




# Utilization of Wind Tunnels for Subsonic and Transonic Flow for Aeronautical and Non-aeronautical Applications: A Review

Sai Sravan Yarlagadda<sup>1</sup> · Siddharth Sriram Sikha<sup>1</sup> · Gaurav Kumar Pandey<sup>1</sup> ·  
Pedi Reddi Varshith<sup>1</sup> · Edison Gundabattini<sup>2</sup> 

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**Abstract** Wind tunnels are built with a certain function in mind and a certain speed range in mind. In this paper, the utility of wind tunnels for varied flow conditions which affect forces on the objects is discussed. As time progresses, more work is being done on wind tunnels which reflects a skilful combination of technology whose roots are based on principles of wind tunnels. Facility characteristics, the principles of operation and therefore the evolution of wind tunnels came to be as they are in today's world are reviewed. Computational analysis, design criteria and flow physics for subsonic and transonic flows are discussed in this article for closed section testing. Subsonic flow around a circular cylinder and transonic flows over a lambda wing is taken as specific cases. The developed analytical models and closed-circuit wind tunnel tests are compared to validate. The average value of drag coefficient in a circular cylinder subsonic flow indicated a 25–9% variation between the numerical models and the wind tunnel in the specific range of fluid flow ( $R_e$ ). The average value of pressure suction coefficient in a circular cylinder subsonic flow indicated a 27 to – 6% variation between the numerical models and the wind tunnel in the same range of fluid flow. The flow topologies measured using different turbulence models are in good agreement with the schlieren images obtained through the wind tunnel testing for a transonic flow over a lambda wing.

**Keywords** Equated results · Crosswinds · Aerodynamic coefficient · Drag coefficient · Suction coefficient · Closed section testing

## Abbreviations

CFD	Computational fluid dynamics
$hl_{1-2}$	Head loss between the first and second ends
$hl_{2-3}$	Head loss between the second and third ends
$hl_{total}$	Total head loss
$P_1$	Pressure at the end one
$P_2$	Pressure at end two
$V_1$	Velocity at the end one
$V_2$	Velocity at end two
$g$	Acceleration due to gravity
$\rho$	Density of fluid flowing inside the tunnel
$R_e$	Reynolds number

## Introduction

To define wind tunnels, they are massive structured tubes with the air flowing inside them. These tunnels were originally intended to replicate the functions of a body/object on the wing [1]. Few of the wind tunnels when compared to one another are very big and can even accommodate vehicles. Scholars use wind tunnels to find out more about how an aircraft would move in through the air around the body/object, making it appear to be the sample considered to be flying [2].

In general, wind tunnels have powerful fans that move air from one side to the other in the tube [3]. The body, or say object to being tested upon, is clipped within that tunnel in such a manner that it will not move. The sample

✉ Edison Gundabattini  
edison.g@vit.ac.in

<sup>1</sup> School of Mechanical Engineering, Vellore Institute of Technology, Vellore 632014, India

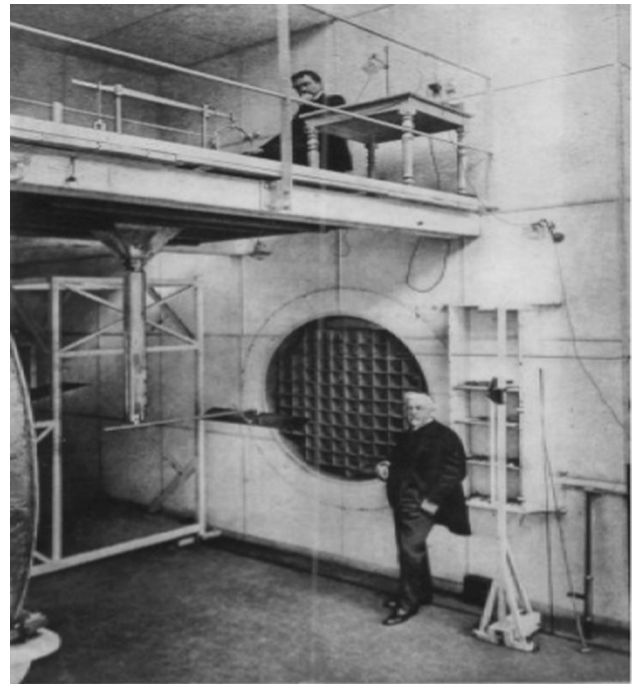
<sup>2</sup> Department of Thermal and Energy Engineering, School of Mechanical Engineering, Vellore Institute of Technology, Vellore 632014, India

that is being considered could be a little model of a vehicle like a ball. The question that would arise in one's mind would be the total airflow in that entity when it would be moving from side to side. Also, how the air moves (a mechanism) is often considered in several ways [4]. Smoke or sometimes dye is often positioned within air and may be seen because it travels. Again, threads are sometimes attached to the body to point out how and why the air present there is travelling. Some of the Instruments are not used often to find or calculate the applied forces of the air on the body [5].

