Addis Ababa University
Addis Ababa Institute of Technology
(AAiT)
School of Mechanical & Industrial Engineering
Railway Engineering Stream

CFD ANALYSIS OF A RAIL WAY TUNNEL VENTILATION

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Declaration

I hereby declare that the work which is being presented in this thesis entitled "**CFD analysis of a rail way tunnel ventilation"** is original work of my own, has not been presented for a degree of any other university and all the resource materials used for this thesis have been duly acknowledged.

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This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

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ABSTRACT

The aim of a tunnel ventilation system is to reach the major safety levels as possible both in fire and service situations. In service situation the system has to guarantee that the atmosphere of the tunnel assembles a suitable condition of comfort and safety for the users; assuring the dilution of the pollutants from the vehicles to admissible limits, and allowing a suitable reaction capacity in case of a quick demand of flow. On the other hand, in case of fire the aims would be to control the smoke layer as far from the users as possible, to avoid the spreading of the incident to zones not implied in the fire and to support in rescue tasks.

ANSYS FLUENT is Computational Fluid Dynamics (CFD) software that allows users to simulate flow problems of ranging complexity. It contains broad physical modeling capabilities needed to model flow, turbulence, heat transfer, and reactions over objects designed by the user.

In this thesis the objective of the study is to analyze the rail way tunnel ventilation system using CFD software to create comfort ventilation system in the tunnel. The comfort ventilation concept refers to the situation when air quality within the tunnel is reduced due to presence of polluted air in the tunnel. Based on the conditions on, Mekele tunnel numerical analysis of air flow field is carried out by the finite element software—CFD and k-ε turbulence model to show the volume flow rate of the expelled air out of the tunnel by using jet fans in this paper.

The result shows that the required amount of air is removed by using a series arrangement of jet fans to create the comfort ventilation system in the tunnel.

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LIST OF ACRONYMS

AAiT *Addis Ababa Institute of Technology*

ERC *Ethiopian Railway Corporation*

CFD *computational fluid dynamics*

CATIA *computer aided three-dimensional interactive application*

1D *one-dimensional*

3D *three-dimensional*

RANS *Reynolds naiver stokes*

RHS *right hand side*

LHS *left hand side*

$\dot{v}$ *air flow through tunnel*

ACH *air change per hour*

NOMENCLATURE

u	the velocity vector
t	the temporal coordinate
p	static pressure
ρ	fluid density
τ	stress tensor
s	a vector containing momentum source term
A_F	fan discharging area
U_F	fan discharging velocity
η	Fan efficiency
P_e	fan electric power
Fj	jet fan thrust of one jet fan
Δpj	pressure rise by one jet fan
η1	jet fan performance or efficiency
η2	wall friction (installation efficiency)
η3	influence between jet fans (efficiency of the total system)
Qj	airflow through the jet fan
uj	fan outflow velocity
A_T	cross section of the tunnel
L	length of tunnel

CHAPTER ONE

INTRODUCTION

1.1 Background

Historically, the first reason for installing ventilation systems in tunnels was the reduction of pollution levels. Although the emissions of pollutants by road vehicles have decreased dramatically over the last decades, this function is still important and must be paid close attention at the design stage. In some cases, natural ventilation due to the piston effect of moving vehicles may be sufficient to fulfil the air quality requirements in normal operation. The need for a mechanical ventilation system is assessed considering the length of the tunnel and the traffic type (bidirectional or unidirectional) and conditions (possibility of congestion). [1]

Removing the smoke from the metro tunnels has been a major concern for the system's designers and operators. It also represented the main push for the development and evolution of safety criteria, due to the need to ensure passengers' safe evacuation in case of a fire. The need for placing ventilation shafts along the tunnels was accepted from the very beginning, but where to place the shafts and how to blend them in a city landscape was never fully agreed upon.

Steam locomotives, requiring special consideration for an effective ventilation system to exhaust the steam and smoke out of the tunnels, powered the first trains used by London Underground. The original solution was to open air stretches of track to disperse the fumes and to provide ventilation shafts at various points along the route, to bring fresh air into the tunnels and to allow the engines to expel steam and fumes outside.

To sustain the trains operation, numerous vent shafts of various designs and depths (Hampstead shaft had 55.2m) were built during the Victorian era and are found around the London area, providing airflow exchange between the street level and the tunnels (one of the 'original' vents is at Leinster Gardens, W2). The 'piston effect' of trains moving through tunnels and entering/exiting the stations was (still is) the main 'method'' to pull in fresher air to platforms and extract stale air. However, these measures have proved to be insufficient for providing clean and cool airflow required for the network of today, particularly in summer months, with rising temperatures and lack of ventilation becoming an increasing challenge.

When the steam-powered locomotives were replaced by electric motors, the need for purging the tunnels was reduced, however, the heat and the foul air had to be pushed out of the tunnel. For this to happen passive vents (also called ‘blow-holes’) were provided at certain distances and they were terminated with gratings at the street level, most often along the sidewalks. The vents allowed fresh air to be drawn in by the passing trains, and also warm, vitiated air to be exhausted by the piston effect. It was noted that initially the air passing through the gratings was sometimes violent (up to 7.4 m/s) and newer systems were designed with larger vent area and gratings. With a mechanical system to supply fresh air to the stations, it was considered initially that the tunnels could be kept clear of smoke and heat. The provision of vents opened to the street level was implemented when the electrically powered trains were adopted and many old subway systems still have the gratings along the walkways (New York, Boston, and Chicago). One of the first design criterion used in tunnel ventilation was to ensure the complete purge of the tunnel air and achieve certain air changes per hour. It was realized that natural ventilation alone, as enhanced by the piston-effect of the moving trains, did not suffice. [2]

The 1.6 mile (2.6 km) long Holland Tunnel was the first tunnel under the Hudson River for motor vehicles and, at the time of the openings , the longest under water ,mechanically ventilated tunnel in the world .Construction of the Holland Tunnel began on October 12, 1920. The first shield was erected in the Canal Street shaft on the New York side. On October 26, 1922 compressed air was introduced in to the shied chamber, and actual tunneling was begun the shield were typically 9.2m on outside diameter and 5m long [3].

The Franco-Ethiopian Railway was constructed from Djibouti to Douanle in 1901 and a train with Swiss made diesel engine commenced operation on this line on July 22 the same year. The main line was then extended to Dire-Dawa after a year and half. The trains under operation had bogie wagons of some with 4 axles weighing 10 tons and carrying 22 tons and some with 2 axles weighing 5 tons and carrying 10 tons. Later in 1915 the main line was extended further to Akaki and the first train reached Addis in 1917. The Railway had 54 locomotives, 46 luxury passenger coaches, 10 mixed first and second class coaches, 26 third class coaches, 2 service coaches and 445 goods wagons. It has finally deteriorated after serving for nearly a century due to lack of maintenance, poor management and lack of commercial focus. [4]

The previous Railway of Ethiopia didn’t have any underground (railway tunnel) on the main line. Hence, there had not been any experience regarding underground (Railway tunnel) in our country so far. However, the construction of the new Ethiopian Railway demands the use of underground (railway tunnel) as there are some tunnels whose constructions are underway. Consequently, the development and implementation of underground (railway tunnel) systems, based on the context of Ethiopian Railways, is of vital importance.

In modern cities around the world, the need for mass transit systems increased significantly as a result of increase in fuel prices and traffic intensity. The tunnel rail transit systems are continuously built in cities whose populations are growing rapidly as they are among the most effective mass transit means in terms of passenger transport capacity. From passengers�SS point of view′, these systems should be fast, reliable, and cheap and above all, they should be safe and comfortable .The safety and comfort issues are closely related with ventilation strategies of these systems and these strategies play an important role in the planning and design process of the overall system. [5].

The ventilation system is an integral part of the safety in tunnels of significant length, and has the dual role of supplying fresh air to limit the concentrations of vehicle exhaust gases to acceptable levels within the tunnel traffic space (normal operation) and to control movement of smoke and toxic gases in the event of a fire (emergency situation). The design of the ventilation system and associated operational strategy requires careful consideration of a number of important factors. These include the influences of length, slope and cross-section of the tunnel, the distribution, power and response time of any powered fans and the considerations of what might be the appropriate ‘design fire’. There may be other important factors to consider also, e.g. the presence of any natural airflow in a sloping tunnel due to a temperature or pressure differential between the tunnel portals. The contribution of each of the above parameters is very complex [6].

The ventilation strategies of these systems should efficiently satisfy the demands of the safety and comfort issues and they play an important role in the planning and design process of the overall system. This paper will focus on the rail tunnel comfort Ventilation system, comfort ventilation is important for passengers, who ought to be subjected to clean and comfortable air conditions, and it requires selection of appropriate ventilation fans and suitable ducting, as well as taking constructional measures to mitigate the adverse effects of air movements induced by train operations. These requirements must be determined and analyzed at the very first stage of planning and design phase of the overall system and the construction of the system must be started after these safety and comfort issues are warranted by technical investigations.

1.2 Statement of the problem

Ventilation in tunnels is required for normal and emergency operation. During normal operation its purpose is to provide a clean air environment and to maintain visibility in the tunnel by preventing the accumulation of pollutants and particulates. During emergency operation ventilation is needed to influence the flow of smoke and combustion products so as to create a safer environment for tunnel users to escape and for emergency services to intervene. This report focuses on establishing the road tunnel ventilation capacity for normal operation.

When the train moves through the tunnel, the passengers which are waiting in stations or the passengers which are in the trains will be affected by the air quality of the surrounding and feel the discomfort arising from polluted air:

- Carbon monoxide (co)
- Oxides of nitrogen (Nox/No_2),
- Carbon dioxide (Co_2)
- Sulphur oxide (So_2)
- Vehicle heat - temperature or suffocation caused by the presence of some chemicals, in tunnel air velocity or some other factors.

From an air-quality point of view, a road tunnel can be viewed as a chamber where traffic emissions from a section of road-which would normally be dispersed into the atmosphere along the length of that section of the road-are concentrated before being released at one or a few points. Compared to a surface road, the air quality as experienced by road users is relatively poor; also, the effect on local residents is redistributed, so that contaminated air is more concentrated near the points where tunnel air is released in to the atmosphere.

Air pollutants emitted from road vehicles are normally dispersed rapidly from the road by wind and turbulence effects (although this may not apply to canyons between tall buildings). The interior of a road tunnel is generally sheltered from the wind and the effects of any turbulence will be limited by the supply of fresh air available to dilute the polluted air.

In a given time, a certain mass of pollutants will be emitted in to the air depending on:

- The number of vehicles in the tunnel
- The intensity and characteristics of vehicle emissions.

The emissions per vehicle are highly variable and depend upon a range of factors. These include vehicle age, speed, size, fuel type, engine specifications, engine temperature, road gradient and factors that are hard to quantify, such as state of vehicle maintenance and driving style. [7]

The other causes of air pollutants are: - Ice, corrosion of the tunnel concrete lining due to thermal deformation processes, fog formation, and the emission of radon from water and rock are some of the factors which hinder the safe operation of rail way tunnels. Irrespective of the season, the basic way of maintaining the essential air quality in the tunnel is to ensure that the ventilation and heating regimes assist the supply of a fixed amount of air at a positive temperature into the tunnel.

Underground railway system usage is growing throughout the developing world and in many cities the underground railway is the most commonly used form of public transport. But the heavy use of electrically propelled train carriages within these systems, the heat generated by the train motors and electric lighting, together with body heat from passengers, is the other problem. It can generate substantial quantities of rejected heat energy. This energy can significantly increase air temperatures within the trains and tunnels. When coupled to high ambient temperatures this can lead to passenger discomfort and health issues [8].

Generally, when considering the ventilation concept of rail tunnel systems, there are two main issues. Namely, emergency ventilation and comfort ventilation. The emergency ventilation concept refers to the situation when one or more vehicles of the operational trains catch fire and the need for safe evacuation of the passengers arises. Whereas, the comfort ventilation concept refers to the situation when the air quality within the stations is reduced due to presence of working mechanical, electrical equipment's, train operation schedules and over-crowded stations. The passenger comfort can also be disturbed by excessive air movements induced by train operations, and thus the need for taking measures arises.

1.3 Objective of the research

1.3.1 General objective

- The general objective of the research is to analyze the rail way tunnel ventilation system.

1.3.2 Specific objectives

- Using CATIA software to create the tunnel model
- Calculate the required amount volume flow rate of air

- To analyze the contribution of jet fan to generate comfortable ventilated air in the tunnel, the number, size and arrangement of jet fans to be installed.
- Minimizing of uncomfortable air from the tunnel.

1.4 Research methodology

1.4.1 Primary data collection

At this stage all the necessary data which are used to do this research regarding tunnel ventilating system, civil work design of Mekele- tunnel such as the length, cross-sectional area of the tunnel, which are collected from Railway Corporation and useful literatures about the CFD analysis will be conducted for the cases of rail way tunnel ventilation. Finally, the results of the CFD will be collected as a form of tables and diagrams.

- Develop the mathematical model of the rail way tunnel ventilation system and drive the governing equations of fluid motion.
- Analyze the model in CFD.
- The type and concept of tunnel ventilating system and its operation principles is to be analyzed.
- The size, type, number and arrangement of fans is determined.
- The effect of ventilation system when the suffocated air is drawn out of tunnel is analyzed**.**

1.4.2 Numerical modelling

The analysis of tunnel ventilation systems can be also conducted using numerical models based on a mathematical representation of the physical phenomena involved. Numerical models are usually highly flexible, significantly more economic than experimental test, and allow for large parametrical studies and sensitivity analysis. The accuracy of numerical models must be always addressed on the basis of a direct comparison of the results to experimental findings in order to assess range of applicability and limitations.

The overall behavior of the ventilation system can be approximated using 1D fluid dynamics models under the assumptions that all the fluid-dynamic quantities are uniform in each tunnel cross section and gradients are only present in the longitudinal direction. 1D models have low computational requirements and are especially attractive for parametric studies where a large number of simulations have to be conducted. In the last two decades several contributions on the application of 1D models to tunnel ventilation flows.

1.4.3 Computation and simulation

CFD simulations require the solution of the complete set partial differential equations asserting the conservation of mass, momentum and energy. Such set of equations is solved numerically leading to detailed predictions of velocity and temperature fields, species concentration, heat fluxes mapping and so forth. The calculations are performed by enforcing the conservation laws on a high number of control volumes generated by a numerical discretization of the computational domain.

Severe limitations to the full numerical solution of the governing equations are induced by the impossibility of resolving the whole range of spatial and time scales involved in the turbulent flows associated with any ventilation in tunnels. This problem has been tackled by modifying the governing equations in order to model the unresolvable turbulent transport phenomena. Typically, two main approaches have been used: The first one is based on a time-averaging of the Naiver-Stokes equations (RANS) while the second one uses spatial averaging by means of specific filter functions. Such technique for turbulence modelling is known as Large Eddy Simulation

1.4.4 Analysis of the results obtained

The results from the CFD analysis will be analyzed according to fluid flow in the tunnel of ventilation system will be investigated. The result of this analysis is then reviewed to see if there is any inconsistency and mismatching with the hypothetically predicted in the beginning of the research. In addition, the result of this analysis will be evaluated and compared with the results of similar studies conducted by other researchers.

The outcome of the whole research will then be thoroughly analyzed with regards to the effect of the uncomfortable tunnel ventilation and briefly synthesized for recommendations to be made on how to improve the effect of rail way tunnel ventilation and number, arrangement of jet fan in the tunnel.

Finally, the result of this analysis will be stated briefly so that it can be a reliable source to be used later in the conclusion stage.

1.4.5 Data presentation

The primary data obtained from the research will be presented in an organized manner in diagram by representing an air flow effect in the tunnel.

The data from the CFD analysis will be presented in table, and diagrams obtained from the superimposition of fluent workbench analysis.

1.5 Scope of the research

- The 3D model of a rail way tunnel is generated using CATIA
- At the new rail way Ethiopian Weldia –Mekele section there are six tunnels, which are Aroley one, Aroley two ,Addionfito, Serghiem, Maicelfo, kokele tunnels, but from these tunnels for this research is used serghiem tunnel . Because the rest of tunnels length are very large, so the RAM capacity of this computer can't able to run to show the result.
- In the ventilation system there are five types of ventilation systems which are:-Natural, Longitudinal, Semi-Transverse, Full-Transverse, Single-Point Extraction ventilation. But this research used longitudinal ventilation system with jet fans. Because it is simple and economical both in construction and operation .ventilation building are not required.

1.6 Limitation of the research

- When considering the concept of ventilation system there are two types of ventilation system emergency ventilation and comfort ventilation .however, this paper will focus on only comfort ventilation system. Emergency ventilation system is the future work of this thesis
- An experimental test will not occur.
- In Ethiopia in other places there is a rail way tunnel, but this research focuses only on Mekele tunnel.
- Usage of jet fans
- The used number of fans are limited due to Ram capacity of computer to run FLUENT.

1.7 Significance of the research

Continual air circulation is required in the tunnels so as to maintain the air quality and temperature for the passengers to create comfort conditions. During normal operation, the ventilation facilities bring fresh air in the train's underground, and remove the heat and moisture generated by passengers and railway equipment.

1.8 Assumptions and suggestions

The air flow in the tunnel is too complex to analyze the processing based on the existing theories. Therefore, in order to facilitate the research, the air flow in the tunnel can be simplified, and the assumptions can be made as follows:

- The fluid in the tunnel is supposed to be continuous medium;
- The fluid in the tunnel is supposed to be incompressible;
- The air flow in the tunnel is supposed to be stable turbulence;
- The fluid in the tunnel meets the conservation principle.
- Usage of One dimensional fluid flow
- Considering that the simulation calculation will be relatively complicated if the actual situation was taken into account, the geometric model of the tunnel is simplified by ignoring the drainage channel, cable trench, and other secondary factors.
- Ignore the effect of the equipment or obstacles which are present in the tunnel
- jet fans are suspended on the celling of the tunnel
- The effect of jet fan through the tunnel is the same due to symmetrical cross section of the tunnel
- Use Longitudinal ventilation system
- There is no train in the tunnel

1.9 Organization of the Research

The research is organized in five main chapters and each chapter comprises subtopics. Chapter one covers the necessary background to the study. In chapter two, the review of some of the journal articles, proceedings and publications which were referred during the course of the research are presented and the need to do this research was delineated. The third chapter covers the modeling issues. In this chapter, the physical, mathematical and the model of the Mekele rail way tunnel are developed. In addition, the governing equation of fluid flow is derived. In chapter four, the developed model was validated and the outputs of the FLUENT is analyzed and discussed. The fifth chapter is dedicated for conclusion, recommendation and future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The aim of a tunnel ventilation system is to reach the major safety levels as possible both in fire and service situations. In service situation the system has to guarantee that the atmosphere of the tunnel assembles a suitable condition of comfort and safety for the users; assuring the dilution of the pollutants from the vehicles to admissible limits, and allowing a suitable reaction capacity in case of a quick demand of flow.

Discussed the aforementioned concepts on ventilation of underground rail transit systems, design criteria and technical issues, amplifying their corresponding importance for safe and comfortable public transport giving specific examples from specific applications in Turkey. In order to have safe and comfortable ventilation, the systems must be planned and designed properly prior to the construction so that structural precautions can be taken more easily and must be maintained and operated with well-defined procedures and methodologies. [5]

Discusses the problem in relation to a train fire occurring in a single track rail tunnel 3 km long. In order to investigate the effect of Saccardo ventilation nozzles on the flow generated by buoyancy from the fire, a computational fluid dynamics (CFD) model was used. The results indicate that a practical Saccardo system can be developed to provide effective smoke control against the effect of buoyancy in a fire situation. Moreover, the predictions indicate that fan "startup" may be achieved against an established buoyancy driven flow by the fire. The time taken to clear the air behind the fire is dependent on the response time of the fans. [9]

The following paper provides an overview of the current status of the planned tunnel ventilation system for the Brenner Base Tunnel. The tunnel ventilation system ensures that the ventilation goals, based on the requirements of operation, are achieved for the normal, maintenance and emergency mode. In this way, the tunnel ventilation system ensures that the temperature and humidity of the tunnel air during normal operation and the quality of the tunnel air during maintenance work fulfil the requirements during operation of the tunnel. For the eventuality that a burning train stops in the tunnel, the tunnel ventilation system ensures that the passengers are protected from smoke in a safe place up to their evacuation. The ventilation concept guarantees in the normal operation, during maintenance work and in the case of an incident (train fire) that the ventilation objectives can be satisfied in most situations. With the aid of extensive aerodynamic and thermodynamic calculations the effect of the tunnel ventilation could be proved. [10]

The present analysis deals with a tunnel system consisting of two long single-track tubes, which are connected by cross-passages used for escape and rescue in case of a tunnel fire. The installation of jet fans in the portal regions supporting the emergency ventilation in the cross-passages close to the portals, is an option discussed here. The present analysis shows that the jet fans are only effective under special conditions.

- When trains are present in the tunnel, the traffic-induced flow dominates over the flow generated by jet fans, so that jet fans are not effective. This situation can generally be encountered in long railway tunnels.
- In medium-sized tunnels, trains can leave the tunnel, but there may still be some residual traffic induced flow, when the jet fans start operating. In this case jet fans can contribute to the emergency ventilation after a time delay, when the traffic-induced flow has decreased.
- Jet fans are quite effective in an initially quiescent tunnel environment. Only short time intervals are required to reach full ventilation power in the cross-passages. In particular, a short-circuit flow through the cross-passages close to the portals is quickly established. It can be concluded that the benefit of jet fans installed close to the tunnel portals is limited in the presence of traffic induced flow. The corresponding ventilation scenarios have to be analyzed carefully before considering the installation or use of jet fans. In the light of these results, the more costly alternative of an emergency ventilation by jet fans installed in the cross-passages themselves could be envisaged.[11]

The research were conducted numerical simulation characteristics of air flow in a tunnel .The jet flow inside tunnel is a little different from the turbulent free jet because of the wall friction and the constraint of space. But the jet trend of axial velocity obtained from simulation results agrees quite well with turbulent free jet theory.in this paper, four calculation models were carried out to investigate the velocity distribution and pressure distribution inside tunnel with different combination modes of jet fan. From the simulation results, it can be concluded that the ventilation performance mainly depends on the series mode and the separation of adjacent groups of fans. The novel combination mode which consists of double paralleled fans and single fan is regarded as the optimum combination mode .when most operational fans are located near the tunnel entrance, it is more conductive in increasing the velocity and pressure inside tunnel. [12]

In this paper, the authors have simulated a realistic full and reduced-scale tunnel in order to evaluate the influence of ceiling and floor roughness height on the velocity field to identify an appropriate material for a future experimental apparatus. The jet fans are simulated as a simple momentum source. The fan is considered to be infinitely thin and the discontinuous pressure rise (pressure drop) across it is defined as a function of the air velocity through the fan. In order to create a reduced-scale model from a full scale, Froude method is applied to preserve geometrical, kinematical and dynamical similitude. The results, provided in terms of axial velocity profile in different tunnel sections, show the overlapping between velocity profiles of full scale numerical model with those of the reduced-scale model, for the both ventilation systems. [13]

A qualitative contribution has been presented by Bari and Naser (2005) [20]. The work addresses the spread of fire effluents within a longitudinally ventilated tunnel 1.6 km in length. The fire represented by a burning bus, was supposed to grow up to a HRR of around 44 MW in 10 s and to extinguish in 4 min. The fire was modelled as source of heat a smoke without dedicated combustion model. Besides the unrealistic design fire, the results were not corroborated by experimental measurements as well as no information about the smoke production modelling was provided.

