pavan

CENTRE FOR WIND ENERGY TECHNOLOGY

C-WET

An ISO : 9001 - 2000 Organisation

A News Bulletin from CENTRE FOR WIND ENERGY TECHNOLOGY, Chennai

www.cwet.tn.nic.in

ISSUE - 14

July - September 2007

EDITORIAL

There was a time when wind conditions in India were considered too low to merit any active consideration in terms of energy conversion. It was at best considered suitable for establishment of small water pumping devices and this view was held until mid eighties. During the late fifties and early sixties, the then National Aeronautical Laboratory made valiant efforts to estimate wind power potential and develop a few proto-types. With virtually free electricity for irrigation, the interest in developing the windmills saw a decline. The oil shocks of the seventies revived interest in alternate sources of energy. This of course was mostly confined to some NGO groups and one or two laboratories. Efforts were made to bring in "appropriate technology" based machines. Even as these developments were underway, the wind data scarcity became more and more apparent. It was realized by the year 1982 that a fresh view needs to be taken about the resource itself. The meteorological records were very helpful in giving general trends but were insufficient to guide large-scale deployment of wind energy hardware. After this realization came through, a national level wind-monitoring program was initiated in 1986 and the centre for wind energy technology is still running the program. But unlike the meteorological practices, the data collection takes place in a highly intensive manner for several years at a given place with Two second sampling rate and averaging interval of one hour (average and standard deviation of 1800 samples) of wind speed and direction. The sites cannot be revisited to obtain a fresh snapshot of winds because the ground situation would have changed so much that no correlations could be drawn with old data. Information on the extreme wind conditions is available from this program. However, this is not taken into account while drawing the extreme wind maps for the country. On the other hand, meteorological observations are made in urban environment where the data is continuously acquired for decades, but the environment could see considerable changes over the years. Hard core wind energy professionals also do not appreciate that we could collect wind data from building tops for estimation of representative wind speeds from a given area. When the question of design of wind turbines for Indian wind conditions comes up, it therefore becomes essential to use the available information from India Meteorological Department sources for extreme wind conditions.

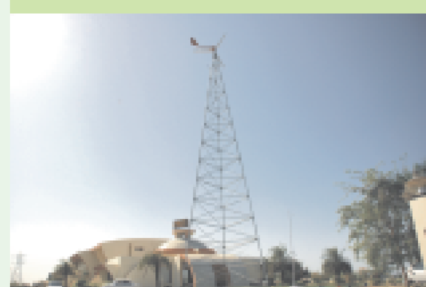
Wind turbine design requires a thorough understanding of all aspects of energy conversion as diverse as wind meteorology, aero-elasticity, structural dynamics, composite technology, control systems and network analysis.

When a mechanical system converts the energy from a continuously varying source like wind, it essentially would give outputs also varying equally rapidly. Though some attenuation would be seen due to the inertia of the conversion system, there would be considerable variations in the output on a temporal scale. From machine designer's point, this problem needs to be solved using principles of structural dynamics. Therefore a careful evaluation of dynamic behavior of the system would be warranted. In smaller machines, the dynamics related aspects were taken into account by simplified load assumptions. It is also possible to work with higher margins of safety while sizing load-bearing components in machines of smaller capacity. But as the wind turbine systems grow larger and competition becomes stiffer, it is essential to look at the structural dynamic aspects far more critically and optimization inevitable. On a parallel, with accumulated knowledge of over two decades, acceptance criteria through certification systems are now available through published standards. As with any evolutionary products, these standards have seen a number of revisions through formal and informal consultations among various stakeholders. The standards or rules are not meant to be design handbooks. However, they do provide a broad structure to any design directly and indirectly.

As can be seen, wind turbine design is serious business and the lessons learnt in other streams of product development cannot be applied directly in this field simply by the nature of the product under consideration. Sufficient domain knowledge becomes essential and painstaking detailing of design is completely unavoidable in order to have a design that work in field with few problems over the service life of the turbine. It is strongly felt that available standards on the subject be studied at great length before embarking on a design exercise. This is particularly important if we are looking at positioning a product in market at an early date. It should not be assumed that such an approach would inhibit innovation.

