

SUPERSONIC FLOW CALIBRATION UNDER DIGITAL TWIN TECHNOLOGY

Submitted in partial fulfilment of the requirements for the award of
Bachelor of Engineering degree in
Aeronautical Engineering

By

GOKULAKRISHNAN.S (Reg. No. 37260015)

SASIDHAR RAJAN G.M (Reg. No. 37260037)



**DEPARTMENT OF AERONAUTICAL ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING
SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with grade “A” by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI – 600119

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SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited with "A" grade by NAAC
piaar Nagar, Rajiv Gandhi Salai, Chennai - 600 119
www.sathyabama.ac.in



DEPARTMENT OF AERONAUTICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of
GOKULAKRISHNAN.S(Reg.No. 37260015) and **SASIDHAR RAJAN G.M** (Reg.
No.37260037) who carried out the project entitled **SUPERSONIC FLOW**
CALIBRATION UNDER DIGITAL TWIN TECHNOLOGY under our supervision
from September 2019 to April 2020.

Internal Guide
MR.MADHAN KUMAR., M.E.,

Head of the Department
Dr. BOOMADEVI, ME., PhD.,

Submitted for Viva voce Examination held on _____

Internal Examiner

External Examiner

DECLARATION

WE GOKULAKRISHNAN.S (Reg.No.37260015) and SASIDHAR RAJAN G.M
(Reg.No.37260015) hereby declare that the Project Report entitled
**SUPERSONIC FLOW CALIBRATION UNDER DIGITAL TWIN
TECHNOLOGY** done by us under the guidance of **MR.MADHAN KUMAR.,
M.E.**, is submitted in partial fulfilment of the requirements for the award of
Bachelor of Engineering degree in Aeronautical Engineering.

DATE:

SIGNATURE OF THE CANDIDATE

PLACE: CHENNAI

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We would like to express my sincere and deep sense of gratitude to my Project Guide **MR.MADHAN KUMAR., M.E.**, for his valuable guidance, suggestions and constant encouragement paved way for the successful completion of our project work.

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ABSTRACT

The flow angularity in the wind tunnel plays a major role in the test section when testing the models. A subsonic wind tunnel is usually calibrated using a normal pitot tube and a supersonic wind tunnel is calibrated with high-efficiency probes. Calibration of the wind tunnel determines the Mach number and the pressure range in the test section of the flow throughout the operating velocity. In this novelty of the work, we have worked with an Augmented reality-powered application integrated with MatLab coding to work well with triangular-shaped wedge dimensions. We took 3 points A, B, C as the length of the wedges. Mach number is identified using the shockwave angle with the help of the reverse formula. A sustained effort has been directed towards the accuracy of the performance of prediction. The required facilities for the new wind tunnel have been established. This report documents the result of many conducted iterations and compilations. The use of standard models and the role of which optical methods have been carried out during tunnel calibration.

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LIST OF SYMBOLS AND ABBEREVIATIONS

M	Mach
θ	Theta – Wedge Angle (Degree)
β	Beta – Shock Angle (Degree)
γ	Gamma (Specific Heat Ratio)
SST	Menter’s Shear Pressure Transport (SST)
SWG	Shock Wave Generato

Chapter 1

INTRODUCTION

1.1 HISTORICAL SKETCH

Early investigators recognized that wind tunnels required good flow quality which was reported by Pritchard, (The council of the Royal aeronautical society agreed in 1870). This council was inaugurated to provide funds for the construction setting of various plane surfaces at any desired angle, capable of simultaneously registering horizontal and vertical forces for all degrees of inclination Wenham and Browning constructed the first wind tunnel and a various set of tests were performed on flat plates.

Dr.Ludwig Mach (son of Ernst Mach) constructed a tunnel at Vienna in 1893 with a test section of 18x25cm which was used for flow observation and calibration .Later, Automobiles were later subjected to wind tunnel research. It's not so much about determining aerodynamic forces as it is about figuring out how to reduce the amount of power needed to drive a vehicle along a highway at a given speed. Some Automotive wind tunnels have incorporated moving belts under the test vehicle in an effort to approximate the actual condition. Wind tunnel testing of aircraft takeoff and landing configuration. During the 18th century a bunch of people were trying to make these machines fly. The inspiration for their designs, as with many engineering marvels, was taken from nature. They were pretty much trying to copy the birds. It didn't really pan out the way they wanted it to. Eventually they came to know what they didn't know previously, how air flows over aircraft surfaces and all that funky fluid aerodynamics stuff.They needed some kind of wind machine. Mounting models of their flying machines on windswept ridges, and later developed makeshift aeronautical centrifuges or whirling arms. Over the years the wind tunnel grew in size and air speed and all the way through the second world war. Humans now needed more powerful machines to test their high-speed devices and constructed many high-speed wind tunnels for their use. The first tunnel made for human flying was designed and built in Canada by Jean st-Germain in 1978 Montreal. Eventually this concept went on to become Aerodium Technologies.

1.2 Supersonic Wind tunnel:

Supersonic wind tunnels are very high-speed wind tunnels which are capable of supersonic speed ($1.2 < M < 5$). The Mach number and flow in the supersonic wind tunnel are determined by the nozzle geometry. Supersonic wind tunnels is a suction type continuous operation which is used for investigations into supersonic and subsonic wind tunnels. Airflow can be studied with the dimensions around the aerodynamic models. In wind engineering. Wind tunnels are used to measure various velocities and pressure or forces upon the structure. A wind tunnel comprises five major parts starting from the front to the back which are in order, The settling chamber, The contraction cone, The test section, The diffuser and a drive section. In supersonic flow compressibility affects the air density. In fact, the density changes by a factor of the square of the Mach number faster than the velocity. As the cross-sectional area of a supersonic flow is reduced, the velocity and pressure of the flow decreases. Similarly, increasing the region increases the velocity while decreasing the strain. At several points on the model, measurements of air pressure and other characteristics provide details about how the total wind load is distributed. Aerodynamic experiments in wind tunnels have been extremely beneficial for solving design problems in vehicles, vessels, trains, bridges, and building structures, in addition to aircraft and spacecraft. Modern aircraft construction requires the use of a wind tunnel. Despite modern aerospace vehicle design's strong reliance on computational fluid dynamics (CFD), wind tunnels have been strengthened and are still in use. Many places where CFD cannot provide precise solutions require the use of a wind tunnel, which can provide critical data in such challenging flow fields A supersonic wind tunnel requires enormous amounts of electricity, on the order of 50 MW per square metre of test section cross-sectional area. As a result, most wind tunnels use energy stored in high-pressure tanks to run intermittently. A continuous-operation suction-type supersonic wind tunnel for research into subsonic and supersonic air flow. It also enables students to investigate two-dimensional air flow around aerodynamic models. A remote control unit for a high-capacity vacuum pump is housed in an instrument frame ..

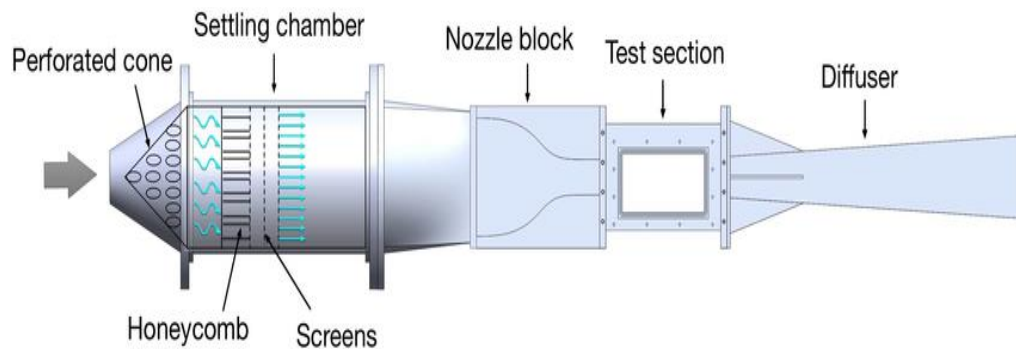


Fig 1.1 supersonic windtunnel

1.3 CLASSIFICATION OF WIND TUNNEL

According to the working methods wind tunnels can be divided into two types, Intermittent wind tunnel and continuous wind tunnel

1.3.1 Intermittent wind tunnel :

Intermittent blowdown wind tunnels, Intermittent in draft wind tunnels, and Intermittent pressure-vacuum tunnels are all examples of intermittent wind tunnels. Because of the high power requirements, high-speed wind tunnels are often of the "intermittent" kind, in which energy is stored in the form of pressure and only a few seconds of each pumping hour is used to drive the tube. Higher compression ratios can be achieved using intermittent wind tunnels. So getting the sporadic tunnel up and running isn't a concern. For Mach numbers between 0.5 and 5.0, intermittent blowdown and in draught tunnels are typically used, whereas intermittent pressure-vacuum tunnels are typically used for higher Mach numbers.

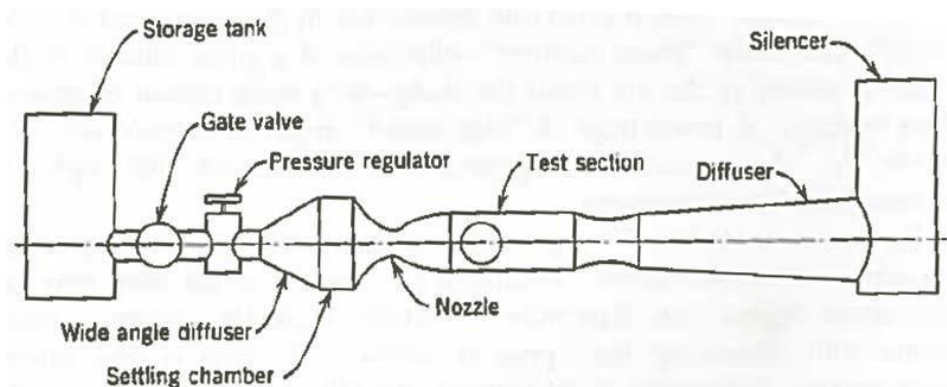


Fig 1.2 Intermittent wind tunne

1.3.2 Continuous Wind Tunnel :

Continuous wind tunnels can run for longer periods of time. For a long period of time, the monitoring conditions can be kept stable. However, pressurising the tunnel reservoir to the necessary pressure takes a long time, resulting in long startup times. Furthermore, when compared to the other type, the size of the air supply system needed for its operation is much larger types of wind tunnel. And it has mach 1.8, it is used for investigating the flow of air in two dimensional models in subsonic and supersonic wind tunnels and also analysis of the profile of the tunnel.