The studies of this research is based on the simulation of CFD analysis of rail way tunnel ventilation system which has not been studied by other paper or research report. It focuses on the Ethiopian Mekele tunnel, because the ventilation of underground is crucial that for passengers .it should have fresh and high quality of air.

CHAPTER THREE

MODEL OF A RAIL WAY TUNNEL

3.1 Model of a rail way tunnel

The model used for the analysis is a new rail way Ethiopian Weldia - mekele section of serghiem tunnel .which is going to be supplied to Ethiopian rail Ways Corporation. The total length of the tunnel is approximately 121 m.

Table 3.1 Main technical parameters of Mekele rail way of Sergiem tunnel

parameter	Value
Tunnel length of serghiem	121 m
Cross section area of tunnel	50 m^2
Maximum Temperature	27^0c
Maximum wind speed	4.7m/s
Altitude	1360 - 2280m ,with altitude difference of nearly 50 - 270 m
Maximum operating speed of passenger train in the tunnel	120 km/h
Area of effective clearance above the single track	31.07 m^2
Tunnels route mainly distributed	D1K164+500 - D1K196+000
Natural slope	10 - 35 ^{o}

Figure 3.1 Mekele single track line tunnel

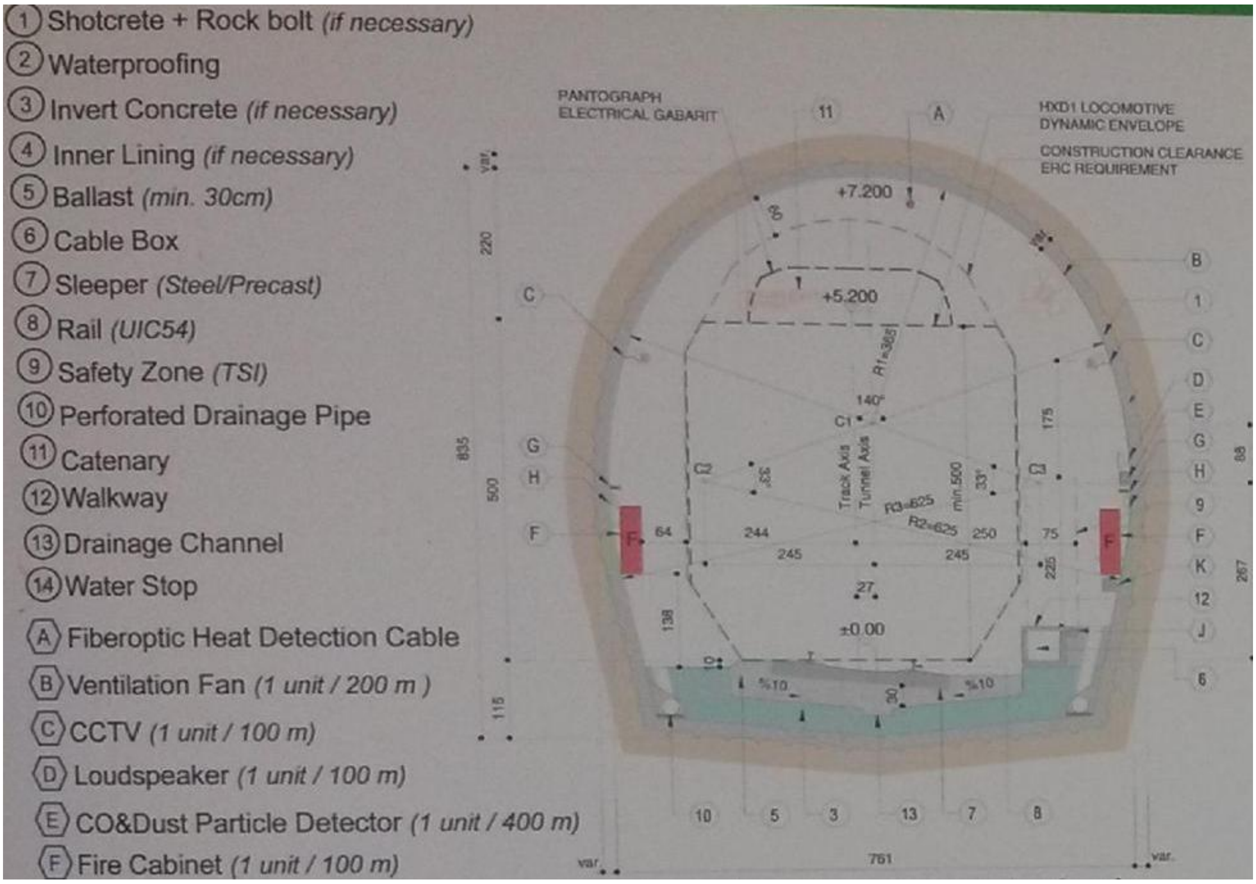


Figure 3.2 Detail drawing of tunnel

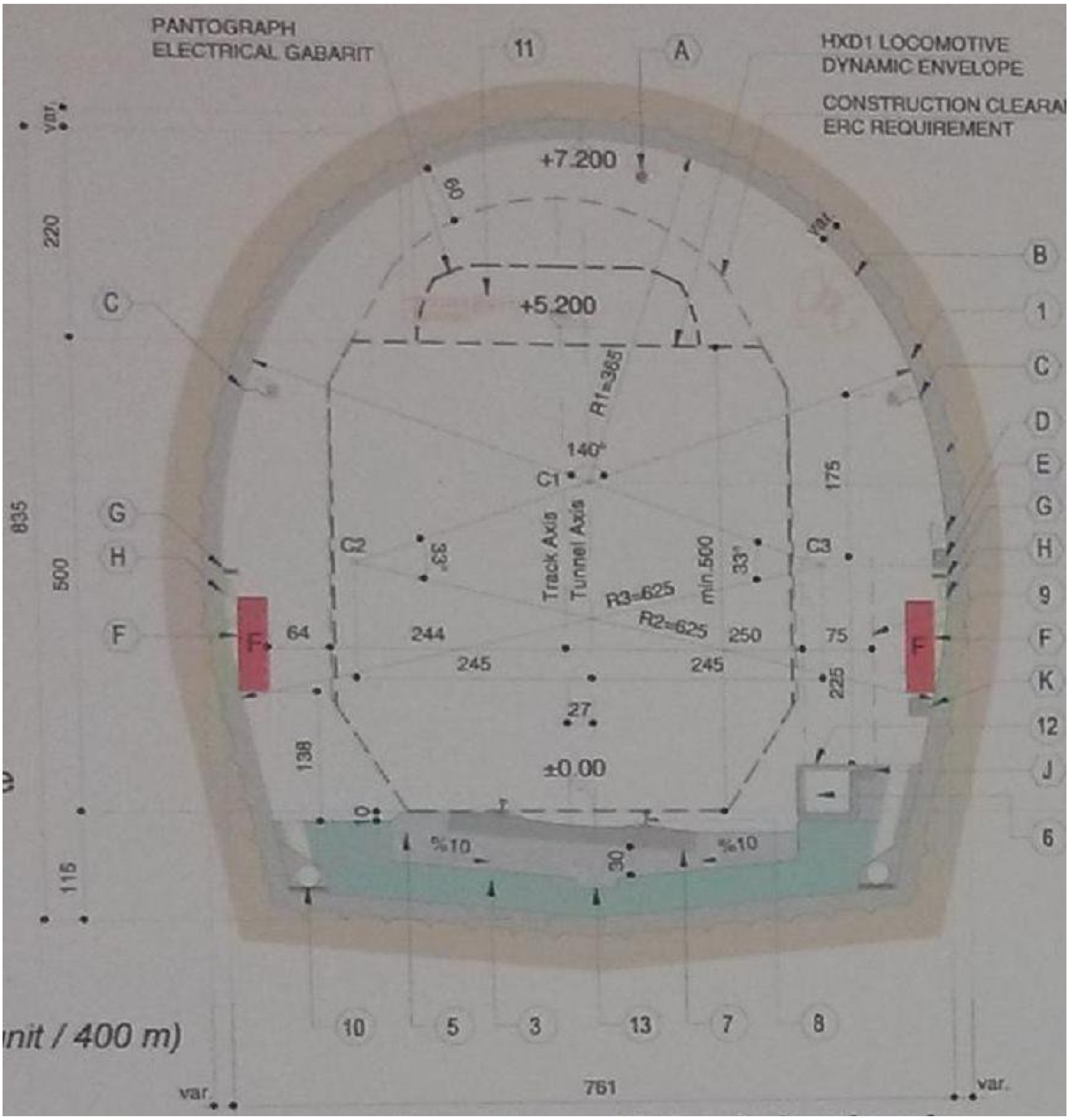


Figure 3.3 detail drawing of tunnel

$A_{exc} \cong 59m^2$

$A_{net} \cong 50m^2$

Ventilation systems

1. Types

Tunnel ventilation systems can be categorized into five main types or any combination of these five. The five types are as follows:

- Natural Ventilation
- Longitudinal Ventilation
- Semi-Transverse Ventilation
- Full-Transverse Ventilation
- Single-Point Extraction

It should be noted that ventilation systems are more applicable to highway tunnels due to high concentration of contaminants. Rail transit tunnels often have ventilation systems in the stations or at intermediate fan shafts, but during normal operations rely mainly on the piston effect of the train pushing air through the tunnel to remove stagnant air.

a) Natural ventilation

A naturally ventilated tunnel is as simple as the name implies. The movement of air is controlled by meteorological conditions and the piston effect created by moving traffic pushing the stale air through the tunnel. This effect is minimized when bi-directional traffic is present. The meteorological conditions include elevation and temperature differences between the two portals, and wind blowing into the tunnel. Figure 3.4 shows a typical profile of a naturally ventilated tunnel. Another configuration would be to add a center shaft that allows for one more portal by which air can enter or exit the tunnel. Many naturally ventilated tunnels over 180 m (600 ft) in length have mechanical fans installed for use during a fire emergency. [14]

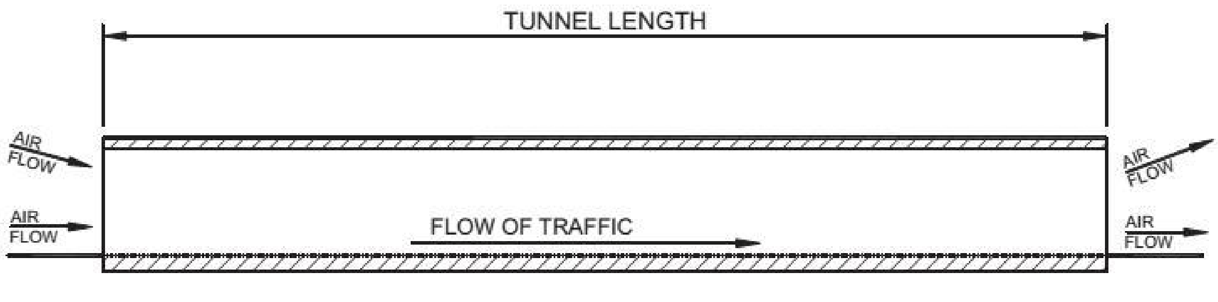


Figure 3. 4 Natural ventilation

Same considerations can be drawn when considering the ventilation flows due to piston effects. Indeed, it depends on a large number of factors, vehicle speed, vehicle spacing, traffic direction, vehicle drag coefficient, and tunnel geometry, and as expected, many of them cannot be controlled. Small-scale experiments have demonstrated that the ratio between air bulk airflow velocity and vehicle velocity is mainly dependent on the traffic conditions and ranges between 15% and 26% [15]. Full scale measurements under various realistic traffic situations performed in a 1.8 km long tunnel in Taipei City provided lower values: the ratio between vehicles and bulk flow speed ranged between 2% and 7% when the traffic density varied between 2 and 20 vehicles per km of tunnel length and the average traffic velocity is 90 km/h [16]. Figure 3.4 depicts the typical correlation between traffic density and induced ventilation flows in a tunnel in the Taipei City tunnel.

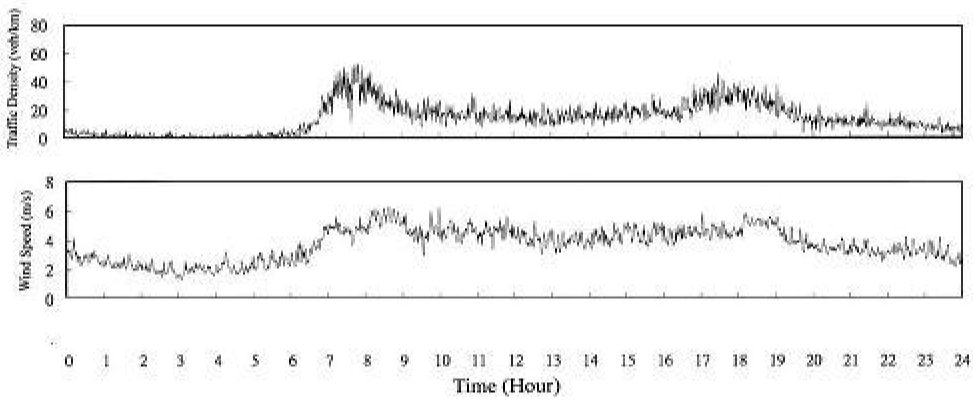


Figure 3.5 typical traffic flow and induced ventilation in the 1.8 km tunnel in Taipei traffic density and induced ventilation

Similar values have been encountered for railway tunnels during the passage of a train [17]. However, the same authors confirmed that, in two-way traffic conditions, the effectiveness of the piston effect is compromised and the ratio between bulk flow velocity and vehicle velocity is radically reduced.

For this reason, natural ventilation systems are applied to short tunnels. Depending on the specific national guidelines, the boundary between short and long tunnels ranges between 350 m-700 m in Germany or 400 m in UK [18].

b) Longitudinal ventilation

Longitudinal ventilation is similar to natural ventilation with the addition of mechanical fans, either in the portal buildings, the center shaft, or mounted inside the tunnel. Longitudinal ventilation is often used inside rectangular-shaped tunnels that do not have the extra space above the ceiling or below the roadway for ductwork. Also, shorter circular tunnels may use the longitudinal system since there is less air to replace; therefore, the need for even distribution of air through ductwork is not necessary. The fans can be reversible and are used to move air into or out of the tunnel. Figure 3.6 shows two different configurations of longitudinally ventilated tunnels.

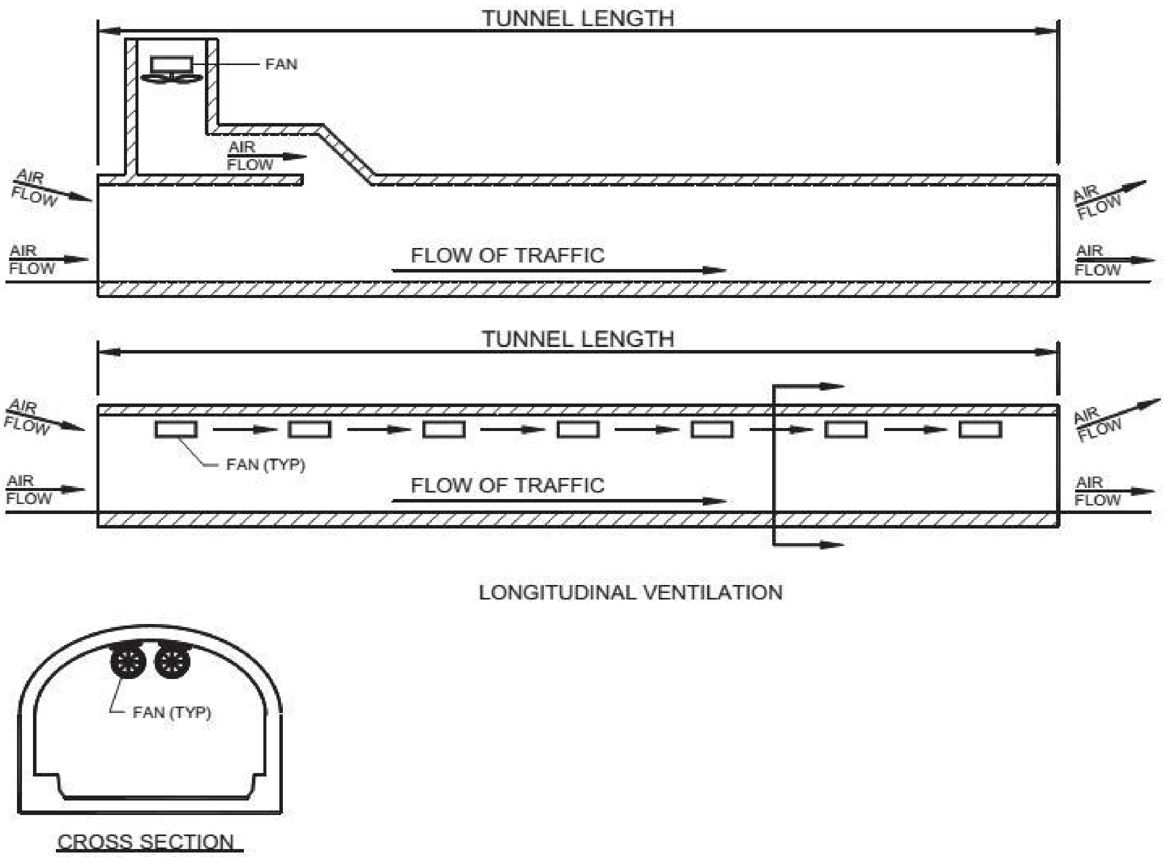


Figure.3.6 Longitudinal ventilation

Longitudinal ventilation systems based on jet fans use series of axial fans (known as jet fans or boosters) installed on the tunnel ceiling characterized by high thrust (hundreds of N) and high discharge ventilation velocities (around 30 m/s). The jet fans can be installed individually, in pairs or even more. A schematic of a jet fan longitudinal ventilation system is depicted in Figure 3.6.

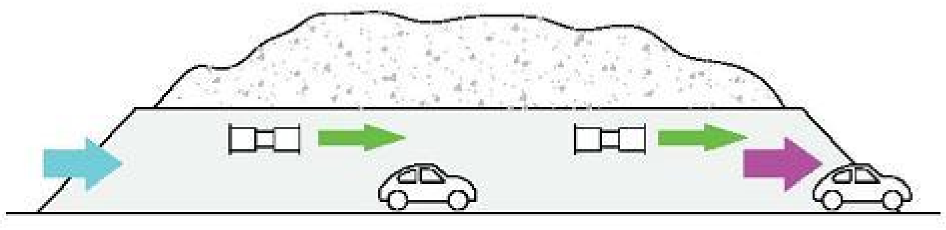


Figure.3.7 a schematic of jet fan longitudinal ventilation system [19]

c) Semi-transverse ventilation

Semi-transverse ventilation also makes use of mechanical fans for movement of air, but it does not use the roadway envelope itself as the ductwork. A separate plenum or ductwork is added either above or below the tunnel with flues that allow for uniform distribution of air into or out of the tunnel. This plenum or ductwork is typically located above a suspended ceiling or below a structural slab within a tunnel with a circular cross-section. Figure 3.8 shows one example of a supply-air semi-transverse system and one example of an exhaust-air semi-transverse system. It should be noted that there are many variations of a semi-transverse system. One such variation would be to have half the tunnel be a supply-air system and the other half an exhaust-air system. Another variation is to have supply-air fans housed at both ends of the

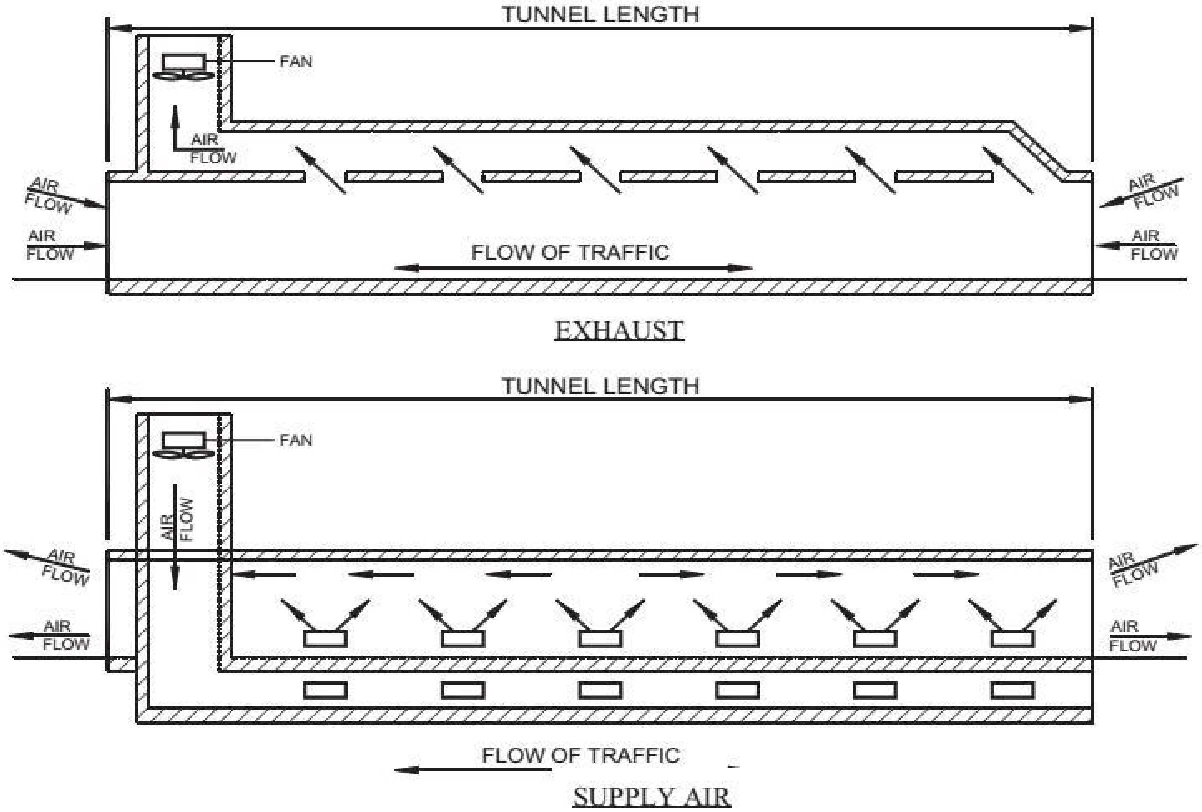


Figure 3.8 semi-transverse ventilation

Plenum that push air directly into the plenum, towards the center of the tunnel. One last variation is to have a system that can either be exhaust-air or supply-air by utilizing reversible fans or a louver system in the ductwork that can change the direction of the air. In all cases, air either enters or leaves at both ends of the tunnel (bi-directional traffic flow) or on one end only (Unidirectional traffic flow.)

d) Full- transverse ventilation

Full transverse ventilation uses the same components as semi-transverse ventilation, but it incorporates supply air and exhaust air together over the same length of tunnel. This method is used primarily for longer tunnels that have large amounts of air that need to be replaced or for heavily traveled tunnels that produce high levels of contaminants. The presence of supply and exhaust ducts allows for a pressure difference between the roadway and the ceiling; therefore, the air flows transverse to the tunnel length and is circulated more frequently. This system may also incorporate supply or exhaust ductwork along both sides of the tunnel instead of at the top and bottom. Figure 3.9 shows an example of a full-transverse ventilation system.

