[DESIGN AND FABRICARION OF SMALL WIND TUNNEL FOR FLOW VISUALIZATION]

By

[AIMADUDDIN BIN MAZLI]

Dissertation submitted to the Mechanical Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
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(Mechanical Engineering)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

DESIGN AND FABRICATION OF

Small Scale Wind Tunnel for Flow Visualization

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AIMADUDDIN BIN MAZLI -1574

A project dissertation submitted to the
Mechanical Engineering Programme
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APPROVED BY,

(RAHMAT ISKANDAR KHARUL SHAZI)
Supervisor
DATE: 1/6/04

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(AIMADUDDIN BIN MAZLI)

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ABSTRACT

The objective of this report is to provide an overview of what have been done in completing the Final Year Project Course. The main content of project work has been divided into five parts, comprises of:

- Feasibility Study and Conceptual Design
- Design activities – also known as Design Basis Memorandum (DBM)
- Fabrication activities
- Tunnel testing result and procedure
- Alternative for flow visualization

Feasibility study included literature review for aerodynamics and wind tunnel theory. The research has been done to develop conceptual design consisting of wind tunnel type and its general configuration.

Summary of design, fabrication and tunnel testing activities has been developed in methodology section and their respectively section to give quick view to reader of activities involved during project stages. Major problem occurred during project implementation and the method used to overcome the problems has also been identified. In addition tools required for completing this project will also be discussed in their respective area.

The scope of study for this course is not very specific to one area only and it determined by the requirement that had been discussed with the respective supervisor. Some of the area concerns of the project have been achieved in form of computer design analysis, aerodynamics analysis, wind tunnel configuration, fabrication activities and Computer Aided Design. The method or action that has been used and taken will be specified in this report in detail. The assessment of this course really helpful for me to explore many new things independently and to gain the knowledge as much I could through the working experience.

At the end, the tunnel can be specified as subsonic, small scale wind tunnel, operating at ~11m/s and average turbulence intensity at ~0.8% and driven by $115m^3$/min exhaust fan.

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CHAPTER 1: INTRODUCTION

1.1 Background of Wind Tunnels

Wind Tunnels were developed during the late 1800's when it was recognized that outside conditions were too uncertain to plan and execute the testing required to aid in man's quest to fly.

What began as a basic tool for investigating aerodynamics has developed into a piece of equipment vital for developing and refining a wide range of a basic scientific knowledge and consumer products. Everything from aircraft, automobiles, computer chips, gas fireplaces, and bicyclists, to the evaporation of common household cleaners can be tested in a wind tunnel (1).

The designs and fabrication of wind tunnels should consider every imaginable configuration. Many standard and sized of wind tunnels available in market nowadays, and it can be modify to fit any research, experiment, educational and demonstration needs.

Aerodynamics has become the most important part of racing during the latest years. It has nearly become the only way for engineers to gain considerable time on their opponents, considering the very strict regulations in today's motor sports. F1 is thereby the one to keep an eye on, as it is the sport where the most money is spent on technical developments (1).

Though the engine power, the tires and much more, the aerodynamic streamline is very important to make the cars that fast. For example, today's formula one cars are designed with CFD (computational fluid dynamics) and CAD (computer aided design) that allows engineers to design a car, and immediately simulate the airflow around it, incorporating environmental parameters like traction, wind speed and direction, and much more.
Further on, the teams can now test fully scaled cars in their tunnels. This where come the important of wind tunnel, where by, the engineer visualize the wind flow around

the car. The boundary layer, the streamline, air velocity, the lift and drag should be understood first in order to deal with the wind tunnel (1).

1.2 Literature Review and Theories

There are two types of tunnel configuration, comprises of Closed circuit and Open circuit wind tunnel. The advantages and disadvantages of this two types configuration will be further discussed in this report. The importance of the tunnel components with the aerodynamics visualization will also be discussed together along this report.

1.2.1 Wind Tunnel Theories

Open Circuit Tunnel

(i) "Suck down" tunnels, with an entry open to the atmosphere (laboratory) and an axial fan or centrifugal blower downstream of the test section. This type of wind tunnel is not a good idea - the entry has to re-ingest the exit flow after it returns through the laboratory, probably with significant swirl and low-frequency unsteadiness (6).

(ii) Blower" tunnels, with a fan or blower upstream of the test section (usually a true centrifugal blower). Blower tunnels are the most flexible type - any desired test-section can be attached to the end of the contraction. Entry swirl is again a possible problem, but in general blower tunnels are much less sensitive to entry conditions than suck down tunnels. The exit flow from a centrifugal blower is non-uniform and turbulent, but without the low-frequency unsteadiness of flow entering directly from a room (6).

If the tunnel discharges its flow to the atmosphere (or laboratory, or pressure vessel, or other unprepared environment) it is called an open-circuit tunnel. If the cross-section of the return path is many times that of the test section, it is hoped that the discharged air will lose most of its mean vorticity, unsteadiness and turbulence before it is re-ingested. Many open-circuit tunnels have diffuser: in the case of suck down tunnels and the fan is usually placed at the end of the diffuser. As the kinetic energy of the air discharged from the diffuser is usually only a small percentage of the kinetic energy of the air in the test section, the power required by an open-circuit tunnel may be less than that required by a closed-circuit tunnel of the same aerodynamic design, because no power is wasted in the drag of the corner vanes (6).

A popular configuration for small tunnels is the blower type (Figure 1), with the impeller (usually a centrifugal blower) at entry, and -- usually -- with no exit diffuser because power consumption is not very important. This allows any type of test section to be fitted without problems of matching to the diffuser. Centrifugal blowers are preferred to axial fans mainly because they will run efficiently, and generate acceptably steady flow, over a wider range of load -- i.e. a wider range of test-section configurations (6).

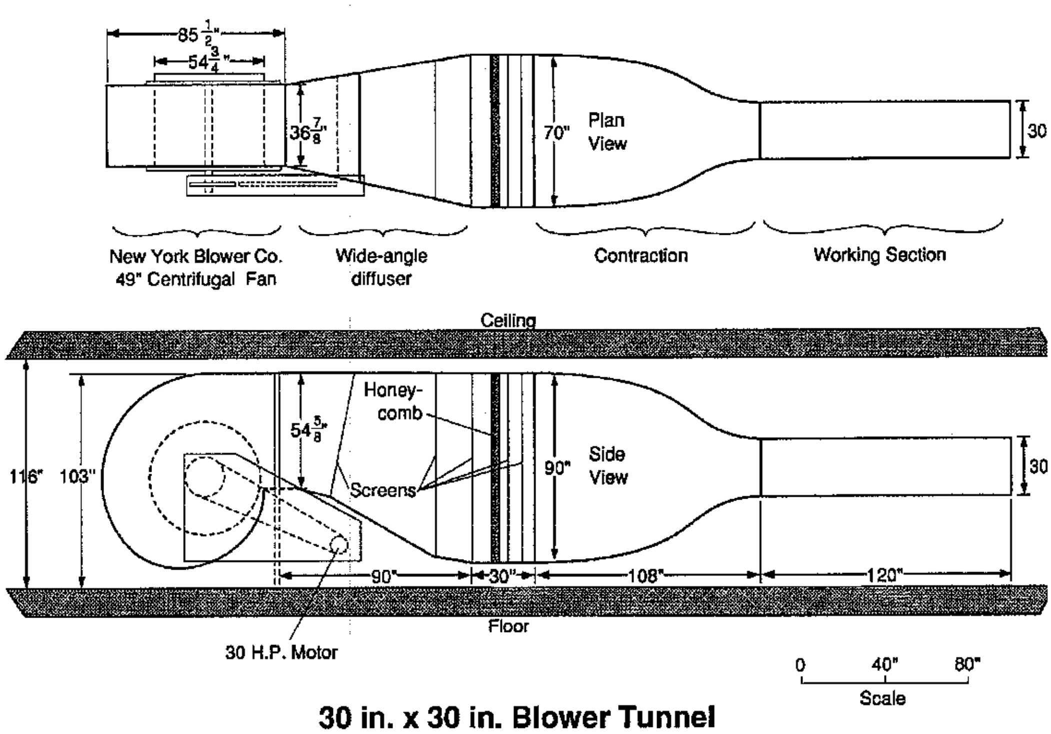


Figure 1 : Blower Type Open Circuit Tunnel

Open-circuit tunnels that take in air from the atmosphere or the laboratory are sensitive to draughts -- the NASA Ames 80 ft x 120 ft (Figure 2) points into the prevailing northwest wind. Centrifugal blowers seem to attenuate most entry disturbances, but they are very sensitive to fluctuating swirl (axial vorticity) in the inlet, which changes the rate of rotation of the blades relative to the airflow. However, blower tunnels are often fitted with commercial air filter panels covering a large box connected to the blower intake, and the filter extracts airflow irregularities as well as dust. It is more difficult to fit a filter to a suck down tunnel because the air entering the intake must have roughly uniform total pressure over the cross section or the "turbulence management" devices (screens and honeycombs) will not be able to deliver adequately uniform total pressure to the test section (6).

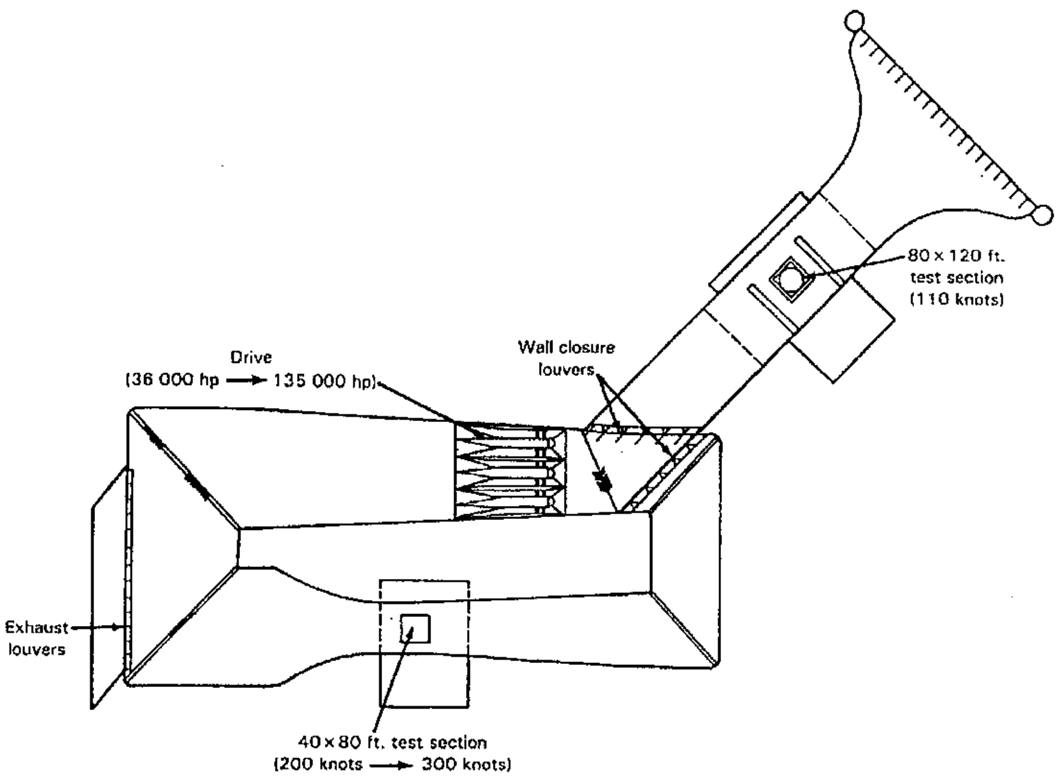


Figure 2 : The NASA Ames 80 ft x 120 ft Open Circuit Tunnel

Advantages and disadvantages of open circuit tunnels can be conclude as follow:

Advantages

- Saving of space.
- Saving of cost.
- Suffer less from temperature change, mainly because room volume higher than tunnel volume.
- Fan performance not affected by disturbance from working section.

Disadvantages

- Inconvenient dimension and length.
- Required enough free room, so quality of flow not significant effect.
- Pressure condition (tunnel pressure always less than atmospheric pressure).

Closed Circuit Tunnel

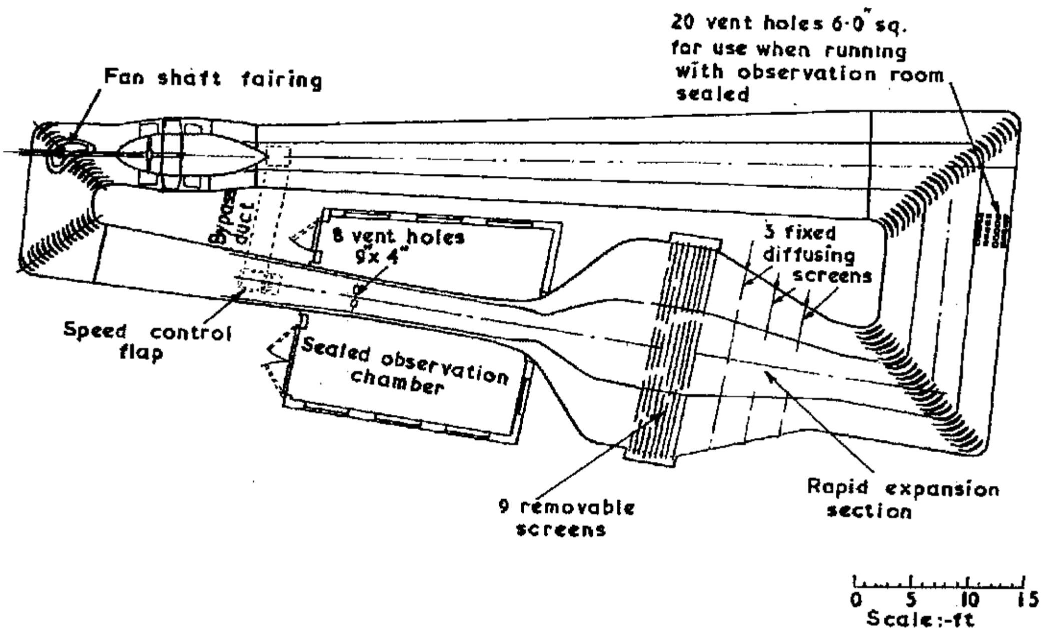
Closed circuit also known as "racecourse" or "closed-return" is usually implemented with an axial fan, or a multi-stage axial compressor normally used in the case of a transonic/supersonic flow. Closed-circuit tunnels have more uniform flow, in principle, than type open type, and are the usual choice for large tunnels, but care is needed to maintain good flow at the entrance to the contraction. The flow at exit from the fourth corner (counting from the test section) is typically not much better than the exit flow from a centrifugal blower, although the corner vanes themselves have some effect in reducing turbulence (they can be regarded as honeycombs with walls in one direction only) (6).

Figure 3 shows a low-speed (100 m/s) closed-circuit wind tunnel of the closed-circuit type, in which the same air is re-circulated. The stream is turned, usually in four steps of nominally 90 deg. each, by rows or "cascades" of closely spaced vanes. There is always a small vent, called a "breather", somewhere in the circuit so that the internal pressure does not increase as the air heats up during the run: it is usual to have a slot around the perimeter at the downstream end of the test section, so that the latter is close to atmospheric pressure to reduce the effect of leaks through the holes usually cut in the walls for model support struts, etc.. If the slot mechanically disconnects the test section from the diffuser it may be useful as a vibration isolator. The remainder of the tunnel is above atmospheric pressure (by almost the full test-section dynamic pressure in the case of the settling chamber) and the flow through any leaks is outward. The compensating inflow through the breather is

(i) Bad for diffuser performance but.

(ii) Easy to detect by releasing smoke just outside the breather.

Sometimes the settling chamber is vented to atmosphere instead, to relieve the structural load on this large section: the test section static pressure is then below atmospheric, with the disadvantage that unless special care is taken air will rush into the tunnel through any holes made for model mountings, cables etc. The British Royal Aerospace Establishment (RAE-now Defense Research Agency-Figure 3) can be run with a vent either in the test section or between the third and fourth corners. In the latter case the observation chamber enclosing the test section is sealed (6).



RAE 4 ft × 3 ft wind tunnel (1946).

Figure 3 : The British Royal Aerospace Closed Circuit Tunnel

Advantages and disadvantages of close circuit tunnels can be conclude as follow:

Advantages

- More uniform flow.
- Doesn't have problem with the atmospheric pressure because the flow will loop back to the entry.

Disadvantages

- Care needed to maintain good flow at the entrance of contraction.
- Need large amount of spacing and cost.

After knowing all these typical types of wind tunnel, the Project Engineer should implement further study on each type of the tunnel components in order to continue with the design procedure. Basically, it can be conclude that the components involved in typical type of tunnel are:

(i) Fan: Axial fan or Centrifugal Blower
(ii) First diffuser
(iii) Test Section
(iv) Contraction
(v) Settling Chamber: Screen and honeycomb
(vi) Screen
(vii) Wide angle diffuser
(viii) Corner vanes
(ix) Second diffuser

Further more in this report, the function and responsibilities of each component will be discussed. The types of tunnel that will be under project consideration have also been identified. In addition further study on aerodynamics, effect of Reynolds and design rules will also be included.

1.2.2 Aerodynamics Theories

Aerodynamicists nearly always prefer to think in terms of what happen when air flows past a stationary vehicle, rather than the real situation where the vehicle moves through the air. This is because it is generally much easier to understand and describe what happens in the former case. Fortunately, in terms of the forces and flow features, it makes no difference whether air is blown past a stationary object in a wind tunnel or the object is moved at the same speed through stationary air. A car traveling through air at 20 m/s will experience exactly the same aerodynamic forces as a stationary car (in wind tunnel) subjected to a head on 20 m/s wind. For road vehicles there is one slight complication in that there is also relative motion between the road and the vehicle, so in the stationary vehicle case, it is necessary to imagine that both the air and the road are moving past the vehicle (7).

Free Stream Speed

When a vehicle is placed in a wind tunnel, the relative speed of the air stream (away from local changes caused by the presence of the vehicle) is referred to as the free stream speed. For the case of a vehicle driving along a road in windless conditions, the corresponding relative speed is simply the driving speed of the vehicle (7).

Connection between Air Speed and Pressure

As show in Figure 4, when air flows from a region of high pressure to one at a lower pressure, the pressure difference provides a force in the direction of flow, and the air therefore accelerates. Conversely, flow from a low pressure to a higher one results in a decrease in speed. Regions of high pressure are therefore associated with low speeds, and areas of low pressure are associated with high speeds (7).

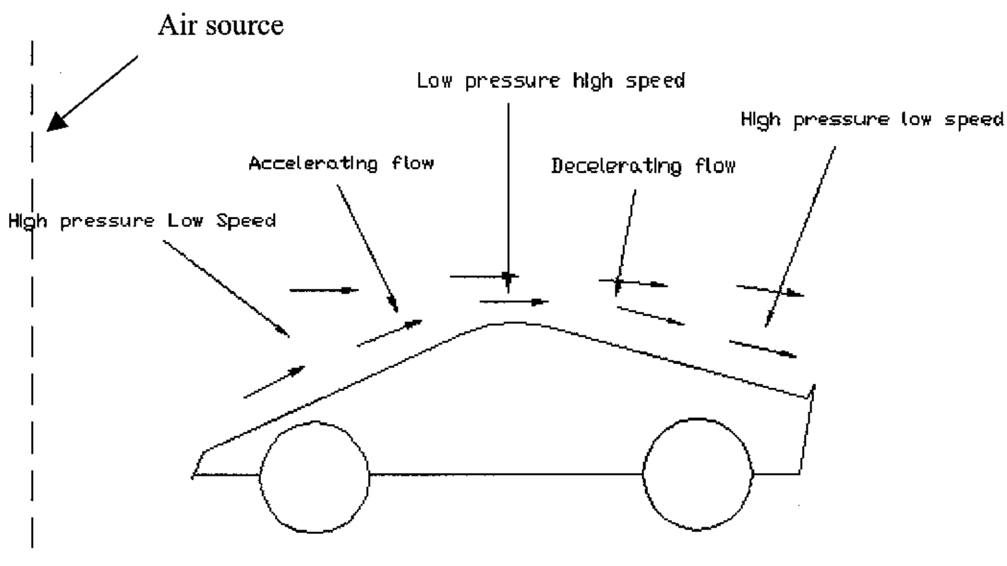


Figure 4 : Air Flow around Car

Although road aerodynamics may not generally lend itself to simple mathematical analysis, there is one relationship that is absolutely fundamental to the study of air flows, and that is Bernoulli equation. For low speed flow, this equation gives the relationship between air speed and pressure. It can be written in several ways, but aerodynamicists normally prefer it in the form given below:

$$(\text{Pressure}) + \tfrac{1}{2}(\text{Density}) \times (\text{Speed})^2 = \text{Constant}$$

It can be seen that this relationship fits the behaviors of the air described above, an increase in pressure must be accompanied by a decreased in speed, and vice versa. The first term of the equation is just the pressure at any point, and also known as static pressure. The second term is the dynamic pressure and it represents the kinetic energy of a unit volume (m^3 or ft^3) of air. Aerodynamics force such as lift and drag are directly dependent on the dynamic pressure (7).

Stagnation Pressure

From Bernoulli's equation it can be seen that at any point in the flow where the speed is zero (the lowest possible value), the pressure must reach its maximum value. Because this maximum pressure is associated with the stagnant conditions (zero flow speed), it is known as the stagnation pressure (7).

Pressure Coefficient

The difference between the local static pressure at any point in a f low and the static pressure in the free stream depends directly on the dynamic pressure of the free stream. Therefore, the ratio

$$\frac{\text{Local Pressure} - \text{Free Stream Static Pressure}}{\text{Free Stream Dynamic Pressure}}$$

remains constant at all speeds. This ratio is known as the pressure coefficient and is denoted by *Cp*. When describing how the pressure varies around the vehicle, it is much more convenient to use the pressure coefficient rather than the actual pressure, because the coefficient will not alter with the vehicle speed. Knowing the value of the pressure at a point, it is a simple matter to calculate the pressure there at any free stream or driving speed, using the above relationship (7).

Streamlines

Streamlines are defined as imaginary lines across which there is no flow. If the flow is steady they also indicate the instantaneous direction of the flow and the path that air particle would flow. For most types of road vehicle there are usually regions of unsteady flow. The instantaneous flow direction can become very erratic in these areas, and the shape of the streamlines changes rapidly with time, but it is still possible to indicate the average flow direction by a form of streamline which denotes a line across which the average flow is zero. Basically it can be denoted that streamline was the line that causes the aerodynamics forces (lift and drag) at the vehicle body. Further view on streamline has been discussed along in this report (7).

The Boundary Layer

An important feature of the flow past a vehicle is that the air appears to stick to the surface. Right next to the surface there is no measurable relative motion. One may notice those loose dust particles are not blown off a car's surface even at high speeds. Individual molecules do not actually physically stick, they move around randomly, but their average velocity component parallel to the surface is zero. The relative velocity of the air flow increases rapidly with the distance away from the surface as illustrated in Figure 5 and only thin layer is slowed down by the presence of the surface. This layer is known as boundary layer.

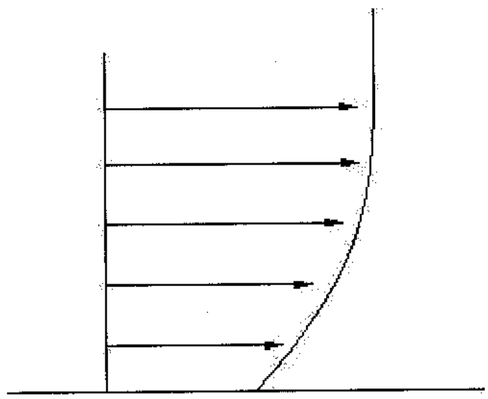
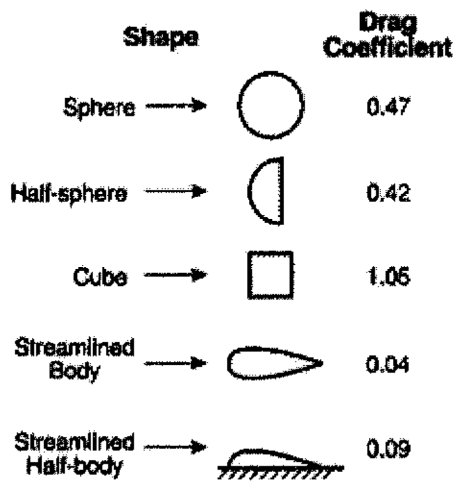


Figure 5 : Boundary Layer Growth

The thickness of the boundary layer grows with the distance from the front of the vehicle, but does not exceed more than a few centimeters on a car traveling at normal open-road speeds. Despite the thickness of this layer, it holds the key to understanding how airflows around a vehicle and how the lift and drag force are generated (7).

Drag

The following table shows C_D, the drag coefficient, of some particular geometric objects.



Measured Drag Coefficients

Table 1 : Drag Coefficients

To calculate the aerodynamic drag force on an object, the following formula can be used:

$$F = \frac{1}{2} CDAV^2$$

Where:

F - Aerodynamic drag force

C - Coefficient of drag

D - Density of air

A - Frontal area

V - Velocity of object

In this system, D as air density was expressed in kg/m^3. The frontal area is the surface of the object viewed from a point that objects is going to. It's expressed in m^3. The velocity should be placed in m/s, where 1m/s is 3.6 km/h (7).

The overall effect on lap times can be calculated with this "Law of Amdahl".

$$S_{eff} = \frac{S_f}{S_f(1-f)+f}$$

Here is f the fraction of the system (when this fraction generates 5% of the car's drag, then f is 0.05) that can be improved, S_f is the improvement factor on this fraction (division of the drag in Newton's and the new drag force after improving that element), and S_{eff} is the overall improvement that will be achieved (7).

Implication for Aerodynamic Design

From the foregoing, it can be seen that reducing the aerodynamic drag can produce a major improvement in fuel consumption even in urban driving conditions. Drag reduction can also produce worthwhile gains in the performance in terms of both top speed and acceleration. In addition it also can be used in dealing with economic analysis in term of reducing fuel consumption.

Reynolds and Mach number

Most important of all is the careful study of aerodynamic phenomena as they are affected by variation of Reynolds number so that useful conclusions can be obtained from tests that do not duplicate the operating Reynolds number

Reynolds number concern with the relationship of inertia forces and viscous forces, where it can be state in formula as:

$$Re = \frac{\text{Inertia forces}}{\text{Viscous forces}} = \frac{v \rho l}{\mu}$$

It can be conclude that a central issue in the sizing of a low speed wind tunnel will be the achievable Reynolds number for the model that can be accommodated. The same question arises for developers who must select from available wind tunnels one in which to carry out the tests in development program. From equation of Reynolds number, ρ V l / μ, lets now choose a Mach number of 0.3 (Mach number rule for low speed testing) as concerned about the effect of Mach number on a typical study. Then, considering sea level at standard atmospheric condition, the maximum V will be 100m/s and unit Reynolds number will be 6.98×10^6. These numbers and the appropriate characteristic length of the rest article give a good approximation to the available Reynolds number in an atmospheric wind tunnel. This fact also influence the developer of making decision of choosing lower speed testing limit, so that lower Re number obtained for the tunnel, in order to comply with these requirement of low speed testing (1).

As reflected in the above discussions, it is not possible to give a rigid rule for the minimum acceptable Reynolds number. In essence the objective when designing a wind tunnel facility is to produce an accurate simulation of the real world conditions in a controllable environment, especially for automotive testing.

General requirement for automotive testing in wind tunnel is that the Reynolds number of the experimental set up matches that of the full scale case.

1.2.3 Conclusion

In order to design and fabrication the wind tunnel the engineer should know first the basic theories of aerodynamics and typical type of tunnel configuration as has been discussed above. Since the project concern was more on designing the wind tunnel for flow visualization purpose, the discussion of aerodynamics will be narrow down to Smoke Tunnels for the vehicle air streamline visualization. In addition, the Low Speed type wind tunnel has been taken into design consideration since the needed of project objective is to design a Small Scale Wind Tunnel System.

1.3 Background of Study

There are a lot of new thing needs has been learned for completing this course completely. Of course, the course offered the student to explore much information and adopt new knowledge that may helpful to undergo the project successfully. Based on the topic, which is "small scale wind tunnel design and fabrication for flow visualization" gave a lot of beneficial since full attention needed to implement the working prototype from the beginning phase of learning process till the project is over. Basically, at the end of project stage, the verification on aerodynamics theory, the tunnel configuration and flow visualization has been done. When involving with the designing, few things like Computer Aided Design (CAD), Computational Fluid Dynamics Analysis (CFD) and tunnel testing has been learned and took into design procedure. It also refers to the overall assessment and the objectives of the project. The basic knowledge of both theories (aerodynamic and wind tunnel) also relies on using the software and hardware. Therefore, the familiarization and integration for both soft wares and hardware has been done together with the design activities. Research and learning activities has been continued till the end of the project.

The fabrication activities in conjunction with design verification have been conducted to fabricate the tunnel by referring to fabrication drawings. Fabrication activities included the main components of the tunnel such as the nozzle, settling chamber, test section, diffuser, fan base and tunnel base. Fabrication stages have been done after all the design stages have been completed. Problem occurred and the fabrication method will also be discussed together with this report. In order to get clearer view of the fabrication activities, pictures have been taken and will be included in the appendices. The importance and working principle of supplementary component in conjunction of main components such as the speed controller has also been specified. Further more, fabrication tools and safety awareness that should be taken along fabrication activities has also been determined. Basically, the tunnel fabrication has been based strongly on the design drawings and specification that has been made, since clashes between design and fabrication activity has to be avoided. However, the entire design rule and aerodynamics objective of full scale tunnel has not been neglected. Current system and configuration also has been observed rapidly since it has many common with the operation and system structure. Fabrication activities gave a lot of experience especially in dealing with machine and interact with people in order to get the best workmanship during project activities.

Apart from that, quality flow testing has also been conducted to verify tunnel capabilities of producing design speed. Of course, the step by step procedure and experimental planning has been understood before the testing started. List of data needed and result expectations have also been specified. The acquired experimental data has been compared with theoretical data to assure that required velocity produced by the designed and fabricated tunnel.

Method of flow visualization that has been identified for the tunnel is by using smoke wire system. However, project partner in the next continuation of the project development will develop this system. One alternative has been found by using thread analysis. In this activity the test section has been scaled so that one can get general view of airflow inside the test section. About 80 threads has been used and installed inside test section.

CHAPTER 2: PROBLEM STATEMENT

At this stage, uncertainties or problem occurs during the investigation of related topic has been solved. The problem gives some significant of the working flow of the overall project assessment. Problems occurred will be discussed together as we go along the content of this report.

2.1 Design and Fabrication Activities

Problems involved with design activities will be discuss first before the fabrications activity take placed, this is to assure that the problems occurs during design activity will not influence the fabrication process and has been solved for ease of the whole project activities:

- Material purchasing and storage of material.
  - All material has been purchased and the list has been updated. The materials have been stored in UTP laboratory facilities. Refer appendices.
- Analysis of 3 dimensional configurations in Star CD
  - CFD analysis has been developed. As has been discussed before, however, it will not be use as design material as has been discussed before.
- The need of honeycomb
  – has not been fabricated, since the fabrication time need for fabricating this component very consumable and due to budget constrain. However, testing procedure has been conducted and the result determined that it is advisable to install the components in the tunnel. It will be based on flow characteristic produce along the test section area. Higher turbulence intensity means the fabrication of this component needs to be continued – this matter has been recommended to project partner for further study on tunnel performance enhancement.
- Type of machine that should be used in fabricating due to lack of workshop facilities.

