UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UPPER AIRWAYS MODELLING AND VALIDATION OF MANDIBULAR ADVANCEMENT SURGERY USING VARIABLE AIRFLOW AND THE EFFECT TO WALL SHEAR

MOHD NUR IMAN BIN MOHD SOFI

BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (AUTOMOTIVE TECHNOLOGY) WITH HONOURS

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Faculty of Mechanical and Manufacturing Engineering Technology

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Mohd Nur Iman Bin Mohd Sofi

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MOHD NUR IMAN BIN MOHD SOFI

A thesis submitted in fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours

Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this Choose an item. entitled "UPPER AIRWAYS MODELLING AND VALIDATION OF MANDIBULAR ADVANCEMENT SURGERY USING VARIABLE AIRFLOW AND THE EFFECT TO WALL SHEAR" is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Name : MOHD NUR IMAN BIN MOHD SOFI

Date : 11 JANUARY 2023

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours.

MOHD FARUQ BIN ABDUL LATIF
Pensyarah
Jabatan Teknologi Kejuruteraan Mekanikal
Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan
Universiti Teknikal Malaysia Melaka

Signature : ....

Supervisor Name : Ts. MOHD FARUQ BIN ABDUL LATIF

Date : 11 JANUARY 2023

DEDICATION

This project is dedicated to my parents who have never failed to give us financial and moral support, for teaching me that even the largest task can be accomplished if it is done one step as a time. I dedicate this Project to all the people who have worked hard to help us complete this project.

ABSTRACT

The pressure, velocity, and airflow characteristics of the human upper respiratory tract have been widely investigated, with a focus on the effect of geometric aspects. Model airflow characteristics and upper airway quality utilising a range of patient circumstances on geometric and operational settings that change because of the availability of contemporary computer hardware and software. For assessing upper airway airflow and preparing patients for surgery, computational fluid dynamics has emerged as a feasible technique. The objective of this project is to conduct a literature review on computational fluid dynamics methods and modelling for upper respiratory tract analyses. Utilization of experimental and computational methods in upper airway research. Physical experiment validation by comparing the experiment procedure. The upper airway flow is simulated using computational fluid dynamics. The simulation model must be tested to ensure that it functions as expected or replicates an actual event. Using clinical data to validate the upper respiratory tract biomechanical modelling model boosted user trust in computational fluid dynamics computations. In the computational fluid dynamics model validation process, experimental data or clinical data standards are commonly utilised to validate simulation results.

ABSTRAK

Ciri tekanan, halaju dan aliran udara saluran pernafasan atas manusia ada telah disiasat secara meluas, dengan tumpuan kepada kesan aspek geometri. Aliran udara model ciri dan kualiti saluran udara atas menggunakan pelbagai keadaan pesakit pada tetapan geometri dan operasi yang berubah kerana adanya kontemporari perkakasan dan perisian komputer. Untuk menilai aliran udara saluran udara atas dan menyediakan pesakit untuk pembedahan, dinamik bendalir pengiraan telah muncul sebagai teknik yang boleh dilaksanakan. Objektif projek ini adalah untuk menjalankan kajian literatur tentang dinamik bendalir pengiraan kaedah dan pemodelan untuk analisis saluran pernafasan atas. Penggunaan eksperimen dan kaedah pengiraan dalam penyelidikan saluran pernafasan atas. Pengesahan eksperimen fizikal oleh membandingkan prosedur eksperimen. Aliran saluran udara atas disimulasikan menggunakan pengiraan dinamik bendalir. Model simulasi mesti diuji untuk memastikan ia berfungsi seperti yang diharapkan atau mereplikasi peristiwa sebenar. Menggunakan data klinikal untuk mengesahkan bahagian atas model pemodelan biomekanikal saluran pernafasan meningkatkan kepercayaan pengguna terhadap bendalir pengiraan pengiraan dinamik. Dalam proses pengesahan model dinamik bendalir pengiraan, data eksperimen atau piawaian data klinikal biasanya digunakan untuk mengesahkan simulasi keputusan.

ACKNOWLEDGEMENTS

Firstly, First and foremost, I had like to thank my supervisor, Ts. Mohd Faruq Bin Abdul Latif, for his constant support of my Bachelor of Mechanical Engineering Technology (Honors) research and study, as well as his patience, encouragement, passion, and vast knowledge. His advice was vital during the research and writing of this thesis.

Next, my appreciation also goes to the School of Mechanical Engineering Technology, School of Engineering Technology for approving my project proposal for doing this modelling and validation of mandibular advancement surgery using variable airflow and the effect to wall shear. It is very interesting project to be done.

Finally, I must also express my gratitude to my parents and friends for the tremendous support and assistance they provided throughout the duration of this project. The completion of this project would have been extremely challenging without their assistance.

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LIST OF SYMBOLS AND ABBREVIATIONS

D,d	-	Diameter
CFD	-	Computational Fluid Dynamics
UA	-	Upper Airways
OSA	-	Obstructive Sleep Apnea
MAS	-	Mandibular Advancement Surgery
CT	-	Computerized Tomography
TKE	-	Turbulence Kinetic Energy
T	-	Temperature
SLS	-	Selective Laser Sintering

CHAPTER 1

INTRODUCTION

1.1 Background

The most prevalent form of breathing problem that occurs during sleep is called obstructive sleep apnea. During the night, it will cause you to continuously stop and start breathing for no apparent reason. There are various subtypes of sleep apnea, but obstructive sleep apnea is by far the most prevalent form. During sleep, you can develop this form of obstructive sleep apnea when the muscles in your throat occasionally relax and restrict your airway. Snoring is one of the most obvious symptoms of obstructive sleep apnea.

There are treatments for obstructive sleep apnea. One treatment option is a device that uses positive pressure to keep your airway open while you sleep. A mouthpiece that pushes your lower jaw forward while you sleep is another possibility. Surgery may also be a possibility in rare circumstances. Obstructive sleep apnea occurs when the muscles at the back of the throat relax too much to enable regular breathing to occur. In addition to uvula and tonsils, these muscles help to keep the tongue and soft palate at their proper positions in the rear of your mouth.

When you inhale, your muscles relax, narrowing or closing your airway for 10 seconds or more. A buildup of carbon dioxide and a consequent decrease in blood oxygen levels might result as a result. When your airway is clogged, your brain rouses you from sleep so that you may reopen it. Because this awakening is so brief, most people don't recall it.

While shortness of breath might jolt you out of a sound sleep, it is quickly alleviated with a few deep breaths. You may snort, choke, or gasp at some point. Five to thirty times or more an hour or more, all night long, this pattern may recur. You won't be able to reach the deep, restorative phases of sleep as a result of these disruptions, and you'll probably feel sleepy during the day.

People who suffer from obstructive sleep apnea may be unaware that their sleep is being disrupted. Many persons with this sort of sleep apnea are unaware that they haven't had enough sleep.

1.2 Problem Statement

Based on the final total article that have been search, several authors explain the experimental procedure. Aside from that, the physical validation model should be applied to a variety of scenarios, and a directory of data might be built from diverse cases due to the time required to wait for the results and data (Faizal *et al.*, 2020).

The results demonstrated that a decreased cross-sectional size of the airway increased airflow characteristics, especially when the lungs are working hard. During heavy breathing, the airway was found to be filled with turbulence. Turbulent kinetic energy, which exposes the behaviour and concentration of mean flow, can be used to estimate the severity of OSA. (Faizal *et al.*, 2021).

1.3 Research Objective

The main aim of this research is to estimate the upper airways modelling and validation of mandibular advancement surgery using variable airflow and the effect to wall shear. Specifically, the objectives are as follows:

a) To study the air pressure of UA

b) To study the impact variation of airflow velocity on the UA wall shear

c) To study the relation of wall shear with UA geometry

d) To develope validation methods for grid sensitivity analysis.

1.4 Project Scope

Provide a validation and computational fluid dynamics investigation on OSA resulting from mandibular advancement surgery with variable airflow and the effect on wall shear. In addition, the year range for articles is 2018 to 2022, to ensure that the data is relevant to the current situation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In the course of doing this research project, a systematic literature review will be conducted. This ensures accurate data collection by excluding and analyzing any articles that are not directly related to the project. The SLR method is difficult and time-consuming, but it allows us to track the growth of our product in increments (Xiao and Watson, 2017).

2.2 Prisma Method

The PRISMA approach was utilised to locate the article for this study. This strategy will direct you in your search for the appropriate article. Also, a systematic review will conduct a comprehensive search of all published reports on the topic to answer a well-defined research question, selecting reports to include in the review based on numerous inclusion and exclusion criteria, and then synthesising the results.

Checklists and a four-phase flowchart are included in the PRISMA guidelines. The flowchart shows how to find, filter for, and include reports that meet the criteria for the review. There are 27 suggestions in the checklist, including topics like the title, abstract and introduction as well as results and discussion. Using this flowchart and checklist, PRISMA items serve as a guide for authors, reviewers, and editors (Selçuk, 2019).

2.2.1 Research Strategies

The first step in applying this process is to come up with alternative meanings for each of the words that are used in the title of the project. This stage is essential because it has the potential to result in a number of different meanings being assigned to each word. Utilizing Teasurus makes the process of discovering alternative words for each individual word much easier.

Table 1 Synonyms for each keywords

Keywords	**Synonyms**
Upper	Uppermost, Top, High
Airways	Air passage, Air shaft
Modelling	Create, Design, Mould
Validation	Acceptance, Proof
Mandibular (mandible)	Bone, Mouth
Advancement	Advance, Improvement
Surgery	Incision, Abscission
Obstructive	Antithetical, Conflicting
Apnea	Hiatus, Pause

2.2.2 Search String

Creating a search string is the next step in the process. A good and detailed search string can aid in locating the exact article that matches your title. An algorithm based on Visual Text Mining is used to help the researcher by suggesting more words to include in their string. Approaches like this aggregate important phrases from a researcher's selected studies and show them in a way that promotes visualization and helps the development and improvement of the search string (Mergel, Silveira and da Silva, 2015).

Table 2 Search string for the searching on website

Data	Search String
`Scopus	ALL (("obstructive sleep$ apnea" OR “obstructive sleep$ snore$” OR "sleep apnea") AND ("upper airway$" OR "uppermost airways$" OR "top airway$" OR “top air shaft” OR “top air passage”) AND (“model$” OR “create$” OR “design$” OR “mold$”) AND (“validation$” OR “acceptance$”) AND (“mandibular” OR “bone” OR “mouth”) AND (“advance$” OR “improvement”) AND (“surgery” OR “incision” OR “abscission”) AND (“airflow” OR “air” OR “ventilation”) AND (“wall shear”))
Science Direct	Obstructive Sleep Apnea Upper Airways Modelling and Validation of Mandibular Advancement Surgery using variable airflow and the effect to wall shear.

2.2.3 Flow Diagram

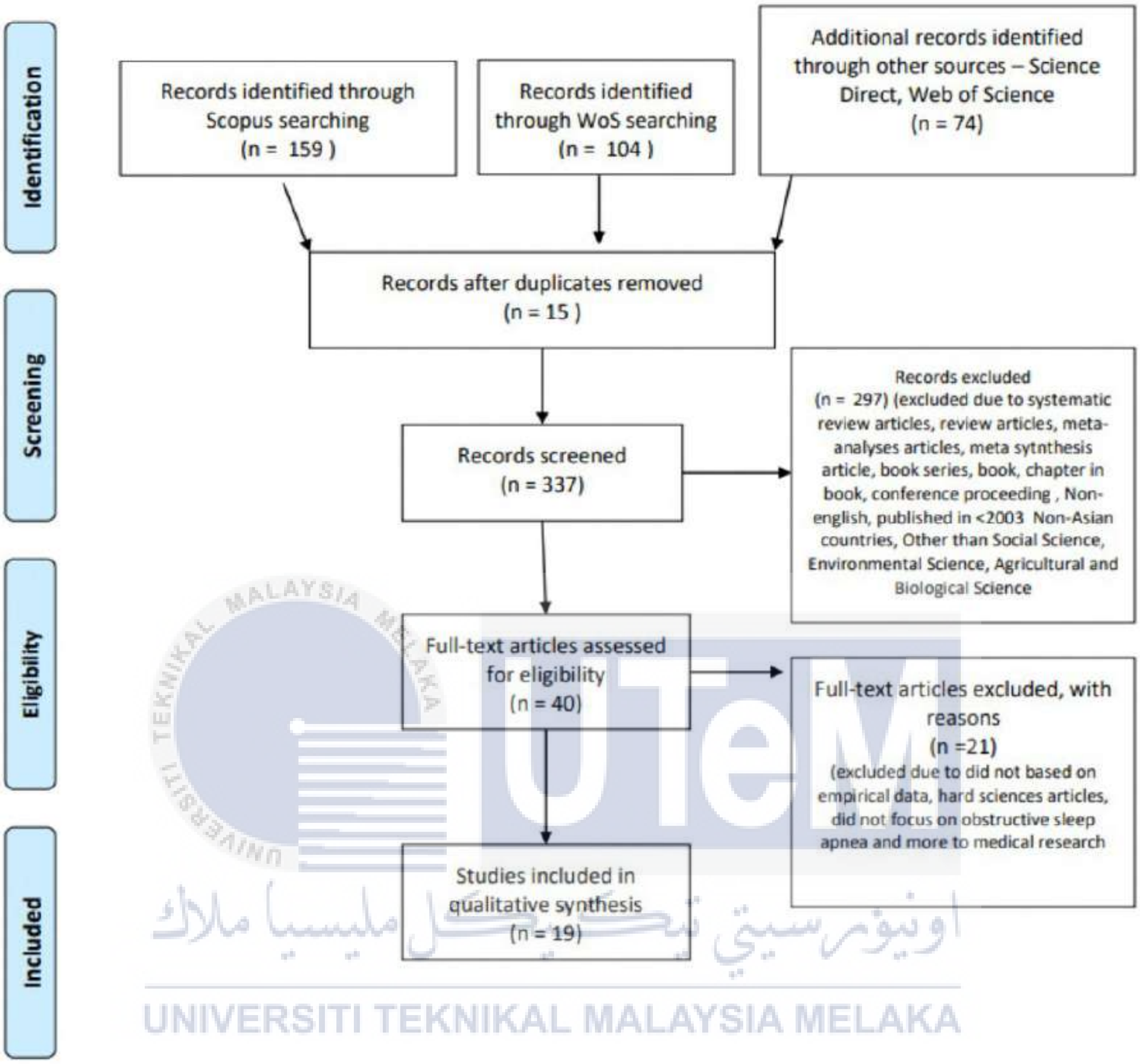


Figure 1 Flow diagram process for searching article

The identifying process involved using the search string that had previously been developed to search the article in the chosen article page. The university has recently acquired a number of websites that will be of assistance to us in our search for information and downloading articles from the internet. The total number of article that have been search from the 3 websites is 337 articles.