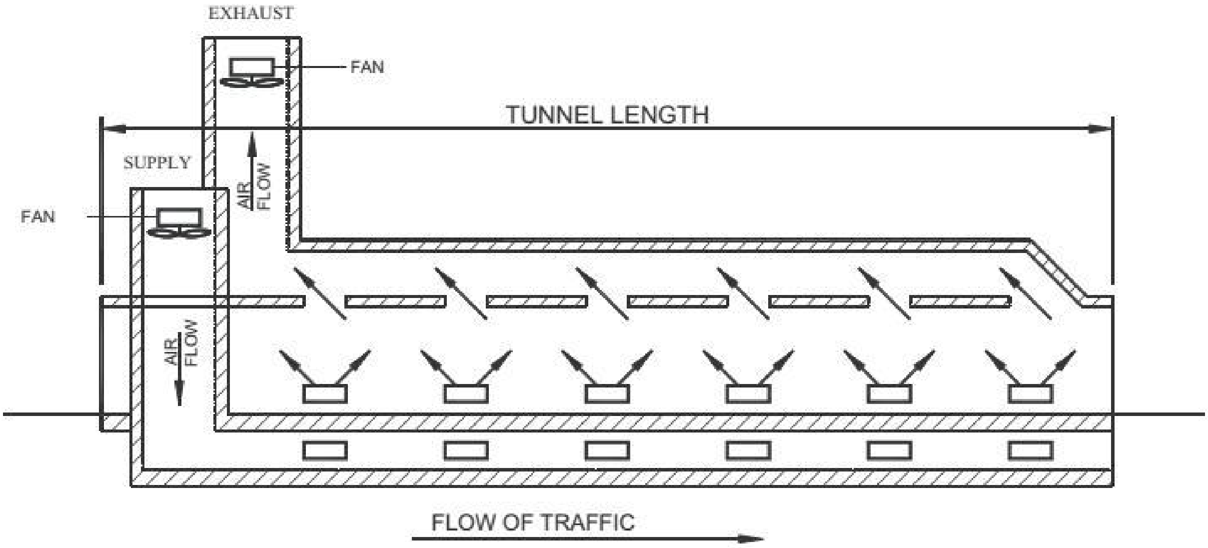


Figure3.9 fully transverse ventilation

e) Single -point extraction

In conjunction with semi- and full-transverse ventilation systems, single-point extraction can be used to increase the airflow potential in the event of a fire in the tunnel. The system works by allowing the opening size of select exhaust flues to increase during an emergency. This can be done by mechanically opening louvers or by constructing portions of the ceiling out of material that would go from a solid to a gas during a fire, thus providing a larger opening. Both of these methods are rather costly and thus are seldom used. Newer tunnels achieve equal results simply by providing larger extraction ports at given intervals that are connected to the fans through the ductwork. [14]

3.1 Mathematical Equation of Fluid Flow in Rail Way Tunnel

3.1.1 One dimensional modelling

Introduction

The main advantage of using 1D models for the analysis of complex network systems, (i.e. the tunnel main gallery and ventilation ducts), is that it allows for a complete and compact description of the system. This characteristic has two major consequences:

- it is possible to define with adequate precision the boundary conditions, such as the ambient conditions at the portals, and
- It is suitable for applications requiring the computation of a large number of scenarios, such as during the assessment of safety strategies for complex tunnels.

Its intrinsic limit is instead due to the fact that the flow in each cross section is assumed homogeneous; it is then identified by a unique value of the variables pressure, velocity, temperature, smoke concentration, etc. This peculiar assumption makes 1D models unsuitable to simulate the fluid behavior in regions characterized by high temperature or velocity gradients. Regions characterized by high temperature gradients are typically encountered close to the fire where well-defined smoke stratification is found. In the case of small fires, smoke stratification is important along large section of the tunnel and determines a peculiar propagation of the smoke front. In fact it proceeds with larger velocity than if it were to occupy the entire cross section. Thus, if 1D models are applied to fire events (particularly in the case of small fires where the smoke is stratified), it is necessary to properly introduce corrections to account for no homogeneity caused by the stratification, otherwise the calculated propagation velocity of the smoke front would be significantly under predicted [21].

Once the smoke away from the fire has occupied the entire, or nearly entire, tunnel cross section, the conditions are close to homogenous and the prediction of the propagation velocity is accurate. Regions with high velocity gradients are also typically encountered close to ventilation devices (i.e. jet fans) where the fan thrust produces highly 3D (tri-dimensional) flows and the flow homogeneity assumption of 1D model fails. Usually, 1D models describe the behavior of such regions on the basis of empirical correlations that must be calibrated on the specific tunnel layout. Indeed, the jet fan thrust curve provided by the manufacturer only applies to the isolated jet fans and it does not describe its behavior once installed in a particular tunnel gallery.

3.1.2 Fluid dynamics model

Modelling flow system requires that continuity and momentum equations are written with spatial dependence on one single coordinate, which, in the case of tunnels, is the longitudinal coordinate, *x*. The starting points are the Navier-Stokes equations, as described in their classical form for a time dependent three dimensional fluid flow. [22, 23]

a) $$\frac{\partial \rho}{\partial t} + \nabla \rho u = 0$$

(1)

b) $$\frac{\partial \rho u}{\partial t} + \nabla(\rho u u) = -\nabla p + \nabla \tau + \sum s$$

Where **u** is the velocity vector, *t* the temporal coordinate, *p* the static pressure, ρ the fluid density is the stress tensor, **S** a vector containing momentum source terms per unit volume (including the gravity term). Equation (1).a, known as continuity equation, states that the rate of flow into a volume must be equal to the rate of change of mass within the volume. Equation (1).b, known as momentum equation, states that the rate of change in the fluid momentum is equal to the sum of forces acting on it. After eliminating the *y* and *z* spatial dependences, and neglecting the viscous stress term which loses its significance in a 1D formulation, the equations become

a) $$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} = 0$$

(2)

b) $$\rho \frac{\partial u}{\partial t} + \rho u \frac{\partial u}{\partial x} = -\frac{\partial p}{\partial x} + \sum smx$$

Where *u* is the longitudinal velocity and S_{Mx} is the longitudinal momentum source but in this thesis momentum source is not considered.

3.2 Turbulence modeling

Turbulence is the three-dimensional unsteady random motion observed in fluids at moderate to high Reynolds numbers. As technical flows are typically based on fluids of low viscosity, almost all technical flows are turbulent. Many quantities of technical interest depend on turbulence, such as:

- Mixing of momentum, energy and species
- Heat transfer
- Pressure losses and efficiency
- Forces on aerodynamic bodies
- etc.

While turbulence is, in principle, described by the Navier-Stokes equations, it is not feasible in most situations to resolve the wide range of scales in time and space by Direct Numerical Simulation (DNS) as the CPU requirements would by far exceed the available computing power for any foreseeable future. For this reason, averaging procedures have to be applied to the Navier-Stokes equations to filter out all, or at least, parts of the turbulent spectrum. The most widely applied averaging procedure is Reynolds-averaging (which, for all practical purposes is time-averaging) of the equations, resulting in the Reynolds Averaged Navier-Stokes (RANS) equations. By this process, all turbulent structures are eliminated from the flow and a smooth variation of the averaged velocity and pressure fields can be obtained. However, the averaging process introduces additional unknown terms into the transport equations (Reynolds Stresses and Fluxes) that need to be provided by suitable turbulence models (turbulence closures).

3.2.1 Turbulence models

- k-ε models
- Standard k-ε model
- Renormalization-group (RNG) k-ε model
- Realizable k-ε model

3.2.2 Setting Up the RNG k-ε Model

- **Differential Viscosity Modification**

The RNG turbulence model in ANSYS Fluent has an option of using a differential formula for the effective viscosity to account for the low-Reynolds-number effects. To enable this option, the **Differential Viscosity Model** option under **RNG Options** in the Viscous Model must be enabled.

- **Swirl Modification**

After you have chosen the RNG model, the swirl modification takes effect, by default, for all three-dimensional flows and axisymmetric flows with swirl. The default swirl constant is set to 0.07, which works well for weakly to moderately swirling flows. However, for strongly swirling flows, you may need to use a larger swirl constant. To change the value of the swirl constant, you must first enable the **Swirl Dominated Flow** option under **RNG Options** in the Viscous Model Dialogue box. [24]

3.3 Axial fan

The key advantages of axial airflow fans are compactness, low cost, and light weight. Axial fans are frequently used in exhaust applications where airborne particulate size is small, such as dust streams, smoke, and steam. Axial fans are also useful in ventilation applications that require the ability to generate reverse airflow. Although the fans are typically designed to generate flow in one direction, they can operate in the reverse direction. This characteristic is useful when a space may require contaminated air to be exhausted or fresh air to be supplied.

Axial fans have a severe stall region that makes them particularly unsuitable for systems with widely varying operating conditions. In this stall region, airflow is insufficient to fill the blades, causing the fan to operate unstably. The consequences of unstable operation include annoying noise patterns, inefficient performance, and accelerated drivetrain wear. This problem of stall can be solved in many axial fans by selecting a fan with an anti-stall device. These devices alter the airflow patterns around the fan blades, allowing stable fan operation over the entire range of airflow and pressure.

Axial fans must rotate faster than comparable centrifugal fans to achieve the same airflow capacity. This characteristic makes them noisier than comparable centrifugal fans; however, the noise signature is dominated by higher frequencies, which are easier to attenuate. [25]

a) Jet fan performance (η_1)

The thrust force, measured in the open in still air on a test bed is in the average 10 % smaller than the calculated momentum. The reasons are air swirl at the fan exit and turbulence: $\eta_1 = 0.9$

b) Wall friction (η_2) - Relative to a position of the jet fan several jet diameters away from the side wall or ceiling, additional wall friction losses occur for smaller distances. Typical η_2 values for un-deflected jets of diameter d at different positions in the cross-section are:

Table 3.2 wall friction

1 jet in a corner, jet edge practically touching wall and ceiling	~ 0.7
1 jet, jet edge at fan exit 1/2 d away from wall and ceiling	~ 0.8
1 jet, jet edge at fan exit 1 d away from wall and ceiling	~ 0.9
1 jet totally in a niche	~ 0.8
Many jets totally in a niche	~ 0.7

From the table select

η_2 ~0.8

c) Longitudinal distance (η_3)

The transfer of the jet momentum to the tunnel air column needs about 10 hydraulic tunnel diameters distance for jet fans without deflectors. In this minimum distance between jet fans, there should be no large obstacles in the jet path such as direction boards.

With deflectors (5 - 10 degrees jet deflection) a quicker momentum transfer can be achieved and the minimum distance between jet fans can be reduced to 6 - 8 hydraulic tunnel diameters. For these distances η_3 equals 1, but the value decreases quickly with shorter distances. [26]

$\boldsymbol{\eta}_3=1$

d) alternates of jet fan location in railway tunnels

As opposed to highway tunnels, the location of the jet fans at the roofing in the railway tunnels is impeded by the smaller cross-sectional area of the tunnel (34 – 55 m^2) as well as the presence of the overhead trolley line in case of electrically driven engines. Thereby, only jet fans with the diameter below 900 mm can be located directly in the tunnel.

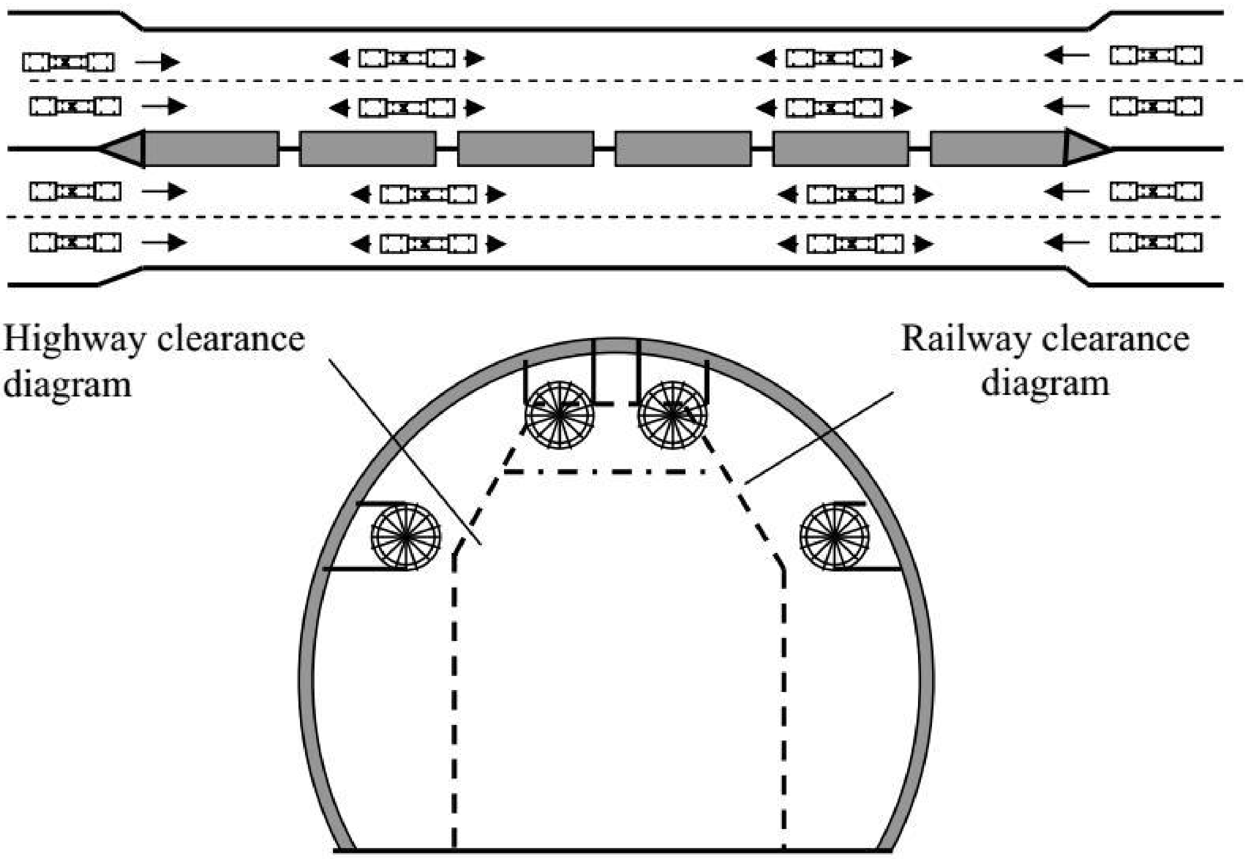


Figure. 3.11 Option of jet fans arrangement in rail way tunnels

In railway tunnels where electric propulsion engines are used the safety design margin limits the number of fans that can be installed in the section down to two fans fixed to the tunnel side walls only (figure 3. 11)

The limited capacity of the traffic sections of the tunnels to locate the required number of jet fans needed to maintain the specified ventilation modes has resulted in attempts to find other design solutions. The options with the jet fan location in niches available or constructed in the side walls of the tunnel (Figure 3.12), in the splayed parts of the tunnel or in special galleries located at the tunnel portals (Figures 3. 13 and 3. 14) have been selected as the most rational ones.

In all cases, the choice of jet fan position depends on the engineering possibility to construct either a gallery of the required design at the tunnel portal or a niche inside the tunnel and is eventually controlled by the construction costs.

Dimensions of the niches and the galleries depend on the standard size of the jet fans and should secure the maximum efficiency of their operation. Correlations between the jet fan sizes and the niche dimensions that would ensure the minimal loss of pulse developed by the fans are shown in Figure 11. Moreover, these fans should be installed so as to ensure air injection in opposite directions, i.e. they should be reversible. [27]

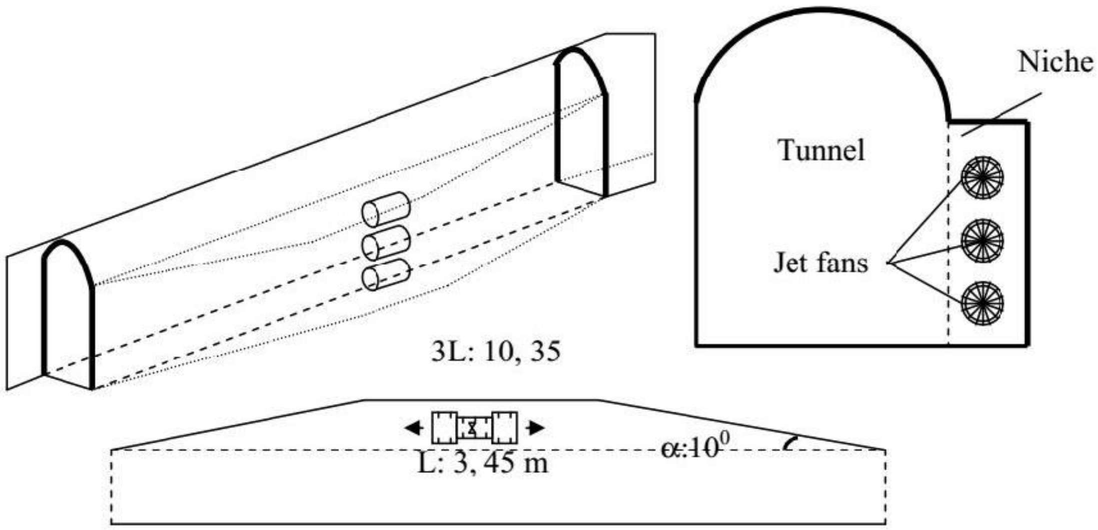


Figure. 3.12 positions of jet fans inside the tunnel

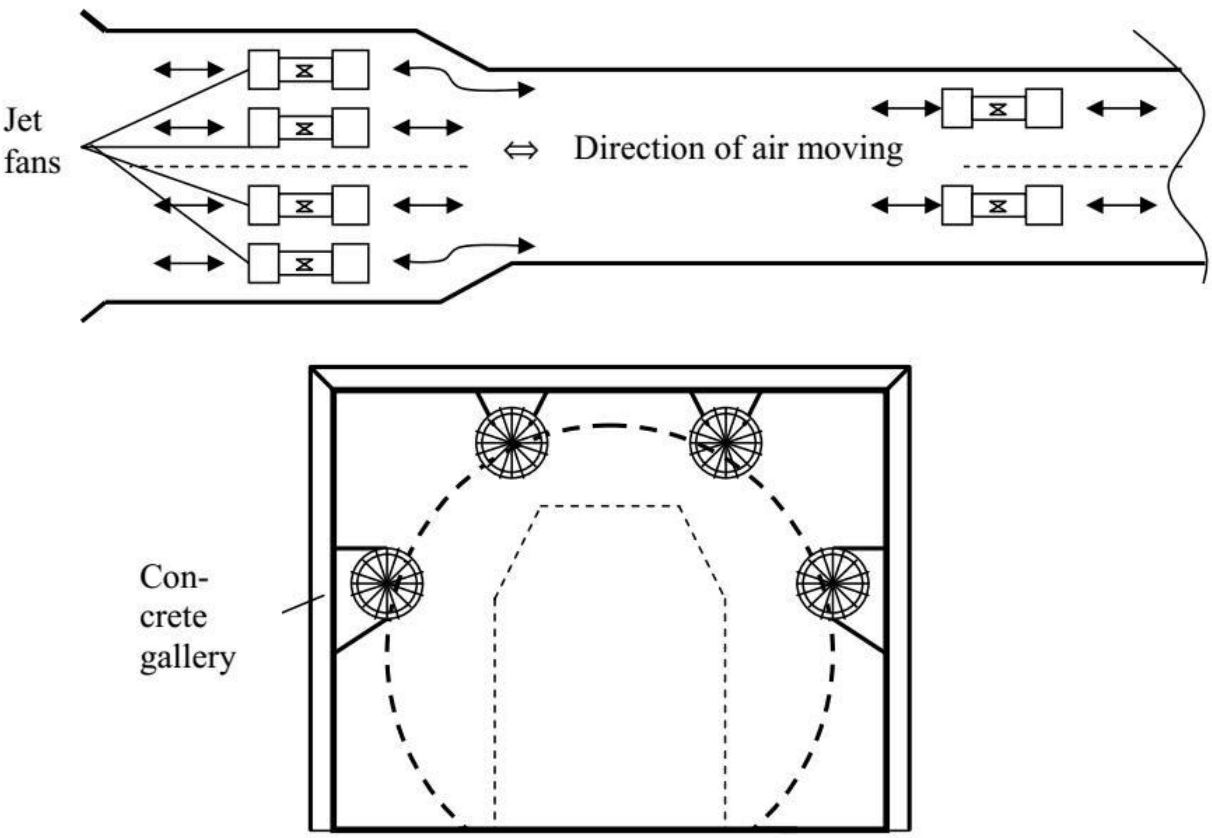


Figure 3.13 arrangement of jet fans in the gallery and inside the tunnel

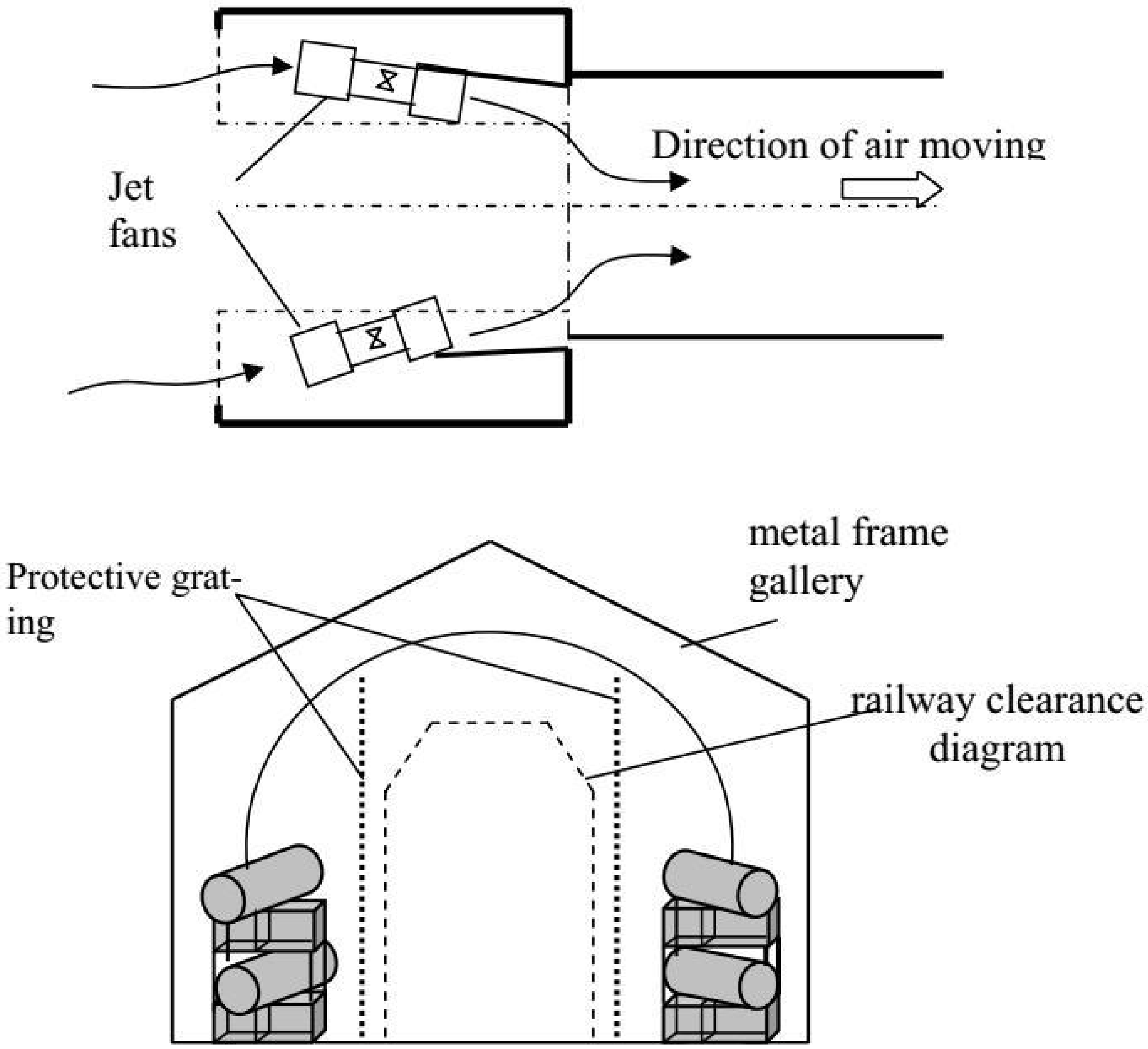


Figure. 3.14 arrangements of jet fans in gallery

3.4 Suggested Air Changes for Good Ventilation

3.4.1 Determination volume flow rate of fans

The most common method used to calculate the flow rate for a given fan or fans is based on complete changes of air in a structure in a given time period. To determine the flow rate required to adequately ventilate an area, divide the room volume (in meter cubic) by the appropriate "Minutes per Air Change" as shown in the chart below.