- Outsource facilities has been used for tunnel fabrication activity.

- Smoke generator design due to insufficient cost and time.
  - All design and fabrication involving smoke activity will be taken over by project partner.
- Software integration
  - No problem seems to occur regarding this matter.

There are not so many problems occur during fabrications activities, however few of them will be discuss further in fabrication activities report. There are also a few problems that under study and will be identify through this report.

2.2 Testing procedure

Problems occur with boundary layer analysis. Initially, the purpose was to get a lot of data within test section surface to the center to develop the boundary layer graph. However, due to hardware failure at the time of implementation, the project has been delayed. Since, time very consuming, other alternatives have been developed to get general visualization of air flow inside test section. In addition, the mounting of test section material (Perspex) made it difficult to drill hole for testing equipment to get through test section. The result is limited since, no data acquired during this process.

2.3 Time constraint

While go through this project, extra time needed to learn and adopt new thing based on the requirement. The ability to understand new knowledge or skill as quickly as possible is not easy as it seen. Sometimes, it does consume a lot of time to familiarize it well that may disturb the progress of the project. Time given can be not enough to do any study or work on required schedule.

2.4 Significant of the Project

Due to the problems occur, there are some effects on performances of assessment. Challenges and difficulty created in dealing with the design and fabrication process and some of them have been overcome as discussed before. Different kind of approach and solution has been developed and implemented during projects works.

CHAPTER 3: OBJECTIVE AND SCOPE OF STUDY

Scope of study has been developed after main project's objective has been understood that is to design and fabricate small scale wind tunnel for flow visualization. Small scale means the tunnel should capable of implementing low speed testing. Hence, after research and literature review has been conducted on small scale – low speed tunnel, the whole project activities and work required has been identified as follow:

1. Study and understanding on the current system architecture for wind tunnel configuration and all of its components.
2. Study and understanding the aerodynamics theories for typical type of vehicle.
3. Able to understand the flow streamline and how to make it appears for visualization.
4. Able to scale down the tunnel system and develop procedure in avoiding effect.
5. Able to develop the feasibility on the compact design of the wind tunnel.
6. Able to develop software recognition modeling (CAD) and aerodynamics analysis (CFD).
7. Able to integrate software modeling with the machine database for fabrication purpose (CIM) – to be implemented by project partner.
8. Design own concept of working prototype based on the specification and requirement of the project, including the feasibility studies.
9. Able to do troubleshooting and design enhancement in order to improving the project from time to time.
10. Understand and able to conduct testing procedure for tunnel flow quality measurement data interpretation.
11. If possible, the tunnel established should have good integration and combination for software and hardware elements.

CHAPTER 4: METHODOLOGY

Methodology will discuss 5 main components of project activities, comprises of:

1. Feasibility study and Conceptual Design
2. Detailed Design – also known as Design Basis Memorandum (DBM)
3. Fabrication Process
4. Testing Procedure
5. Flow Visualization

Method used for all above activities has been further discussed one by one as follow:

4.1 Feasibility study and Conceptual Design

Research has been done to familiarize with type of wind tunnel, the purpose of wind tunnel, typical configuration and the aerodynamics theory behind the wind tunnel design. Apart from that, the size of vehicle and velocity required has also been specified. Some alternatives for flow visualization has been studied and identified for the use of the tunnel.

4.2 Detailed Design – Design Basis Memorandum (DBM)

Detailed design has been developed after all tunnel components have been familiarized. Detailed design verified the size of tunnel components and its purpose by referring to the Design rules that has been specify by, Jewel B.Barlow, William H.Rae, Alan Pope, R.D Mehta and P Bradshaw (refer references). Some decision has been done based on some problems faced during these design activities. 3 dimensional drawing has been developed by using Dassault System Catia V5R6 software to finalize on tunnel dimension and sizes. Material selection has been developed by referring to market availability. Fabrication drawings and tunnel specification has been prepared to assist the fabricator to fabricate the tunnel.

4.3 Fabrication Process

Tools required have been identified first before the fabrication started. In order to avoid any injuries and accident Safety Precautions that should be aware during fabrication has also been familiarized.

Fabrication activities involved with fabrication of wind tunnel main components comprises of:

- The Settling Chamber
- The Nozzle
- The Test section
- The Exit Diffuser
- The Fan Base

Fabrication activities have been done by referring to fabrication drawings that have been developed before. Some problems occurred during this activities has been identified as discussed respectively. In addition, fabrication quality checking has also been conducted to compare the dimension of design drawings and fabricated wind tunnel dimension.

4.4 Testing Procedure

Hot wire analysis has been identified for wind tunnel flow quality testing in the test section. The hardware and software configuration has been familiarized first before the experiment started. The tunnel test section has been modified to make sure that it's capable to conduct the testing procedure. Experimental planning has been developed and the step by step procedure has been understood. About 1024 result obtained, and the average velocity and turbulence intensity inside the test section has been acquired.

4.5 Flow Visualization

The smoke system will be developed by project partner in next semester of project continuation. Hence, one alternative has been found so that general air flow can be visualized inside the test section by using thread analysis. The test section has been modified to allow installation of threads. Two piece of 1 cm diameter aluminum rods at length of 40cm each have been used as thread holders and installed horizontally and vertically at the inlet of test section. About 80 threads have been used and the spacing between each of them is about 1 cm to make sure it will cover the whole area of test section. This is to make sure threads visualization can be apply anywhere within the test section. The test section has been scaled so that one can basically know which parts of the test section has better streamline flow.

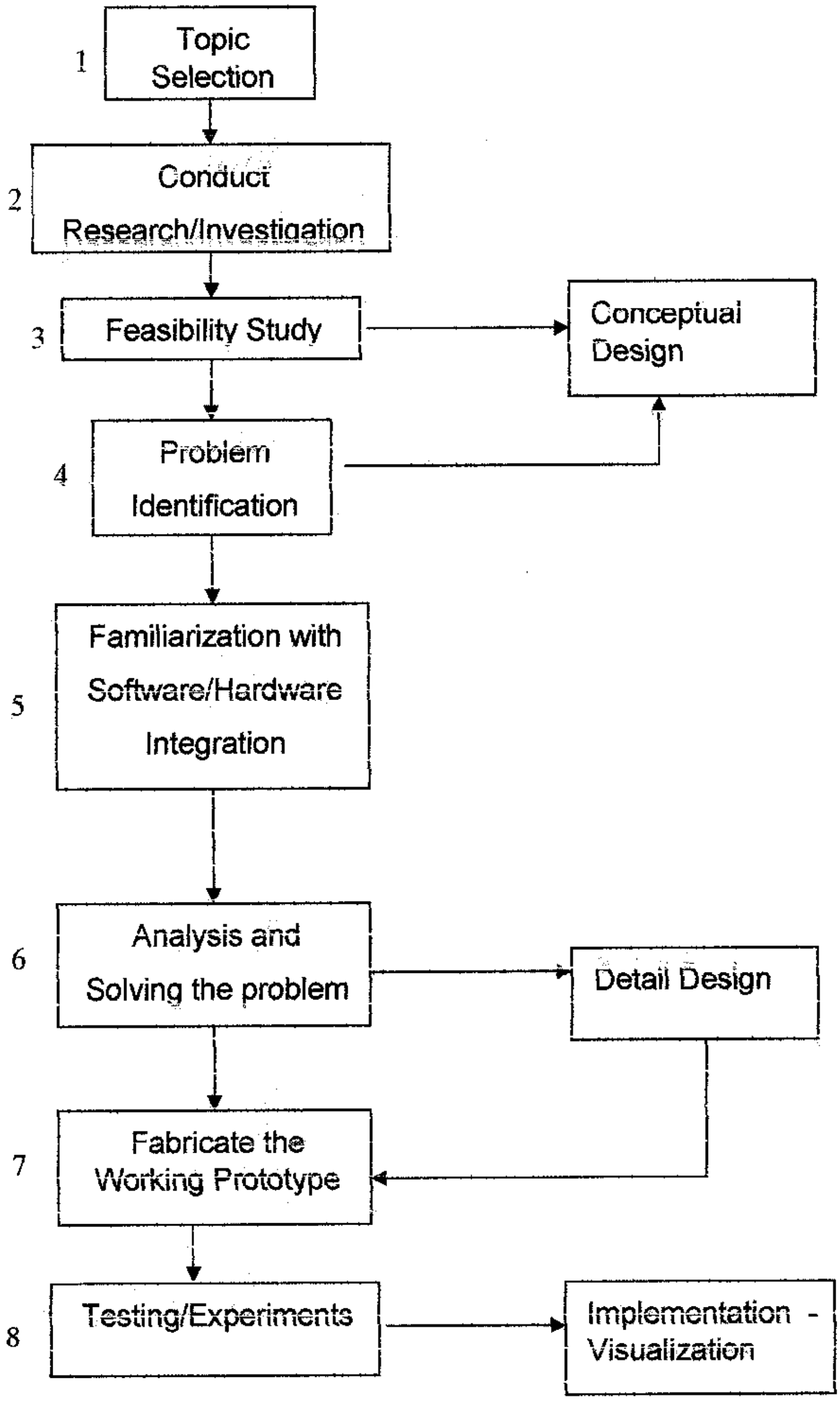


Diagram 1: Methodology Flow Chart

CHAPTER 5: TOOLS, SOFTWARE AND HARDWARE

5.1 ANSYS 5.4 / Star CD

This software has been used in dealing with flow analysis along tunnel area. The required velocity and size of parameter has been identified first before the analysis can be done. The analysis will indicate the flow characteristic, normally whether its turbulence or laminar. In addition pressure distribution has been determined. Basically the result has been used to get an idea of flow characteristic along the tunnel and test section area.. However, the result of the analysis will not be discussed since it is not applicable to simulate the real fabricated wind tunnel and it is not easy to simulate the fan swirl at the end of the diffuser. The analysis will be used to get a rough idea of the air flow behavior along the tunnel, specially the test section.

5.2 Dassault System Catia V5R6 / AutoCAD 2002

This is the type of software that has been used to develop the 2 dimensional and 3 dimensional drawing of the tunnel design. The entire design dimension will be based on the small scale size of the tunnel. Although it is not that easy, the author will try to develop the 3 dimensional design of the tunnel as it should look like in real world. In addition at this stage the fabrication drawings and updated drawings for fabrication process have been developed. Fabrication drawings have been generated by using AutoCAD 2002, while updated 3 dimensional drawings has been generated by Dassault System Catia V5R6. Refer appendices

5.3 Master Cam

This type of software has not been used at this point of design and fabrication activity. The use of this machine will be very helpful when for fabrication of smoke rack mechanism and the smoke generator. In addition it has been found that the basic shape of CAD drawings in Autocad can integrate with this software. Nevertheless, this will help a little bit in dealing with this Master Cam software. To be specified the software will be used by project partner in next project continuation when we try to fabricate the smoke injector for the tunnel.

5.4 Fabrication Tools

Several tools required for fabrication has been identified. Fabricator has provided full information along this process. Major tools required for the fabrication activities were as follow:

- Bench saw
- Nail gun
- T square
- Wood glue
- Jig saw
- Handy removable saw

CHAPTER 6: DESIGN ACTIVITIES - DESIGN BASIS MEMORANDUM (DBM)

Summary of design activities until fabrication process:

- Literature review
- Setting up objectives
- Identification of tunnel components
- Identification of Design rules
- Setting up minimum and maximum speed
- Check for market availability
- Development of conceptual design
- Verification of tunnel design – size and dimension
- Check for market availability
- Development of CAD drawings
- Modification of CAD drawings base on market availability
- Identification of raw material
- Preparation of materials list
- Development of construction drawings

6.1 Conceptual Design

6.1.1 Tunnel configuration

A large open circuit tunnel would be of rather inconvenient dimensions, mainly in length. Also, an open circuit tunnel requires free room around it so that the quality of the return flow is not affected significantly (remember that an open circuit tunnel in a room is really a closed circuit tunnel with a poorly designed return leg). The choice may be restricted by maximum available fan/blower size. A working section Re per meter of more than about 3×10^5 a speed of about 40m/s is rare in blower tunnel of whatever size, and commercial blowers capable of producing such a speed in a section more than about $1m^2$ in area are also rare.

As stated above, the main advantage of open circuit tunnel is in the saving of space and cost. They also suffer less from temperature change (mainly because room volume higher than tunnel volume) and the performance of a fan fitted at the upstream end is not affected by disturbed flow from the working section. One disadvantage that should be taken into consideration of any open circuit tunnel with an exit diffuser is that the pressure is always less than the atmospheric, although this can be remedied by obstructing the tunnel outlet and creating an overpressure in the working section (1).

6.1.2 Tunnel Components and Velocity Criteria

The objectives have been understood to design and fabricate small scale tunnel with flow visualization as has been discussed before. Small scale mean low speed tunnel, because it is rare to find the fan that can produce very high speed at this scale. The use of this kind of tunnel is because they make it possible to use model that can prepare early in design stages (model). In fact, they also capable of providing large amount of reliable data (as will be discussing in testing section) for the means of aerodynamics research and to support design decision. Although it is small, its use can save both money and lives.

Type of flow visualization has been identified by using smoke wire system. Open circuit tunnel has been specified as our design criteria. The selection base on saving of space and cost as has been discuss in literature review. Main components of tunnels comprises of:

- The Settling chamber
- The nozzle
- The test section
- The diffuser
- The fan base

Tunnel design base on cost effectiveness and most available fan (referring to size and flow rate and) size of vehicle model that has been specified to 1/10 of full scale size. Base on this Porsche 911 has been specified as car model to be visualized in test section. The size of this model is 17 cm × 13 cm × 44 cm, which is suit above requirement.

Initially, in order to specify the maximum speed for the tunnel, maximum speed currently been studied by Malaysian Government has been taken into account that is 120 km/h (33.33 m/s, 1.05 x 10^8 Re) for full or real scale size. Hence, since the tunnel has been specified to visualize air flow about 1/10 of real car size, dimensionally, the tunnel now should be able to supply about 1200 km/h (333.33m/s - 0.9 M) to maintain Reynolds number which is impossible to produce by small scale tunnel. Thus, further study has been developed to overcome this problem in term of aerodynamics theory under Verification of Aerodynamic Theory – Preparation for Construction.

6.2 Detail Design - Tunnel Design Verification

After conceptual design has been developed, verification has been done based on each size of wind tunnel components. The verification on detail design has been made by referring to journal and some books. This verification will go upstream to downstream of wind tunnel components. Basically the verification was strongly based on the availability of the components in the market (e.g the size, flowrate,). Reduction of cost was also one of the criteria that have been taken into account along this process. Tunnel design was strongly based on fan specification, since it hard and not easy to acquire the fan that really suits the requirement (to supply velocity of 333.33 m/s – to maintain full scale condition). However in preparation of construction we will discuss the effectiveness of reducing the fan speed based on higher requirement before. Below is the summary of verification for our main wind tunnel components:

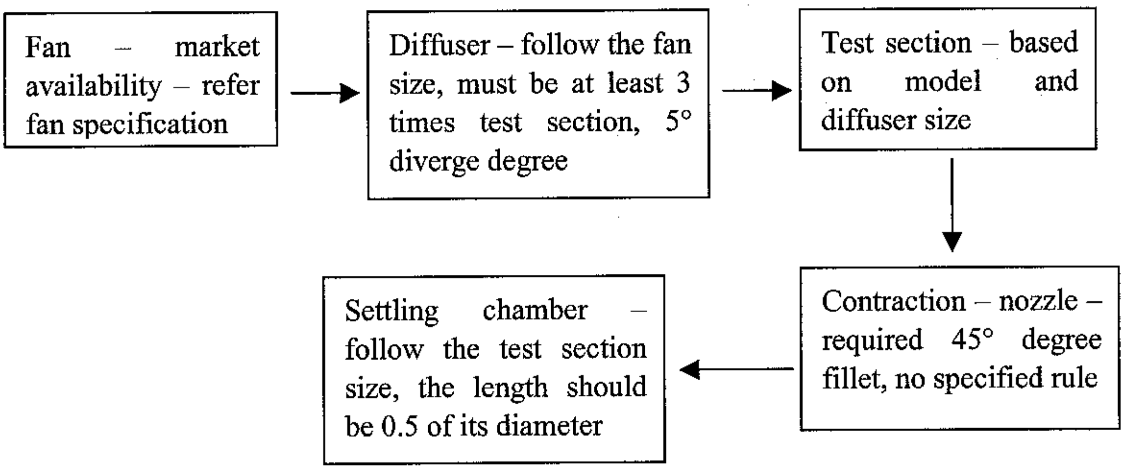


Diagram 2: Wind Tunnel Verification Flow Chart

6.2.1 Verification Aerodynamic theory

6.2.1.1 Preparation for Construction

In practice it is seldom possible to match both Reynolds number and Mach number to full scale in a model experiment. In fact, it is frequently the case that neither Reynolds number nor Mach number can be matched (1). Choices must then be made on the basis of which parameter is known to be most important for the type of flow situation consideration. For our cases, it is difficult to maintain the Re of 1.05×10^8 since it is almost impossible to supply the velocity of air at 333.33 m/s (33.33 m/s, 120 km/h at full scale condition – current allowable speed study by Malaysian Government) for the downscale model.

Since our main objective is to design and fabricate the wind tunnel for flow visualization purpose, we will now consider the simulation speed of 0-15m/s in our test section. The decision has been made due to fan availability in the market (refer fan specification). The relationship of this high and low speed testing should be further study (if possible), otherwise other setting up experimental application will be considered. Bear in mind the main objectives of visualize flow phenomena around the model will be main priority for the project instead of analyze the aerodynamic (drag, lift, forces).

Unit Reynolds number

As can predict and calculate at 15m/s the Reynolds number will be ~4.72×10^6 (lower than 6.98×10^6 (100 m/s, 0.3 M) which is very suitable for low speed testing (1). However the availability of fan forcing the air at ~11m/s will assure that the Reynolds and Mach number will be in the range of low speed testing (<100 m/s , 0.3 M).

Most important of all is the careful study of aerodynamic phenomena as they are affected by variation of Reynolds number so that useful conclusions can be obtained from tests that do not duplicate the operating Reynolds number. For many studies it is not necessary to produce the full scale Reynolds number, but it must be of a reasonable value. Much low speed testing involves aircraft takeoff and landing configurations where the Mach number is typically in the 0.15-0.30 range or lowers (1). Thus, this value should be lower for small scale automotive tunnel.

Primary decision is the choice of the minimum acceptable value of Reynolds number. Because much of low speed testing is at high lift condition, the effect of Reynolds number at high lift must be considered, if possible.

6.2.2 Verification of Tunnel Main Components

6.2.2.1 Settling Chambers

Settling chamber length is required for honeycombs and screen to reduce turbulences, if they are to be used; a settling chamber length of 0.5 times the inlet diameter has been used as recommended by design rule (1).

Honeycombs

Honeycomb is used in the main to reduce non-uniformity and straighten the flow. They introduce turbulence of their own which after a suitable settling length may be broken down using a fine mesh. Somewhere before our test section, there is a need of a section of the tunnel that takes the turbulence out of the air. The air coming from the atmosphere will be quite turbulence. To avoid this we will force the air through a couple feet of tubes (straw), which will take all the swirls and whorls out of the air and make the flow laminar. For maximum overall benefit the cell length has been design to be about 6-8 times its diameter. The cell size should be smaller than the smallest lateral wavelength of the velocity variation roughly 150 cells per settling chamber diameter. The honeycomb will be installed upstream of settling chamber so that the flow static pressure and angles have had chance to become more uniform. This component should be (straw) will be just push fitted into its own frame. (2). However, since time and cost consuming as has been mentioned before, installation of honeycomb has been purposed to project partner.

Screen

Two important properties have been considered:

- For the pressure drops through the screen to be completely independent, the spacing will be such that the static pressure has fully recovered from the perturbation before reaching the next screen (2).
- For full benefit from turbulence-reduction point of view, the minimum spacing will be of the order of the large energy containing eddies (2).

The design based on founding that a screen combination with a spacing equivalent to about 0.2 settling chamber diameters perform successfully (2). The optimum distance between the last screen and the contraction entry has also been found to be about 0.2 cross section diameters (2). If this distance is much shorter, significant distortion of the flow through the last screen may be expected. On the other hand, if this distance, or for that matter the overall length of the settling chamber, is too long then unnecessary boundary layer growth occurs (2).

6.2.2.2 Contraction nozzle

Contraction is required to produce a uniform velocity distribution and reduce the turbulence intensity. The nozzle has been design to achieve a uniform velocity distribution at outlet; the local velocity vector should be parallel to the axis of the tunnel and the free stream turbulence level should be low. In practice there is considerable variation in the actual flow conditions found in the available tunnels (4). A readily achievable specification, sufficient for the majority of automotive purpose, is given below:

- Spatial velocity variation less than ±1% within the core flow
- Turbulence intensity less than 1%
- Mean flow yaw angle less than 1° and pitch angle less than 0.2°

This component has a very significant effect on the overall design of the tunnel. This part will be installed directly upstream of the working section and its main purpose is to produce a uniform velocity distribution at its exit (2).

There is no basic rule in the determining the length of the nozzle, however the overall length should be keep to minimum to conserve space. The design has ensured that the velocity gradients are positive everywhere along the walls or at least not cause separation. It is always possible to avoid separation in the contraction by making it very long, but these results in an increase of tunnel length, cost and exit boundary layer thickness (1).

To minimize the flow problem at the edge of test section inlet, a 45-degree of fillet nozzle has been used. This fillet is to prevent boundary layer growth in corners between the test section and the nozzle.

Typical area ratios are in the range of 7-12, although lower and higher values are not uncommon (1). The contraction ratios about 6-9 usually use at least for small wind tunnel (ref 2), but this will cause the fabrication cost to increase. Let say we want to maintain the cross section of settling chamber to be 80cm by 80cm, the size of our test section will decrease to about 13cm by 13cm (ratio of 6) which is not suitable for flow visualization purposes. The decision has been made that the contraction ratio will be maintained at 4:1 (80 cm × 80 cm: 40 cm × 40cm), in order to satisfy the fillet nozzle at 45 degree and maintains the fabrication process at lower cost.

6.2.2.3 Test section

This is the part of the tunnel where the model is positioned. Usually the model hook to some sort of apparatus that can hooks it steadily in the airflow while also measuring parameters such as lift and drag.

The size of the test section will have a lot to do with how much airflow can cause through it. Larger test section means that more power needed to push air through it because large amount of velocity required.

$$V_1 A_1 = V_2 A_2$$

Equation above assured that the larger the size of the test section, the higher the power of fan and flow rate required to force the air through it and surely this will increase the cost of tunnel fabrication. However, larger test section can give more space for the flow to perform better streamline than small one. Minimum size of test section can assure homogenous flow since the allowable space for the boundary layer to grow minimized (1).

The test section, length to hydraulic diameter has been chosen to be two, in contrast to the shorter test sections of earlier era tunnels (1). In our wind tunnel there is a section between the test section and deturbulence (the screen and honeycomb) section that necks down the cross section of the tunnel (the nozzle). It has been placed after a section of settling chamber and before the test section where it reduces the tunnel from let say two feet by two feet to one feet by one feet. This will increase the velocity of the airflow. After that, there will be another section that expands the cross section out again to the fan (3). The test section has been design with flat removable walls for ease in installing models, changing models, installing ground planes or other modifications for nonstandard tests (1).

Additional information on test section

The wind tunnel test section needs to be sufficiently long so that these separated flow region "close" before encountering the end of test section and the entry of diffuser. Otherwise the pressure in separated region will not be correct and a large influence on drag will exist. In addition, the length to width ratio of automobiles is greater than for aircraft while the width to width ratio is much less. A wind tunnel test section sized for automobiles is therefore typically longer than a test section sized for aircraft and width to height ratio approximates the width to height of standard automobile. Ideally the blockage, the ratio of model frontal area to test section area, will be ~5% or less. This is based on confidence (or rather lack of confidence) in blockage correction method. Sufficient progress in correction methods has been made in recent years so that higher blockage factors are increasingly accepted as a trade against cost (1). Much greater values of blockage (up to 20%) are therefore allowed if the test section is specifically designed for automotive work, which is parallel with our tunnel requirement (4).

The power losses in the test section are sizeable, thus, power can be saved by keeping it short. However, contractions do not deliver a uniform velocity distribution to the beginning of the test section. Therefore, a constant-area duct before the test section is usually employed. The lengths of the test section of wind tunnel that are expected to be used to test articles with large volume of separated flow need to be sufficiently long so that all separated flow zones will close before the beginning of the diffuser (1).

6.2.2.4 Exit Diffuser

The purpose of diffuser is to reduce the speed as little energy loss as possible. Minimum energy loss corresponds to maximum pressure recovery. Obtaining good performance from the diffuser is critical to the success of the tunnel. Diffuser is sensitive to design error that may cause either intermittent separation or steady separation. Such separation can be hard to localize but can cause vibration, oscillating fan loading, oscillations in test section velocities (surging) and increase losses in the tunnel downstream of their origin (1). Commonly used cross sections are rectangular or nearly rectangular with reason closely paralleling the reasons given for choosing the test sections with plane walls.

The diffuser has been design with three test section length. The area ratio is about 1.5 (1). Diffuser are fitted downstream of the test section and have gentle expression with a diffuser included angle not exceeding 5° (for best flow steadiness, although best pressure recovery is achieved at about 10°). This also to avoid separation causes by adverse pressure gradient in the diffuser. In addition, the diffuser has been designed to efficiently convert the kinetic energy of the back flow to pressure energy. And this will ensure that there is no back flow in diffuser which can causes problem. The area ratio will not exceeding about 2.5. It is important to have a reasonable degree of flow steadiness in the exit diffuser, since otherwise the pressure recovery tends to fluctuate with time, and, therefore, so does the tunnel speed if the input power is nearly constant (2). The design of this diffuser is well catered by existing methods (Cockrell and Markland, 1974).

Additional Information

Diffusers are common elements in fluid flow devices, and in many applications the equivalent cone angle can be quite large. The design has put the constraint on the angle so that it is sufficiently small so that the turbulence boundary layer does not separate. The flow leaving the wind tunnel test section is uniform. There can be wakes from model mounting struts.

It is found that the losses in divergent section are two to three times greater than the corresponding losses in a cylindrical tube, although the progressively decreasing velocity would seem to indicate losses in the diffuser. The reason for the added loss is that the energy exchange near the walls is of such a nature that the thrust expected from the walls is not fully realized. Effectively, the pressure force is thereby added to the skin friction forces. The adverse pressure gradient in a diffuser will lead to separation if it is made too large.

Apart from all that, the nozzle and diffuser also has been used to increase the velocity of airflow inside the test section.

6.2.2.5 Fan Selection

As has been discussed above, for 1200 km/h (333.33 m/s – if we want to simulate as real condition at 1/10 scale at 120 km/h)) to be operated in tunnel the fan flow rate required is 3477m3/min, which is almost impossible to get in market due to cost as has been stated above and verified below. In addition the Mach number of 0.9 is not applicable for low speed tunnel. We will now refer back to required Mach number for low speed tunnel that should be in a range of 0.15-0.30 or lower. By referring to this rule, most available and cost effective fan has been identified and can produce flow rate at 115m^3/min. this amount of flow rate can produce speed of 11m/s-12m/s at about 0.03M inside the test section which compatible with above rules, fan specification were as below:

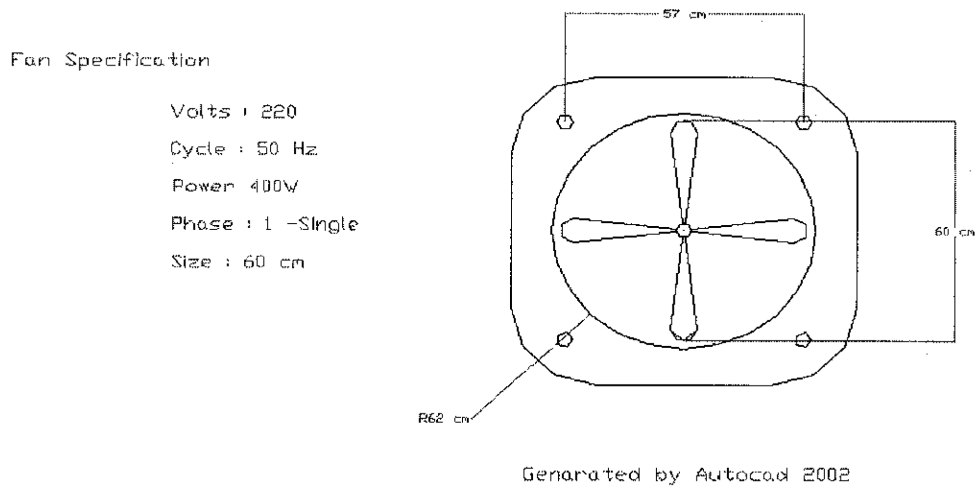


Diagram 3: Fan Specification

Hence, fan selection process can be concluded as below:

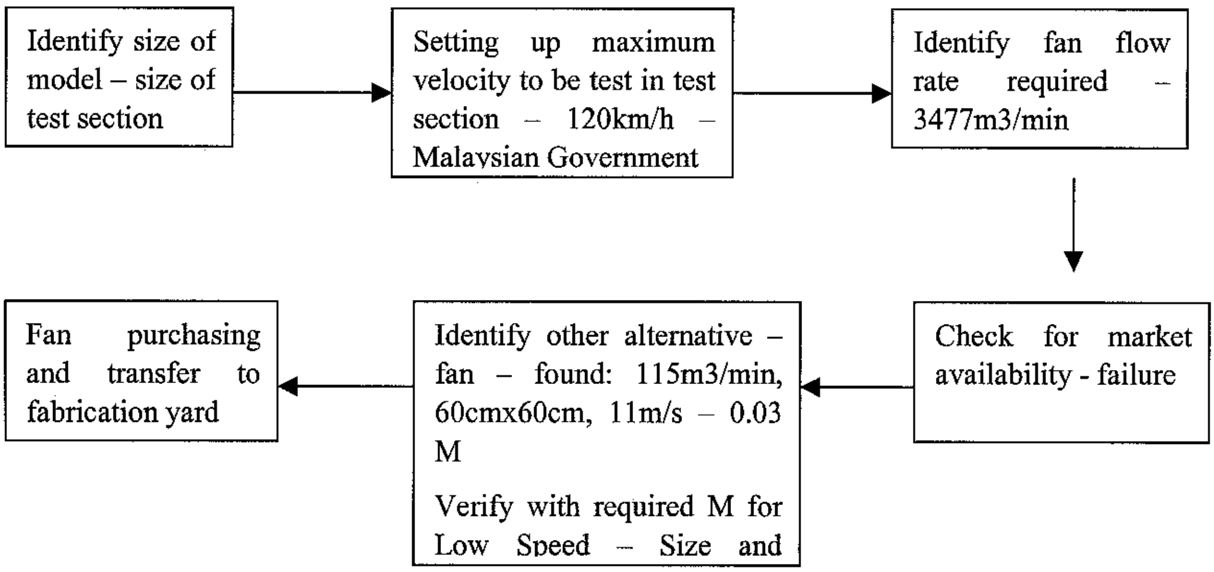


Diagram 4: Fan Selection Process Flow

6.3 Development of CAD Drawings

6.3.1 Dimensional Design Drawing and Small Scale Dimension

3 dimensional drawing has been developed by using Dassault System Catia V5R6 software. The development was based on the actual car sizes that need to be simulate in the wind tunnel and tunnel components design rules. The scale of the drawing is 4m: 40mm. The 3 dimensional drawing was part of the detail design by not including the fan and the turbulence screen design.