## Evolution

Till recent times, with the understanding of wind tunnels, a man was able to foresee the aerodynamic behaviour of any structure. Wind tunnels have helped us in investigating aerodynamic stability and its related parameters. The simplest result for a matter of flow, i.e. Reynolds number, comes by operating a comparatively big tunnel (dimension say,  $2 \times 2$  m) at a relatively high and at extremely freezing temperatures using air rich in nitrogen. The primary structure that was built was a low-speed tunnel at the NASA Langley research facility in the year 1972. This was an inspiration as the scholars at research centres around the world have started an enormous number of cryogenic wind tunnel projects [6]. Now the development of wind tunnels is traced back to the 1700s. The inspiration for their designs, like many engineering marvels, was taken from nature. They were just about trying to urge their concept right by observing birds, but this was not working out for them. Credit must be given to Frank H Wenham of the "Aeronautical Society" of the whole at that time England, Scotland and Wales for the primary design and process of a real and working structure in 1871. It is worth noting down that horizontal wind tunnels are being considered for now [4]. People have been concentrating on the development and usefulness of numerical algorithms which have been improving day by day [7].

This tunnel was between 10 and 12ft long, 18 inches square and driven by a lower blower external combustion engine [8]. Over the years the wind tunnels grew in size and in terms of design and war seemed to be the main driving force and inspiration for brand spanking new pioneering technologies in the field of wind tunnel's vertical structure [9]. Trying to work out when the primary vertical structure was built was not easy [2]. Many websites and sources claim the primary or first type was built in the late 1920s, but the authors had narrowed it right down to a NASA facility at Langley within the 1920s. In 1941, they built the primary vertical structure which was 20 ft and therefore the top speed being 58 miles per hour to test the spin [10], Fig. 1.



**Fig. 1** Eiffel in the vacuum chamber of its wind tunnel in the Boileau street (© Aerodynamic Eiffel)

## Types of the Wind Tunnels

Wind tunnels are often divided or segregated into four types:

Type No. I—Open versus loop structure: In an open-circuit structure, the air is now taken from the environment into the given structure and disallowed back to the same environment; now, this structure has claimed to possess a special circuit, an open-air circuit. In the closed circuit, which is an alternative name, an equivalent volume of air is being dispersed in a manner that the given structure neither draws fresh air from the neighbouring nor does it return it to the environment. The structure is claimed to possess a closed-air circuit [11].

Type No. II—subsonic versus supersonic structure: The criteria for classification are the maximum "distance per time travelled" achieved by the structure. It is a traditional and standard practice to use the ratio of the velocity of the object to that of the fluid or another object and therefore the speed of velocity. This number is widely called the Mach number termed after the Scientist Mach, who was the nineteenth-century physicist. Based on wind speed inside the structure the wind tunnel could be classified. If the maximum possible speed attained by the structure is a lower amount than the speed of the sound in the air medium, then it is a subsonic type [12]. The speed of the sound in the air is about 343 m/second, and here, Mach number is a lesser amount than one (M1). If the speed of the airflow is

more than 1 but less than 5, then it is a supersonic structure [13].

Type No. III—Education versus research structure: The measure for sorting is that the reason for which the structure is designed that being exploration or learning. Search structure is termed when the structure is for research. If, however, it is designed to be used for learning, then the structure is known by an academic structure. This is not a main mode of classification and it is only mentioned for the reader's purpose just to allow them to know that there is a separate structure for educational and research purposes [14].

Type No. IV—Laminar versus turbulent structure: Wind tunnels could also be classified concerning the airflow that is laminar and turbulent. It is common to know that streamlined flow is essentially the right fluent flow of a fluid during a certain region [15]. In simple words, a laminar structure is one where the flow of the wind is uninterrupted, whereas turbulent flow is the one where fluid (gas or liquid) undergoes irregular fluctuations. In this flow, the speed of the taken fluid at some point is endlessly changing in magnitude and direction at the same time. So, it is hard to analyse and calculate the output of a turbulent structure in comparison to a laminar structure, but it is a practical approach since turbulent flow is observed in real life, viz. automobiles (for climate testing) [16].

## Theoretical and Computational Analysis

Wind tunnels are used by aerospace engineers to test the aerodynamics of the aircraft and engine. This testing is done on prototypes. Through the help of wind tunnel testing the engineers can get an idea of how the fluids move around the model/prototype. The output shows them the lift, drag and pressure forces that acted on the model during the testing. Wind tunnel testing is directly linked to the design of any automotive. The tests give data on the lift, drag, moments, forces acting on the side, pitch, yaw, roll, distribution of surface pressure, the influence of vehicle design and details, cooling drag, brake cooling flows. Because aerodynamics plays such an important part in car performance, proper aerodynamic planning aids in lowering drag and lowering fuel consumption. The virtual wind tunnel online and CFD simulation are critical in the design of a car before the basic model is built to assess the airflow round the vehicle and compute the zones of high pressure, wind velocity and other parameters.

Over years the civil industry has skyrocketed in its development and technology with an increase in demand. Having taller structures is the new trend and with taller structures comes the structural safety of these tall skyscrapers. Utmost evaluation is required to test the

design to withstand wind loads, wind-induced vibration and all sorts of weather conditions. This is again tested by using prototypes in wind tunnels. Often instead of using a physical wind tunnel in several of its applications, virtual wind tunnels are used in these fields. CFD or FEA are used for virtual simulations. The structural design of a building's ability to handle wind loads and wind-induced vibration is often a determining factor in its structural integrity. Wind tunnel testing of moderate models is a scheme commonly used to correctly analyse the structural integrity of wind loading from the influence of across wind vibration [17].

