Cooling and Exhaust Mechanism of an Off-Road Vehicle

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Submitted in partial fulfillment of the requirements for the degree of

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FINAL YEAR PROJECT REPORT

We hereby recommend that the dissertation prepared under our supervision by Muhammad Hassan Asghar (NUST201201402), Ali Hamza (NUST201200908) and Ali Hussain (NUST201200627), Titled: Cooling and Exhaust Mechanism of an Off-Road Vehicle be accepted in partial fulfillment of the requirements for the award of Bachelors of Engineering in Mechanical Engineering degree with (grade)

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Declaration

We certify that this research work titled "*Cooling and Exhaust Mechanism of an Off-Road Vehicle*" is our own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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Copyright Statement

Dedicated to our beloved parents and teachers

Acknowledgments

First of all we would thank ALLAH Almighty, who gave us knowledge and dedication to be able to complete this research. Also, we would like to thank our advisor Dr. Emad ud Din and co-advisor Brig. Dr. Waheed and Dr. Aamir Mubashir for their ultimate valuable support at all points during the project. Furthermore, we would like to acknowledge AWM (AARDIC) of HIT Taxila, Mr. Awais Qutab for his counsel and support during the project for us. We would also like to extend our gratitude to Lab Engineers Mr. Usman Abdullah and Mr. Faizan Saifullah for their assistance in our lab work.

Abstract

This project is co-sponsored by Heavy Industry Taxila. The project involves the optimization of the air intake of diesel engine of Al Khalid tank at low RPMs. This engine 6TD2 is preferably made for the cold environment of Ukraine. When the engine was brought here in Pakistan the engine starts to seize at low rpm because of change in environmental conditions. The visualization model is present to demonstrate how the exhaust is working in the tank.

Originally at higher RPMs atmospheric air flows through the radiator exchanging heat with the coolant and engine exits through exhaust nozzles at a high speed creating sufficient draught pressure for suction of further atmospheric air. At low rpms there was a drop in the engine cooling system.

We worked on different solutions and found that the installation of fans would be the most economical and feasible solution after the comparative analysis (cost, quality, life cycle, objective completion) according to the given space and conditions to manipulate with.

Our proposed solution is mainly applied on the diesel engine of Off-Road defense vehicles that are in service. Additionally, it can be applied to heavy off road vehicles like tractors, forklifts, cranes, bulldozers etc.

Key words:

- Heavy Industry Taxila
- Engine 6TD-2
- Off-road defense vehicles
- Engine cooling system

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Technical terms

CFM: Cubic Feet per Minute

This refers to the amount of air a fan is able to move.

Pressure

"Inches of water" is a common method of measuring the pressure a fan will generate.

RPM: Revolutions per Minute

This refers to how fast the fan or motor is spinning. This has a direct connection to the air pressure and volume of air it can move.

Density

The flow, pressure or head, needs to be specified at a given density which is affected by temperature and altitude.

Blower

Centrifugal fans are often referred to as blowers.

Wheel

In centrifugal fans the impellers are frequently referred to as wheels.

Ps - Static Pressure.

Resistance to airflow measured in inches of water gauge.

bhp: Brake Horsepower.

Bhp is a measure of power consumption. It is used to determine the proper motor horsepower and wiring.

Hp: Horsepower.

Hp is used to indicate a fan's motor size.

TS: Tip Speed.

The speed of the tip of a fan wheel or prop measured in feet per minute.

AMCA: Air Movement and Control Association.

A recognized association which forms standards for fan testing and performance ratings.

Chapter 1

Introduction

1.1 Need Statement

At high engine rpm the cooling system works quite good because the combustion gasses are ejected from the ejector at a much high speed thus vacuum is sufficient and draws the amount of air needed to cool the radiator. But at low engine rpm the combustion gasses passing through the ejector don’t have enough speed and hence the draught pressure induced is very low. This cause a very low air flow through the radiator and hence the engine starts to heat up.

1.2 Aim and Objectives

The aim of this project is to optimize the air intake of diesel engine of an off-road vehicle at low rpms. The following objectives were identified in order to achieve the overall aim of this research:

1) Optimization or air intake by studying different alternative solutions and selection of the best one through comparative analysis
2) Verifying the results through simulations in ANSYS, COMSOL & SOLIDWORKS.
3) Installation of the solution in the off-road vehicle and demonstrate the model in the department.

1.3 Problem Analysis and Specifications

The cooling system is intended to ensure the optimal conditions of engine operations Liquid coolant is used in the cooling system. The system is of closed type with forced circulation of coolant through the radiators cooled by air drawn with the help of ejection of exhaust gases.

Originally at higher RPMs atmospheric air flows through the radiator exchanging heat with the coolant and engine exits through exhaust nozzles at a high speed creating sufficient draught pressure for suction of further atmospheric air. Vacuum causes outside air to pass through the radiators. The air cools the radiator and then mixes with the exhaust gases in the mixing chamber and is removed out.

At high engine rpm the cooling system works quite good because the combustion gasses are ejected from the ejector at a much high speed thus vacuum is sufficient and draws the amount of air needed to cool the radiator.

But at low engine rpm the combustion gasses passing through the ejector don't have enough exhaust speed and hence the induced draught pressure is very low. This causes a very low air flow through the radiator and hence the engine starts to heat up.

1.4 Research Methodology

The schematic of overall research methodology is shown as:

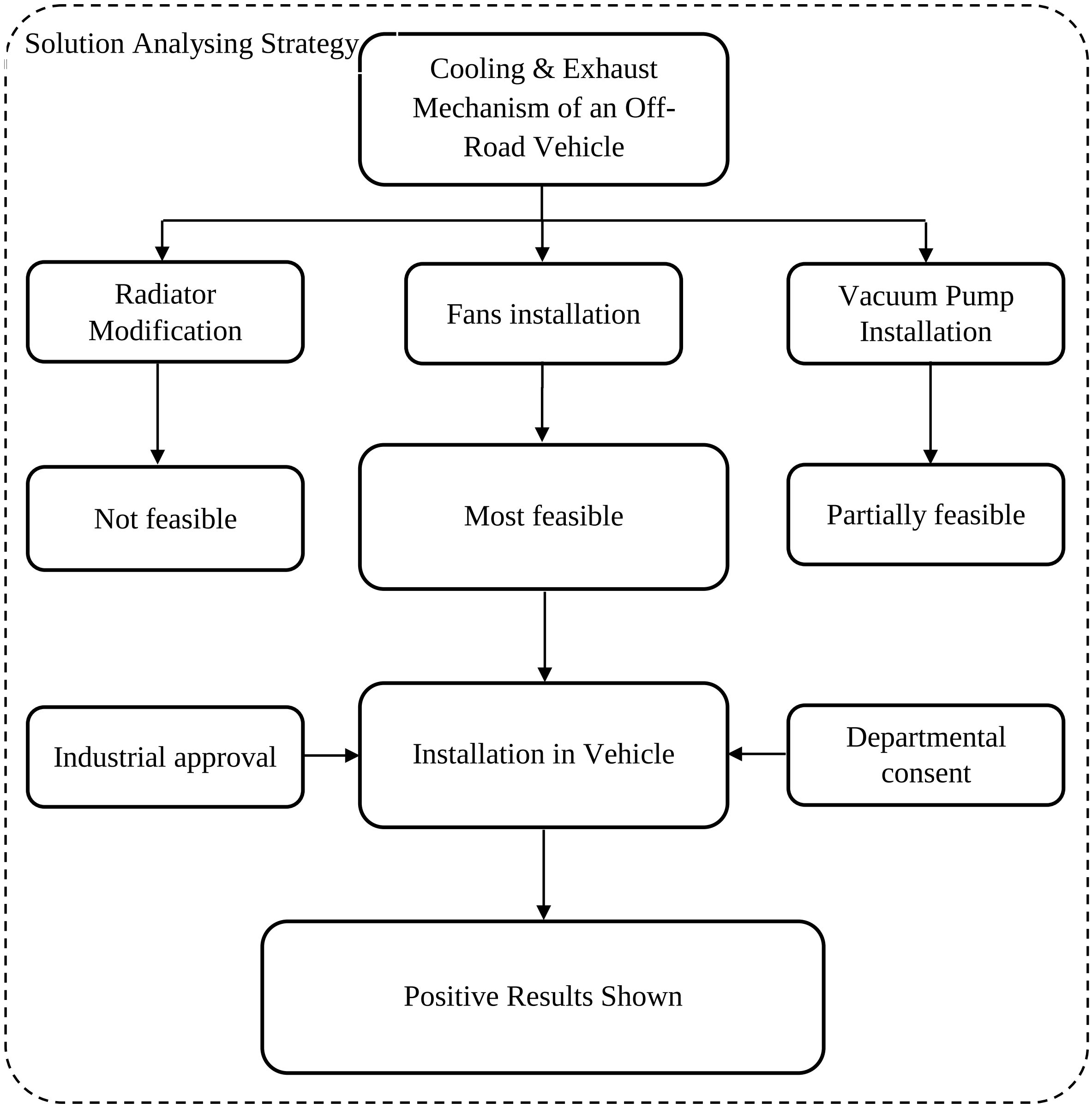


Figure 1.1: Overall Schematic of Research Methodology

Chapter 2

Literature Review

2.1 Cooling Mechanism

The cooling system is intended to ensure the optimal conditions of engine operations Liquid coolant is used in the cooling system. It operates at high coolant temperature .The system is of closed type with forced circulation of coolant through the radiators cooled by air drawn with the help of ejection of exhaust gases.