The thickness of the wind tunnel external body has been draw with 0.002m (base on material specification). This is to allow the construction/fabrication of the tunnel body. The base of the tunnel has been appointed to be at the test section and at the end of the diffuser since they are the main part of the tunnel body

In addition of 3 dimensional drawing designs, the material for the general part such as the tunnel body and its visualization screen has been specified. Tunnel body will be using Medium Density Fiber (refer Material Procurement Package) and the screen will be using plastic (Perspex) material. Refer to appendices for CAD drawing of the wind tunnel design and its dimension. 3 dimensional drawing has been updated by referring to machine capabilities during fabrication process.

6.4 Material Selection

Materials list has been updated from time to time by referring to purchasing activities. Refer appendices for Material Procurement package.

CHAPTER 7: FABRICATION ACTIVITIES

Detail summary on fabrication activities until preparation for wind tunnel flow quality testing:

- Material Purchasing
- Identification of safety precaution and tools required
- Development of construction drawings
- Transportation preparation for material transfer
- Material transfer to fabrication site
- Safety awareness identification
- Fabrication on main tunnel components started on diffuser body
- Fabrication continue on test section
- Fabrication continue on nozzle and settling chamber
- Installation of turbulence screen (wire net) inside settling chamber
- Fabrication continue on fan base
- Installation of fan into fan base
- Fabrication continue with tunnel base
- Fabrications continue on preparation for tunnel assembles.
- Tunnel assembly for stability checking and for test run on fan performance
- Surface finishing and preparation for tunnel transfer
- Transportation preparation for tunnel transfer
- Fabricated tunnel transfer to UTP laboratory facilities
- Fabrication activity continues on tunnel assemble
- 3 dimensional drawing updated due to fabrication facilities capabilities
- Fabrication continue on purchasing supplementary components
- Installation of supplementary components –honeycomb, variable speed controller, wiring
- Familiarization on wind tunnel flow quality testing procedure – Hot Wire Anemometer

- Fabrication continue on preparing test section for testing procedure – traverse system – hanging mechanism
- Installation of traverse system and hanging mechanism inside the test section
- Tunnel preparation for testing procedure

As has been mentioned, few pictures will be included along the discussion in order to give clearer view on fabrication activities.

7.1 Construction Drawing

Construction drawing has been developed in order to assist the fabrication activities. The drawing has been done carefully by referring to machine capabilities to avoid any uncertainty to fabricator. Refer appendices

7.2 Safety Precautions

Safety awareness should be first identified before the fabrication process can be started. This identification is to assure there will be no damage, failure or accident that can causes any injuries during fabrication process. Identification will include the fabrication environment and the Safety Protective Equipment (SPE). The environment of the fabrication area should be consider as dangerous area since the material used (MDF) produced a lot of small particle that can cause breathing injury. This problem can be avoided by using SPE, which comprises of:

- Goggle
- Safety shoe
- Mask
- Safety jacket

Apart of that, method required for machine handling should identify first. Correct method can avoid this dangerous situation to occur.

7.3 Material

All materials excluding honeycomb (straw) has been purchased earlier at design stage in order to continue with fabrication activities. Analysis has been done to compare with approved budget by the Project Committee. In addition all material cost has also been update. Refer appendices for Material Procurement Package.

7.4 Fabrication Process

7.4.1 The Diffuser

Fabrication process has been started after the material has been dimension. The tunnel diffuser was the first part that been fabricated. Material involved was Medium Density Fiber (MDF). Problems occurred when we try to cut the diffuser angle. Due to machine capabilities, the material need to be hold strongly so that it would not move, otherwise it can cause problem in acquiring the right angle. Problem also occurred when we try to connect each side of the diffuser body. At initial stage of connectivity glue has been used to hold the material, however, since we need a few times to make sure that it works, nail gun has been used to hold the material so that it would not be deposition. Refer appendices for fabrication drawings and pictures.

7.4.2 The Test Section

No problem occurred during fabrication process. As previous component, this part has been fabricated by referring to its respective drawings. These are some pictures of fabrication activity. Two types of materials were involved during this activity, which comprises of:

- Medium Density Fiber
- Perspex

Perspex has been used as visualization screen for the tunnel. It has been installed as part of test section body since this is where the visualization will occur. Apart from that, the Perspex has been mounted as removable side panel so that the process of model installation inside the test section will be easier. Refer appendices for fabrication drawings and pictures.

7.4.3 The Nozzle and Settling Chamber

Material involved was Medium Density Fiber (MDF). Problem occurred when we try to fabricate the fillet before the test section. This is because of:

- Capabilities of material to hold force of stress.
- Material is hard but brittle, means that its can easily break due to bending force.

To cater this problem, plywood with small thickness has been used. Refer appendices for fabrication drawings and pictures. The fillet of the nozzle was not available in fabrication drawings, since the difficulties of building this part has been taken into consideration. However, it is always best when the difficulties can be overcome as shown in fabrication pictures and 3 dimensional drawings.

7.4.4 The Turbulence Screen

Turbulence screen (wire net) has been installed by referring to specification that has been mentioned in Design Activities. There are two turbulence screens involved and this component has been installed inside the settling chamber. The dimension and space between screens are 80 cm × 80 cm and 16 cm respectively. Refer appendices for drawings and fabrication pictures.

7.4.5 The Fan and Tunnel Base

The base for the fan also has been fabricated by fabricator experience. However, a few steps has been taken into consideration to make sure that it would not produce back flow that can cause back pressure inside the tunnel. The fabrication process also has been monitored to make sure it would not effect the inside dimension of the tunnel. Refer appendices for fabrication drawings and pictures.

7.4.6 Method of Assembly

The tunnel has been fabricates with four major part comprises of:

- The nozzle and settling chamber
- The test section
- The diffuser
- The fan base

In order to assemble all these four major part, about 1.5 cm holes have been drilled to at all their respective bases. 3 inch bolts and nuts have been used together with washers to assemble all these part together. Refer appendices for fabrication drawings and pictures.

7.4.7 Supplementary Components

7.4.7.1 Variable Speed Controller

The needs of this component because, the fan must be design such that we can control its motor speed by controlling the amount of voltage received, thus controlling the velocity inside the tunnel. This is to assure that we can get the value of velocity where the smoke will disperse and maintain the streamline.

7.4.7.2 Wiring

Electrical appliance and regulator for fan wiring has been purchased. As has been discussed before, the purpose of regulator is to control the voltage so that we can get variable speed of the fan motor, hence variable velocity in test section. Wiring has been done such that the regulator will connect to wiring of the fan and to the power supply. Wiring has been done properly to make sure all wires are parallel. Only life cable allowed to connect to the regulator otherwise the components will experience failure.

7.5 Fabrication Quality Checking

Fabrication quality checking has been developed to compare the dimension of design drawings and fabricated wind tunnel dimensions. The development of quality checking was to study about the effectiveness of fabrication methods that has been implemented during fabrication activities. The method was by specifying the tolerance between design and fabrication dimension. Checking has been done component by component from inlet of settling chamber to the outlet of diffuser. The data has been obtained as follow:

Settling Chamber

Data required	Dimension (cm)		
	Length	Width	Cross section area
Design	40	80	80 × 80
Fabricated	39.5	80	80 × 80
Tolerance	0.5	0	0

Table 2 : Fabrication Quality Check Comparisons at Settling Chamber

Nozzle

Data required	Dimension (cm)		
	Length	Angle - converge (°)	Area ratio
Design	65	45	80 × 80 : 40 × 40 4 : 1
Fabricated	65	45	80 × 80: 40 × 40 4 : 1
Tolerance	0	0	0

Table 3 : Fabrication Quality Check Comparisons at Nozzle

Test Section

Data required	Dimension (cm)		
	Length	Width	Cross section area
Design	80	40	40 × 40
Fabricated	79.5	40	40 × 40
Tolerance	0.5	0	0

Table 4 : Fabrication Quality Check Comparisons at Test Section

Diffuser

Data required	Dimension (cm)		
	Length	Angle – diverge (°)	Area ratio
Design	240	3.5	40 × 40 : 60 × 60 1 : 3
Fabricated	240	3.5	40 × 40 : 60 × 60 1 : 3
Tolerance	0	0	0

Table 5 : Fabrication Quality Check Comparisons at Diffuser

As reflected above data, there were not so much differences in comparisons of both dimensions. However, as expected there still amount of tolerance occurred as can be seen in Table 2 and 4 which 0.5 both. This maybe because of the parallax (human error) while dimensioning the material before cutting process took place. Hence, conclusion can be made that fabricated tunnel was in high quality since the amount of tolerances were low.

CHAPTER 8: WIND TUNNEL QUALITY FLOW TESTING PROCEDURE

Turbulence is an important process in most fluid flow and contributes significantly to the transport of momentum, heat and mass in the test section, which play a role in transporting the smoke particles in the test section. Turbulence also plays a role in the generation of fluid friction losses and fluid induced noise. In order to understand the behavior of fluid flows and in order to design and evaluate vehicles performance (to get good streamline flow) in the test section, the study of turbulence is therefore essential. Such studies are carried out by means of suitable instrumentation like hot wire anemometer (CTA) or laser Doppler anemometers (LDA) and recently with particle imaging velocimetry (PIV). Measurements will be made as supplement to computer modeling (Computational Fluid Dynamics, CFD). This method will be used in determining velocity, turbulence intensity and boundary layer growth within the surface of tunnel test section.

8.1 Hot Wire Anemometer – An Introduction

Hot wire anemometer (often called CTA or constant temperature anemometers – with reference to operating principles) testing procedure has been identified for tunnel testing activity. The reasons for using this method because the handling and the software is easier (ease of use), the output is an analogue voltage which means that no information is lost and very high temperature resolution. In addition, CTA is more affordable than LDA or PIV systems.

The CTA anemometer works on the basis of conductive heat transfer from a heated sensor to the surrounding fluid, the heat transfer being primarily related to fluid velocity. The discussion of all steps needed in order to carry out reliable measurements starting with selection of equipment, followed by experiment planning, system configuration and installation, anemometer set up, velocity and directional calibration and data acquisition will be included further in this report.

8.2 Vehicle Model Preparation

Based on ideal blockage ratio of about 15%-20% (ref 4), 1/10 of Porsche 911 model has been selected for flow visualization. Blockage ratio is the ratio of car frontal area to the test section cross section area. The size of the model has been used in selecting point for test section testing procedure. The points has been selected at the front, top and rear of the car, since this are the point where we need to consider most to get a good flow visualization. All the points will be further identified in the next section of the report. See further detail in Traverse System and Hanging Mechanism.

8.3 Traverse System and Hanging Mechanism and Probe Positioning

Several points have been identified for tunnel testing. The point selected based on the size of the model to be visualize in the test section. Model length about 44cm and height is about 17cm. Test section has been modified for hanging mechanism (the traverse system) for tunnel testing procedure by referring to selected point. Traverse system consists of clamper and hanging bar has been developed and fabricated to allow the probe of hot wire system placed in the test section. Size and length between each point have been after all the position has been finalized. Figures below show the point that has been selected for the velocity measurement. See appendices for 3 dimensional drawings and pictures of the system.

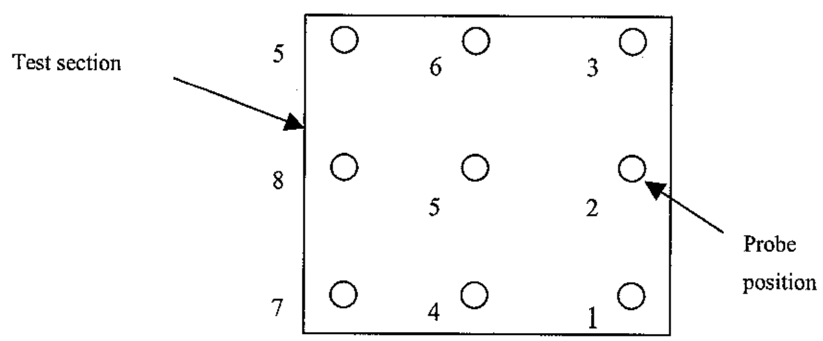


Figure 6 : Probe Position

Point	Location
1	Back right
2	Back center
3	Back left
4	Middle right
5	Middle center
6	Middle left
7	Front right
8	Front center
9	Front left

Table 6 : Positioning Number and Location

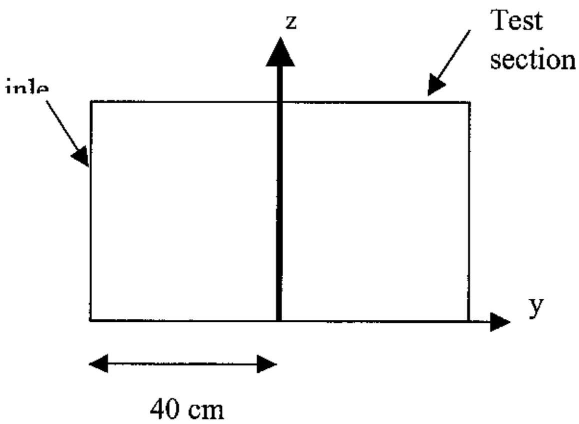


Figure 7 : Side View of Probe Positioning

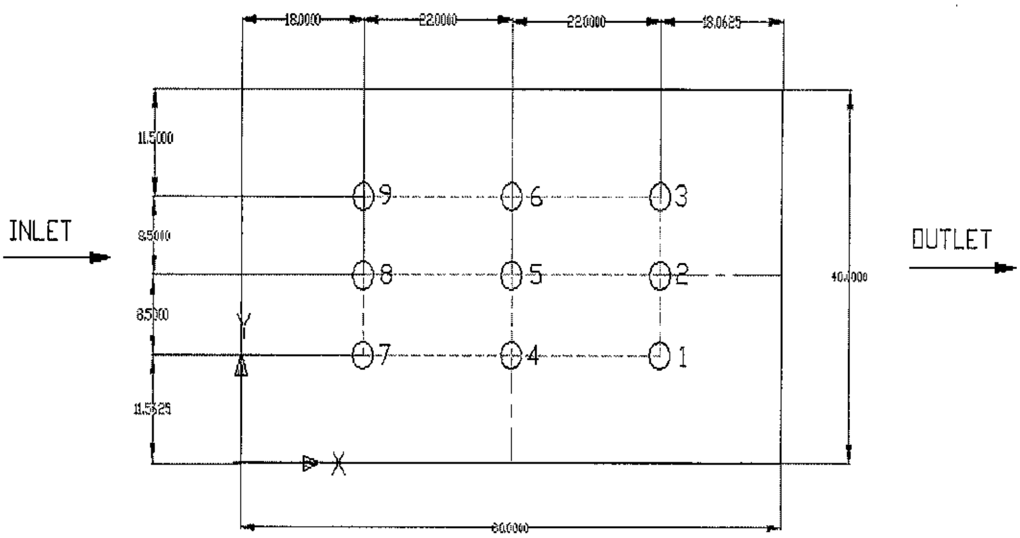


Figure 8 : Point of Measurement – Top View

8.4 Experimental Planning and Checklist

The quality of fluid dynamics measurements and the efficiency of the experimental procedure very much depends on the selection of the equipment, inclusive the application software, and on the planning of the experiment. Qualified decisions depend on the capability to identify the measurable quantities and to select the data analyses needed to provide required result.

What to do:

1. Know what we want to measure, the physical variable, the statistical functions, and the ultimate presentation.
2. Know the result beforehand. Guess, crosscheck, explore.
3. Design the measurement.
4. Estimate optimum data rate, measurement time, number of sample needed.
5. Check the function of equipment by varying parameters. Is the system immune to small changes in bandwidth, range or gain?
6. Monitor the result online – things may change: temperature, condition during a traverse.
7. Do not leave and go to coffee!

These are the checklists that has been developed for experimental planning:

Quantities to be measured:

Turbulence Intensity

Define distribution of measuring point:

Profiles (probes traverse) – left and right - 9 points

Equipment and Software on basis of:

Flow medium – gas (air)

Dimensions – 1 direction

Fluctuations – turbulence intensity

Temperature – Constant

Quantity to be measured – velocity components

Experiment procedure on the basis of:

Type of flow field – internal flows, boundary layer flow

Point distribution – distributed

Data analysis – time

Data analysis on the basis of

Required result versus measured quantity (turbulence intensity versus velocity)

8.5 Experiment Step by Step Procedure

When the flow and parameters of interest are defined and the necessary hardware is installed and configured, the experimental procedure consists of the following steps:

1. Hardware set up
    - Adjust overheat ratio
    - Measure ambient temperature, if temperature variations are expected
    - If need be, check system response with square wave test
    - Set low pass filter in signal conditioner

2. Velocity calibration
    - Expose the probe to set known velocities and determine the transfer function

3. Directional calibration
    - Only for 2 and 3 D probes, and only if high accuracy is required. Otherwise use manufacturer's defaults for yaw and pitch coefficient

4. Conversion and data reduction
    - Transfer function provided velocities
    - Data analysis module provides reduced data

5. Define experiment
    - Select hardware setup – leave overheat resistor constant
    - Probe movement – define traverse grid (for measurement in many points)

6. Define data acquisition

7. Test run
    - Placed the probe in the flow and acquire data. Check that reduced data (mean velocity, standard deviation etc) are as expected

8. Run experiment
    - Move the probe to position, readjust hardware, if need be, and acquire probe voltages

9. Convert and reduce data
    - Load the data and apply the selected conversion/reduction routine

10. Presentation of data
    - Present data in graphs or export them to a report generator.

All the steps should be used in conducting the experiment.

8.6 Theoretical Data

The objective of the testing is to acquire information about velocity profile inside the test section. The amount of velocity inside the test section should be the same as calculated velocity (by referring to fan specification) that has been specify during design stage (refer progress 1). This value has been calculated as follow:

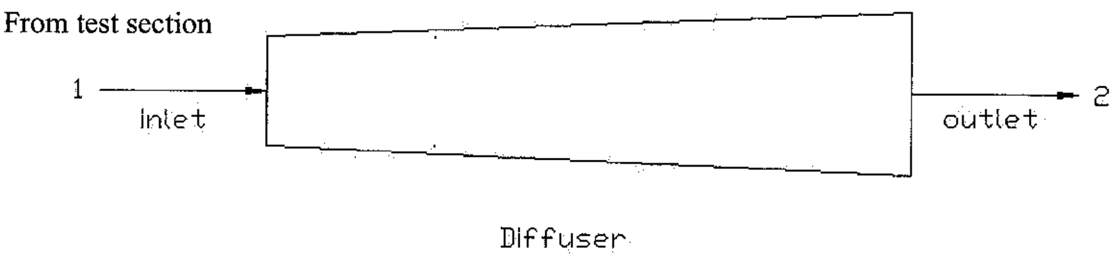


Figure 9 : Diffuser Layout

By referring to design basis memorandum

Q_2, Fan flow rate at outlet = 115m3/min

A_2, diffuser outlet cross section area = 0.6m × 0.6m = 0.36m^2

V_2, diffuser outlet velocity

A_1, diffuser inlet cross sectional area = 0.4m × 0.4m = 0.16m2

V_1, diffuser inlet velocity

By basic aerodynamics theory:

$Q = AV$

Q_2 = 115m3/min = 1.91667m3/s

$V_2 = Q_2 / A_2$

= 1.91667m3/s / 0.36m2

= 5.324m/s

Hence by,

$A_1V_1 = A_2V_2$

We can now calculate the amount of velocity that should be produced by fan inside the test section.

$V_1 = A_2V_2 / A_1$

= 1.91667m3/s / 0.16m2

= 11.975m/s

~11m/s – 12m/s

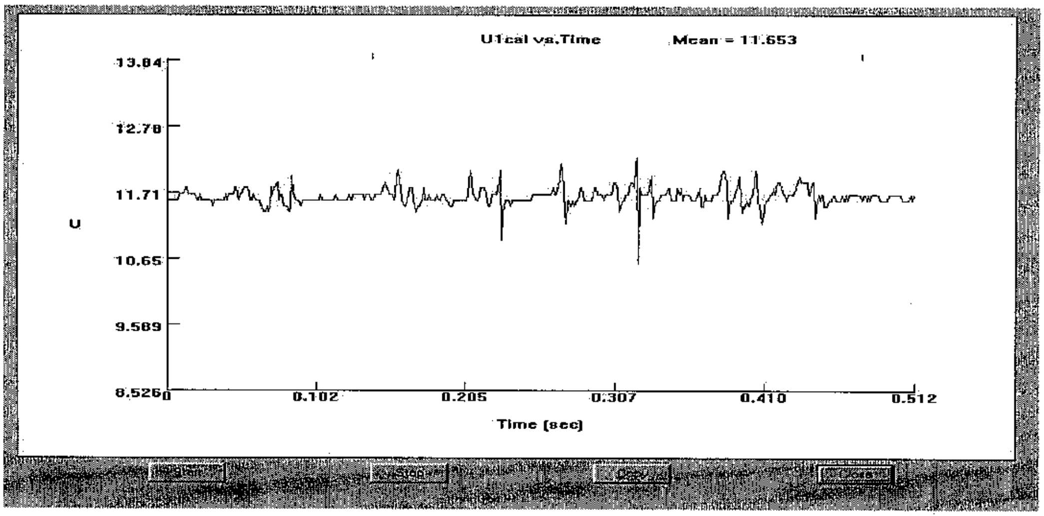
Test section should acquire this velocity as has been specified by Mach number about ~0.03 in Design Activities - DBM. This comparison also will be used to show that the tunnel design has successful in producing the amount of velocity required in test section by referring to desired Mach number for low speed wind tunnel (refer DBM). This calculation was based on fan speed that has been specified during design stage. As has been stated before, the fan has been purchased and installed so that it would be able to supply this required velocity inside the test section.

8.7 Result Data and Discussion

Testing has been done after all procedure has been understood in previous report. About 1024 reading has been taken in 1 second in order to assure testing accuracy. This report will only provide the first 35 data values. The average and mean velocity will be included.

All the data values were based on measurements point that has been specified before. Fan flow rate and speed is 115 m^3/min and 5.33 m/s respectively. All velocity data has been attached in the appendices. Average velocity, and mean velocity for each point has been stated along this report. Average velocity has been calculated from acquired measurement data for each point. The different between average and mean velocity because, mean velocity has been acquired during online analysis, so the graph varied from time to time. In addition the graph (Velocity VS Time) acquired for each point has also been included. Turbulence intensity has been calculated from acquired reduce data (refer appendices) and also has been stated along. Experimental data can be conclude as below:

Data at point 1 (Back Right)



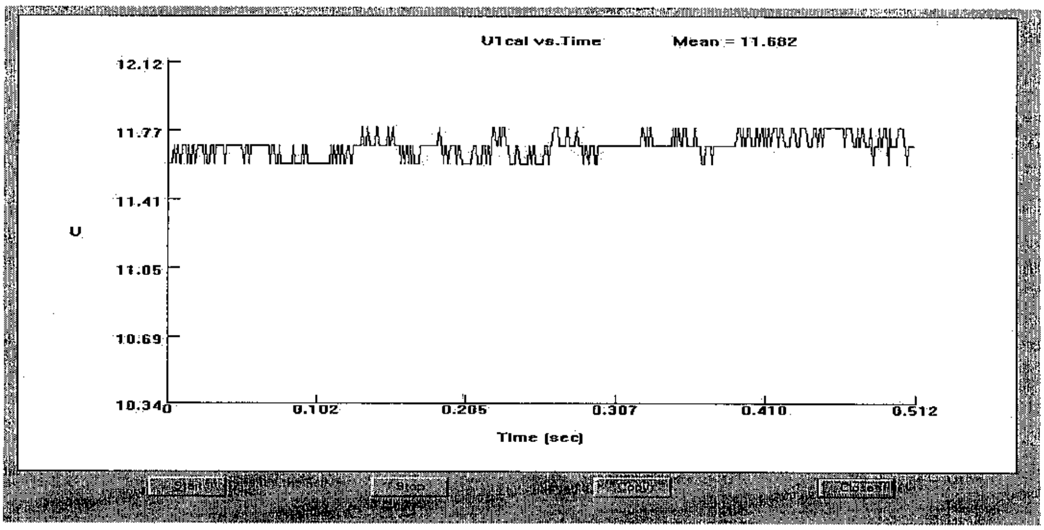
Average velocity = 11.53m/s

Mean velocity = 11.653m/s

Turbulence intensity: U_{RMS}/U_{MEAN} = 0.071 / 11.526 = 0.60%

(Refer hot wire training manual)

Data at point 2 (Back Center)



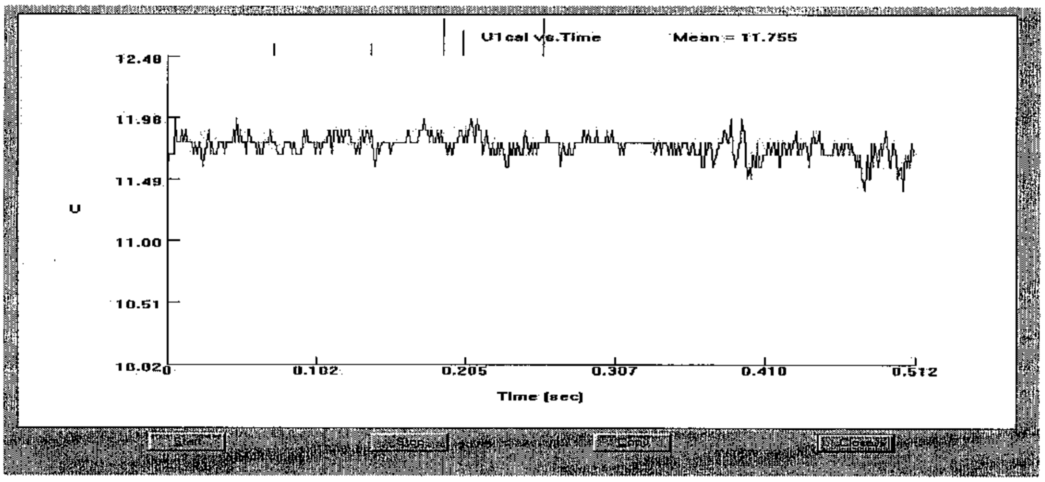
Average velocity = 11.87m/s

Mean velocity = 11.653m/s

Turbulence intensity: U_{RMS}/U_{MEAN} = 0.056 / 11.865 = 0.47%

(Refer hot wire training manual)

Data at point 3 (Back Left)



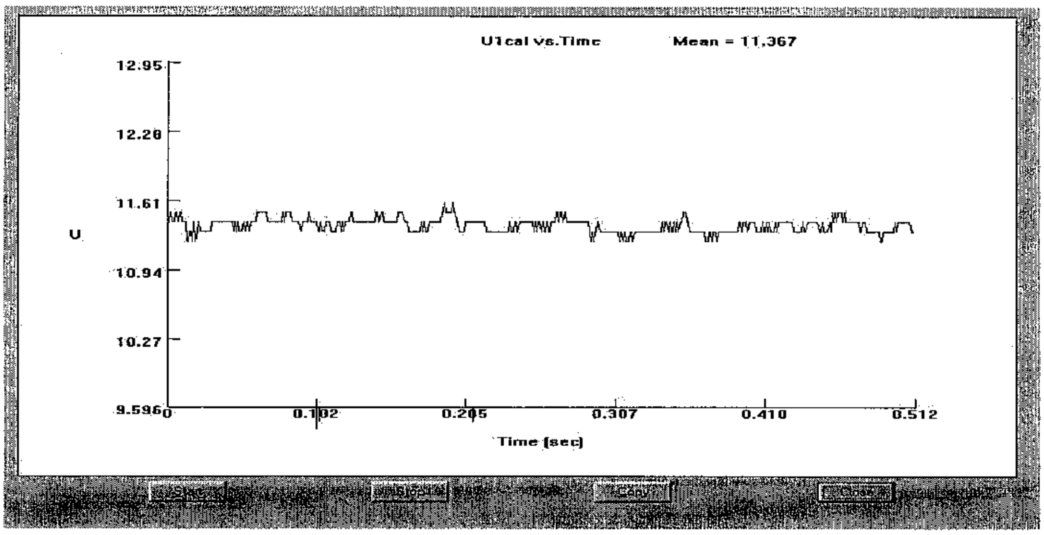
Average velocity = 11.66m/s

Mean Velocity =11.755m/s

Turbulence intensity: U_{RMS}/U_{MEAN} = 0.081 / 11.656 = 0.69%

(Refer hot wire training manual)

Data at point 4 (Middle Right)



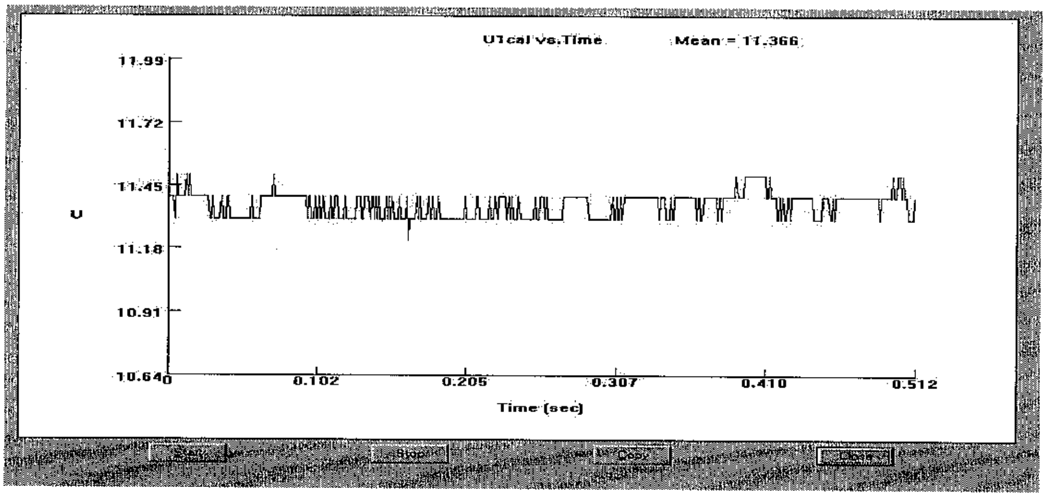
Average velocity = 11.43m/s

Mean Velocity = 11.367m/s

Turbulence intensity: U_{RMS}/U_{MEAN} = 0.243 / 11.435 = 2.1%

(Refer hot wire training manual)

Data at point 5 (Middle Center)