Another step in the research process is screening. This step necessitated the exclusion of everything but the papers below from 2018, as well as systematic reviews and meta-analyses and Meta-synthesizes in books and book chapters. For the eligibility procedure, it is an article that we have full access to, as well as those that have undergone some final review. This is to exclude hard scientific and non-obstructive sleep apnea-related items. There will be a total of 19 articles utilized for references and citations. This essay will serve as a guide for us to complete our research.

2.3 Advancement of Study

This subtopic will concentrate much of its attention on our completed pieces of study. The experimental and computational processes that have been carried out will be broken down in further detail in the next section. In addition, discuss each publication's research methods and findings.

2.4 Fishbone

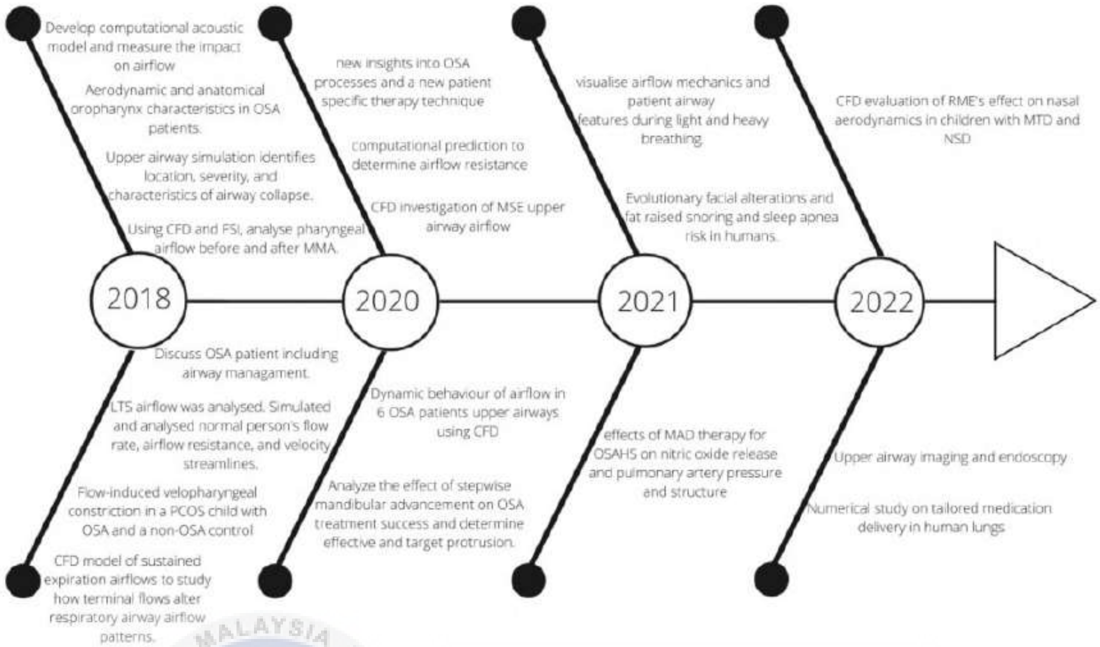


Figure 2 Fishone diagram with all the articles

Using a Fishbone diagram, one may look at the relationships between consequences and the underlying factors that lead to or exacerbate those effects. Because of its purpose, the Fishbone diagram is often known as a cause-and-effect diagram. The structure of the graphic is evocative of the skeleton of a fish. In order to have a more full view of the causes and sub-causes, it may be necessary to include qualitative and quantitative risk ratings of the causes and sub-causes, along with their names and codes (Ilie and Ciocoiu, 2010).

2.5 Validation

To put it another way, validity is the degree to which a method accurately assesses what it claims to. When a study has a high degree of validity, the findings are correlated to real-world qualities, characteristics, and variations. When a measurement is very reliable, it provides proof that it is trustworthy. This paper's contribution is that it examines several forms of validation using examples from studies, evaluates the problems that were identified as relevant, and describes how they were handled in each instance (Gunnar and M., 2010).

Airflow research has utilized fluid mechanics techniques including computational fluid dynamics (CFD) and fluid structure interactions (FSI). Accurate simulations of airflow in the airway have been successfully validated using CFD. CFD, on the other hand, believes that the airway is a rigid, inflexible structure, while FSI allows the airway tube to bend. (Chang *et al.*, 2018).

2.5.1 Cone Beam Computed Tomography (CBCT)

CBCT scanners use a 2D digital array with a region detector for volumetric tomography. Using a three-dimensional x-ray beam in conjunction the x-ray source and a reciprocating area detector travel around the patient's head in a single 360° scan using the cone-beam technique. (Practice, Scarfe and Farman, 2006).

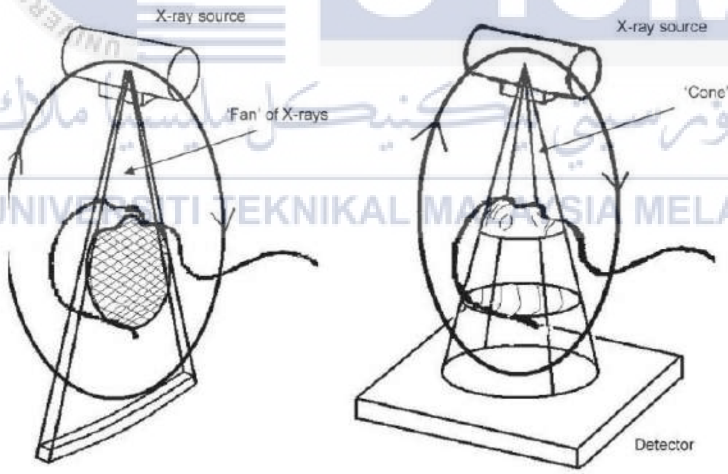


Figure 3 Single detector array X-ray beam projection approach comparing fan-beam CT (a) and cone-beam CT (b) geometries.

Two patients who met these requirements were chosen. At least 6 months after surgery, polysomnography and cone-beam computed tomography (CBCT) scans were conducted to enable edema to reduce, healing to be complete, and results to stabilize. All CBCT examinations were performed with the patient's head in its natural position (Chang *et al.*, 2018).

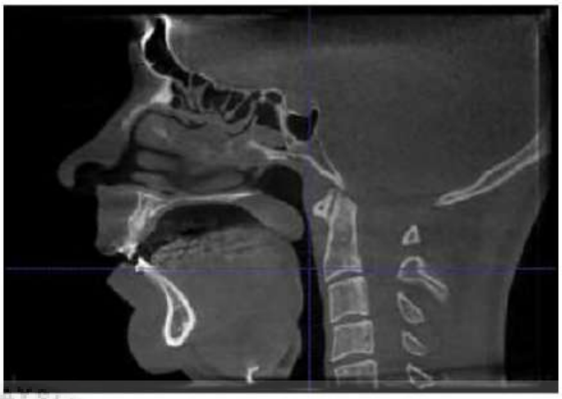


Figure 4 Presurgery CBCT scan and midsagittal view (patient 2)

Figure 5 Postsurgery CBCT scan and midsagittal view (patient 2)

2.5.2 Upper Airway Modelling, CT Scan and Meshing

The scanning area encompassed the entire UA, including the head. A customized frame that maintains the patient's head in a fixed position has helped to improve the accuracy of the medical image, as has the effort to maintain the Frankfort plane's stability before and after MAD placement. With and without MAD, the images were taken successively. Segmenting DICOM pictures semi-automatically was used to construct the UA geometry. To generate the mesh, GID17 was utilized. Tetrahedrons with a boundary layer were used in this work to create meshes. It was necessary to do a mesh sensitivity analysis in order to ensure that the simulations were accurate, which resulted in a 3D volume mesh consisting of 2,500,000 10 percent tetrahedral elements. All twelve acquisitions were made using the same medical imaging techniques, image processing, and volume mesh method. In Fig. 6, you can see a portion of the mesh (Martínez *et al.*, 2020).

Figure 6 Sagittal view of upper airway mesh with details: (a) sagittal plane slice above the pharynx, (b) boundary layer detail, (c) axial plane section in the bottom part of the soft palate.

2.6 Computational Fluid Dynamis

It was possible to convert the stereolithographic file format from Aviso (FEI) to the mesh-generation software ICEM-CFD 16.1. (ANSYS, Inc., Canonsburg, PA). The discretized equations of fluid flow were solved using an ICEM-CFD hybrid tetrahedral-prism mesh with about 6 million unstructured graded tetrahedral components (ANSYS, Inc.). A three-layer prism element with a prism thickness of 0.15 mm per layer was created at the airway walls. Mesh quality analysis confirmed that the aspect ratio of the hybrid mesh was sufficiently smoothed to avoid deformed components from compromising the precision of our numerical simulations. The choice of mesh density was compatible with a rigorous mesh sensitivity study reported by Frank-Ito, which demonstrated that about 6 million elements will offer mesh independent numerical results at the level of the overall model and the stenotic area. In this work, mesh refinement analysis was judged unnecessary since an approximately 6-million-element graded mesh sufficiently caught all stenotic areas (Cheng *et al.*, 2018).

Continuous, incompressible inspiratory airflow in the airway was simulated using ANSYS Inc.'s Fluent 16.1 (FLUENT, Inc.). Both with the mouth closed and with the mouth open were utilized to replicate inhalation airflow, which was done in two distinct ways (inspiration through nostrils and mouth with open lips). Simulations of the inspiratory airflow for each intake design were performed using three different pressures (10, 25, and 40 Pascal's [Pa]). In order to mimic turbulent airflow, the k-x model was utilized with low Reynolds number modifications. It was adjusted to 1 millimeter turbulence length and the turbulence intensity at the intake to 5%. This model has been shown to successfully predict pressure drop, velocity profiles, and shear stress in transitions between turbulent flows.

There was also an outlet-to-pressure boundary condition in place, which was implemented in steps 57–59. (Carina with 210, 225, or 240 Pa gauge pressure). The nose (and lips, if the mouth is open) input pressure is zero. A static airway wall was assumed for the respiratory channel since there was no velocity at air–wall contact and no slip shear. A static airway wall was assumed for the respiratory channel since there was no velocity at air–wall contact and no slip shear. (Cheng *et al.*, 2018).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will explain the different types of methodologies that were utilized to analyze data that were relevant to the study. Computational modelling and physical validation will be required in two phases. The project's data is derived from a CT scan of a hospital patient dealing from obstructive sleep apnea. Each of the parameters that have been assigned to this chapter will go through the project in depth.