Contents

Editorial Board



DEVELOPMENTS IN R&D UNIT

Testing of small wind turbine

The Unit is set to take up testing of an aero generator of 5 kW at WTTS, Kayathar. The necessary testing facilities have been established. The Test Plan has been finalized in association with the client. Power measurement, duration test and safety & function tests will be conducted on the turbine over a duration of six months.

Monograph on "Recommendation on design and maintenance of gearboxes of wind turbines" was published for stakeholders of the wind industry.

Scientists of R&D Unit delivered the following lectures at the Third International Training Programme on "Wind Turbine Technology and Applications" organised during 8th-17th August 2007:

1) Wind Turbine Component

2) Grid Integration of Wind Turbines

3) Tower and Foundation Concepts.

Shri. K. Boopathi, Scientist delivered a lecture on "Wind Turbine Technology and Applications" at Technical Teachers' Training Institute, Taramani.

MOVE ON IN WRA UNIT

Presently, fifty-three wind monitoring stations are operational under various wind monitoring projects like wind resource assessment (WRA) in uncovered/new areas, WRA in north-east region and consultancy projects.

Seven verification procedure of wind monitoring have been taken up for various developers viz. M/s. Suzlon Energy Ltd., Pune, M/s. Enercon India Ltd., Mumbai, M/s. Vestas Wind Technology Indian Pvt. Ltd., Chennai and M/s. Dahivel Energy Project (P) Ltd., Mumbai under consultancy projects.

Micro-survey studies at 3 locations in Kerala have been taken up for Agency for Non-Conventional Energy & Rural Technology, Thiruvananthapuram under consultancy projects.

Two consultancy projects for 50 MW wind farm & 15 MW wind farm have been started for Steel Authority of India Ltd., Salem, and M/s. SRF, Gurgaon respectively.

Wind resource assessment studies at three different locations have been initiated for M/s. Poorva Powergeno Ltd., Bangalore and M/s. Hindustan Paper Co-operation Ltd., Kolkata under consultancy projects.

STEPS FORWARDED IN TESTING UNIT

The measurements for Provisional Type Testing (PTT) of Suzlon 1500 kW wind turbine at Moti Sindhodi, Gujarat have been completed and the analysis & reporting is in progress.

The measurements for PTT of Enercon 800 kW E53 wind turbine at Jodphar, Gujarat are in progress since July 2007.

The measurements for PTT of IWPL 250 kW wind turbine at Gujarat are in progress since April 2007.

The measurements for PTT of Siva 250 kW wind turbine at Kayathar are in progress since July 2007.

PTT of Suzlon 350 kW wind turbine at Gujarat is expected to start shortly.

An agreement has been signed between C-WET and M/s. Chettinad Energy Private Ltd., to test their 600 kW with 46m rotor diameter at Thirumangalakurichi, Tamilnadu and the measurements are expected to start in the next windy season.

Blade instrumentation for M/s. Shriram EPC's LEIT WIND Model LTW77 1.35 MW was carried out at Oothumalai, Tamilnadu, as requested by them.

Scientists of Testing Unit delivered the following lectures at the Third International Training Programme on "Wind Turbine Technology and Applications" organised during 8th-17th August 2007:

1) Power Curve Measurement

2) Safety and Function Test

3) Load Measurement.

Shri. R. Kumaravel, Scientist delivered a lecture on "Wind Energy and its Application" at the national level workshop on "Energy Sources" conducted at St. Joseph College of Engineering, Chennai.

MARCHING AHEAD IN S&C UNIT

Provisional Type Certificate for Pawan Shakthi – 600 kW wind turbine model under Category II as per TAPS – 2000 (amended) has been issued to M/s. Vestas RRB India Limited.

Agreement has been signed with M/s. Chettinad Energy Private Limited for Provisional Type Certification under Category – III, as per TAPS – 2000 (amended) for Chettinad 600 - 600 kW wind turbine model.