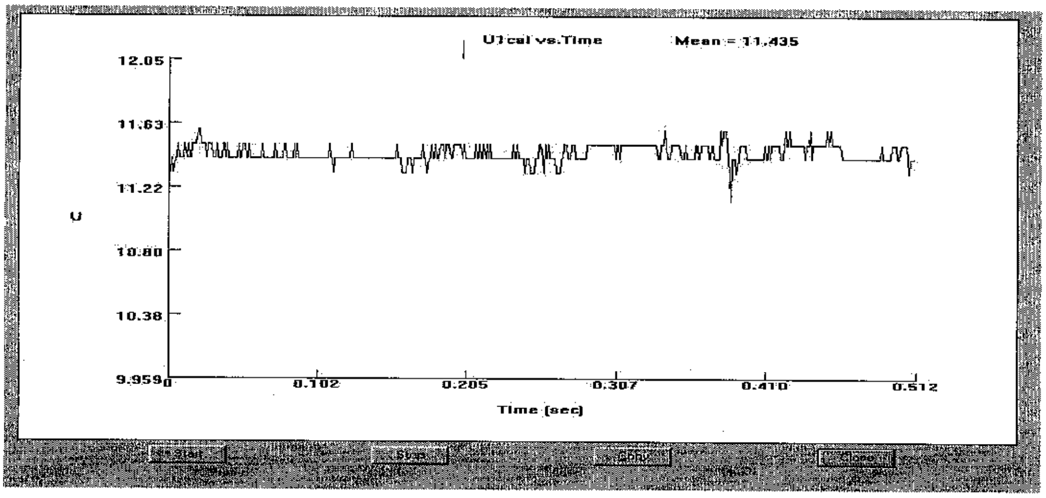
Average velocity = 11.52m/s

Mean Velocity = 11.366m/s

Turbulence intensity: U_{RMS}/U_{MEAN} = 0.07 / 11.516 = 0.61%

(Refer hot wire training manual)

Data at point 6 (Middle Left)



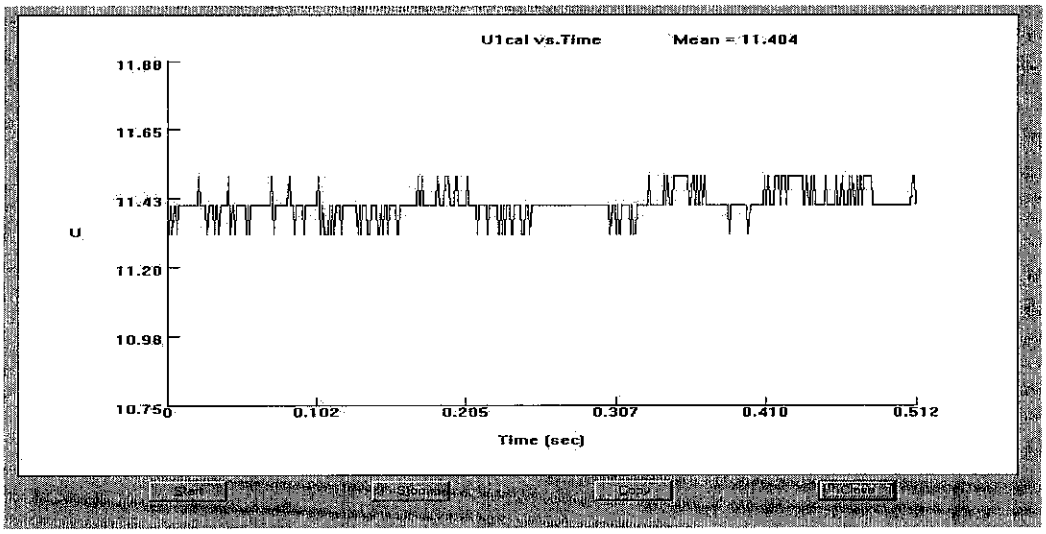
Average velocity = 11.45m/s

Mean = 11.435m/s

Turbulence intensity: U_{RMS}/U_{MEAN} = 0.147 / 11.448= 1.28%

(Refer hot wire training manual)

Data at point 7 (Front Right)



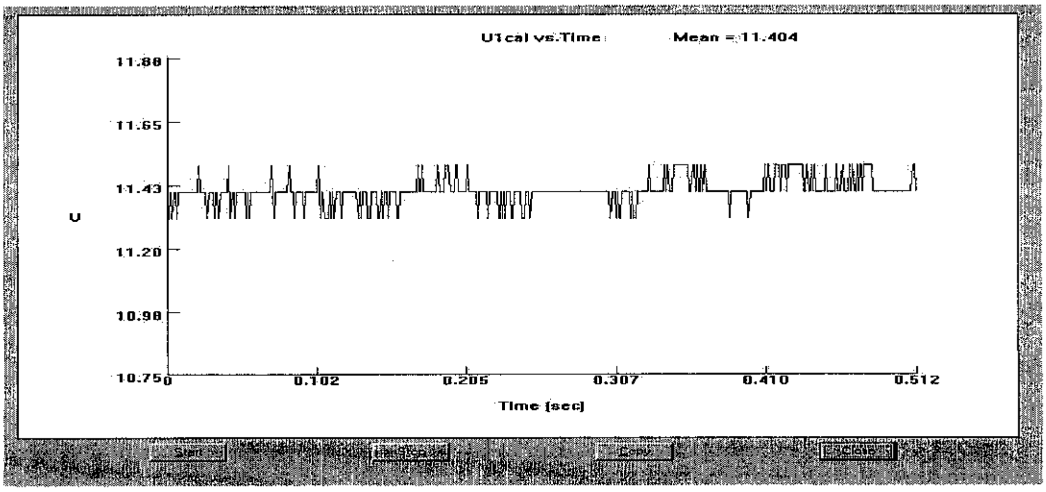
Average velocity = 11.15m/s

Mean Velocity =11.154m/s

Turbulence intensity: U_{RMS}/U_{MEAN} = 0.105 / 11.154= 0.94%

(Refer hot wire training manual)

Data at point 8 (Front Center)



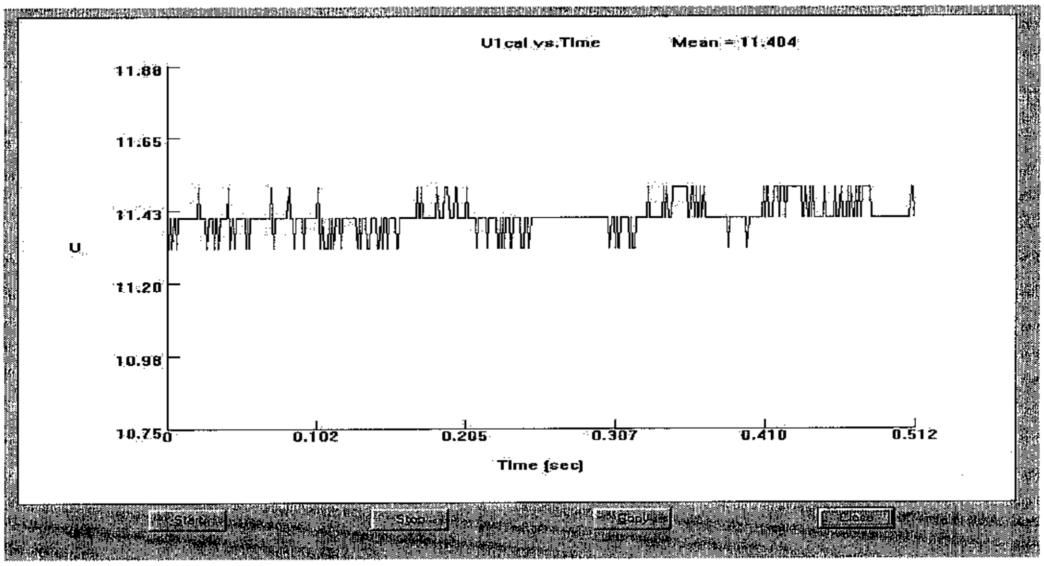
Average velocity = 11.38m/s

Mean Velocity =11.404m/s

Turbulence intensity: U_{RMS}/U_{MEAN} = 0.058 / 11.376= 0.51%

(Refer hot wire training manual)

Data at point 9 (Front Left)



Average velocity = 11.58m/s

Mean velocity = 11.404m/s

Turbulence intensity: U_{RMS}/U_{MEAN} = 0.073 / 11.582= 0.63%

(Refer hot wire training manual)

It seem that the tunnel design has successfully for supplying required velocity inside test section that is about ~11m/s – 12m/s. Amount of turbulence has been expected and can be reduce by installing honeycomb in the settling chamber to produce more uniform flow and reduce the intensity. Average turbulence intensity calculated to be ~0.8%, however there are sudden increase in this value at middle right and middle left of data point which is 2.1% and 1.25% respectively. Hence further study recommended to project partner to verify the values and identify the causes of the problems. The value of good turbulence intensity should be below 0.1%. Overall project has been successful and installation of smoke rack and generator should be proceeded to achieve the objective of flow visualization.

8.7.1 Error

Error can be occurred by:

1. Human and parallax error – Miss handling and positioning the probe. The probe must be place very carefully in the test section in order to main the right angle of the wire probe at each of measuring point.
2. Voltage – unconformity of voltage supply by laboratory will affect the speed of the fan, hence effect the flow and amount of velocity produce inside the test section.
3. Temperature conditions in the laboratory also influence the probe in acquiring the measurement data.

Refer appendices for experiment calibration data

8.8 Alternatives for Flow Visualization

8.8.1 Boundary Layer Visualization

The purpose of boundary layer visualization is to identify the turbulence location and boundary thickness inside the test section within its surface area. Boundary layer can be defined by:

Air region in contact with body surface has same velocity as body surface

While, boundary layer thickness can be define by:

Distance from surface to point where the velocity in boundary layer is 0.99 times velocity outside the layer region

Apart from that, this visualization is also to identify the best location to install the vehicle model in the test section. In addition, the visualization will also be used to get an idea of good airflow area inside the test section. The method has been identified by using hot wire, meaning that more point of measurement need to be identified. About 40 point of the test section needs to be measure. However, as has been stated before in problem Statement, this method will not be implemented due to this problem:

- Hardware failure – hot wire computer configuration did not start application at the time of implementation
- Test section preparation – test section surface need to be drill in order to allow the probe holder (hanging mechanism) to enter the test section from top due to space consumption.
- Time – there is not enough time to conduct the experiment due to project schedule and submission of final report

However, if possible this method can be enhanced by project partner in the next continuation of the project development.

8.8.2 General Flow Visualization

This is the other method that has been implemented to visualize the air flow in the test section. The method has been specified by using threads. No data acquired in this activity. However the test section has been scaled, so that from the visualization one can know which part of the tunnel test section has a good turbulence flow. About 80 threads have been used along the test for these activities, as shown below:

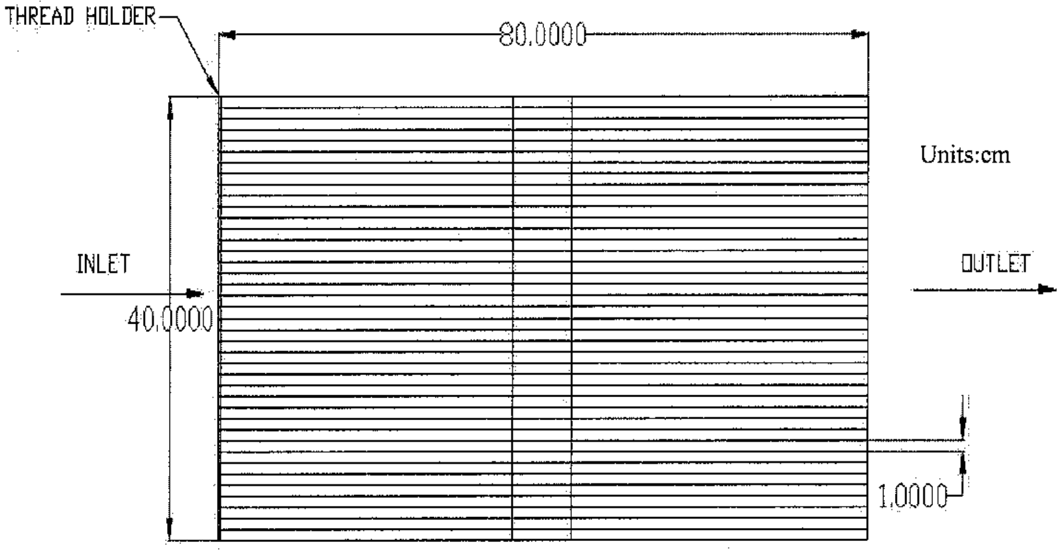


Figure 10 : Thread Position from Top and Side View

Spacing between each thread is 1cm.Refer appendices for preparation pictures

8.8.2.1 Thread Analysis

Analysis has been done by scaling the test section by 1cm to 1cm, as shown below

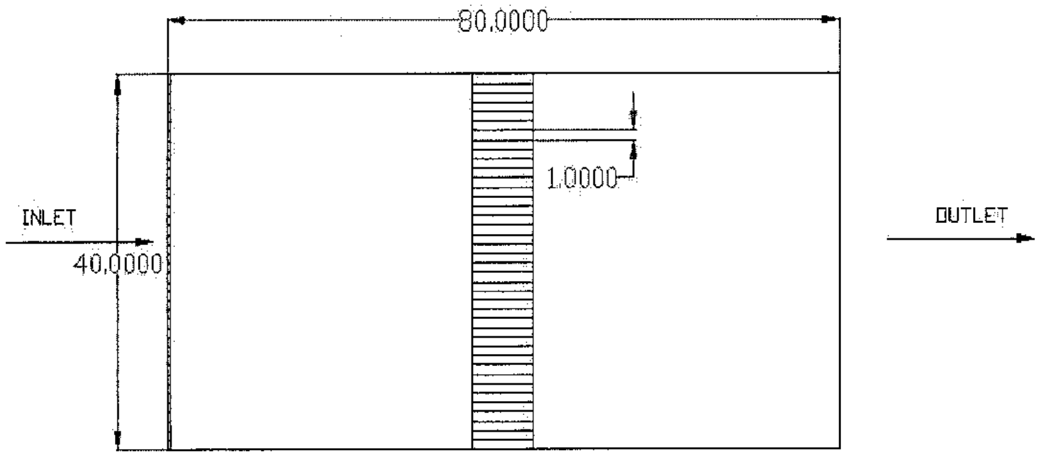


Figure 11 : Scaling Position from Top and Side View

Allowance is 5cm for test section chassis. The analysis has been done by observing the thread behavior along this scaled section in two portions at the top and side os tunnel surface. The portion has been separated by at the center of the test section as shown in pictures below:

Side View

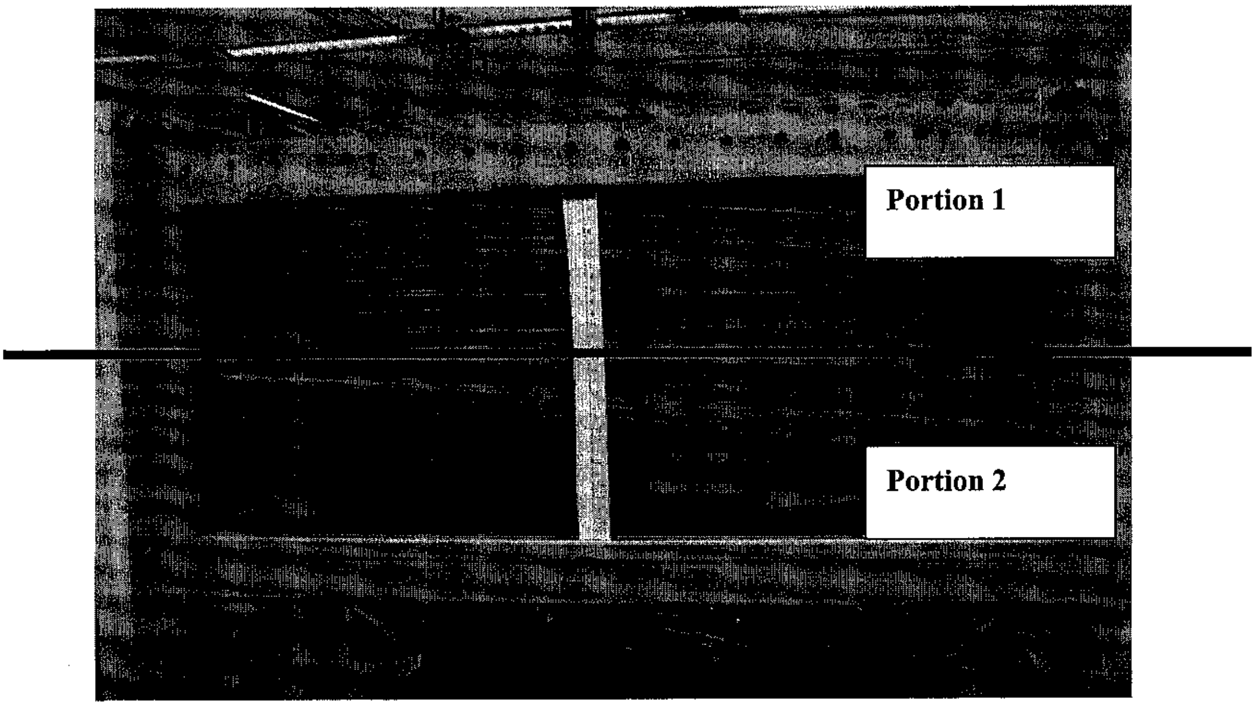


Figure 12 : Test section-Side View

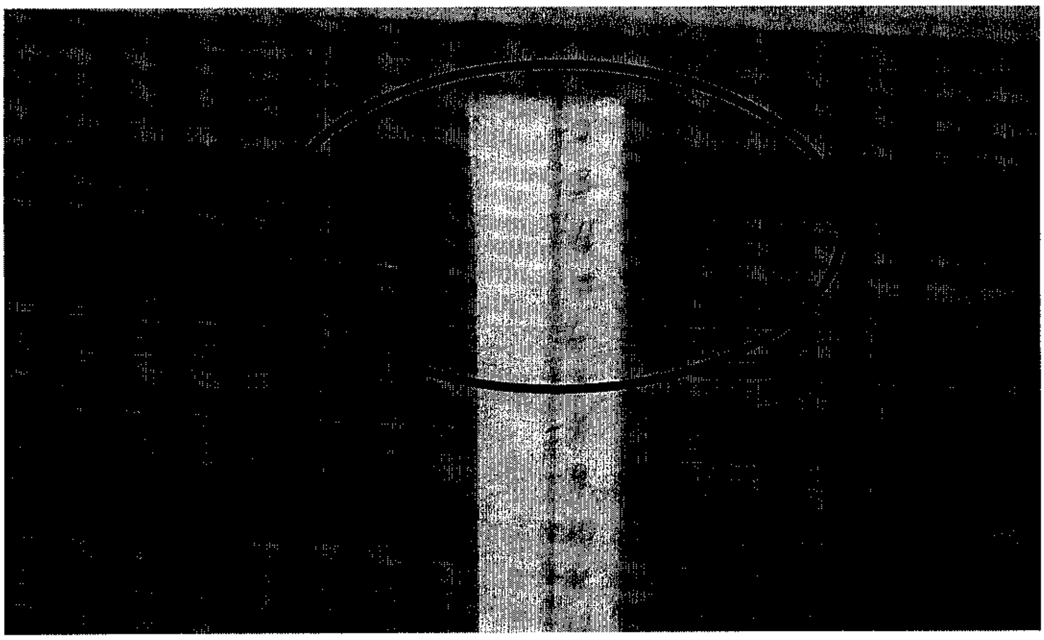


Figure 13 : Portion 1 from Side View

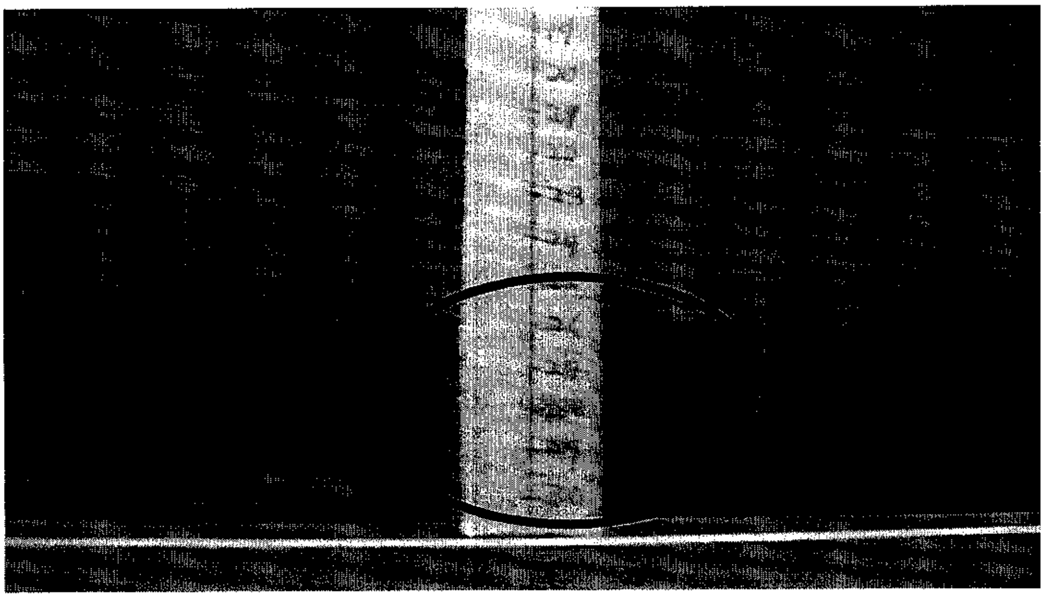


Figure 14 : Portion 2 from Side View

Side view used to visualize the general air flow at top and bottom of test section. As can be visualize from portion 1 Figure 13, spacing within surface is from 0cm-4cm (0cm-9cm -after allowance has been considered). This can be caused by the weight of the thread. Portion 2 from Figure 14, showed that the spacing from the surface is very small, which is about 0cm-5cm (after allowance has been considered).

Top View

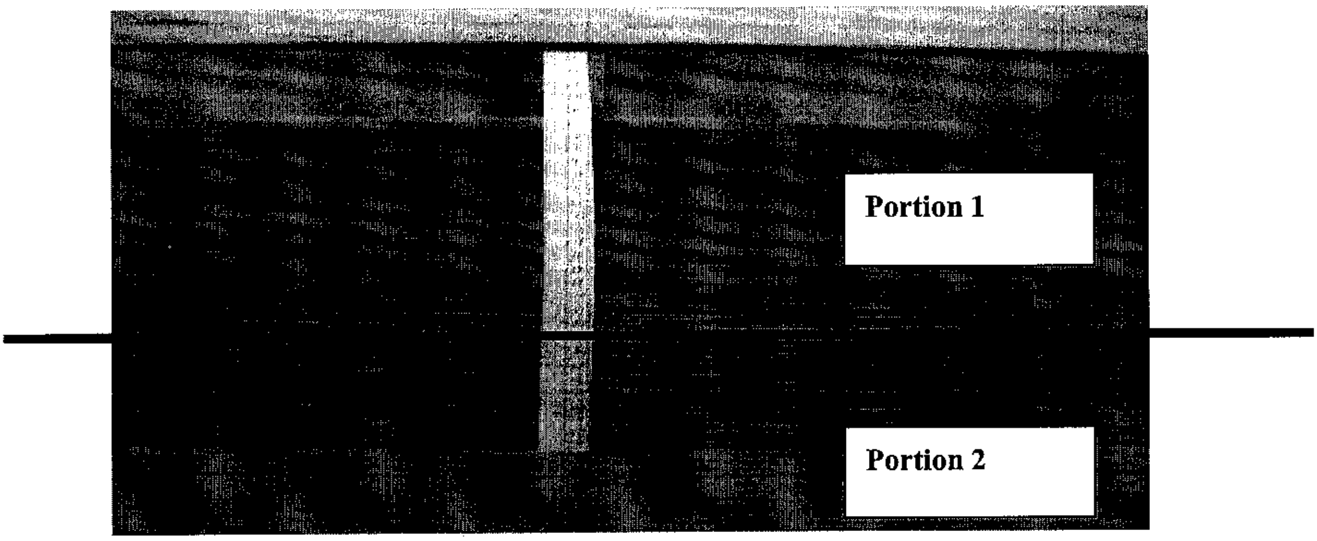


Figure 15 : Test Section-Top View

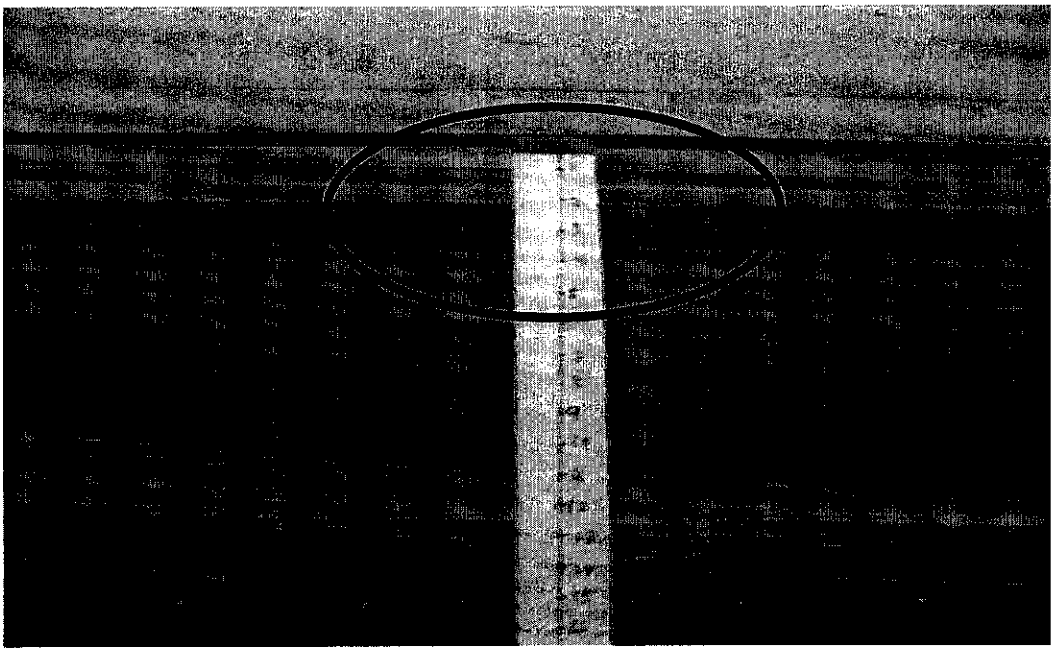


Figure 16 : Portion 2 from Top view

It can clear be seen from Figure 15, there isn't so much spacing within surface and thread, which can be suitable for model installation. However portion 1 Figure 16 shows that the spacing is from 0cm-3cm (0cm-8cm - after allowance has been considered).

The flow observed from figure 14 and 15 shows the best area of air flow, since the spacing within surface and thread is very small.

RECOMMENDATION

These recommendations proposed to project partner for the enhancement of wind tunnel performance. The recommendation comprises of:

1. To verify back velocity at center of test section and study the problem occur, if any.
2. To install honeycomb for the enhancement of quality flow performance.
3. To verify the relationship between high and low speed testing.
4. To use implement hardware and software integration by using Master Cam for the fabrication of smoke generator.
5. To install smoke system (smoke injector and smoke generator) for visualization purposes.

CONCLUSION

Major theories of aerodynamics and the tunnel system have been understood in order to design and fabrication the wind tunnel. Since the project concern was more on designing the wind tunnel for flow visualization purpose, the discussion of aerodynamics narrowed down to vehicle air streamline visualization. The fabrication has finished accordingly. Major problems occurred during fabrication activities has been identified and solved respectively. Type of fan to drive the tunnel has been purchased. Tunnel assembles for all major and minor parts have been conducted. Test run has been implemented to check for tunnel ability and sustainability. Testing procedure has been conducted to study more detail on flow behavior inside the test section. Flow characteristic and turbulence intensity inside the tunnel has been observed. The tunnel is now ready to produce 11m/s inside test section with turbulence intensity ~0.8% and prepared for installation of smoke system.

REFERENCES

1. Jewel, William, Alan Hope. 1999, Low Speed Wind Tunnel testing, *Wiley Interscience Publication – page 35, 71.*
2. Technical notes- R.D Mehta P. Bradshaw 1979, Design Rules for Small Low Speed Tunnel.
3. Email – Rob Hafernik, Engineer, various, *Shockwave Software, Inc*, *Mad Science Network*
4. Journal – Mohd Arief Mohd Noor, Lecturer, UTP, Wind Tunnel Testing
5. A practical guide – Finn E Jorgensen, How to measure turbulence with hot wire anemometer, *Dantec Dynamics*
6. http://vonkarman.stanford.edu/tsd/pbstuff/tunnel/tunnelconfig.html
7. R.H Barnard. 1996, Road Vehicle Aerodynamics Design, *Addison Wesley Longman limited.*

Appendices

A. Project Milestone

B. Material Procurement Package Updated

C. Construction Drawing

D. Design Drawings Updated

- **3 Dimensional Drawings**
  - **a. Main Components**
  - **b. Supplementary Components**
  - **c. Detail on test section and settling chamber**
- **2 Dimensional Drawing**

E. Formulas from Hot Wire training manual

F. Experimental and calibration data

G. Fabrication Pictures

APPENDIX A

Project Milestone

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■													
	-Propose Topic														
	-Topic assigned to students														
2	Preliminary Research Work		■	■											
	-Introduction														
	-Objective														
	-List of references/literature														
	-Project planning														
3	Submission of Preliminary Report			●											
4	Project Work				■	■	■	■							
	-Reference/Literature														
	-Design Activities														
5	Submission of Progress Report								●						
6	Project work continue								■	■	■	■			
	- Design Activities														
7	Submission of Interim Report Final Draft												●		
8	Oral Presentation													●	
9	Submission of Interim Report														●

● Suggested milestone

■ Process

MILESTONE FOR SEMESTER TWO OF FINAL YEAR PROJECT

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continue		■	■											
	Design Review Design Confirmation Analysis Comparison Construction Drawing Preparation														
2	Submission of Progress Report 1			●											
3	Project Work Continue				■	■	■	■							
	Analysis Comparison – cont Construction Drawing - cont Material Selection Material Preparation Fabrication														
4	Submission of Progress Report 2								●						
5	Project work continue								■	■	■	■			
	Fabrication – cont Testing - Laboratory Work														
6	Submission of Dissertation Final Draft												●		
7	Oral Presentation													●	
8	Submission of Project Dissertation														●

APPENDIX B

Material Procurement Package

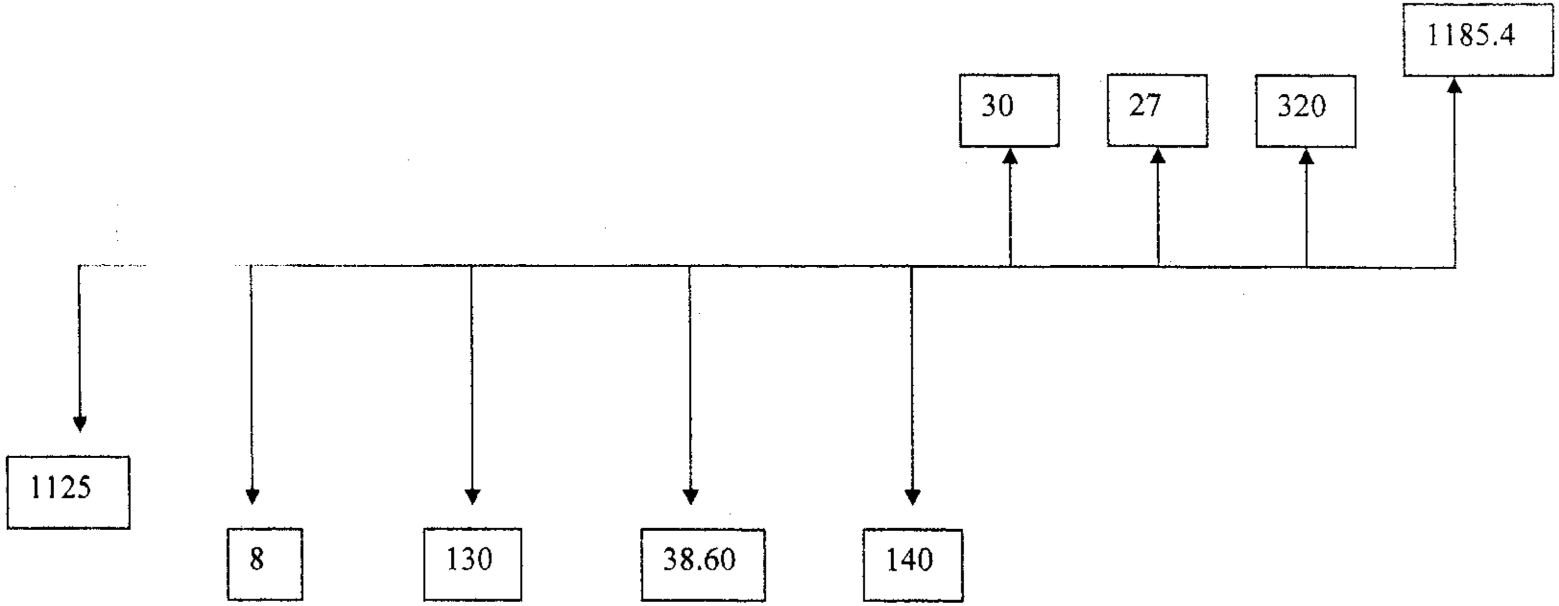
Procurement Package - Preparation of Material Selection for Fabrication Process

Parts	Material	Size Required (m)	Size available (m)	Quantity Required	Cost/piece (RM)	Cost (RM)	Receipt number
Diffuser	MDF	3 × 1.2 × 0.01	1.22 × 2.44 × 0.006	4	24.00	96.00	k42861
Test Section	Perspex	1.2 × 0.8 × 0.01	0.6 × 0.6 × 0.003	4	35.00	140.00	159859
Nozzle	MDF	1.3 × 1.6 ×0.01	1.22 × 2.44 × 0.006	3	24.00	72.00	k42861
Settling Chamber	MDF	1.6 × 0.8 × 0.01	1.22 × 2.44 × 0.006	2	24.00	48.00	k42861
Base -1	MDF	1.54 × 1.4 × 0.03	1.22 × 2.44 ×0.018	1	55.00	55.00	k42861
Base -2 (2 part)	MDF	1.54 × 0.82 ×0.03	1.22 × 2.44 ×0.018	1	55.00	55.00	k42861
Delivery Charge						30.00	k42861
Screen	Wire	1.6 × 1.6	0.9 × 0.9	2	7.20	14.40	162190
Honeycomb	**Straw (0.011 m)**	**6800 straw (1/2)**	**240 straw 1 pack**	**15 pack**	**3.50**	**60**	**Project continuation**
Outsource services	Fabrication					320.00	F01
Variable Speed Controller	Electronic			1		50	
Fan				1		280	72658
Consumables(Bolts, nuts and washer, nails, Glue)						11.40	162795

Electrical Appliance(Wire, adaptor, plug)				1		7.00	161173
					Total	1238.80	

Above list has been developed by referring to all receipts gained from seller and fabricator. The need of honeycomb should depending on flow quality inside the tunnel test section. This material will not be purchased if the tunnel already has a good flow quality. However, we can only decide after the tunnel has been put under testing procedure. A variable speed controller is going to be purchased as soon as possible after the tunnel has been installed, since we need it to run testing procedure. The need of this equipment is to get variable since we need to visualize at what condition the smoke will disperse.