CFD is an alternative for wind tunnel tests so that the aerodynamic forces acting on the body such as drag and lift are obtained. Most of us are aware of the bridges being constructed and the number of vehicles using these bridges daily, but one must look into many other aspects before constructing it like whether it can take the required load and how the wind moves across a moving vehicle on a bridge [18]. The path that the wind follows is very complex and unpredictable which makes understanding is of the utmost importance.

Wind tunnel test is the common way of understanding this by manually making up a set-up and keeping it in a wind tunnel and air entering the tunnel through different ways and at different angles and understanding the properties and the of the wind flow and the wind direction. As discussed above, another way of understanding the above forces in CFD is to run the simulations and know what all information is required. In simulations, Reynolds averaged Navier–Stokes equation also known as the RANS equation was used, and large eddy simulations was used to get more accurate values [19].

The unsteady RANS equation works on the principle that is to find the average of the instantaneous governing equations of the flow. So, during the simulations, a CFD code is written to solve all the equations. Other than this the SIMPLEC Algorithm (it is generally used for pressure and velocity coupling), the second-order implicit method and much more work together during these simulations. So, by integrating the pressure and the shear forces on the surface the required results could be obtained which is done through the help of simulations. The range of Reynolds numbers [20] between 2000 and 8000 is very suitable for a natural insect aircraft and can provide the impetus for technological advancement. These unstructured codes of geometries and complex configuration which has processed wind tunnel flow with more accuracy and effort [21]. Hence, for the theoretical and computational analysis of the RANS method, the SST-k omega turbulence model will be used, the boundary conditions are to be specified, and meshing details, the time step process and others for finding out the solution are to be used to the above-mentioned example's simulations. In this paper, the

utilization of wind tunnels is contrasted with the various analytical models. Subsonic flow around a circular cylinder and transonic flows over the lambda wing configuration is taken as specific cases. The developed analytical models and closed-circuit wind tunnel tests are contrasted to verify the utility of a wind tunnel for a variety of applications.

### Restrictions of Wind Tunnel Investigation

Despite its extensive usage in a wide range of industries and applications, there are certain limits to employing wind tunnel testing alone. Engineers seek additional methods to further check and validate their designs. The utmost apparent constraint is the size of the simulated designs, which must be scaled down to fit within the wind tunnel. This can have detrimental consequences and alter aerodynamic properties like Reynolds number. The size also limits any movement, which is important when assessing aerospace or even automobile designs. Along with the tunnel's size, the walls serving as a boundary layer can affect the flow and cause clogs by constraining and limiting the domain's size. Experiments in wind tunnels are very expensive, from running simulations to building numerous prototypes, and findings cannot be taken instantly. Nevertheless, the virtual wind tunnel testing using online CFD and FEA avoids these practical problems and offers a simple, quick and cost-effective alternative.

### CFD Analysis Fluid Flow in a Wind Tunnel

CFD analysis is a very important method to find the analysis of many flow-related problems. CFD analysis concept is based on diffuser performance by using CFD for subsonic aerodynamic research laboratory with improving the adequacy of the wind tunnel in Subsonic Aerodynamic Research Laboratory [22, 23]. The initial loss of efficiency was seen to be around 30% [24]. Given below is a figure of the wind tunnel and fan duct of the diffuser section as shown in Figs. 2 and 3. Wind tunnels are generally of two types: blower type and suction type. In a blower-type wind tunnel, the fan assemblies are positioned downstream of the wind tunnel and the air is taken through the wind tunnel with suction. And suction-type wind tunnel sucks the air away from the test section of the wind tunnel. Blower-type wind tunnels are most commonly used in open-circuit wind tunnel testing. The open-circuit wind tunnel is one in which air that passes through the test section is the air that is in the room that the tunnel is situated. It is converse of a closed-circuit wind tunnel that air that passes through the exit section of the wind tunnel comes back to the test section through a series of vanes and ducts.

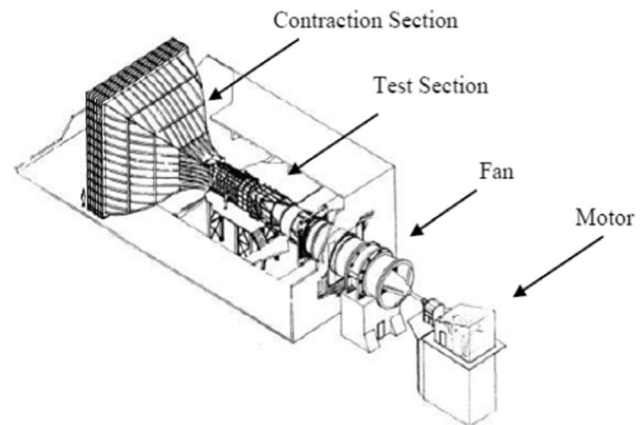


Fig. 2 A Graphic picture of the wind tunnel [25]

Previous studies showed that the ratio of the inlet and outlet of the diffuser and the dimensions of the diffuser are the factors that may directly affect the pressure which has to be recovered from the diffusers. The CAD model and the CFD analysis could be done through SolidWorks and the Flow Works which is a flow analysis tool that provides the solution with the help of Navier–Stokes equation and the k-omega turbulence model.