Revised List of Models and Manufacturers of Wind Electric Generators/ Wind Turbine Equipment (RLMM) has been issued on 11.07.2007.

The certification projects, taken up as per TAPS – 2000 (amended), are under progress.

The continual improvement and maintaining the Quality Management System are ongoing.

Scientists/Engineers of S&C Unit delivered the following lectures at the Third International Training Course on "Wind Turbine Technology and Applications" organised during 8th-17th August 2007:

1) Type certification of wind turbines as per TAPS – 2000
2) Basic Aerodynamics
3) Overview of wind turbine design
4) Wind turbine control and protection system requirements
5) Types of wind turbine generators.

HIGHLIGHTS FROM ITCS UNIT

Third International Training Course :

Information, Training and Commercial Services Unit had successfully organized the Third International Training Course on "Wind Turbine Technology and Applications" during 8th – 17th August 2007 sponsored by MNRE, Government of India. It was designed to help the countries in the region of Asia and Africa in wind farm development. The objective of the training course was to transfer knowledge and special skills needed by the wind energy personnel working in the technical and operational fields and to share the experiences from the lessons learnt over the last two decades. The course was attended by nine participants from Cuba, Jordan, Mauritius, Mozambique, Sri Lanka, China and Maldives. The training programme was inaugurated by Shri. V. Subramanian, Secretary, MNRE.

The course content for the training was a carefully thought out syllabus with subject experts giving lectures and quoting specific case studies. The training course addressed the following aspects:

- Introduction to Wind Resources
- Wind Energy Technologies
- Integration of Wind Energy with Grid
- Wind Energy Prediction Methodology
- Testing & Certification
- Wind Energy Measurements and Prospects
- Clean Development Mechanism
- O & M Aspects of Wind Farms
- Cost Benefit Analysis of Wind Energy Projects
- HRD in Wind Power Projects

The course provided detailed information regarding various implementation phases of a wind energy project, i.e., planning, pre-investment, implementation and operation phases.

Manufacturing facility and wind farm site visits were arranged during the course to give a complete picture of the know-how and how to go about setting up a co-ordinated wind energy programme at a national level.

College visit to C-WET facility:

Physics students along with their faculties of Sri Meenakshi Women's College, Chennai visited C-WET facility on 17th September 2007 as part of their curricular requirements and learned about the wind turbine technology.

Participants in front of C-WET campus


Executive Director, C-WET explaining wind turbine technology

Global wind power capacity may double by 2011 - Merrill Lynch

Global wind power capacity was likely to more than double to a projected 33,500 MW by 2011, placing suppliers under more stress to iron out supply constraints, a report by financial management and advisory company, Merrill Lynch said. The company predicted that growth would be underpinned by strong demand in the US and Asian markets. Europe was still the largest wind energy market, accounting for 65% of total capacity, with Germany and Spain taking up most of the installed capacity.

The US was the next largest market, but Merrill Lynch predicted that the Asian markets, in particular India and China, were expected to accelerate the use of wind energy. Merrill Lynch said that it the market for new installations had grown by 42% in 2005, 30% in 2006, and that it was expecting growth of 25% in 2007.

New power plants in the post-2010 time period would "inevitably" be wind farms, as the expectation of high carbon prices, coupled with high oil prices, were disincentivising power companies from building fossil fuel fired plants. Wind power was also far more suitable for large scale roll-out of renewable energy capacity, Merrill Lynch stated. The world's largest solar power plant was a 40 MW project, comprising a million solar panels, while the largest wind plant was almost 20 times the size at 780 MW.

The growth in the global wind energy market would put "tremendous pressure" on a stretched component supply chain, which the report noted was already at full capacity. The main bottlenecks had been found in large bearings and gearboxes. "Most turbine manufacturers appear to have secured component supply for their 2007 needs and the build out of new capacity in gearboxes and bearings has begun but equilibrium is unlikely to be reached before the end of the decade," Merrill Lynch said. It added that the move to larger turbines had aggravated this trend, as there was greater availability of component supply for smaller turbines than the 1.5 MW to the 2.5 MW, or mainstream, class. But, despite the market growing at double digits, there had been very few new entrants, Merrill Lynch said. "We see little risk of new entrants as the absence of proven technology and, importantly, an operating track record represents a key barrier to entry," it stated.