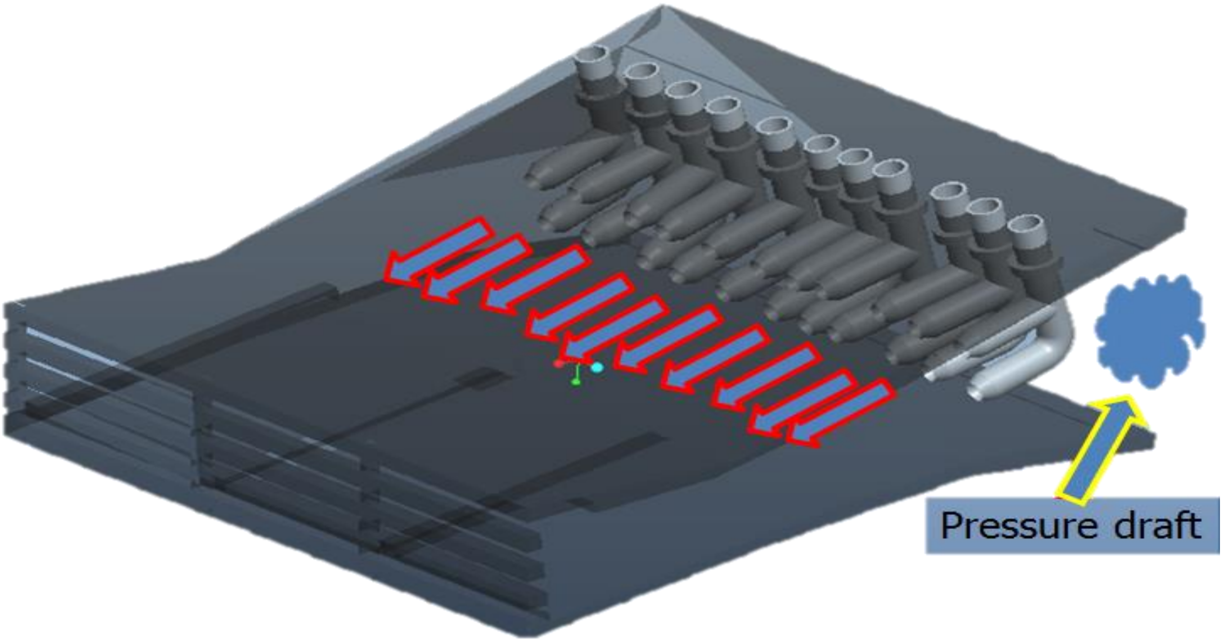


Figure 2.1 Ejection of Exhaust gasses causing Vacuum

When engine is running, combustion gases move through the duct to the ejector nozzles and are ejected from the ejector at high speed thus creating vacuum under the radiators.(Fig. 2.1)

Vacuum causes outside air to pass through the radiators. The air cools the radiator and then mixes with the exhaust gases in the mixing chamber and is removed out. (Figure 2.2)

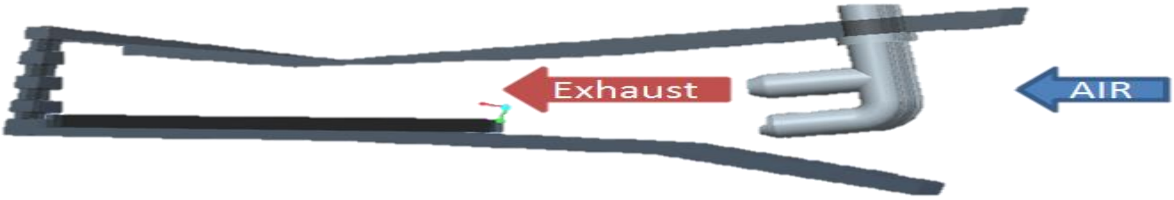


Figure 2.2 Air flow through Ejector

2.1.1 Technical Specifications Power Pack Engine

Type	6 cylinder , two –stroke , multi-fuel diesel with supercharger and two –sided power takeoff
Model	6TD2
Maximum power kw (hp)	882(1200)
Crankshaft speed at maximum power , rpm	2600
maximum Crankshaft speed , rpm	2950
Minimum stable Crankshaft speed , rpm	800 (on the diesel fuel) 1000 (on the gasoline and its mixtures)
Specific fuel consumption (maximum power)g/kWt*h(g/hph)	218+14-7 (160+10-5)
Average oil Consumption per hour .1/h	3.4+1.1 -0.6

Cooling System

Type	Liquid –cooled , closed type ejection cooling special coolant with three component additive (in summer), antifreeze 40, 60;TOSOL A-40 TOSOL A-65 (in winter)
System capacity ,1	88±3
Ambient temperature , K(0C)	No more than 328 (+55)

2.1.2 Cooling System

The cooling system includes ejector, engine water pump, radiators, surge tank1, air-steam valve, heater, engine cavities, coolant passages of the gas duct joint engine coolant drain valve-valve for draining coolant from the heater and pipelines.

2.1.3 Water radiators

Two water radiators are installed in the cooling system. The radiators have the same design and are connected in series. They remove heat from the coolant and are mounted in the ejection box of the top deck.

The radiator consists of tubes and fins and has detachable manifolds. Manifolds are secured to the core by bolts with fixing strips. Gasket is installed between the core and manifold. Manifolds are provided with handles for mounting and removing the radiators. The connecting pipe of the right radiators has the filling neck closed with the plug

2.1.4 Surge tank

The surge tank is a reservoir for the coolant which expands during heating and it provides collection and condensation of steam. The surge tank with the capacity of 20 l is mounted in the top deck.

The tank lid is provided with three threaded holes for mounting, such as:

- Air-steam valve
- Filling plug
- Coolant level sensor

2.1.5 Air- Steam Valve

The air- steam valve (pressure – vacuum relief valve) is intended to maintain positive pressure in the cooling system. It is mounted in the surge tank. The protection cap protects the air- steam valve from dust.

The air-steam valve spring is designed to open the valve at positive pressure in the system of 0.31-0.36 MPa (3.2 – 3.7 kg/ cm2). The air-steam valve spring ensures opening the valve when negative pressure in the system is up to 0.02 MPa (0.2 kg/cm2).

2.1.6 Water Pump

The centrifugal water pump serves to create continuous circulation of the coolant in the cooling system. The pump is driven from the engine crankshaft.

2.1.7 Coolant Level Sensor

The coolant level sensor is intended to inform the driver when coolant level in the surge tank drops below the permissible limit.

The sensor and the alarm shaping Unit provide light indicator on the warning light panel (the indicator NOWATER blinks bright).

When the cooling system is filled with coolant and the engine is running. Dim light indication appears which means that coolant level is normal and the sensor operates properly

Note: When charge the type of coolant, make sure that the switch of Alarm shaping Unit is set to the appropriate position.

2.1.8 Coolant Temperature Sensors

The sensor is used to signal when coolant temperature is too high. It is installed in the line through which coolant flows from the engine.

At reaching the maximum coolant temperature, the sensor and Alarm Shaping Unit activate the WATER MAX indicator on the warning light panel. The light will blink bright.

2.1.9 Bypass Gas Duct

The bypass gas duct with valve is placed in the top deck. The valve serves to adjust operating temperatures of the engine coolant and oil. Depending on position of the bypass gas duct valve exhaust gas flow is directed partially or fully to the ejector. The efficiency of the cooling system is regulated by the amount of gas passing through the ejector. The bypass duct valve is controlled by the driver by means of handle; when the handle is set to the extreme forward position "COOLING", the valve is complete closed (gases are directed to the ejector); when the handle is set to the extreme rear position "HEATING" the valve is completely open (gases are directed to the bypass duct).

2.1.10 Functioning of Cooling System

The liquid coolant is pumped by engine water pump and circulated through the engine cavities and it cools down the cylinders. The heater coolant coming out of the engine is divided into three flows:

- Main flow is supplied through the pipe into radiators where it cools down .After losing heat in the radiators the coolant is supplied through the pipe to the engine water pump
- Parallel flow comes to the water pump of the preheater, passes through the preheater and goes back to the water pump of the engine;
- Compensating flow circulates through coolant passage of the gas duct joint , and then to the surge tank .

From the surge tank, the coolant is directed through the pipe into the engine water pump coolant temperature is controlled by the electric thermometer, for which gauge is installed on the driver's panel

In case the engine shuts off at the coolant temperature of 383-391K (110-118oC), a sensor activates the pre-heater water pump and WATER MAX TO light indication of interface unit. Water pump of the pre-heater is de-energized when the sensor opens its contacts or we set Master switch to off.

2.2 Types of fans

It is common to classify fans in

- Axial and/or propeller fans
- Centrifugal (radial) fans
- Mixed flow fans
- Cross flow fans

Type of fan	Peak Efficiency Range
Centrifugal Fan	
Airfoil, backward curved/inclined	79-83
Modified radial	72-79
Radial	69-75
Pressure blower	58-68
Forward curved	60-65
Axial fan	
Vanaxial	78-85
Tubeaxial	67-72
Propeller	45-50

Figure 2.3 Efficiency comparison between axial and centrifugal fans

The pressure head of different types of fans with equal boundary speed of the wheel are compared in the diagram below:

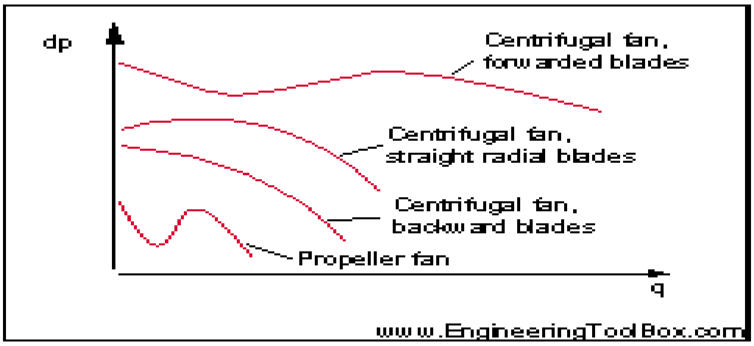


Figure 2.4pressure head

Centrifugal fans with forwarded blades are favored for application with higher air flow volumes and pressures. Axial propeller fans are more useful for applications with lower volumes and pressures.

2.2.1 Axial and Propeller Fans

Figure 2.5 Axial fans

Axial fans are efficient high volume low pressure machines. These fans are good for general purposes like avionics/electric or personnel cooling, AC and ECS systems, especially if a fan is needed to move air through a heat exchanger. These fans are also ideal for scavenging as the parts that come in contact with the air/sand mixture are more easily hardened than the complex shapes of other types of fans.

Axial fans come in two types

1) Vane-axial 2) Tube-Axial

Vane-axial fans differ from tube-Axial's as they have stationary vanes, sometimes called straightening vanes as they "straighten" the air outlet by counteracting the rotational angle from the turning impeller blades. These vanes allow a higher pressure capability and add efficiency.

2.2.2 Tube-Axial vs Vane-Axial

A basic fan is a propeller / impeller mounted on a motor shaft. Add housing around the propeller and motor and you have a "tube axial". Add "guide vanes" also called "straightening vanes" and you have a vane axial fan.

In an axial fan the air flows in parallel to the shaft. It is common to classify axial fans upon their wheel like:

- C-wheel - Blades can be adjusted while running. High efficiency, small dimensions, variable air volume
- A-wheel - Blades can be adjusted only when the fan is standing still. High efficiency, small dimensions, adaptive to recommended air volume
- K-wheel - Blades cannot be adjusted. Simple, small dimensions

The pressure head developed for single stage is up to 300 N/m^2. Axial fans are suited for relatively large volumes compared to pressure.

