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STUDY OF HEAT TRANSFER AND FLUID DYNAMICS PREDICTION OF A LAWN MOWER TRACTOR EXHAUST SYSTEM

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ABSTRACT
The objective of this study was to investigate the present cooling system of a lawn mower tractor engine and to modify the system for better cooling since engine compartment was exhausting hot air that caused operator discomfort. The test section was created to measure the velocity and temperature at several predetermined locations around the engine compartment based on their assumed experimental importance by using several Pressure transducers along with Pitot tubes and Thermocouples. Since the experiment was run in a laboratory setting, the combustion products of the engine were vented to the environment through a venting system. The gathered data was used to produce an accurate computer model for simulation and to compare several different design adaptations. Based on experimental and computational data some modifications were recommended, such as the baffling system, fan system, and grill alterations as an attempt to alter the airflow characteristics of the engine compartment to redirect the hot air away from operator's feet. Among those, grill alteration came out with satisfactory results.

Keywords: Heat Transfer, CFD, Tractor Engine Cooling Mechanism.

1. INTRODUCTION
The engine compartment of a lawn mower tractor has tremendous heat rise after operating for a long period of time. The engine chamber is currently cooled by air using a radiator system. A hood containing four windows covers the engine. The ambient air is sucked in by a fan from the top window and after cooling the engine this air leaves through two side windows and one front window. The operator's foot pedal is right behind the side windows. The temperature and airflow systems have been analyzed experimentally and by CFD simulation to better understand the problem. Velocity and temperature readings were initially gathered from the equipment via laboratory experimentation. It has been observed that the engine compartment was exhausting air that was causing discomfort to the rider and potential harm to the area near their feet. Modifications were made to the tractor, such as adding fans, constructing baffles, and removing the front grill to redirect the airflow allowing more comfort for the rider Further velocity and temperature readings were gathered with all of those modification. Experimental data shows that the single most advantageous alteration was the removal of the grill. Although complete removal is not feasible, alterations to this area will provide the best results of all alterations tested. The existing model and grill removal modification were chosen to do CFD simulation. Based on the combination of experimental testing and computer modeling further modification was made on grill and further CFD simulation was done with this new model.

2. LABOROTORY FACILITIES
The entire facility consists of a lawn mower tractor, venting hose, data acquisition system, power supply, pressure transducer along with pitot tubes and thermocouples. Thermocouples were used to measure temperature throughout the experiment. The pressure transducers and pitot tubes were used to measure the velocity. Pitot tubes were selected since several velocity measurements had to be taken at different locations simultaneously. The engine RPM was set at 3060 RPM measured by a Digital Photo Tachometer. One very large part of this project was the adaptation and use of a ventilation system.

This was required to remove the toxic CO in the exhaust produced by the internal combustion engine located inside the hood of the tractor. Adequate removal of the fumes from the working area was necessary to ensure safety during testing.

Generally known and accepted experimentation practices were followed in the acquisition of experimental data.

3. EXPERIMENTAL PROCEDURE

Several key locations were considered including the top, left, right, front outside, front inside, oil and exhaust areas. Figure-1 shows those different locations. Data was recorded every 5 seconds once the tractor had reached steady state (oil temperature stabilizes). Throttle was adjusted until engine speed reached 3060 RPM measured by a Digital Photo Tachometer. 40 readings were recorded at 5-second intervals. Pressure transducers were used to convert the pressure output from the pitot tubes to voltage. The Data Acquisition System was connected to these devices in order to transmit and save the data collected.

After the baseline data set was collected, the setup was adjusted to alter the airflow around the engine compartment to reduce the heat to the operator. First, fans were introduced on either side of the tractor near the operator's feet, but located inside the engine hood. The fans were connected to a power supply and turned on. The tractor was allowed to reach steady state once again, and then the data was recorded. Once 40 readings were obtained, the fans were turned off and the next adjustment was made to the tractor. This procedure was repeated two more times, once with the grill off and then again with cardboard baffles installed. The data was recorded and appropriate statistical analysis was done. Finally the new data was compared to initial readings collected

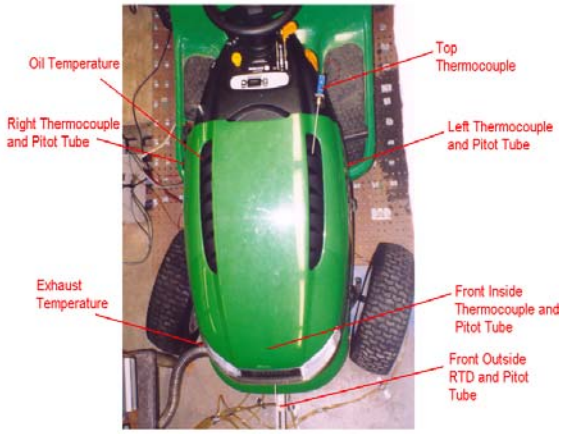

Fig 1: Location of Instrument Settings

Table 1: Base line Readings of Velocity and Temperature

Location	Velocity (m/s)	Temperature (k)
Top	3.03	27.3
Front Grill	1.2	318.1
Side Exit	5.65	312.5
Engine Body	N/A	374.6