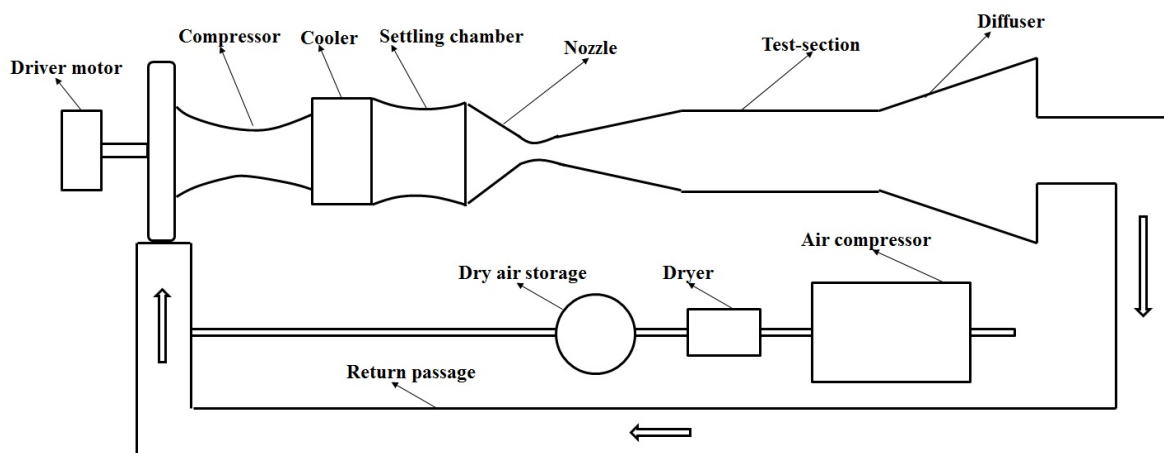


Fig 1.3 continuous wind tunnel

1.4 AUGMENTED REALITY

. Augmented reality (AR) is used as Digital visual elements have been put to great use in the physical world which has helped humans to connect with technology on another level. AR has been used not only in visual but also in sound and other sensory simulations. These properties have been put to use in our app to find the reality shockwave angle and the mach number of the given wedge image. AR systems incorporate virtual knowledge into a person's physical world, allowing them to view it as though it were already there. AR can be used to promote the retailers and other users to promote their products or services, collect unique user data and for marketing campaigns. Where augmented reality adds the world as it is, unlike virtual reality creates its own cyber environment. And augmented reality gives us overlaying visual experience and other important information onto the world to enhance the better experience of augmented reality.

Chapter 2

LITERATURE SURVEY

P. Kevin Tucker , Wei Shyy(1993), A supersonic flow numerical analysis. The methodology of this article is a numerical study of supersonic flow over an axisymmetric afterbody, k-esplon, and k transport turbulence model. The turbulence closure is the big remaining problem to be resolved to be a design variable in the cases computed on the baseline grid with higher order schemes. Second upwind scheme, third order upwind scheme, and second order central scheme are all differentiating schemes. For this article, numerical analysis was used as an experimental technique.

Robert Placek, Paweł Ruchała(2018) are the author of this article, Analysis of the flow separation growth in a subsonic airfoil. Objective To investigate the evolution of the separation phase in a subsonic flow regime. The schlieren method was used to visualise the data, and pressure measurements were used to estimate the lift and drag coefficients. At the architecture variable at the V2C airfoil. The trisonic N-3 wind tunnel is used for analysis. The reference paper for this article is a correlation of low-speed, airfoil section stalling characteristics with Reynolds number.

Mukesh didwania, kamal kishore khatri(2009) are the authors of this article, CFD Analysis of shockwave in vortex core. And aim to investigate the effects of drag, lift, and pressure coefficient in the flow area, as well as the effects of shock waves and vortex core. The vortex core methodology was calculated using a k-omega SST turbulent model and a Q criterion procedure with vortices magnitude. This example shows a computed vortex center over a supersonic aircraft's flapped wing at various angles of attack and Mach numbers. computational fluid dynamics (CFD) and NACA 23012 airfoil was selected to Study dynamics of shock vortex interaction on flap wing by CFD tool.

Z. chen, S.H.yi,L.F.tian,Y.Z.zhu(2013) is the author of this article, Flow visualization of supersonic laminar flow. The aim is to study Flow visualization of supersonic laminar flow over a backward facing step via NPLS. NPLS testing system used, A dual cavity Nd:YAG pulsed is used and carried out in indraft low-noise Wind Tunnel which can generate $Ma=3.0$ in supersonic flow is the methodology . Here the supersonic flow

changes the nozzle size and the size of the cross section in the supersonic tunnel is the design variable used. Flow visualization with high spatiotemporal resolution has recently been developed for supersonic turbulence research. The secondary corner vortex in benchmark turbulent backward facing in velocimetry will be investigated in an in draft low noise wind tunnel.

Dirk Goossens, Zvi , Gary London(2000) is the author of this article, and article is wind tunnel calibration. The goal is to precisely detect the saltation transport periods of five aeolian sand traps. The BMFT wind tunnel technique was used to conduct the experiments. The wind speed interval tested was D50, which ranged from 132 to 287 mm. In the area, measuring the saltation flux is more difficult than in the wind tunnel. Aeolian sediment traps abound. The experimental technique is modified wilson and cooke (MWAC). Aeolian transport into the foredunes is measured using saltation sand traps.

Slavica ristic(2007) is author of this article, and is article Flow visualization of subsonic laminar flow. and the aim is to flow visualization in subsonic flow in Non optical method both wind tunnel and water tunnel. The flow visualization by tufts and on surface flow on wind tunnels is the methodology. The shock wave motion can be recorded using high-speed cameras with exposure times of 10^{-6} to 10^{-9} in conjunction with associated illumination systems. To describe and review the most widely used methods for flow visualization in wind tunnels. Numerical simulation using CGv electrolytic dye production is an experimental technique. flow visualization in the Langley unitary wind tunnel.

John Laufer(1991) is author of this article. And the article is Aerodynamic noise in supersonic wind tunnels. The goal is to investigate supersonic wind tunnel aerodynamic noise. The disruptions were often velocity variations, and the technique was vortices. The amplitudes of mass-flow fluctuations increase rapidly as the flow Mach number increases, according to a supersonic wind tunnel study. Taylor's theoretical work was validated by the turbulent boundary layer along the nozzle and tunnel wall that produced this sound area. The experimental method used was a hot wire probe and a hot wire amplifier. This article is based on the statistical theory of turbulence

Obula Reddy Kummithaa, K.M. Pandeyb , Rajat Guptab(2018), did the CFD Analysis of shockwave in a scramjet combustor. The scramjet is accelerated to supersonic speeds by using external mechanisms such as rockets or planes as the design component in a CFD study of a scramjet combustor with cavity centred flame holders. The Reynolds-Averaged Navier-Stokes (RANS) equations and the shear stress turbulence (SST) k model, as well as a finite rate, are used. The presence of cavity flame holders extends the residence time. The experimental technique is the ANSYS 16-FLUENT method. B-52 Star fortresses and a solid rocket booster, as well as a description of scramjet fuel injection techniques.

Schilden, Thomas; Schröder, Wolfgang(2017) is the author of this article, and the article is Numerical analysis of high speed wind tunnels. Stagnation point probes were used in a numerical study of high-speed wind tunnel flow disturbances. Direct numerical simulation technique is used to provide decomposition methods for tunnel noise. The heat flux and pressure at the stagnation point are investigated in relation to various disturbance modes and input functions. The Euclidean norm is used to calculate the ratio of heat flux and pressure response, as well as the condition number of the transfer matrix S. The experimental technique used was stagnation point probes. Braunschweig stagnation point probe in hypersonic flow Hypersonic Ludwig Tube.

R. Yano, V. Contini E. Plonjes, P. Palm, S. Merriman(1999) is the authors of this article, and the article is Flow Visualization Nonequilibrium Plasma in supersonic WindTunnel. And aim is To investigate the visualization of supersonic non-equilibrium plasma flow in a wind tunnel. The technique is to generate plasma in an aerodynamically stabilized high pressure glow discharge in the plenum of a supersonic nozzle. Extensive gas dynamic experiments were carried out to determine the size and length of the supersonic test flow that could be accomplished in a wind tunnel. Model variable in aerodynamically stabilized high pressure glow discharge of supersonic nozzle. Schlieren device schematic A small scale non equilibrium plasma wind tunnel is an experimental technique that uses a transverse glow discharge to study shock waves in the plasma.

J.E.Sargison, G.J.walker , R. Rossi(2004) did the article on calibration of wind tunnels in 2-D contraction. The aim To study the calibration of WindTunnel in the process of

design optimization. It's using the CFD to model the contraction at the curvature at the contraction inlet. A wall tapping in the plane of the pitot tube was used to measure static pressure and static pressure were changed at the end of contraction. CFD has been used to optimize the design of the wind tunnel contractions. CFD software package CFX[5] is an experimental tool used. The Reynolds SST model of turbulence and Design rules for small low speed wind tunnels is followed.

Rui He, Guoming Chen, Che Cong(2019) are the authors of this article. And the article is data driven in digital twin technology. The aim is to use digital twin technology to optimise control in a data-driven process system. This digital twin framework integrates virtual modelling and optimised control into a cooperative architecture for automated process application. The main goal is to estimate the fault sensor signal XMAS using standard sensor signals (4). The technique is focused on soft-sensor technology. The data-driven digital twin system is to reduce extreme fluctuations and ensure safe industrial process controls. Simulations on the Tennessee Eastman process, virtual system monitoring and diagnosis, and real-time risk monitoring system for chemical plants are all being tracked.

Bernhard H.Anderson, Jon tinapple, Lewis surber(2009) did the article on Optimal control of shock wave turbulence. The aim of this research on microarray flow control is to demonstrate the feasibility and cost-effectiveness of RSM. Shock pressure rise caused by 10° was used to measure the efficacy of three micro-array devices. Methodology is a shock generator that separates the turbulent supersonic sheet. The aim of the design is to change the properties of the supersonic boundary layer by creating a cascade of micro-vortices near the wall. Without boundary bleed, microarray system micro-vane, and micro-ramp arrays, the shock wave boundary layer interaction on the main flow was minimised. Bleed in supersonic compression inlets controls shock wave boundary layer interaction.

B.W.Skews(1997) is the author of this article, this is an article named Aspect ratio effects of shock waves. The aim is to investigate the shock wave reflection transition's aspect ratio effects in the wind tunnel. In supersonic facilities for Mach reflection, the transverse wave patterns and flow fields around double wedge experimental

arrangements are investigated. The lateral path feeding details to the middle could be influenced by the transverse curvature of the prandtl-Meyer waves. From normal to mach reflection, the wave system is reflected from two wedges with small aspect ratio. Reconsideration of oblique shock wave reflections in steady flows and wave system from two wedges of minimal aspect ratio.

