Thermal Comfort Analysis for Two Tractors Based on CFD

Industrial Training Report

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Abstract

This report contains details relating to the compulsory industrial training that I have carried out as required for the Engineering degree at the University of New South Wales. It is written in the format set out by the School of Mechanical and Manufacturing Engineering. I have completed a total of 60 days of industrial training over my industrial training period.

During the industrial training process, I accomplished a major project and two minor projects, namely thermal comfort analysis on two tractors, analysis on a simplified add-on HVAC system for a tractor and analysis on the system's deicing function. They are all based on CFD, and the commercial software used is STAR-CCM+.

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CHAPTER 1

Introduction

This chapter briefly described the company I worked in during the industrial training period and the work I took there.

1.1 LUOYANG TRACTOR RESEARCH INSTITUTE CO., LTD

I completed my whole industrial training process in the CAE department of Luoyang Tractor Research Institute. Luoyang Tractor Research Institute is a national core research and development institute on tractors and other agricultural machineries.

The CAE department of the institute utilizes tools like FEM and CFD, as well as laboratory experiments with 3D printed prototypes to design and improve their products. It is responsible for providing feedback and advices on current products' design and performance, as well as future products. The institute covers a wide range of consulting projects like improvement of engines, valves, transmission systems and HVAC systems on agricultural machineries.

I was directly supervised by Mr. Fangyuan Liu and my director is Mr. Shuo Yu. As a associate engineer, I was assigned to analyze a main case of evaluating and improving the thermal comfort of two tractors' cabin. There are also two minor cases related to the main project as a further investigation, namely analysis on a simplified add-on HVAC system for a tractor and analysis on the system's deicing function.

One of the tractors involved in the main project (Type A) is one that already pushed into sale, and the feedback from the market reflected a less positive user experience in the cabin's HVAC system, so it is compared with Type B tractor, which is one from other company and got a better design for its HVAC system. After figuring out the problem in the original type, an advanced version (Type C), which is also a prototype that subject to change in further design procedure, is introduced as the platform of the two minor cases.

I worked at Luoyang Tractor Research Institute from 23 November 2017 to 14 February 2018 for a total of 60 working days.

CHAPTER 2

Engineers Australia Competencies

2.1 knowledge and skill base

1.1 Comprehensive, theory based understanding of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline.

My work at the institute is first of all related to HVAC, then it's a CFD problem. So it required me to have solid understanding of knowledge such as heat transfer and thermal dynamics. These knowledge formed the ground for my work.

I have both graduated from HVAC engineering in my bachelor's degree, and got a high score in the Refrigeration and Air Conditioning course (MECH4880), so I am very confident that I have those knowledge and engineering principles to accomplish the task.

1.2 Conceptual understanding of the mathematics numerical analysis statistics and computer and information sciences which underpin the engineering discipline.

Solid understanding of CFD theory and ability to use commercial softwares are crucial for my work at Luoyang Tractor Research Institute given the work is largely based on CFD analysis.

Since my work is to analyze the performance of the tractors' HVAC system using CFD, I had to ensure that I am able to handle the tool used confidently. I had completed the Computational Fluid Dynamics course (MECH4620) at university and I am doing my thesis based on CFD, so I am familia with basic principles of CFD analysis so as understanding and applying them to actual scenarios. However, the commercial software used in the institute is not ANSYS Fluent, which I used at university, but rather STAR-CCM+. So I had to get myself familia with the software and understand its operation and UI. It took me a week to familiarize myself with the software before cutting into the main project.

2.2 ENGINEERING APPLICATION ABILITY

2.3. Application of systematic engineering synthesis and design processes. Before all the simulation work were taken out, I did some research on the field of simulating the HVAC system in cars and cabins for other vehicles. I found that the study specifically on tractors was not as popular as that on passenger vehicles. However, the ideas are very similar. I developed a schedule for each of the three cases in order to proceed step by step.

The schedule for the main project is as listed:

1. Compare the wind field in simulation and the data gathered from experiment. At this stage, I set up the same sampling point according to the national standard GB/T 13877.2-2003 to verify the reliability of the model and mesh. This is to form a sound foundation for the following simulations.
2. Simulate the process of temperature rising in the cabin due to exposure to sun. This is to form a basis for validating the HVAC system's cooling ability.
3. After the air temperature got steady, activate the HVAC system to validate it's cooling capacity.
4. After all the previous tests are done and make sure that all the setups, including model, mesh and boundary conditions, all meet the requirements, introduce human model. Then the TCM model in STAR-CCM+ is activated to analyze the passenger's thermal comfort level.
5. Based on the previous results, adjust the angle of outlet panels to improve the passengers' thermal comfort level.

The process applies for both the tractors here.

2.1. Application of established engineering methods to complex engineering problem solving. During the process of generating the body mesh that is capable for calculation, many problems have occurred, and the experience I learnt from dealing with those problems was valuable. For example, assign inlet and outlet before generating the body mesh could form regular prism layers on the assigned surface. Compared to the standard process, which generates the body mesh before assigning function to surfaces, this method generates better mesh nearby the inlet and outlet, which reduces the instable level of the flow, and could provide a well developed initial fluid field.

After generating the initial body mesh, cell sets were introduced to see the cross section of the body mesh and check the mesh quality inside the domain. It can be found that under default settings, prism layers in some region will overlap each other, which will lead to unprecise results. I take some approach to improve the mesh quality in these regions. The approaches include increasing the mesh density in these regions, regenerate prism layers and so on.