3.2 Flow Chart

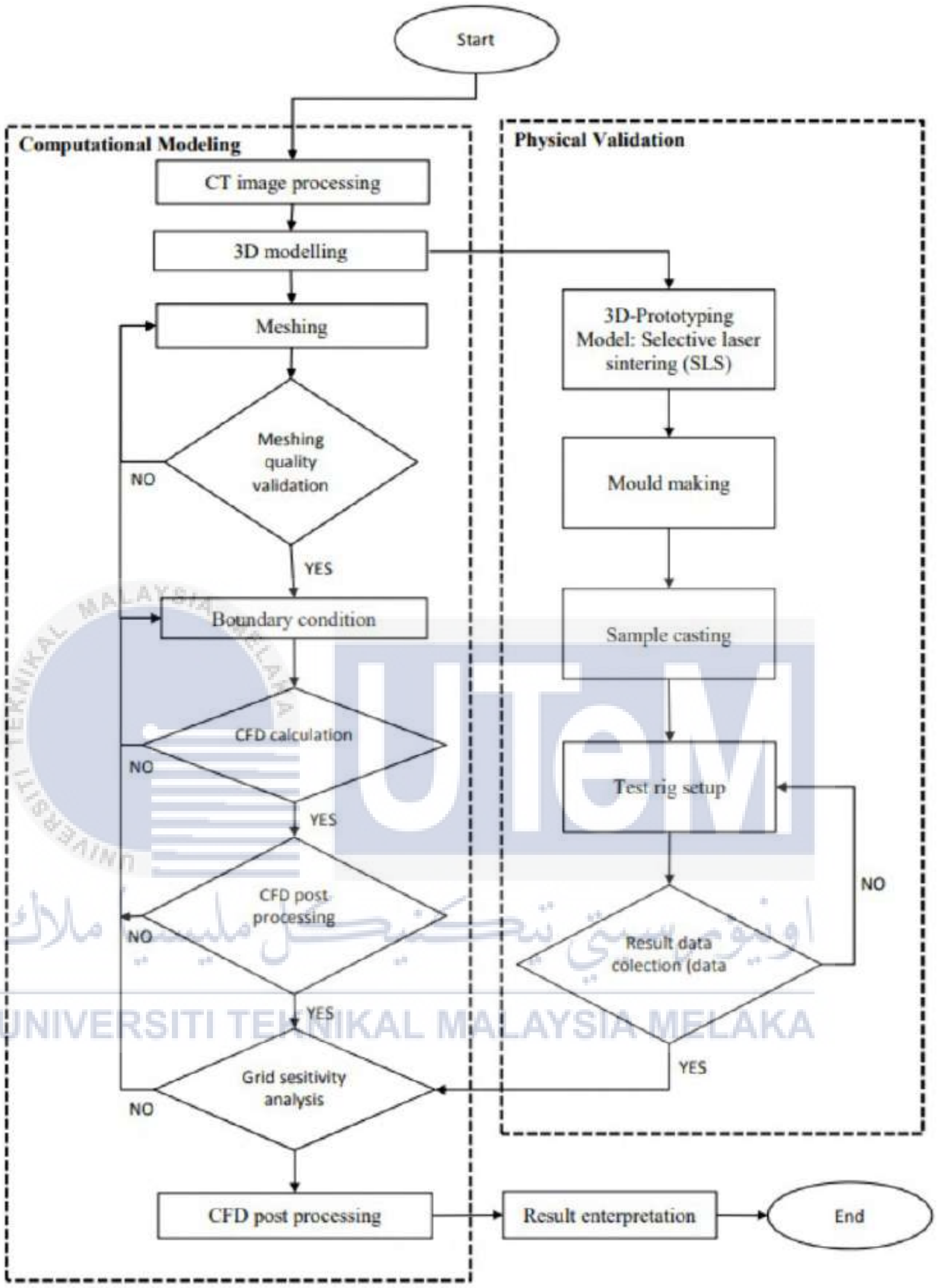


Figure 7 Flow chart for methodology

3.3 Computational Modeling

3.3.1 CT Image Processing

CT sagittal image and 3D upper airway mesh model are shown in Figure 8. The nasal-to-pyrngeal region was the focus of the model for the subject of interest. The computed tomography (CT) picture marked an anatomical location that was incorporated in the CFD modelling. Using the CFD model's inlet boundary as the starting point, the upper airway's 3D model began at P2 (nasal choana level). The model's exit point was selected as the base of the epiglottis (P1). CT scan images with a threshold depending on the grey image's intensity were used to detect the airway boundary(Faizal *et al.*, 2021).

Figure 8 the airway model's upper airway side view from the ct scan.

By utilizing the image from the CT scan, the image may then be transferred to Mimics. It is a software tool that processes images and is suitable for 3D design and modelling. This programmed sees a lot of use in the medical and dental fields.

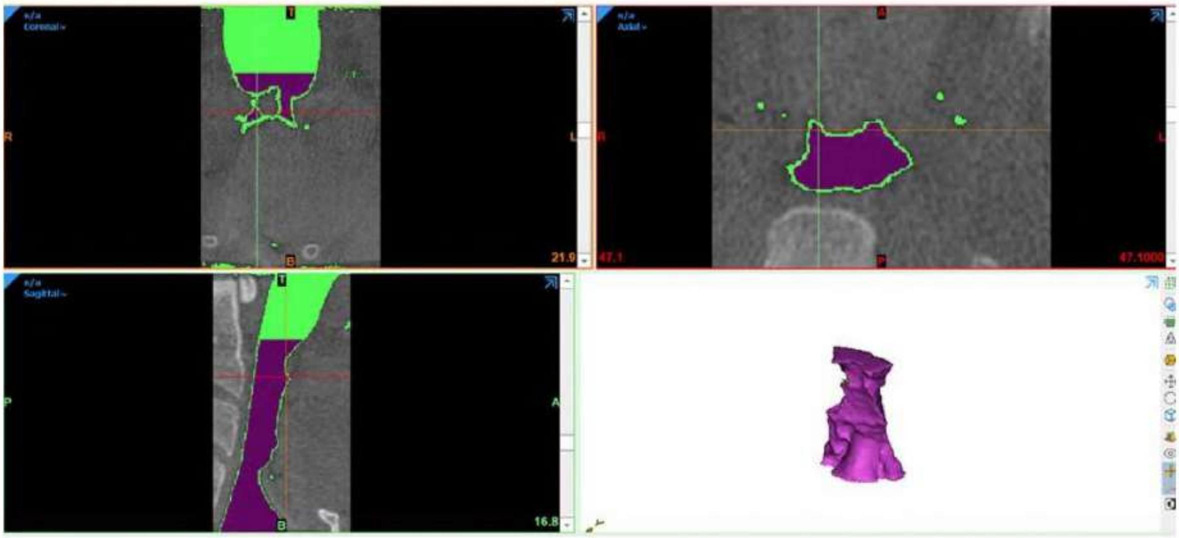


Figure 9 Upper Airways on Materialise Mimics Software

On Materialise Mimics software the CT scan was import. However the image still cannot be use for 3D printing due to the model was not smooth on the surface. The software can be used to make the specimen smooth and no scatter surface. Then only it can be transfer to 3 Matics Mimics Software.

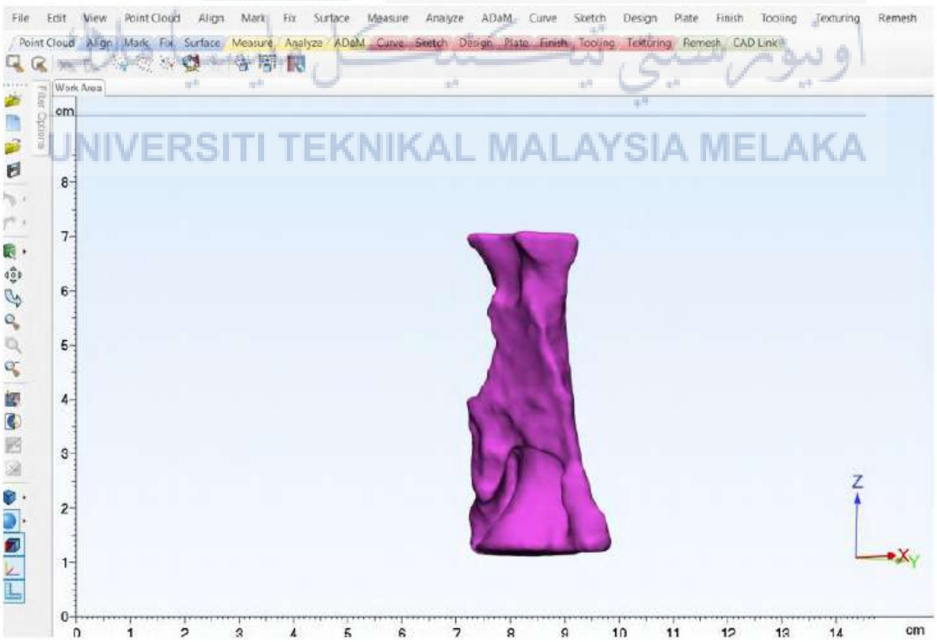


Figure 10 Upper Airways Specimen on 3 Matics Mimics

3.3.2 3D Modelling

Following the completion of the image processing on the CT scan with the mimics software, the data was then transferred to the Catia V5 software. The specimen will now have an outlet, an inlet, and a pressure point thanks to this addition. We draw a cylinder with a diameter of 40 millimeters for the inlet, and we draw a cylinder with a diameter of 20 millimeters for the outlet. This is because the experimental test was done after printing the specimen, and it resulted in the creation of 14 pressure points on the top of the specimen. Due to the fact that this specimen was ran through the experimental test, the inlet and outlet are the same as they are for every other member.