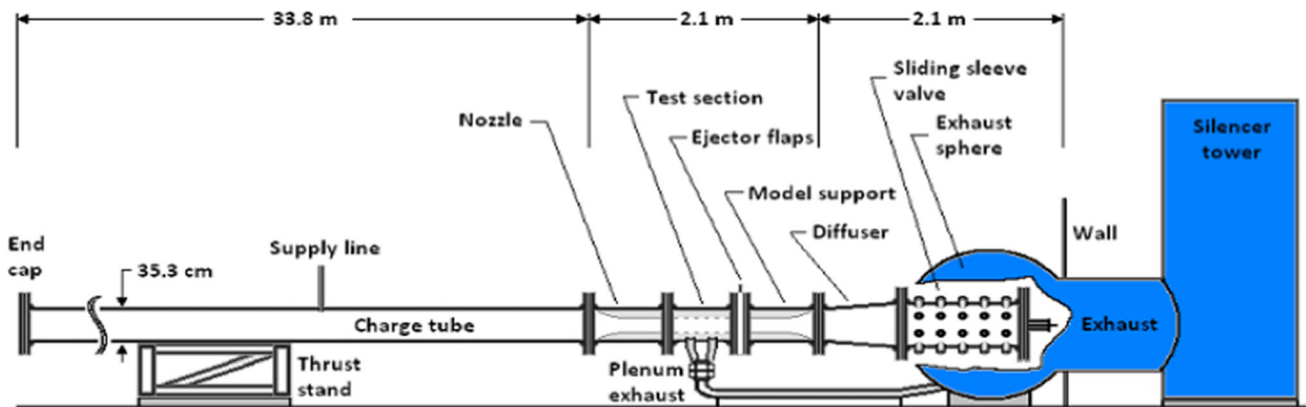
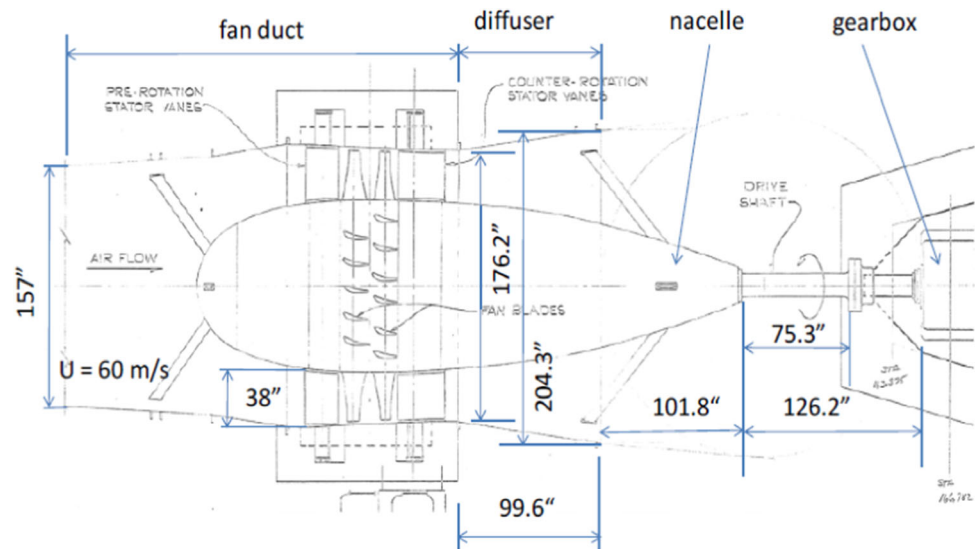
### Facility Characteristics and Facility Characterization

The transonic wind tunnel is used for testing aircraft models for higher speeds, Fig. 4. Transonic flows contain a combination of subsonic and supersonic flow types [24]. Shocks may occur in subsonic and transonic flow, but there is no sufficient pressure to assume flowing properties similar to those of supersonic flows [27, 28].

The following section discusses the primary level characteristics of a wind tunnel that define the facility.

- a. *Driving system* This characteristic defines how the word fluid moves through the test section, there are various systems in which a particular system works on a particular system, and the selection of the system depends on the medium in which the operation is done [29, 30]. The fan and the compressor are the two drive systems in a wind tunnel. Pressurized air is normally sent from a compressor from one tank to another in a controlled way through tanks. Fans are generally belt-driven and sometimes it depends on performance. Systems with fan drive systems can operate incessantly than a compressor, but the price is a bit high if a fan-based system is used. Usage of compressor driving system facility is seen in NASA research centre which uses 20-inch supersonic wind tunnel [31].
- b. *Operating fluid* When there is a leakage, first the working fluid has to be changed, when the working

**Fig. 3** Wind tunnel air channel and exit diffuser section in a subsonic aerodynamic research laboratory [25]



**Fig. 4** Schematic of a transonic wind tunnel [26]

fluid is not matched to the conditions the pressurized air or water could be used to fasten the hole to avoid discharge of water. One more reason to use pressurized gas as an operating fluid is at the specified temperature there is a density increase and this leads to matching the Reynolds number. For operations using two-phase flow, a water drill could be used, but water drills have to be fastened to stop the discharge of water normally pumps are also used for operation [32].