Y.Yamamoto,S.Nagai,T.koyama(2002) is the author of this article and CFD analysis of hypersonic interaction heating . The aim is To study the CFD analysis of hypersonic shock-shock interaction heating for two hemisphere cylinders. The hyper TSTO cruise conditions are used and small cylinders are inclined to large one in order to study shock. Infrared image is taken after one second from the injection at the condition of total pressure of 4Mpa,total temperature of 1073k. hypersonic aerodynamic interactions for two hemi-sphere cylinders have been investigated numerically . Inclined setting of these hemi-sphere cylinder, Tunnel test and CFD computations ,Shock interference heating in hypersonic flow.

P.J.Waltrip , F.S.Billigt(1997) is the author of this article and article is Structure of shock wave in wind tunnel and To study the structure of shock wave in wind tunnel in cylindrical ducts. The wall static pressures, read through a scanning valve arrangement and all other pressure are measured by strain-gage transducers calibrated of their full scale. The data points for shock structures originating close to the duct exit show the lowest value of P_f/P_a in some shape of the pressure distribution Wall pressure and instream pitot pressure distribution for shock structures in cylindrical ducts supersonic flows in cylindrical parts, johns hopkins lab propulsion research facility supersonic diffusers for wind tunnels.

Wang deng pan, Zhao yu-xin,Xia Zhi-Xun(2012) is the author of this article, and article flow visualization of supersonic laminar flow. The aim is to visualize supersonic flow over a finite cylinder. Complex structures of shock wave and 3-D vortices in a supersonic flow over a finite cylinder are visualized using nanoparticle-based planar laser scattering in a supersonic quiet wind tunnel at mach no=2.68. Experimental and computational methods, upstream flow of the cylinder by flow visualization, time space evolutionary characteristics of coherent structures in supersonic flow over finite cylinder.

S.Subramanian,C.J.Sullivan, S.M. Batill(2014) is the authors of this article, and article is subsonic wind tunnel calibration and to study the design of a subsonic wind tunnel for acoustic measurements and the NPLS testing system used,A dual cavity Nd:YAG pulsed is used and carried out in indraft low-noise wind tunnel which can generate $Ma=3.0$ in supersonic flow. The fundamental problems of airfoil, cascade, and propeller-gust interaction, as well as gutin noise and turbulence-generated noise. The acoustic output of the free-jet test portion, as well as the diffuser/muffler and inlet, was well within the limits needed for low-speed aero acoustics, according to the theory of turbulent jets.

Azad M Madni, Carla C. Madni, Scott D.Lucero(2019) did research on the Digital twin technology in system engineering, and The aim of this project is to demonstrate the benefits of combining digital twins with device simulation and IoT in MBSE. This digital twin framework integrates virtual modelling and optimised control into a cooperative architecture for automated process application. The primary goal is to estimate the fault sensor signal XMEAS using standard sensor signals (4). Soft-sensor technology is used. The aim of a data-driven digital twin system is to reduce extreme fluctuations and ensure safe industrial process controls. Tennessee Eastman Process Simulations Virtual device control and diagnosis, real-time risk monitoring system for chemical plants.

Slavica ristic(2016) the authors of this article, and article is CFD Analysis of shockwave in scramjet combustor A scramjet combustor with cavity-based flame holders was studied using CFD. It's using the CFD to model the contraction at the curvature at the contraction inlet, A wall tapping in the plane of the pitot tube was used to measure static pressure and static pressure was changed at the end of contraction. This sound field is caused by the turbulent boundary layer that runs along the nozzle and tunnel wall. Taylor's theoretical work was validated by the Hypersonic Ludwig Tube Braunschweig.

Yu Zheng,Sen Yang,Huanchong cheng(2018) the authors of this article, and The article is about the implementation method of complete parametric virtual modelling and the construction idea for DT application subsystems using ambient intelligence and humanised computing. System and application structure for digital twins Data storage

, data processing, and data mapping are the three functional module structures of the information processing layer. Both parameterized DT space, as well as the virtual environment platform (VMP) and the DT application subsystem, synchronous and asynchronous coupled mapping, and the virtual environment platform (VMP). A new model for future workshops is the digital twin workshop. Artificial intelligence is implemented using the Comput Integr Manuf Framework.

CHAPTER-3

AIM AND SCOPE

3.1 AIM

The aim of this novel work is to calibrate the supersonic flow using digital twin technology by Augmented reality using the digital content. To measure the shock wave angle and to determine the Mach number in supersonic wind tunnels.

3.2 FUTURE SCOPE OF THIS WORK

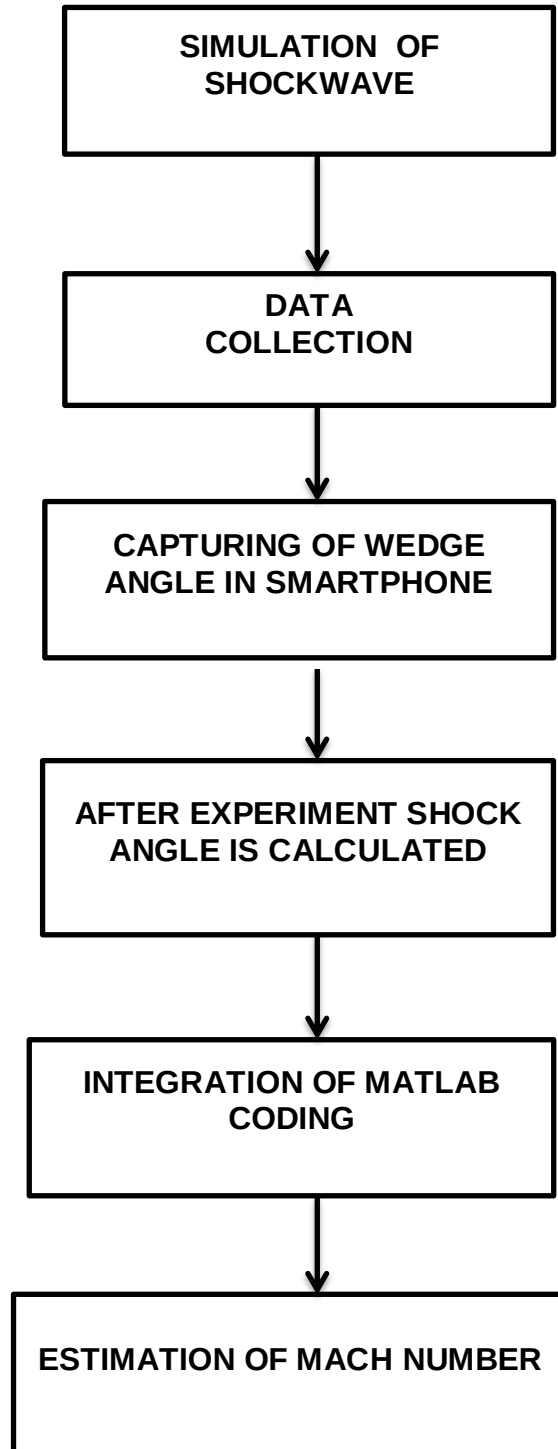
This novel works bring in the hands of every individual a mobile app which can measure Mach number. This cutting-edge technology defines a new method for wedge shock wave visualization and mach angle calculation. First time in supersonic where shock wave Mach number is calculated using a non-intrusive and very cheap cost method Development of software that enhances the visualization of shock-wave interaction and wedge body configuration.

In this work we will be capturing the shockwave formation without the help of any devices but with a free app installed in our smartphone. The captured shockwave angle is measured and the mach number can be predicted. An attempt to capture the Shockwave using a smartphone is first of its kind .This is the first time Shockwave has attempted to capture a smartphone .The digital twin technology is also used in the work. Here cloud computing is used along with digital twin technology. The half wedge body has been considered in this work with a relative post wedge angle that is representative of a high-speed flow vehicle. This work also focuses on capturing the shock-wave interaction during high-speed flows and estimation of free stream Mach number for varying oscillated speeds. With these points in mind the main objectives of this work are as follows which will expand the range if shock wave angle dimensions that has been preprogrammed in the java programming language which we use the theta, beta which is formulated to give the mach number of relation of the shock wave. Which explore the shock-wave angle for definite wedge body configuration which would be kept inside the supersonic wind tunnel flow calibrations. Where the free stream mach number for the operating results subtends to supersonic wind tunnel running conditions. To investigate the effect of the free stream mach number were the augmented reality is used to find the free stream mach number and shock wave. And the relation for varying oscillating conditions under digital twin technology.

CHAPTER - 4

METHODOLOGY AND EXPERIMENT

METHODOLOGY:



4.1.1 DATA COLLECTION:

Length, wedge angle, beta value, Mach value data are collected and compiled into the AR powered app which can generate planes with the support of AR incorporated in the app.

4.1.2 .CAPTURING OF WEDGE ANGLE USING SMARTPHONE:

The app is installed in a smartphone which uses the camera which is used in order to find a plane which is created using triangle geometry which consists of three edges which are marked as points A, B, C respectively.

4.1.3 CALCULATION OF SHOCK ANGLE:

Identify each cutting edge of the triangle and mark them accordingly, Degree of each marked point is measured and the shock angle is calculated. Once each wedge is identified they are saved. A Shock wave is a propagating wave which moves faster than the speed of sound and causes changes in pressure, temperature and density of the medium through which it is propagating through. There are three basic types of shock waves which are Normal, Oblique and Bow Shocks. Shock Wave Shock waves are the waves that travel greater than the speed of waves in the medium of supersonic regime. Shock waves are strong pressure waves. Shock waves occur when the velocity of an object exceeds the speed of sound. Shock waves are discontinuous waves which are propagating disturbance in the supersonic flow. The characteristics of shock waves are change in temperature, velocity and density. Shock waves can also be in the form of compression waves or expansion waves. Shock waves are responsible for creating drag forces in the supersonic regime.

4.1.4 Integration of Matlab coding:

MATLAB Code produces C and C++ code for a range of hardware platforms, ranging from desktop computers to embedded devices. It supports the majority of the MATLAB language as well as a large number of toolboxes. You can use the created code as source code, static libraries, or dynamic libraries in our projects. It can be used in collaborative sessions as well as as a batch task. This tutorial will give you a thorough

introduction to the MATLAB programming language. Its aim is to help students become proficient in the MATLAB programming language. To make learning quick and efficient, problem-based MATLAB examples have been presented in a clear and easy manner.

4.1.5 Estimation of Mach number:

Mach number is a parameter which plays an important role when it comes to solving or to get a better understanding of shock waves. Mach number does not have any units, it's a dimensionless quantity. It helps us to define the flying object regime at various compressibility effects. It is the ratio of an object's local velocity to the sound speed in the medium. Mach number indicates the mach regimes of a flying object at different types. The generated code will estimate the shock angle and the mach number of the wedge. Finally the shadow wedge number is calculated and the exact mach number can be estimated.