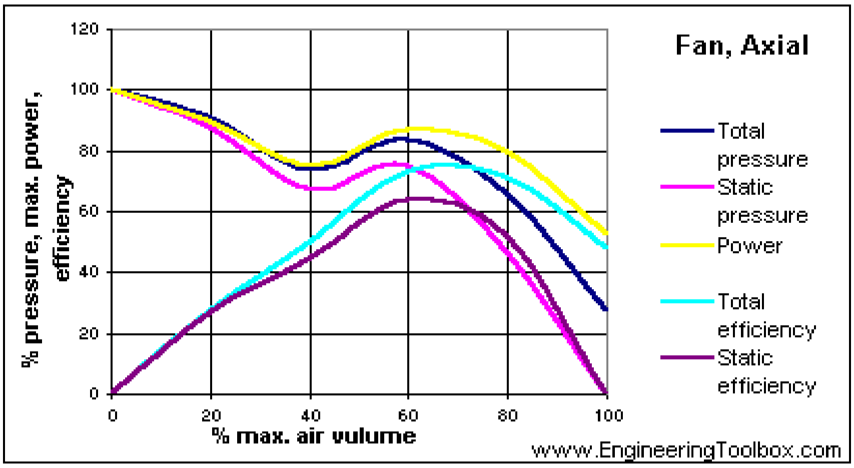


Figure 2.6 Axial fans pressure head graph

2.2.3 Centrifugal fans (Radial fans)

Figure 2.7 Centrifugal fans

Centrifugal Fans also called Blowers are used for high pressure, lower flow applications such as NBC and other types of filtration. They are also used for low pressure, lower flow, general purpose applications as they can be made inexpensively by simple plastic and aluminum parts.

Centrifugal Fans are also used for AC systems where there is very long ducting that adds up to a lot of pressure drops.

In a centrifugal fan the air flows is in a radial direction relative to the shaft. Centrifugal fans can be classified by their wheel like

I. F-wheel - Curved forward blades. High efficiency, small dimensions, changing in pressure has little influence on pressure head.
II. B-wheel - Curved backward blades. High efficiency, low energy consumption, changing in pressure has little influence on air volume. Low noise emission, stable in parallel running.
III. P-wheel - Straight backward blades. High efficiency, self-cleaning, changing in pressure have little influence on air volume
IV. T-wheel - Straight radial blades. Self-cleaning. Suitable for material transport

Types of blades used in centrifugal fans are

- Straight steel plate paddle wheel
- Forward multi-vane multi-blade
- Backward turbo-vane

The different blades can be characterized as shown in the capacity diagram below:

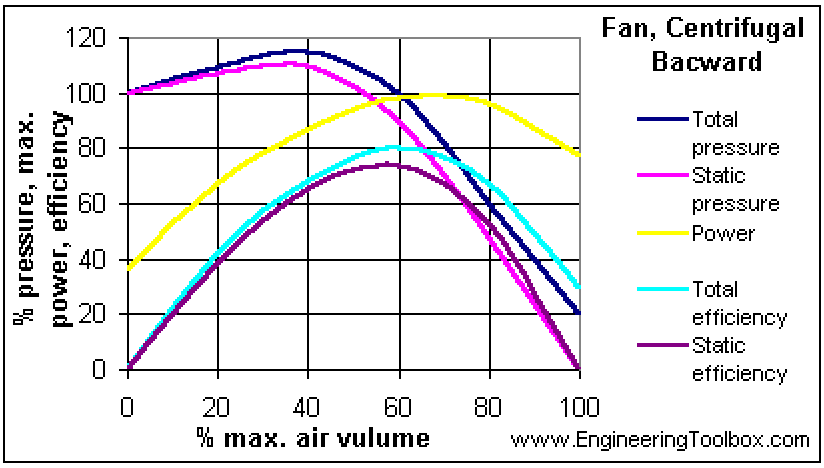


Figure 2.8 Capacity Diagram

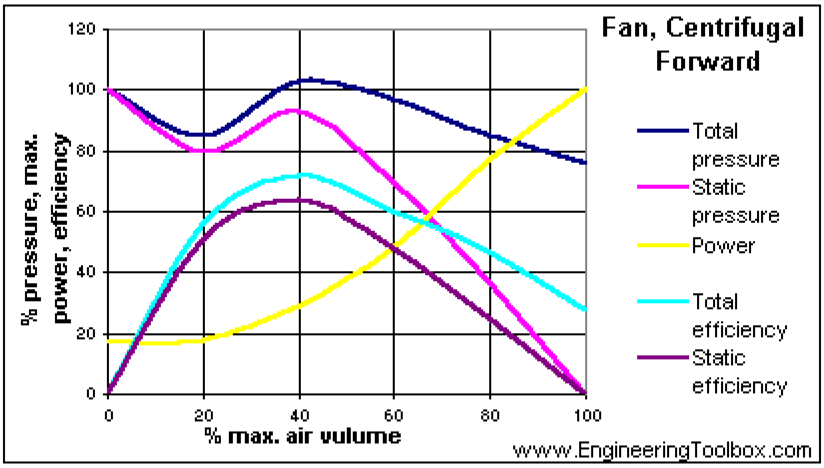


Figure 2.9 Capacity diagram (Forward)

2.2.4 Mixed flow fans

In a mixed flow fan the air flows in both axial and radial direction relative to the shaft. Mixed flow fans develop higher pressures than axial fans.

Mixed Flow Fans are called mixed as they are a sort of combination of axial and centrifugal fan. They are basically Vane-axial fans, but the impeller is shaped like a bevel gear, where the fan blades are at an angle. This means the air is moved by a combination of aerodynamic/ mechanical pushing of air, and the centrifugal action of spinning the air against the housing. In a blower, the housing is called a scroll, and in the mixed flow, the housing is called a shroud.

Mixed flows are usually made for NBC, or other critical applications for a specific design point where high efficiency and lower noise is required as these tend to be more expensive given their complex design. Mixed-flow fans tend to be quieter than other types because of their efficiency and that their moving parts are partially blocked by the shroud.

2.2.5 Cross-flow fans

In a cross flow fan the air flows in an inward direction and then in an outward radial direction.

Chapter 3

Fan selection criteria

3.1 Effects of different conditions

3.1.1 Effect of horsepower

1) Once the required fan horsepower (BHP) is known, several variables such as efficiencies and environmental factors, will determine the rated or installed driver horsepower. Hudson's Tuf-Lite fan selection program shows fan brake horse power prerequisite for the selected operating point. Drive system inefficiencies will consequence in an increased driver horsepower requirement.

2) Environmental losses arehard to control but are a function of actual fan tip clearance, fan inlet conditions, number and size of beams under the fan and structural geometry. These losses must be taken care of when determining driver power requirement.

$$HP_{in} = \text{Total Horsepower Required} = \frac{\text{Fan Horsepower Required}}{(\text{Eff Motor})\,(\text{Eff Drive})\,(\text{Eff Environment})}$$

3.1.2 Effect of density

Density, or weight of air per unit volume, is controlled by air temperature and altitude at the plane of the fan. These are the inlet air conditions on a forced draft fan or the exit air conditions for an induced draft fan. A constant RPM, constant pitch fan is considered to be a "constant volume machine". That is, it will move a constant volumetric flow (ACFM) of air regardless of the density.

Assume a change in ambient temperature for a forced draft fan. If the temperature decreases, air density (lb/ft^3) increases. Usually, resistance to airflow by the cooling tower fill or exchange tubes (static pressure) increases, since the fan is moving in the same volume of denser air thereby increasing the necessary horsepower and vice versa.

Air density decreases, along with the static pressure and required horsepower. Static pressure decreases, and the required horsepower decreases. As stated, Hudson's fan curves show operation at standard density of lb/ft^3 at 70°F and sea level.

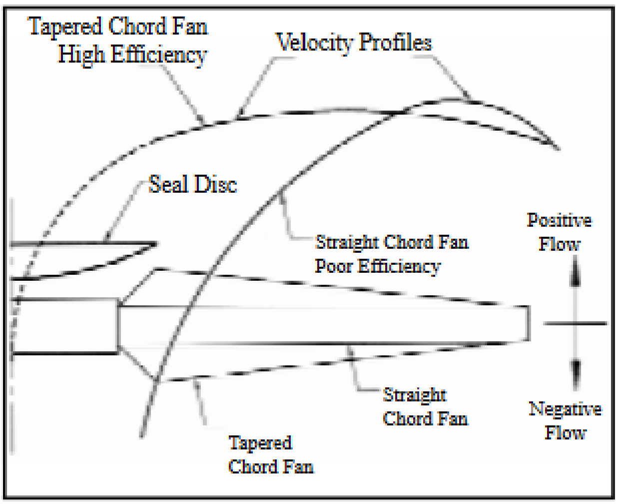
3.1.3 Effects of number of blades

The greatest amount of work a fan performs is done by the outer portion of the blade. As a result, the fan solidity is critical. Solidity ratio is defined as the ratio of the sum of the blade widths to the fan's circumference.

Increase in the number of blades to 6, the solidity ratio would be 6/4 x 0.1 or 0.15. Likewise, for 8 blades, SR would be 0.2. So theoretically at least, 6 blades would do 50% more work than 4 blades, and 8 blades would do 100% more work. In reality a 6 blade fan only does about 40% more work than a 4-bladed fan; however, the principal is that: the work a fan can provide is proportional to the number or width of blades. Likewise, 4 wide blades can do more work than 4 narrow blades by the ratio of the blade widths even if the blade shapes are not similar.

3.1.4 Effect of blade shape

Airflow across the plane of the fan is non uniform changing from positive at the tip to negative at the center of the fan. Blade shape and twist of the air- foil along the blade affects the shape of the velocity profile. Velocity profile of a well-designed tapered blade with a generous twist compared to a constant chord blade with minimal twist is shown in Fig. 3.1.



Velocity Profiles-Tapered vs. Constant Chord Blade

Figure 3.1

Work performed by a fan blade is basically a function of three factors at any point or radius:

i. Chord width
ii. Airfoil twist
iii. Tangential velocity squared

At mid radius (0.25D), tangential velocity is only 25% of the velocity at the tip. To compensate for this decrease in velocity, the chord width and twist must be increased. This is the reason for the increased efficiency and more uniform airflow from a tapered blade.

For a constant chord width blade, exit velocity decreases rapidly inboard of the tip and typically becomes negative outboard of the seal disc. A typical aluminum blade’s chord width and twist do not vary along the blade. The advantages of a tapered, well-designed blade with even airflow across the fan result in higher efficiencies and lower horsepower to attain design performance.

3.1.4 Effect of flow conditions

Fans to be selected are conditional on the basis of flow properties like temperature, pressure, mass flow etc. its selection is restricted by space limitation that is given for installation. The flow conditions are determined using test bench in the industry and then the fans are selected on the basis of those conditions.

Conditions are:

I. Temperature varies from 60^0C to 70^0C.
II. Flow velocity varies from 6m/s to 8 m/s.
III. Space is limited to 170mm in height so the diameter of fan is restricted by this. And this is the main criteria of selection of fans.

3.2 Steps for proper selection of a fan

3.2.1 Choosing fan type

I. Centrifugal blower
II. Axial flow fan

A centrifugal blower wheel draws air into the inlet of the blower housing, through the wheel, and discharges it at 90° out through the discharge of the blower housing. An axial fan uses a propeller to draw the air into the fan and discharges the air in the same axial direction. A centrifugal blower housing has a "scroll" whereas an axial fan is an "in-line duct type" fan or a "wall" fan.

There is a variation of axial flow duct fan that uses a blower wheel instead of a propeller. It is referred to as a Tubular Centrifugal.

3.2.2 Total airflow (ACFM)

Airflow is rated in cubic feet of air per minute (CFM) or in metric equivalent, it is rated in cubic meters per hour (M^3/Hr).