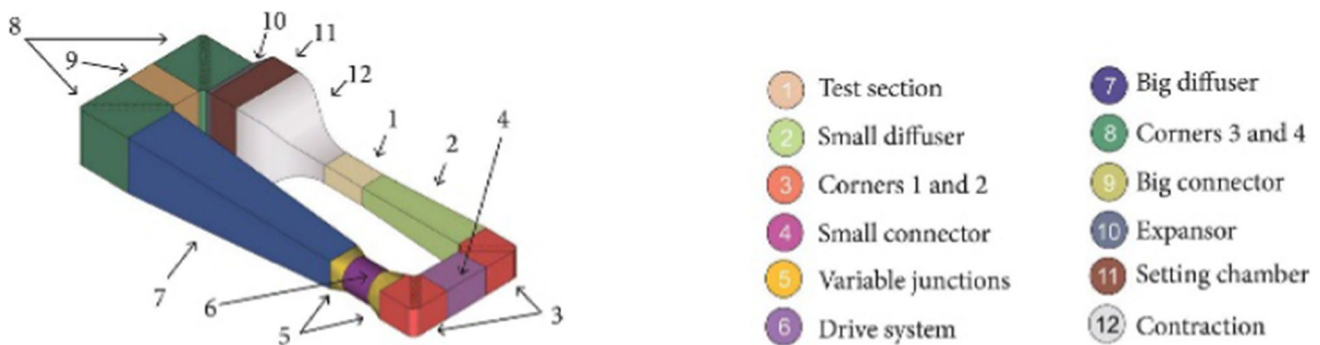
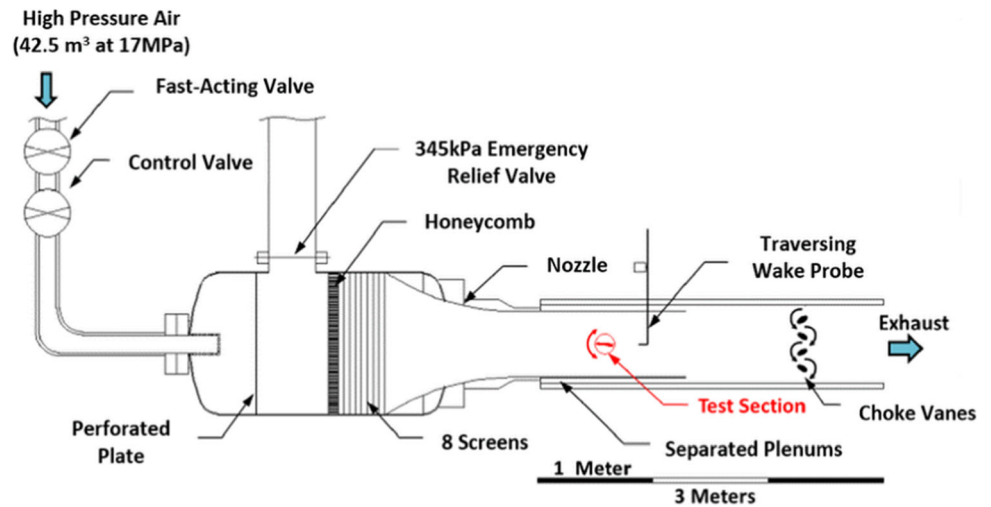
- c. *Duct current* Generally, wind tunnels are manufactured with two varieties of duct circuits first one open-circuit and the other one is a closed-circuit duct. Open-circuit duct gets air from one ambient at one end passes through the tunnel and releases at ambient, whereas closed-circuit duct retains a fixed mass of air and circulates through various wind tunnel components [1].
- d. *Operational flow regime* Supersonic facilities (with  $M > 1$ ) have vitality and enhancement costs; the facilities must be structured to maintain pressure differences across the walls and high temperatures as

well as forces generated by shock waves. The test section should be structured with a suitable converging and diverging nozzle [33].

Transonic facilities (with  $M < 1$ ) generate favourable circumstances for many civil and military aircraft. Basically, subsonic facilities are used to stimulate flight by slower aircraft [31]. Given in Fig. 5 is an unsteady transonic wind tunnel and Fig. 6 is a low subsonic wind tunnel [34].

- e. *Flow uniformity*: A changeless speed should be maintained in the test section and there must be a small deviation from the plug profile for the core of the test section. There are different methods to measure velocity profile like pitot probe through test section, this method is an inexpensive but time-consuming process. The flow uniformity is described as either a maximum–minimum or an RMS (root mean square) deviation from the mean velocity in the test section [10].

**Fig. 5** Unsteady transonic wind tunnel [34]



**Fig. 6** Low subsonic wind tunnel [10]

### Design Criteria and Configuration

In the design of a wind tunnel, the required components are flow conditioners, tunnel driver and also fabrication cost, space, etc. The size of the flow conditioning section is generally determined by section size and flow quantity. The size of the settling duct is determined by the size of the inlet test section that houses flow conditioners such as the honeycomb and screens [35].