Source: http://www.engineeringnews.co.za.

India's clean energy to rise eight-fold

India says its renewable energy installation is set to rise eight-fold to 80,000 megawatts in next 25 years. Renewable energy installations in the country will see an exponential increase in capacity by 2032, the government announced. "By 2032, the installed capacity of renewable energy sources will be 80,000 megawatts," said Vilas Muttemwar, the Minister for New and Renewable Energy. He said the current installed capacity of renewables such as wind, solar power and biomass is about 10,000 megawatts. The ministry is planning to provide electricity to around 75 million rural un-electrified households through renewable energy sources, Muttemwar said.

According to Muttemwar the government is formulating a biofuels policy to encourage the use of biofuels, mainly in the transportation sector. While addressing a conference in New Delhi, Muttemwar said India has the largest government initiated renewable energy program in the world. India stands fourth in renewable energy in the world with an installed capacity of 7,000 megawatts of wind energy. The minister said private players are harnessing power from small hydro power projects ranging from 1 megawatt to 50 megawatts. Biomass and co-generation projects have an installed capacity of 1,200 megawatts that's also contributing to the growth of the renewable energy sector, Muttemwar said.

Source: http://www.earthtimes.org

Asia improves ranking in wind energy output

While Asia is emerging strongly on the installed wind power capacity map, Africa too has, for the first time, made its mark in global statistics of wind energy generation by the World Wind Energy Association (WWEA). "The world is witnessing a rapid shift from Europe to Asia and America. Asian giants, China and India, are adding capacities like never before. Lately, wind power majors have also started taking interest in African market where the economies are doing slightly better than before and seeking more power," said Anil Kane, president of WWEA.

Asia's installed capacity has increased to 10,345MW by 2006-end from 7,000MW in 2005. With this, Asia's share in total installed capacity has increased to 14% from 12% before. On the other hand, despite adding about 7,500MW of capacity, Europe's share in world wind power has slipped to 66% in 2006 from 70% in 2005. According to sources, the European market is losing its charm and becoming stagnated since the new installations are not coming up rapidly. Meanwhile, America added about 3,400MW during 2006 and increased its share from 17% to 18% globally. America had installed capacity of 10,036MW by 2005-end. However, Australia retained the same position with 1% since it added little over 132MW in 2006 to 985MW. The global installed capacity in the wind energy is likely to cross 90,000MW by the end of current calendar year compared with about 74,000MW by 2006 end.

India alone added about 2,000MW wind power generation capacity between 2005 and 2006. China, after a modest start, recently doubled its installations to 2,600MW by 2006 end compared with the corresponding period a year before. "Countries like Egypt and South Africa are some of the emerging areas in global wind energy market. The marketers are yet to explore African countries but it is expected that the continent must have promising future for wind power," said Mr. Kane.

Source: http://economictimes.indiatimes.com

BASIC AERODYNAMICS

1.0 Introduction :

The classical aerodynamics theory has been developed for aircrafts first and later on applied to any fluid structure interaction problems. Hence an understanding of the basic aerodynamic theory is worth for people who are dealing with wind turbines, since the state-of-the-art wind turbine concept has been built on top of the classical aerodynamics theory. The physics involved is sophisticated, when a solid body interacts with a flow of fluid, unlike the interaction of two solid bodies, since the fluid changes its shape. This is because the point of contact is everywhere on the surface of the body. The transmission, or application of mechanical forces occurs through the fluid pressure. The paper does not deal with details of fluid structure interaction problem, instead deals with aerodynamic aspects.

2.0 Theory of Aerodynamics :

The major forces generated because of a fluid structure interaction are: Drag and Lift forces.

i) Drag Force: The force that acts parallel to the direction of fluid flow is known as Drag Force. It is due to the combined effect of Viscous forces (shear stresses) and Pressure forces.

ii) Lift Force: The force that acts perpendicular to the direction of the fluid flow is known as Lift Force. It is again due to the combined effect of Viscous forces and Pressure forces.