These are the summary of cost by depending on Form 03. Amount of reduction and addition has been taken by comparing the above material list and Form 03. Cash flow diagram for this process were as follow:



Cash flow diagram for coat comparison of form03 and above list

Material	Reduction(RM)	Addition(RM)
Spray Paint	8.00	
Speed Controller	130.00	
Consumables	38.60	
Perspex	140.00	
Fan		30.00
Electrical Appliance		7.00

Fabrication		320.00
Total	316.60	357.00

Table 1: Reduction and Addition of Cost by referring to Form 03 and above list

It seems that the budget has increase to RM1185.40 which is not parallel to Form 03. However this budget can be decrease if we are not using the honeycomb as has been discussed before.

Doc. Ref. No.	Issue Version	Date
UTP-ACA-PROG-FYP-01.03	1.0	22 JUNE 2001

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FORM 03

FINAL YEAR PROJECT REQUISITION FORM

(Note: Supervisor can use this form to request (a)purchasing consumables and quipment , (b)technical support, (c) nomination of advisors and other related resources to the project, (d) visit for data collection.)

REQUESTED BY	
ervisor's Name	Mohd Arief Mohd Nor
ject Title	Design and Fabrication of Small Scale Wind Tunnel
ervisor's Signature	[signature]
lent's Name	Aimaduddin Mazli
e	12-01-04

Description	Purpose	Qty	Est Cost (RM)
MDF (1.22m×2.44m×0.006m)	Building Diffuser, Nozzle, Settling Chamber	9	216
MDF (1.22m×2.44m×0.018m)	Building the Base	2	48
Spray Paint	Surface treatment	2	8
Wire (0.9m×0.9m)	Screen	2	3
Large Size Straw (240 per pack)	Honeycomb	15	60
Fan	Creating Flow Field	1	250
Perspex	Building Test Section	4	280
Variable Speed Controller	Flow field variation	1	180
Consumables (Nails, Glue, String and etc)	Assembly		50
Delivery Charges			30
Working space	For material storage		
Special Tools (ME workshop lab)	Fabrication		
		Total	1125

ORSEMENT BY CO-ORDINATOR	
e	Saravanan Karuppanan
ramme	ME
ature	[signature]
	16/1/2004

ment:
. The constructed model l be used as teaching aid Automotive System Course.

APPROVAL BY COMMITTEE CHAIRMAN	
Name	Assoc Prof Dr. Fakhruldin Bin Mohd Hashim Lecturer, Programme Head Mechanical Engineering Programme
Programme	Universiti Teknologi PETRONAS 31750 Tronoh Perak Darul Ridzuan, MALAYSIA
Signature	[signature]
Date	16/1/04

Approval

☑ Approve ☐ Not Approve

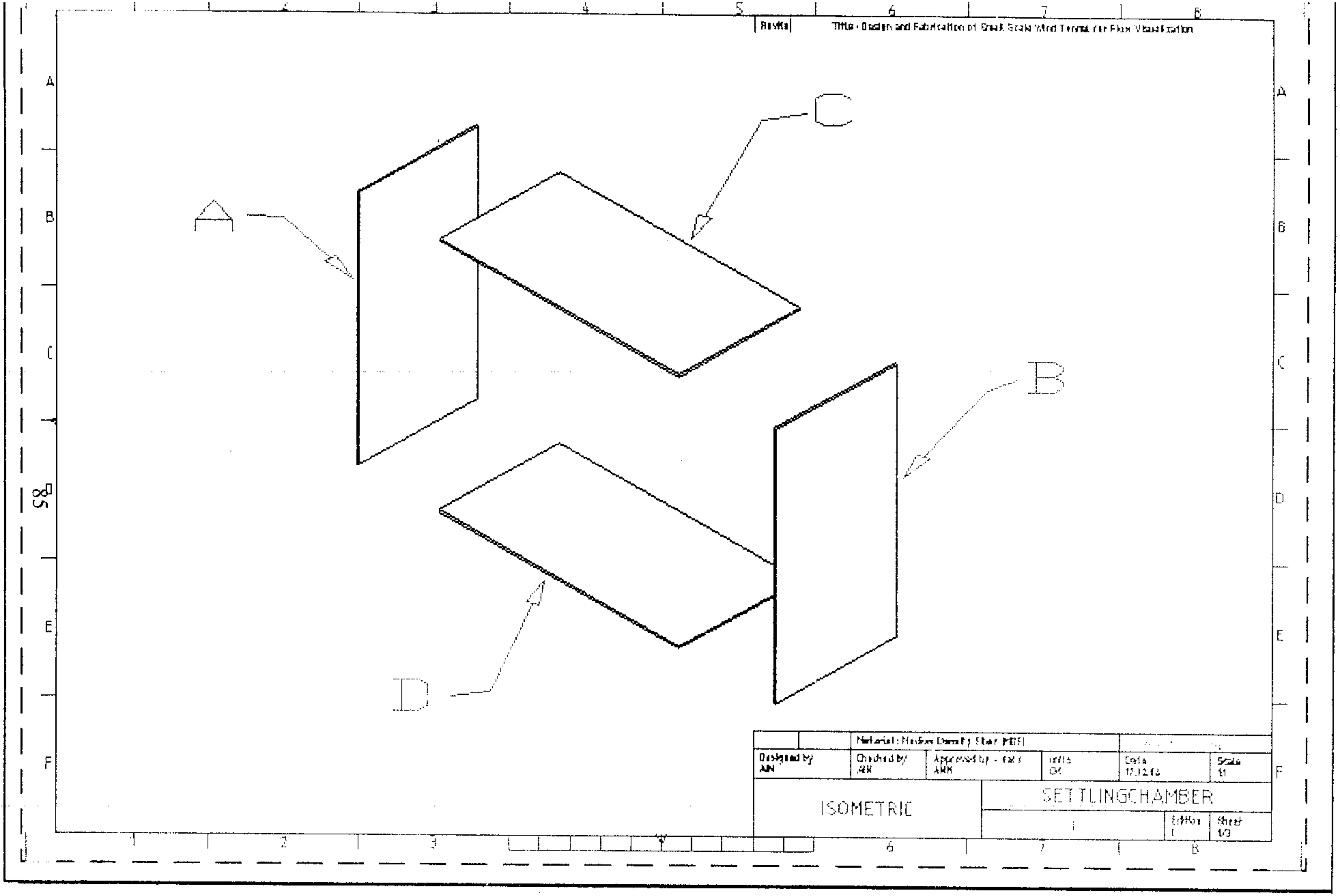
Comment: The prototype to be used for at least 2 sessions & to complement flow measurement Wind Tunnel project by Dr. Asuraini.

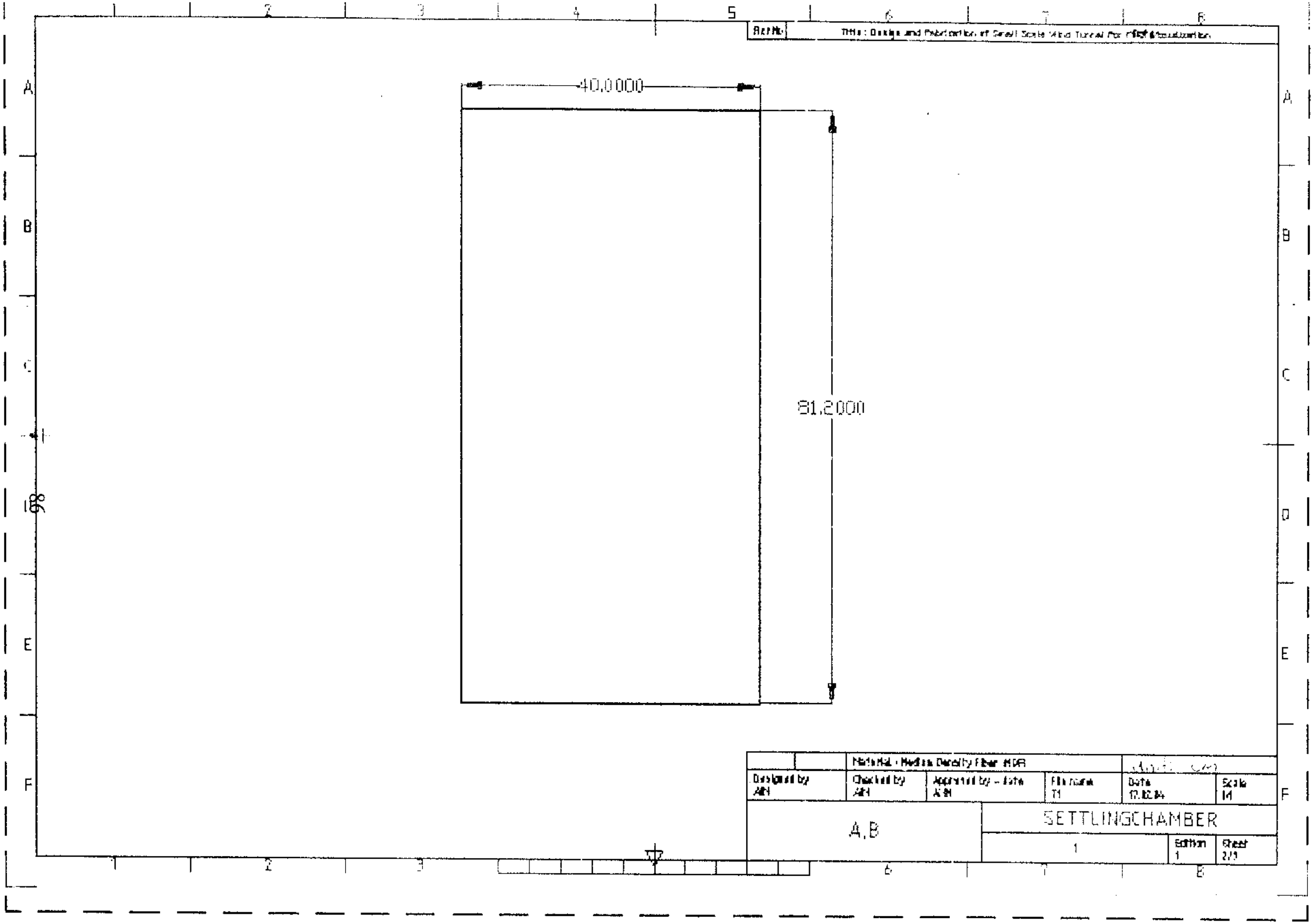
APPENDIX C

Construction Drawings

- Settling Chamber
- Nozzle
- Test Section
- Diffuser

Generated by :AUTOCAD 2002


A
B
C
D
Designed by
Checked by
Scale
Sheet
1/3
ISOMETRIC
SETTLINGCHAMBER



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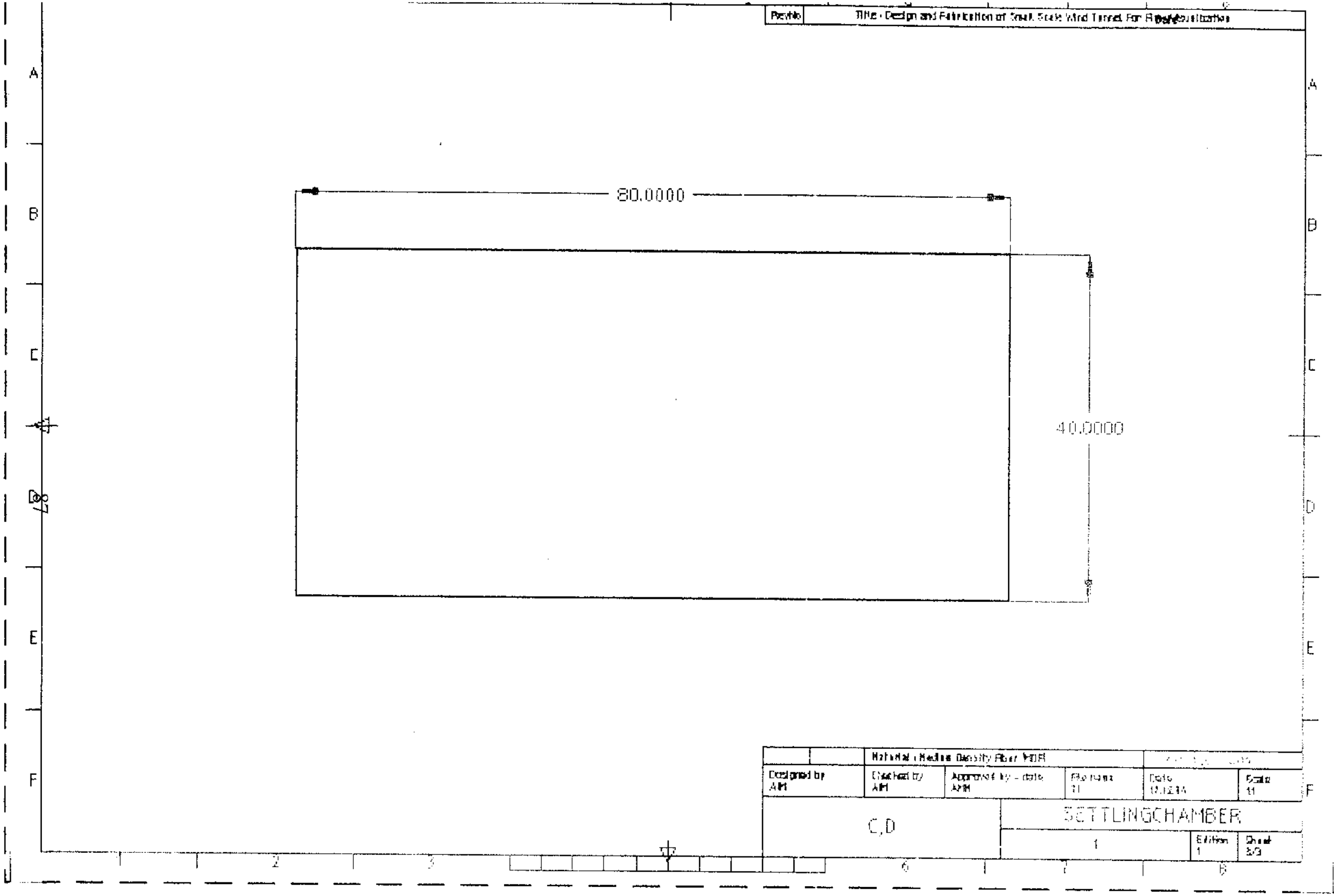
40.0000
81.2000
Material : Medium Density Fiber MDF
Designed by
AIH
Checked by
AIH
Approved by - date
AIH
File name
T1
Date
17.02.14
Scale
1:1
A,B
SETTLINGCHAMBER
1
Edition
1
Sheet
2/3



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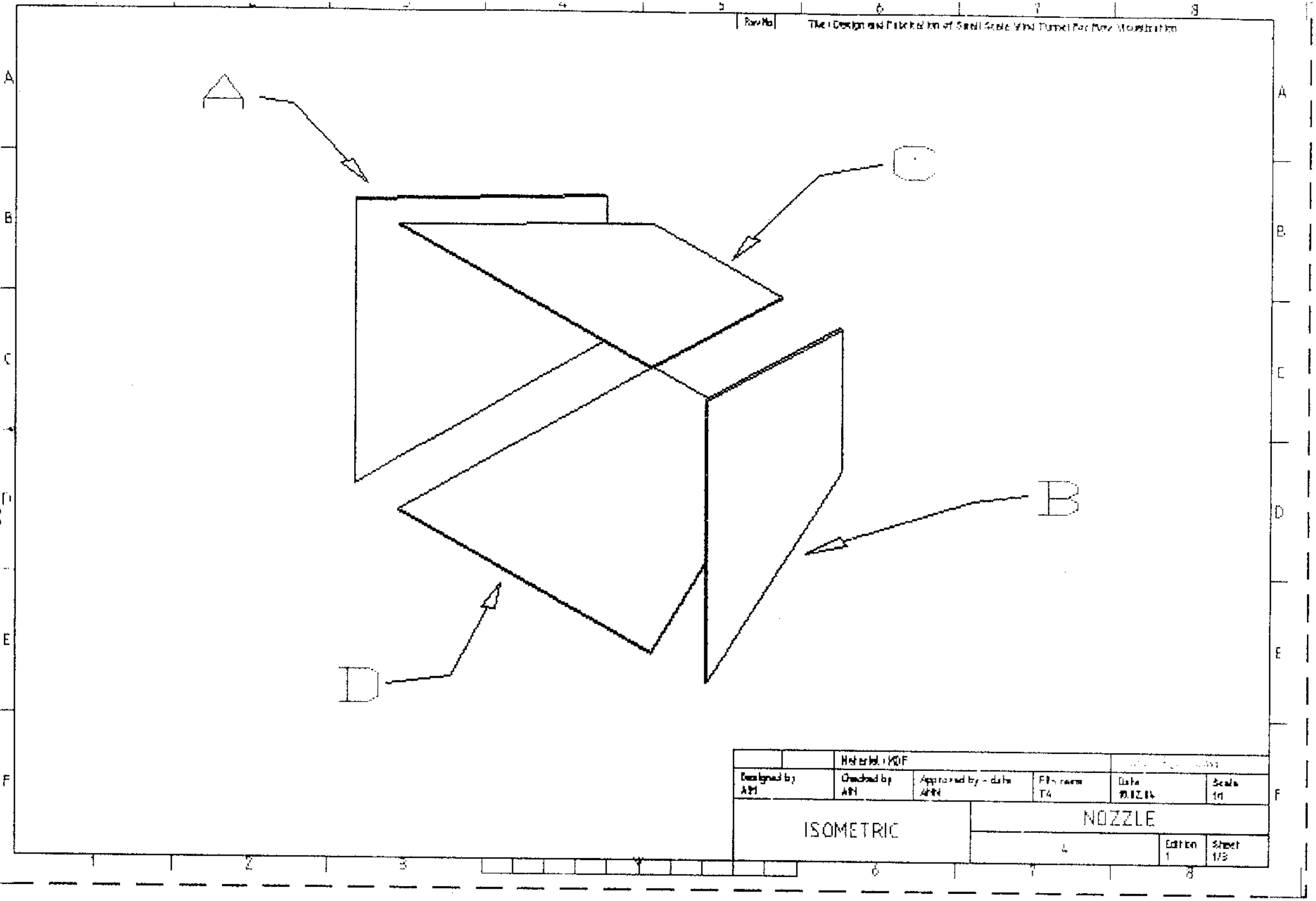
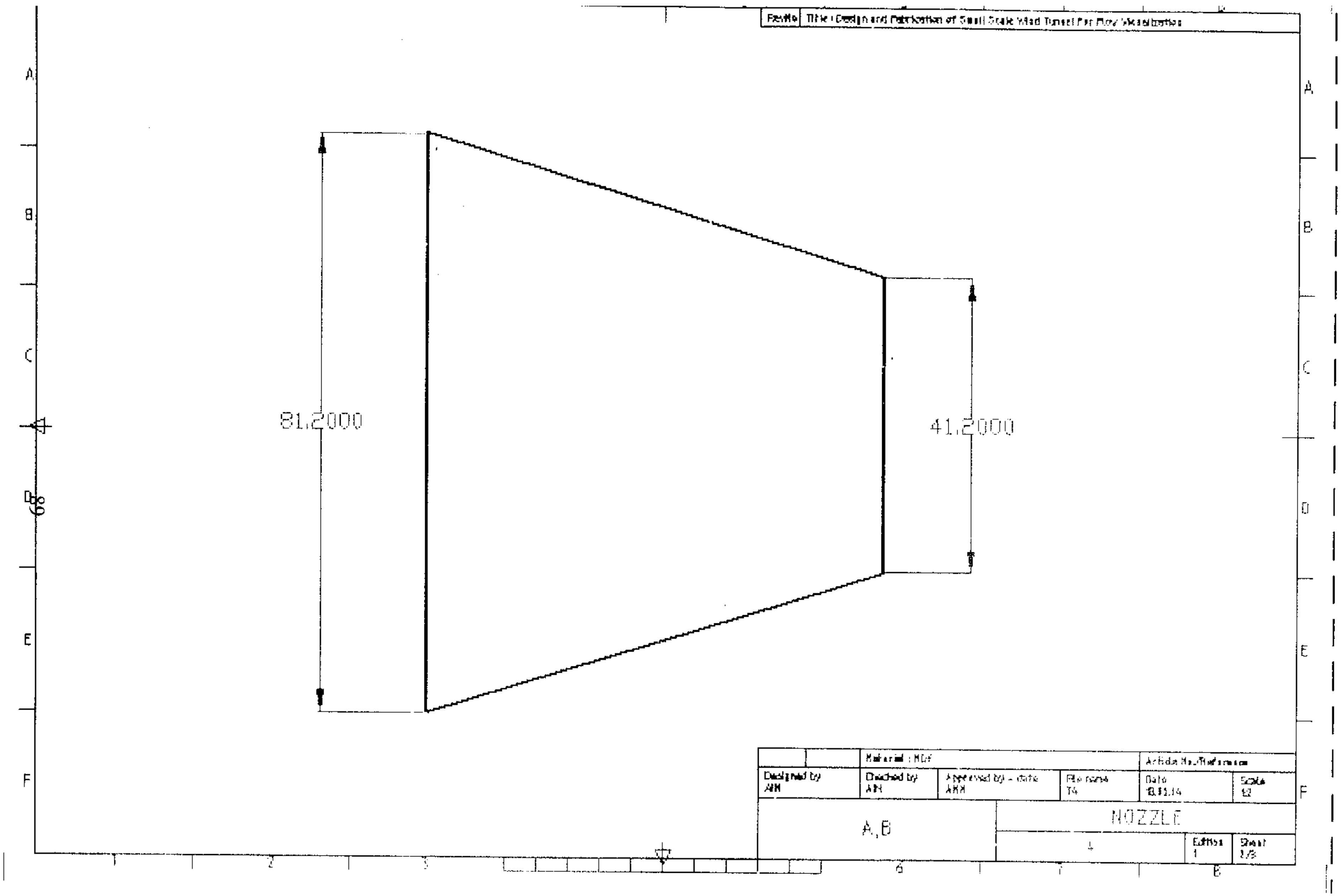
Designed by
AHM
Checked by
AHM
Approved by - date
AHM
Scale
1:1
SETTLINGCHAMBER
C,D
1
Edition
1