Additional considerations when determining the number of air changes are:

- Local code requirements on air changes
- Specific use of the space
- The type of climate in the area

In the most severe conditions select the lower number (in the series shown on table 3.3) to change the air more frequently. For moderate conditions, select the mid-range. For less severe conditions in cool climates, the higher number will provide adequate ventilation. [28]

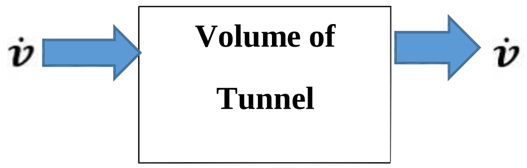


Figure. 3.15 air flow representation of tunnel

Table 3.3 minute per change for tunnel

Type of space	Minute per air change
Tunnels	6-10 air change

$$\dot{v} = \frac{\text{volume of tunnel}}{\text{minutes change}} \quad (3)$$

The task of ventilation is to clear the suffocated air from the tunnel before the train enters the tunnel, i.e. ventilation schemes should be designed on compensatory principles. In order to completely remove the suffocated air from the tunnel it is necessary to inject the amount of air that equals the total volume of the tunnel, i.e.

$$\text{Volume of tunnel} = \text{length} * \text{width} * \text{height } [m^3] \quad (4)$$

Or $V = A * L$

$$V_{tunnel} = 50 * 121 = 6050 m^3$$

$$\dot{v} = \frac{6050 \text{ m}^3}{8 \text{ min}}$$

$$\dot{v} = 12.6 \text{ m}^3/\text{s}$$

From this we can conclude that the volume flow rate of the tunnel out let is 12.6 m^3/s

3.4.2 Air changes per hour

Air changes per hour, or air change rate, abbreviated ACH or ac/h, is a measure of the air volume added to or removed from a space (normally a room or house) divided by the volume of the space. If the air in the space is either uniform or perfectly mixed, air changes per hour is a measure of how many times the air within a defined space is replaced.

In many air distribution arrangements, air is neither uniform nor perfectly mixed. The actual percentage of an enclosure's air which is exchanged in a period depends on the airflow efficiency of the enclosure and the methods used to ventilate it. The actual amount of air changed in a well-mixed ventilation scenario will be 63.2% after 1 hour and 1 ACH. In order to achieve equilibrium pressure, the amount of air leaving the space and entering the space must be the same.

$$\mathrm{ACH} = \frac{\dot{v}}{\mathrm{VOLUME\ OF\ TUNNEL}} \tag{5}$$

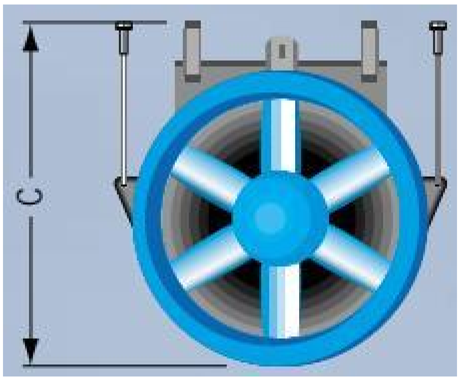
$$\mathrm{ACH} = \frac{12.6\ \frac{m^3}{s}}{6050\ m^3}$$

ACH = 0.002/s

ACH = 7.5 /hr

3.4.3 Determination of Fan size

Using the calculated volume flow rate can select the jet fan from standard fan catalogue Howden Jet Fans for reversible thrust, Type APR



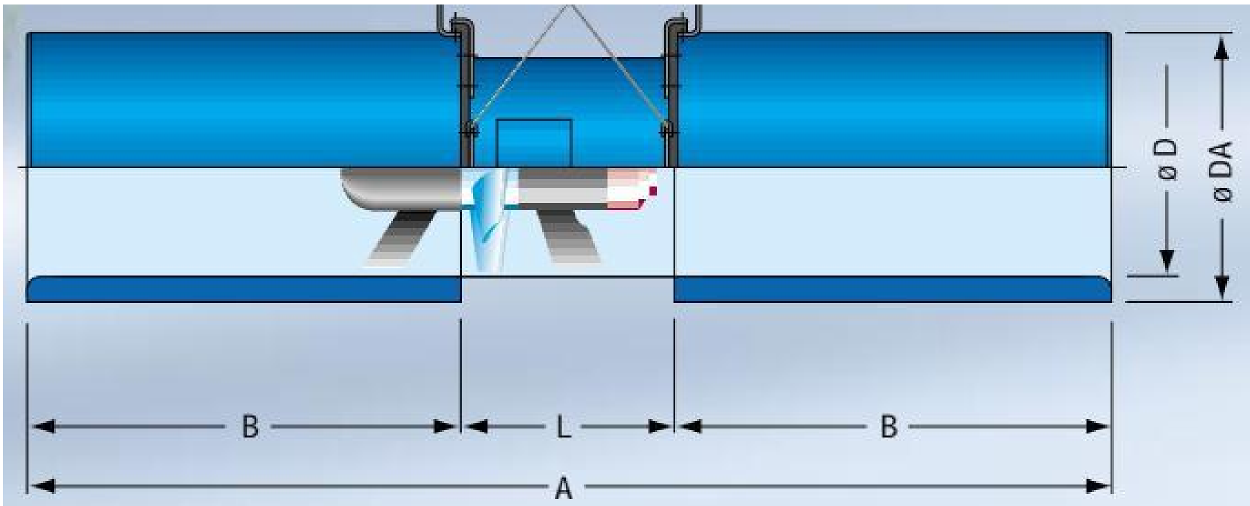


Figure. 3.16 geometrical dimension of APR type of jet fan

Table 3.4 geometrical dimension of APR type of jet fan

Fan type	A	B *)	C **) min.	Ø D	Ø DA	L
APR - 630 / 280	2174	772	1080	630	790	630

Table 3.5 specification of APR 710/330 jet fan

Fan type	Static thrust* [N]	Air flow [m³/s]	Outlet velocity [m/s]	Shaft power* [kW]	Motor-rating [kW]	Fan speed [1/min]	Thrust power ratio [N/kW]	LW(A) [dB(A)]	LP(A)** [dB(A)]	Emergency temperatures max. 2h 250 °C	max.2h 400 °C
APR - 630 / 280	365	10.0	32.0	11	11	2890	33.2	103	75	X	X
	440	11.0	35.1	15	15	2910	29.3	103	75	X	X
	495	11.6	37.3	18.5	18.5	2930	26.8	103	75	X	X
	535	12.1	38.8	22	22	2925	24.3	103	75	X	X
	555	12.3	39.5	26.5	28	2920	20.9	103	75	X	

Determination of the fan efficiency

$$\text{fan efficiency} = \frac{\text{shaft power}}{\text{moter rating}} \tag{6}$$

$$\text{fan efficiency} = \frac{26.5}{28} = 0.94 = 94\%$$

3.4.4 Determination of fan gauge pressure

$$\text{P gauge total} = \text{p static} + \text{p dynamic} \tag{7}$$

First determine static pressure,

$$p_{static} = \frac{F_{static}}{A_{fan}} \quad (8)$$

From the fan catalogue the static force is given

F static = 555N

But area of fan is

$$A_{fan} = \pi \frac{d^2}{4} \quad (9)$$

$$A_{fan} = \pi \frac{0.63^2}{4} = 0.311566m^2$$

So that

$$p_{static} = \frac{555\ N}{0.311566\ m^2} = 1781.3 \frac{N^2}{m}$$

Next to that determine the dynamic pressure

$$p_{dynamic} = \frac{\rho v^2}{2} \quad (10)$$

From the ERC data air speed is 5 m/s

$$p_{dynamic} = \frac{1.2*5^2}{2} = 15N/m^2$$

P gauge total = p static +p dynamic=1781.3+15=1796.3 N/m^2

3.4.5 Determination of inlet velocity of tunnel

The cross sectional area of the tunnel is symmetrical so its area and volume flow rate are 50 m^2, 12.6m^3/s respectively. From this we can get the tunnel inlet velocity.

$$v_{in} = \frac{\dot{q}}{A} \quad (11)$$

$$v_{in} = \frac{1\dot{2}.6}{50} = 0.25m/s$$

3.4.6 Suspension of Jet Fans

The optimal distance to the ceiling is listed over the construction size, whereas „optimal" is to be judged as a compromise between distance to the ceiling and distance to the clearance gauge.

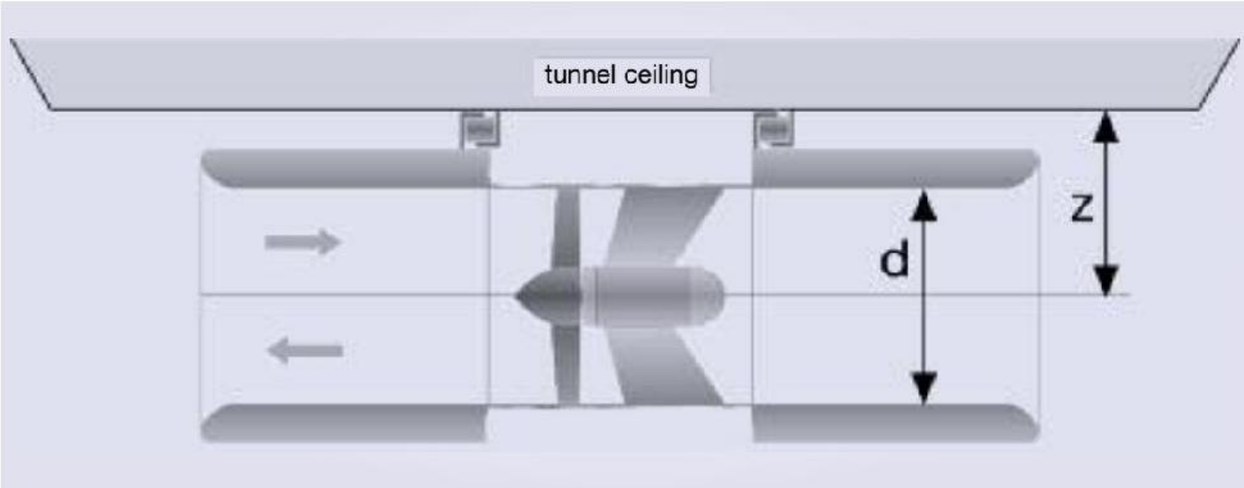


Figure. 3.17 optimal distance from the celling

3.4.7 Representation of Jet fan

A jet fan is represented as a constant volumetric flow rate device. Here it should be recognized that the constant flow rate is applied only to the flow actually going through the jet fan. The flow induced by the jet fan in the entire tunnel is not held constant. Indeed, the interaction of the jet (produced by the jet fan) with the surrounding air determines how much flow gets induced in the tunnel. The induced flow also depends on the size, shape and length of the tunnel, wall roughness, and on the presence of flow obstacle. A jet fan is simulated by a combination of sources and sinks. The specific details are as follows:

- The control volumes within the fan region are blocked-off, i.e., they are treated as solid.
- Mass and momentum sources and sources for turbulence parameters are introduced in the fluid control volumes adjacent to the discharge end of the fan. The strengths of the mass and momentum sources are determined from the fluid density at the intake end of the jet fan, the fan capacity, and the discharge velocity. The sources for k and ε are calculated using specified input for turbulent intensity and length scale at the jet fan intake. For the energy equation, the total enthalpy entering the fan from the intake end is introduced as source at the discharge end. Thus, there is no energy addition within the jet fan. A similar practice is used for smoke.
- Mass sinks are introduced in the fluid control volumes next to the intake end of the fan.[29]

CHAPTER FOUR

MODEL VALIDATION, RESULT AND DISCUSSION

4.1 Geometric modeling

The analysis of ventilation system of a tunnel starts with geometric parameterization of shape, length, and cross sectional area of a tunnel. To analyze this system two models are developed. The tunnel has a length of 121 m with a cross sectional area of 50 m^2, but the selected five jet fans have the diameter of 630 mm and the silencer length of 2174 mm suspended on the ceiling of the tunnel. The gap between these five fans is 28 m. For the purpose of this study, the 3d model is done using Catiav5 modeling software. The number and gap between jet fans is limited for this thesis due to the RAM capacity of the computer.

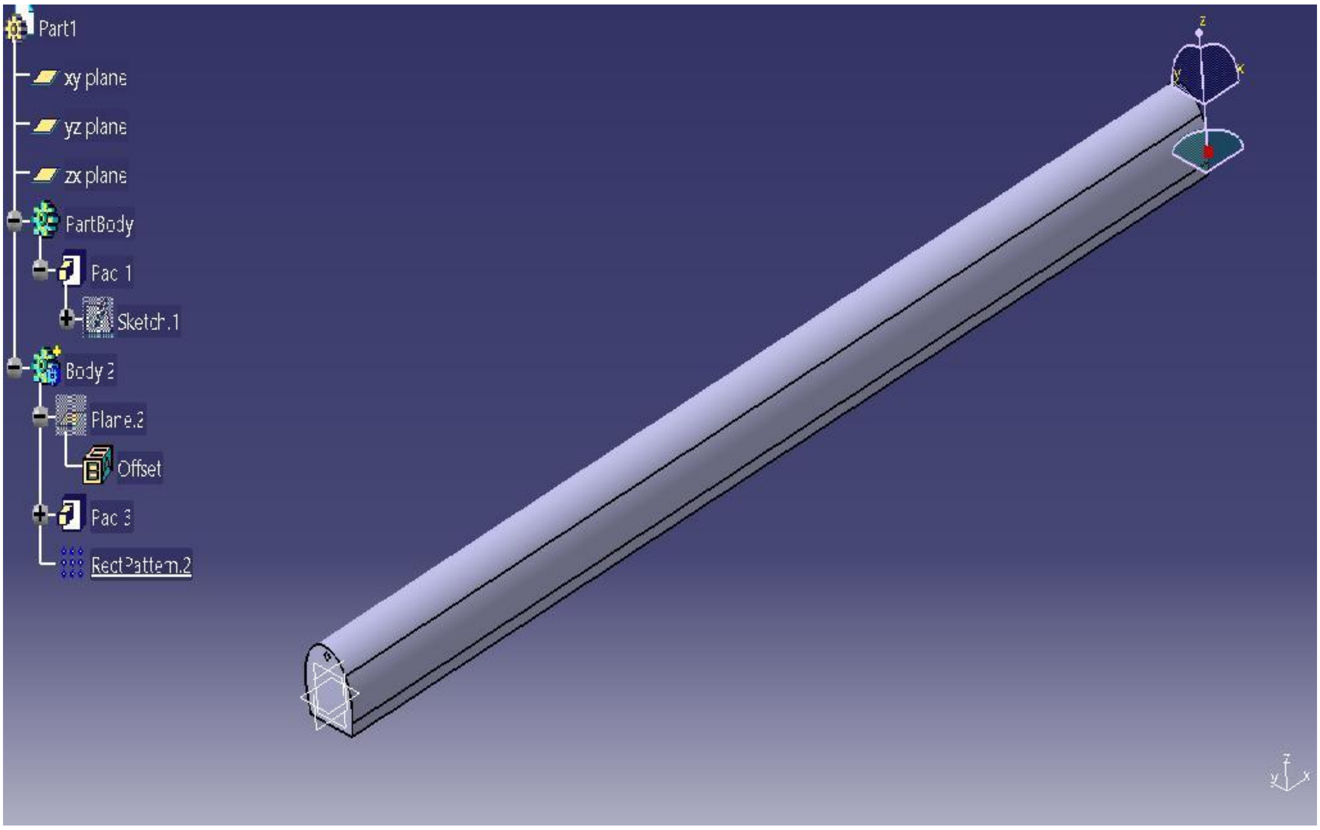


Figure 4.1 3D model of tunnel using CATIA

4.2 Analysis using ANSYS Fluent

The tunnel ventilation model is based on the buoyancy-augmented k-ε turbulence model and includes component models for representing jet fans. These component models were implemented in the general-purpose CFD software package COMPACT-3D.

The unstructured grid was used for the simulations and the standard k-ε turbulent model was applied to the 3D models. The non-slip stationary wall boundary condition is applied on the walls of tunnel and jet fans.

Steps in Fluent Analysis

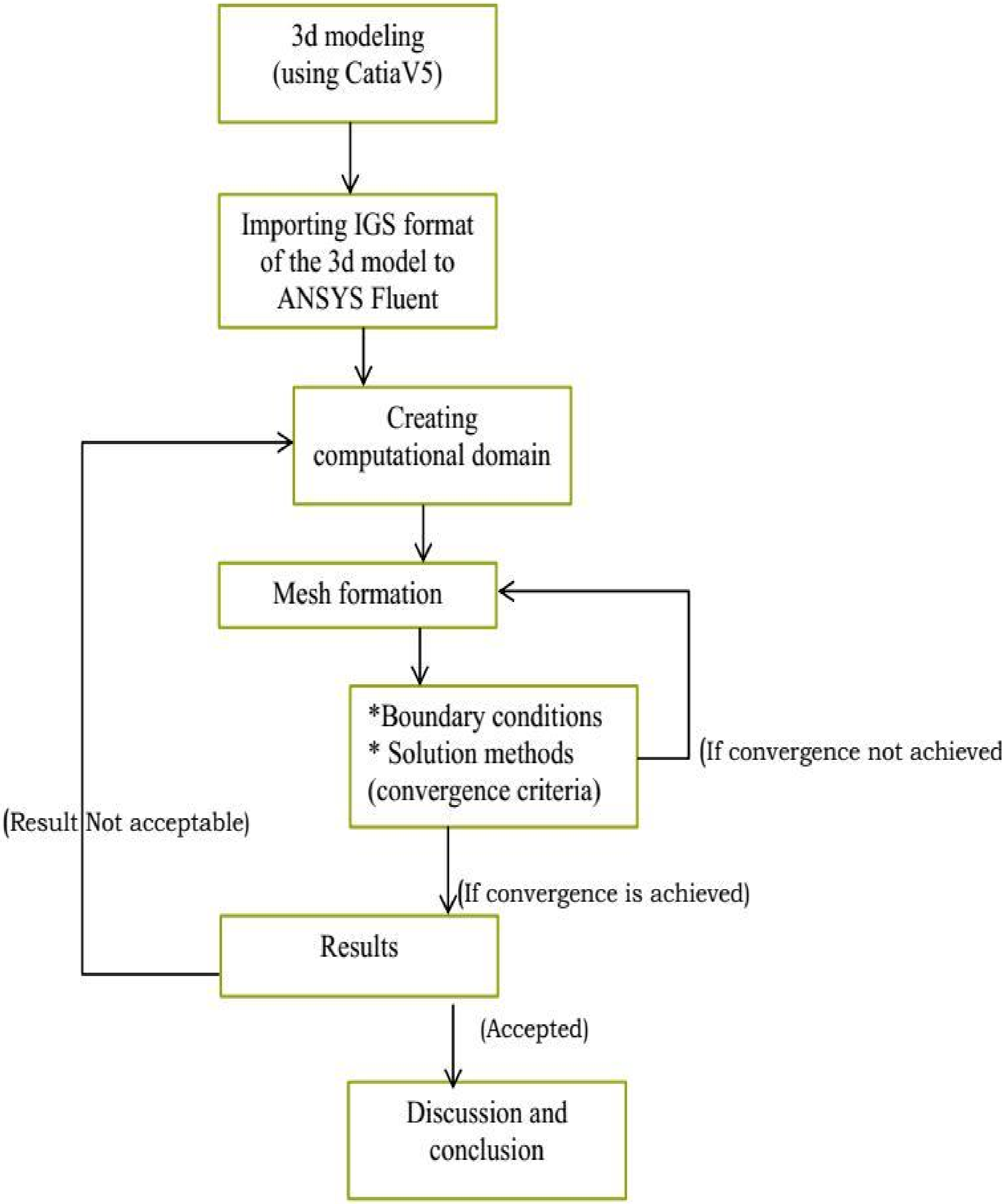


Figure 4.2 steps in CFD analysis using fluent

4.3 Computational domain of Jet fan arrangement in the tunnel

After the basic shape of the tunnel with jet fans have been imported to ANSYS, create Boolean method to subtract tool bodies of jet fans from target body of tunnel model.