4. ANALYSIS

4.1 Velocity

Since air exits through the front grill and travels back around the engine hood and out the openings toward the operator's feet, the area of concentration was mainly on the left and right side of the tractor where the air exits. The outlet velocity of hot air was measured 1.2 m/s at front grill and 5.65 m/s at side exits. Table-1 shows some average readings of velocity and temperature at front grill and side exits.

4.2 Temperature

The hottest location would be inside the hood compartment, directly in front of the engine where most of the exhaust was released. The right and left sides were in the range of 310 k to 315 k. This was critical since the analysis was performed to reduce the heat leading to the feet of the operator, thus, it was important to see what temperatures the tractor was producing. Since the ambient conditions were about 293 k, it should be noted that the temperature values would be even higher where the environment or ambient temperatures could reach 310 k plus. The exhaust temperature reached 546 k, which was important for determining the material for the exhaust tubing. After determining the extreme heat that was produced, 1-5/8th inch stainless steel flexible tubing was purchased and installed. The steady state condition for testing was determined using the oil temperature, although it never actually settled at an exact temperature.

5. MODIFICATION

5.1 Baffle Construction

Baffles were used to adjust the size of the hood openings on either side. Rather than producing an entirely new plastic hood, cardboard was used to adapt the current hood. Cardboard allowed for easy fabrication using simple cutting tools. Two cardboard pieces were cut and fit in the opening located on ether side of the tractor. This data differs from what was expected to occur after adding baffles. It was thought that baffles would decrease the airflow on either side, thus reducing the heat around the operator, but it did not.

5.2 Fan Addition

In an attempt to redirect hot engine air, two small electric fans were added at both sides of engine. An additional 12V power source was needed to power the fans. The fans were installed in an orientation that would allow them to "blow" air out of the engine compartment and slightly forward. The addition of the fans increased the temperature the most, which was surprising to see.

5.3 Grill Removal

This adaptation was very simple. No modifications other than completely removing the grill from the front of the tractor. Removing the grill gave the lowest velocity and temperature at side exits. This may be due to more hot air being allowed to escape from empty front. The removal of the grill also removes any flow restriction the grill may have imparted on the airflow.

Table 2 shows the average readings of velocity and temperature for the alterations explained above.

Table 2:Readings of Velocity and Temperature For Different Alterations

Alteration	Velocity (m/s)		Temperature (k)	
	Side	Front	Side	Front
Base Line	5.65	1.20	312.5	318.1
Grill Off	4.95	1.28	309	319.0
Baffle	7.20	1.12	315.8	318.2
Fan	6.60	1.25	318.2	317.1

6. CFD APPROACH

In order to accurately understand and analyze the fluid flow behavior CFD software is wisely employed. CFD application greatly reduces trial time and allows for intermediate variable modifications rather than complete laboratory restructuring.

6.1 CFD Procedure

The next step in this process was to create and mesh the model in Gambit. Figure 2 shows the 2D model, which is the horizontal section of hood and engine compartment. Then proper boundary condition was set and exported to the solver software Fluent. The segregated solver equation, which evaluates the conservation of mass, momentum and energy, was used to iterate the solution. The standard k- ε model, a semi-empirical model based on model transport equations for the turbulence kinetic energy (k) and its dissipation rate (ε) was set to evaluate viscous effect. The model transport equation for k is derived from the exact equation, while the model transport equation for ε was obtained using physical reasoning and bears little resemblance to its mathematically exact counterpart.

The baseline data collected from the experimental testing was used as the input values for the CFD analysis.

6.2 CFD Analysis

Figures 3 and figure 4 represent the velocity and temperature profile of model 1 where the grill opening is considered. Figures 5 and figure 6 represent the model where the bars of grill are considered. In comparison of velocity profile and temperature profile to model 1 and model 2 it is observed that having bars in grill increases the velocity and temperature at the two side exits.

Then model 3 was created with changing the boundary condition where two side inlets were closed and grill was open. Figure 7 and figure 8 shows that the velocity and temperature have been reduced more in model 3 than model 2 where all side inlets were open and grill bar was considered. These help us to develop an idea to modify the hood to lower the velocity and temperature at side exits. That is, opening the grill and closing two side inlets of engine shroud. But since removal of whole grill is not feasible, our concept design was modified to tilt the grill bar which will allow more space for hot ail to come out instead of removing of whole grill.

