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Computational and experimental flow simulation of vertical water flow tunnel

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ABSTRACT

In fluid dynamics, there are many complication occurs in visualization of exact nature of flow field. Most of the technique are present in flow visualization, they are developed to provide high quality visualization of vortex interactions at high angle of attacks. Flow visualization technique is conduct to know the separation of flow over the body with three dimensional accuracy. There are many technique used for displaying the streamlines over the body. In view of water the hydrogen bubbles , inks, lycopodium and particles of aluminium are used. On account of turbulent flow visualization, wind tunnel is complicated when it compares to water flow channel. Because the fluid viscosity of water is higher than air. These techniques can be used to know and optimize the design of body involving the flow of liquid and gases. The flow characteristics exhibited at high Reynolds number in air can be simulated at low Reynolds number in water tunnel. By taking water tunnel the introduction of vertical water tunnel having velocity and flow separation benefits when compared to horizontal water tunnel. The vertical flow visualization helps for the innovation of now aerodynamic parts and equipment by accurate three dimensional result. Improvement in model designs with accurate conclusion makes the vertical water flow tunnelas the diagnostic tool in flow visualization. The introduction of vertical water flow tunnel is very help for future innovations. The flow separation in our model is known by injecting a dye over the body in the test section. The continuous flow of water in vertical direction cooperates the flow separation clearly than compared to any other water and wind tunnels. Let we study about vertical water flow tunnel in detail.

1.0 INTRODUCTION

An instrument used for creating moving airstreams for experimental studies is known as a WIND TUNNEL. where the water is used instead of air, the it is called as WATER TUNNEL. Water tunnel used in important aspects of fluid flows such as instabilities, vortex shedding, boundary layer stability and transition. In water tunnel flow visualisation the water is used in a closed circuit. The horizontal positioning water tunnel is present in existence we introduce vertical positioning tunnel, so the tunnel is called as VERTICAL WATER FLOW TUNNEL(VFWT). The vertical water tunnel are very helpful tool for developing modern technologies in aircraft by perfect analysis methodologies. The flow patterns are recorded as similar to wind tunnel when conducting experiments. To observe the separation of flow of water the dye is injected into the moving water through the array. The father of modern fluid dynamics **"*PRANDTL*"**, who realised water is better medium than

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air for such experiments. These tunnels are fabricated to provide the steady and uniform flow speed with the test section area(10*10cm). we fabricated a quite and simple low cost vertical water flow tunnel for small models for quantitative and qualitative fluid flow measurements. There are many methods involve in water flow visualisation they are dye, shadowgraphs and schileren, water bubbles, florescence, phosphorescence and so on. We planned to go for dye injection for this vertical flow water tunnel. Because dye helps in clear visualization than any other methods in vertical position. The array helps to inject the dye at an equal level. The major aim for fabricating vertical water flow tunnel is acquiring accurate result and less cost when we go for construction.

2.0 LITERATURE SURVEY

H.Werle in 1973 published "HYDRODYNAMIC FLOW VISUALIZATION", in this paper the principle methods of visualizing flows applicable in studies of liquids and by hydraulic analogy of gases are studied. He conduct experiment only in water by various visualization methods such as solid tracers, liquid tracers, gaseous tracers etc,..are employed in various flow tunnels. Finally the experiments in water permits interesting information and yields better result than in air or by other means are conclude.

Chi-chuanwang and etc in February 2002 published "Flow visualization of annular and delta winglet vortex generators in tin and tube heat exchanger application". In this paper flow experimental tests are performed only in water flow tunnel by using dye-injection technique. The study of this paper shows flow visualization and frictional results of enlarged tin and tube heat exchangers with and without the use of vortex generators. Here two types of vortex generators and plain fin geometry were examined in water flow tunnel using dye-injection method. As a result the frictional penalty of vortex generators is about 10 to 65% higher when compares to plain fin geometry

Wolfram von funck and etc in 2008 published "Smoke Surfaces: An interactive flow visualization technique inspired by Real-world flow experiments. In this paper tests are conducted by using smoke that is "Semi Transparent Streak Surfaces" an alternative method which gains the advantage on the surface shows a smoke like look even in turbulent areas. The experiments conducted over the smoke nozzles, wool tufts, and time surface using this technique. As a result by avoiding an expensive adaptive remeshing of the surface by introducing streak surfaces for first time for an interactive visualization of time dependent flow fields..

L.S.Longston and M.T.Boyle in 1982 published "A New Surface Flow Visualization Technique". In this paper new surface streamline flow visualization technique is used for flow experiment. Here air is a medium, Experiments done in low speed wind tunnels, This experiments gives the result in permanent trace of ink that shows the surface streamline direction and shape. The whole experiment is carried out to compares the result of conventional flow technique with this new surface streamline technique. As a result we get accurate surface streamlines in this new surface streamline flow visualization is concluded.

B.R.Clayton and B.S.Massey in 1966 published " Flow visualization in water: a review of techniques". In this paper all the flow visualization principal techniques in water are conducted and reviewed. Here all the experiments are conducted in the water flow tunnel. They use static methods and kinetic methods to get quantitative and qualitative information. Advantage of these methods are simple and expensive. For unsteady flows and ease of pulsing the generation of bubbles it gives the accurate flow visualization results. As a result, author reviewed the flow techniques and get the position of boundary layer separation to be accurately determined are concluded.

Christine Beckner and Robert E.curry in 1985 published “water tunnel flow visualization using a laser”. In this paper all the flow visualization principal techniques in water are conducted and reviewed. Here all the experiments are conducted in the water flow tunnel. The practical application of the laser enhanced visualization includes laser power level, flow seeding, model preparation and photographic techniques. The benefit of the technique is that a complex three-dimensional flow field can be reduced to two dimensional images from which both qualitative and quantitative data can be extracted. The main drawback is simple water tunnel test setup and the requirement for safety precautions.

G.R.Baker and etl in 1974 published “Laser anemometer measurements of trailing vortices in water”. In this paper all the flow visualization principal techniques in water are conducted and reviewed. Here all the experiments are conducted in the water flow tunnel. Laser- Doppler velocimeter is used to measure two components of velocity in the vortex wake. Velocity has been measured downstream of the model from five to sixty chord length. As result, the effects of vortex wandering upon the measurements are computed and corrected.