To convert M^3 /Hr to CFM multiply M^3 /Hr x .58858

3.2.3 Static Pressure (SPWG)

Static Pressure is the resistance to airflow (friction) caused by the air moving through a pipe, duct, hose filter, hood slots, air control dampers or louvers. Static pressure is rated in inches of water gauge (SPWG), or in metric equivalent, it is rated in Pascal's (Pa)

3.2.4 Density

Standard air is based on a temperature of 70° F., 29.92" barometric pressure and .075 pounds per cubic foot. Density changes resulting from temperature and/or barometric pressure variations, such as higher altitudes, must be corrected to standard conditions before selecting a fan or blower based on standard performance.

3.2.5 Air Temperature

The temperature of the air going through the fan or blower will affect the performance of the fan or blower. Temperature should be shown in degrees Fahrenheit (F).

Make the following correction for degrees Centigrade (C).

$$°F = 1.8 \times °C + 32$$

3.2.6 Altitude

The altitude the fan or blower will be operating at, will also affect the performance of the fan or blower.

3.2.7 Material Handling

Material of fans and its blades is selected on the basis of type of medium present and quantity of clean air passing through it.

Following questions to be asked before selection of material, For instance:

- i If the air is clean?
- ii If dirty, is material granular or powdery?
- iii If dirty, is material long and stringy like paper trim or fibers?
- iv For any material, will the material be wet or moist?
- v For any material, will the material be dry?
- vi If transmission material, what is the weight of the material in pounds per cubic foot?
- vii If transmission material, how many pounds will you be conveying in pounds per hour?

3.2.8 Ambient temperature

The ambient temperature is the temperature of the air outside the fan or blower. This can affect the operation of the motor and the fan bearings and/or belts for any belt driven fans or blowers

3.2.9 Safety conditions

These conditions play a vital role in fans selection.

- I. Is there anything going through the fan or blower or outside the fan or blower that is explosive and/or flammable?
- II. Will the area outside the fan or blower be explosive or flammable?

3.3 Basic Calculations

$$cfm_{New} = \frac{rpm_{New}}{rpm_{Old}} \times cfm_{Old}$$

$$Ps_{New} = \left(\frac{rpm_{New}}{rpm_{Old}}\right)^2 \times Ps_{Old}$$

$$Bhp_{New} = \left(\frac{rpm_{New}}{rpm_{Old}}\right)^3 \times Bhp_{Old}$$

Figure 3.2

Chapter 4

Finite Element Modeling and Optimization Process

4.1 Introduction

The modelling and simulations were performed on different Softwares keeping in view the results and input data. Softwares used are:

1) ANSYS
2) SOLIDWORKS 2014
3) COMSOL (5.2)

In SOLIDWORKS modelling of the entire cooling chamber was done. ANSYS' module FLUENT was used for the 2D planar flow analysis of the chamber to characterize the flow conditions in the required area where fans are to installed. SOLIDWORKS flow simulation module is used to animate the flow in the chamber and get the required simulation verified results by comparing pressure, temperature and mass flow rate with and without the installation of fans and vacuum pump. COMSOL is used to model and simulate our third alternative study of modification in the radiator.

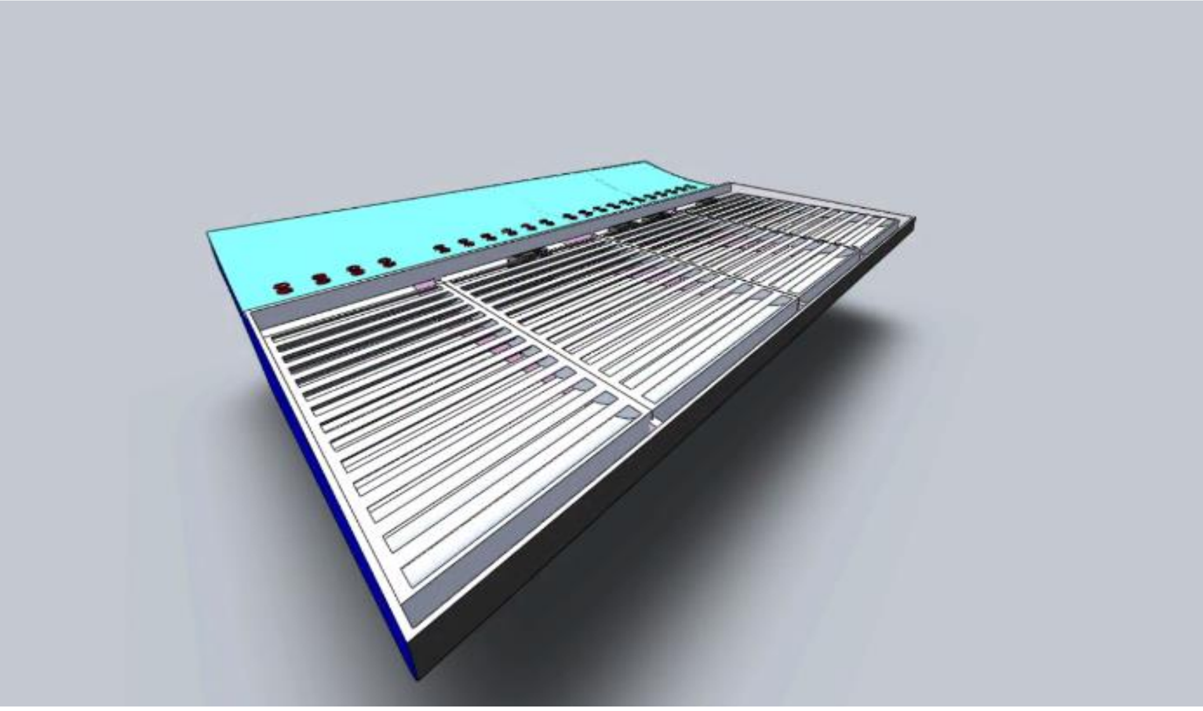


Figure 4.1. Model of the chamber in SOLIDWORKS 2016

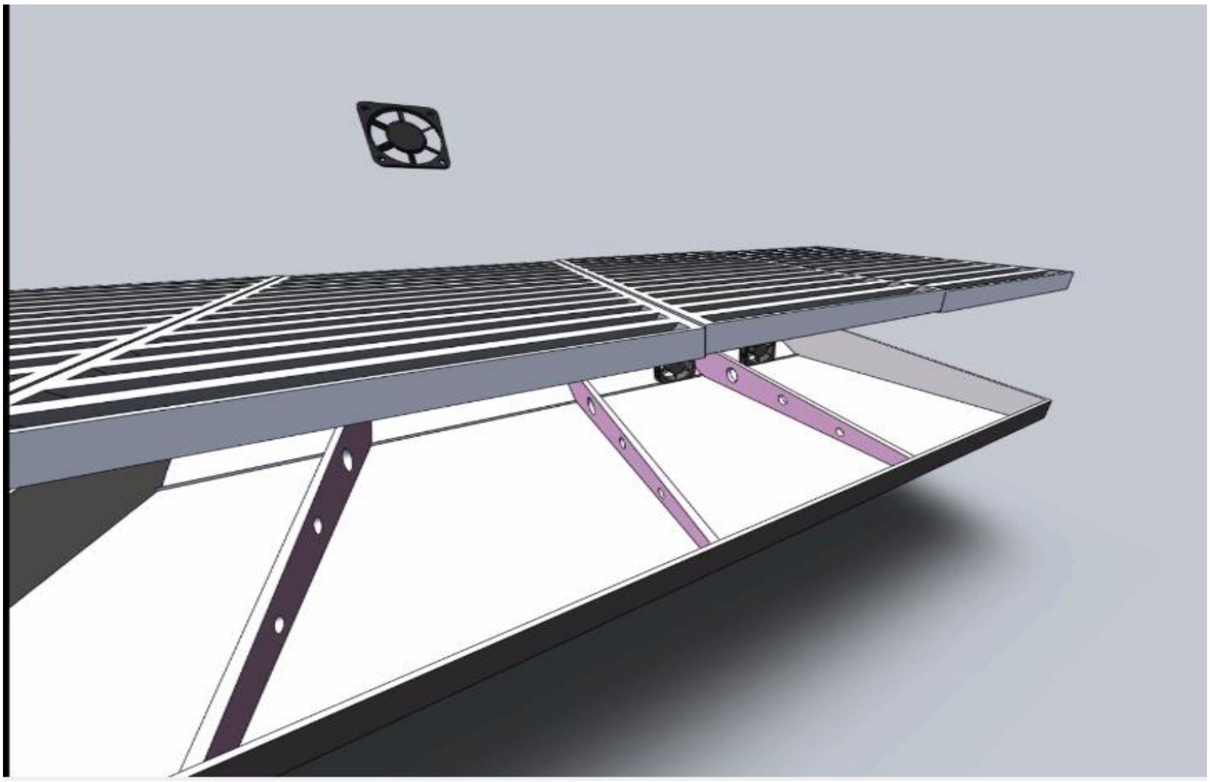


Figure 4.2. Model of the chamber in SOLIDWORKS 2016 (exploded view)

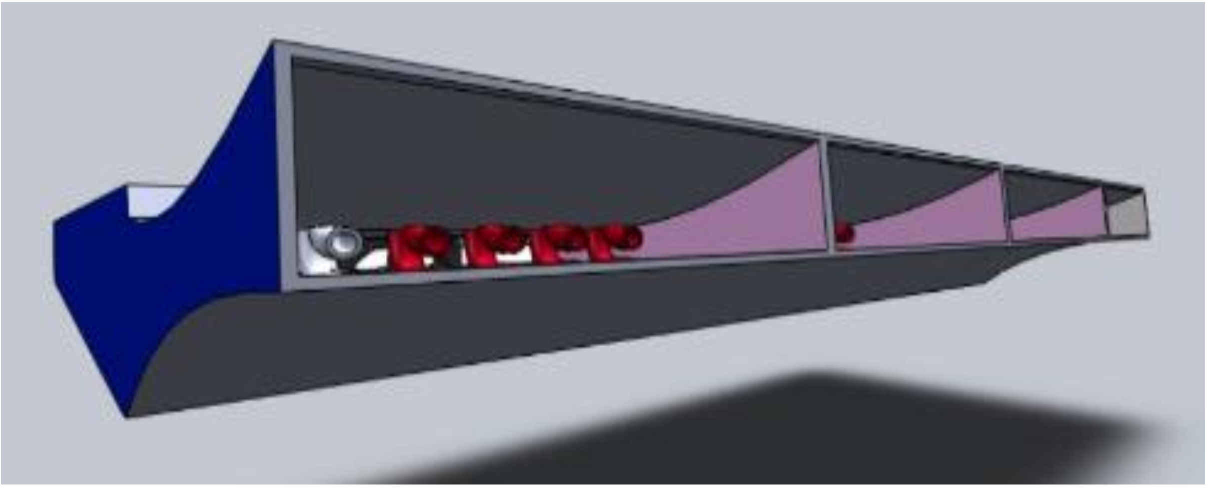


Figure 4.3. Model of the chamber in SOLIDWORKS 2016 (rear view)