A
B
C
D
Designed by
Checked by
ISOMETRIC
NOZZLE
Edition
Sheet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41.2000
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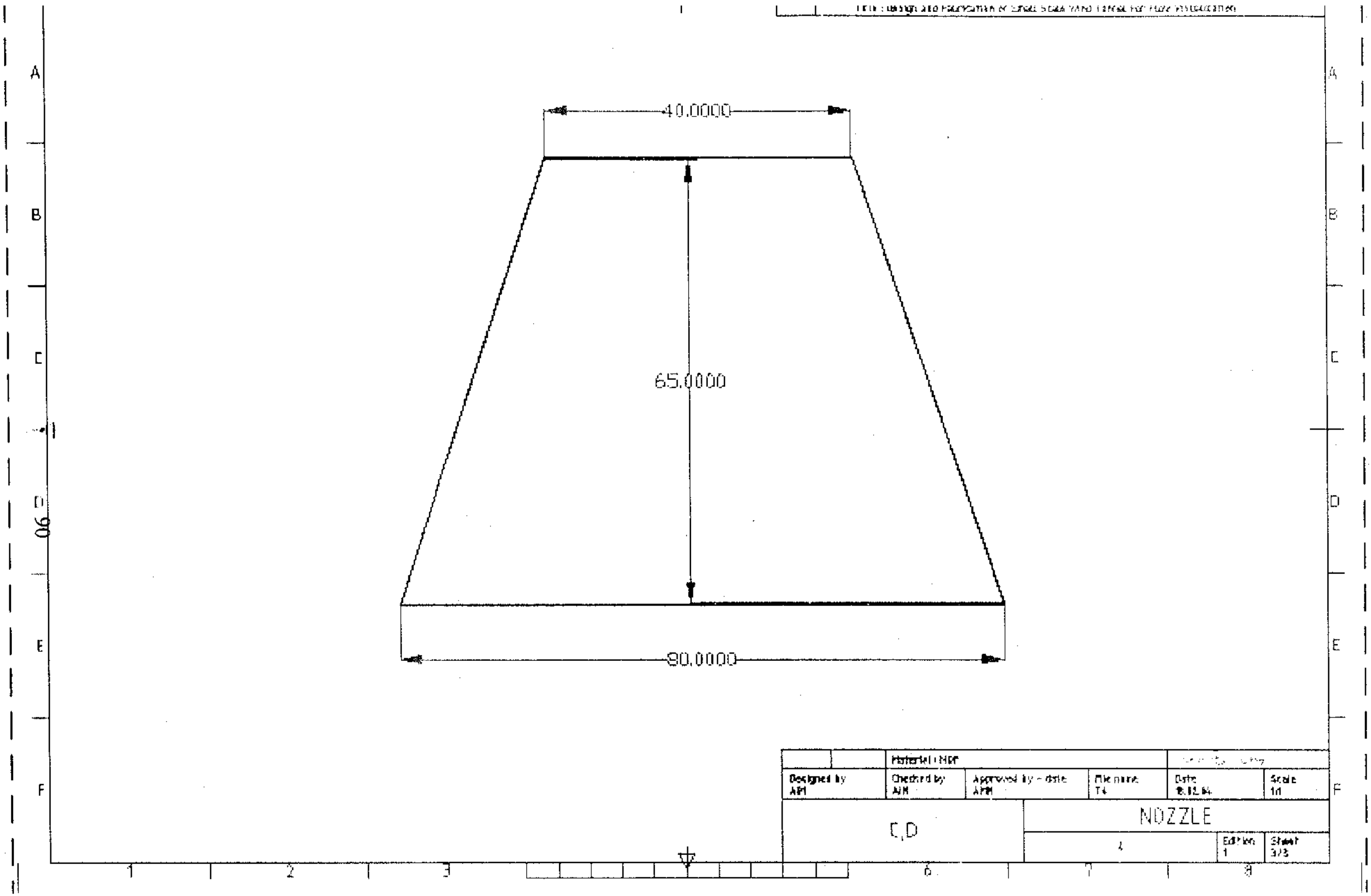
Checked by
Approved by - date
File name
Date
Scale
A,B
NOZZLE
Edition
Sheet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65.0000
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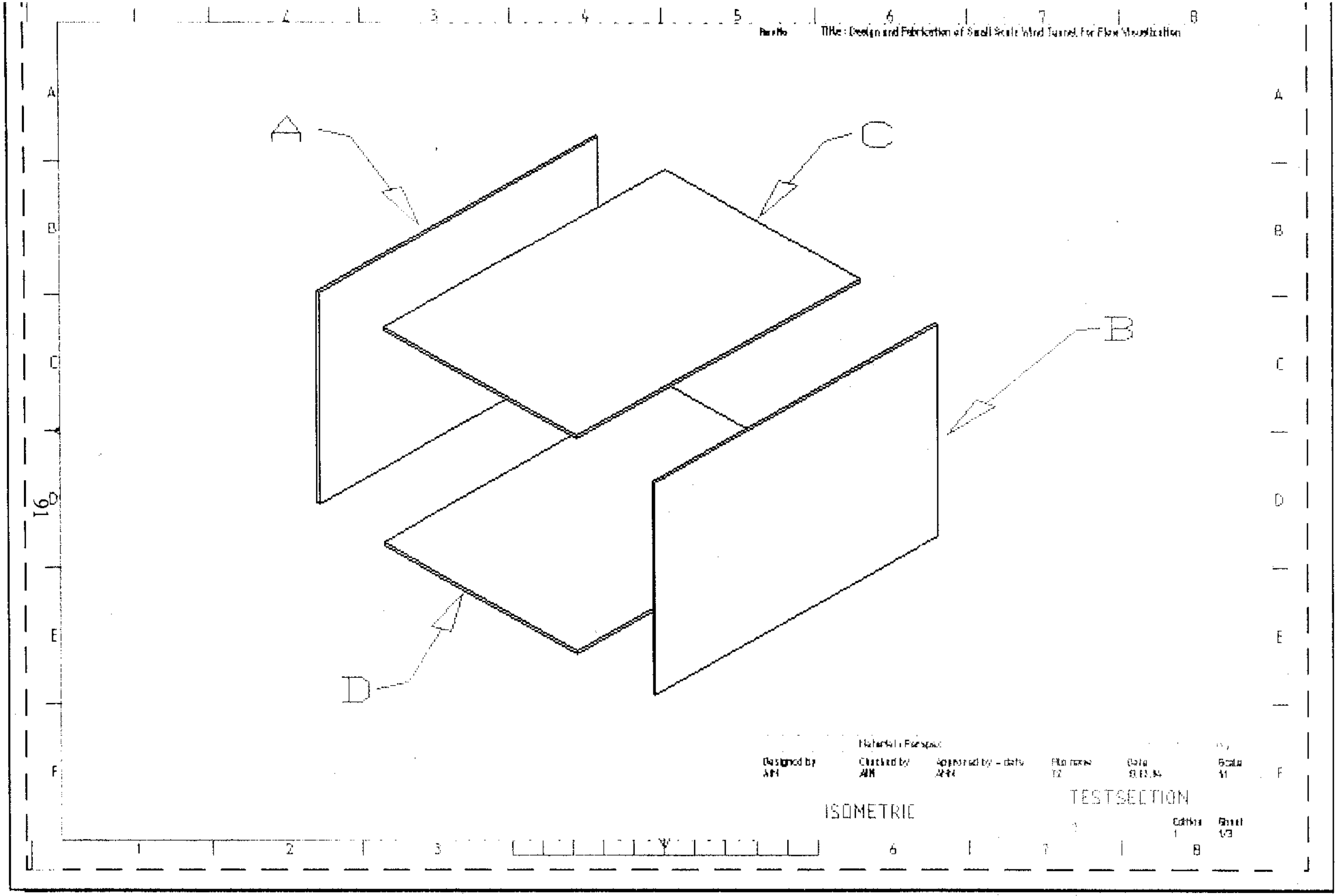
Checked by APM
Approved by - date APM
File name T4
Date
Scale 1:1
C,D
NOZZLE
Edition 1
Sheet 3/3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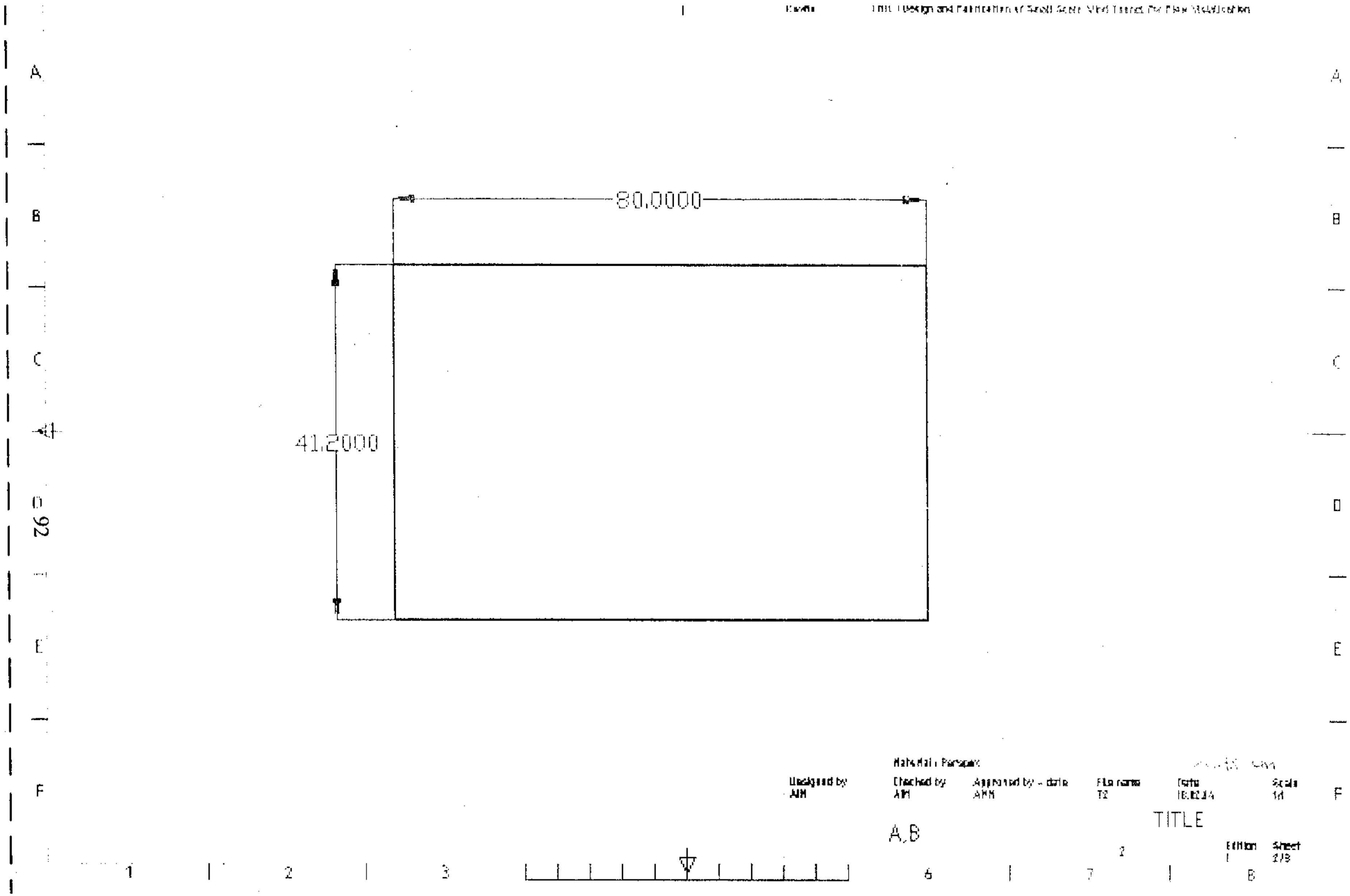
A
B
C
D
Designed by
Checked by
Approved by - date
Date
Scale
ISOMETRIC
TESTSECTION
Edition
1
Sheet
1/3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AIM
Checked by
AIM
Approved by - date
AHM
File name
T2
Date
16.02.14
Scale
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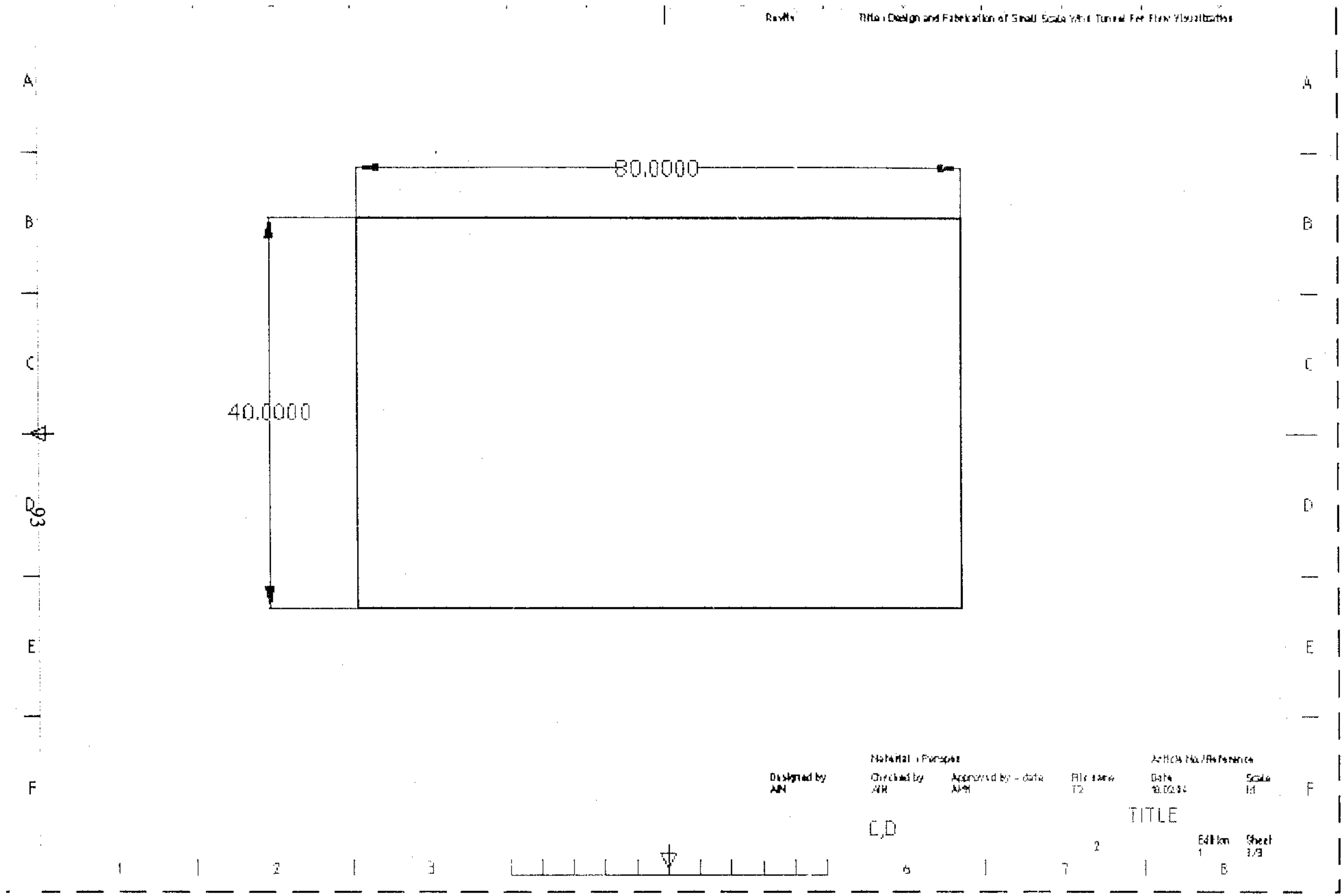
Materials: Perspex
A,B
TITLE
Edition
1
Sheet
2/3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Designed by
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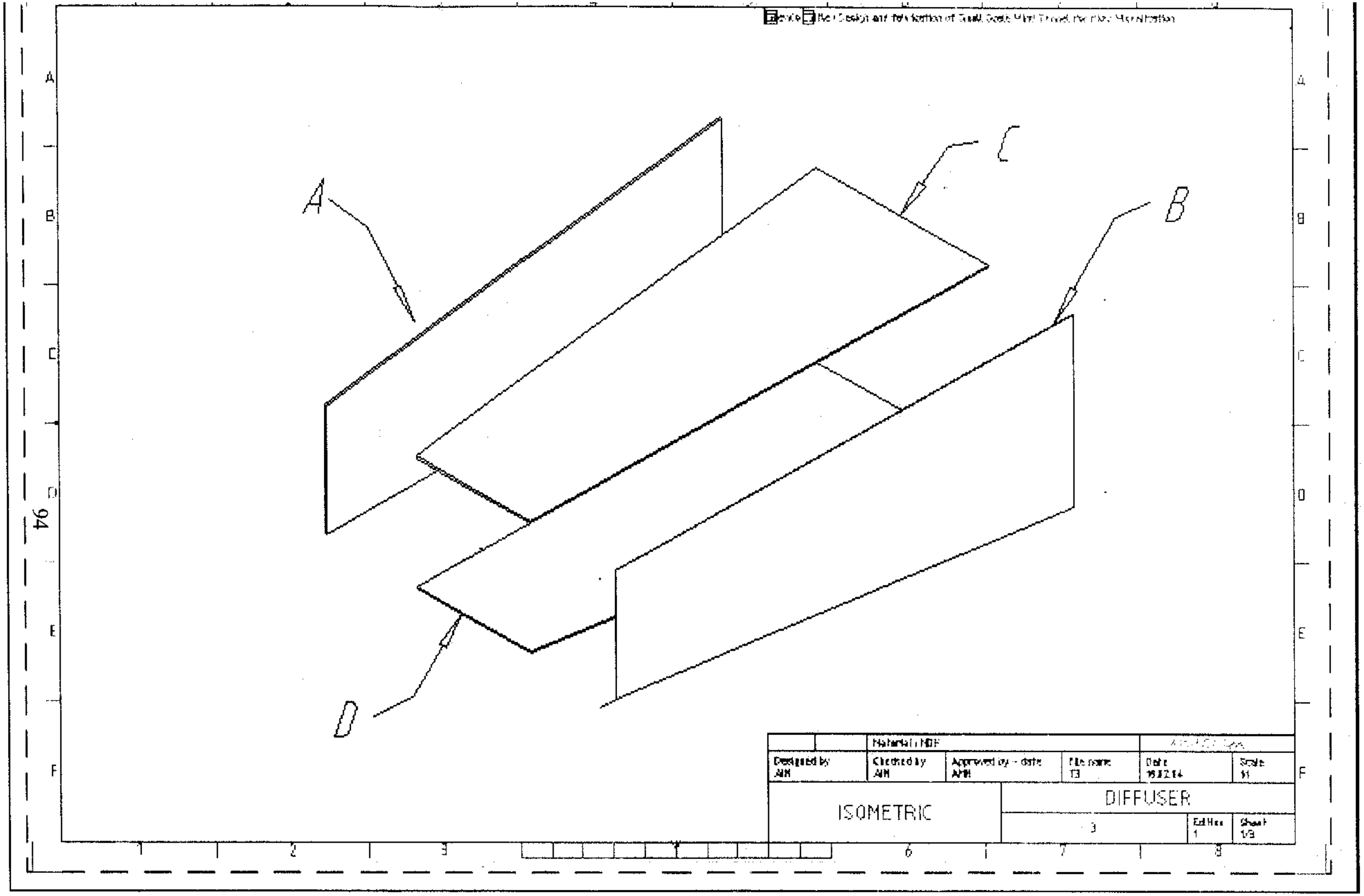
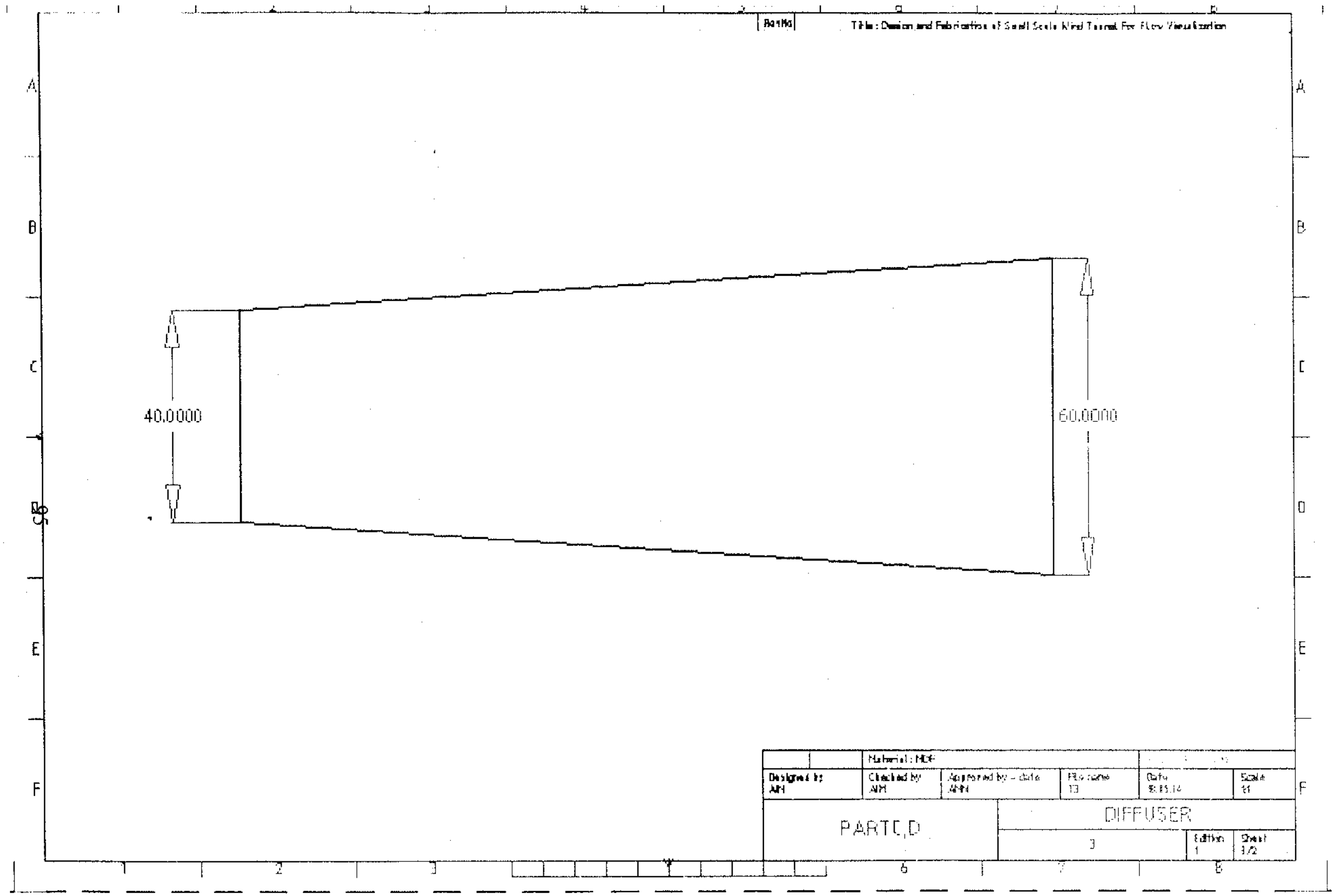
Date
Scale
TITLE
C,D
Edition
1
Sheet


A
B
C
D
Designed by
Checked by
Approved by - date
File name
Date
Scale
ISOMETRIC
DIFFUSER
Sheet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PartNo
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60.0000
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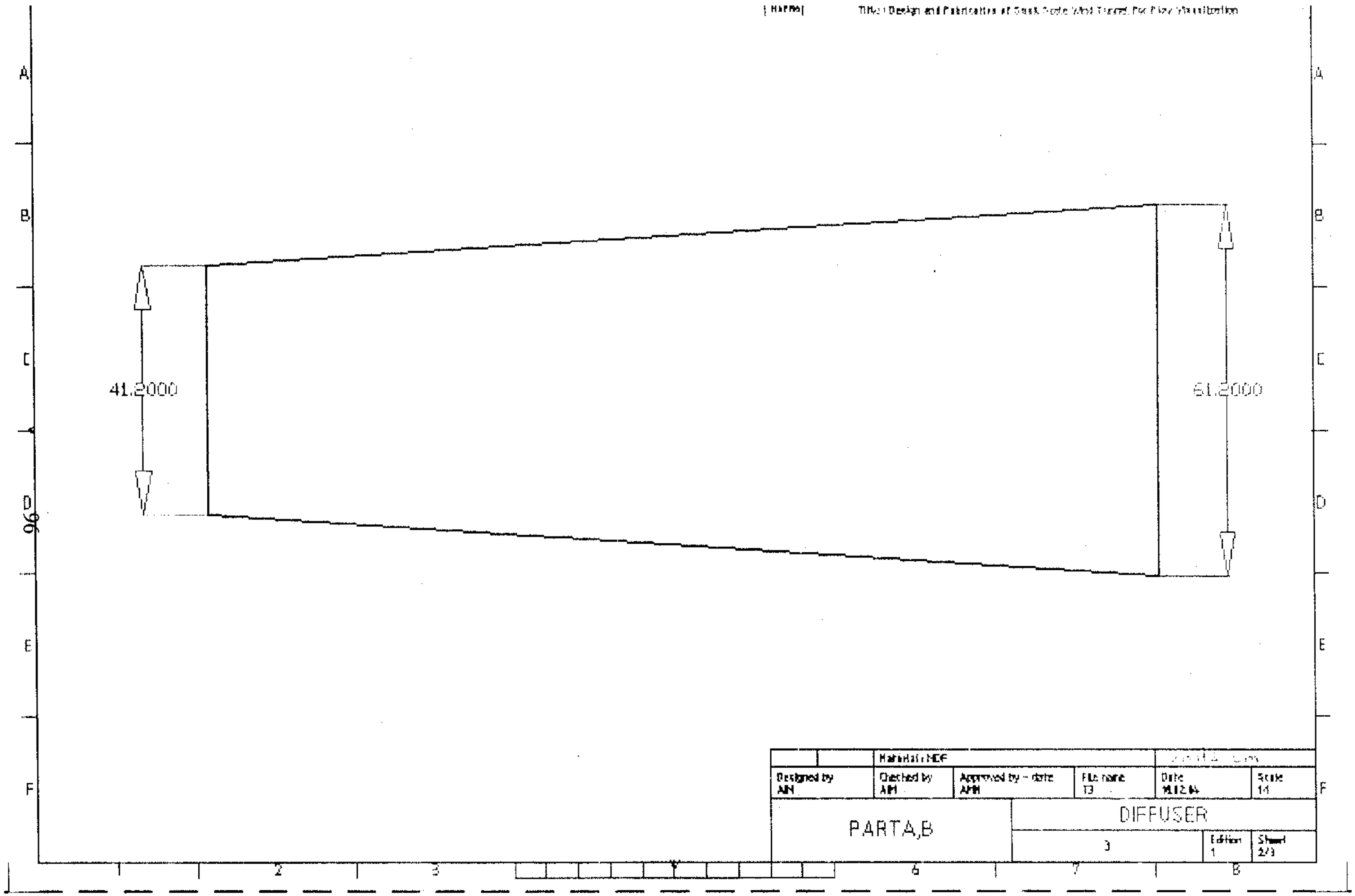
Designed by AIM
Checked by AIM
Approved by - date AHN
File name 13
Date 18.05.14
Scale 1:1
DIFFUSER
PART C,D
3
Edition 1
Sheet 1/2

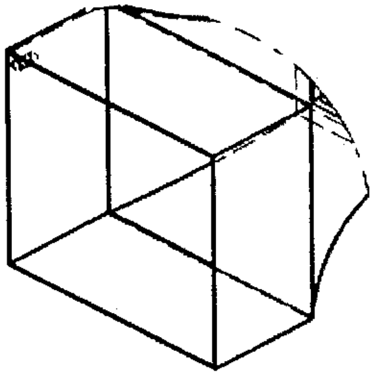

41.2000
61.2000
Designed by
AIH
Checked by
AIH
Approved by - date
AHH
File name
T3
PARTA,B
DIFFUSER
3
Edition
1
Sheet
2/3
Scale
1:1

APPENDIX D

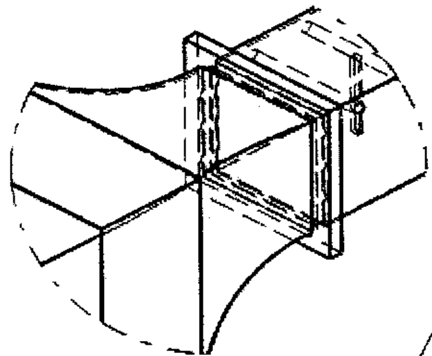
Design Drawings

- Main Components
- Supplementary Components
- Plan View
- Side View
- Front View

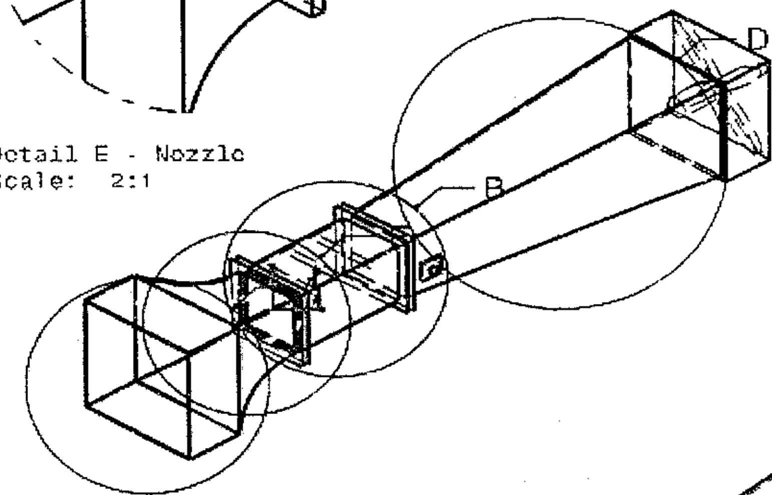
Generated by :Catia V5R6



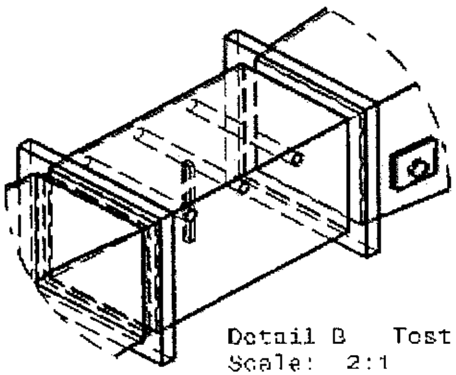
Detail A - Settling Chamber
Scale: 2:1



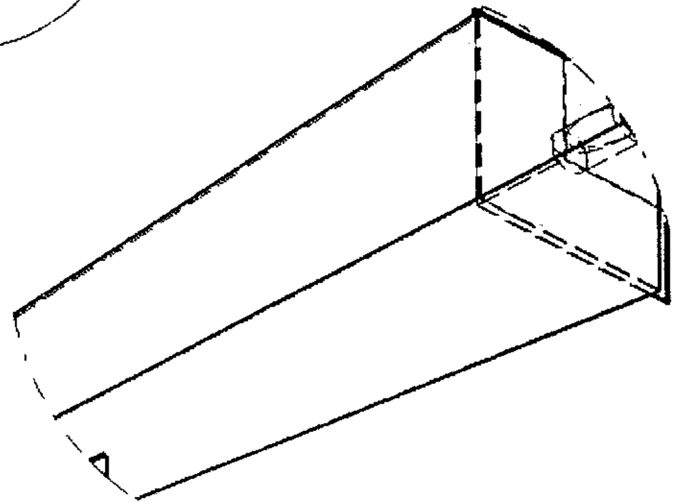
Detail E - Nozzle
Scale: 2:1



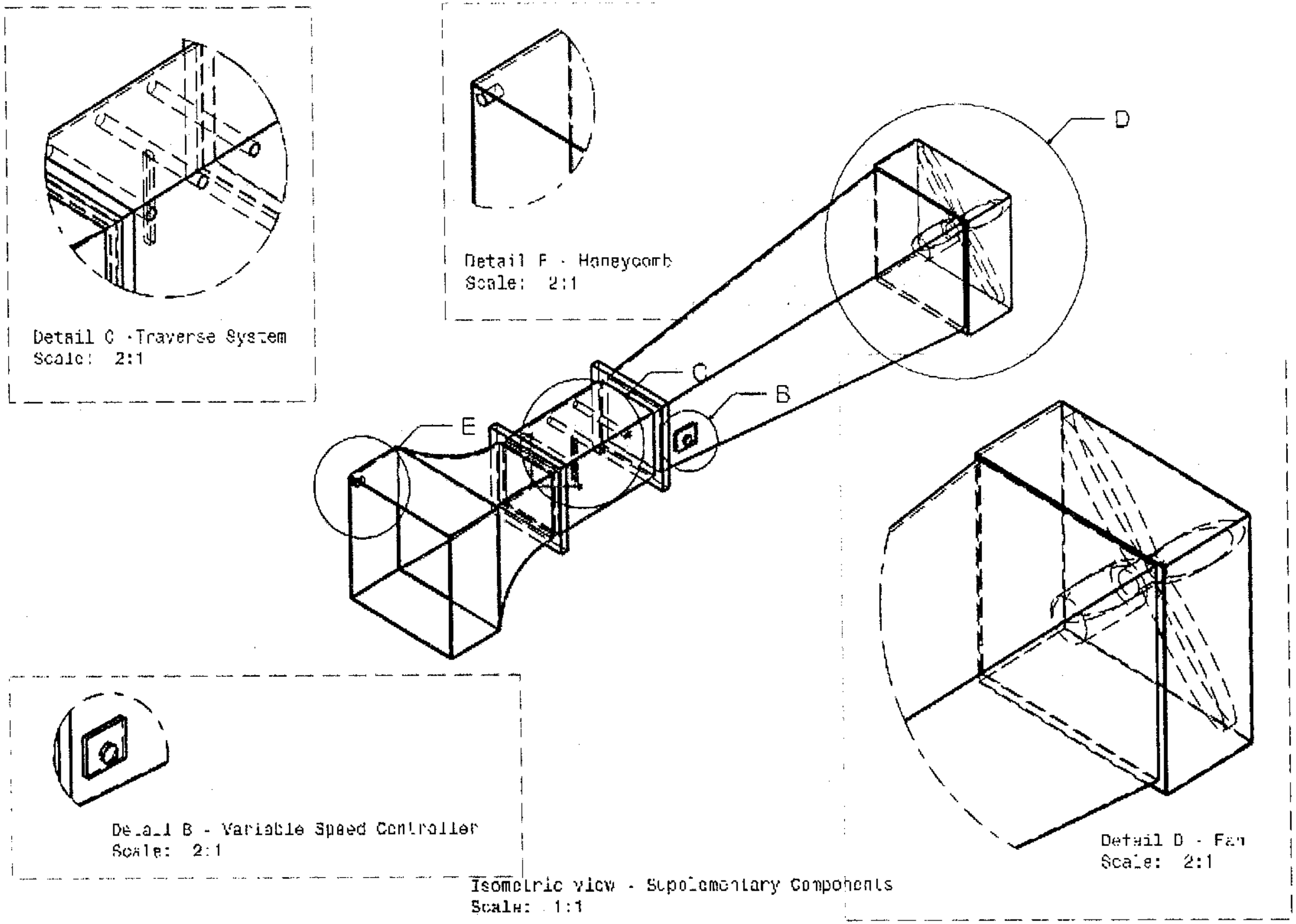
Isometric view - Main Components
Scale: 1:1