4.2 MODEL:

The shockwave formation is created with the help of a supersonic tunnel and the simulation is repeated multiple times to get the exact Mach number. A list of data has been collected to run iterations for different experiments. To analyze and measure the shock wave angle, static pressure and Mach number of air flowing over 10 degree and 20 degree half-angle cones and wedges. In order to perform our analysis with our known information we must make some assumptions and create a simple model we can analyze. Although we consider the compressibility of the air, we must assume a steady, two-dimensional, uniform flow and assume perfect gas behavior, calorically perfect conditions, and neglect viscous forces. Although these assumptions provide some limitations in our analysis, we are able to generate valid conclusions. Oblique shocks are generated when a supersonic flow has to turn into itself and are, in essence, a collection of tightly packed Mach waves, so close together that there seems to be a discontinuity in the thermodynamic properties of the flow. The shock wave angle is related to the velocities and pressures of the flow as well as the geometry of the body it flows over; therefore, the angle is to be measured to be able to calculate the other properties. In order to visualize the shock-wave we utilize Schlieren imaging.

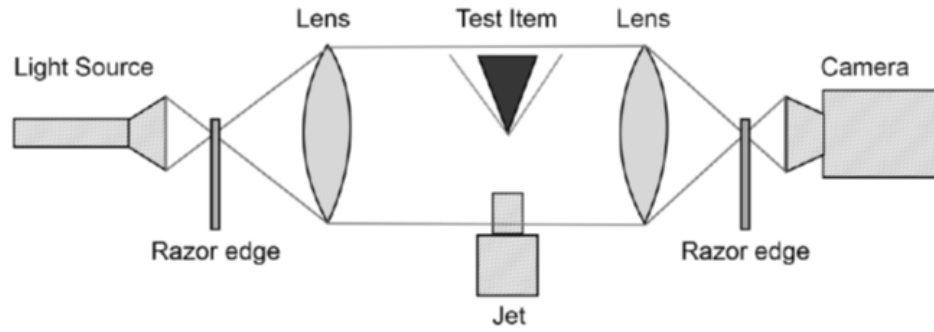


Fig 4.1 EXPERIMENTAL SETUP

In the present experiment, the shock-wave angle and wedge angle configurations for different free stream Mach numbers had been inbuilt under the augmented reality software and coding has been done using the formula given.

$$\tan(\theta) = 2 \cdot \frac{1}{\tan(\beta)} \cdot \frac{M_1^2 \cdot \sin(\beta)^2 - 1}{M_1^2 \cdot (\gamma + \cos(\beta)^2) + 2}$$

Oblique shockwave relation already has an existing formula given above, variable shock angle, wedge angle, inlet Mach are taken. According to these data's formula is structured reversed we give that and beta to find the Mach angle, data contains everything, to which theta which Mach, generate formula in the table.

$$M_1 = \sqrt{\frac{2 \cos \theta \cos(\theta - \beta)}{\{(2 \cos \theta \beta \cos \cos \beta) - (1.4 \sin \theta \cos \beta) - (\cos^2 \sin \theta \sin \beta)\}}}$$

Using the above formula, the coding has been developed and constrained values of different data has been digitally given through augmented reality software and interaction of shock waves with graphical plotting imaging has been built. The first one by keeping the wedge angle constant and free stream Mach number variations are fed inside the app program and data has been stored for analytics of augmented reality platforms. The second one by keeping the camera position for sensing the element of half-wedge body in the configuration that coincides the data analytics that has been

stored in the first one handling.

In the following, the aforementioned digital technology platform, the virtual viewed half-wedge body has been scanned completely and shock-wave which has been developed in the schlieren image was captured and results are graphically delivered in the digital form using data analytics that has been previously encoded.

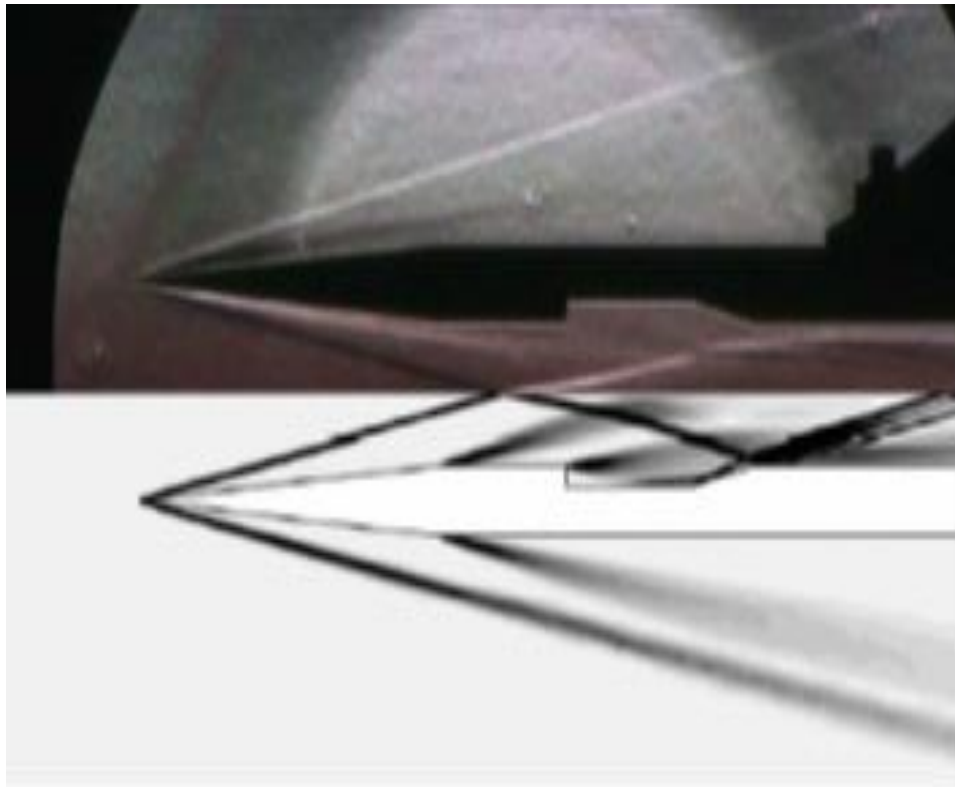


Fig 4.2 shock wave

To evaluate the shock-wave interaction without any theoretical, computational work, this digital twin technology platform helps us to visualize as well as for estimation of shock-wave angle and free stream Mach number ahead and behind the shock-wave. The augmented reality coding for different data analytics of shock-waves software will be developed in future and different geometrical structure coding will be built accordingly.

CHAPTER - 5

EQUIPMENT USED

5.1 SUPERSONIC TUNNEL:

A supersonic wind tunnel is a wind tunnel that produces supersonic speeds of $1.2 < M < 5$ and Changing the density level of pressure in the settling chamber changes the Reynolds number. As a result, a high pressure ratio is needed (on the order of 10 for a supersonic regime at $M=4$). Apart from that, if the static temperature drops low enough, moisture condensation or even gas liquefaction will occur. This necessitates the use of a drying or pre-heating facility in a supersonic wind tunnel. Since supersonic wind tunnels need a lot of electricity, they're usually designed for intermittent rather than continuous operation. At the test part, the minimum pressure ratio should be less than or equal to the total pressure ratio over normal shock. In addition, there are power requirements. Is 50MW per square meter of cross-sectional area of the test segment. And the tunnel needed a sufficient supply of dry air.

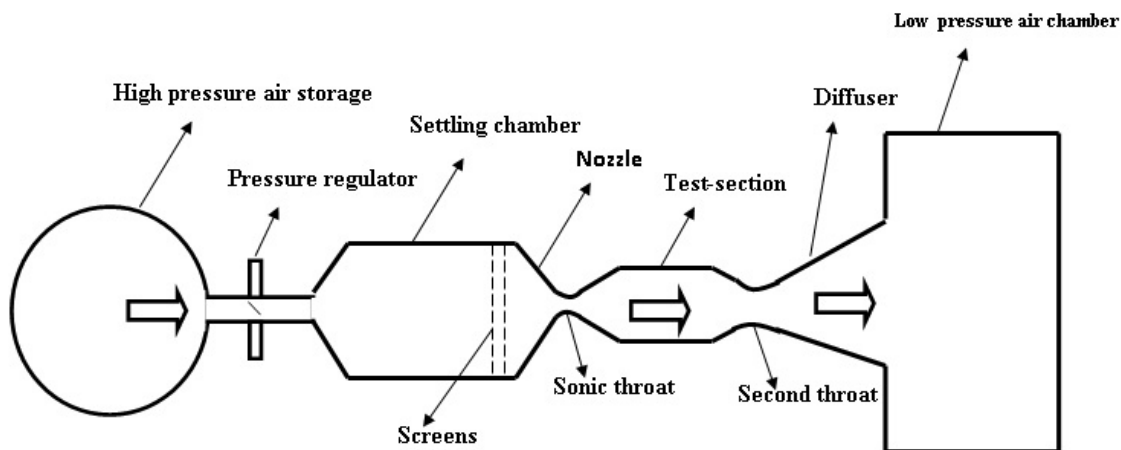


Fig 5.1 supersonic tunnel

5.2 WEDGE MODEL

A wedge is a triangular body which is sharp at one end and it caused the supersonic flow to generate a shock wave. The wedge when passed through gas the molecules are deflected around the object. If the object is travelling at a speed higher than that of the supersonic flow then the density remains constant. When the Mach number of the

supersonic stream is sufficiently high and the wedge angle is sufficiently low, a shock wave is generated. When the above conditions are met, an oblique shock wave is usually produced, and the shock is usually attached to the sharp leading edge of the wedge. The resulting Mach is normally greater than the supersonic flow's inlet Mach, and the pressure ratio is greatly increased as a result of the wedge models' effect.