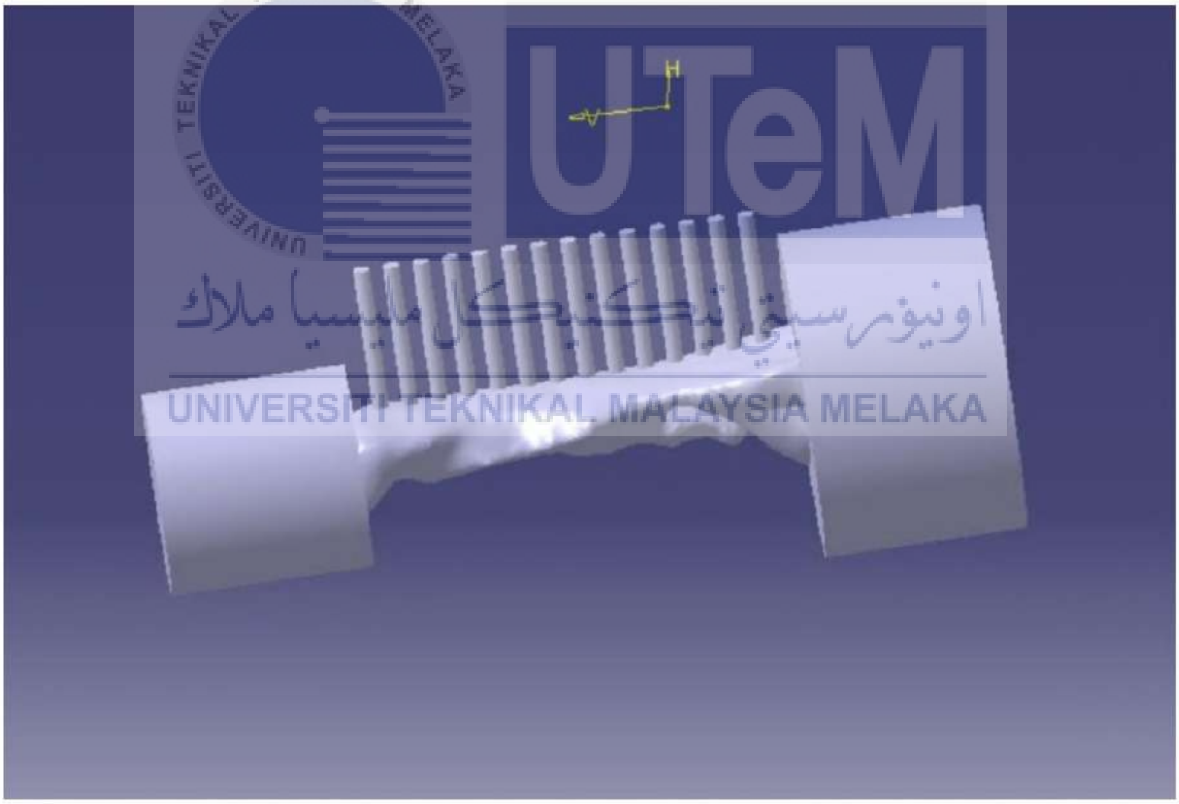


Figure 11 A three-dimensional model of the upper airway on Catia V5

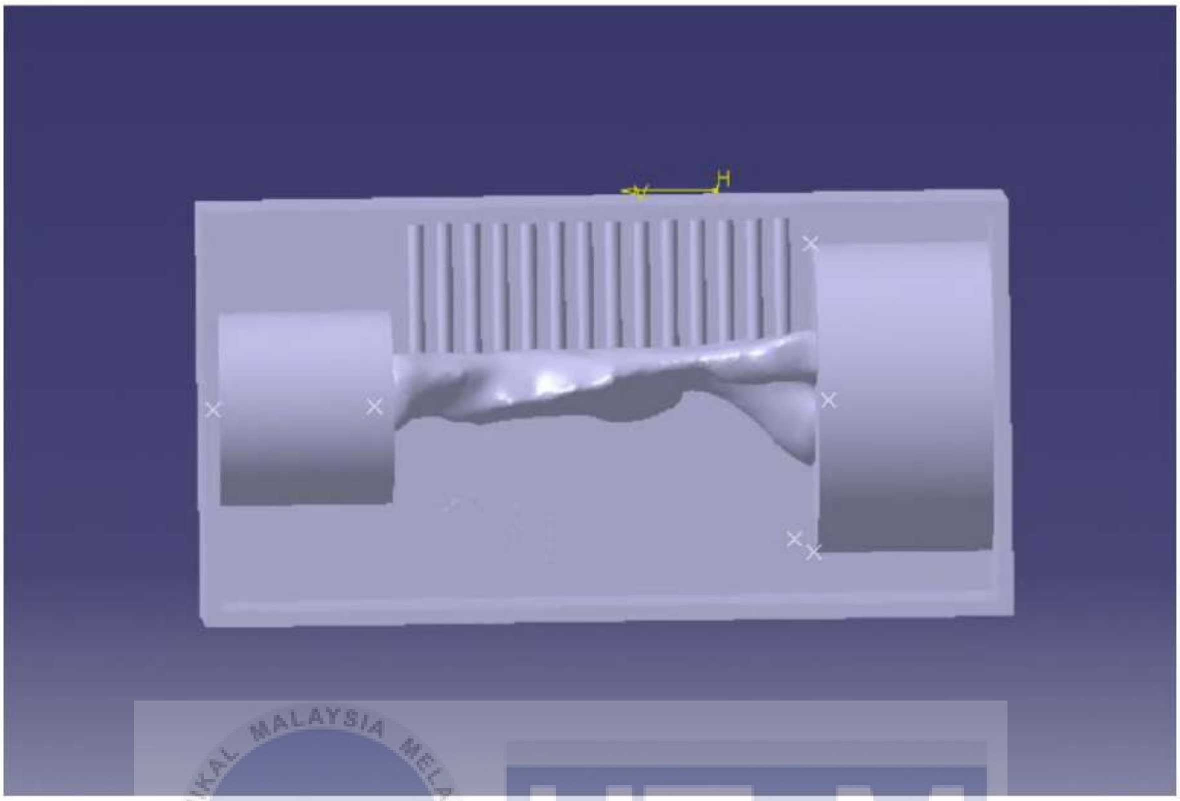


Figure 12 Left Upper Airways Modelling for SLS Printing on Catia V5

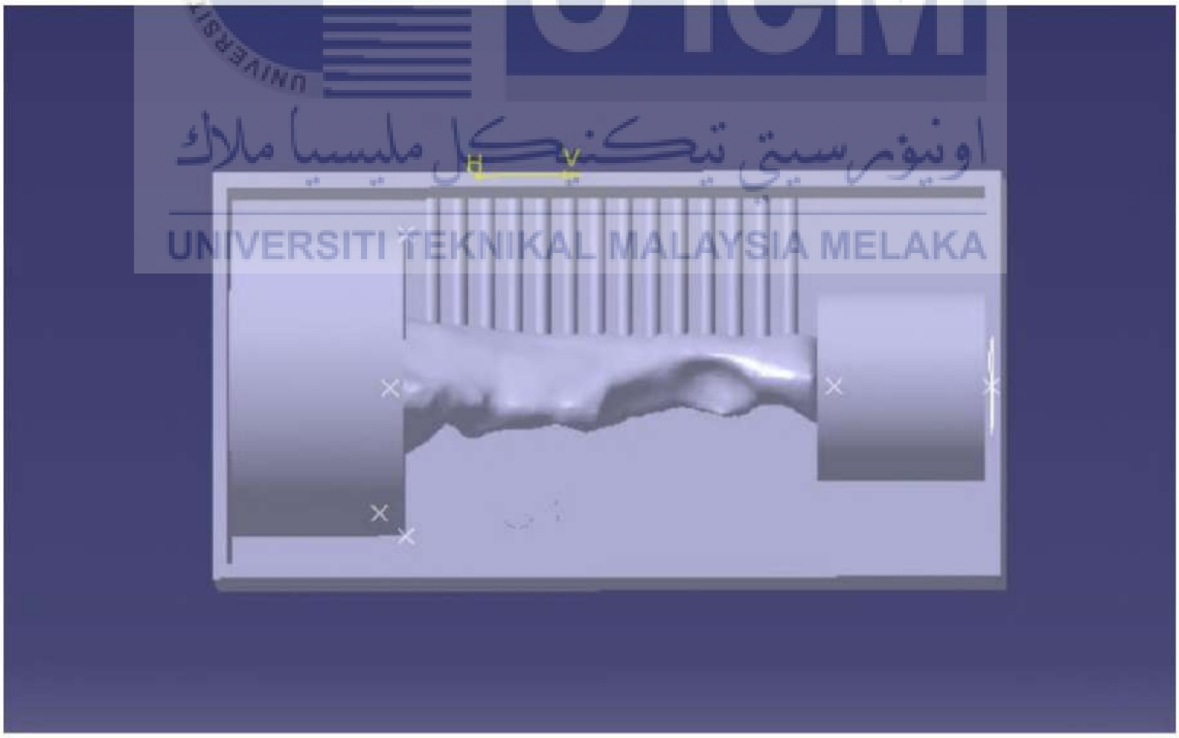


Figure 13 Right Upper Airways Modelling For SLS Printing

3.3.3 Meshing

Hypermesh is a finite element pre-processing programed that was created in the United States by Altair Corporation. It contains extensive functions related to finite element pre-processing and is able to give customers with high-quality and high-efficiency mesh division technology. In addition to being able to read several formats of geometric model files and produce finite element model files for use with a variety of different solvers, Hypermesh is compatible with the majority of the commercially available CAD and CAE applications on the market today. For the objectives of this simulation, the meshing element size range that has been used is from 0.2 to 0.6. The steps that were taken to carry out the simulation are depicted in the figure below.

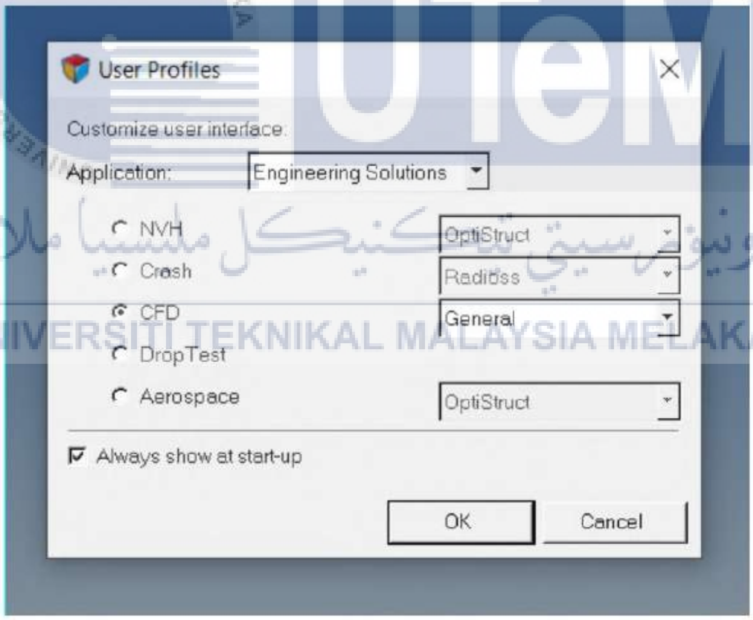


Figure 14 First step to run Hypermesh

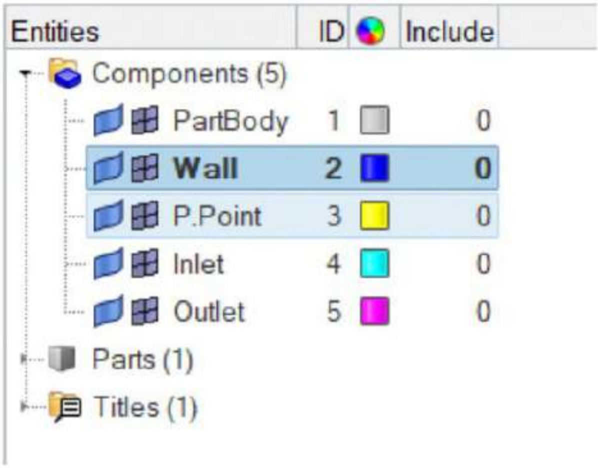


Figure 15 Create 4 components for the parts

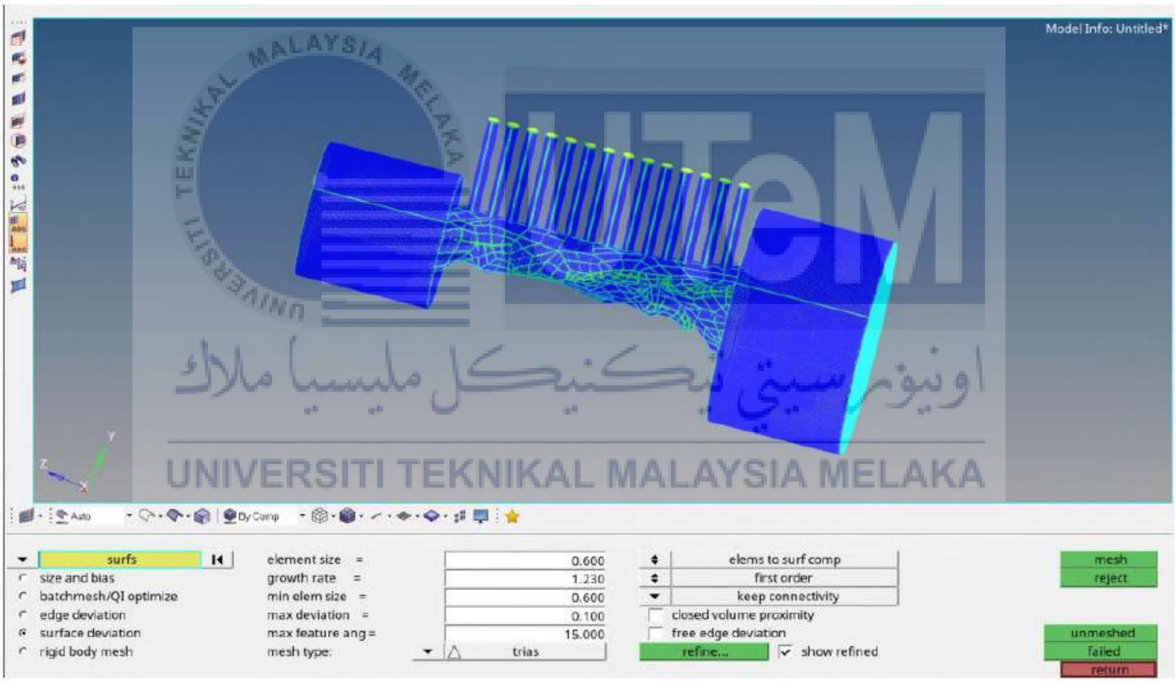


Figure 16 Automesh Step on the geometric model

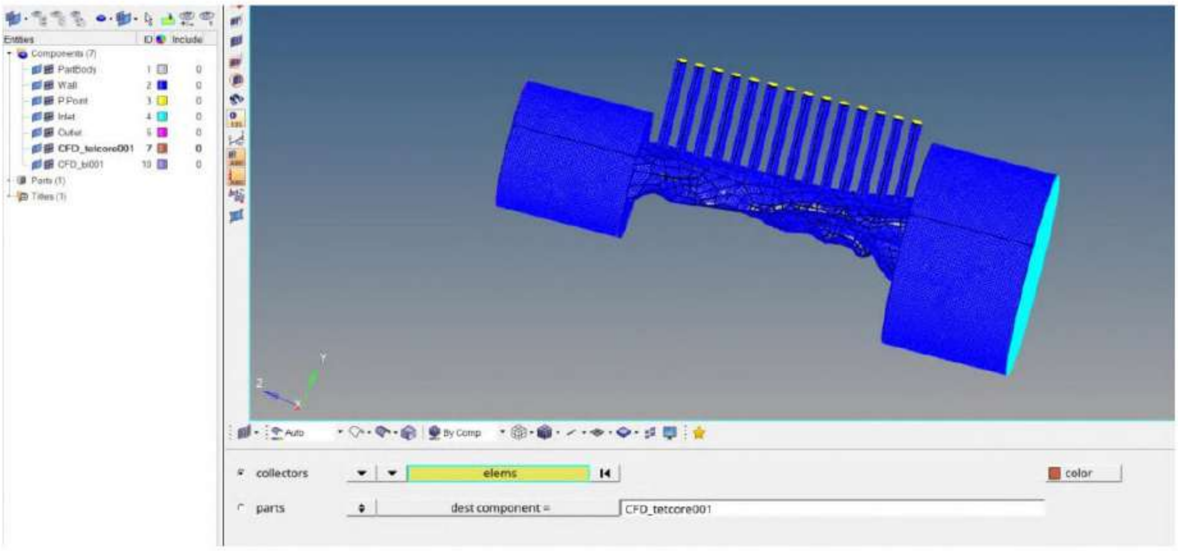


Figure 17 CFD Tetramesh on the Geometric model

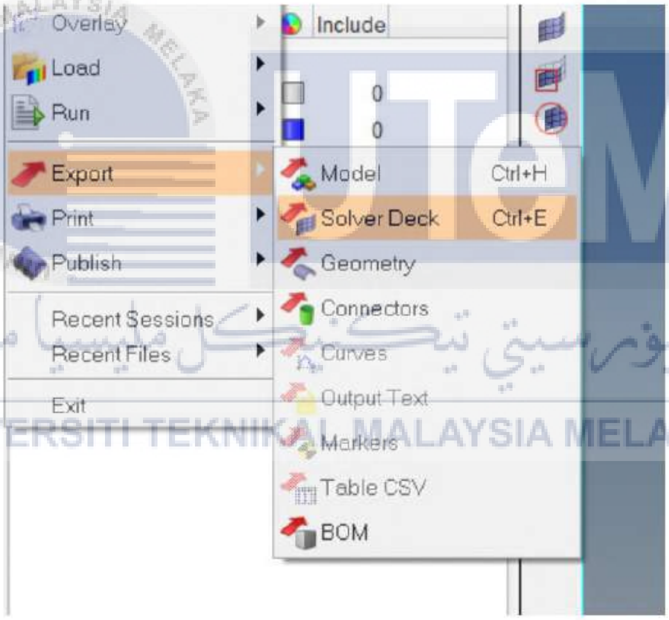


Figure 18 Last step is export to solver deck

3.3.4 Boundry Condition

This section explains how the precise computational airway flow is calculated. In this part, we will discuss the methodology behind determining the accurate computational airway flow. It is necessary to establish boundary conditions and do so in accordance with the modelling simulation and the analysis. Before beginning the simulation of the design in question, the conditions of the intake and outflow for the working air, including the velocity or pressure, and the temperature, are determined. In this regard, the following aspects are taken into account: In this design that simulates, the air that is contained within the tubes and the shell functions as the working fluid. The shell and tube walls are each given the constant wall temperature that they are to maintain. In order to determine the relative pressure drop that exists between the inlet and the output nozzle, the outlet wall is given a zero gauge pressure assignment. Throughout the whole of the simulation, the velocity of the air entering the system remains constant.

