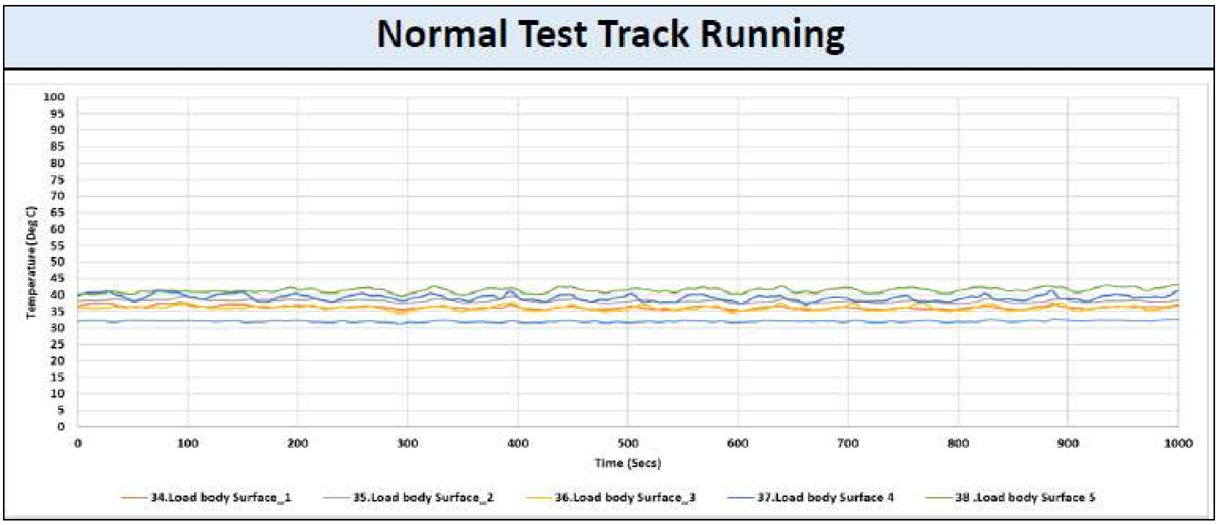
Chart 2: Temperature comparison between angled diffuser vs base line open type diffuser design

3.1 Peripheral Parts Surafce Temperature Analysis

Due to vehicle running conditions in field, vehicle testing at rated condition conducted and skin temperature of load body recorded.

In chart 1.3 the comparison of skin temperature with final diffuser orientation measurement shown.





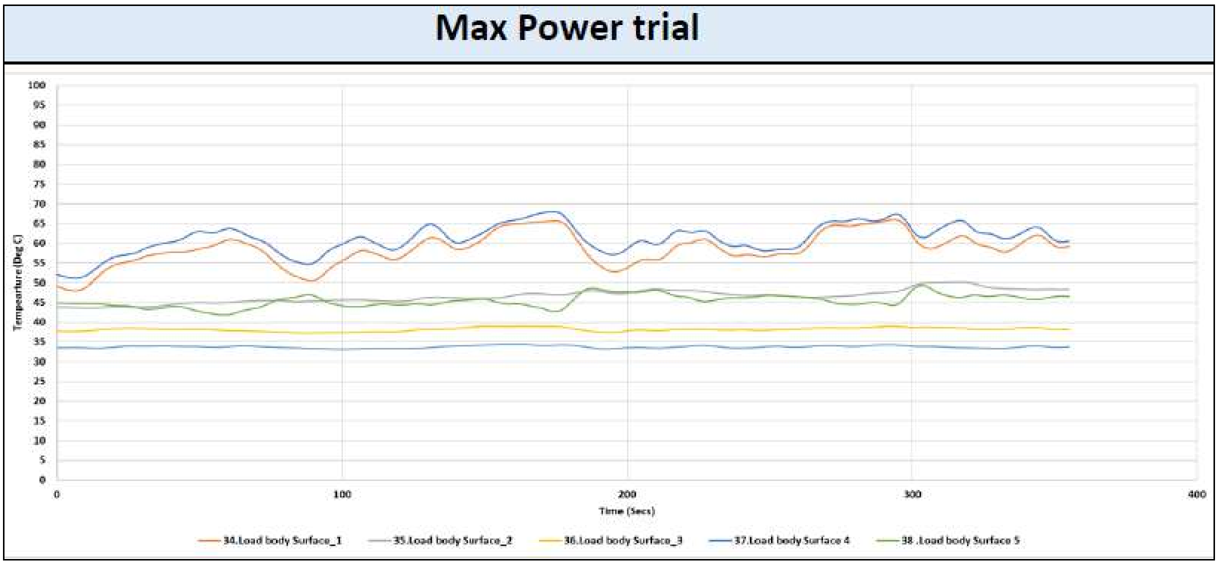


Chart 3: Load body surface Temperature mapping

4. Conclusion

- Tipper Application vehicles with vertical exhaust is challenging with regards to Exhaust system packaging which result in "hot gases ingress inside Co-Driver cabin these challenges are resolved by Engineering efforts with help of Virtual analysis capability and followed by vehicle level test.
- Initially ROA (rise over ambient) Temperature inside cabin was 12.3 dec C and final design ROA is 8.4 deg C. Total 3.9 deg C temperature drop measured.
- Conventional method opted of introducing heat shield and system validation with vehicle level analysis resulted in no level of thermal discomfort to driver
- Co-driver rear top window frame level, No thermal discomfort was felt, however a gust of warm air felt while holding rain channel outside Co-driver window top rear side at high speed i.e. 40 kmph and above. No thermal discomfort was felt inside cabin at both driver and co-driver seat levels.
- Design improvements are acknowledged and perceived during trial at highway by Jury members.

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