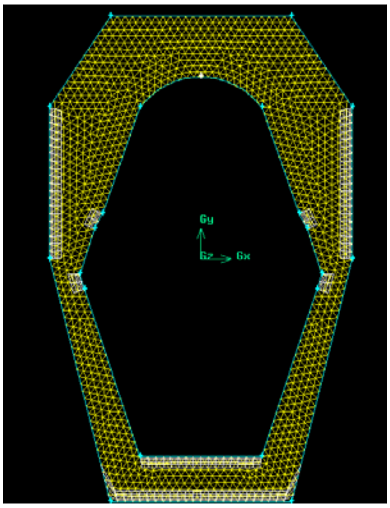

Fig 2: 2D Meshed Model

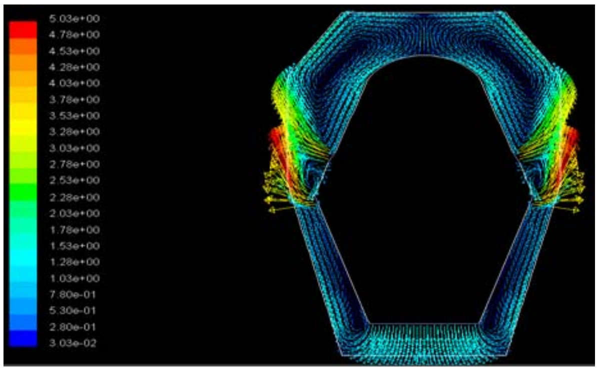

Fig 3: Velocity Profile (Model 1)

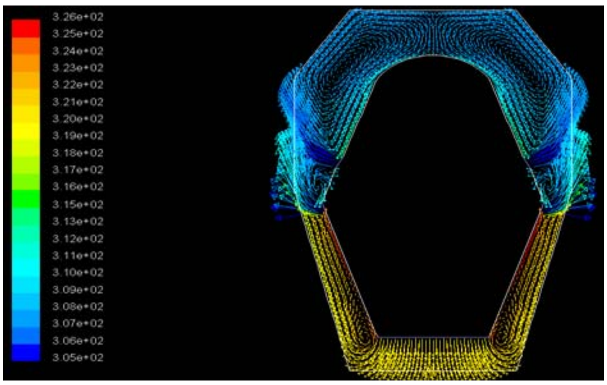

Fig 4: Temperature Profile (Model 1)

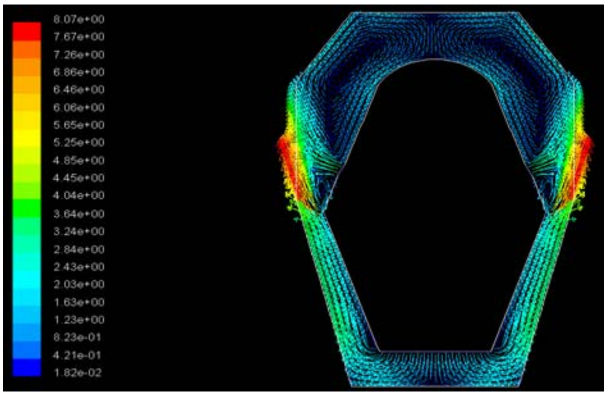

Fig 5: Velocity Profile (Model 2)

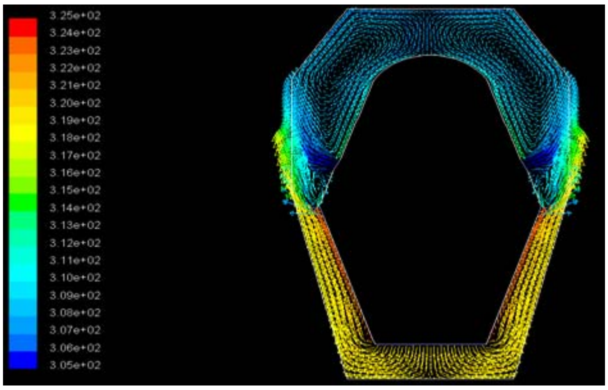

Fig 6 Temperature Profile (Model 2)

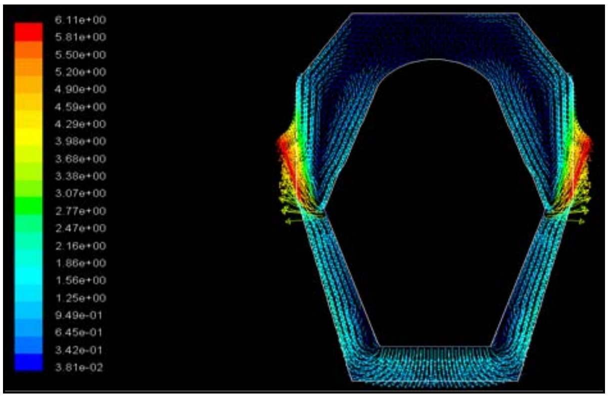

Fig 7: Velocity Profile (Model 3)