3.3.5 CFD Calculation

Following a discussion, it was decided that the choana plane, the palatal plane, and the superior order plane of the epiglottis would be investigated. The pharynx is a structure that may be broken down into three distinct parts: the nasopharynx, the oropharynx, and the hypopharynx. The volumes (Vol) in each of the areas were subjected to a series of measurements. After running the simulation, cross-sections were taken at regular intervals of 10 millimeters along the Y axis, beginning at the nostril and ending at the choana. The results of the CFD study were used to compute nasal resistance (R = P/Q, the ratio of pressure changes from external nares to the choanae and total flow rate), maximum velocity of the nasal cavity, and pressure declines (P = Pmax-Pmin). The pharynx was evaluated for wall shear stress, maximum negative pressure, and maximum velocity. In our investigation, because the flow rate remained constant, P reflected the variations in resistance for each pharyngeal segment.

3.3.6 CFD Post Processing

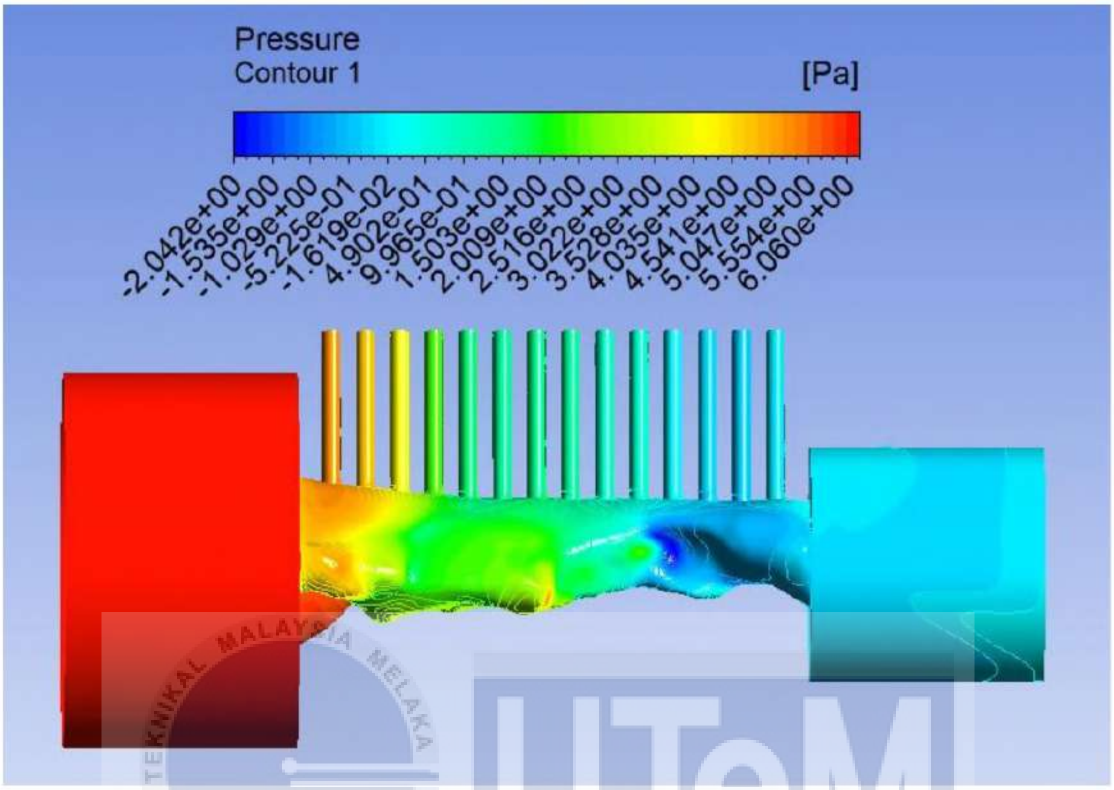


Figure 19 Post Processing CFD for pressure

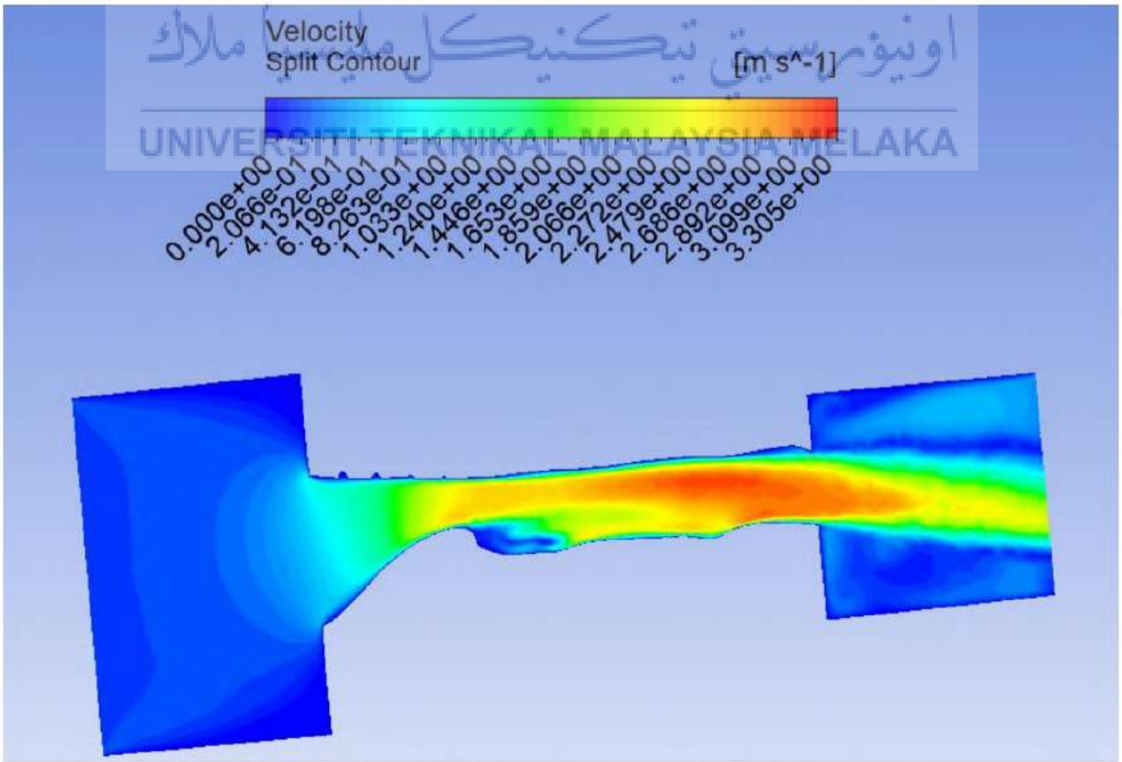


Figure 20 Post Processing CFD for velocity

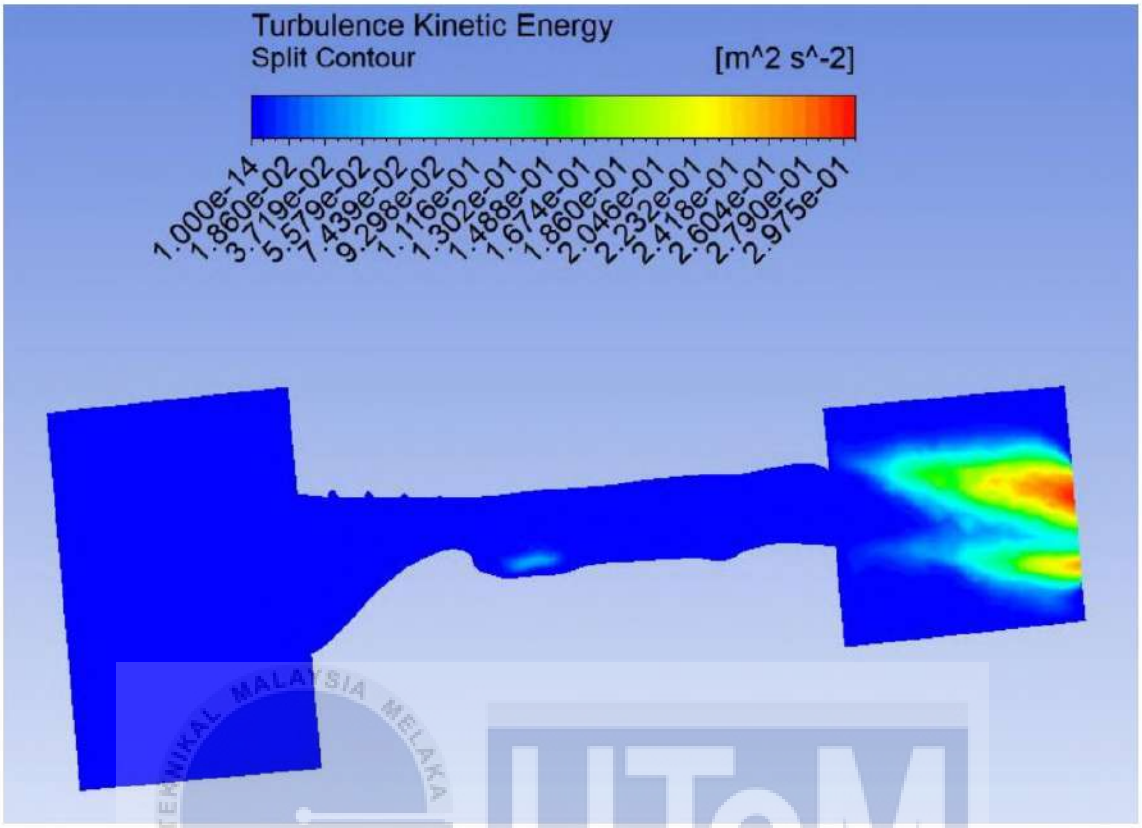


Figure 21 Post Processing CFD for TKE

3.4 Project Validation

3.4.1 3D-Prototyping Printing Model: Selective Laser Sintering (SLS)

The industrial 3D printing technology known as selective laser sintering, or SLS for short, can generate precise prototypes and fully functional production components in as little as one day. There are a number of materials that are based on nylon, as well as a thermoplastic polyurethane (TPU), which may be used to make very durable final components that require resistance to heat and chemicals, as well as flexibility and dimensional stability. Because SLS 3D printing does not require the use of support structures, it is a cost-effective alternative for situations in which greater numbers of 3Dprinted components are required. Additionally, it makes it simple to nest many elements into a single build.