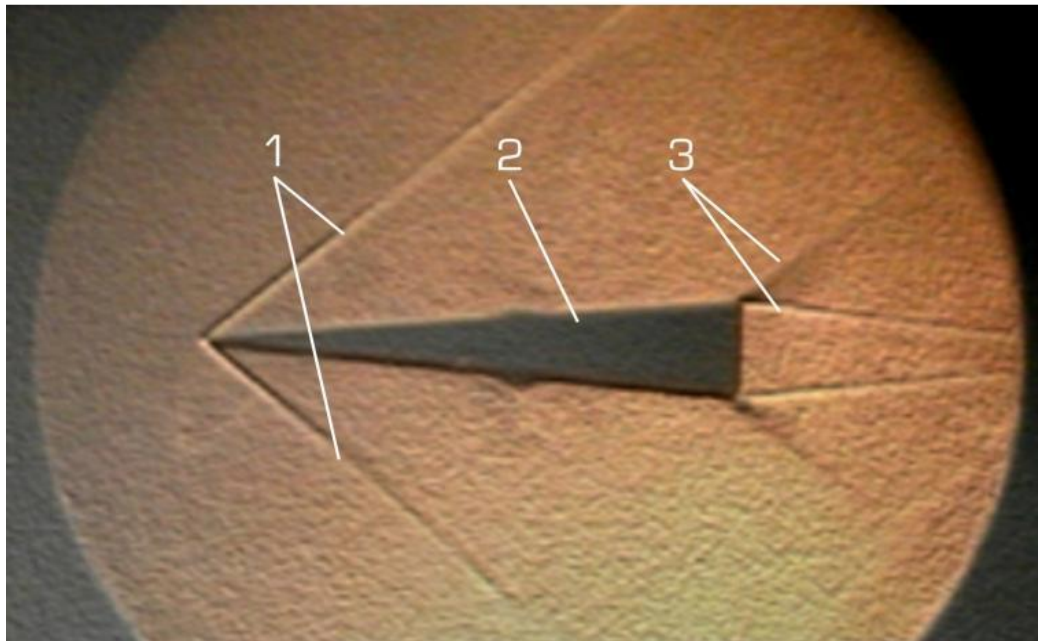


Fig 5.2 wedge module

4.3 AUGMENTED REALITY:

Augmented reality (AR) is a technologically enhanced version of the natural world that is achieved by the use of digital visual elements, sound, or other sensory stimuli. It's a growing trend among businesses that deal with mobile computing and business applications. These properties were used in our app to calculate the shockwave angle and mach number of a wedge image. AR systems incorporate virtual knowledge into a person's physical world, allowing them to view it as though it were already there. Additionally, AR can be used to advertise retailers and other users' goods or services, as well as to gather specific user data and run marketing campaigns. Unlike virtual reality, which adds to the existing reality landscape, augmented reality creates its own cyber environment. And augmented reality allows us to overlay visual experiences and other essential knowledge onto the physical world to improve our augmented reality experience

CHAPTER - 6

RESULT

6.1 IMAGE CAPTURING IN SUPERSONIC TUNNEL

First time in supersonic where shock wave mach number is calculated using a non intrusive and very cheap cost method .A patent for the project of supersonic flow visualizations using AR/VR can be obtained.This novel works bring in the hands of every individual a mobile app which can measure mach angle.This cutting edge technology defines a new method for wedge shock wave visualization and mach angle calculation. Further more complex geometry and their mach angles could also be calculated. Below we have attached some images of the shockwave captured from the wind tunnel at three different stages of the shock wave passing.

This fig 6.1 image is captured before the passing of the shock angle. Shock wave oscillation in a supersonic flow can be called an acoustic perturbation source in a supersonic wind tunnel.

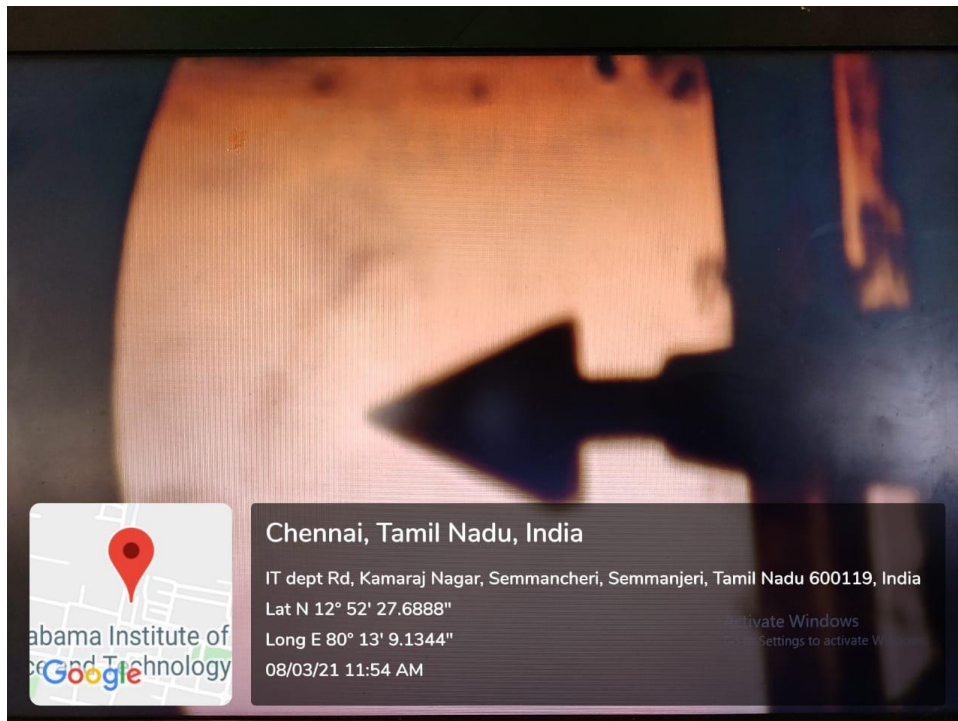


Fig 6.1 Wind tunnel before passing of shockwave

The Fig 6.2 image is after the passing of the shock wave. A triangle geometry is formed when the tunnel is turned on. When a supersonic stream wise vortex collides with a shock wave, the shock wave's discontinuous pressure increase may be enough to burst the vortex. The composition of the vortex determines the details of the shock wave/vortex interaction, as well as whether or not the interaction causes vortex breakdown.

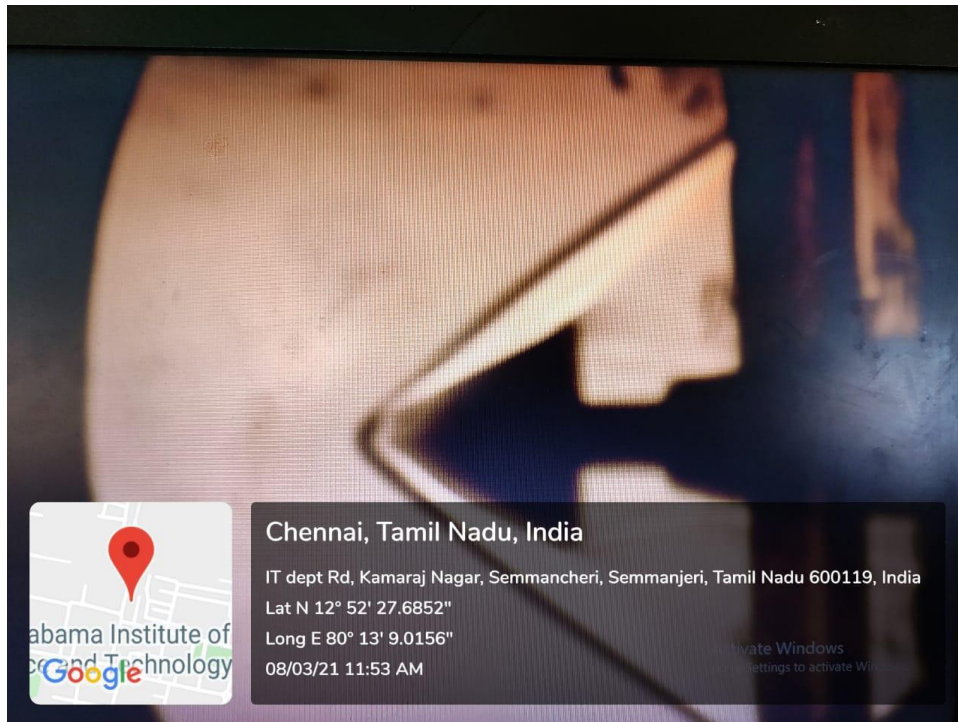


fig 6.2 passing of shockwave

fig 6.3 image is after the capturing of the shockwave image the wind tunnel is shut down and its mach number is calculated using the app which is integrated with Matlab coding The above image shows the wind tunnel once it's turned off.

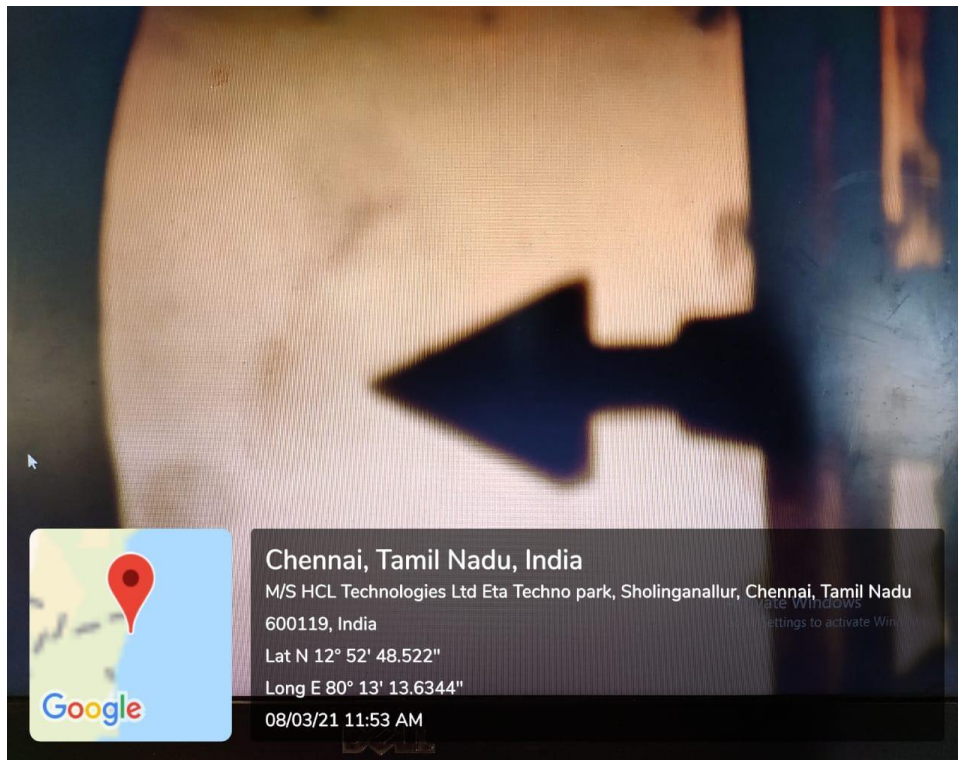


fig 6.3 after shockwave is passed

6.2 COMPUTATIONAL FLUID DYNAMICS

The Navier-Stokes equations, which describe the relationships between velocity, pressure, temperature, and density of a moving fluid, are the foundation of CFD. CFD has been used in a number of experiments to test the precision of numerical analysis techniques, but only a handful have attempted to visualise the simulation results. In several fields of study and industries, including aerodynamics and aerospace analysis, CFD is used to solve a broad variety of research and engineering problems. Weather modelling, natural science and environmental engineering, industrial system design and analysis, biological engineering, fluid flow and heat transfer, and engine and combustion analysis are some of the topics covered in this course. Start with the C-NS in incompressible navier-stokes equations. Assume the density is constant at all times and in all places. Another way to calculate the I-NS is to conclude that the mach number and temperature variations in the fluid are both very small. As a consequence, the mass- and momentum-conservation equations are decoupled from the energy-conservation equation, and the Navier-Stokes equation falls into a hierarchy of fluid flow equations, highlighting the hierarchy of flow equations solved using computational fluid dynamics.