- a. *Flow conditioners* In almost every tunnel, the flow conditioner comprises a honeycomb screen and a settling duct. The honeycomb arranges the discharge with the centreline of the drill and dismantles unsteadiness. These honeycombs are available in various shapes, but the hexagonal shape is the most preferred one because it has the low-pressure drop coefficient, it should have sufficient structural rigidity to bear the forces in the operation, and screens are placed in the settling duct to reduce turbulence [30].
- b. *Contraction* The contraction increases the speed and arranges to flow into the test section, the structure and dimensions of the contraction determine the turbulence level in the test section. Dimensions of contraction

mainly the length has to be small, if the length is small, it will reduce the growth in the boundary layer and cost is not sufficient to reduce major pressure gradients around the wall nowadays CFD drawings are used in modern design schemes [36]. Given in Figs. 7 and 8 are the contraction and the aerofoil testing of a wing in a wind tunnel, respectively

- c. *Test Section* It is a closed type of wind tunnel testing and in this, the test section design should leave simple accessibility and installation of the structure. In a closed test section, full-scale performance of a certain model is almost similar to aerodynamic performance. Due to pressure differences in the turbulent layer, values of sound have a very low ratio of signal to noise radius in a closed test section, and the length of the test section also influences the properties of a wind tunnel as in a closed tunnel the area of the cross section for the test section is small and the velocity at which the air flows is fast [15].
- d. *Diffuser* The diffuser decreases the speed of flow in the test section and it will achieve constant pressure difference and reduce the load of the drive system [26]. The flow in the diffuser is partly disturbed by the flow whether it is a laminar flow or turbulent flow leaving

Fig. 7 Contraction [37]

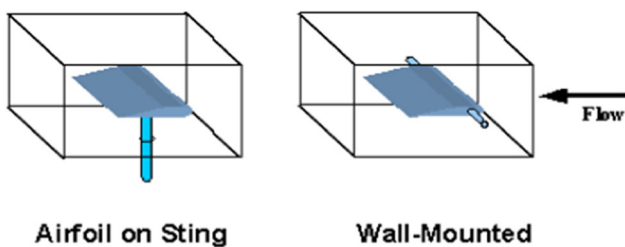
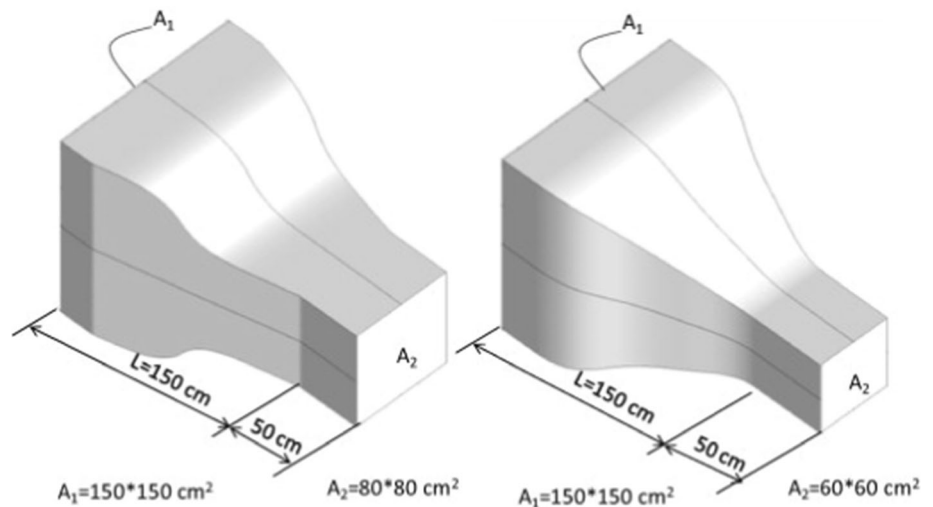


Fig. 8 Wind tunnel test section [37]

the test section. The cross section of the diffuser rises linearly along its centre it will prevent separation of flow in the test section [13].

- e. *Drive System Selections* The main purpose of this is to create volume flow and compromise the losses that occurred due to pressure difference, and there are some types of drivers like a fan, flower or a compressed gas with a certain volume flow rate. Load curves of efficiency of fan and losses in pressure as a function of flow rate are used to judge the performance of the fan and also the rotational speed of the fan is used to determine load curves [25].

### Flow Physics in the Test Section of a Wind Tunnel

As discussed, the flow physics principle is centred on fluid dynamics. It is a branch of physics concerned with the study of moving fluids. This featured length groups consisting of aerodynamics, which studies the movement of air and gases and hydrodynamics that examine the movement of liquids [35]. The Navier–Stokes (NS) equation, which is a series of differential equations whose fundamental statements are the conservation laws, is the formula describing the movement of fluids: mass conservation, momentum conservation and energy conservation [37].

Fluid dynamics, for example, the plane wing profile, any cylinder or any vehicle, studies the fluid in motion (flow) neighbouring a particular body. The efficiency of the flow surrounding these three bodies will, under similar conditions, be different in each case [38]. Thus, not only on the fluid characteristics but also on the shape of the chosen body, the flow behaviour or flow efficiency depends. Besides, by only increasing/decreasing the flow velocity, it is possible to adjust the flow efficiency [37].

In general, flow is of three types and could be distinguished as laminar, turbulent and transitional. Laminar flow arises when there is no interaction occurs between the layers of the flow, i.e. the layers of the fluid are not intersecting with each other. If the high-velocity fluid says, water dripping from the tap or in a waterfall, before the water drops, a laminar flow could be found in that case also [35]. The flow of laminar is considered to occur at low velocity and viscosity should be high [37]. It is turbulent when the flow layers are toughly mixed, flow happens and the flow is no longer parallel. In an isolated space, the complete set-up of the experimental process is carried out. Flow visualizations are conducted using the tufts, laser reflection and smoke dispersion. The motion of the flow is captured employing a sensor or a camera [35].