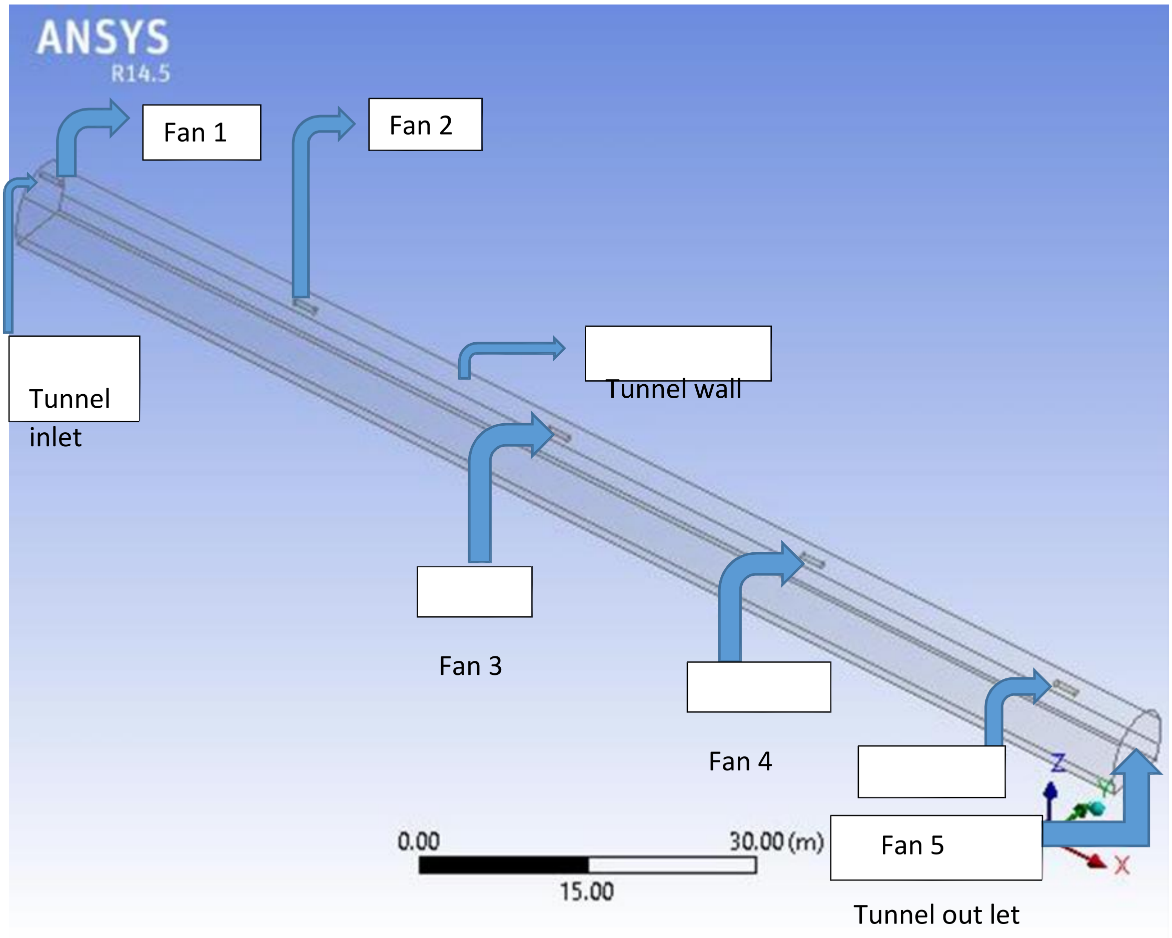


Figure 4.3 the design modular of tunnel on ansys

4.4 Mesh creation

CFD uses finite volumes method which means that a mesh has to be created. The cells of the mesh contain the information of the flow. A finer mesh leads to a more accurate result but it also means longer computational time and that more computer resources are needed. In this thesis uses skewness method. It Increases the quality of the final numerical mesh. After the meshing is generated on the surface of the tunnel. Evaluation of air flow in the tunnel can be performed using analytical method or CFD approach.

Table 4.1 mesh information

Number of nodes	42583
Number of elements	196556
Mesh metric	skewness
min	7.85734821354689E-04
max	0.780418959040841
Average	0.241697704544887
Standard deviation	0.12490310848115

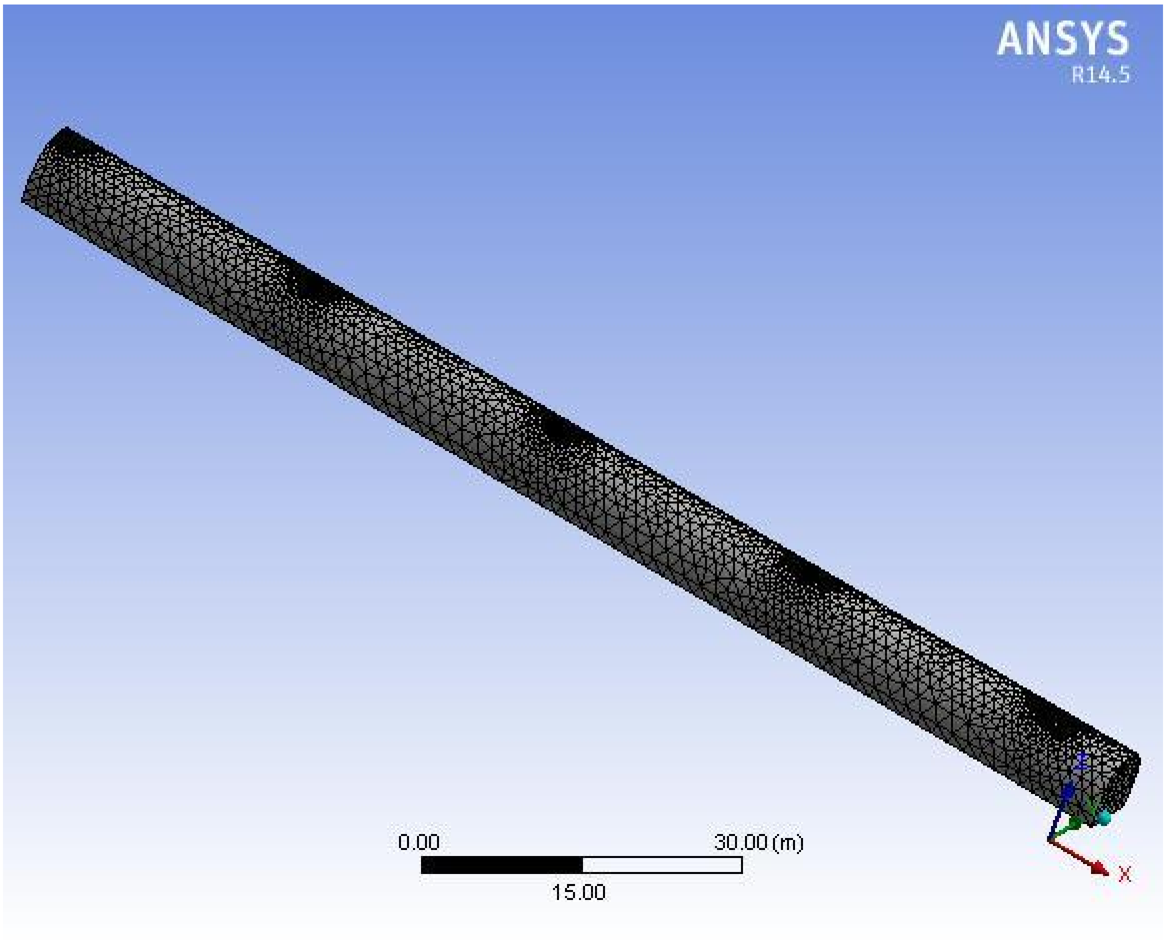


Figure 4.4 mesh diagram of tunnel and jet fan

Sizing method to mesh the diagram the relevance center, and smoothing are fine and high respectively and also the element size of tunnel and jet fans are 5, and 1mm respectively.

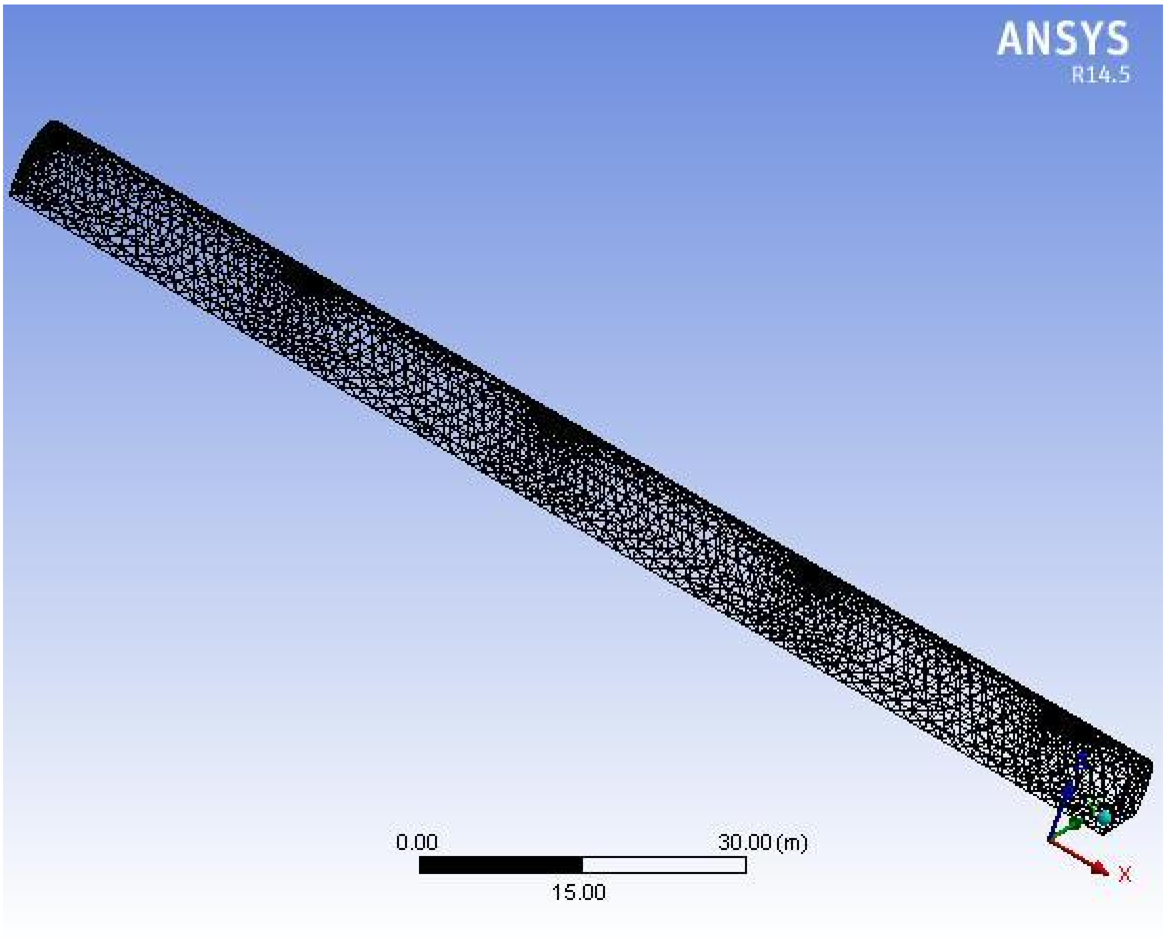


Figure 4.5 wire frame mesh diagram

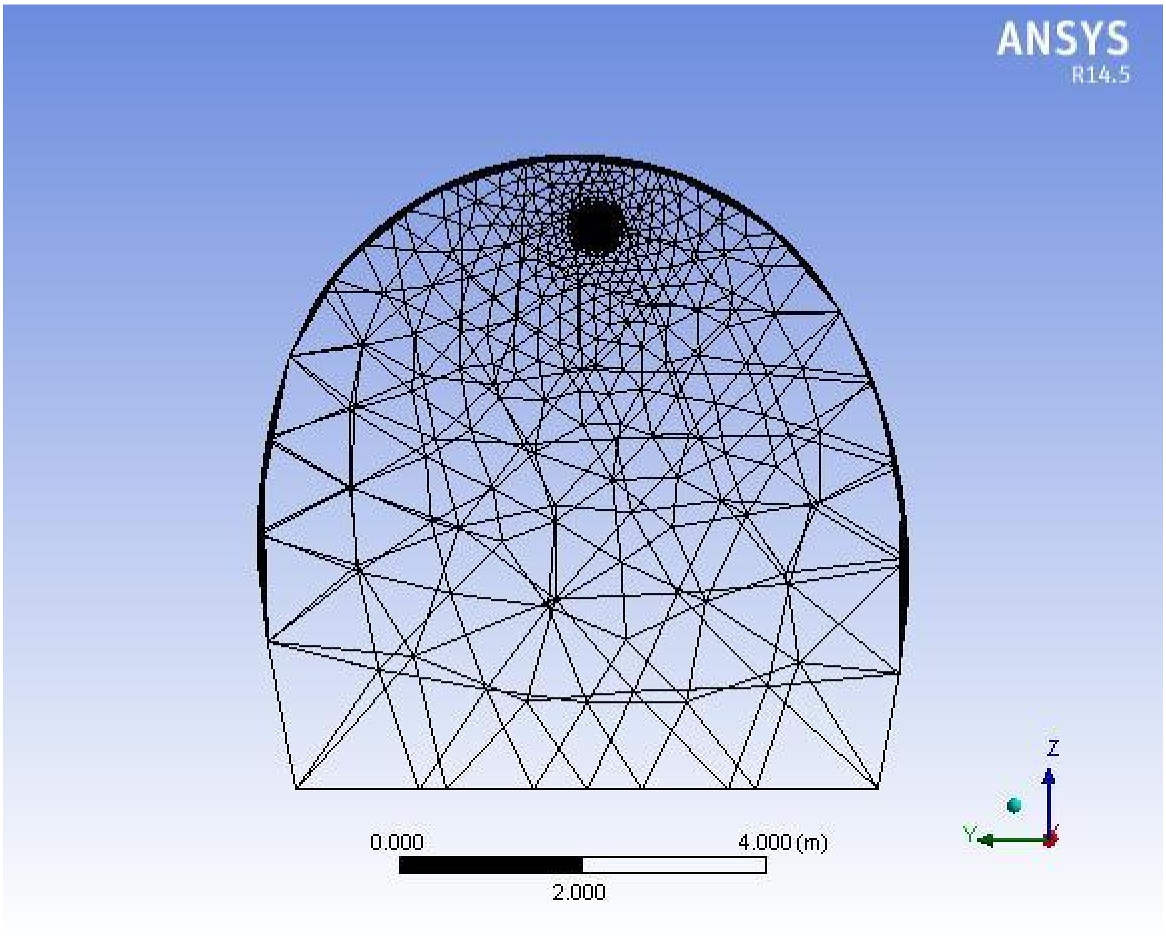


Figure 4.6 front view of mesh diagram

4.5 Solution setup in ANSYS

When we set up for ANSYS simulation, we specify the condition and the direction of the flow. An ANSYS model comprises all the nodes, elements, material properties, real constants, boundary conditions, and other features that are used to represent the physical system. Different boundary conditions are used.

Table 4.2 property of air used in CFD

Property	**Units**	**Method**	**Value(s)**
Density	kg/m3	constant	1.225
Viscosity	kg/m-s	constant	1.79E-05
Molecular Weight	kg/kg mol	constant	28.966

Table 4.3 domain boundaries

DOMAIN	BOUNDARIES	TYPE
Fan 1	Fan 1 inlet	Velocity inlet
	Fan 1 outlet	Pressure out let
	Fan 1 wall	wall
	Interior fan 1	jump
Fan 2	Fan 2 inlet	velocity inlet
	Fan 2 outlet	Pressure out let
	Fan 2 wall	Wall
	Interior fan 2	Jump
Fan 3	Fan 3 inlet	Velocity inlet
	Fan 3 out let	Pressure out let
	Fan 3 wall	wall
	Interior fan 3	Jump
Tunnel	Tunnel inlet	Velocity inlet
	Tunnel out let	Pressure out let
	Tunnel wall	wall

4.5.1 Determinations of typical input parameters and boundary conditions

The determined typical input parameters and boundary conditions in this research are:-

- The non-slip stationary wall boundary condition is applied on the walls of tunnel and jet fans.
- Mass flow rate in the fan , and the rest are stated in table

Table 4.4 boundary values

Boundary condition	Velocity (m/s)	Pressure (pa)
Fan inlet	40 m/s	
Fan out let		1796.3 pa
Tunnel inlet	0.25 m/s	
Tunnel out let		101325 pa

4.5.2 Viscous model

The model which is used in this thesis was, k-epsilon with the model of RNG, but the RNG option is swirl dominated flow with the near wall treatment of standard wall function.

4.5.3 Solution methods

Pressure-velocity coupling

Table 4.5 solution methods

scheme	simple
Gradient	least squares cell based
Pressure	standard
Momentum	Second order upwind
Turbulent kinetic energy	Second order upwind
Turbulent dissipation rate	Second order upwind

4.6 Results and discussion

The developed computational model is simulated for the normal ventilation process of rail way tunnel ventilation. Simulations for the model used boundary conditions which are stated in Table 4.4. And also the five jet fan configurations are simulated in normal conditions with the arrangement of fan 1, fan 2, fan 3, fan 4, and fan 5, by dividing the length of the tunnel in to four equal parts at 0, 28, 56, 84, and 112 meters respectively.

Velocity contour

The values of velocity contour is determined according to the arrangement of jet fans in the tunnel. The result shows that on the planes which are located 10 m away the exit of each jet fans, its value is goes to maximum moves from plane one to plane four and it decreases to when the air reaches at the tunnel exit its maximum value is 12.1 m/s.

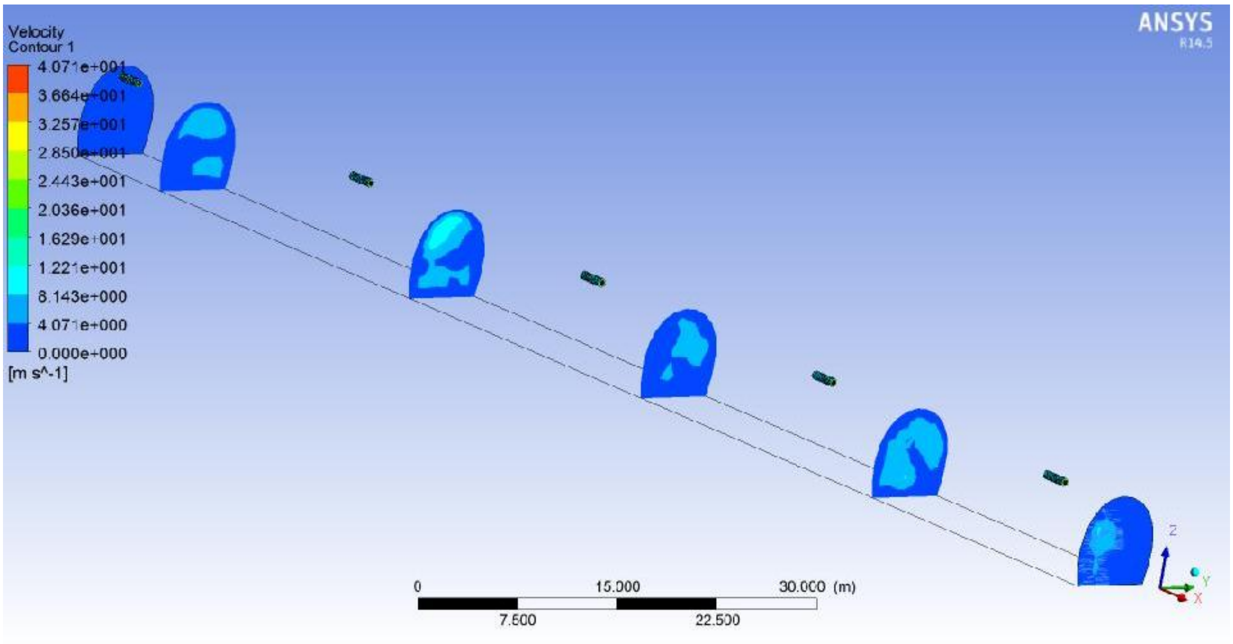


Figure 4.7 velocity vector diagram of tunnel

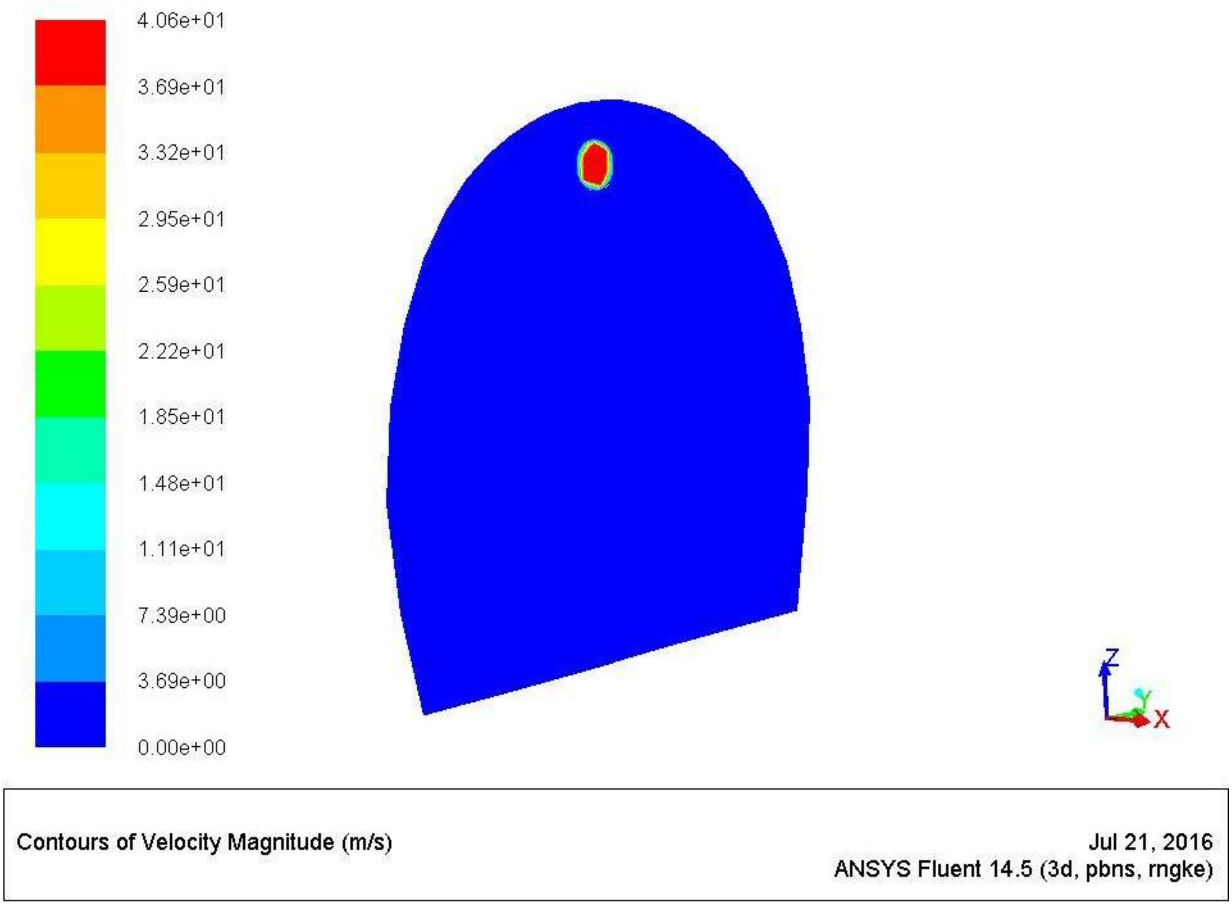


Figure 4.8 contour of velocity magnitude at tunnel inlet and fan 1 inlet

As the result shows that velocity contour at the tunnel inlet is zero.