6.2.1 18 DEGREE WEDGE IMAGE

Below is a computationally analyzed image with a wedge degree of 18. This image is printed and the printed copy is used to experiment with the app. The image is placed under bright light for accurate results. The shock angle and the inlet mach number are calculated for the taken wedge image. The Shock angle produced from the analyzed image is captured in bright yellow color. The theoretical value we got for this wedge image is 4.5(Mach number) and for shockwave angle as 12.78 and the experimental value is 4.8(Mach number) and for shockwave angle is 12.94 which are tabulated and shown below in table 6.1

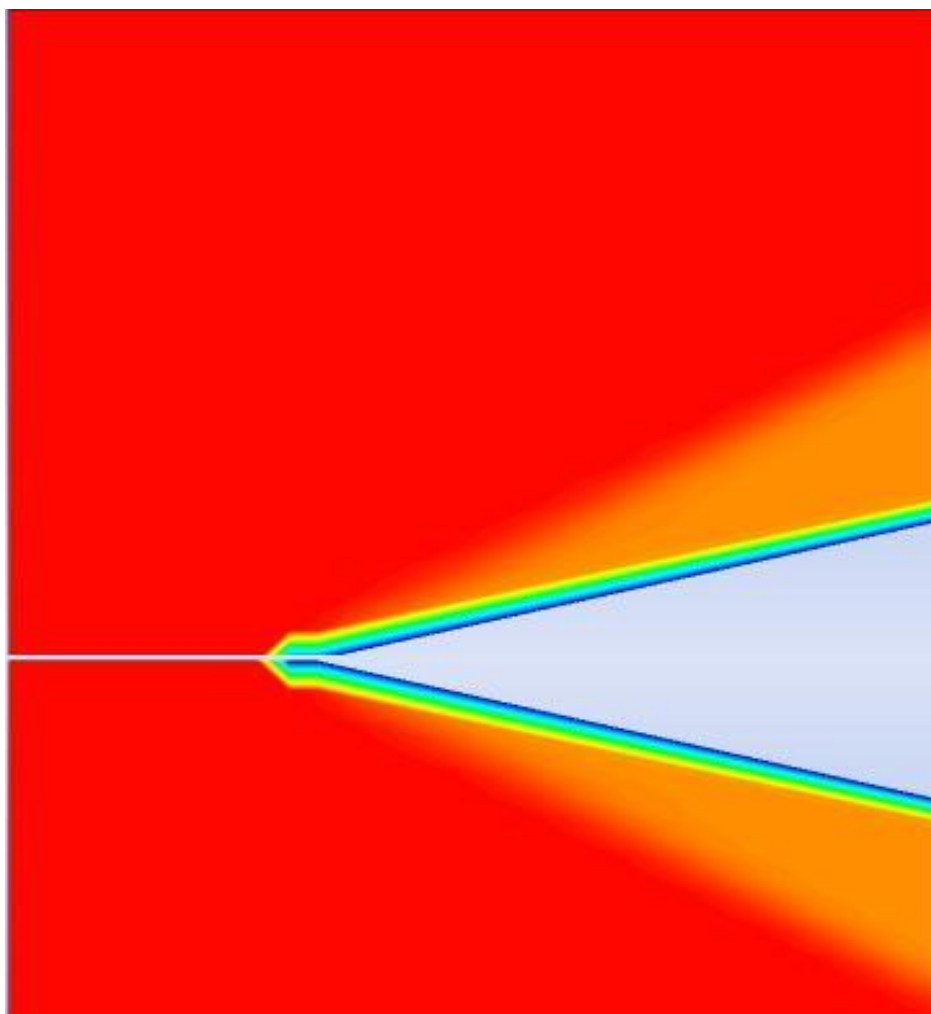


Fig 6.4 18 Degree CFD wedge image

6.2.2 20 DEGREE WEDGE IMAGE

The 20 degree wedge image is taken and various iterations has been conducted for this image and the theoretical value we got is 4.7 for mach number and 12.99 for shockwave angle and the experimental value is 5.0 for mach number and 13.07 for shockwave angle which are tabulated below.in table 6.2

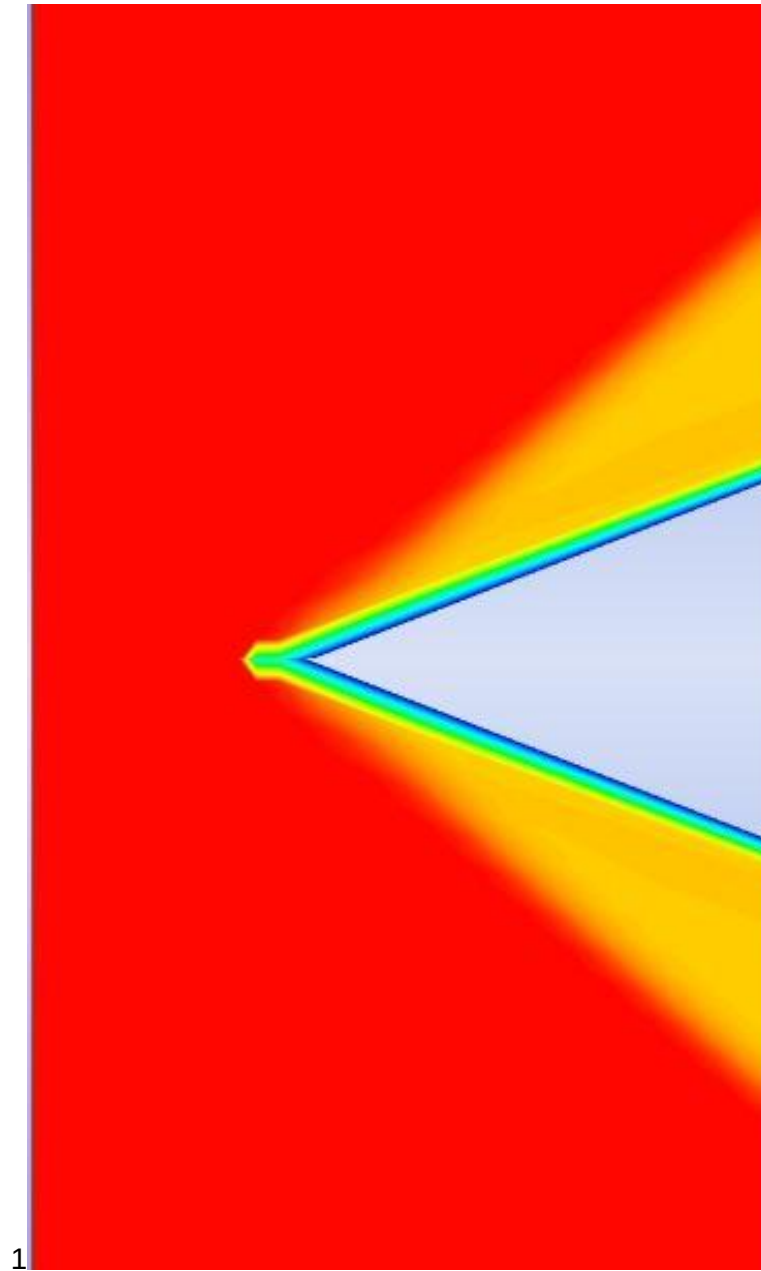


fig 6.5 20 degree CFD wedge image

6.2.3 28 DEGREE WEDGE IMAGE

The 28 degree wedge image is taken and various iterations has been conducted for this image and the theoretical value we got is 4.9 for mach number and 13.11 for shockwave angle and the experimental value is 5.1 for mach number and 13.29for shockwave angle which are tabulated below

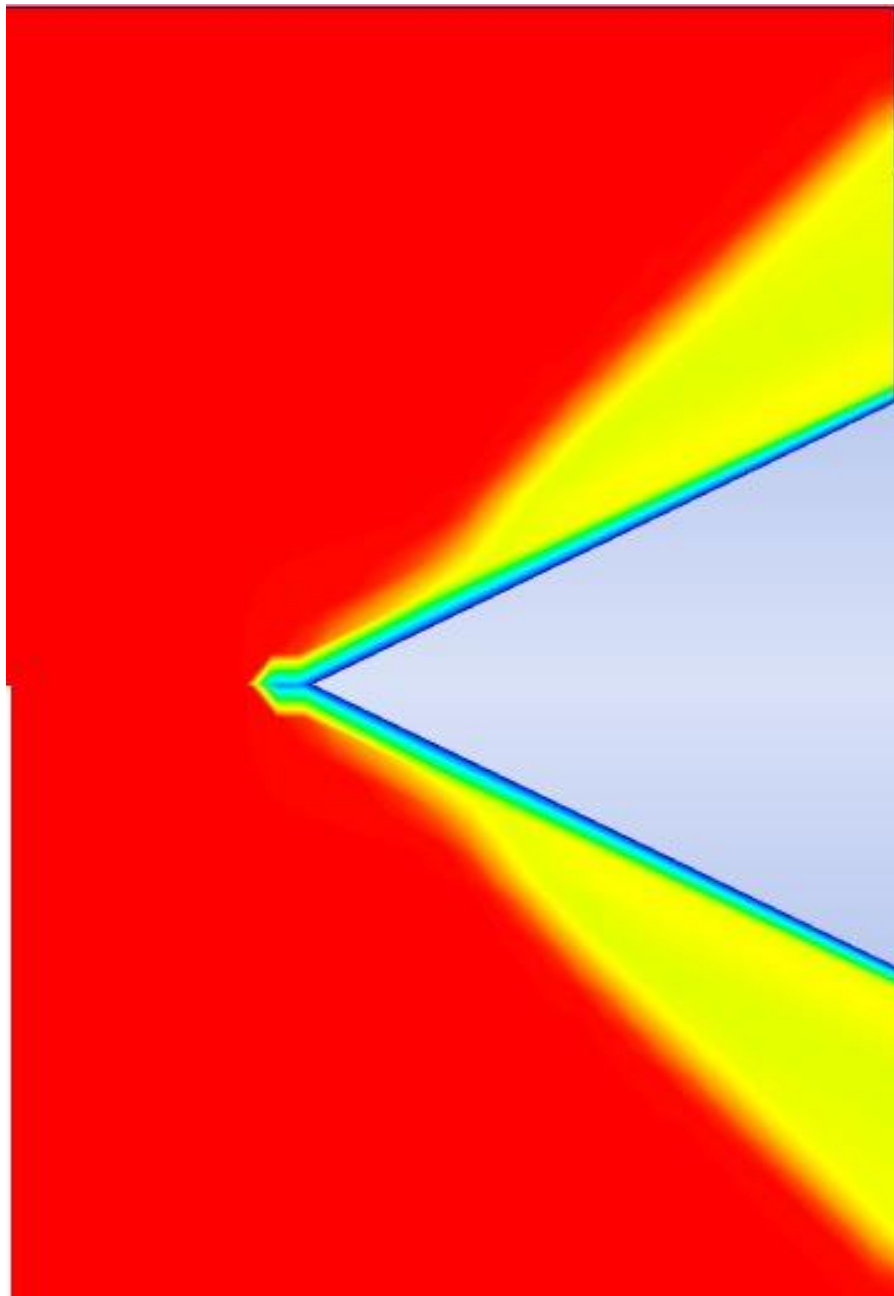


fig 6.6 28 degree CFD wedge image

6.3 APP STRUCTURE

The app structure is to depict the next part of the shockwave visualiser app where it shows the angle of each side measured using the app which is integrated with our smartphone camera. The inlet mach and the shockwave of those sides are displayed at the bottom part of the page. This particular fig 6.7 image which is posted below is the inlet mach number and shockwave angle of the wedge image of 18 degree