Pressure force = P * A (1)

Shear force = * A' (2)

Where P – Pressure

A – Area perpendicular to the pressure

– Shear stress

A' – Area parallel to the surface along which the shear force acts.

The magnitude of these forces depend on several factors such as:

i) Density of fluid

ii) Viscosity of fluid

iii) The orientation of the object relative to the fluid velocity direction (angle of attack).

iv) Velocity of fluid

v) Size and shape of the object

vi) Surface geometry of the object (Texture).

2.1 Boundary Layer Concept:

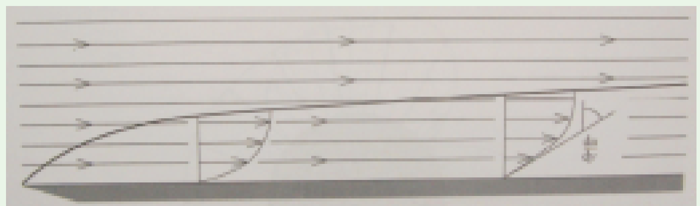
Boundary layer is a thin layer next to the body and predominantly viscosity effect is felt within the boundary layer. Outside the boundary layer, the viscosity effect is negligible. The fluid velocity outside the boundary layer is called free stream velocity and is the same as the upstream velocity of the object.

The factors affecting the boundary layer are:

i) Reynolds Number, which gives information about the state of the fluid, such as laminar or turbulent.

ii) The state of the fluid is dependent on the location of the body for external flows.

The concept of Boundary layer is well explained by means of flow over infinitesimally thin flat plate.



Boundary Layer Showing the Velocity Profile

Fig. 1 (Source: Wind Energy Hand Book by Tony Burton et al.)

The upstream uniform velocity is aligned with plate. At the plate surface, the fluid has the same velocity as the plate. Fluid viscosity provides internal friction that tends to retard the flow, and these viscous forces cause each layer of the fluid to exert a small force on the layer above it, reducing its velocity slightly. This is the reason why near the start of the plate, fluid layers remain well defined and farther down the plate, an instability initiates the transition region, which lasts over an uncertain length. At the end of the transition region, turbulent flow continues until the end of the plate. In the laminar region the viscous forces retard the velocity of each layer slightly. However, viscous effects eventually die out at some distance perpendicular to the plate and at all distance past this location, the velocity is again uniform, as it was upstream of the plate. In this region there are no velocity gradients and the flow in this region is called Inviscid Flow. The location at which the separation of viscous and inviscid flow takes place, defined as the distance at which the boundary layer thickness, δ, from the plate to where the boundary layer velocity reaches 99% of the free stream velocity, is known as boundary layer. This thickness increases the farther the flow is from the leading edge of the plate. In the turbulent region, bulk mixing of the flow is more efficient than viscous forces in smoothing out velocity gradients and the boundary layer thickness grows at a faster rate than in the laminar region.

There are three distinct flow behaviours present in the turbulent boundary layer:

i) Laminar sub layer: Near the wall, where the fluid velocities are low, viscous forces dominate, the flow is laminar and the region is said to be laminar sub layer.

ii) Turbulent layer: Far from the wall, turbulence dominates and the region is said to be turbulent layer.

iii) Buffer layer: Between the turbulent and laminar sub layers, the flow has characteristics of both the laminar sub layer and turbulent sub layer and the region is said to be buffer layer.

The transition begins at a distance from the leading edge of a body and depends on the following parameters:

i) Flow velocity
ii) Type of fluid
iii) Surface roughness
iv) Free – Stream turbulence level
v) Condition of the surface – heated or cooled etc.
vi) Surface shapes
vii) Orientation of the surface to the free stream.

The transition location is characterized by the Length Reynolds Number,

$$\mathbf{Re = (\rho v_\infty L)/\mu \quad (3)}$$

Where L – distance from leading edge of the body

ρ – fluid density

v_∞ ? free stream fluid velocity

μ – viscosity of the fluid

Transition or Critical Reynolds Number: The length Reynolds Number at which transition occurs.