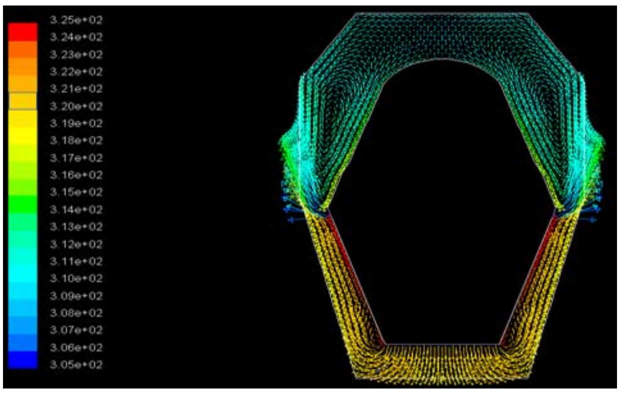

Fig 8 Temperature Profile (Model 3)

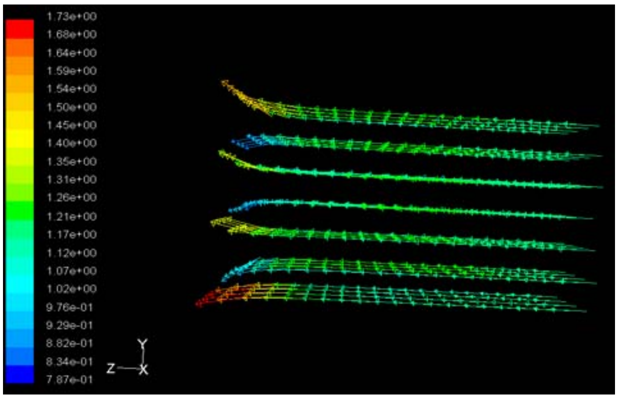

Fig 9: Velocity Vector (Present)

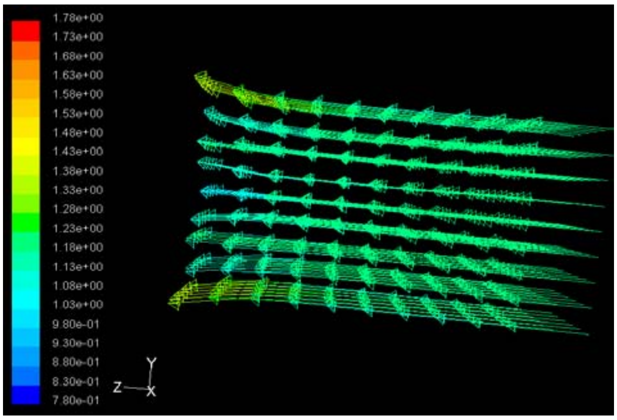

Fig 10: Velocity Vector (Modified)

Figure 9 and figure 10 are the comparison of present grill and modified grill where it is clearly observed that due to having tilted bar the velocity vector is straight where as the velocity vector converges at the narrow grill opening in present situation.

7. CONCLUSIONS

The data that was experimentally obtained were used as boundary conditions in the CFD simulation. Each time a model was used in an analysis, the data from testing was used to constrain it. It could be improved further by modifying dimensions to more closely resemble the actual tractor. The ultimate purpose of this project is to come up with a computer simulation that will allow alterations and testing to be done to the tractor's cooling system before actual construction, when changes are much easier and less expensive. From the CFD analysis it could be recommended to reduce the temperature and velocity at side exits or to redirect the hot air away from side exits by tilting the grill bar and closing two side inlets.

Although the testing and results provided here are great starting points, further testing should be conducted to ensure accurate results. As with all design changes, this data can be used as a basis for further testing and design adaptations. A three-dimensional model will ultimately be the most useful to designers of future tractors. The first step, as with the two-dimensional models, will be to construct a working simplified 3-D model. Once the simplified model is operational and fairly accurate at predicting the actual systems parameters, a more complete model should be constructed and analyzed. 3-D simulations can then be compared to the data given here, or further experiments can be run to obtain more.

Many parameters were neglected in this analysis. Future testing may want to concentrate on making the system more realistic. All testing was performed statically, meaning that although the engine was running to produce the air movement, the tractor itself was kept stationary. The movement of air in and around the tractor body will change as the tractor is driven through both stagnant and moving air. To incorporate this aspect into the analysis, while still allowing computer data acquisition, a fan can be used to simulate movement. For future analysis on the airflow around the engine housing, it would be beneficial to add a fan to simulate movement of the tractor. Since in real-life conditions the operator would be riding the lawn tractor, the ambient air would probably cause a cooling effect on the engine air being exhausted.

8. REFERENCES

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