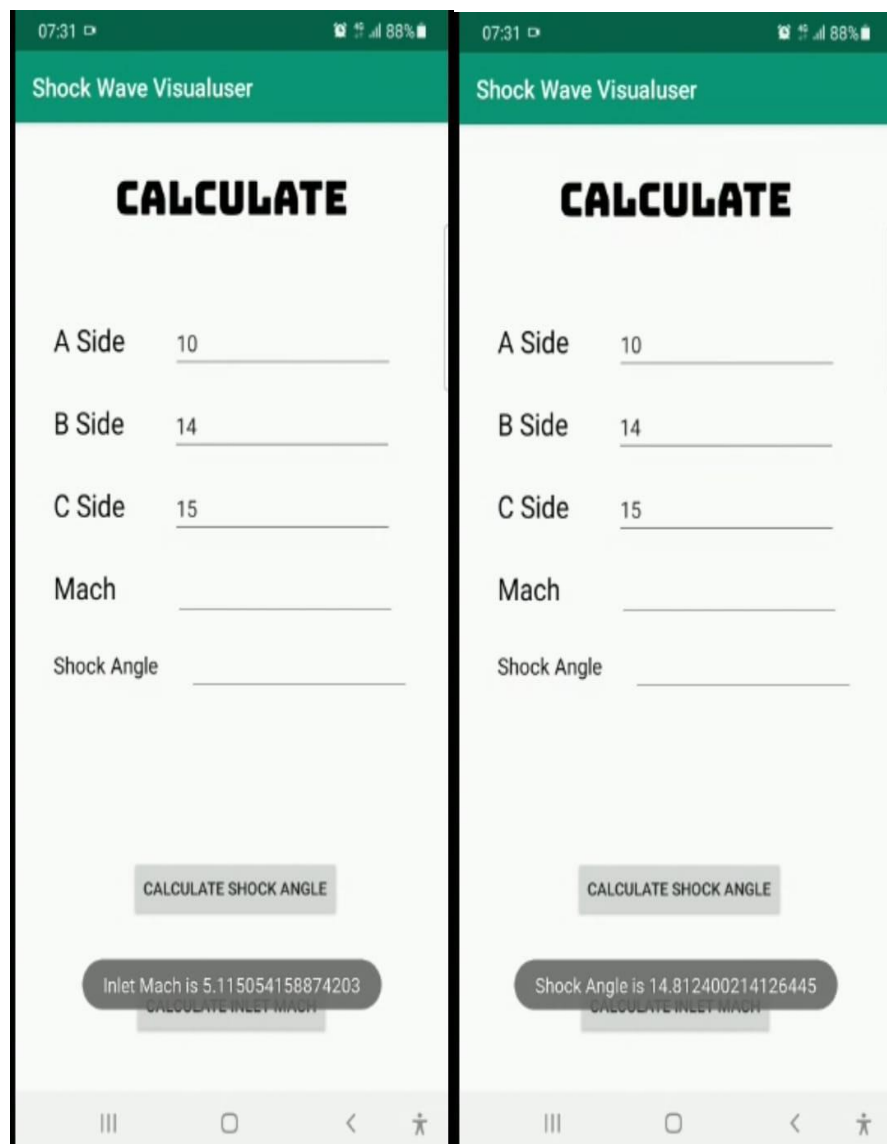


fig 6.7 Calculation page of 18 degree wedge

The below fig 6.8 image shows us using the app to calculate the sides of the taken wedge image. In this case we are displaying the 18 degree wedge image sides are being measured.

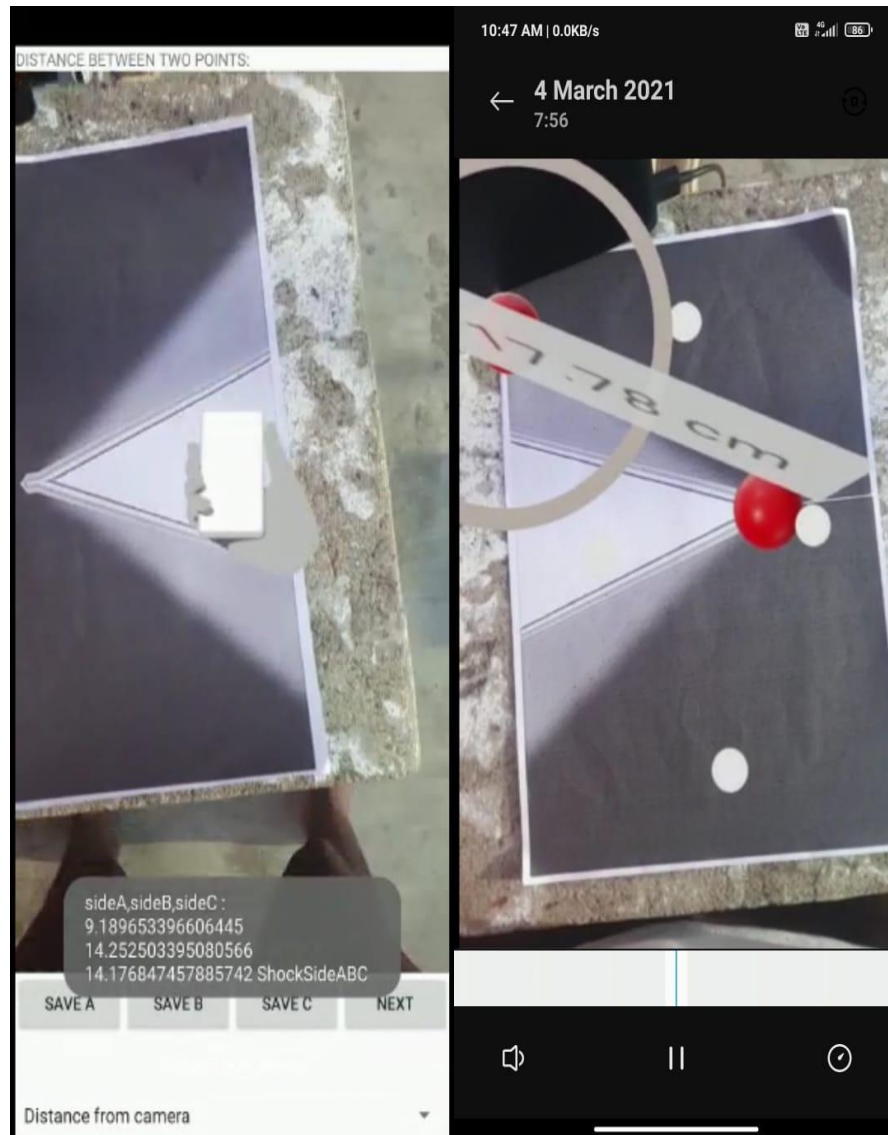


Fig 6.8 wedge sides capturing

The below image fig 6.9 and 6.10 shows us using the app to calculate the sides of the taken wedge image. In this case we are displaying the 20 degree wedge image sides are being measured.

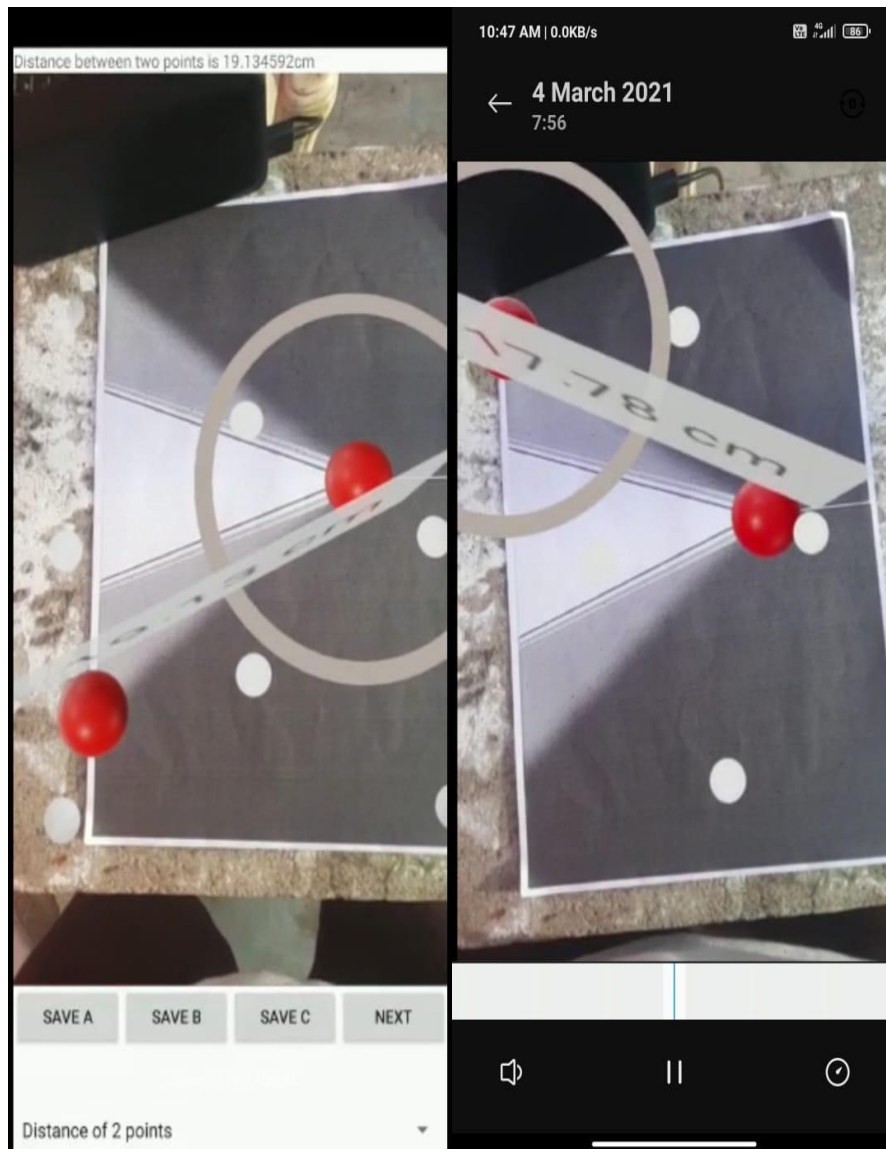


Fig 6.9 wedge sides capturing

This fig :6.10 depicts the next part of the shockwave visualiser app where it shows the angle of each side measured using the app which is integrated with our smartphone camera. The inlet mach and the shockwave of those sides are displayed at the bottom part of the page. This particular image which is posted below is the inlet mach number and shockwave angle of the wedge image of 20 degree