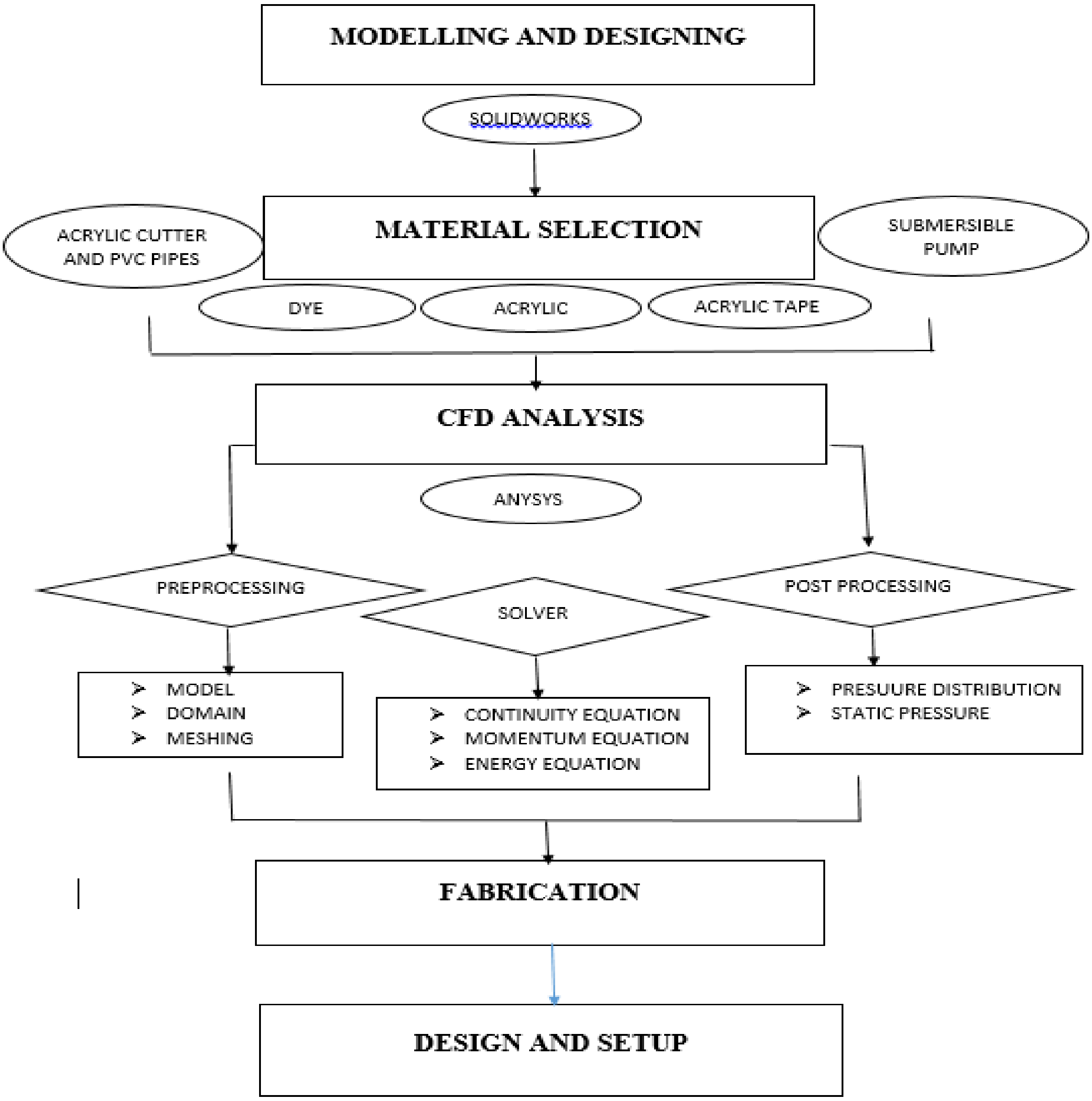
Richard E.bland and ThomadJ.Pelick in 1962 published “The Schlieren method applied to flow visualization in a water tunnel”. In this paper all the flow visualization principal techniques in water are conducted and reviewed. Here all the experiments are conducted in the water flow tunnel. From existing the existing model which is conducted by air here innovatively done by water. The schlieren method paved a way to shadowgraph and interferometer methods which is not explored seriously. As a result, the difficulties should not be greater than those encountered when measurements are made in air.

AlaBouhanguel and etl in 2010 published “Flow visualization in a supersonic ejectors using laser tomography techniques”. This paper presents flow imaging technique developed for investigating flow in ejectors. Although the flow visualizations are primarily qualitative. These visualization technique can also be used to guide the application of other investigation technique like particles sizing and laser doppler anemometry. Further works are in progress to obtain quantitative data on the flow instabilities and flow velocities.

Sutrisnol and etl in 2019 published “Sukhoi SU-47 Berkut and Eurofighter Typhoon models flow visualization and performance investigation using GAMA water tunnel”. In this paper all the flow visualization principal techniques in water are conducted and reviewed. Here all the experiments are conducted in the water flow tunnel. The study used a water tunnel to observe the aerodynamic flow and forces that occurs in both wings. SU-47 which has front swept wings, therefore they have two vortex cores which produce rolled up vortices that induce lift coefficient or CL while typhoon has only one vortex core.

Calif and etl in 1998 Published "Water tunnel flow visualization insight into complex three-dimensional flow field". In this paper all the flow visualization principal techniques in water are conducted and reviewed. Here all the experiments are conducted in the water flow tunnel. Water tunnel techniques and flow visualization techniques have been developed at Northrop to provide high quality visualization of vortex interaction at a high angle of attack. Results have provided considerable insight into highly complex three-dimensional flow field generated by contemporary fighter aircraft.

3.0 METHODOLOGY



4.0 MODELLING AND DESIGNING

All the models are designed and assembled in solid works software. It has the capability of converting 2d designing into 3d and assemblies. All dimensions are designed by taking the reference of existing horizontal tunnel of about 1:2 ratio.