Chapter 5

Results and Discussion

5.1 Flow Characterization

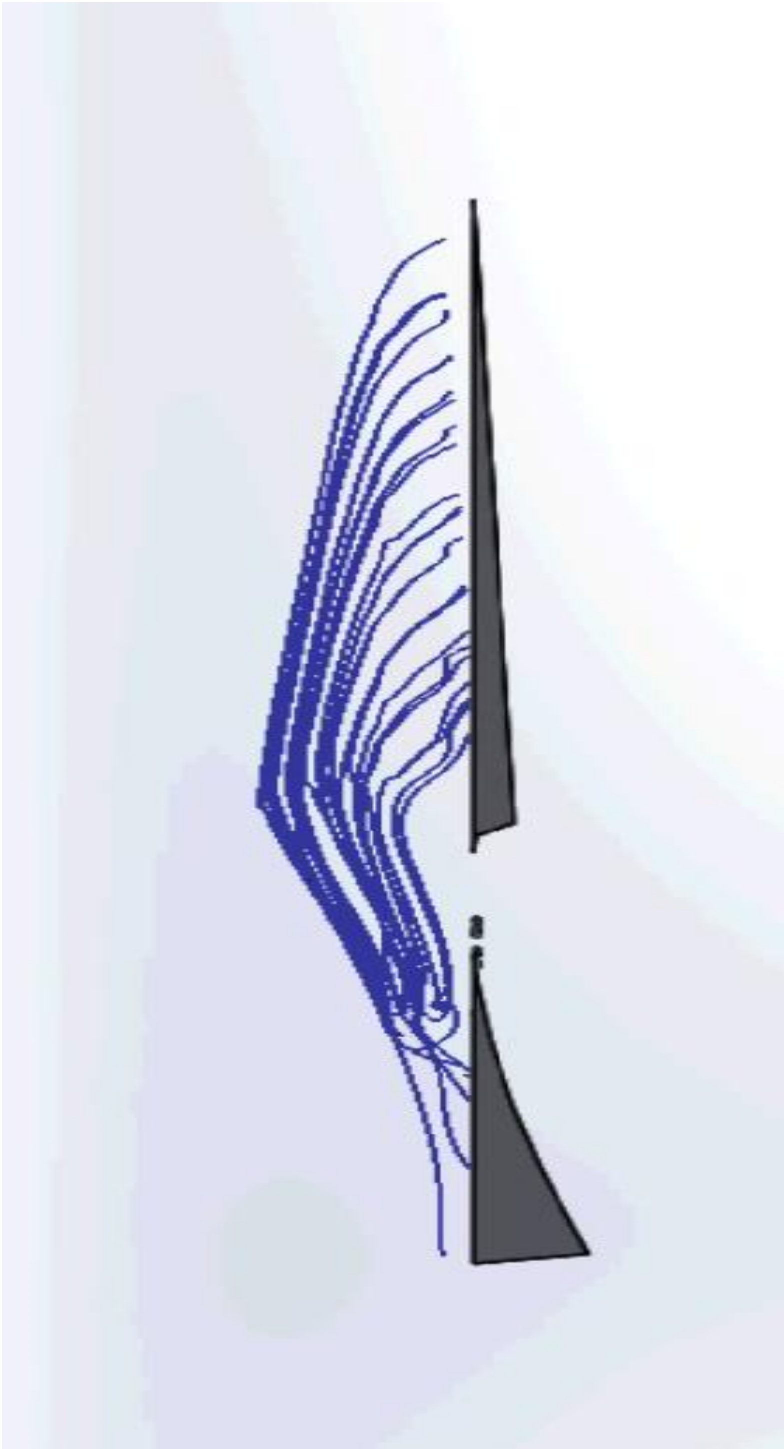
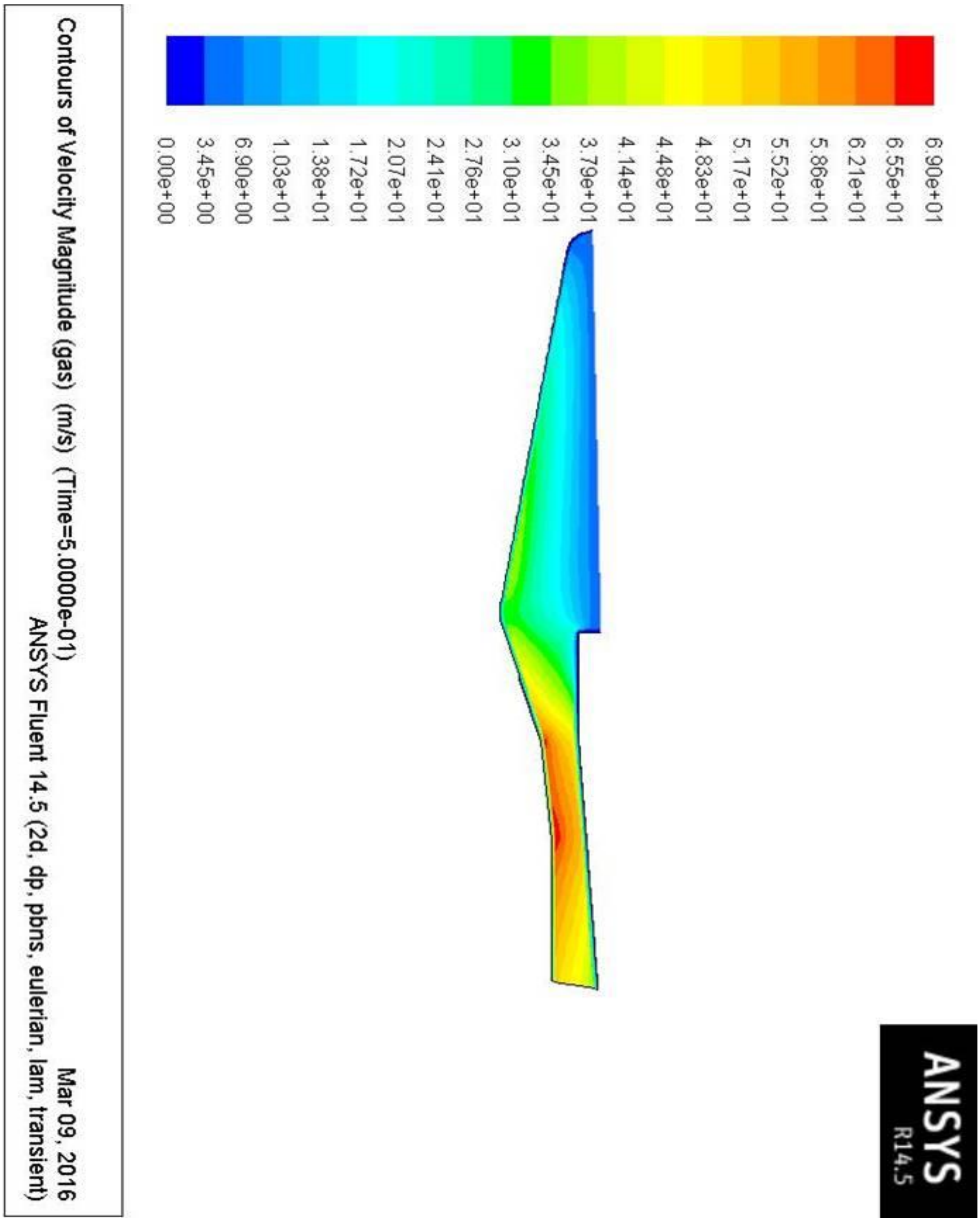


Figure 5.1. Flow visualization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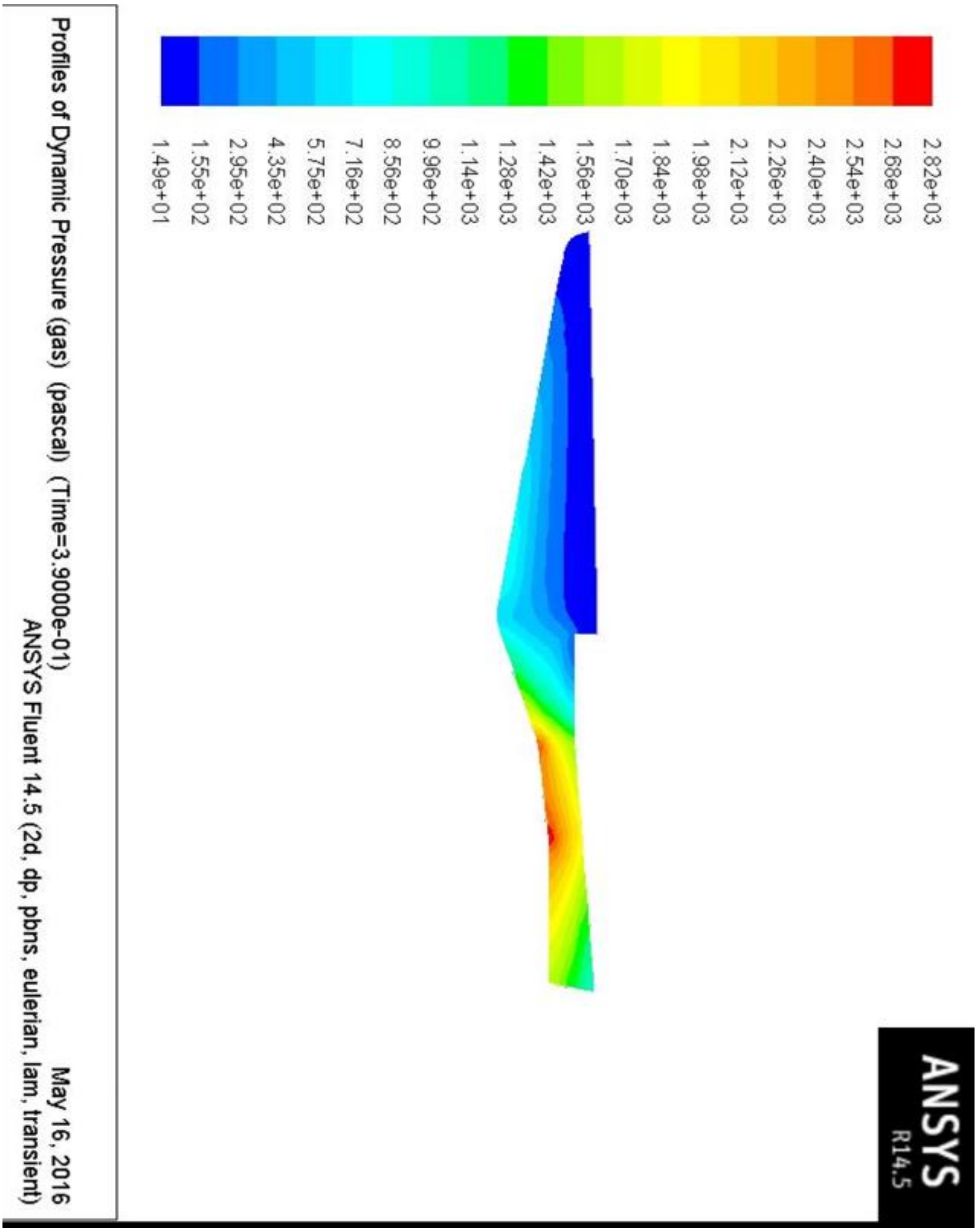
ANSYS
R14.5
Contours of Velocity Magnitude (gas) (m/s) (Time=5.0000e-01)
Mar 09, 2016
ANSYS Fluent 14.5 (2d, dp, pbns, eulerian, lam, transient)

Figure 5.2.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9.96e+02
8.56e+02
7.16e+02
5.75e+02
4.35e+02
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1.49e+01
ANSYS
R14.5
Profiles of Dynamic Pressure (gas) (pascal) (Time=3.9000e-01)
May 16, 2016
ANSYS Fluent 14.5 (2d, dp, pbns, eulerian, lam, transient)

Figure 5.3.