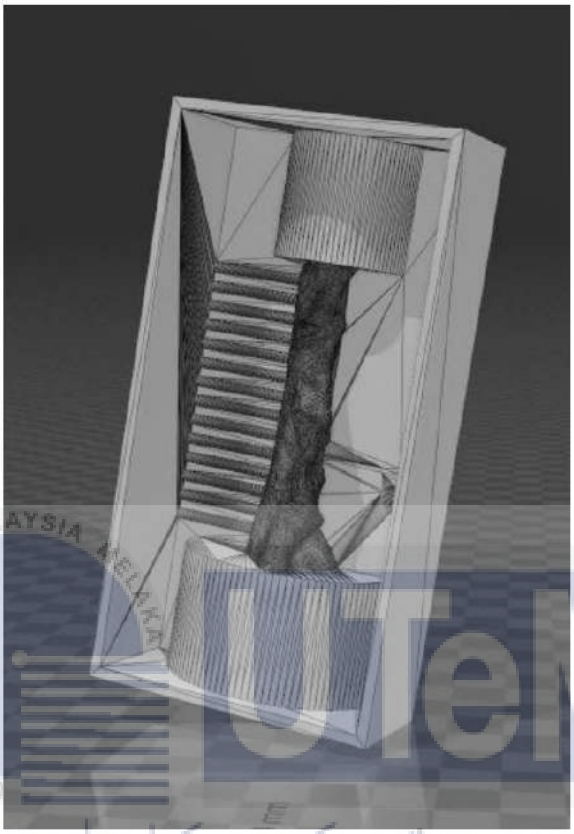


Figure 22 3D drawing for SLS 3D printing

3.4.2 Mould Making and Sample Casting

The finished product, after which the SLS 3D printing process was completed, was then followed by the casting of a sample mold. Silicon rubber casting was used for the process, it is the right casting to use due to it characteristics after harden. The specimen was completely hardened after a period of around two days. After that, it will be able to be used to its full potential for the trial test on the test rig.

Figure 23 Rubber silicon for the sample casting

3.4.3 Test Rig Setup

The data for the experiments are measured with the help of the test equipment. It depends on how many pressure points there are on the specimen, and in order to acquire an accurate average of the data, you should collect it three times. There will be a buffer interval of three minutes between each pressure point's data measurement to ensure that the correct pressure reading is obtained. The experimental results and the simulated results will be compared with the help of these data.

Table 3 Test rig setup step

No.	Step	Picture
1.	Assemble all the equipment	
2	Connect the pressure tube at the specimen	
3	Set zero pressure to the testing device	

4	Set the right air flow	
5	Record all the data for all the pressure point	

Figure 24 Test rig flow

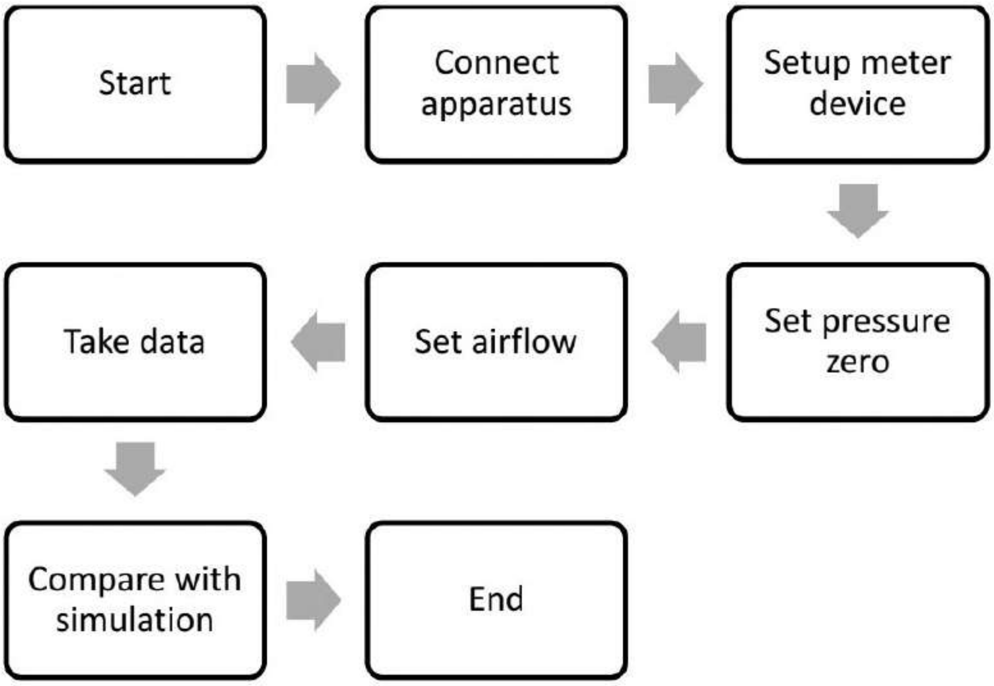


Figure 25 Test rig step

This step is for data collection, which will be compared to simulation results to determine element selection. The selected element will be applicable to different element size to accomplish the research objective.

CHAPTER 4

RESULTS AND DISCUSSION

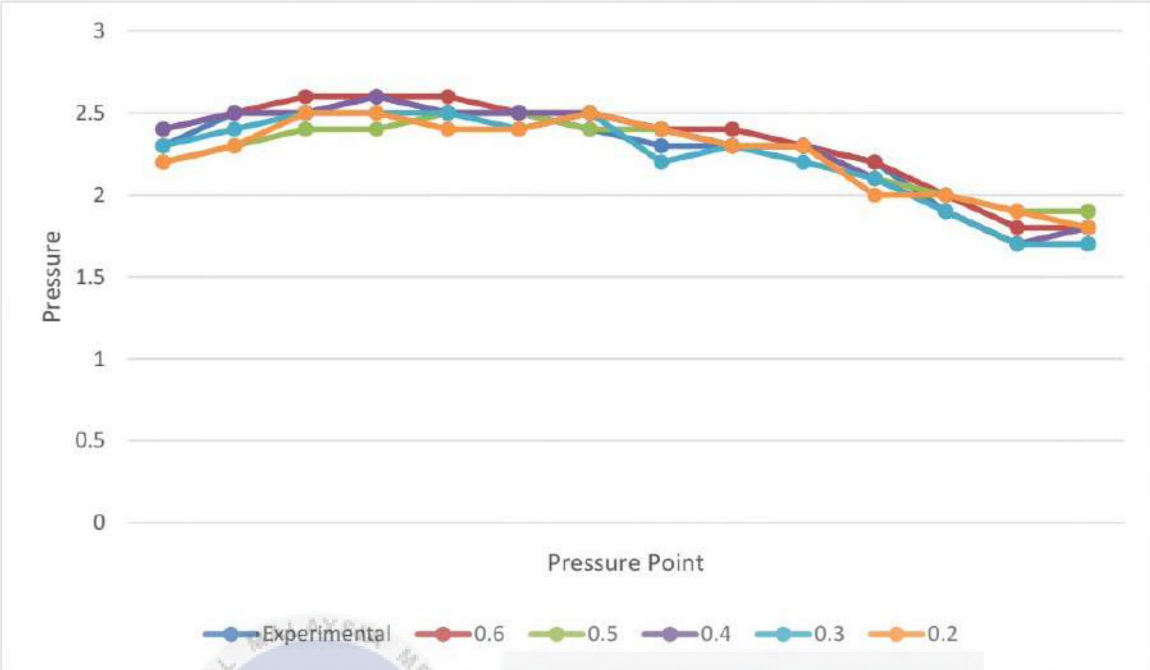
4.1 Grid Sensitivity Analysis

CFD simulations need grid sensitivity testing to ensure that the generated grid was capable of producing reliable and convergent simulation results. For evaluating the pharyngeal airway, the CFD formulations were put through two separate validation procedures (grid sensitivity and solver verification). Using the grid sensitivity test, we were able to verify the correctness of our findings for the evaluation of the upper airway of the human body. Consequently, we utilized the same procedures and methodology that were in use. In addition, a comparison was done between the current results and the simulations conducted before. The grid sensitivity test was performed to identify and validate the optimal grid necessary to produce consistent and accurate CFD results. Ansys Fluent was used to run a total of five different element sizes of UA for the CFD data. These element sizes were 0.6, 0.5, 0.4, 0.3, and 0.2. The data from the simulation that is 0.4 element size is the most accurate. This is because it is the data that is most similar to the experimental data that was tested on the test rig. In order to acquire an accurate view of the overall trends, the experimental data was repeated three times. All of the information that was gathered at the test rig and from the simulation of the upper airway is shown in the table that may be found below.

Table 4 Simulation and Experimental Data

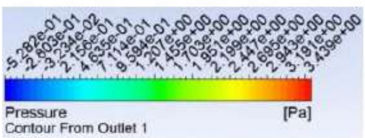
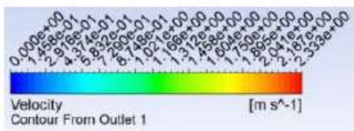
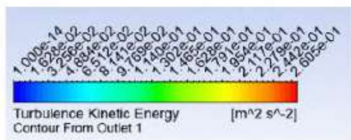
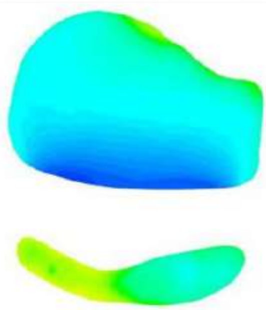
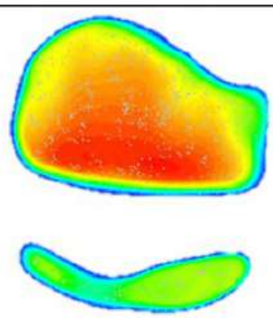
Node	Test Rig	Simulation (Element Size)				
		0.6	0.5	0.4	0.3	0.2
1	2.3	2.4	2.2	2.4	2.3	2.2
2	2.5	2.5	2.3	2.5	2.4	2.3
3	2.5	2.6	2.4	2.5	2.5	2.5
4	2.6	2.6	2.4	2.6	2.5	2.5
5	2.5	2.6	2.5	2.5	2.5	2.4
6	2.5	2.5	2.5	2.5	2.4	2.4
7	2.4	2.5	2.4	2.5	2.5	2.5
8	2.3	2.4	2.4	2.4	2.2	2.4
9	2.3	2.4	2.3	2.3	2.3	2.3
10	2.3	2.3	2.3	2.3	2.2	2.3
11	2.2	2.2	2.1	2.1	2.1	2.0
12	1.9	2.0	2.0	1.9	1.9	2.0
13	1.7	1.8	1.9	1.7	1.7	1.9
14	1.7	1.8	1.9	1.8	1.7	1.8

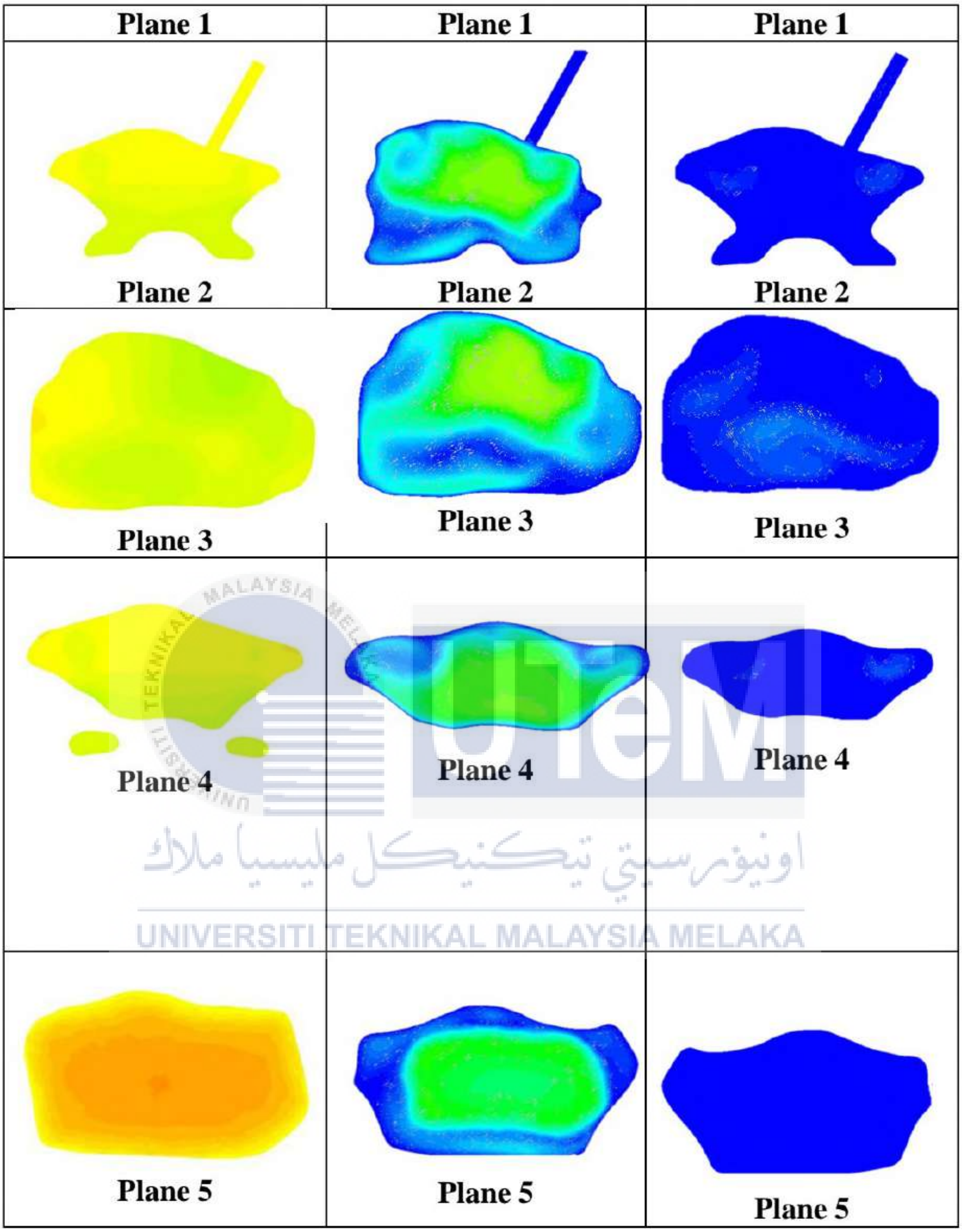
Table 5 Graph for simulation and experimental