4.1 EFFUSER

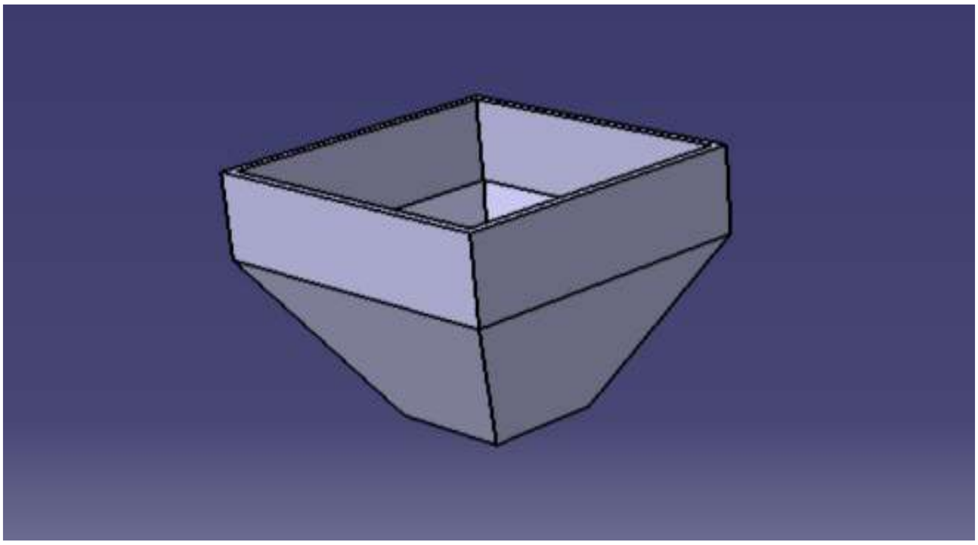


Fig 1. isometric view of Effuser

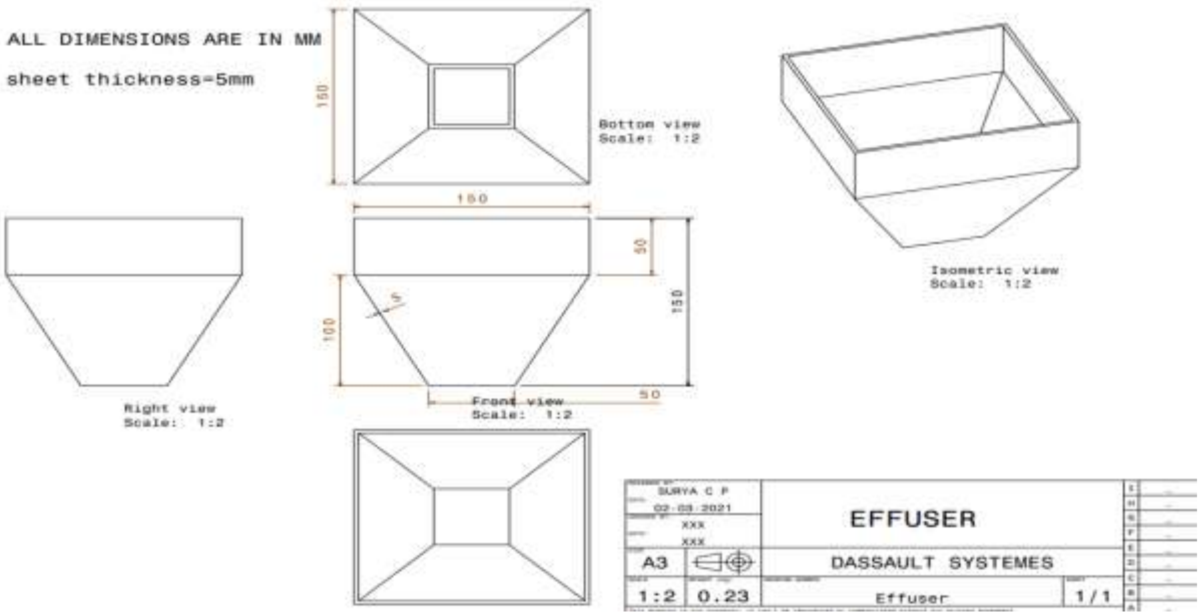


Fig 2. Dimensions ofEffuser

4.2 TEST SECTION

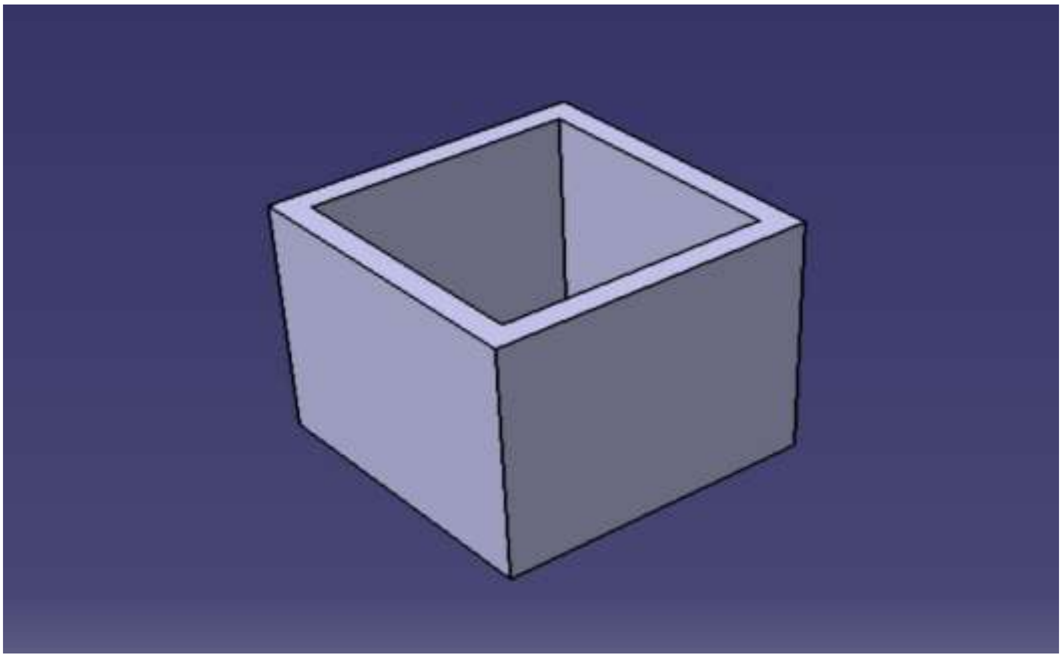


Fig 3. isometric view of Effuser

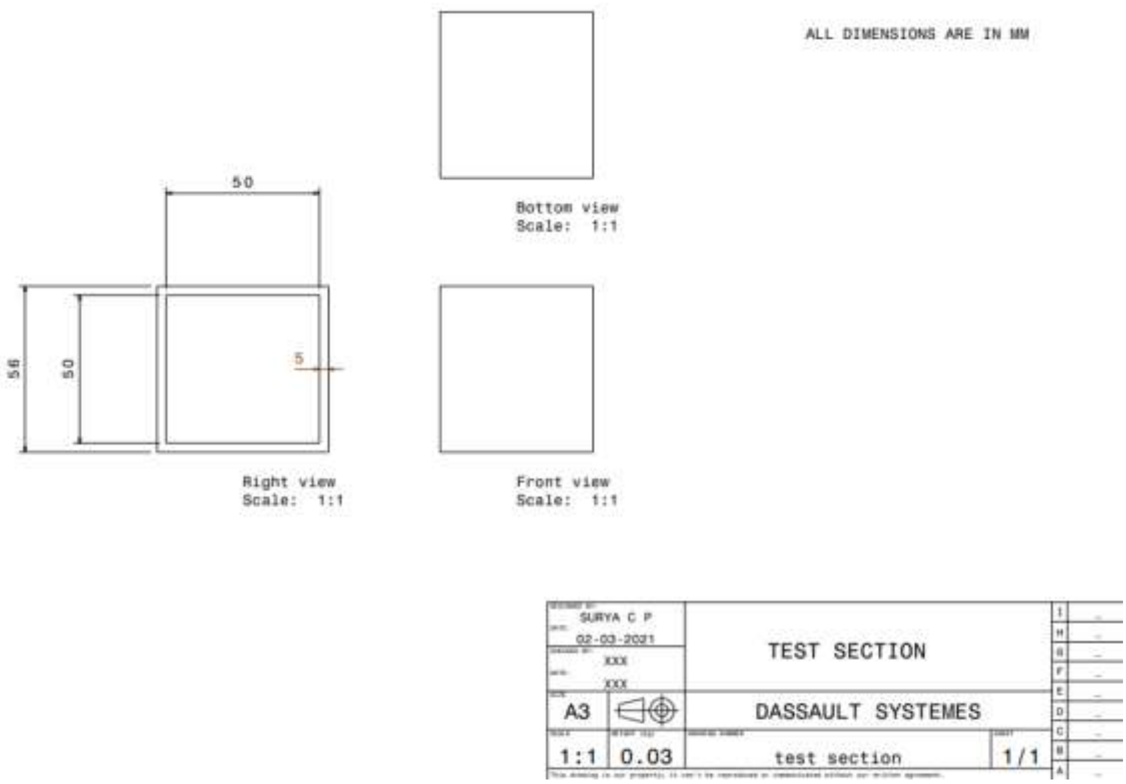


Fig 4. Dimensions of Test section

4.3 DIFFUSER

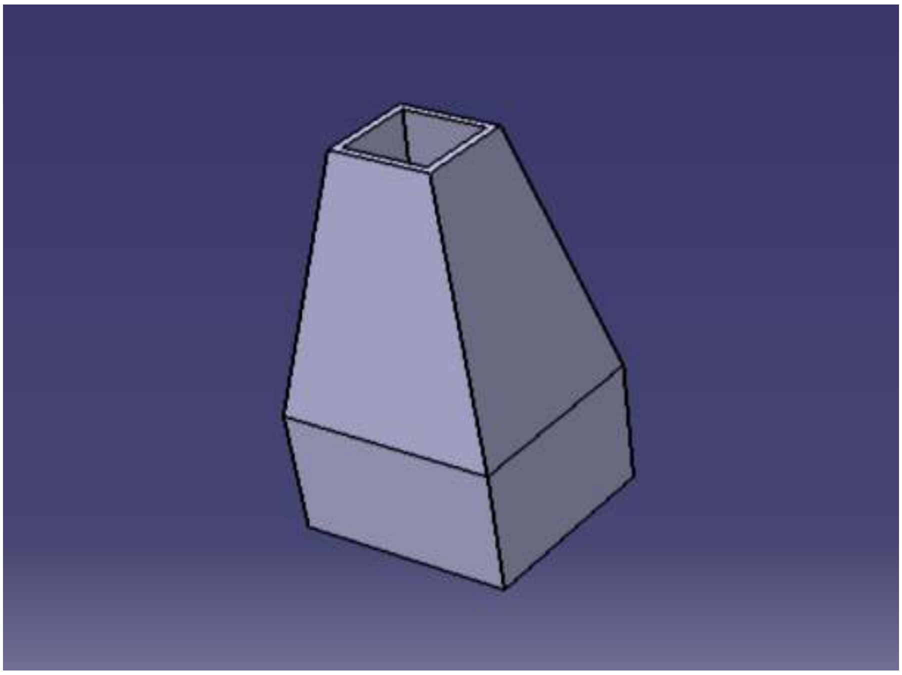


Fig 5. Isometric view of Effuser

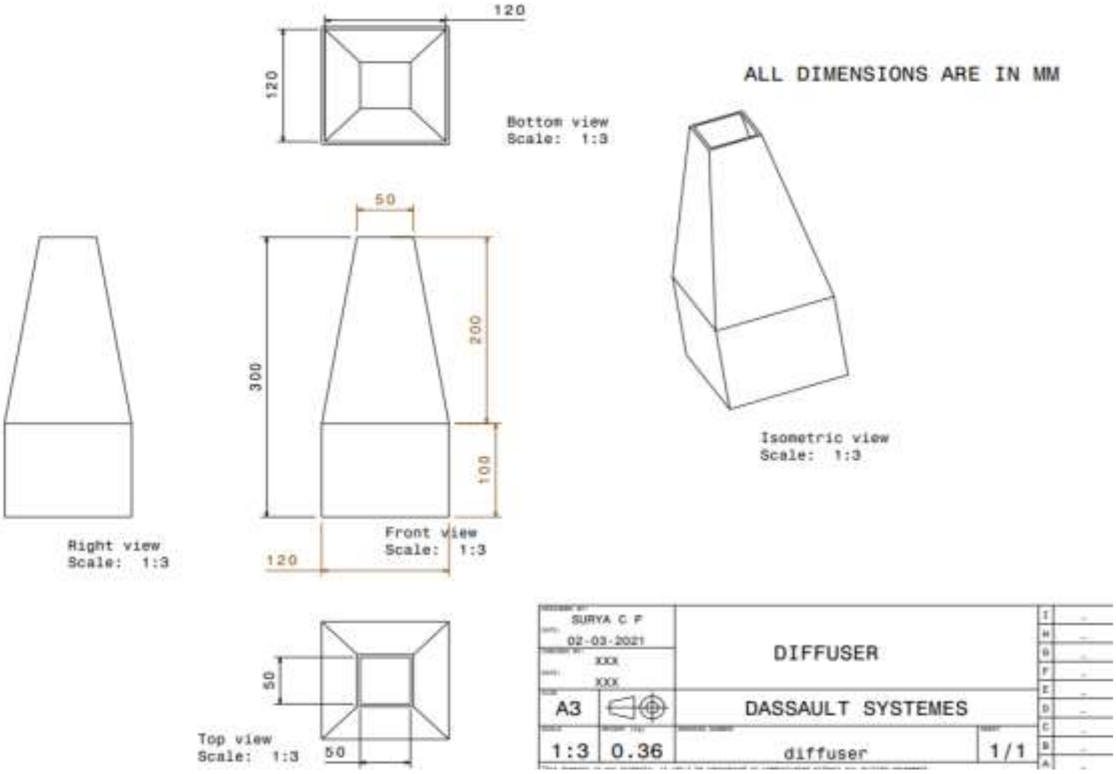


Fig 6. Dimensions of Diffuser

5.0 MATERIAL SELECTION

- Acrylic sheet
- Acrylic tape
- Submersible pump
- Collecting tank
- Dye

5.1 ACRYLIC SHEET

Poly methyl methacrylate also known as acrylic sheet . Acrylic sheet is used for the fabrication of vertical flow water tunnel. We use 5 mm and 2 mm for construction crylux, Plexiglas, acrylate, Lucite, perclax are the trade name of acrylic.

PROPERTIES

- Acrylic sheet is strong, tough and light weight material.
- The density of acrylic is about 1.17-1.20 g/cm^3 which is less than half that of glass .
- Acrylic having higher impact strength, higher than both glass and polystyrene