Chapter 6

Alternative Solutions

6.1 Radiator

6.1.1 Original Working

Originally, liquid coolant is used in the cooling system. It operates at high coolant temperature .The system is of closed type with forced circulation of coolant through the radiators cooled by air drawn with the help of ejection of exhaust gases.

Two water radiators are installed in the cooling system. The radiators have the same design and are connected in series. They remove heat from the coolant and are mounted in the ejection box of the top deck. Heat transfer occurs between air (ambient air passing through the top deck) and water which is flowing inside the tubes of radiator. The animation below shows the passage of air through radiators and out from the ejectors.

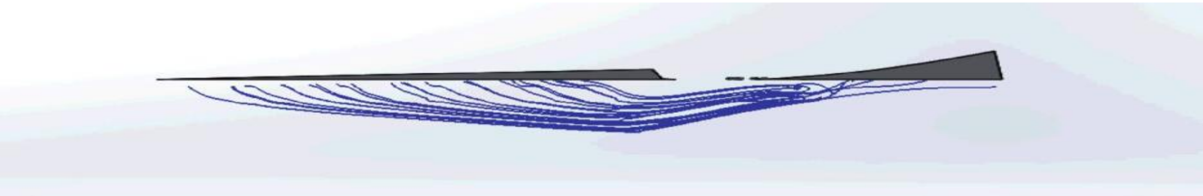


Figure 6.1.

The radiator consists of tubes and fins and has detachable manifolds. Manifolds are secured to the core by bolts with fixing strips. Gasket is installed between the core and manifold. Manifolds are provided with handles for mounting and removing the radiators.

Figure 6.2.

All four radiators are placed above these guide vanes shown above which is then covered by a netted block through which air comes in. Given below are water and oil radiators.

Figure 6.3.

6.1.2 Calculations with Water as Coolant

The following excel table shows the theoretical calculations of radiators with water as a coolant.

				Air										Water				
RPM	Ti	To	MFR	Conductivity [W/m·K]	C_p [kJ/kg·K]	Prandtl Number	Density [kg/m³]	Viscosity [N·s/m²]	Velocity m/sec	Ti	To	MFR	Conductivity [W/m·K]	C_p [kJ/kg·K]	Prandtl Number	Density [kg/m³]	Viscosity [N·s/m²]
2200	25	54.6557	7.1636	0.0263	1.007	0.707	1.1614	1.85E-05	5.675	375	380	10.1388	0.681	4.22	1.7	1000	0.00027
2400	25	46.51874	9.8724	0.0263	1.007	0.707	1.1614	1.85E-05	7.8175	375	380	10.1388	0.681	4.22	1.7	1000	0.00027
2600	25	51.93859	11.0406	0.0263	1.007	0.707	1.1614	1.85E-05	8.7425	375	382	10.1388	0.681	4.22	1.7	1000	0.00027
2800	25	50.36573	11.7252	0.0263	1.007	0.707	1.1614	1.85E-05	9.285	375	382	10.1388	0.681	4.22	1.7	1000	0.00027
3000	25	38.44538	12.6223	0.0263	1.007	0.707	1.1614	1.85E-05	9.995	370	374	10.1388	0.679	4.214	1.8	1000	0.00029

Q				Heat Transfer
KW	Reynolds No.	Tube height	RPM	KW
213.9287	7712.048	0.0216	2200	213.9287
213.9287	10623.6	0.0216	2400	213.9287
299.5002	11880.63	0.0216	2600	299.5002
299.5002	12617.86	0.0216	2800	299.5002
170.8996	13582.72	0.0216	3000	170.8996

MFR represents Mass Flow Rate of air and water respectively.

Heat Transfer = mass flow rate x cp x Temperature difference

Above formula is used to calculate the heat transfer. Mass flow rate of air was determined as a product of density, air velocity and area of top deck. Velocity of air was calculated by Anemometer, a duct was made on top deck and anemometer was placed inside the duct. Maximum air velocity results were found at 3000 RPM which was 9.995 meters per second.

Mass flow rate of water was given in the radiator manual.

Ti = Inlet Temperature

T_0= Outlet Temperature

At concerned RPMs (2400) we found heat transfer to be around **214KW**

6.1.3 Radiator Dimensions

The following excel table shows the dimensions of water radiator. All dimensions are in meters.

Geometry of Radiator		Geometry of Tubes		Fins Geometry	
Length	0.85	Length	0.85	Length	0.66
Width	0.66	Width	0.0026	Height	0.153
Height	0.153	Height	0.015	Thickness	0.000023
		No. of tubes	567	No. of Fins	287
				Gap between fins	0.78399

6.1.4 Simulations with Water as a Coolant

We used COMSOL 5.2, Heat Exchanger module, for simulation of radiator. Given is a result of simulation.

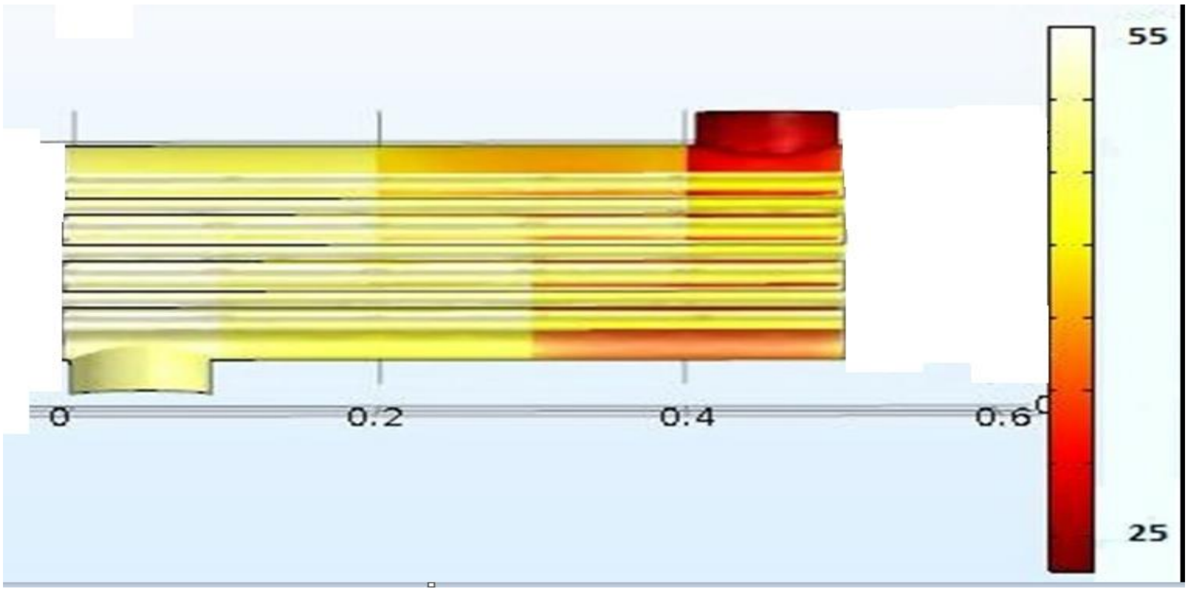


Figure 6.4

We used shell and tube simplification for our analysis. In heat exchanger shown above there is water flowing inside the tubes and air is introduced in shell portion. At air entry temperature is **25 ^{o} C** which is ambient air temperature. When air comes out of the exchanger by transferring heat with water its temperature was raised up to **55 ^{o} C** as indicated by the scale aside.

6.1.5 Suggested Alternative for Coolant

Originally water was used as a coolant which has a thermal conductivity of 0.6 W/m.K .Materials with higher thermal properties are required to increase the performance of radiator. The use of Nano fluids is one of the methods to increase heat transfer in radiators as they have higher thermal conductivities.

6.1.6 Choice of Nano Fluids as Coolant

Recent research has indicated that dispersions of nanoparticles in a base fluid, known as Nano fluids can significantly increase the thermal conductivity and hence heat transfer. Typical nanoparticle concentrations may range from 0.01wt% to 50wt% and common particle materials include silica, alumina, copper oxide etc. Water often serves as the base fluid.

6.1.7 Calculating thermo-physical properties of Nano fluid

As Nano fluids are being used for thermal applications, therefore, it is necessary to determine their thermo-physical properties which are basically thermal conductivity, viscosity, heat capacity, density. Each of these properties are dependent on volume fraction, material type of nanoparticles, base fluid and temperature of base fluid.

1. **Density**

$$\rho_{nf} = (1 - \phi)\rho_f + \phi\rho_p$$

where, ρ_f, ρ_p and ρ_{nf} represent densities of the base fluid, the nanoparticle and the nanofluid, respectively.

2. **Specific Heat**

Effective specific heat can be determined by following relation

$$C_{pnf} = \frac{\phi\rho_p C_p + (1 - \phi)\rho_f C_{nf}}{\rho_{nf}}$$

where, C_p and C_{nf} is specific heats of the nanoparticle and the nanofluid, respectively. This is the standard equation

3. **Thermal Conductivity**

$$K_{nf} = \left[\frac{K_p + 2K_f - 2(K_f - K_p)\phi}{K_p + 2K_f - (K_f - K_p)\phi}\right] K_f$$

where, K_f, K_p and K_{nf} is thermal conductivity coefficients of the base fluid, the nanoparticle and the nanofluid, respectively. Where K_f it's a function to the temperature.