4.2 Contour Middle Split Plane

Table 6 Contour middle split plane on ansys

Pressure	Velocity	TKE
		
		

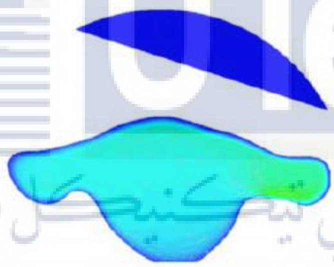
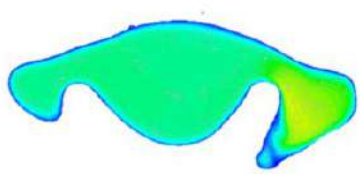
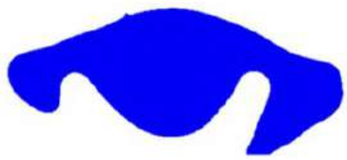

Plane 1
Plane 1
Plane 1
Plane 2
Plane 2
Plane 2
Plane 3
Plane 3
Plane 3
Plane 4
Plane 4
Plane 4
Plane 5
Plane 5
Plane 5

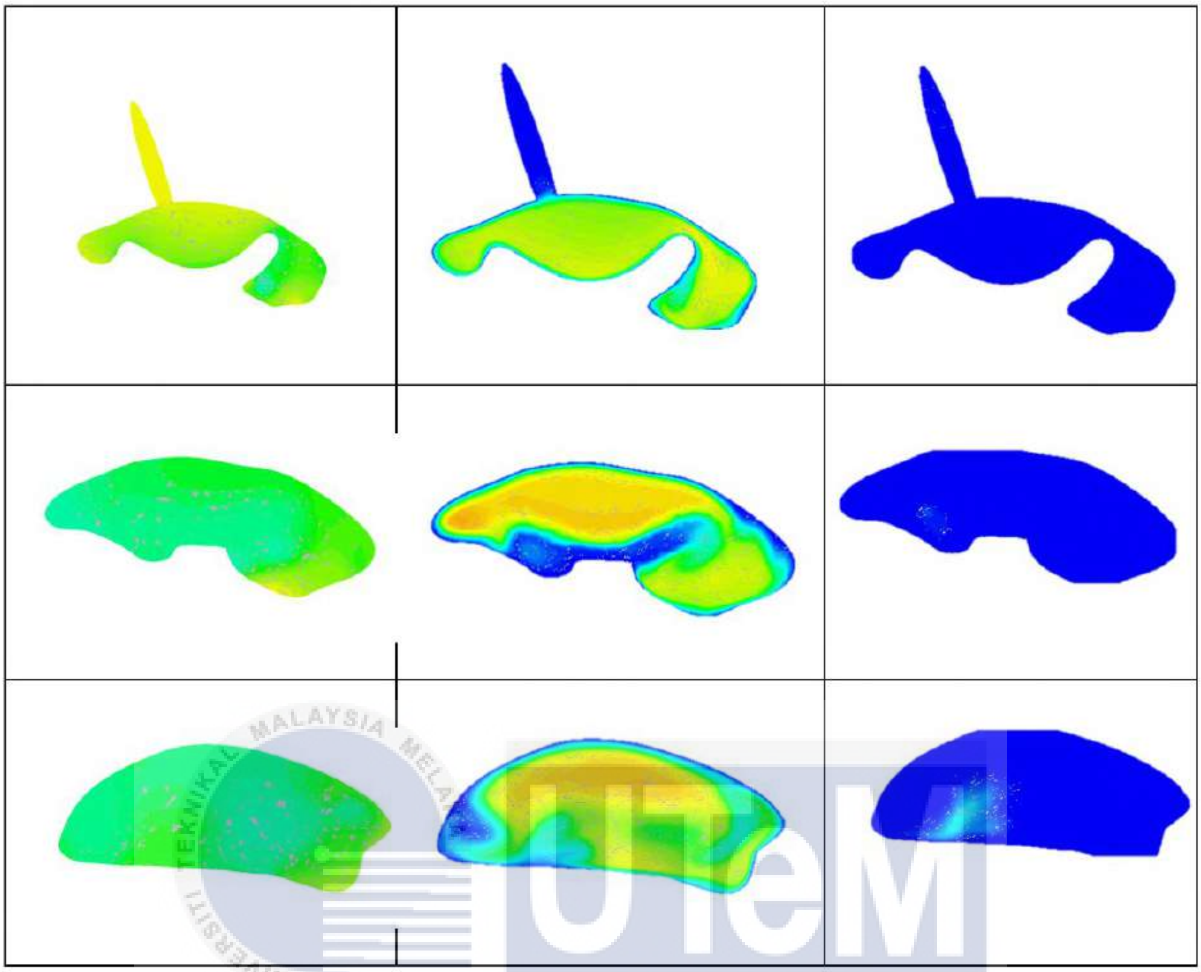
4.3 Comparison Between Pre and Post

The comparison between pre and post, are different. This can be decided by looking at the diagram on simulation and also experimental. On chapter 4.1 the element size of 0.4 for pre, is the size guide that have been chosen as the data comparison for experimental and simulation. Also, for post-surgery specimen 0.4 element size is chosen to act as the guide for running the simulation on Ansys.

4.3.1 Pre Analysis Simulation Data

Table 7 Pre Split Contour

Pressure	Velocity	TKE
		
		



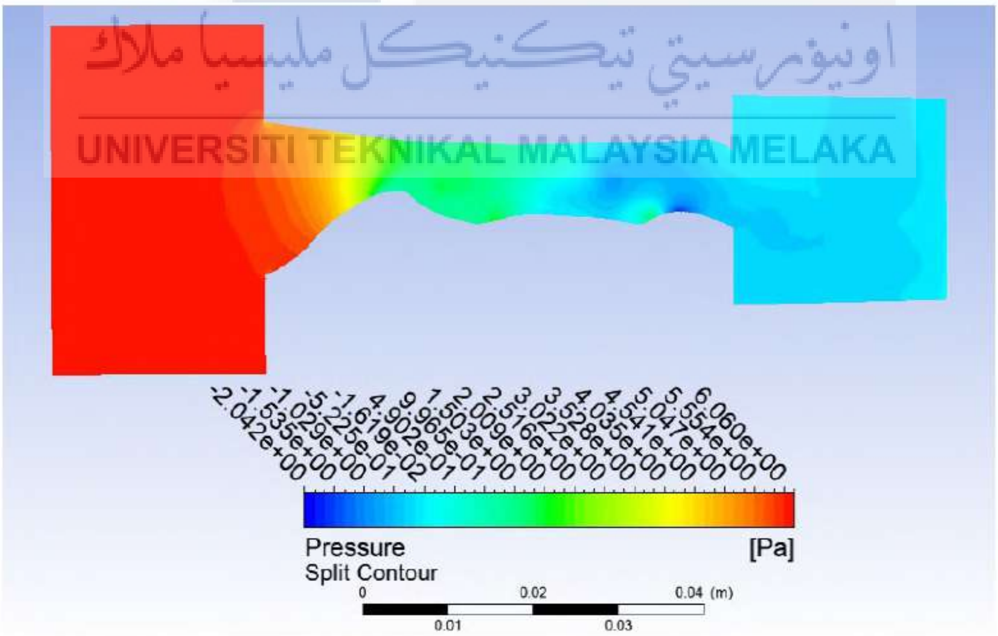


Figure 26 Pressure Pre Split Plane

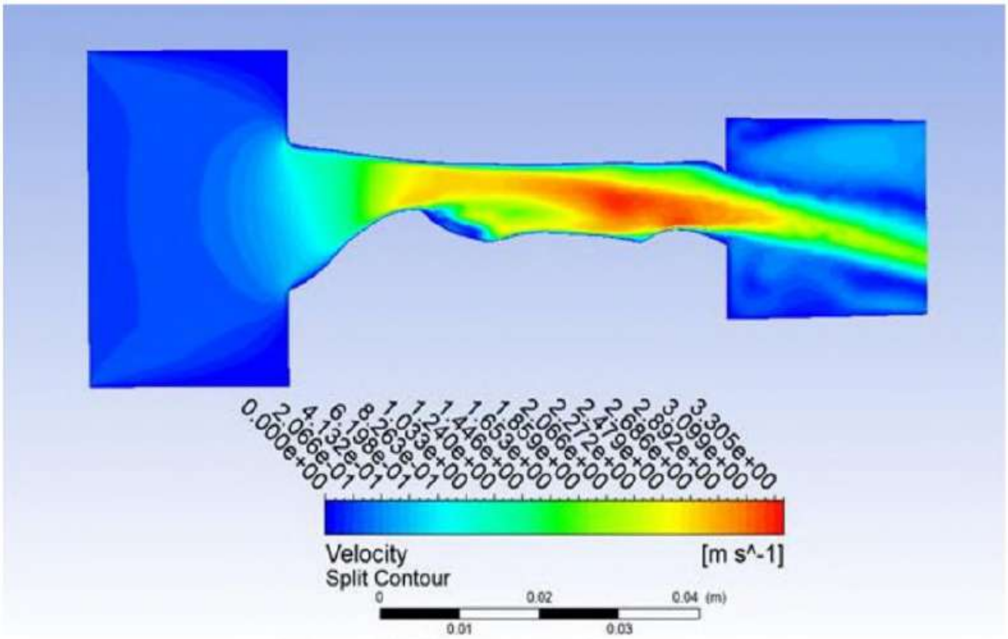


Figure 27 Velocity Pre Split Plane

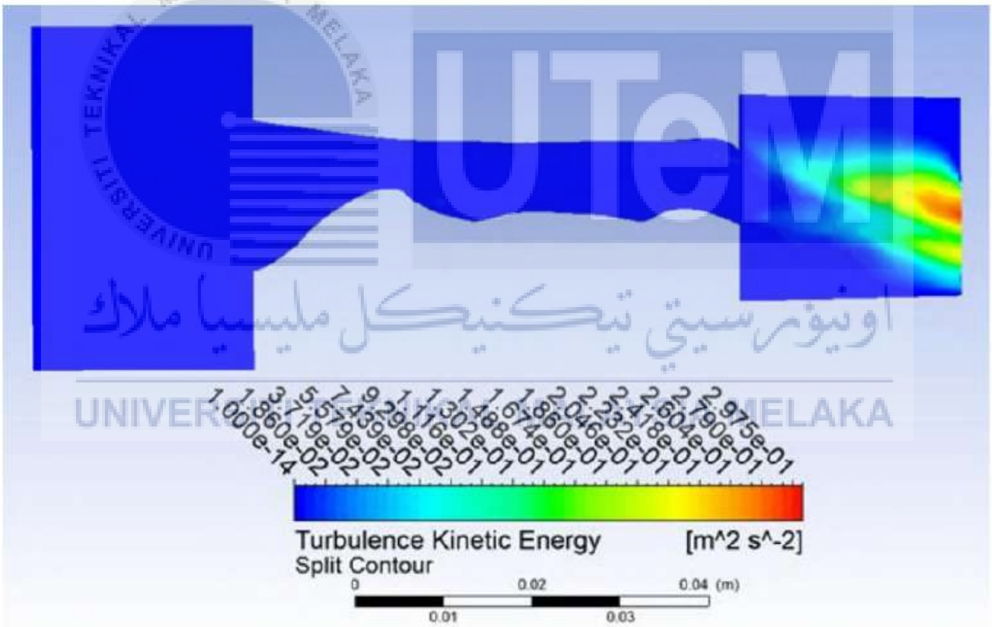
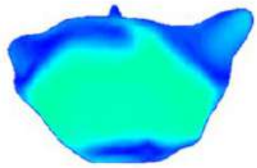
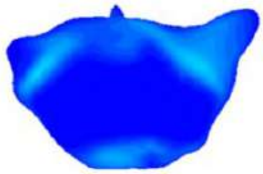
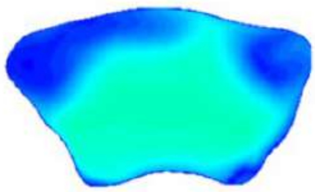
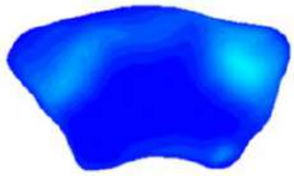
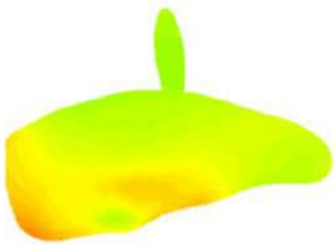
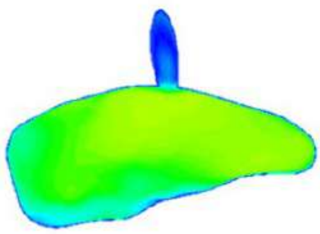
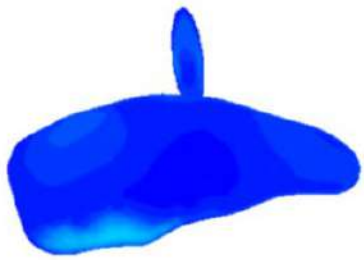