- It can be able to transmits upto 92% of visible light
- This sheet also gives the reflection of about 4% from each of its surface due to its refractive index.

MAJOR REASON FOR CHOOSING ACRYLIC SHEET FOR FABRICATION

- Acrylic is easy to fabricate and shape.
- Acrylic is 50% lighter than glass, but more stronger than any other sheet.
- Acrylics are highly transparent.
- Acrylic is easy to maintain.

5.2 ACRYLIC TAPE

- High strength acrylic tap is used to joint the acrylic sheets. All parts are assembled by this acrylic tape.
- It has very high strength to joint the various pieces.
- It avoids leakage of water.
- Acrylic tape is reinforced acrylic foam tape with high tack and shear strength performance adhesive.

5.3 SUBMERSIBLE PUMP

- For pumping system, submersible pump is used
- Model :- spring 5’ feet
- Voltage:-230 volts AC, 50 HZ
- Wattage:-18 watts

5.4 COLLECTING TANK

Water required for the flow was taken from the collecting tank and discharged through the exit valve and the water is recirculate for the experiment.

5.5 DYE

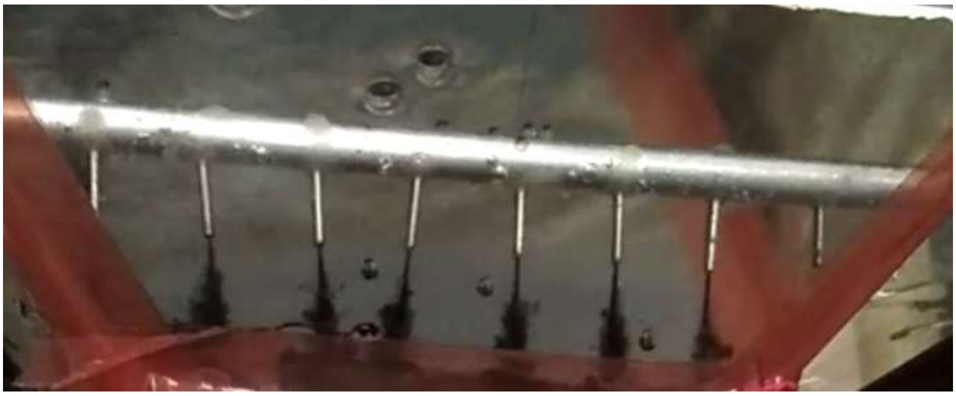


Fig 7. Dye through injected through array

Dye is used to visualize the flow in the test section, which is injected by syringe through array.

5.6 PVC PIPES

PVC pipes used to transfer the water for the whole setup. The diameter of pipe about ¾inch. We choose the pvc pipe with respect to diameter of the submersible pump mouth

6.0 CFD ANALYSIS

We use ANSYS software for CFD anlysis.CFD analysis is used to solve the problems in fluid flow by suing numerical methods and data structures. Here we conduct CFD analysis to know to characteristics and flow paths. There are three main process involves in CFD analysis. They are pre processing, solver, post processing.

6.1 PREPROCESSING

Pre processing is the conventional method we want to done before actual simulation. During this process we create domain before meshing the whole CAD model. Meshing is creating cluster of small cells around the model. In CFD analysis we will create domain and meshing of model for finite element analysis.