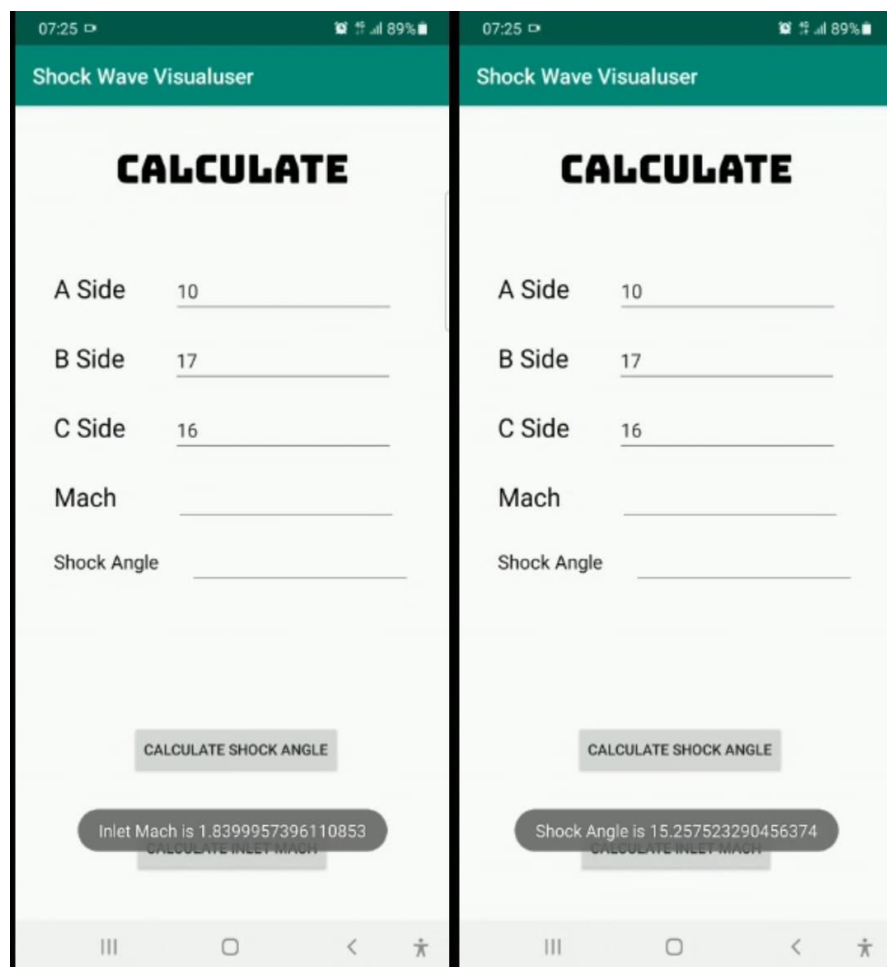


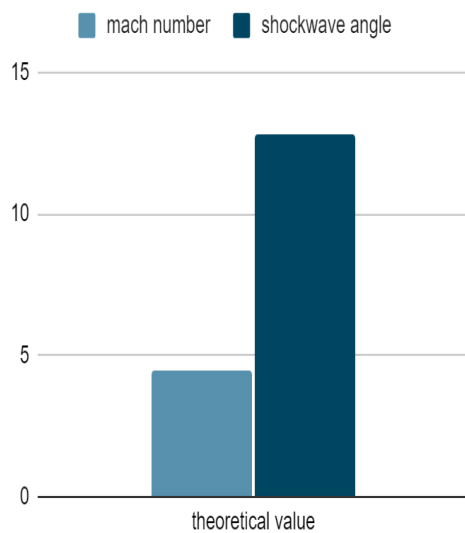
Fig 6.10 Calculation page of 20 degree wedge

6.3 DISCUSSION

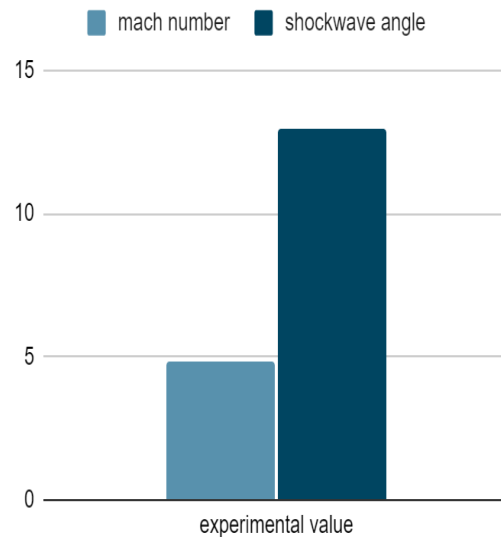
TABLE 6.1 18 DEGREE

THEORETICAL VALUE		EXPERIMENTAL VALUE	
Mach number	Shockwave angle	Mach number	Shockwave angle
4.5	12.78	4.8	12.94

Points scored



Points scored

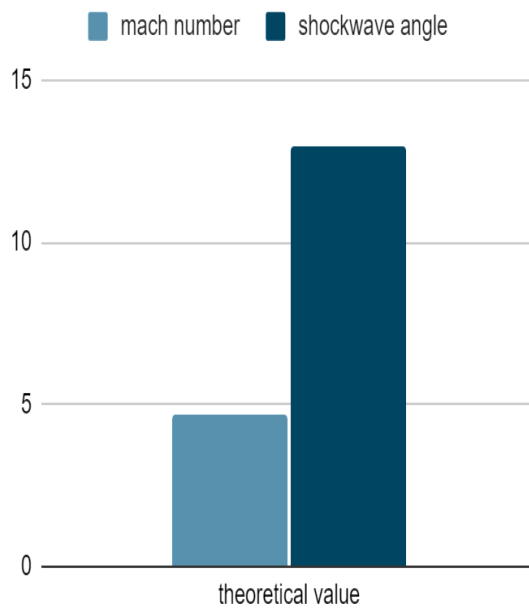


Graph compare the 18 dregree wedge of theoretiacal and experimental and The above table 6.1 shows the comparison between the theoretical value and the experimental value of the 18 Degree wedge model which shows the Mach number and shockwave angle with 20% error.

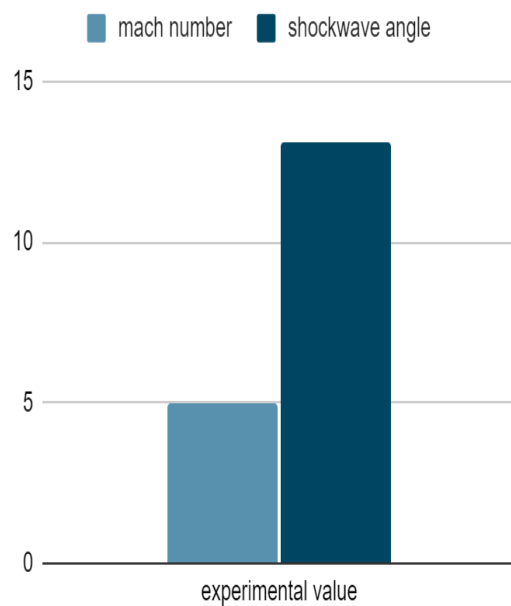
TABLE 6.2 20 DEGREE WEDGE

THEORETICAL VALUE		EXPERIMENTAL VALUE	
Mach number	Shockwave angle	Mach number	Shockwave angle
4.7	12.99	5.0	13.07

Points scored



Points scored

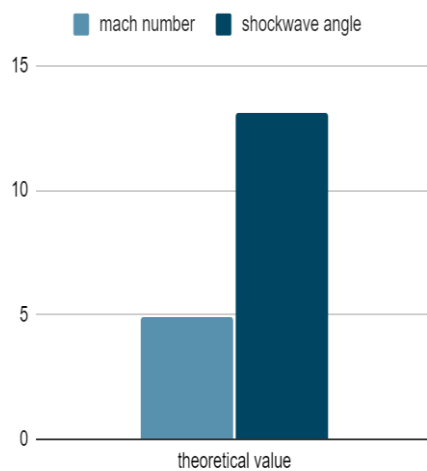


Graph compare the 20 degree wedge of theoretical and experimental and The above table 6.2 shows the comparison between the theoretical value and the experimental value of the 20 Degree wedge model which shows the Mach number and shockwave angle with 18% error.

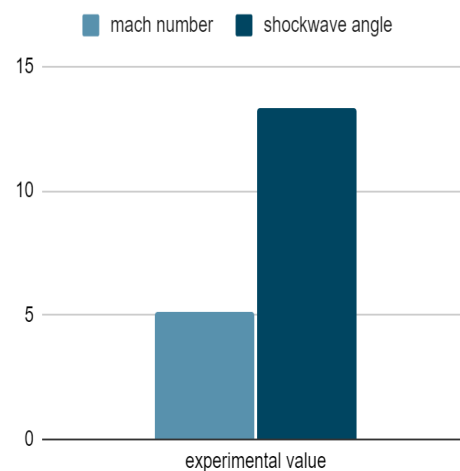
TABLE 6.3 28 DEGREE WEDGE

THEORETICAL VALUE		EXPERIMENTAL VALUE	
Mach number	Shockwave angle	Mach number	Shockwave angle
4.9	13.11	5.1	13.29

Points scored



Points scored



Graph compare the 28 degree wedge of theoretical and experimental and The above table 6.3 shows the comparison between the theoretical value and the experimental value of the 28 Degree wedge model which shows the Mach number and shockwave angle with 20% error.

CHAPTER 7

CONCLUSION

Thus far we have successfully calculated the shock angle and the mach number of the taken wedge model using the app which we developed using matlab ,java, kotlin coding. The matlab code integrated in the app helps us to find the shock angle from the wind tunnel,this app can be further developed accordingly to find shock angle for other dimensions.this work can be carried on by other students using the supersonic wind tunnel and update the app. The development of this app will immensely help in reducing the cost and time of the user. Right now to conduct an experiment we require a high speed dslr camera and the accuracy of the result is vaguely satisfying. We have tried to counter the difficulties faced by the users, this app can be made available In the Google play store. The experiment will be started in the wind tunnel and the shock wave is passed through the test section inside a dark room and a mirror will be placed in such an angle that the shadow of the shock wave is made to fall a white sheet which is spread on the floor to capture the shock angle and the shadow of the shockwave is measured using the app which inturn will provide the mach number and the shockwave angle.

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