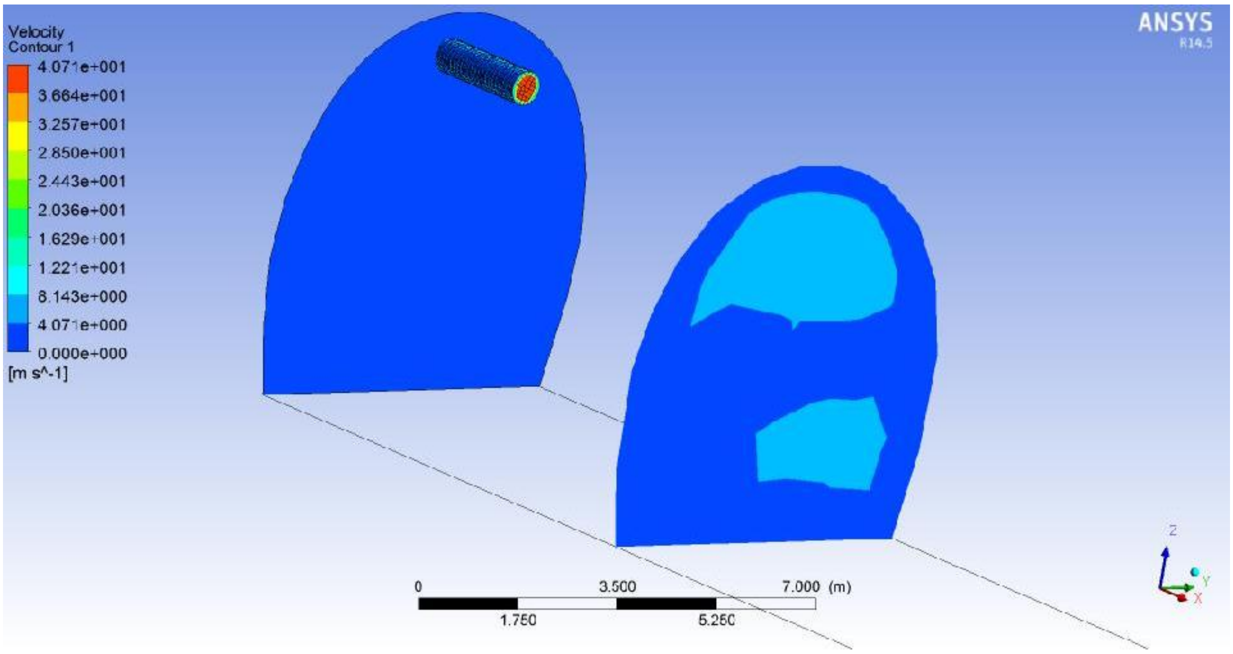


Figure 4.9 shows the effect of velocity contour of fan 1 at plane 1

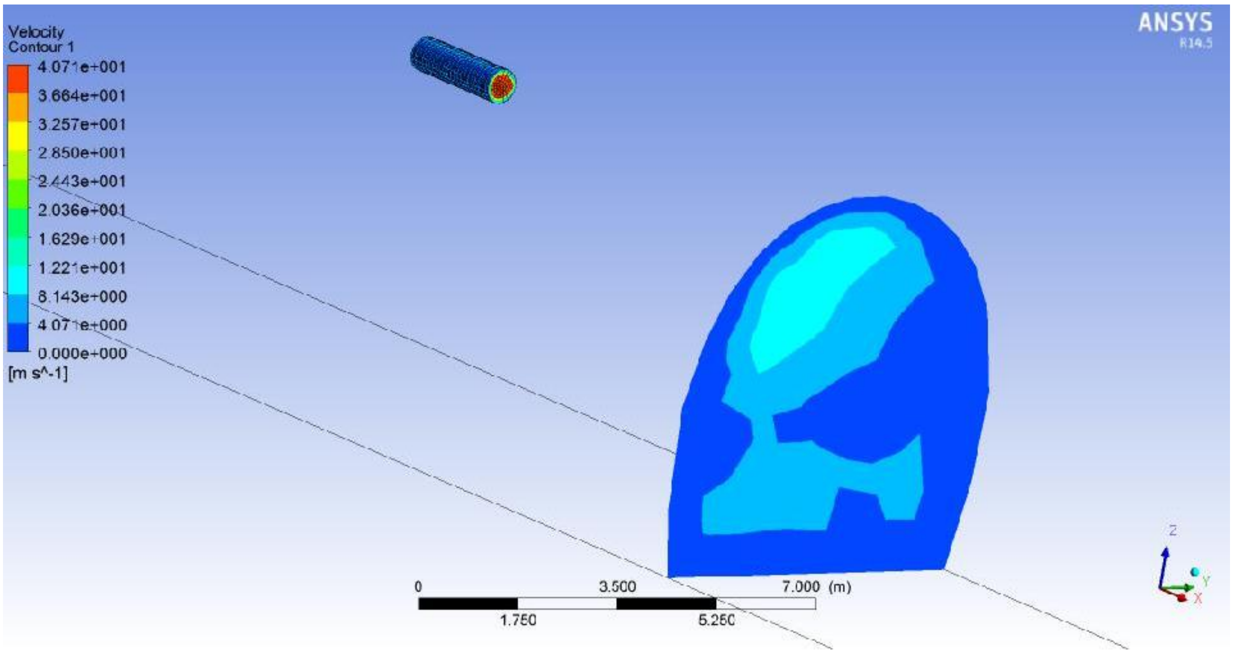


Figure 4.10shows the effect of velocity contour of fan 2 at plane 2

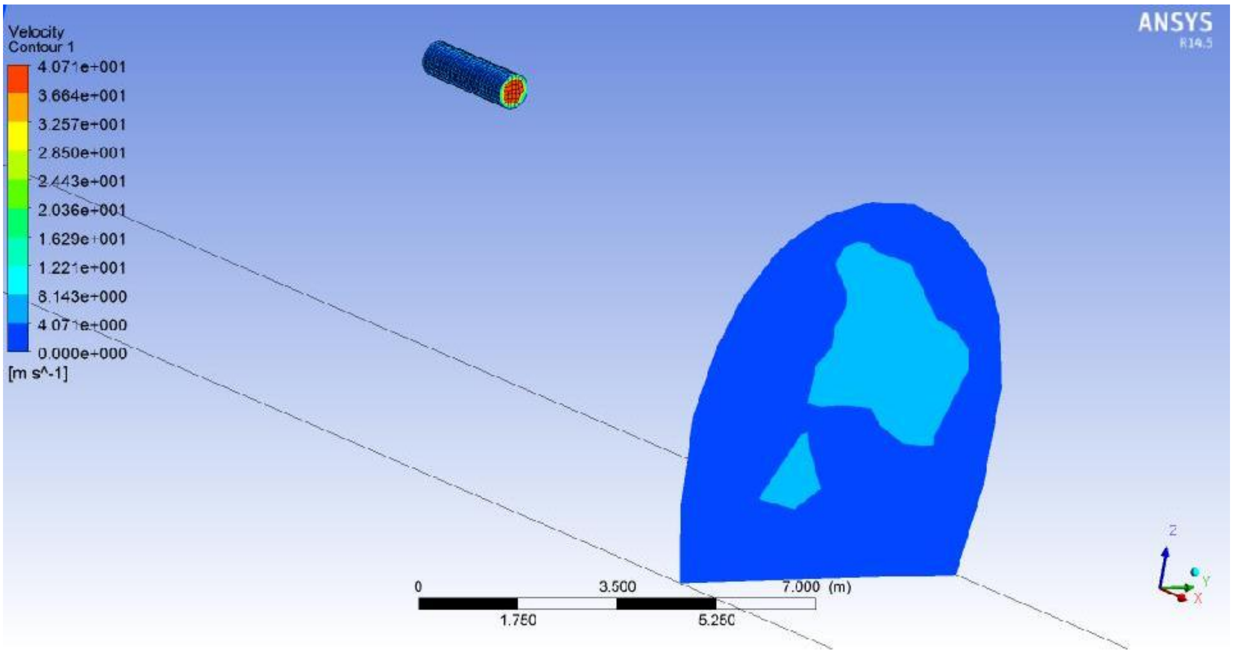


Figure 4.11 shows the effect of velocity contour of fan 3 at plane 3

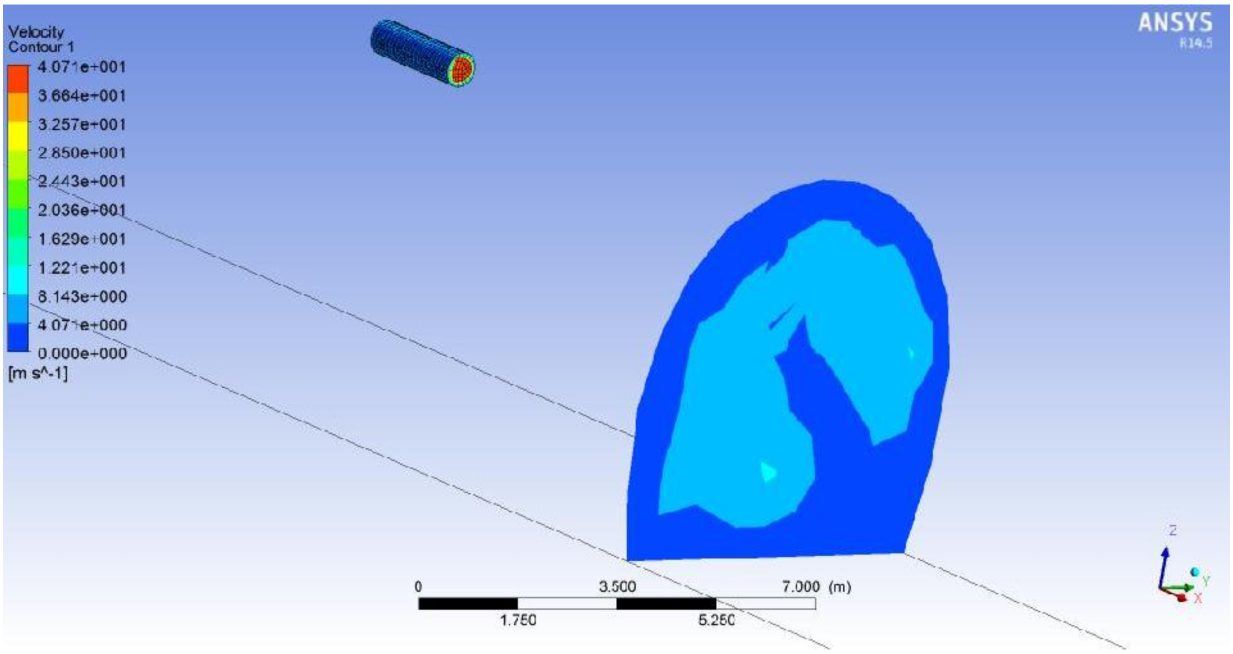


Figure 4.12 shows the effect of velocity contour of fan 4 at plane 4

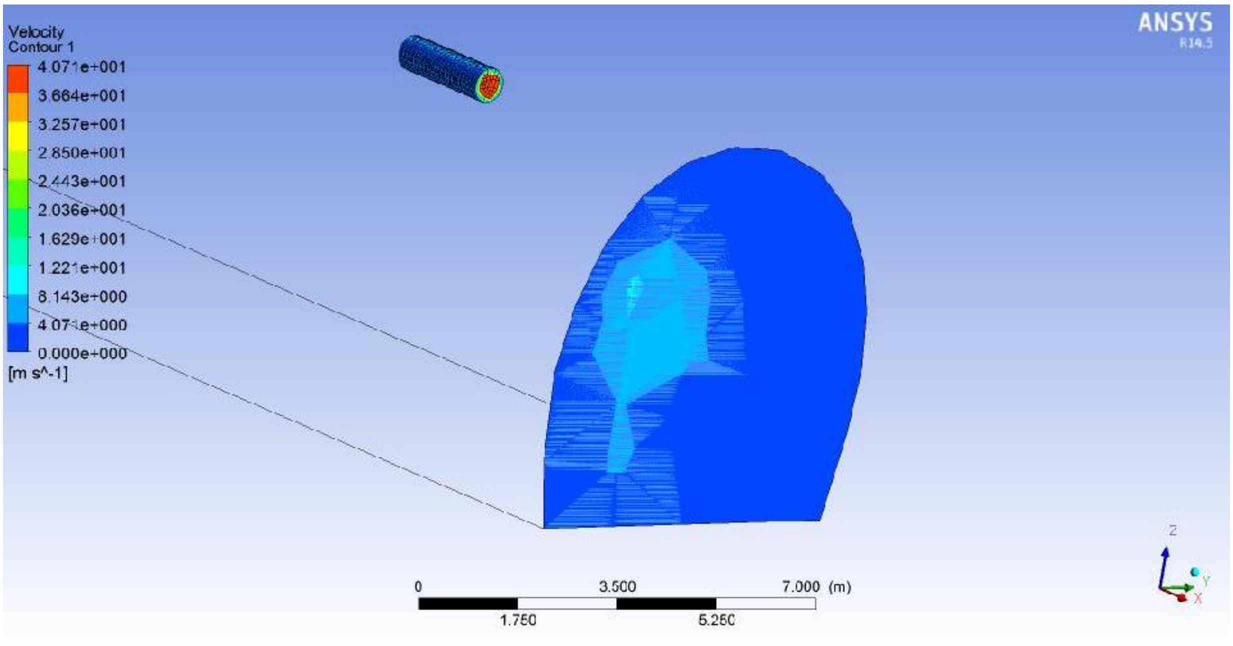


Figure 4.13 shows the effect of velocity contour of fan 5 at tunnel out let

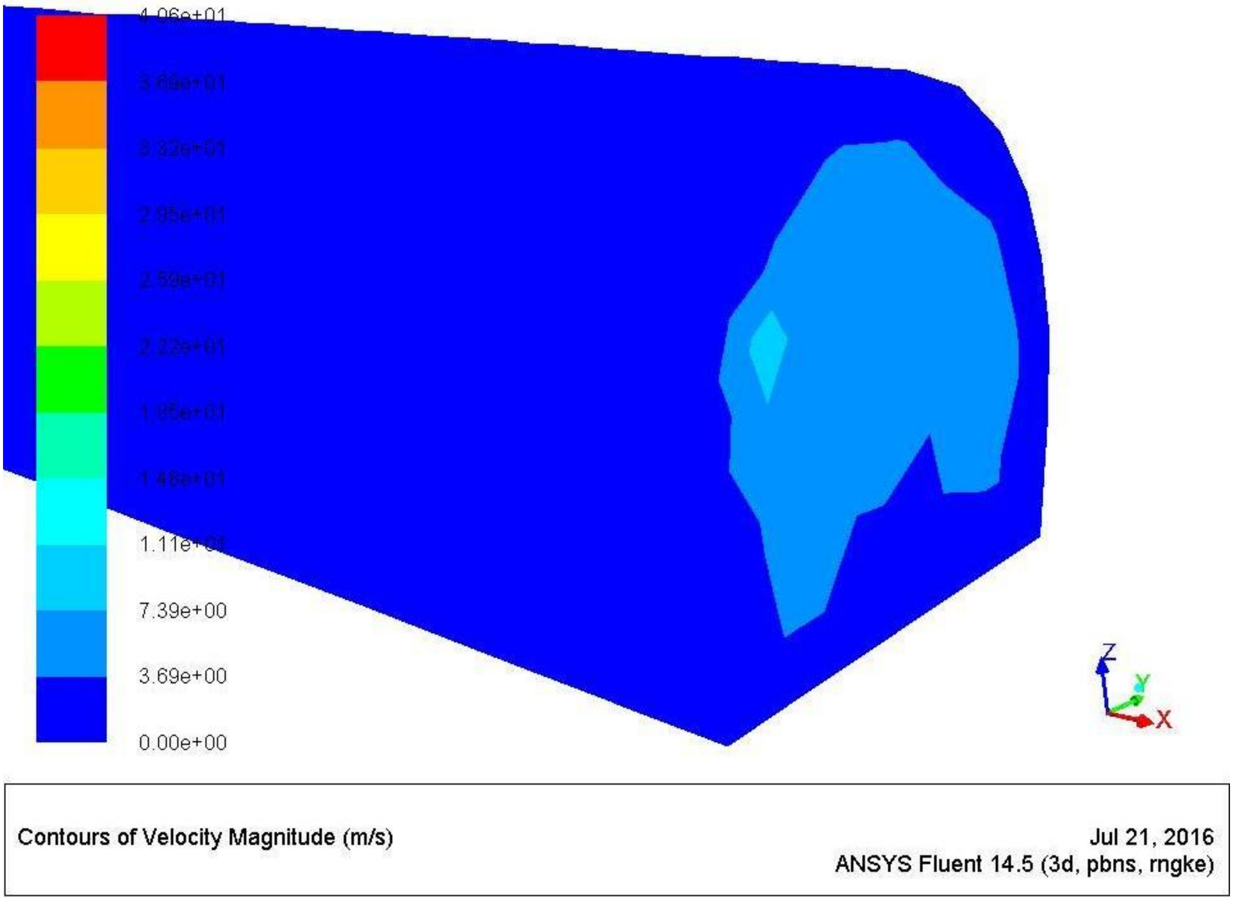


Figure 4.14 shows the effect of velocity contour at tunnel out let and tunnel wall

Table 4.6 summarized value of velocity contour

Effect of velocity vector at location	**Minimum – maximum value of velocity vector in m/s**
Fan 1 at plane 1	4 - 8.1 m/s
Fan 2 at plane 2	8.1 - 12.2 m/s
Fan 3 at plane 3	4 - 8.1 m/s
Fan 4 at plane 4	8.1 - 12.1 m/s
Fan 5 at tunnel out let	8.1 - 12.1 m/s