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MODEL

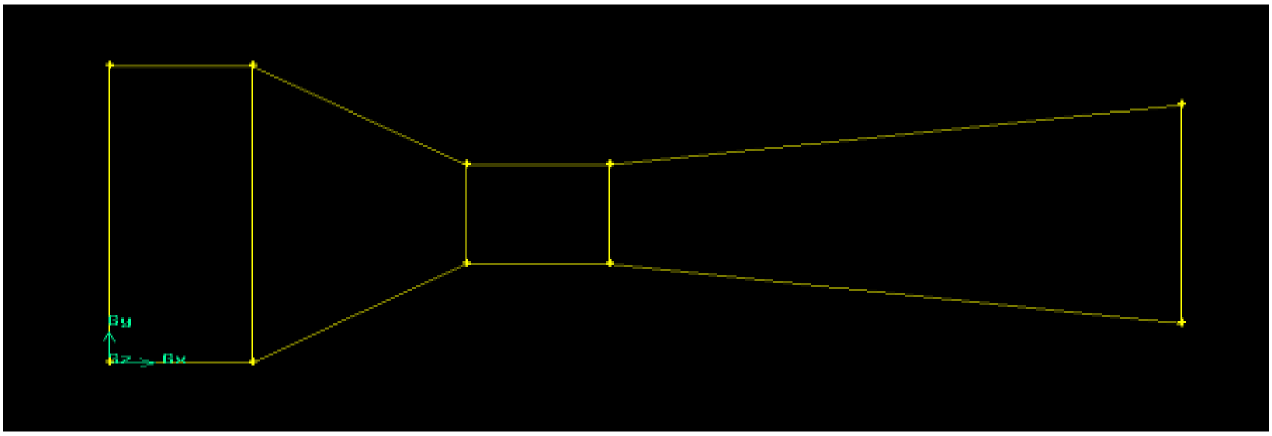


Fig 8. CFD analysis(model of vertical tunnel)

DOMAIN

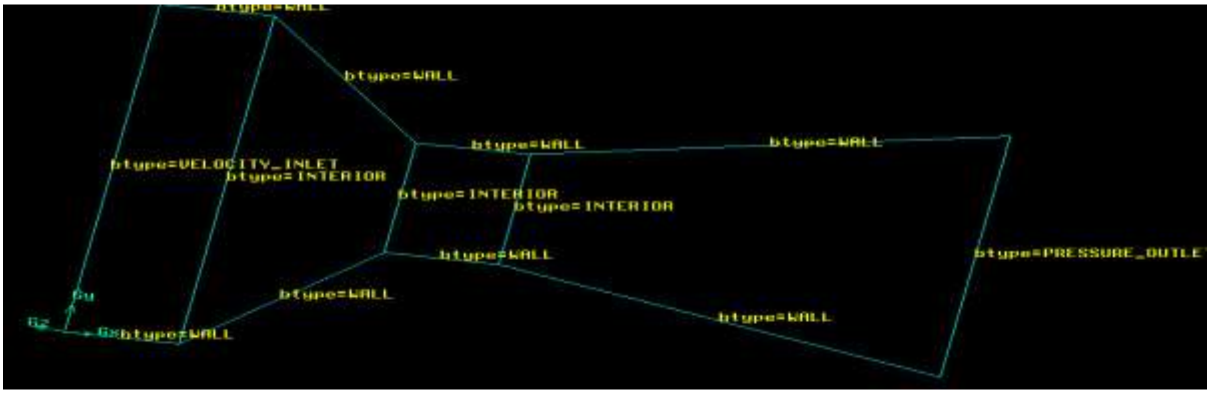


Fig 9. CFD analysis (domain of vertical flow water tunnel)

6.2MESHING

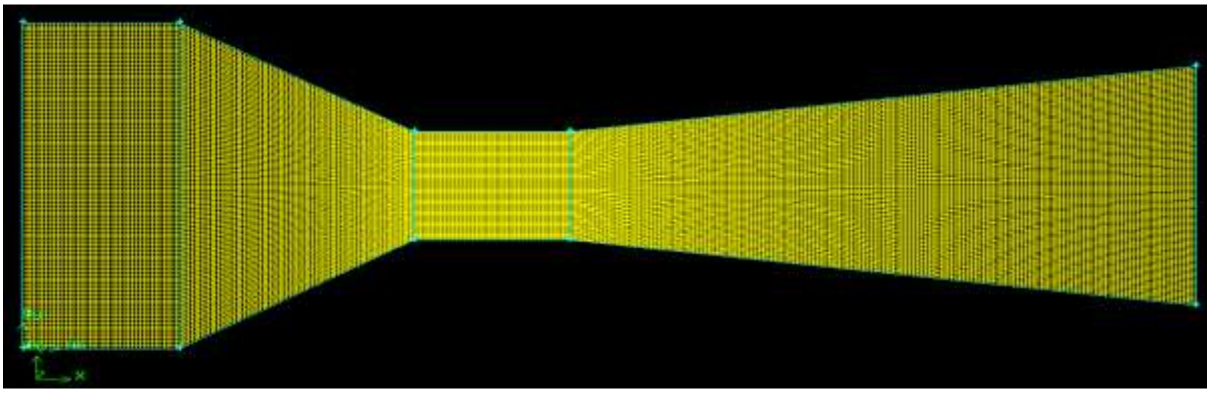
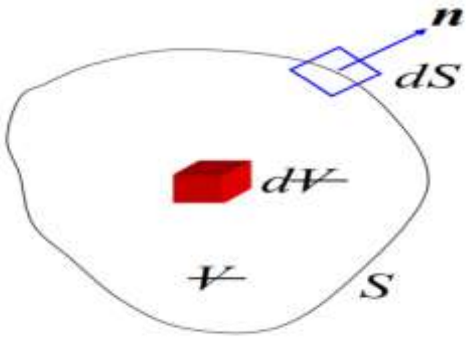


Fig 10.CFD analysis(quad meshing structural cells)

6.3 SOLVER

CONTINUITY EQUATION



1.Consider a volume V bounded by a surface S that fixed in space the mass is given by R V ρdV

rate of decrease of mass in V = − d/dt Z V ρ dV = − Z V ∂ρ/∂t dV……. (1)

2.If mass is conserved, Eqn. 1 must equal the total rate of mass flux out of V . The rate of outward mass flux across any small element dS of S is ρ v · dS where the magnitude of dS is equal to the element's area and we take dS along the outward normal. Integrating over the whole surface we have

rate of mass flux out of V = Z S ρ v · dS = Z V ∇ · (ρv)dV………. (2)

3.where we used Green's formula to convert to a volume integral

∇ · (ρv) = ∂(ρu)/∂x + ∂ (ρv)/∂y + ∂ (ρw)/∂z . (3)

The continuity equation: ∂ρ/∂t + ∇.(ρv) = 0.