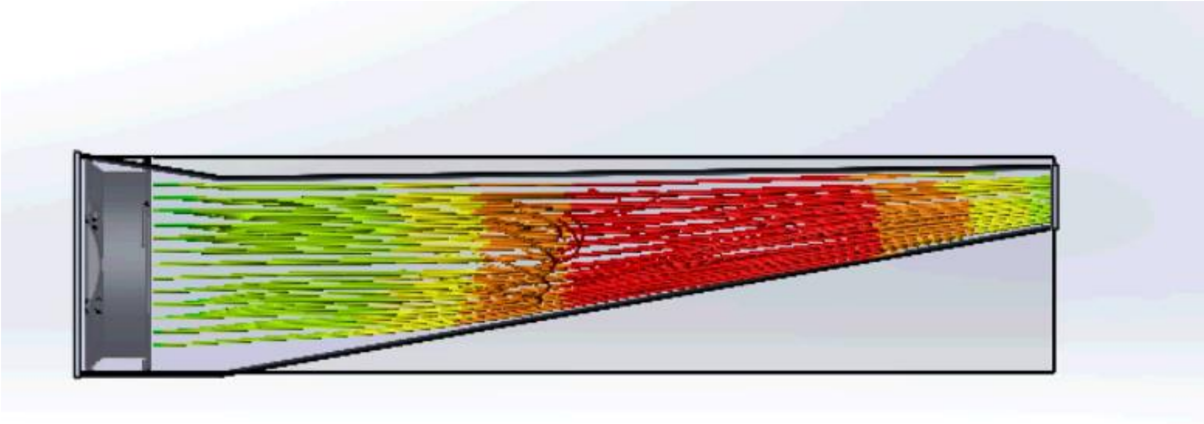
For our own purpose we used CuO (copper oxide) as nanoparticle and water as a base fluid. We get a 40% increase in thermal conductivity. Thermal conductivity of Nano Fluid came out to be **0.85W/mK.** And hence heat transfer was increased significantly.

6.1.8 Limitations in using Nanoparticle

1. It may cause corrosion in radiator pipes.
2. It is very expensive
3. Its leakage can be dangerous

6.2 Fans

6.2.1 Simulation Results



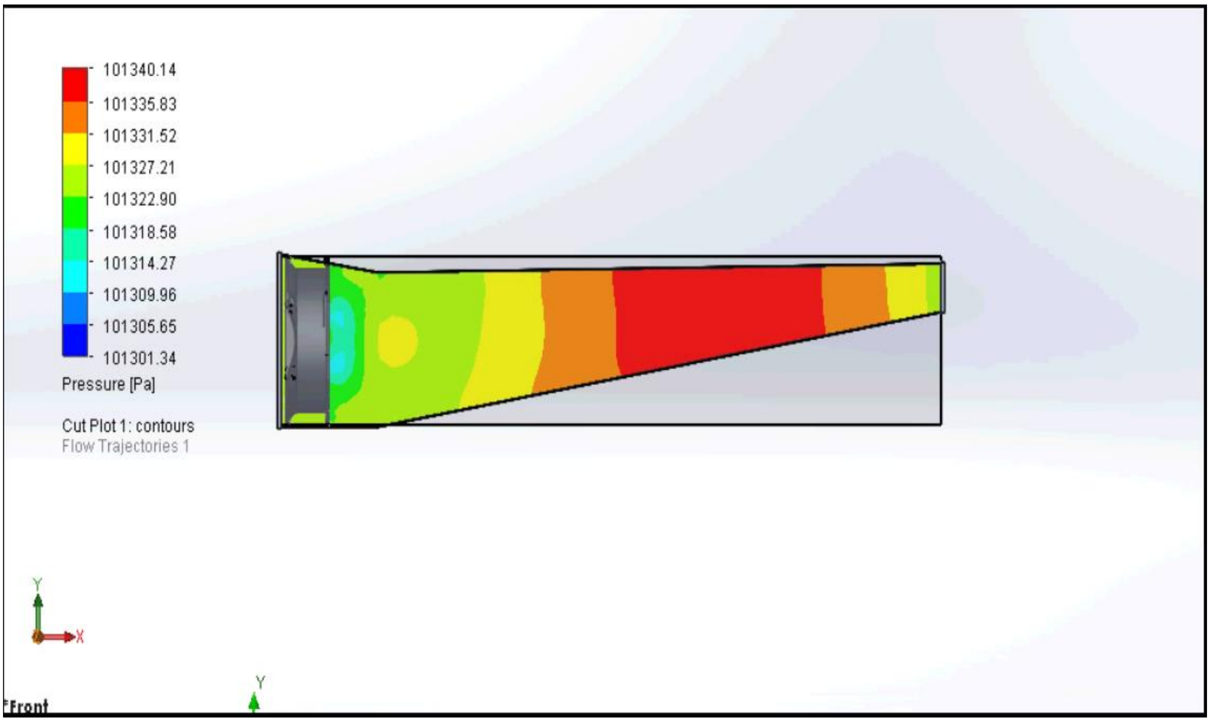


Figure 6.5

6.3 Vacuum Pump

6.3.1 Simulation results

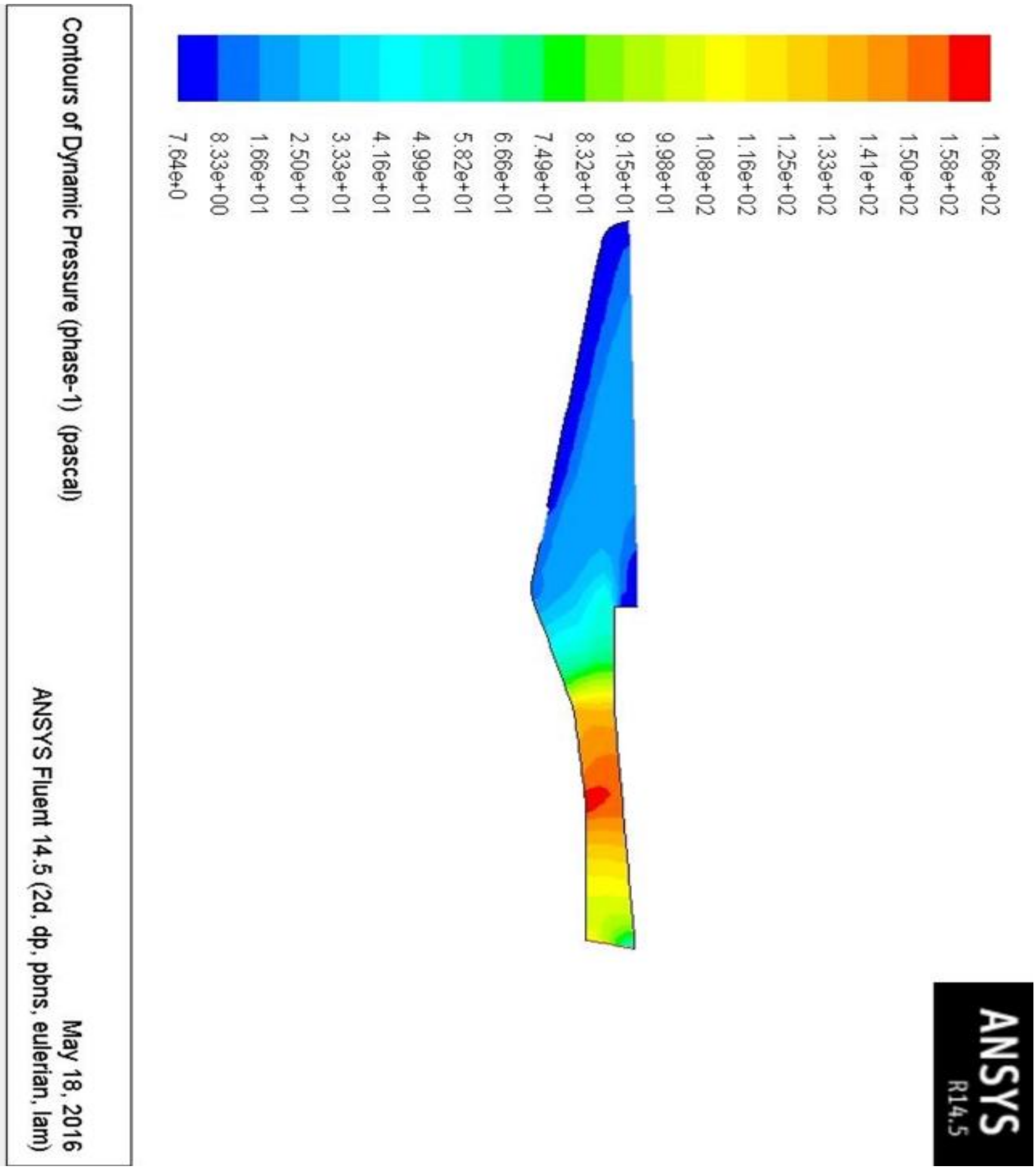
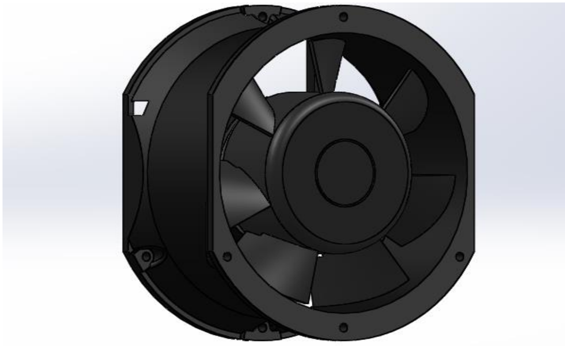


Figure 6.6.

6.4 Selected fans



SPECIFICATIONS

(RoHS Compliant)

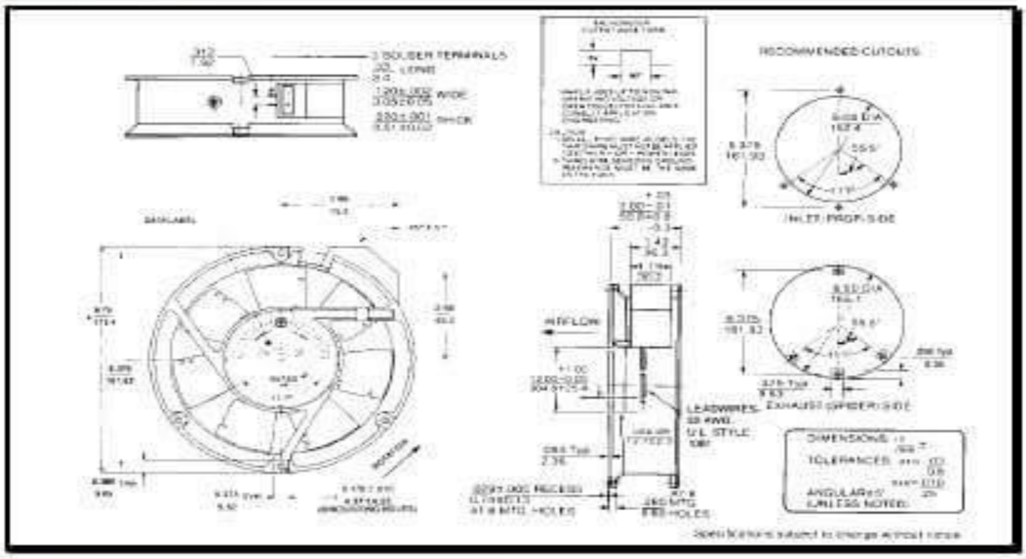
Model Number: PQ24B4

Part Number: 19031084A

December 15, 200!