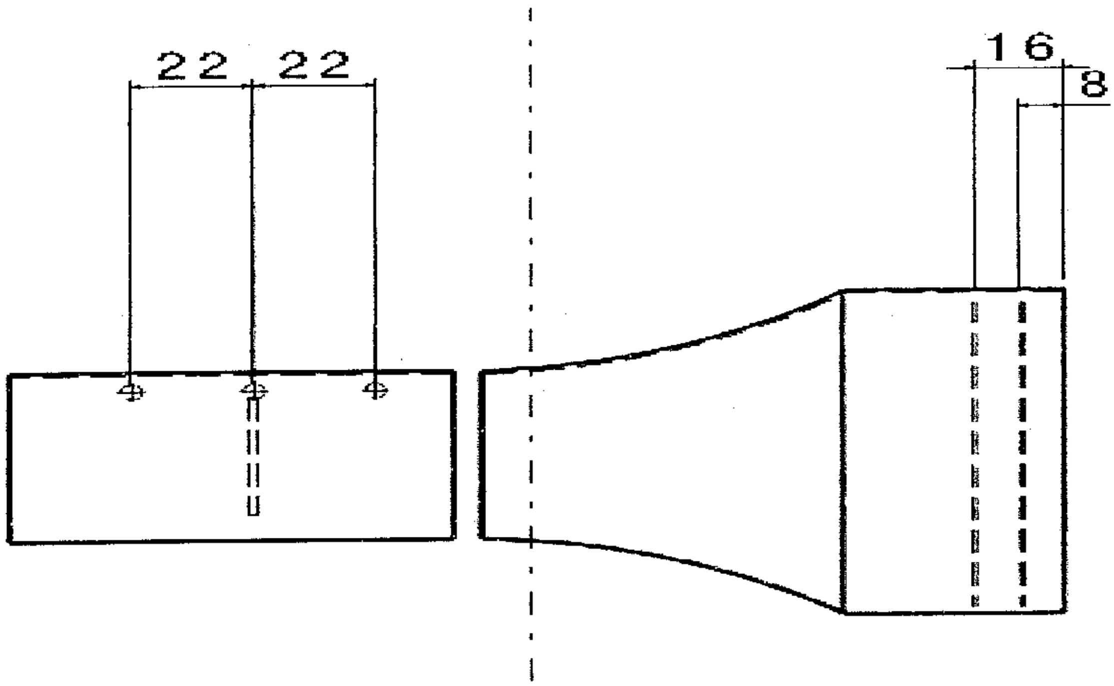


Detail B Test Section
Scale: 2:1

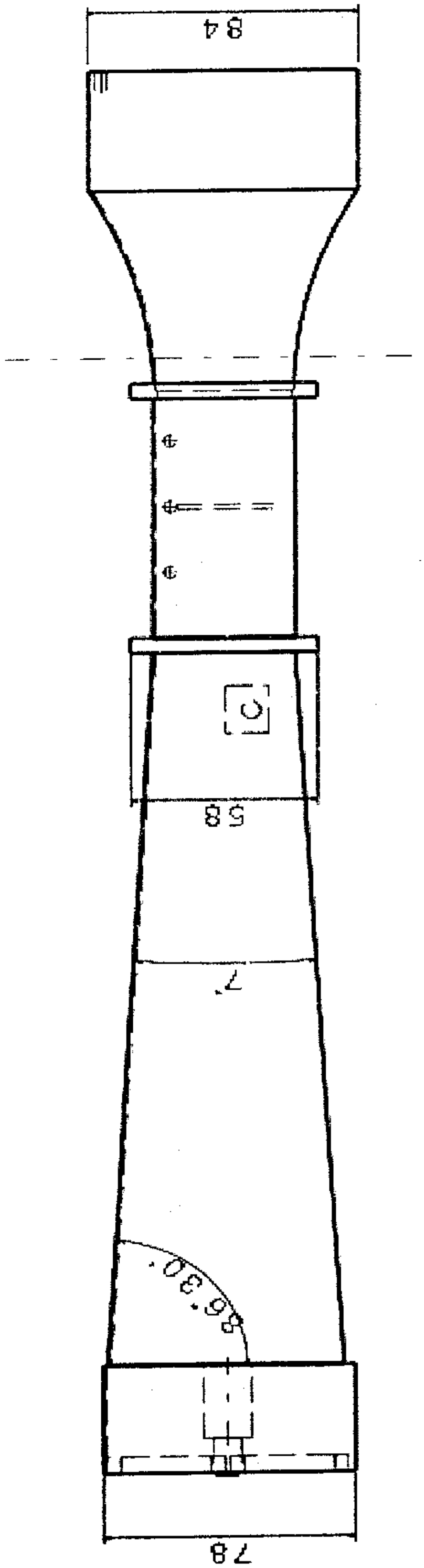


Detail D - Diffuser
Scale: 2:1

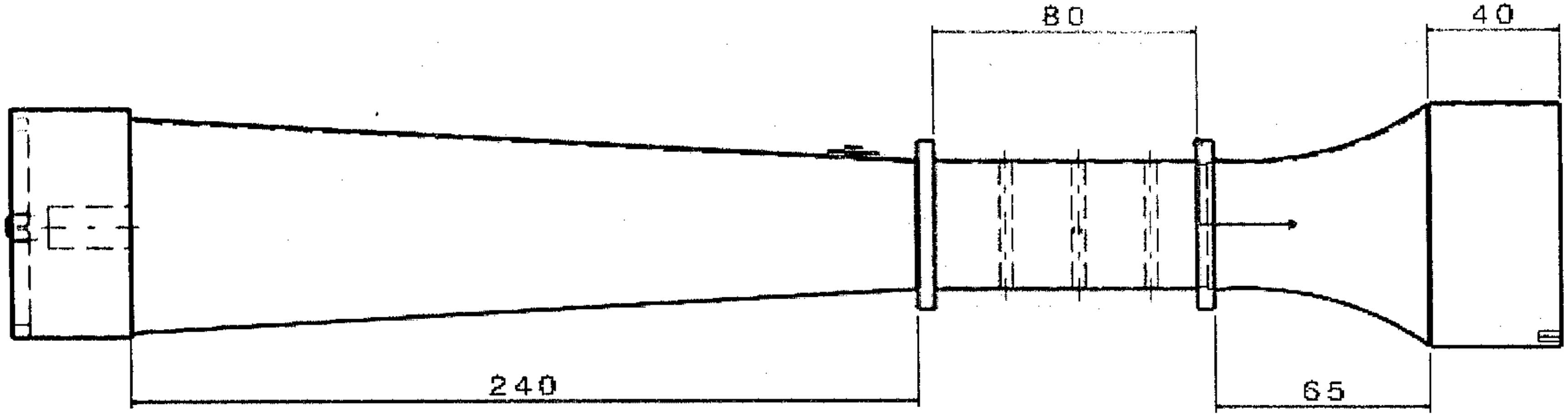

Detail C - Traverse System
Scale: 2:1
Detail F - Honeycomb
Scale: 2:1
D
C
B
E
Detail B - Variable Speed Controller
Scale: 2:1
Detail D - Fan
Scale: 2:1
Isometric view - Supplementary Components
Scale: 1:1



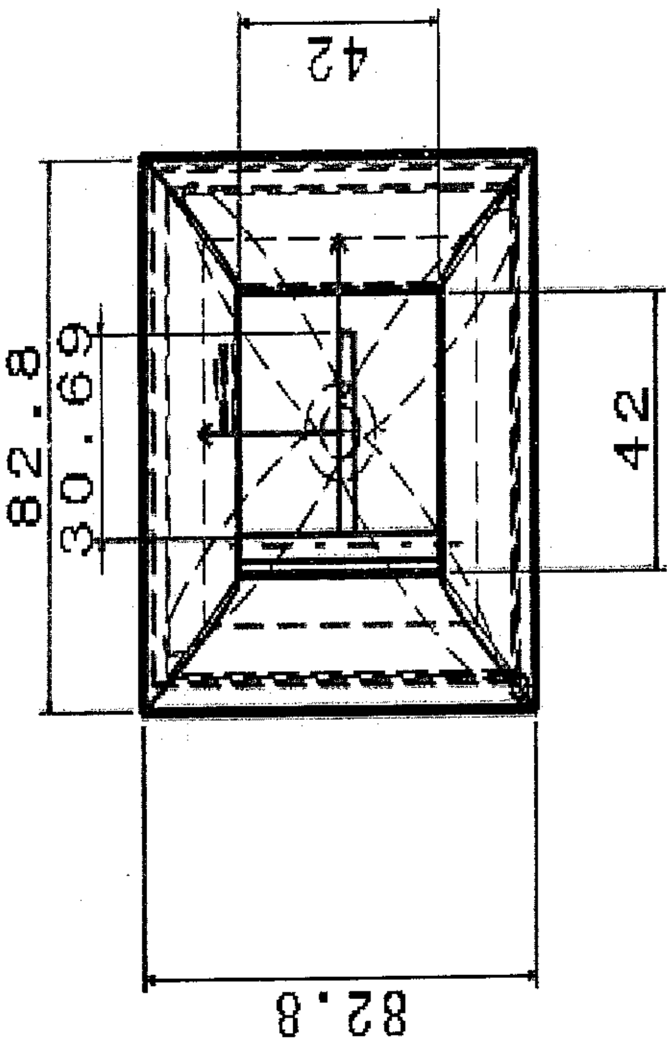
Side View
Scale:
1:1



Side view
Scale: 1:1



Plan view
Scale: 1:1



Front view
Scale: 1:1

APPENDIX E

Formulas from Hot Wire Training Manual

10. DATA ANALYSIS

As the CTA signal from a turbulent flow will be of random nature, a statistical description of the signal is necessary. The time series can be analysed or reduced either in the amplitude domain, the time domain or in the frequency domain. The following procedures all require stationary random data.

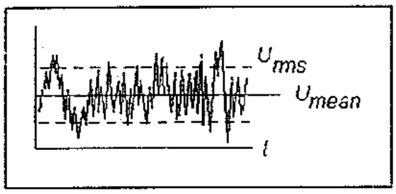
CTA application software contains modules that perform the most common data analysis, as defined below. The standard procedure is to select the wanted analysis and apply it to the actual time series. The reduced data will then be saved in the project and be ready for graphical presentation or for exporting to a report generator.

10.1 Amplitude domain data analysis

The amplitude domain analysis provides information about the amplitude distribution in the signal. It is based on one or more time series sampled on the basis of a single integral time-scale in the flow. A velocity time series represents data from one sensor, converted into a velocity component in engineering units.

A *single* velocity time series provides mean, mean square and higher order moments.

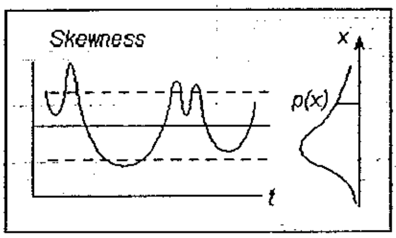
Moments based on a single time series:



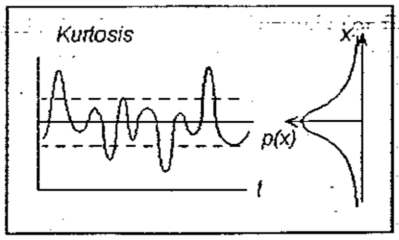
Mean velocity: $$U_{mean} = \frac{1}{N}\sum_{1}^{N} U_i$$

Standard deviation of velocity: $$U_{rms} = \left(\frac{1}{N-1}\sum_{1}^{N}(U_i - U_{mean})^2\right)^{0.5}$$

Turbulence intensity: $$Tu = \frac{U_{rms}}{U_{mean}}$$



Skewness: $$S = \sum_{1}^{N}\frac{(U_i - U_{mean})^3}{N \cdot \sigma^3}$$



Kurtosis (or flatness): $$K = \sum_{1}^{N}\frac{(U_i - U_{mean})^4}{N \cdot \sigma^4}$$

where the variance σ is defined as:

$$\sigma = \left(\sum_{1}^{N}\frac{(U_i - U_{mean})^2}{N-1}\right)^{0.5}$$

The Skewness is a measure of the lack of statistical symmetry in the flow, while the Kurtosis is a measure of the amplitude distribution (flatness factor).

APPENDIX F

Experimental and Calibration Data

Calibration data

File info:

==========

Database ID: C:\WINDOWS\DESKTOP\PROCEDURE\1D\1DSETUP.SDB

Project ID: 1DSETUP

Raw Data Event Time: 12:22:42 AM

Raw Data Event Date: 04/21/2004

Raw Data Event ID: BCENTER

Group no.: 1

=========

Number of probes selected: 1

Number of positions: 3

Local variables:

A B C D E

Data acquired with:

A/D board: National Instruments AT/PCI-MIO-16E-4

Size of file header: 372

Size of user header: 290

Size of probe info: 550

Size of data header: 78

[USER HEADER]:

Creator: aima

Account/project number: 1

Comments:

[PROBE HEADER]:

Probe info.:

===========

Probe name: 55P11

Cable length(m) 4

No. of Sensors 1

Probe type: Wire/Fiber

Data from library:

TCR, alfa, %/deg.C: 0

Bridge ratio: 1:20 (20 ohms)

Bridge top, ohms: 0

Shape: Wire

Data from hardware setup:

Bridge:

Bridge connected: Yes

Total resist., ohms: 0

Sensor resist., ohms: 0

Decade resist., ohms: 0

Cable resist., ohms: 0

Overheat ratio, a: 0

Tref, deg.C: 0

Filter: 13

Gain: 8

Cable comp.: 8

Signal Conditioner:

Lowpass filter, kHz: 30 kHz

Highpass filter, kHz: BYPASSED

Signal offset: 0

Signal gain: 1

AC/DC voltage: DC

Velocity Calibration:

Cal. ref. temp.: 0

Algorithm: Polynomial

Probe sensor no.: 1

Order of polynomial: 4

Min. calibration point (prim.par., Volt) : 0.199571 1.42353

Max. calibration point (prim.par., Volt): 19.8443 2.26315

Coefficients:

C0: -48.5649

C1: 104.547

C2: -77.4192

C3: 19.6983

C4: 2.89071e-008

C5: 0

Conversion/Reduction:

Conversion level: Velocity in probe coordinates

Temperature correction: No

Corrected sensor temp. coefficient:

0.35

[DATA HEADER]:

Position no.: 1

============

Coordinates (x,y,z,a)

(mm,mm,mm,deg): 0 0 0 0

Local variables:

0 0 0 0 0

Block no.: 1

Acquisition date: 04/21/200412:23:04 A

Acquisition time: 12:23:04 A

Sample freq.,kHz: 1000

No. of samples: 1024

No. of columns: 2

Data format: Floating point

Data type: StreamWare Raw Data

Data status: OK

Data Reduction

X pos	Y pos	Z pos	A pos	U mean	U rms
bcenter					
0	0	0	0	11.865	0.056
0	0	0	0	11.651	0.111
0	0	0	0	11.839	0.064
bleft					
0	0	0	0	11.656	0.081
0	0	0	0	11.643	0.122
0	0	0	0	11.762	0.068
bright					
0	0	0	0	11.526	0.071
0	0	0	0	11.657	0.202
0	0	0	0	11.526	0.246
midcenter					
0	0	0	0	11.516	0.07
0	0	0	0	11.384	0.086
0	0	0	0	11.419	0.06

midleft

0	0	0	0	11.448	0.147
0	0	0	0	11.47	0.102
0	0	0	0	11.444	0.093

midright

0	0	0	0	11.435	0.243
0	0	0	0	11.581	0.174
0	0	0	0	11.523	0.232

frontcenter

0	0	0	0	11.376	0.058
0	0	0	0	11.446	0.074
0	0	0	0	11.454	0.061

frontleft

0	0	0	0	11.582	0.073
0	0	0	0	11.549	0.057
0	0	0	0	11.537	0.08

frontright

0	0	0	0	11.154	0.105
0	0	0	0	11.134	0.114
0	0	0	0	11.144	0.115

Point 1 | **Point 2** | **Point 3**

time	u(m/s)	time	u	time	u
0	11.59	0	11.782	0	11.495
0.001	11.59	0.001	11.782	0.001	11.59
0.002	11.59	0.002	11.878	0.002	11.686
0.003	11.59	0.003	11.878	0.003	11.782
0.004	11.59	0.004	11.878	0.004	11.782
0.005	11.59	0.005	11.878	0.005	11.686
0.006	11.59	0.006	11.878	0.006	11.59
0.007	11.59	0.007	11.976	0.007	11.686
0.008	11.59	0.008	11.976	0.008	11.686
0.009	11.59	0.009	11.878	0.009	11.686
0.01	11.59	0.01	11.878	0.01	11.686
0.011	11.59	0.011	11.878	0.011	11.59
0.012	11.495	0.012	11.878	0.012	11.686
0.013	11.59	0.013	11.878	0.013	11.686
0.014	11.59	0.014	11.878	0.014	11.686
0.015	11.59	0.015	11.878	0.015	11.686
0.016	11.59	0.016	11.878	0.016	11.686
0.017	11.59	0.017	11.878	0.017	11.782
0.018	11.686	0.018	11.878	0.018	11.686
0.019	11.686	0.019	11.878	0.019	11.782
0.02	11.59	0.02	11.878	0.02	11.782
0.021	11.59	0.021	11.878	0.021	11.782
0.022	11.59	0.022	11.878	0.022	11.782
0.023	11.59	0.023	11.878	0.023	11.782
0.024	11.59	0.024	11.878	0.024	11.782
0.025	11.59	0.025	11.878	0.025	11.782
0.026	11.686	0.026	11.878	0.026	11.782
0.027	11.59	0.027	11.878	0.027	11.686
0.028	11.59	0.028	11.878	0.028	11.686
0.029	11.59	0.029	11.878	0.029	11.686
0.03	11.59	0.03	11.976	0.03	11.686

0.031	11.59	0.031	11.878	0.031	11.686
0.032	11.495	0.032	11.878	0.032	11.686
0.033	11.59	0.033	11.878	0.033	11.686
0.032	11.495	0.032	11.878	0.034	11.782

Point 4		**Point 5**		**Point 6**	
time	u	time	u	time	u
0	10.845	0	11.59	0	11.495
0.001	11.213	0.001	11.59	0.001	11.495
0.002	11.213	0.002	11.59	0.002	11.495
0.003	11.4	0.003	11.59	0.003	11.59
0.004	11.686	0.004	11.686	0.004	11.495
0.005	11.4	0.005	11.686	0.005	11.495
0.006	11.306	0.006	11.59	0.006	11.59
0.007	11.306	0.007	11.59	0.007	11.59
0.008	11.495	0.008	11.59	0.008	11.495
0.009	11.495	0.009	11.59	0.009	11.59
0.01	11.686	0.01	11.59	0.01	11.495
0.011	11.4	0.011	11.59	0.011	11.59
0.012	11.686	0.012	11.59	0.012	11.495
0.013	12.672	0.013	11.59	0.013	11.495
0.014	12.074	0.014	11.59	0.014	11.59
0.015	11.976	0.015	11.59	0.015	11.495
0.016	11.59	0.016	11.59	0.016	11.495
0.017	11.495	0.017	11.59	0.017	11.495
0.018	11.495	0.018	11.495	0.018	11.495
0.019	11.59	0.019	11.59	0.019	11.59
0.02	11.59	0.02	11.59	0.02	11.59
0.021	11.686	0.021	11.59	0.021	11.59
0.022	11.59	0.022	11.59	0.022	11.495
0.023	11.59	0.023	11.59	0.023	11.59
0.024	11.59	0.024	11.59	0.024	11.59

0.025	11.4	0.025	11.59	0.025	11.59
0.026	11.4	0.026	11.59	0.026	11.59
0.027	11.495	0.027	11.59	0.027	11.495
0.028	11.4	0.028	11.59	0.028	11.59
0.029	11.4	0.029	11.59	0.029	11.495
0.03	11.4	0.03	11.59	0.03	11.59
0.031	11.495	0.031	11.59	0.031	11.495
0.032	11.495	0.032	11.59	0.032	11.59
0.033	11.59	0.033	11.59	0.033	11.59
0.034	11.59	0.034	11.686	0.034	11.59

Point 7

time	u
0	11.028
0.001	11.028
0.002	11.12
0.003	11.12
0.004	11.12
0.005	11.12
0.006	11.12
0.007	11.12
0.008	11.12
0.009	11.213
0.01	11.213
0.011	11.213
0.012	11.213
0.013	11.12
0.014	11.12
0.015	11.12
0.016	11.12
0.017	11.213
0.018	11.12

Point 8

time	u
0	11.4
0.001	11.4
0.002	11.306
0.003	11.4
0.004	11.4
0.005	11.4
0.006	11.4
0.007	11.4
0.008	11.4
0.009	11.4
0.01	11.495
0.011	11.4
0.012	11.495
0.013	11.4
0.014	11.495
0.015	11.495
0.016	11.4
0.017	11.4
0.018	11.4

Point 9

time	u
0	11.495
0.001	11.59
0.002	11.4
0.003	11.59
0.004	11.495
0.005	11.686
0.006	11.59
0.007	11.59
0.008	11.495
0.009	11.59
0.01	11.59
0.011	11.495
0.012	11.495
0.013	11.495
0.014	11.495
0.015	11.4
0.016	11.495
0.017	11.306
0.018	11.495

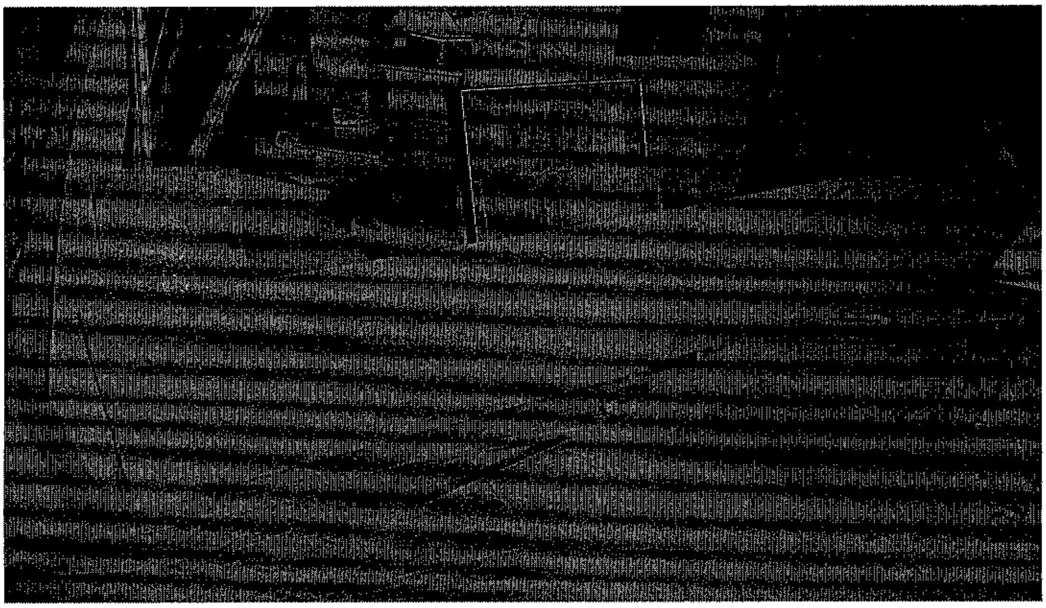
0.019	11.12	0.019	11.495	0.019	11.4
0.02	11.12	0.02	11.4	0.02	11.59
0.021	11.12	0.021	11.4	0.021	11.686
0.022	11.12	0.022	11.495	0.022	11.59
0.023	11.12	0.023	11.4	0.023	11.59
0.024	11.213	0.024	11.4	0.024	11.59
0.025	11.213	0.025	11.495	0.025	11.12
0.026	11.213	0.026	11.495	0.026	11.12
0.027	11.213	0.027	11.495	0.027	11.495
0.028	11.213	0.028	11.495	0.028	11.59
0.029	11.213	0.029	11.4	0.029	11.59
0.03	11.213	0.03	11.495	0.03	11.59
0.031	11.213	0.031	11.495	0.031	11.495
0.032	11.213	0.032	11.495	0.032	11.495
0.033	11.213	0.033	11.495	0.033	11.4
0.034	11.213	0.034	11.495	0.034	11.495

APPENDIX G

Fabrication Pictures

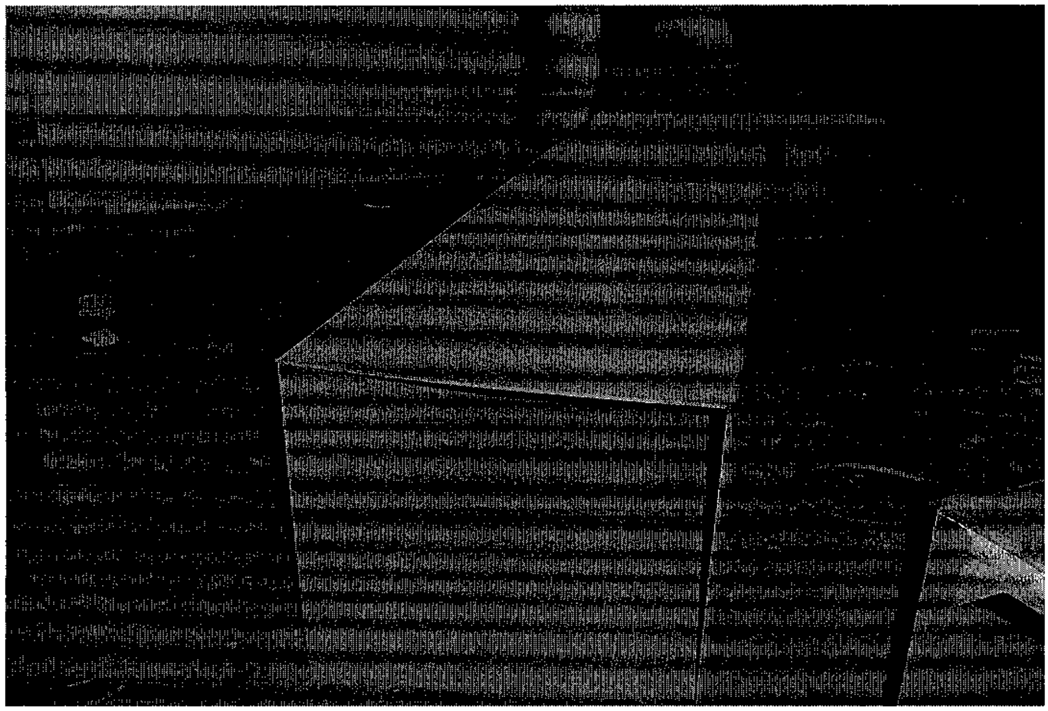
Fabrication Pictures

The Diffuser



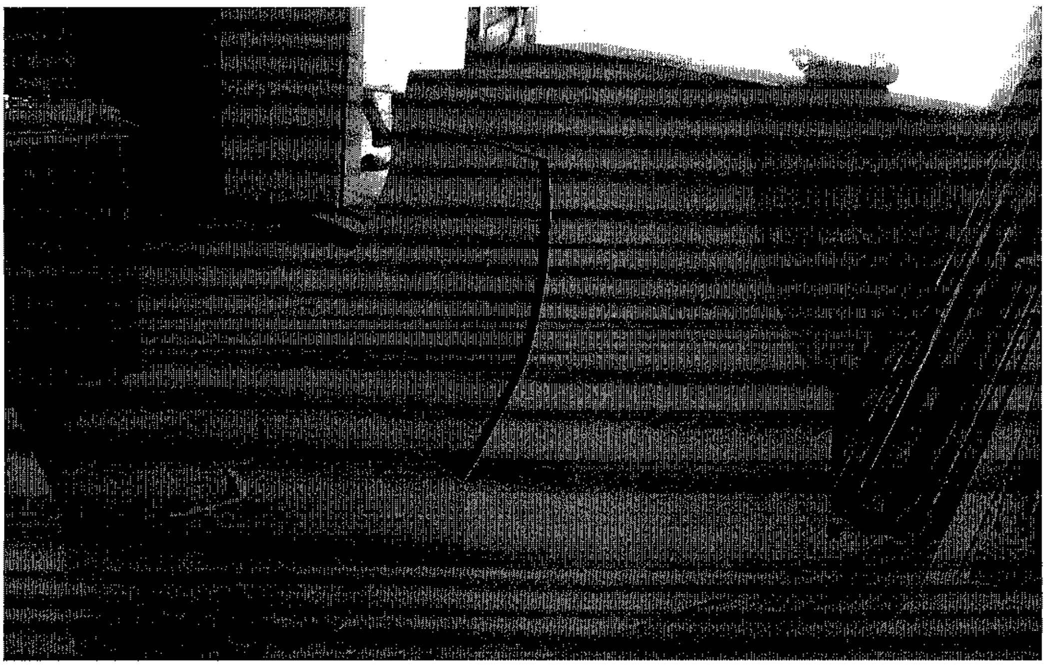
Diffuser part body after cut

Diffuser body after has been assembled - 1



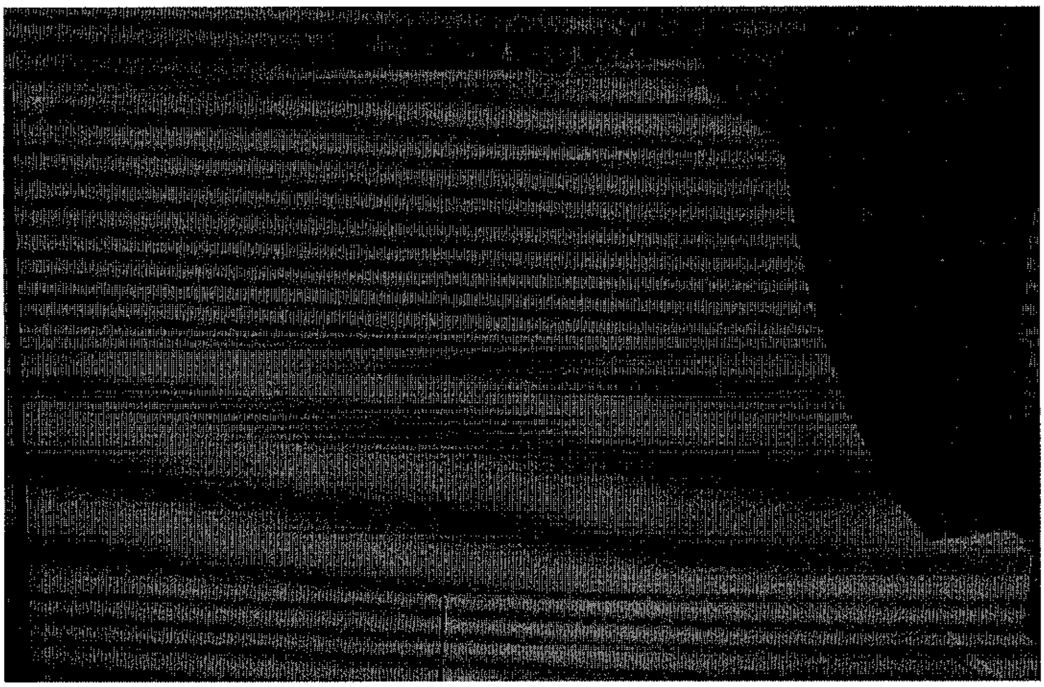
Diffuser body after has been assembled - 2