### Results and Discussion

*Case I* Subsonic flow around a circular cylinder.

The measurement competences of a wind tunnel are evaluated via a detailed characterization of subsonic flow around a circular cylinder compared with numerical simulations available in the open literature. A comparison between numerical predictions and experimental measures through wind tunnel was made for both the pressure suction coefficient and the drag coefficient. With the equipment provided in the wind tunnel, the referenced results

were utilized to estimate the flow range in which the wind tunnel delivers correct outcomes. The qualitative and quantitative effects of three turbulence models, shear stress transport (SST), Transition SST and scale-adaptive simulation (SAS), on the numerical findings, were investigated. Figures 9 and 10 show a pretty excellent agreement between wind tunnel data and experimental observations from the literature. The wind tunnel application for subsonic flow is validated by a quite good agreement between the numerical results and those connected with comparable research in the past for the laminar domain [39].

The pressure suction coefficient values for the various numerical models are compared to the wind tunnel testing values for a specific range of Reynolds numbers. Rosetti and  $k-\omega$  SST model indicates + 28% variation of the value of drag coefficient with the wind tunnel measurements in the initial values of Reynolds number of the specific range. At the higher values of the specific range, pressure suction coefficient values converges. Williamson model indicates + 30% variation of the value of pressure suction coefficient with the wind tunnel measurements in the specific Reynolds numbers range. SAS models indicate + 52 to - 45% variation of the value of pressure suction coefficient with the wind tunnel measurements, whereas the pressure suction coefficient value for the Transition SST model indicates + 52 to - 26% variation in the specific range of Reynolds numbers.

Similarly, the drag coefficient values for the various numerical models are compared to the wind tunnel testing values for a specific range of Reynolds numbers. Rosetti and  $k-\omega$  SST model indicates a  $\pm 25\%$  variation of the value of drag coefficient with the wind tunnel measurements. Weiselberg's model indicates a 35% variation of the value of drag coefficient with the wind tunnel measurements in the specific Reynolds number range. Transition SST and SAS models indicate  $\pm 47\%$  variation of the value of drag coefficient with the wind tunnel measurements, whereas the drag coefficient value converges for the Transition SST model at higher values of Reynolds numbers. Nevertheless, the laminar model indicates a similar

variation of the value of drag coefficient with the  $k-\omega$  SST model.

*Case II* Transonic flows over delta or lambda wing.

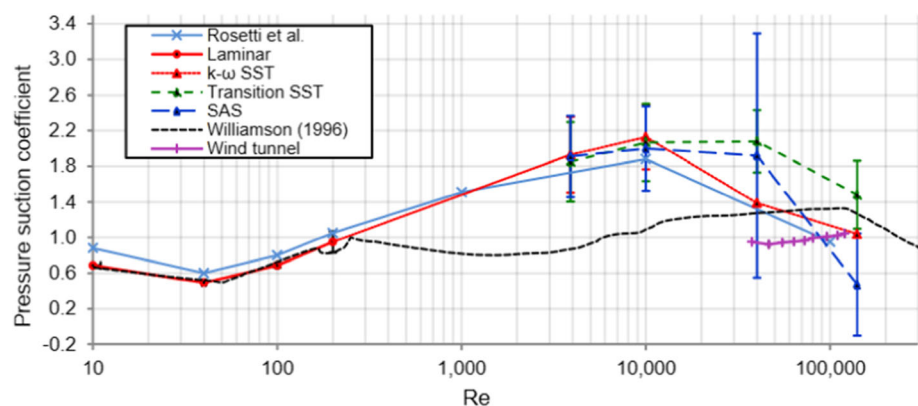
Wind tunnel experiments were conducted at the German–Dutch Wind Tunnels' transonic closed-circuit wind tunnel DNW-TWG. The flow mechanics and aerodynamic properties of delta or lambda wing designs were studied at transonic speeds, Fig. 11. For surface oil flow pictures on the flow field, experimental testing was carried out using a conventional DNW-TWG schlieren system. By integrating density changes throughout the whole flow field, three-dimensional schlieren pictures were produced, which replicate the position of shocks and perhaps vortices and give essential data for verifying numerical results.

To acquire data essential for the design of a given configuration, both experimental and numerical research are combined. CFD is increasingly being utilized as a supplement to experimental research since it is regarded as a trustworthy technique for predicting complicated vortical flows at high angles of attack, Fig. 12. A wind tunnel model was used to conduct several experimental and numerical investigations in the subsonic speed range and to validate the numerical results. The empirically measured flow topology is compared to topologies derived computationally using different turbulence models utilizing surface oil flow pictures and schlieren images, Fig. 13.

Delta wings with various leading edge geometries, curvature radii, Mach numbers, Reynolds numbers and transition effects were studied using both experimental and computational methods. The impact of the leading edge geometry on the vortical flow around a delta wing shape is investigated using turbulence models and compared to experimental data through wind tunnel testing [40].