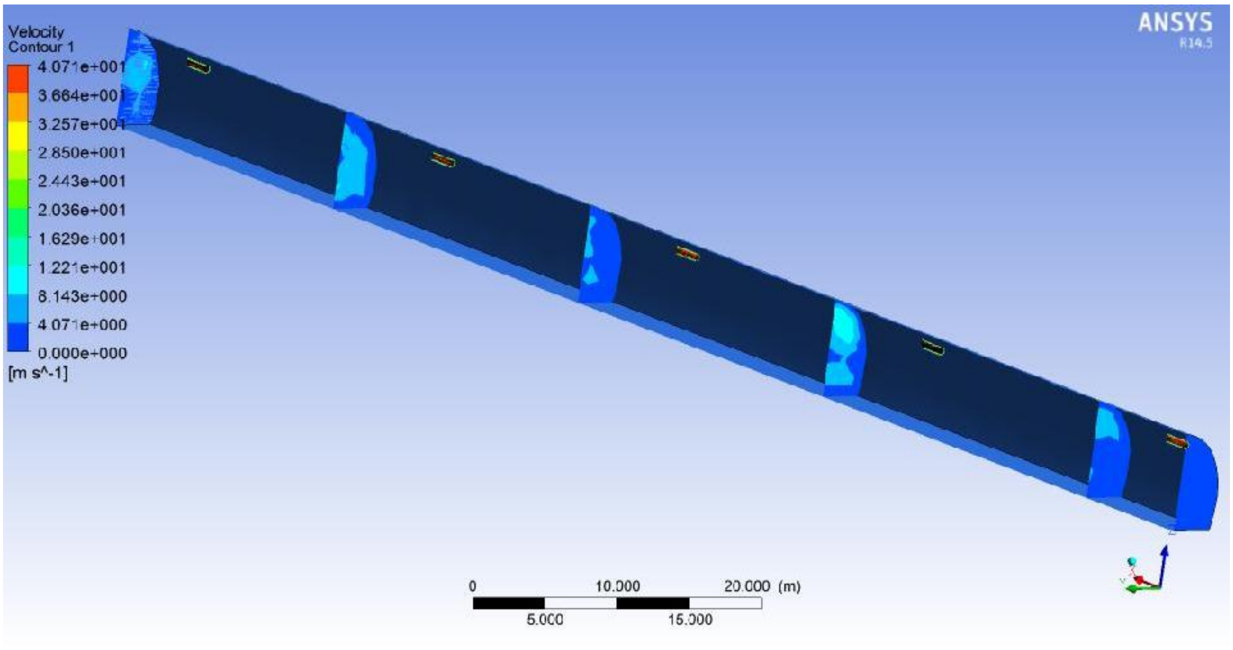


Figure 4.15 cross sectional view of jet fan with tunnel

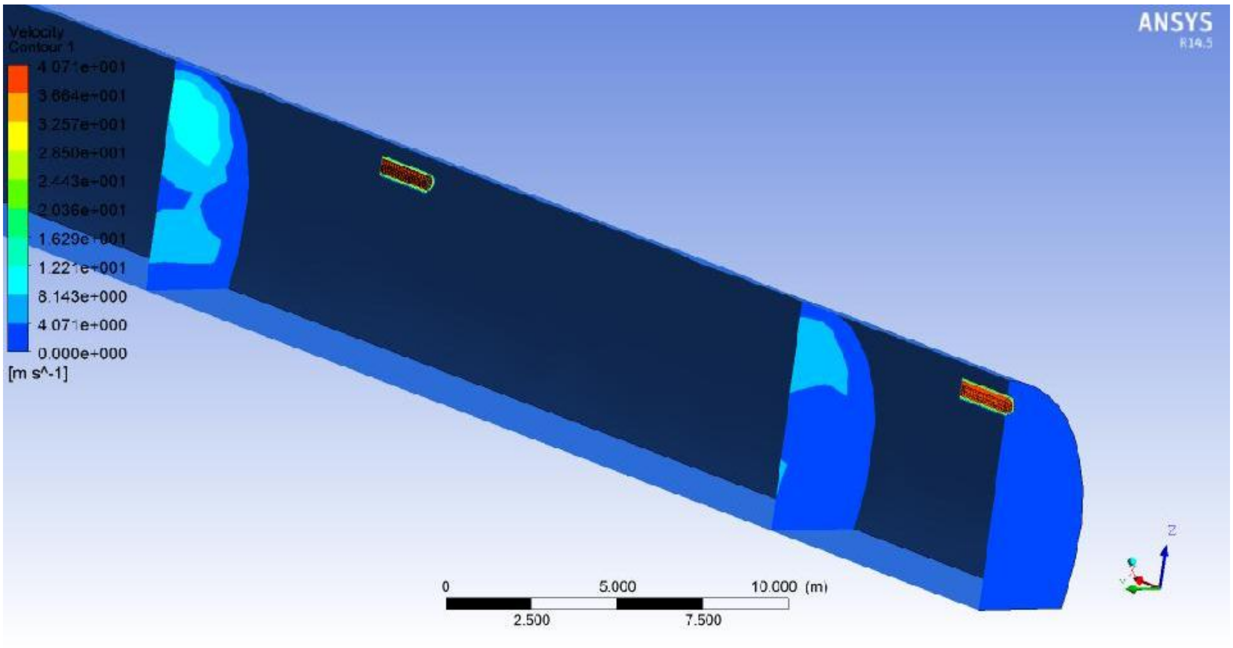


Figure 4.16 the cross sectional view of fan 1and fan 2

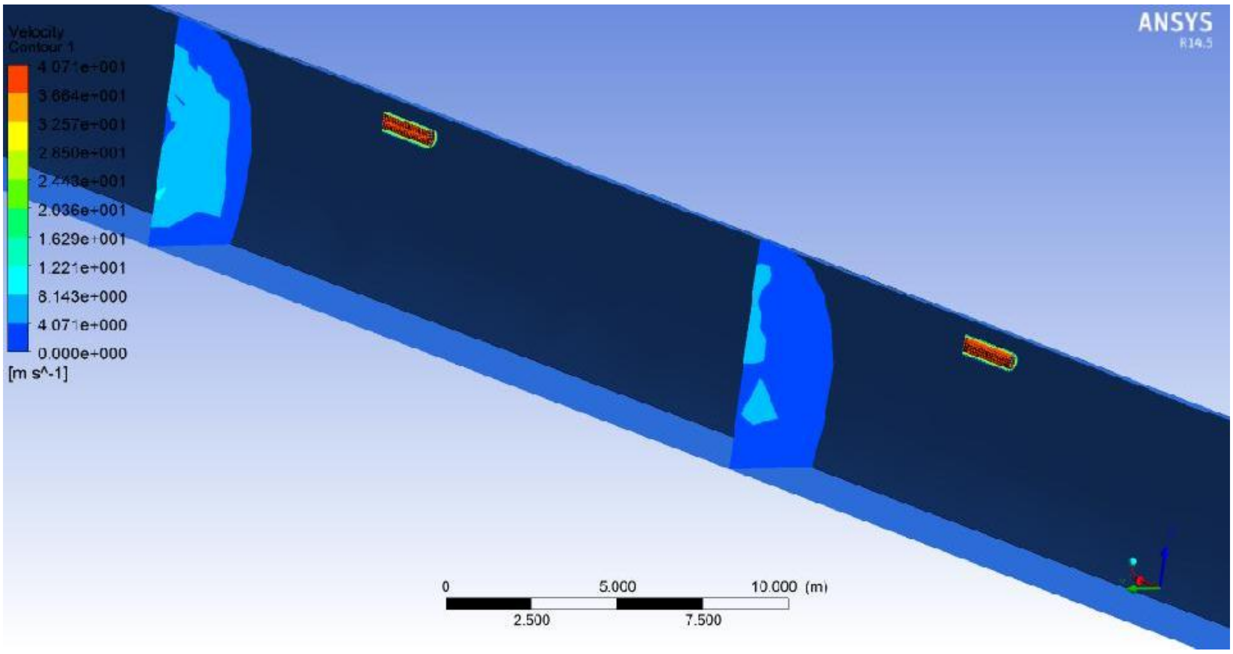


Figure 4.17 the cross sectional view of fan 3 and 4

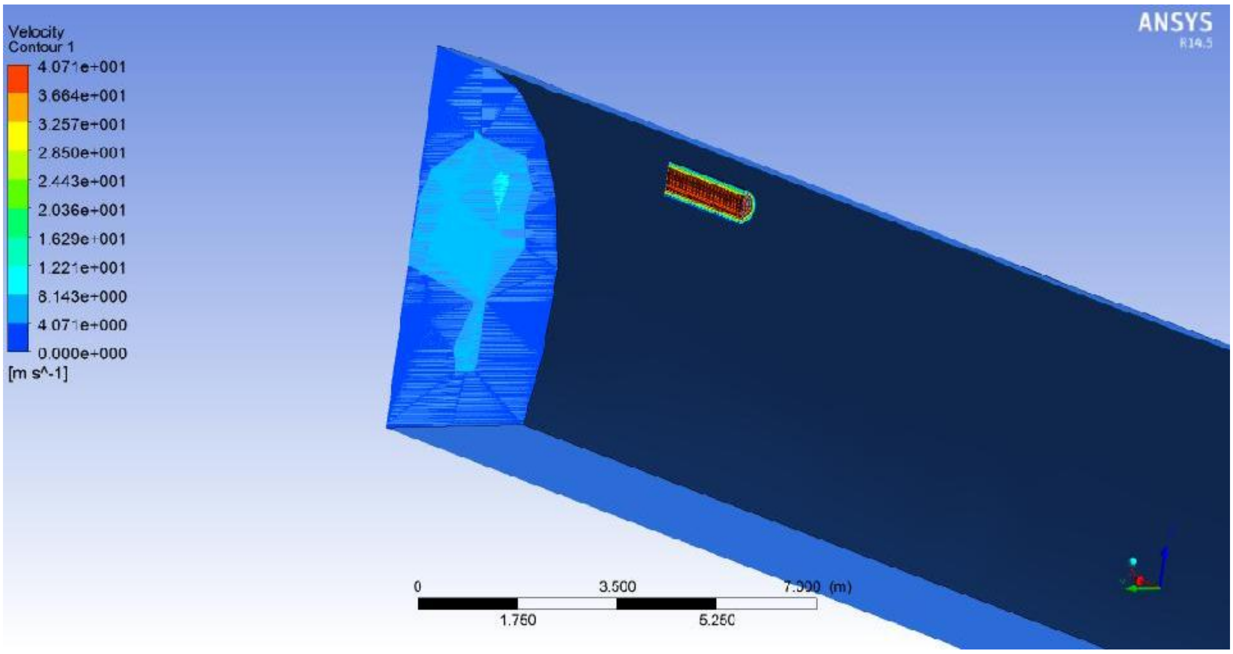


Figure 4.18 cross sectional view of fan 5

Pressure contour

The maximum value of air pressure at the tunnel is 101600pa

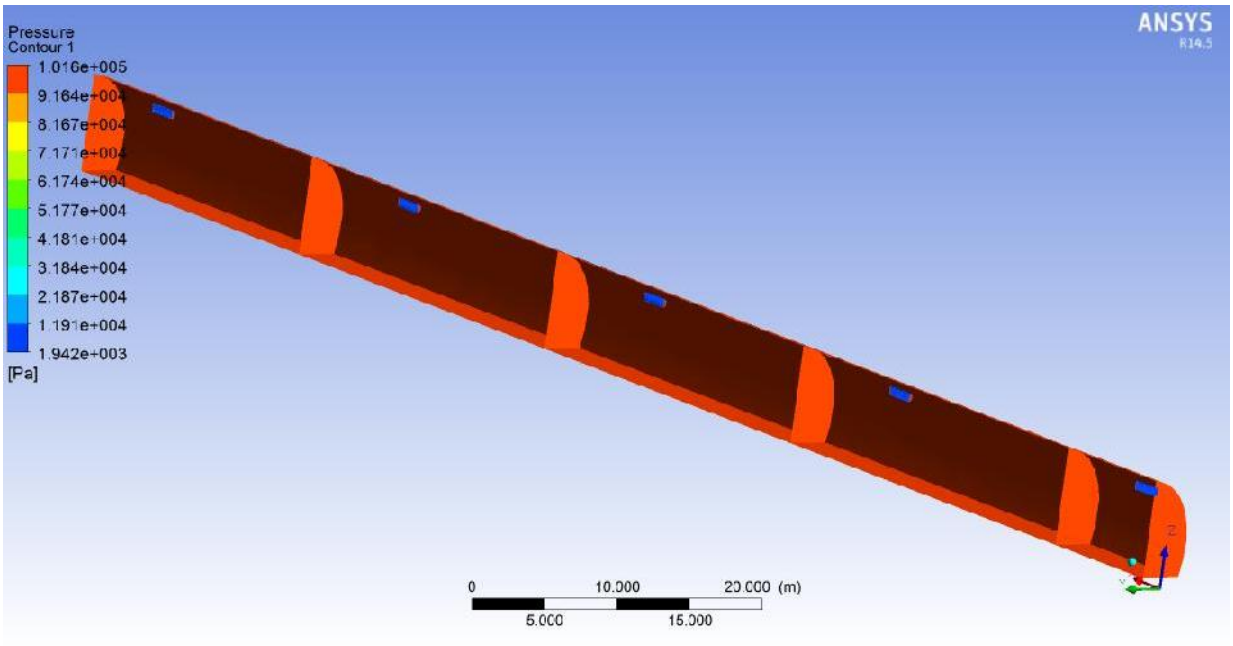


Figure 4.19 shows the pressure contour of tunnel

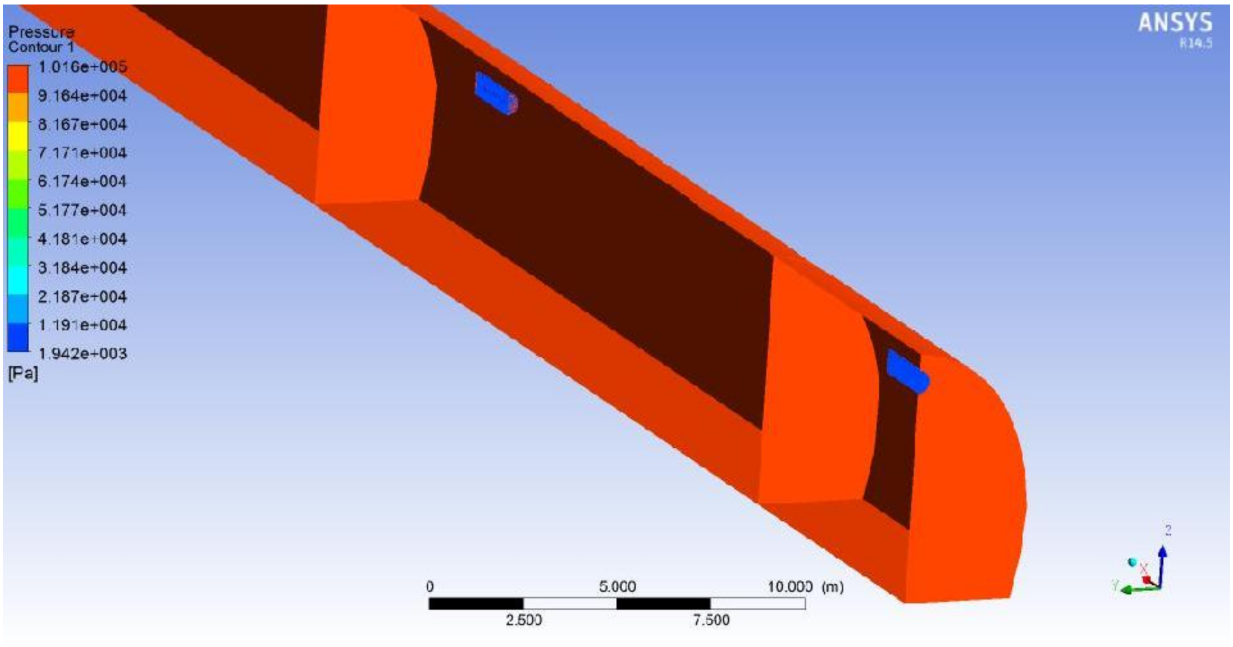


Figure 4.20 pressure contour of fan 1and fan 2

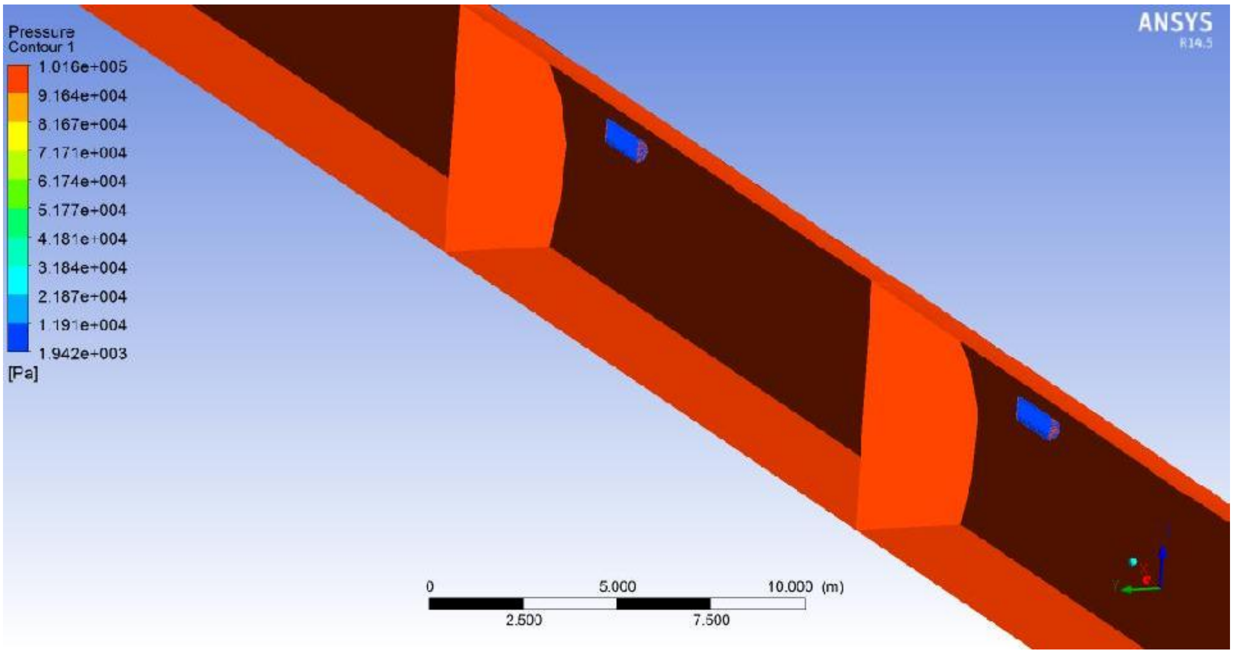


Figure 4.21 pressure contour of fan 3 and fan 4

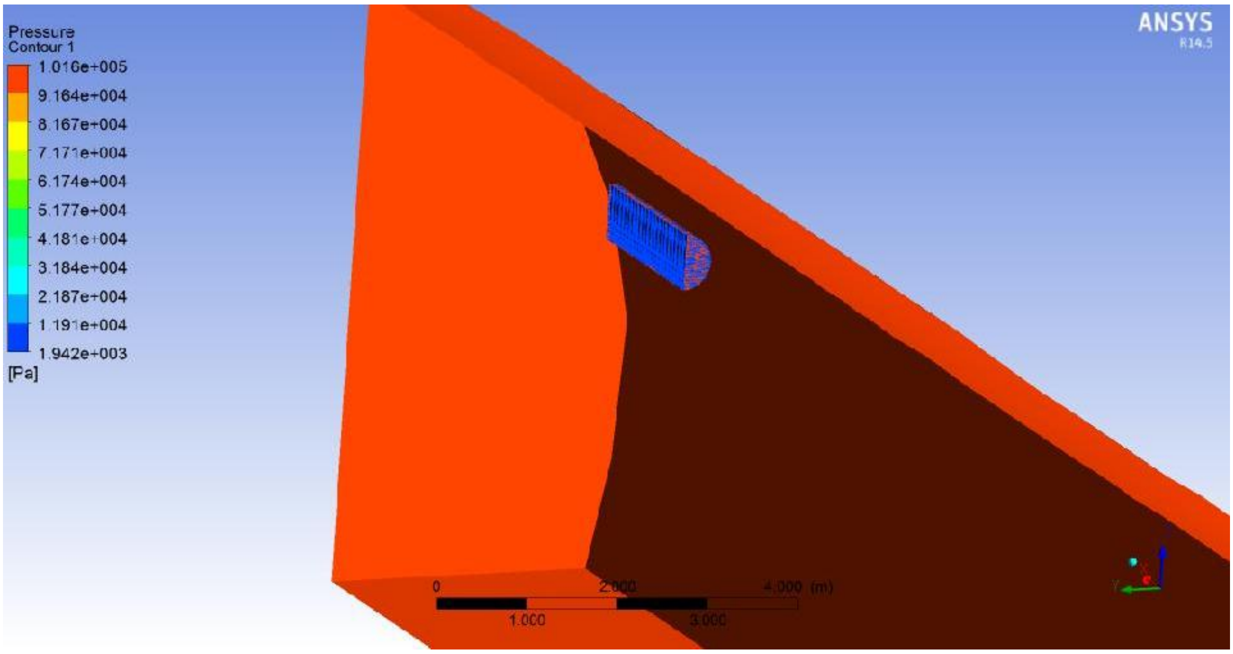


Figure 4.22 pressure contour of fan 5

Velocity vector

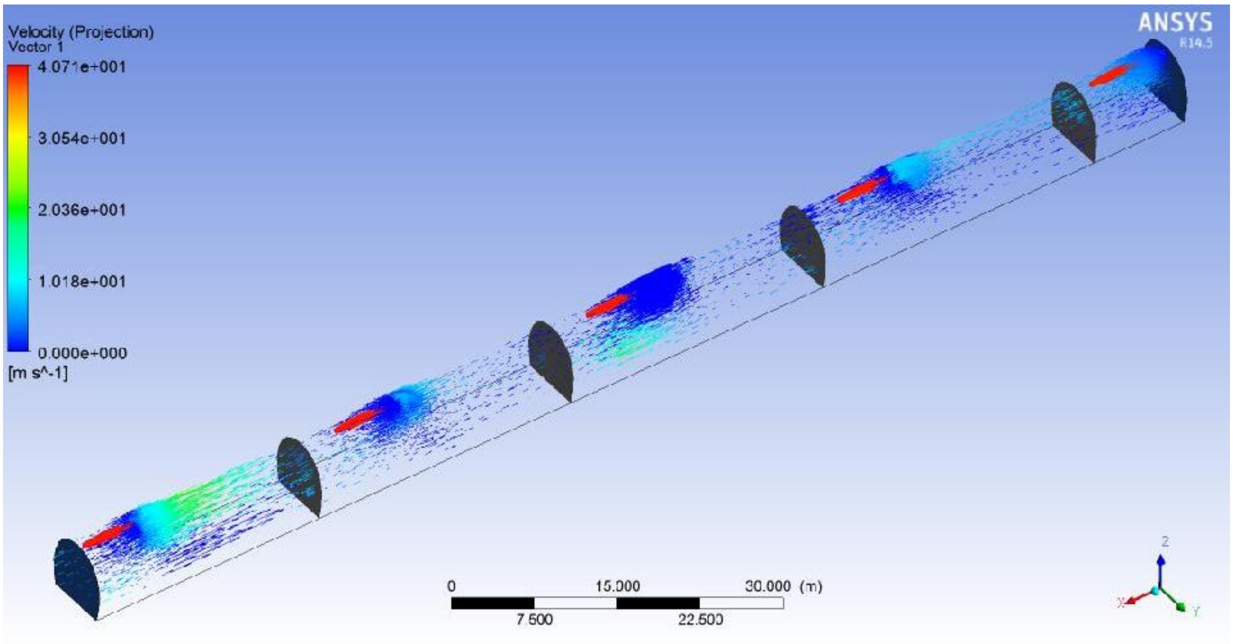


Figure 4 .23 velocity vector diagram

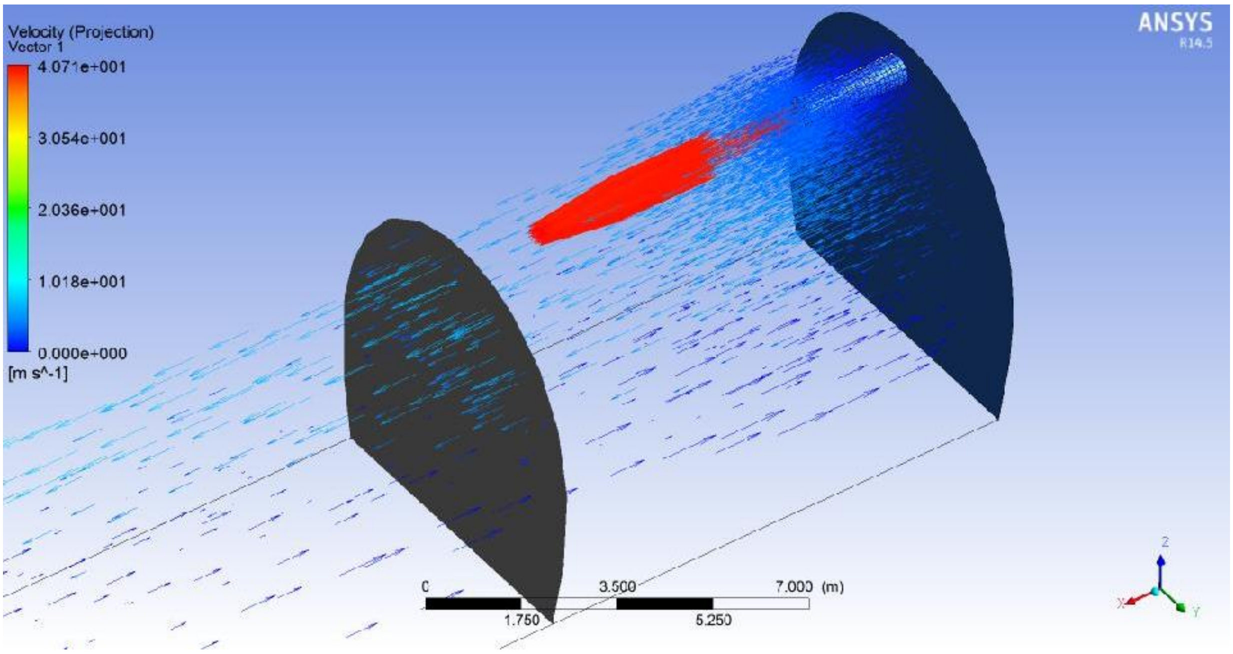


Figure 4.24 velocity vector at fan 1

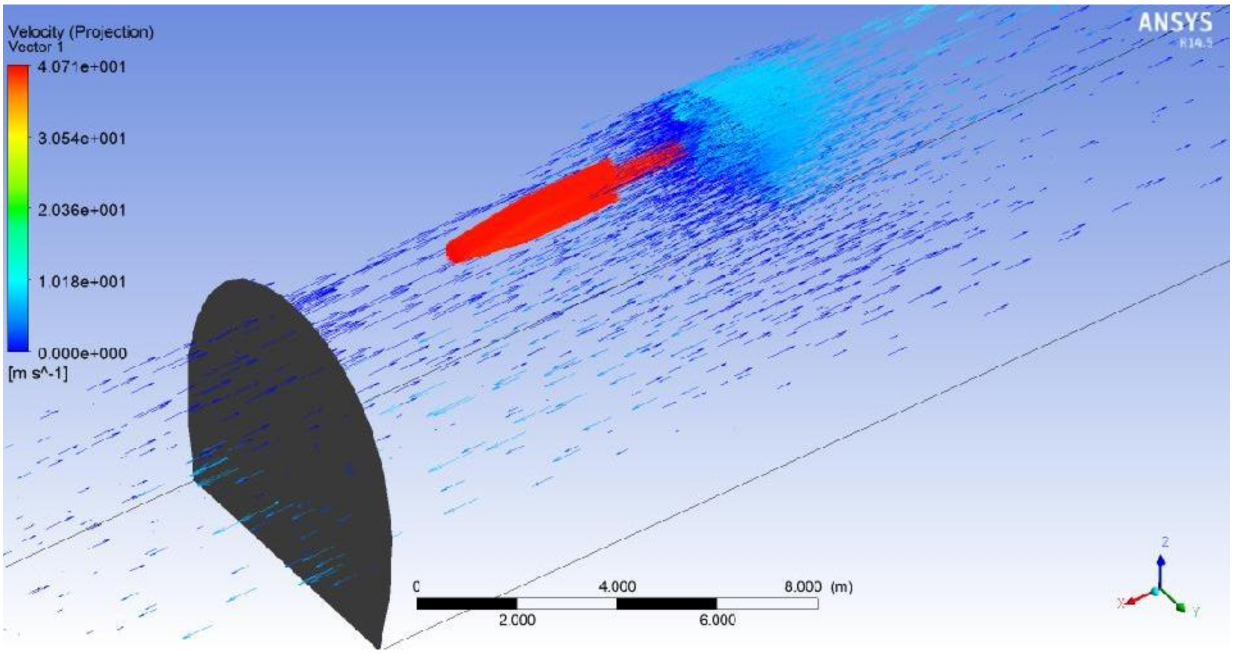


Figure 4.25 velocity vector at fan 2

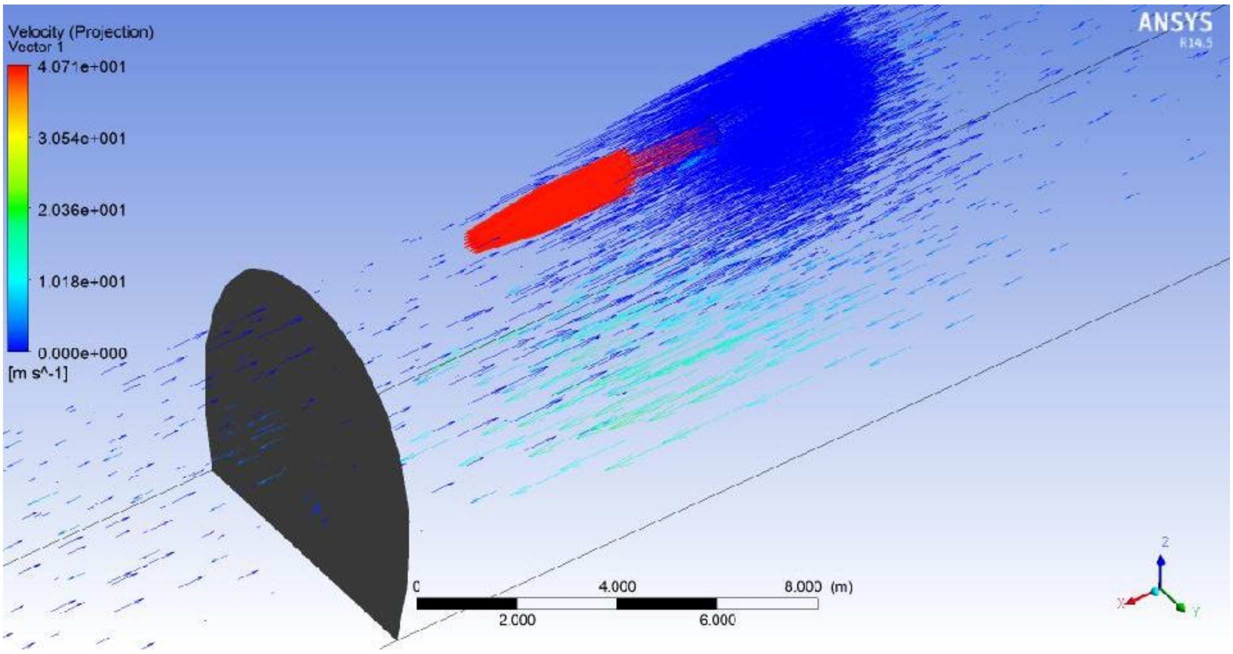


Figure 4.26 velocity vector at fan 3

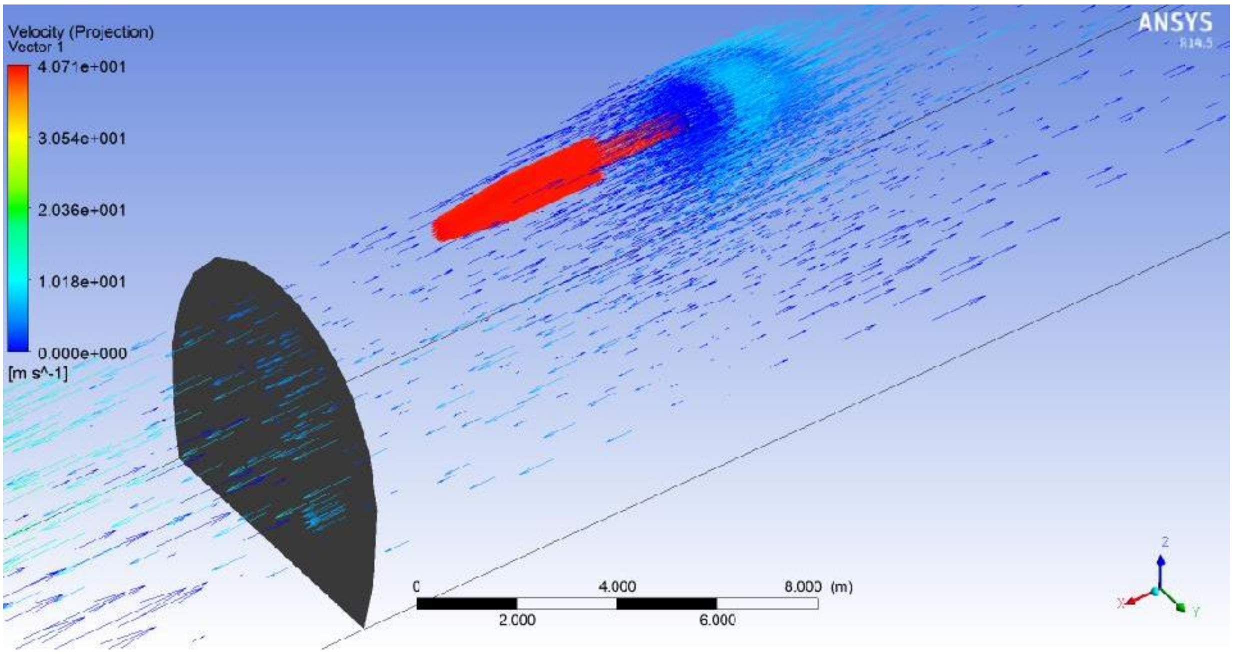


Figure 4.27 velocity vector at fan 4

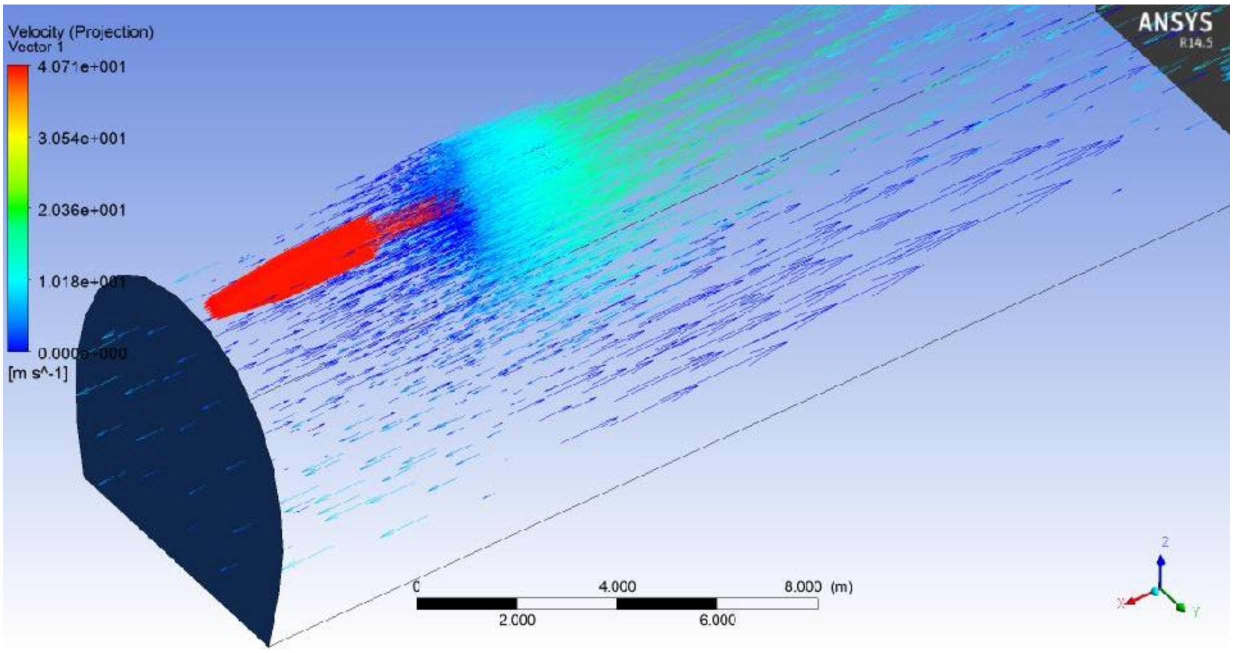


Figure 4.28 velocity vector at fan 5

Stream line

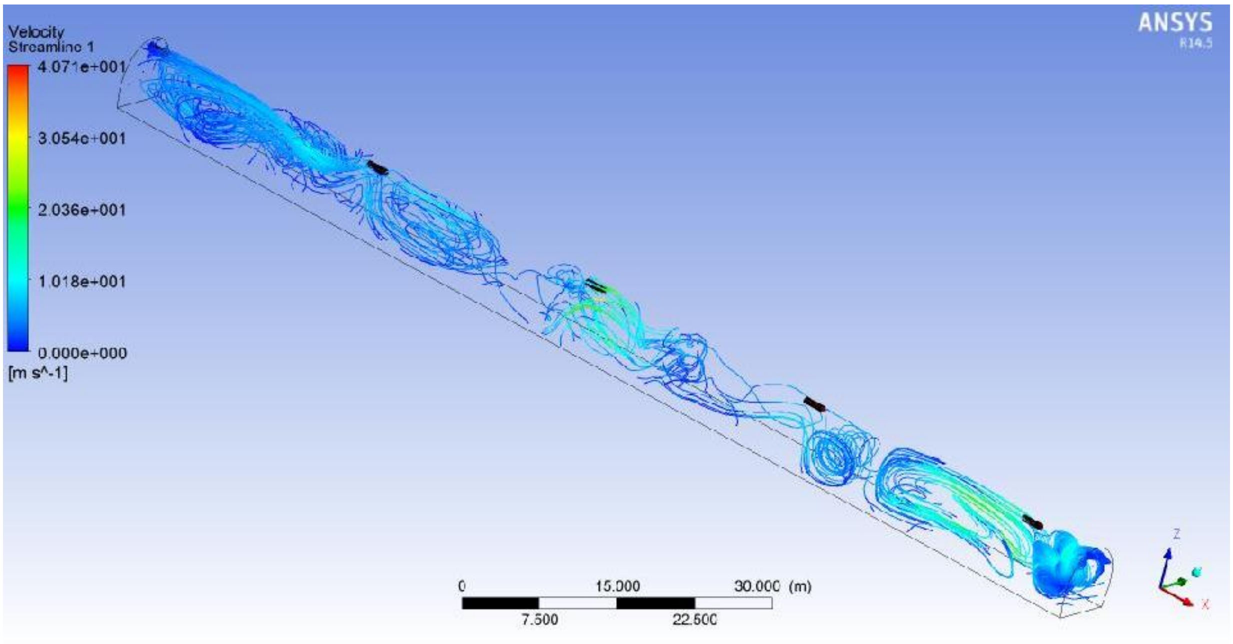


Figure 4.29 stream line

Volume rendering

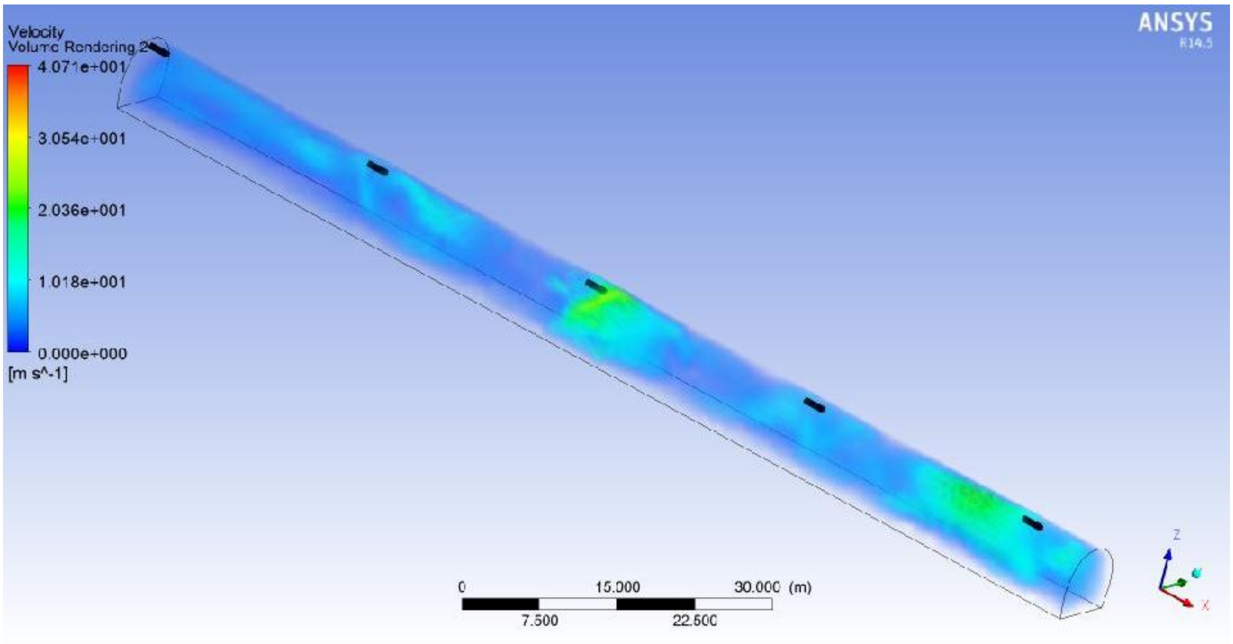


Figure 4.30 volume rendering

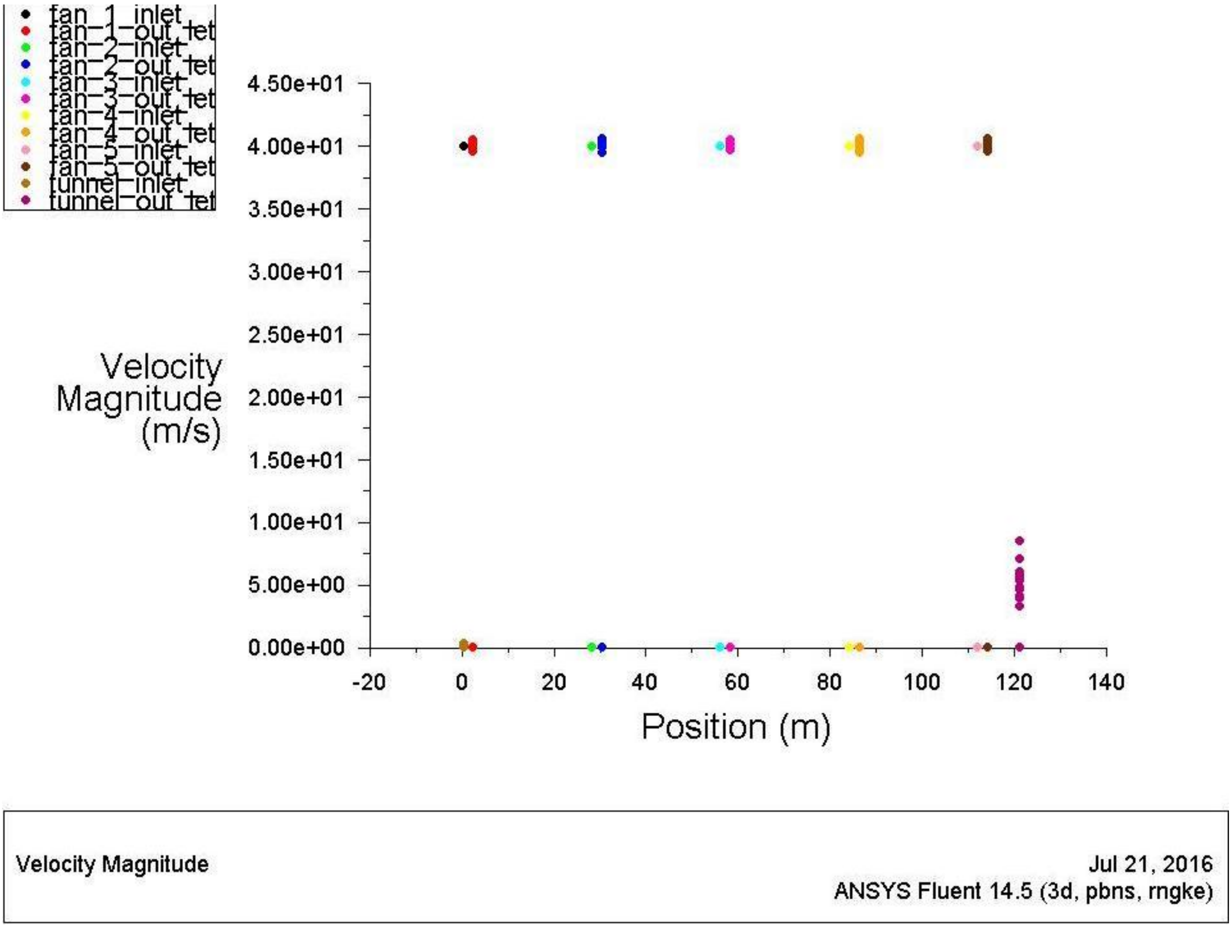


Figure 4.31 shows the velocity magnitude

CHAPTER FIVE

CONCLUSION, RECOMMENDATION AND FUTURE WORK

5.1 Conclusion

Numerical simulations were conducted to research the characteristics of air flow in a tunnel. In this paper, calculation models were carried out to investigate the velocity distribution and pressure distribution inside tunnel with different arrangement modes of jet fans. From the simulation results, it can be concluded that the ventilation performance mainly depends on the series mode of fans.

As the simulation showed that the effect of velocity contour and pressure contour of air flow in tunnel that created by using these five jet fans by swirl dominated flow. The result of velocity contour at the plane of 10m away from the exit of jet fans and tunnel out let maximum velocity is 12.1 m/s and the value at tunnel inlet and tunnel wall was zero, but the maximum value of pressure contour at tunnel was 101600pa.