COMAIR ROTRON

Mechanical Drawing:



Motor:

Nominal Voltage	= 24 vdc
Operating Voltage Range	= 12 - 28 vdc
Nominal Running Current	= 1.00 amps
Locked Rotor Current	= 2.00 amps
Running Power	= 24 watts
Average Speed	= 3500 RPM
Bearings	= Ball
Air Flow	= 235 CFM
Acoustic	= 51.2 dBA

Construction:
Venturi: Single Piece, Die-Cast Aluminium, Black
Propeller: Plastic, Black, UL 94V-0

Life Expectancy:
This fan is designed for continuous duty life of 75,000 hours at 40°C.

Additional Features:
Brushless DC Motor
Polarity Protected
Locked Rotor Protection
Automatic Restart Capability

Operating Temperature:	-10°C to 70°C
Storage Temperature:	-40°C to 85°C

Termination:
0.110" Terminals (2)

Agency Approvals:
UL, CE

Chapter 7

Conclusions and Future Work

7.1 Conclusions

Different solutions were analyzed based on simulations and hands on calculations and the best solution has been chosen.

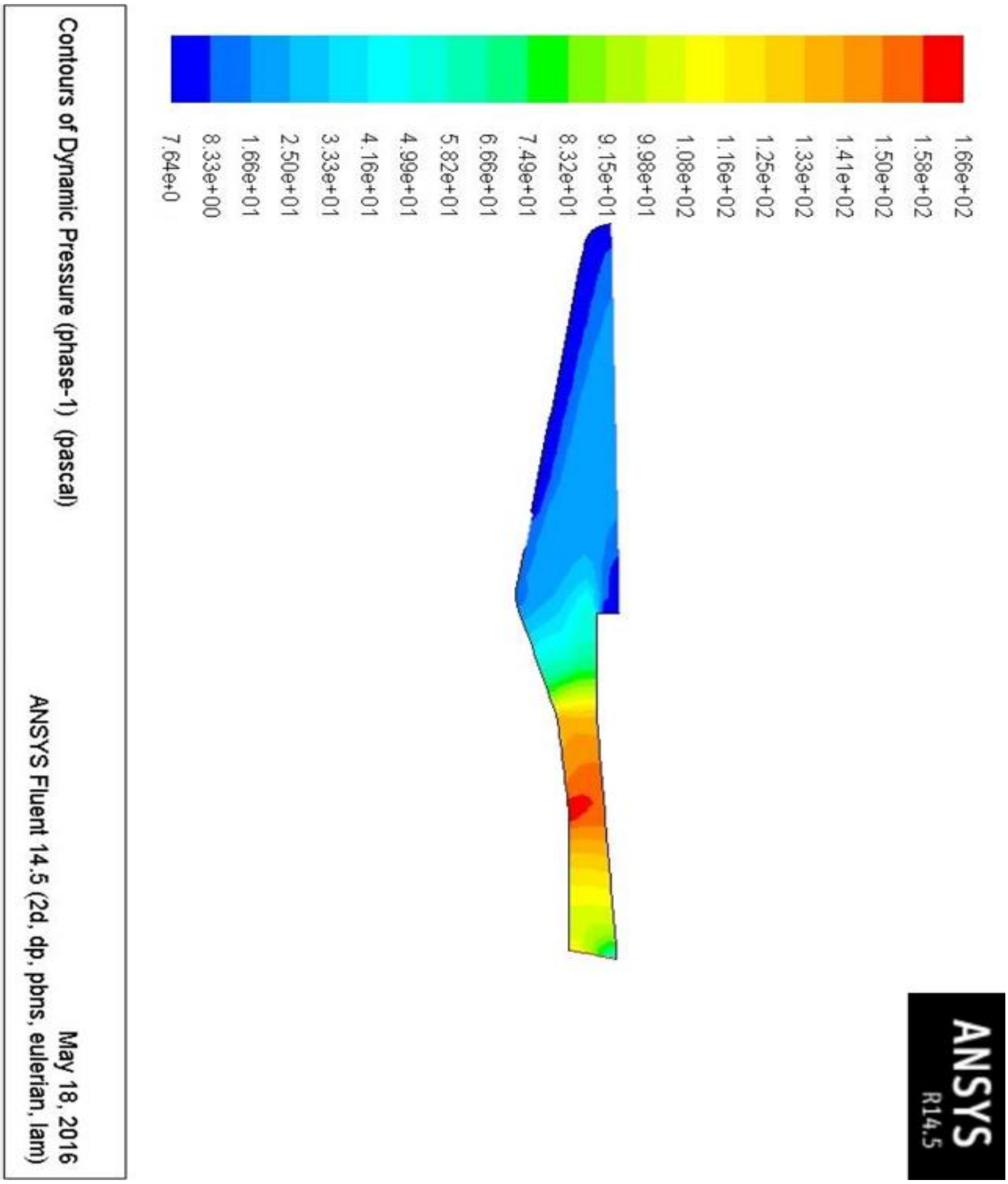


Figure 7.1. Effect of Vacuum

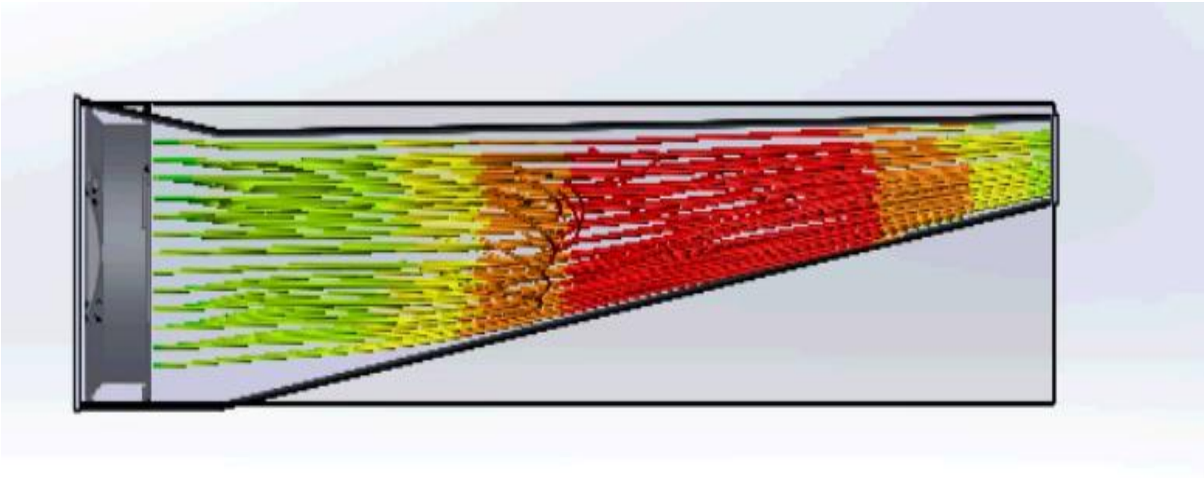


Figure 7.2. Flow visualization due to fan

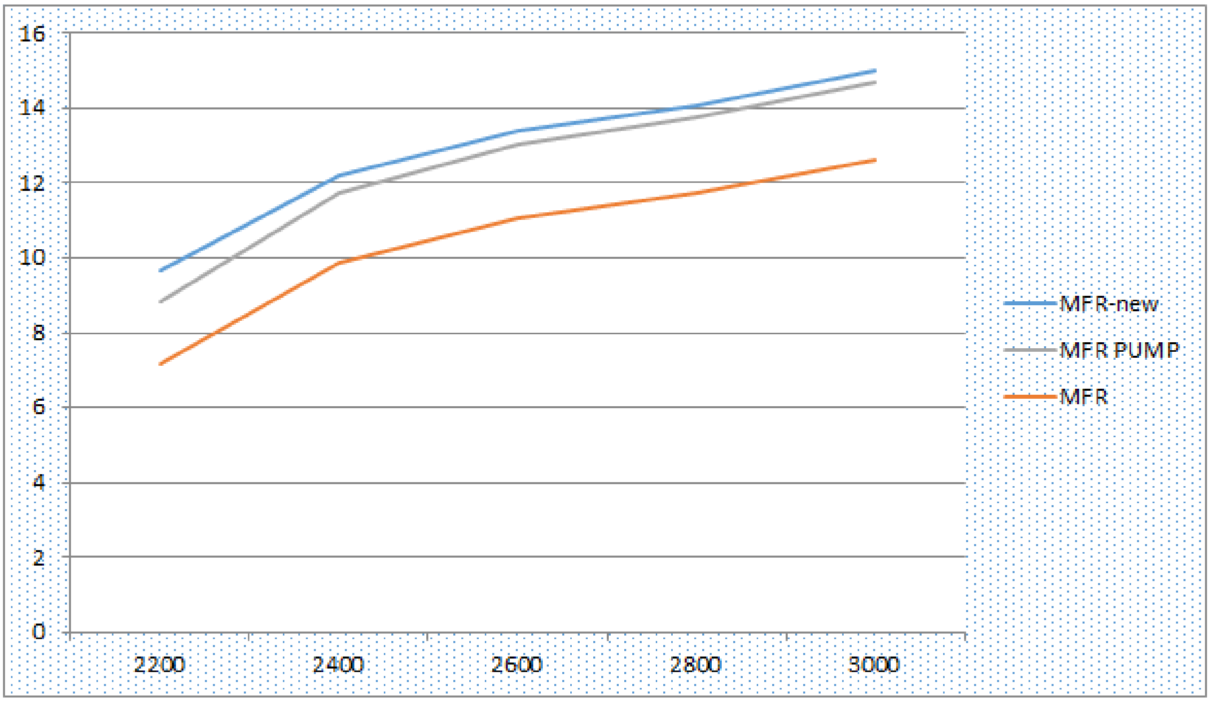


Figure 7.3 Comparison between three alternatives

Chapter 8

Results and Discussion

All the alternatives were discussed and studied carefully. Eventually the best alternative has been chosen after comparative analysis, which was installing fans in the chamber. We have been successfully able to modify the system and increasing the mass flow rate of air. Consequently, the force heat induction increased and hence seize of engine is averted. Results from the test bench shows that now the temperature inside the chamber at low rpm is as desired.

Our proposed solution is mainly applied on the diesel engine of 500 defensive off road vehicles that are in service. Additionally, it can be applied to heavy off road vehicles like tractors, forklifts, cranes, bulldozers etc. So it has vast field of application.

Chapter 9

Future Work

9.1Deductions

We have been successfully able to install our proposed solution in the vehicles of the industry as shown in figure. We also fabricated a demonstration and visualizing model for the department where all the alternatives were studied and simulated in Softwares.

Figure 9.1. Installed Fans and visualization model (GreenHeck, 2005) (GreenHeck, 2005)

9.2Future Recommendations

1. Experimental validation of results of the conducted research.

2. Expansion of application of work to other types of off road vehicles such as cranes and fork lifters etc.

References

[1] GreenHeck, *Fans Fundamentals*, 2005.

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