MOMENTUM EQUATION

1.Consider a volume V bounded by a material surface S that moves with the flow, always containing the same material elements. Its momentum is R V dV ρ v

rate of change of momentum = d/dt Z V dV ρ v = Z V dV ρ Dv/Dt

Total force (body + surface) = Z V dVρg + Z S [Π] · dS = Z V dV (ρg + ∇ · [Π]).

By Newton's second law, Eqns. 9 and 10 must be equal for any V , so we get finally

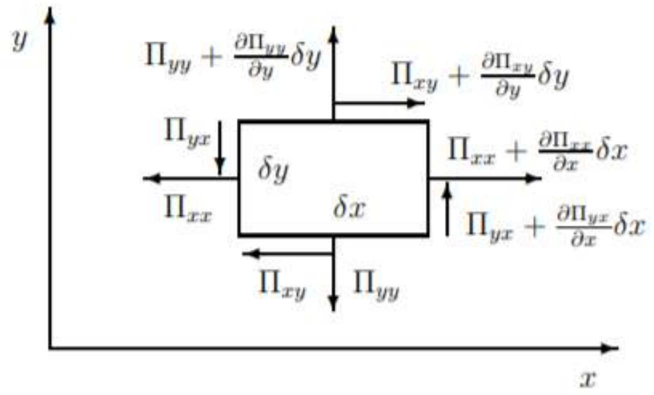
the Cauchy equation: ρ DvDt = ρg + ∇ · [Π]

The physical meaning of this is seen clearly in Cartesian coordinates

Momentum, x: ρ Du Dt = ρgx + ∂ ∂x(Πxx) + ∂ ∂y (Πxy) + ∂ ∂z (Πxz)

Momentum, y : ρ DvDt = ρgy + ∂ ∂x(Πyx) + ∂ ∂y (Πyy) + ∂ ∂z (Πyz)

Momentum, z : ρ DwDt = ρgz + ∂ ∂x(Πzx) + ∂ ∂y (Πzy) + ∂ ∂z (Πzz).



ENERGY EQUATION

One of the most fundamental laws in nature is the **first law of thermodynamics**, also known as the **conservation of energy principle**, which provides a sound basis for studying the relationships among the various forms of energy and energy interactions. It states that *energy can be neither created nor destroyed during a process; it can only change forms.* Therefore, every bit of energy must be accounted for during a process

Apply the Reynolds Transport theorem to derive an equation for energy conservation in a control volume

$$N = E, \quad \text{and} \quad \eta = \frac{E}{m} = e$$

On the LHS we have , which from the First Law of Thermodynamics is

$$\frac{dE}{dt} = \dot{Q} - \dot{W}$$

Where Q is the rate at which heat is added to the system and $\dot{W}$ is the rate at which work is done on/by the system. Work due to shear forces is small and is usually neglected. Heat added Q becomes important only occasionally in problems involving heat transfer.

Upon substituting for various terms we have,

$$\dot{Q} - \dot{W}_s - \dot{W}_p = \frac{\partial}{\partial t}\int_{CV}(u + gz + \frac{1}{2}V^2)\rho d\forall + \int_{CS}(u + gz + \frac{1}{2}V^2)\rho\vec{V}.d\vec{A}$$

$$\dot{Q} - \dot{W}_s - \int_{CS} p\, dA\cdot V = \frac{\partial}{\partial t}\int_{CV}(u + gz + \frac{1}{2}V^2)\rho d\forall + \int_{CS}(u + gz + \frac{1}{2}V^2)\rho\vec{V}.d\vec{A}$$

$$\dot{Q} - \dot{W}_s = \frac{\partial}{\partial t}\int_{CV}(u + gz + \frac{1}{2}V^2)\rho d\forall + \int_{CS}(u + \frac{p}{\rho} + gz + \frac{1}{2}V^2)\rho\vec{V}.d\vec{A}$$

$$\dot{Q} - \dot{W}_s = \frac{\partial}{\partial t}\int_{CV}(u + gz + \frac{1}{2}V^2)\rho d\forall + \int_{CS}(h + gz + \frac{1}{2}V^2)\rho\vec{V}.d\vec{A}$$

6.4 POST PROCESSING

In post processing the flow characteristics like velocity, pressure, temperature, density etc., can be performed throughout the model. After these process performed we can able to visualise the flow and result. A mathematical model of the physical case and a numerical method are used in a software tool to analyse the fluid flow. For instance, the Navier Stokes equations are specified as the mathematical model of the physical case

VELOCITY GRADIENT

Here the velocity equally distributed in the test section. This equal distribution makes the flow experiment accurate and gives perfect visualization of flow when we inject dye over model.