The Nozzle and Settling Chamber



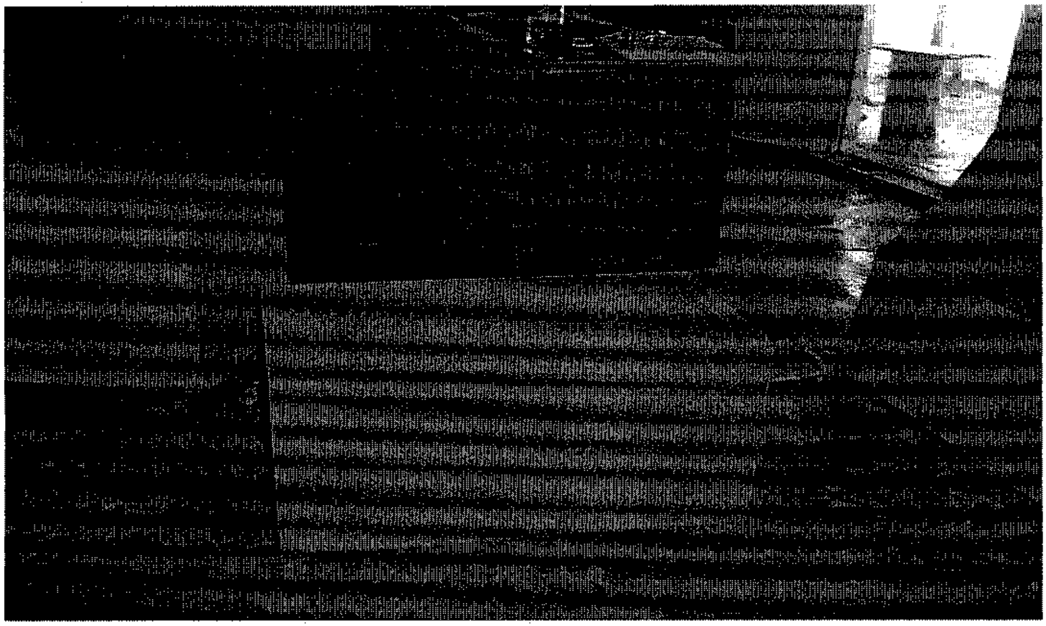
Nozzle before plywood installation

Nozzle before plywood installation



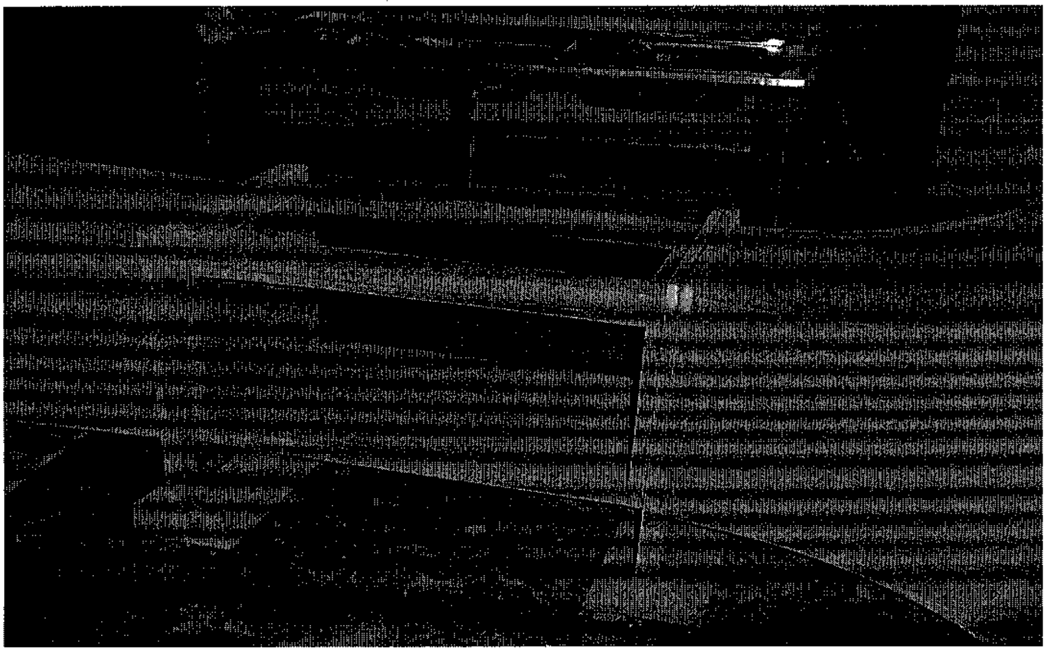
Nozzle after plywood installation

The Test Section



Test section before installation of Perspex

Test section before installation of Perspex

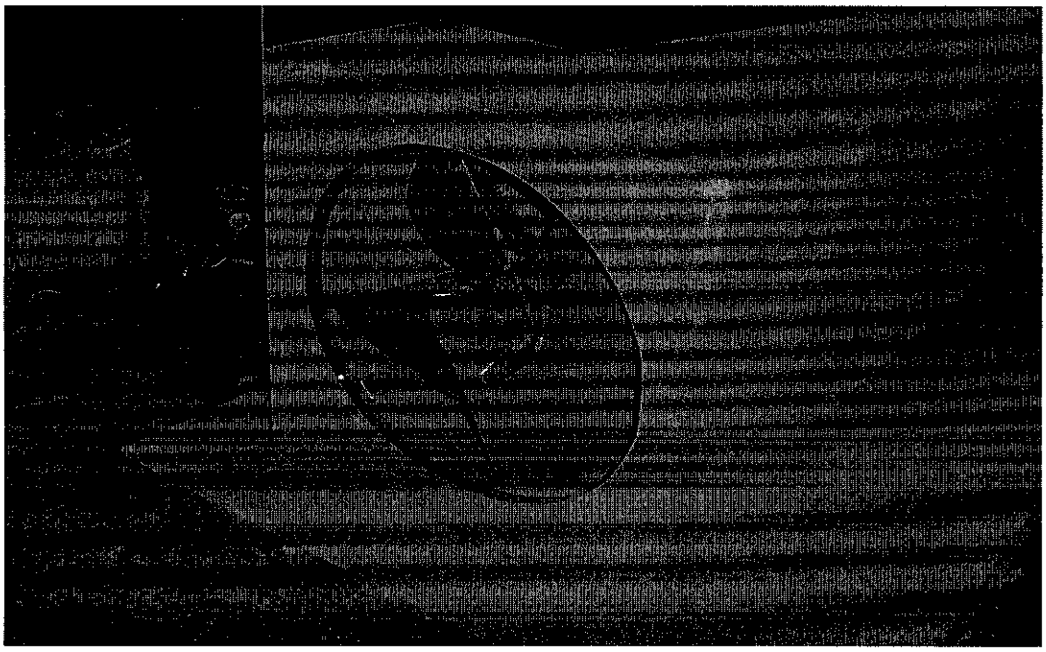


Test section after installation of Perspex

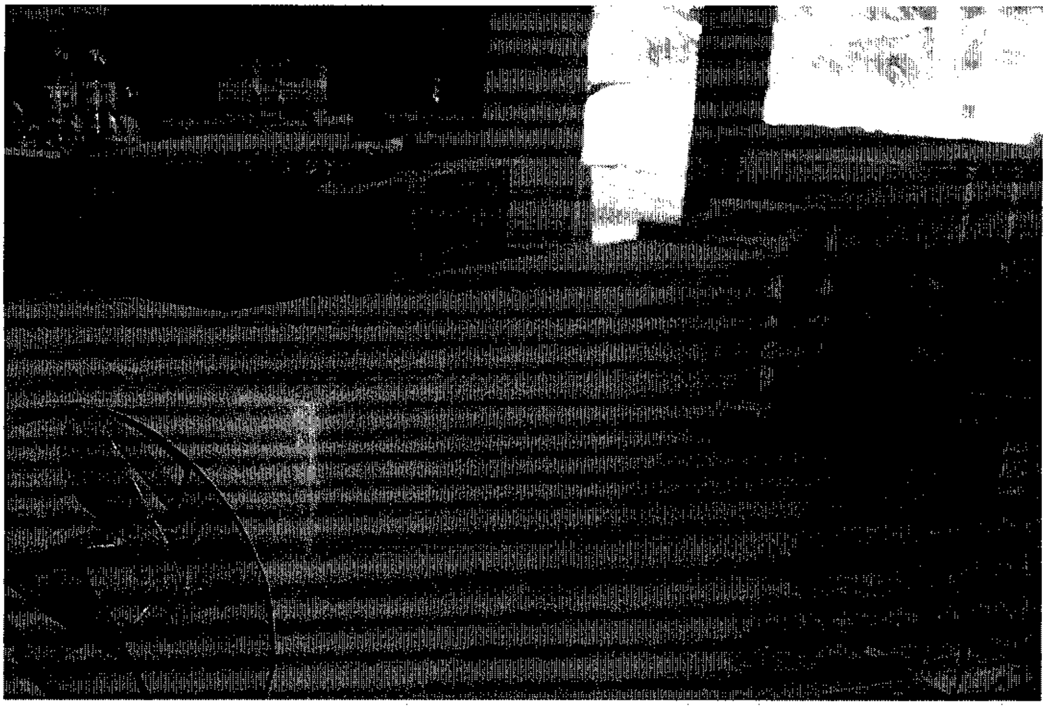
Test section – removable side panel for model installation

Test section with nozzle installation

The Fan Base

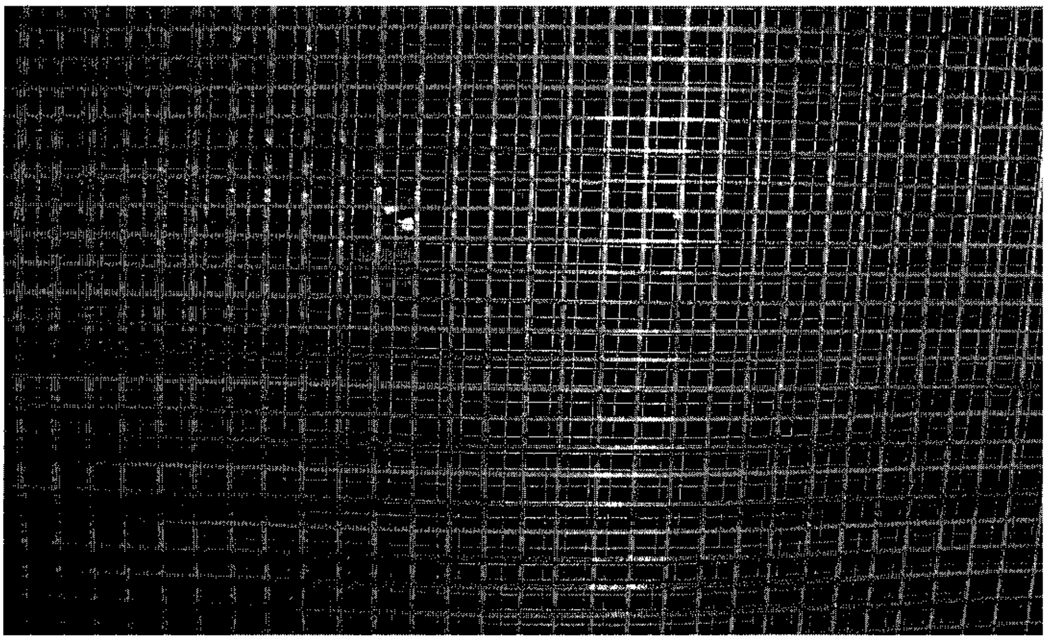


Fan base -1

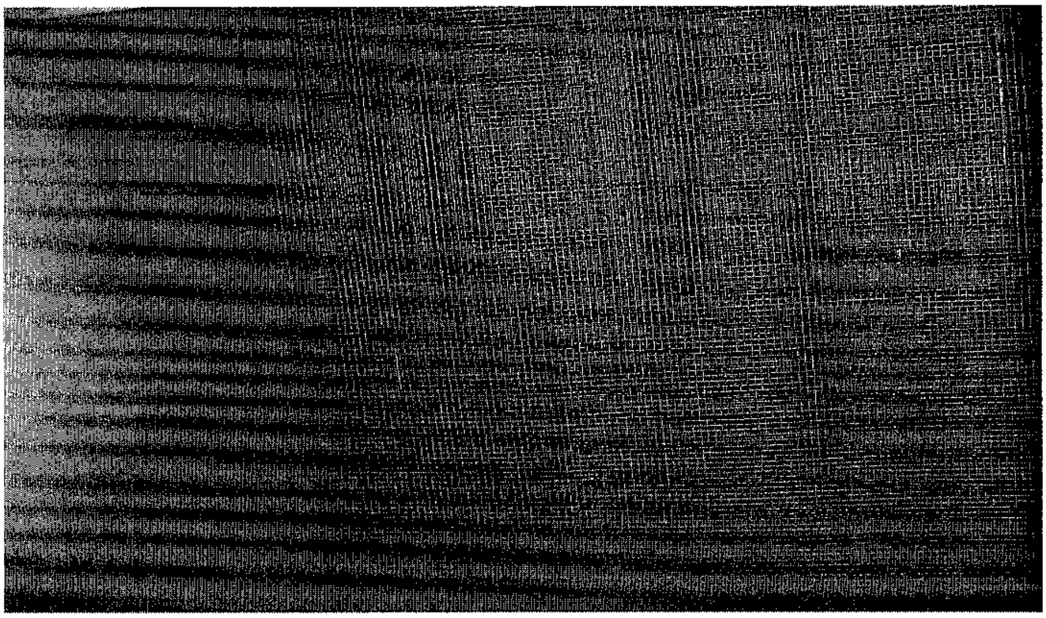


Fan base - 2

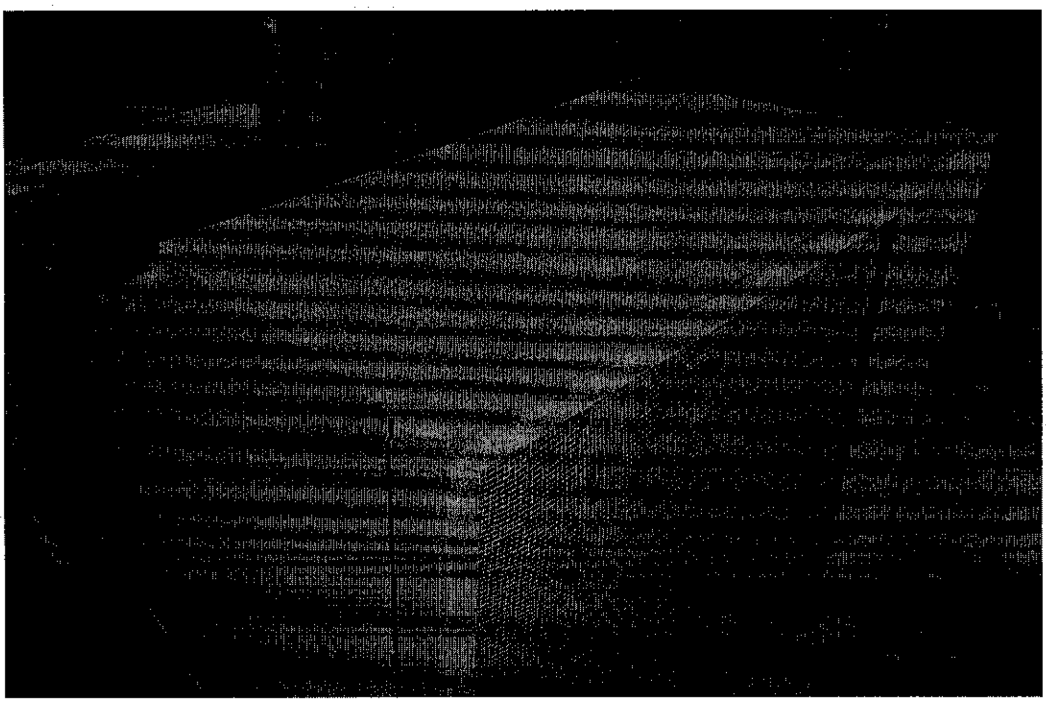
The Turbulence Screen



Turbulence Screen after Installation in settling chamber - 1

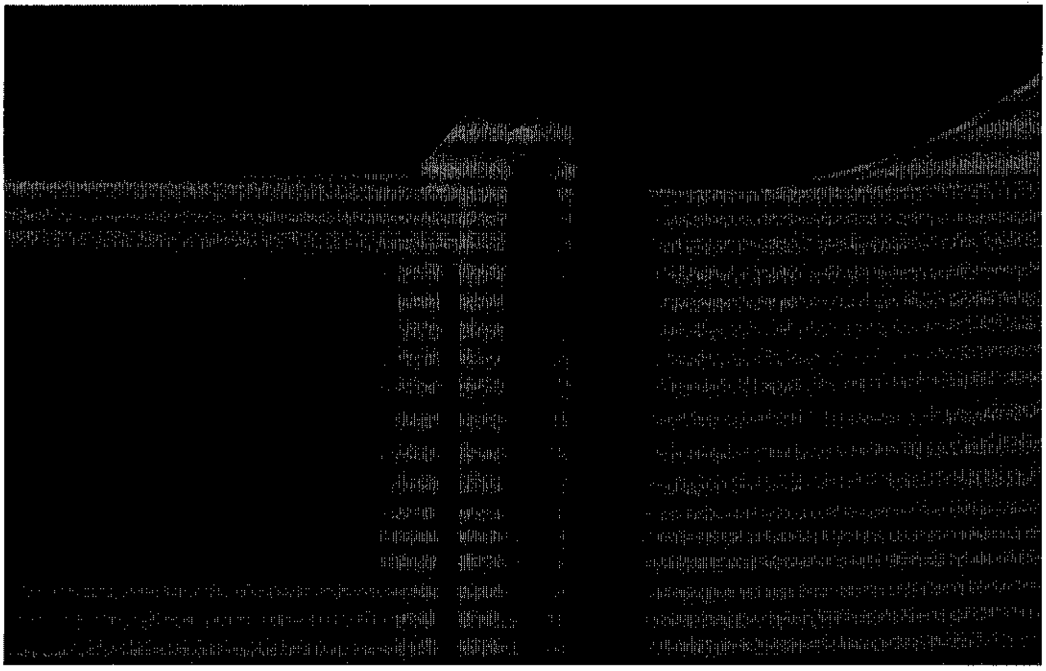


Turbulence Screen after Installation in settling chamber - 2



Turbulence Screen after Installation in settling chamber - 3

Assembly

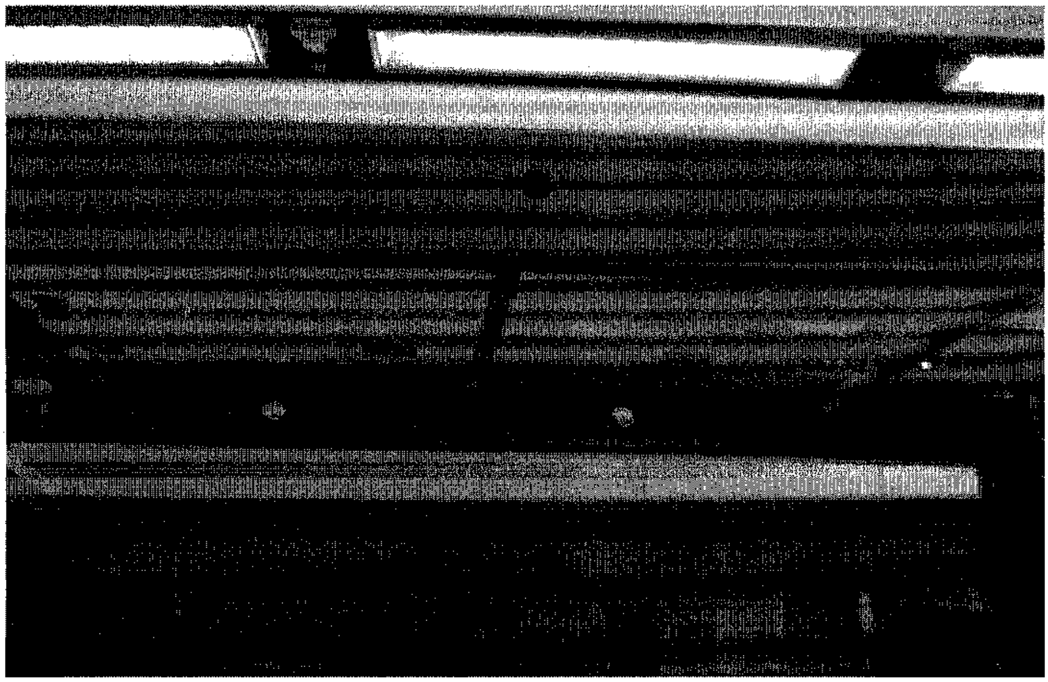


Before assembly process

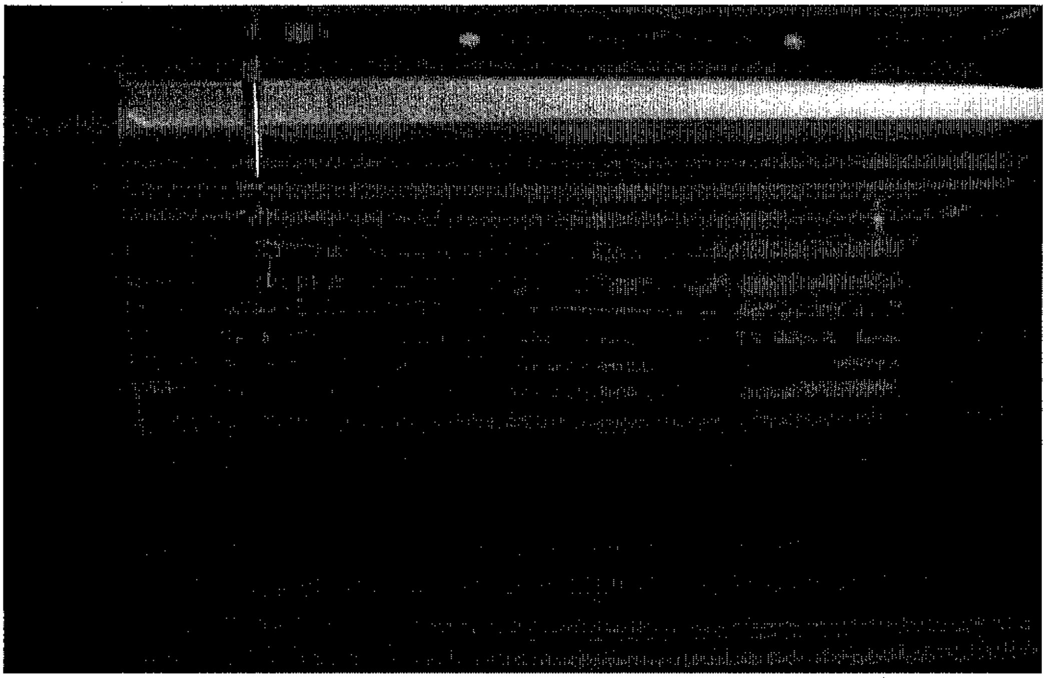
Assembly process – screw installation

Assembly process – finished installation

The Traverse System

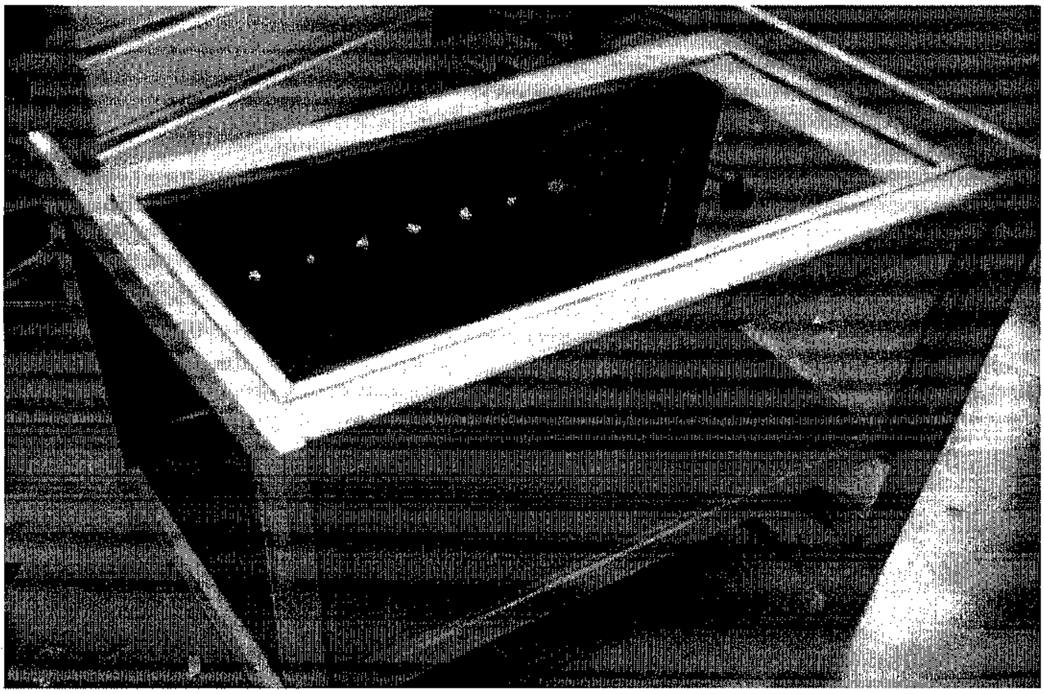


3 bars placed at top of test section

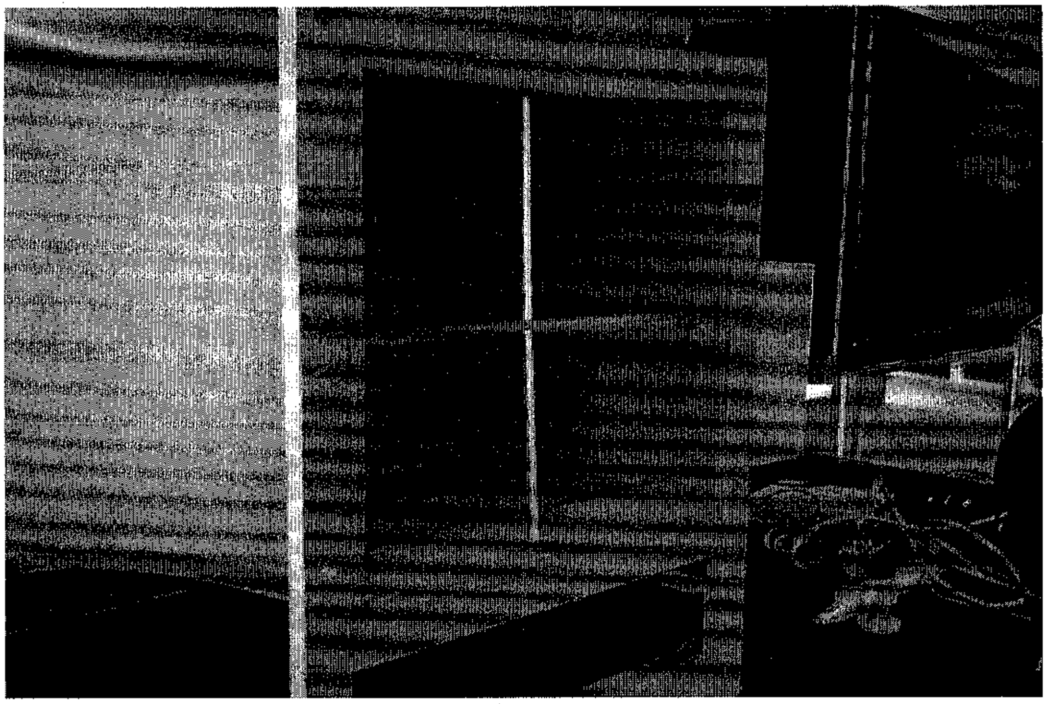


Probe clamper hanged to the bar

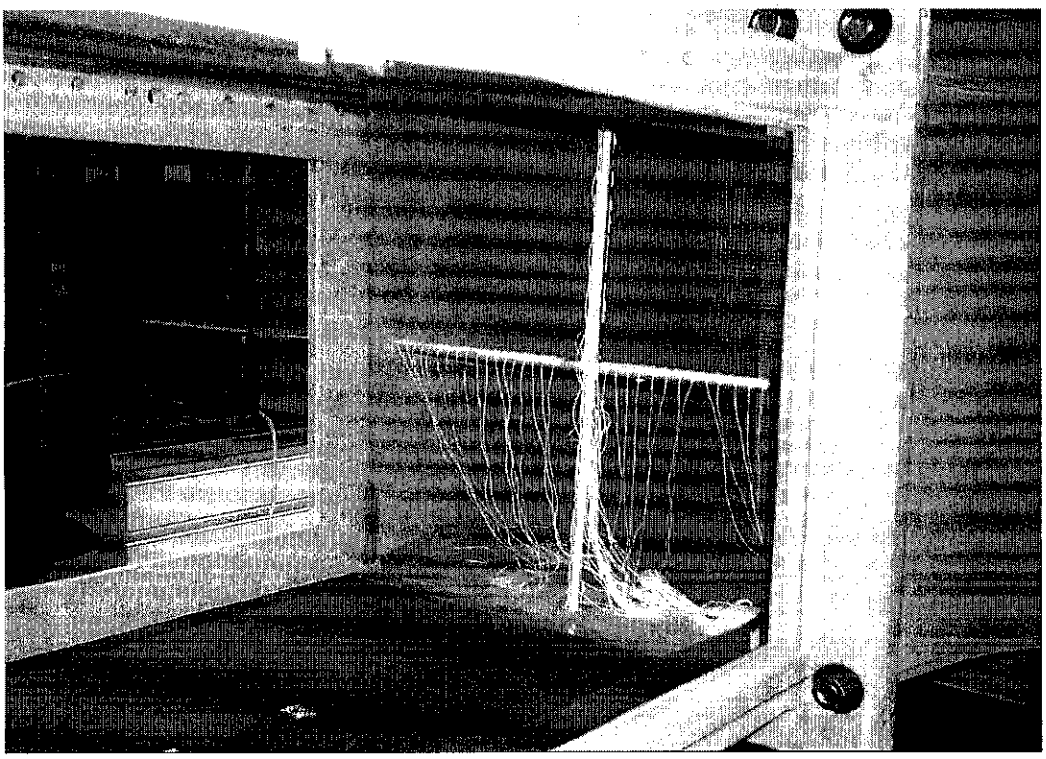
Test section preparation for alternative visualization



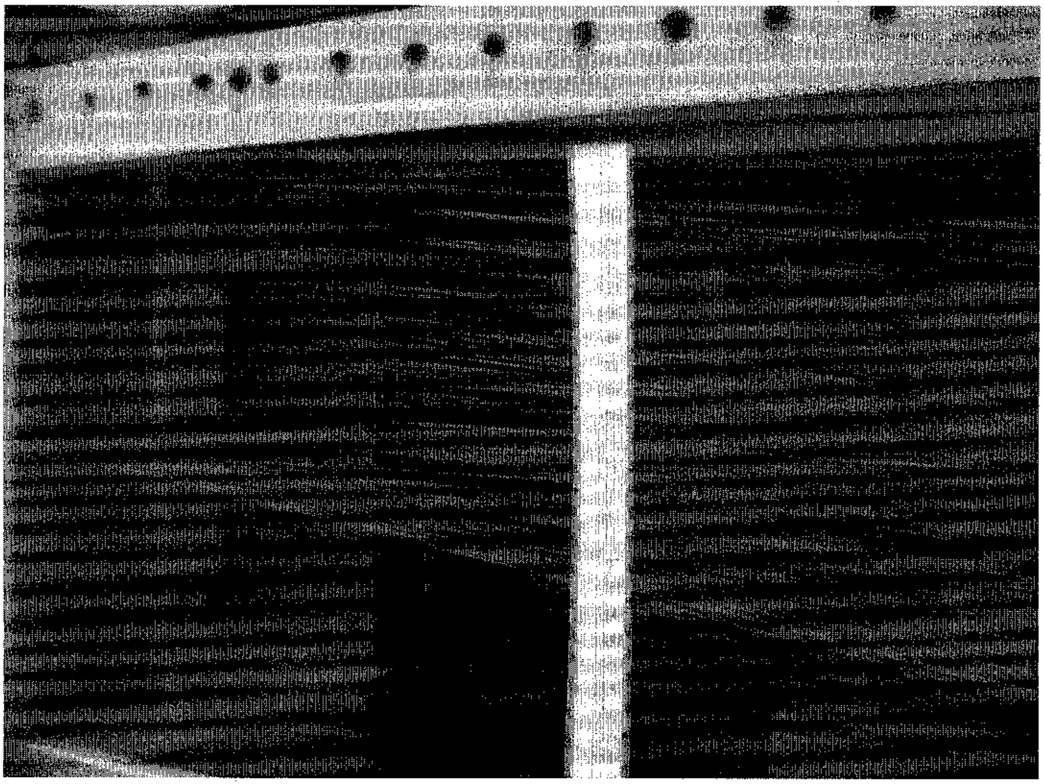
Test Section before thread installation



Test section after installation of thread holder



Test section after installation of thread to thread holder



Test run for thread analysis