As the result shows that the fresh air at the inlet is set to be sufficient by the effect of jet fan to change the suffocated air inside the rail way tunnel, but presence of jet fan is actually bring a different in dilution and making sure there is no stagnant air areas inside the tunnel ventilation.

So that, according to different arrangement modes of jet fans, can get the required amount volume flow rate at the tunnel out let.

5.2 Recommendation

- Increasing the cross-sectional area of the tunnel that used to increase the air flow simply out of the tunnel.
- Longitudinal ventilation by means of jet fans is a solution that is commonly adopted in tunnels, namely for its simplicity of installation combined with reduced capital and maintenance costs. However, the overall performance of a jet fan in a longitudinally ventilated tunnel is significantly reduced by the proximity of wall or ceiling where important shear stress losses occur. This research focuses on the longitudinal ventilation system by means of jet fans arrangement without some inclination. The usage of jet fan inclination used to for the reduction of these losses; reducing losses means improved

installation efficiency manifested by increased ventilation flow for the same fan power input.

- Good ventilation systems using jet fan will contribute to maintain air quality in the tunnel. In order to improve ventilation performance in normal traffic condition, use a group double paralleled jet fans.

5.3 Future work

The assessment of the ventilation system performance required a comprehensive study of the ventilation strategies within the tunnels. In particular, the study aims to understand the consequences on the tunnel flow of making changes to the fan configurations.

For further work the following are recommend:

- In this research only the effect of axial air flow using je fan in the rail way tunnel was analyzed without consideration of train in side of the tunnel.
- On the concept of tunnel ventilation system in this research only comfort ventilation is analyzed .In the event of an emergency ventilation, the ventilation system would be operated to force the smoke and hot gases in the direction of empty tunnel to provide a clear and safe environment behind the fire to evacuating people and fire fighters.

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