Figure 28 TKE Pre Split Plane

4.3.2 Post Analysis Simulation Data

Table 8 Post analysis split contour

Pressure	Velocity	TKE
		
		
		
		
		

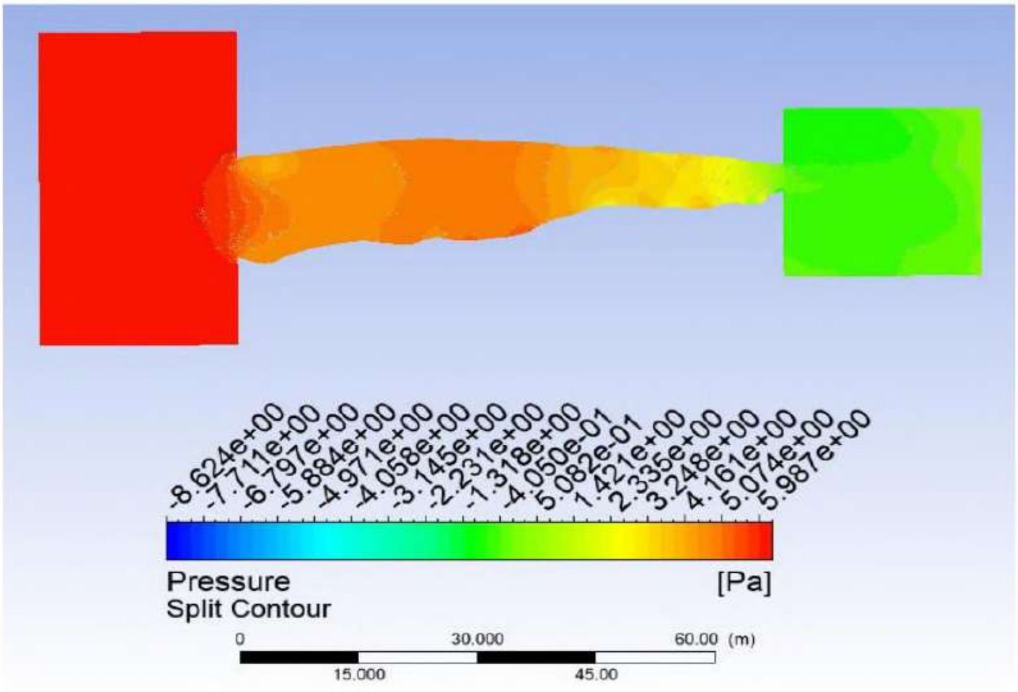


Figure 29 Pressure Post Split Plane

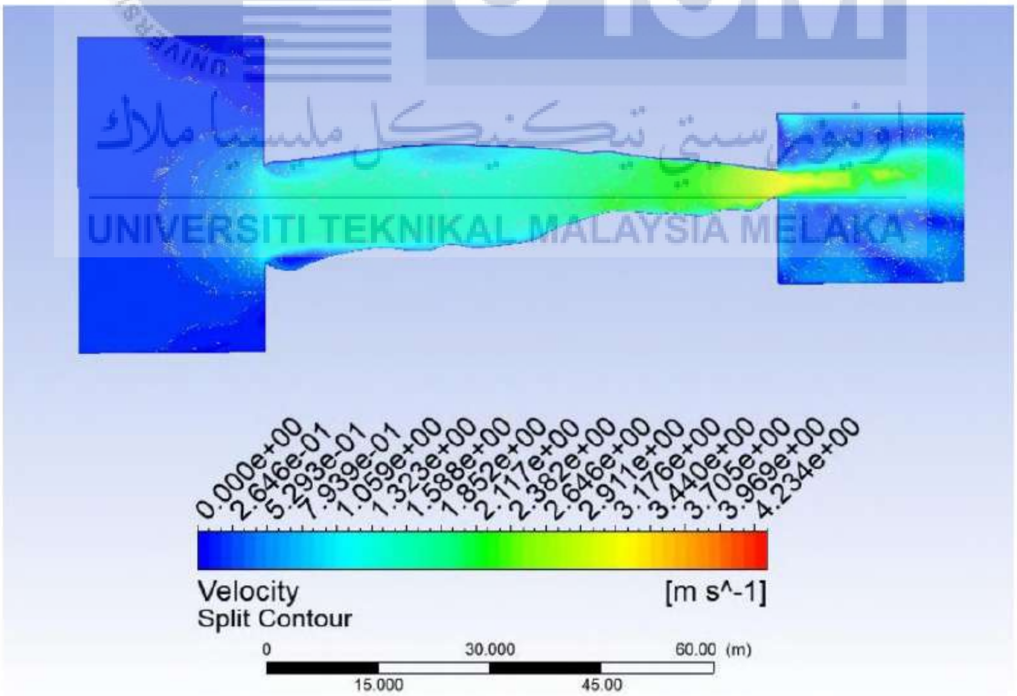


Figure 30 Velocity Post Split Plane

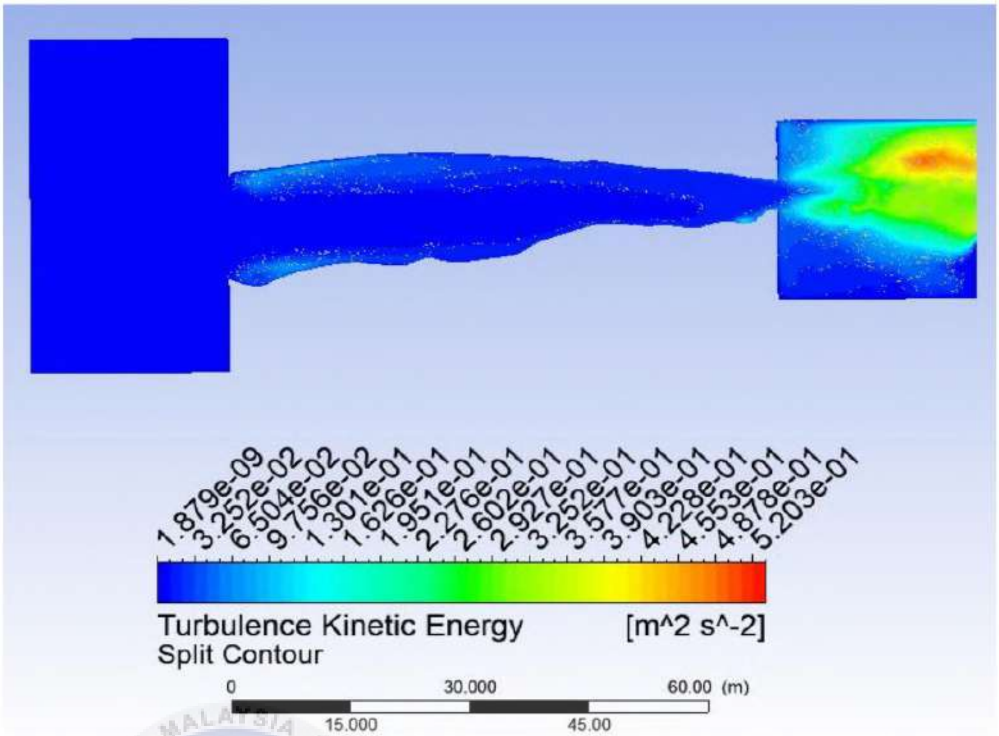


Figure 31 TKE Post Split Plane

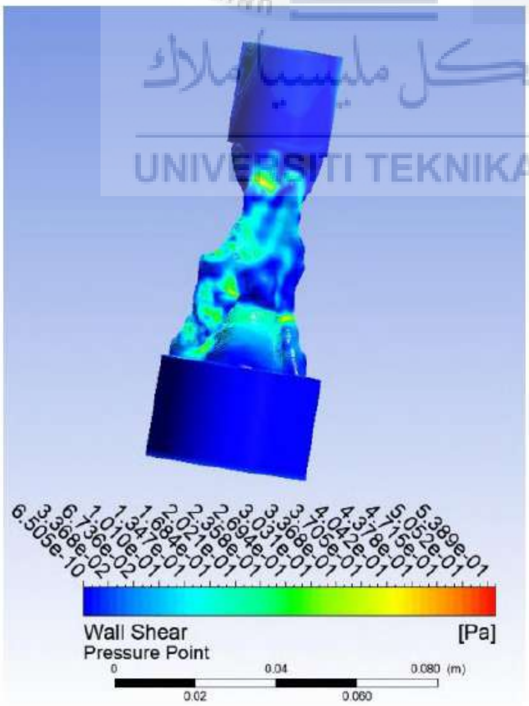
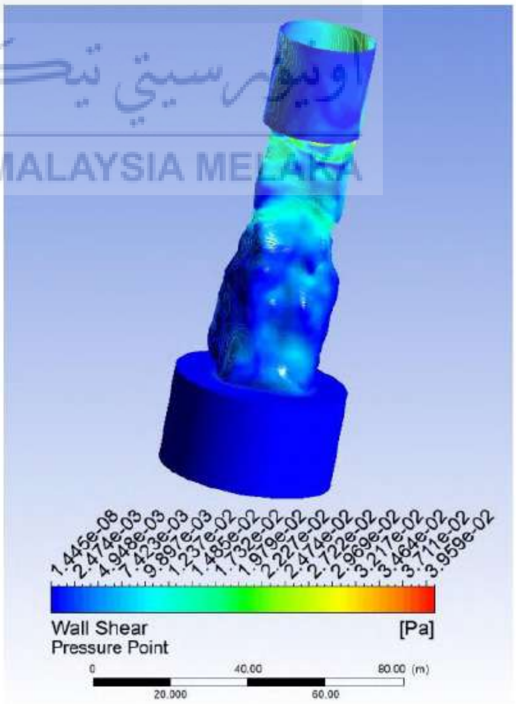
Table 9 Data comparison pre and post

Node	Pre	Post
1	5.3	4.4
2	4.7	4.5
3	4.1	4.6
4	2.5	4.8
5	1.7	4.9
6	1.5	4.9
7	1.6	4.9
8	1.4	4.3
9	0.9	4.4
10	0.7	4.2
11	0.1	3.6
12	-0.3	3.4
13	-0.4	2.8
14	-0.1	1.0

According to the results of the simulation, there is a significant difference between the pre- and post-surgery states. The pressure from pre is not consistent; it has dropped from 4.1 to 2.5 in a very short amount of time, and it is continuing to fall. Snoring occurs because of a vacuum that forms in a particular region of the upper airways when the surrounding air pressure is low. This is the cause of snoring. Snoring happens when the middle section of the upper airways has a blue tone, as shown in figure 24. Snoring is a sign of upper airway obstruction. After surgery, the patient's pressure will continue to fall but will remain stable. Whereas, as shown in picture 27, the simulation does not contain any blue color.

4.4 Wall Shear

Table 10 Pre and post wall shear

<table>
<tr><th>Pre</th><th>Post</th></tr>
<tr><td>
</td><td>
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The findings of the simulation indicate that there is a distinction to be made between the pre-surgery state and the post-surgery state. According to the statistics, there is a noticeable improvement on the wall shear after surgery. By performing the calculations, percentage-wise, the change between before and after surgery is 5%. Because of this, we are able to draw a correlation between the pressure in the upper airways and the increase in wall shear that occurs when the pressure rises.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Conclusion

In conclusion, to make more accurate pretreatment projections and fully characterise OSA's UA behaviour, a comprehensive evaluation is required. The model is insufficient for effectively predicting the flow of human UA. Additionally, it is possible for the airflow during inhalation to be greater, hence specifying the position of the air intake in the upper airway model.

The nasal cavity must be removed since its presence complicates the investigation. Deleted void features and surface smoothing are emphasised in the modelling of the upper airway in order to decrease the complexity of the CAD model. Excellent meshing capabilities are hampered by complicated geometry, resulting in poor CFD convergence. This approach is valuable as a reference, but additional published data on sensitivity and specificity are necessary.

Both CFD and experimental produced a results that's indicate that the airflow improve after surgery. The result related the Bernoulli principle as the fluid decrease, the pressure increase. The impact of variation airflow can make a large difference on the upper airways. Lastly, the objective for this research has achieved.

5.2 Recommendation For Future Work

The advice for work to be done in the future is to make adjustments to the test rig configuration in order to better understand the experimental findings. If the test equipment is set up in the most effective way possible, the outcome may be more accurate. When executing the experimental data, the environment in which the test is carried out might also make a significant difference in the results. It can have an effect on how the pressure data are read in relation to the simulation data. Last but not least, when designing the 3D model, you need to make sure that you have the correct specifications that are exact. The 3D printing process will be able to achieve greater accuracy as a result of this, and the mold will become more solid.

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