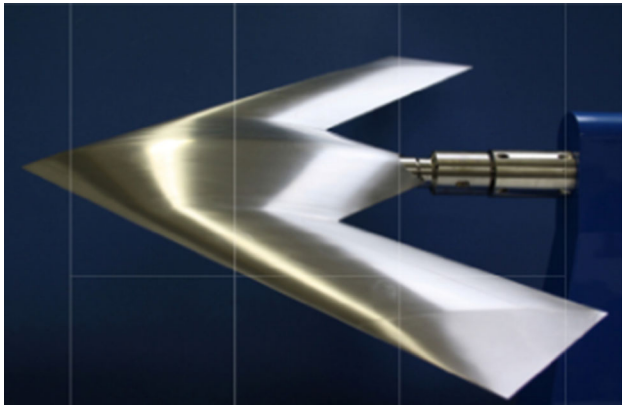
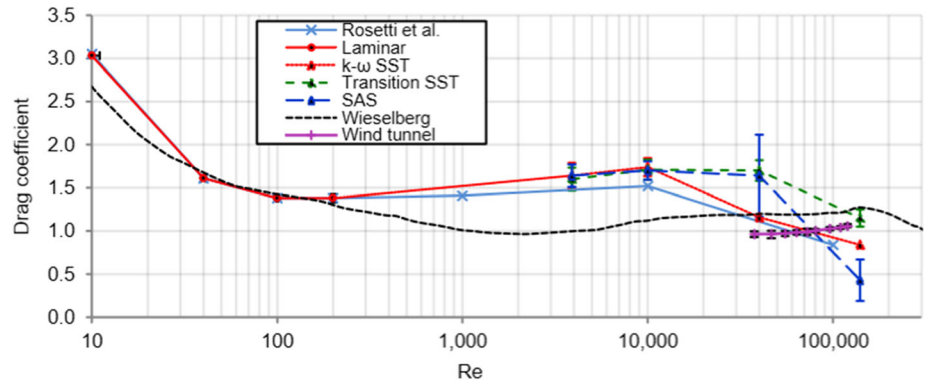
The wind tunnel and computational fluid dynamics assessments of transonic base pressure distributions on a winged re-entry vehicle design are compared. The results demonstrate that the axial force data from the wind tunnel agrees well with the data from the flying tests [40, 41].

**Fig. 9** Pressure suction coefficient contrast of wind tunnel and comparable research from the open literature [39]

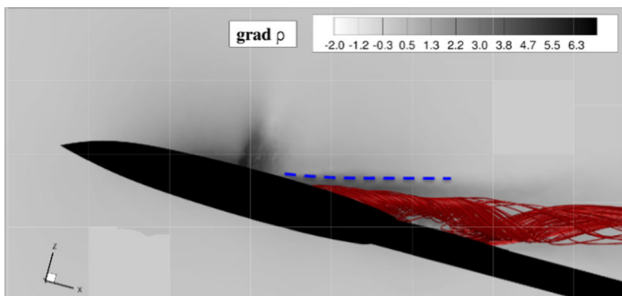




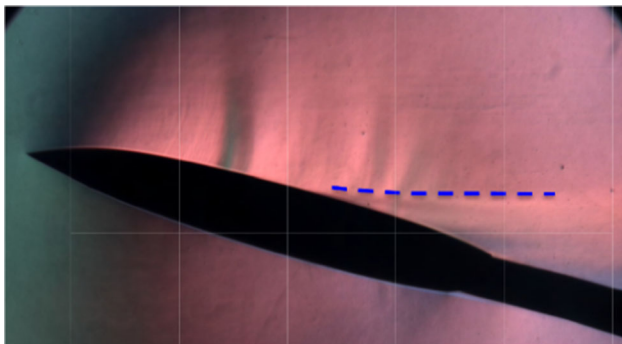
**Fig. 10** Drag coefficient assessment of wind tunnel and comparable research from the open literature [39]



**Fig. 11** Delta or lambda wing in a DNW-TWG of the German–Dutch wind tunnel [40]



**Fig. 12** CFD analysis on a vortical flow about a lambda wing [40]



**Fig. 13** Experimental surface oil flow schlieren images [40]

### Future Scope

This paper deals with how the wind tunnels are being used in time and how accurate the results are when compared to computational results and found out that wind tunnels are not accurate or precise and deals with many losses such as frictional losses, head losses that could be reduced to achieve accuracy which is similar to the computational results. Hence, a modified wind tunnel design to analyse the subsonic, supersonic and transonic flows is the need of the hour. The analysis attained through the modified wind tunnels is handy in validating the results obtained through the numerical analysis.

### Conclusion

In this article, more focus has been kept on how accurate wind tunnels are when compared to simulations. In this paper, various analytical models and closed-circuit wind tunnel tests are discussed and validated. Also, the facility characteristics of a wind tunnel in subsonic flow around a circular cylinder and transonic flows over a lambda wing are analysed. The average value of drag coefficient in a circular cylinder subsonic flow was found to be converging from 25% variation to 9% between the numerical models and the wind tunnel in the specific range of Reynolds numbers. Similarly, the average value of pressure suction coefficient in a circular cylinder subsonic flow was found to be varying from 27 to – 6% between the numerical models and the wind tunnel in the same range of fluid flow. In the second case of study of a transonic flow over a lambda wing, the measured flow topologies using various turbulence models are found to be in good agreement with the schlieren images obtained through wind tunnel testing.

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