The method to determine thermal comfort used in this project is mainly local mean vote (LMV), STAR-CCM+ can plot out LMV for each part of the human body, indicating if the part feels too hot or too cold. However, the software took the whole region's temperature and take an average, which does not reflect the real thermal feeling. Element like velocity would also affect the thermal feelings. In order to take those facts into consideration, distribution of velocity in the domain, streamline of velocity were also introduced as a reference.

Apart from that, mean age of air is also introduced using the function called "Passive scalar" to evaluate the HVAC system's ability to circulate the air.

After simulation were taken out, the result from comparison showed that the HVAC system's outlet distribution for A type is not ideal. The distribution leads coll air blowing onto the passenger's head and face straight, which is very uncomfortable; another disadvantage of the layout is that both the inlet and outlet are put on top of the cabin, which contributes to the poor air circulation at lower and back area of the cabin. While B type have a good design in this.

To achieve a better distribution in temperature field and prevent cold air from blowing directly towards the driver, I adjusted the inlet angle for A type. As for the method of adjusting the angle, what engineers do in previous projects is assigning different normal vectors perpendicular to the surface. This method is not as intuitive, so I used Euler angle to adjust the inlet direction, which is more intuitive, and is easier to do some small changes. After some tests, I found that pushing down the directing panels of A type could improve the degree of comfort, as well as improving the air circulation. Considering the real world scenario, keep pushing down the directing panels would reduce the amount of air, and could cause potentially worse cooling effect, so the final plan is to rotate the directing panel to -45°. It is found that for A type, adjusting the directing panels is a effective way of improving the degree of comfort.

Investigation to B type showed that the distribution of inlets and outlets is way better than A type, changing its directions would not make huge different, so the original design is considered as excellence.

Above is the analyzing for the main project, the two minor projets are based on C type.

- Minor project 1: Air duct and blower system
  The boundary conditions used for the main project, especially the inlet velocity and direction, are at simplified and ideal condition. It does not take filter and air duct into consideration, which would potentially affect the amount of air blowing in. And due to regulations from HVAC industry, there should be a positive pressure in the cabin. To obtain a more accurate boundary condition, I introduced a simplified HVAC system for the tractor, which contains filters for both fresh air and return air, air ducts, and blowers, etc. Note that the cabin in real world should not be a perfectly sealed space, air would leak out from gaps between windows and doors. To simulate those leakage, I opened 20 little gaps at the back of the model, which also made adjusting the amount of leakage a easy job.
  The newly introduced HVAC system brought some new challenges such as the setting for the rotating blower fins, calculation for the filters(as porous media) etc. The key feature for defining the filter is to obtain its porous inertial resistance and porous viscous resistance. Those parameters are gained from fitting into data provided by the filters' manufacturer (amount of air, pressure drop and dimension) using quadratic polynomial. The liner term is viscous resistance, while the quadratic term is the inertial resistance.
  For the rotating fan blades, it could be modeled via both moving reference frame (MRF) and rigid body motion (RBM) in STAR-CCM+. However, RBM method requires transient simulation approach, which need more computational resources and time, so after some simple teat comparing those two methods, I found that MRF is eligible for this problem. During the procedure of setting up the mesh for rotating blades, mesh were generated separately for different parts, using this method could make adjusting and regenerating mesh a easy task, which could save much computational resources and time.
- Minor project 2: Defrosting
  After the thermal comfort condition were met, it is also necessary to verify the HVAC system's ability for defrosting. In STAR-CCM+, analyses on defrosting can be achieved by adding thin film at the

outer side of the windshield.
The defrosting simulation is made up of two stages, namely steady state simulation and transient simulation. Steady state is used to provide a well developed fluid field, as well as adjusting the angle of defrosting inlet to make sure that air blown out hits the windshield. Transient simulation is then introduced and defrosting model is activated to simulate the defrosting process. Simulation shows that after 900s, most of the ice layer (0.5mm) have melted, so it is adequate to conclude that the defrosting system works well.

Initialize the fluid field using steady state simulation before changing to transient simulation is very effective approach, it could be used in any transient problem developed in steady fluid field.

2.3 PROFESSIONAL AND PERSONAL ATTRIBUTES

3.2. Effective oral and written communication in professional and lay domains. During the execution of the whole project, I constantly communicate with my workmates and my supervisor to discuss technical details and problems. It is during the discussion that I am able to improve my project, change methods and solve difficult problems. During the period of my industrial training, technicians from ANSYS Fluent visited my workplace and shared their new solution for solving problems related to airway in engine. After their presentation, I had a discussion with them about some common problems regarding the use of Fluent. Their feedback helped me greatly on my thesis since I am using Fluent for my thesis.

At the end of my industrial training, I made a presentation using Microsoft Powerpoint to my supervisor and workmates, showing my achievements regarding the projects. Alone with the presentation, I also submitted a professional report. Both the presentation and report received good feedback from my supervisor.

CHAPTER 3

Reflection & Conclusion

Working at Luoyang Tractor Research Institute allowed me to gain a lot during the period of industrial training. The work I took there required me to have sound knowledge and skill base in both HVAC system and CFD, as payback, the work not only improved my skills regarding CFD and HVAC, letting me realize what kind of approximation is acceptable in engineering practice, it also gave me some experience in real world teamwork & communication. The experience of going through the whole big project is also very valuable. After the industrial training, I have a better understanding of how different departments in a company work together to achieve a common goal. I also learned how to make some professional presentation and how to write a professional industrial report.