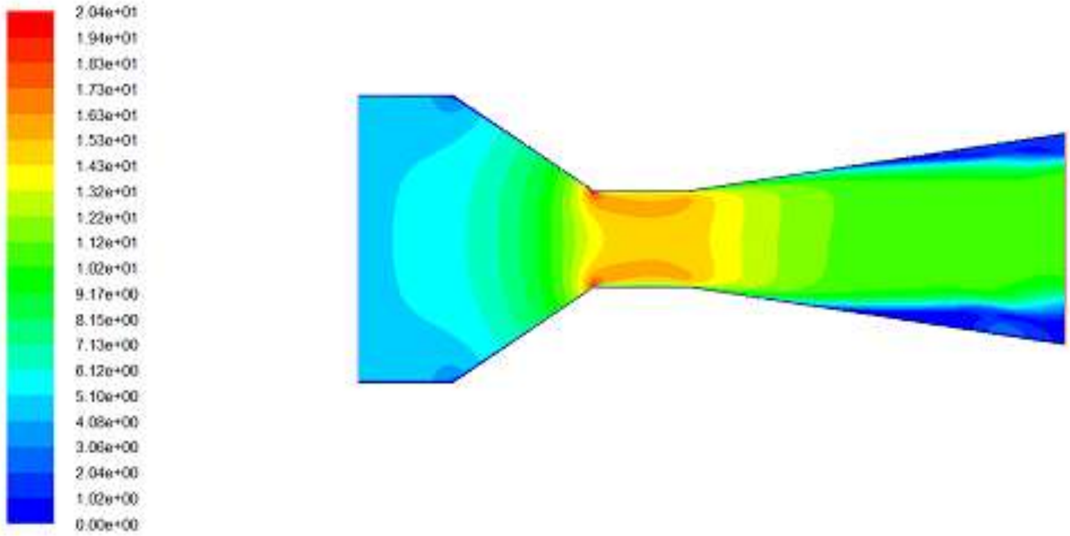


Fig 11. CFD analysis (velocity gradient)

PRESSURE DISTRIBUTION

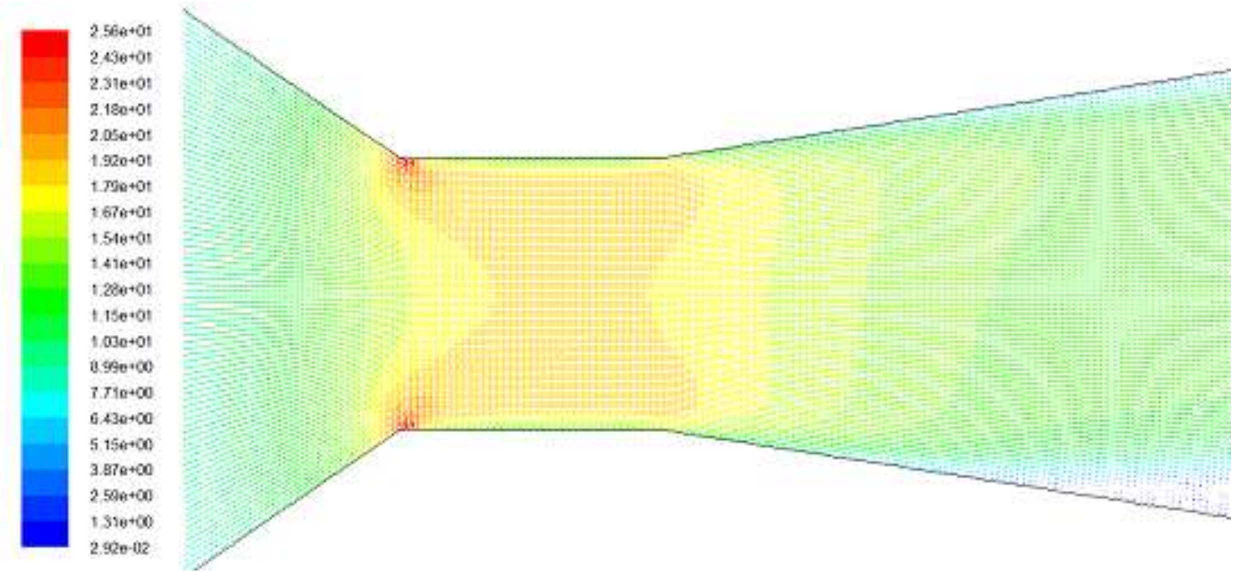


Fig 12. CFD analysis (pressure distribution

WATER FLOW STREAMS

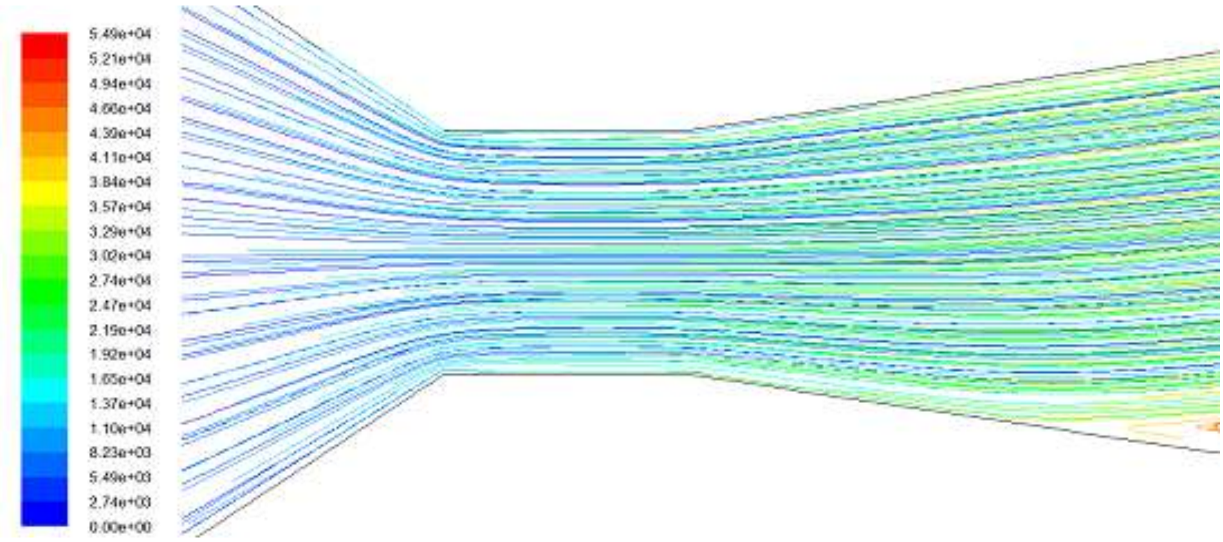


Fig 13.CFD analysis (water flow streams)

7.0 CONCLUSION

As we design and fabricate the VERTICAL FLOW WATER TUNNEL with the help of materials mentioned above. The flow visualisation gives accurate result so its helpful to many innovative experiments. Here we made experiment through the body of cone. The flow separation over the surface of the body is visualised with help of dye is conducted.

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