2.2 Governing Equations:

The governing equations for the fluid structure interactions are derived based on the following laws:

i) Law of Conservation of Mass
ii) Law of Conservation of Momentum
iii) Law of Conservation of Energy.

In order to get information about lift and drag, these governing equations need to be solved. Since analytical solutions for these equations are not available, these have been solved using Numerical Analysis on a case to case basis. For complex flows and bodies, these are solved using Computational Fluid Dynamics (CFD) codes, which gives data on pressure and shear distributions over the complete surface of the body, thereby giving lift and drag forces.

2.3 Illustration of the theory:

The theory of boundary layer may be well explained through simple cases of flat plate. For detailed understanding, the reader may refer any fundamental textbooks on aerodynamics.

Case 1: An infinitesimally thin flat plate aligned with a flow past it.

Consider an infinitesimally thin flat plate, oriented in such a way that the area perpendicular to the flow direction is zero ($A = 0$), which means that parallel to the flow, the Pressure force = $P * A = 0$. This results in no pressure force in x direction. However, because of the no-slip condition, the flow past the flat plate will exert a force and the force is solely due to the shearing stresses (the viscous force effect), caused by the relative motion of the fluid past the plate. Hence in this configuration, the drag force is caused only due to the shear stress.

Case 2: An infinitesimally thin flat plate, which is set perpendicular to the flow field:

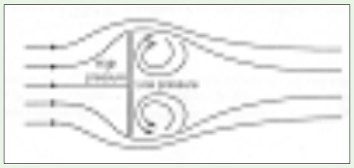


Fig. 2

Since the plate is infinitesimally thin, the area parallel to the surface is zero ($A' = 0$), which means that the shear force = $\tau * A' = 0$. However, the flow does exert a force on the plate. This force is solely due to a pressure distribution imbalance around the plate. The pressure on the upstream face of the plate is greater than that on the downstream face.

In neither of the above cases there is an imbalance in the forces in the direction perpendicular to the flow field and hence no lift force is generated.

Case 3: Asymmetrical object:

A symmetric flow around a symmetric object causes a drag force parallel to the direction of the free-stream velocity, but there will be no force perpendicular to the direction of flow. If the object is asymmetrical or if the flow is asymmetrical around an object, a lift force will be created. The best example for asymmetric object is Airfoil.

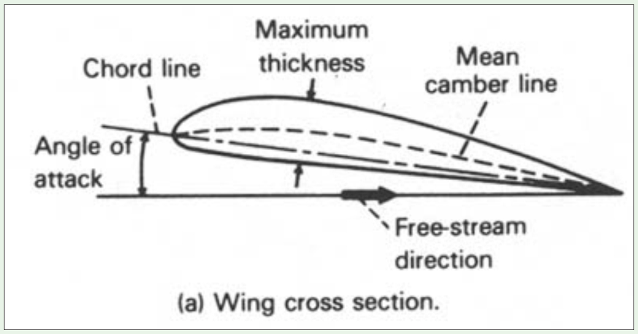


Fig. 3

Lift is created by the unequal flow of fluid over the top and bottom surfaces of the airfoil. The flow reaching the leading edge of an airfoil splits into two streams. Because of the airfoil's curved geometry, the upper stream accelerates, while the lower one decelerates. Boundary layers on airfoils are thin; viscous effects are significant only near the wing and in the wake trailing the wing. As a result, the flow field outside the boundary layer may be treated as an inviscid flow. The pressure distribution in the flow field around the airfoil can be obtained from the solution of an inviscid flow around an object. The pressure distribution may be obtained from Bernoulli equation. Just before the flow splits at the leading edge, the velocity and pressure are known. The second location can be taken along the surface of the airfoil. The velocities over the top surface are greater than those over the bottom surface. Therefore, from the Bernoulli equation, the pressures on the top surface will be smaller than those on the bottom. Integrating the pressure distribution results in a net upward force, which is known as lift.

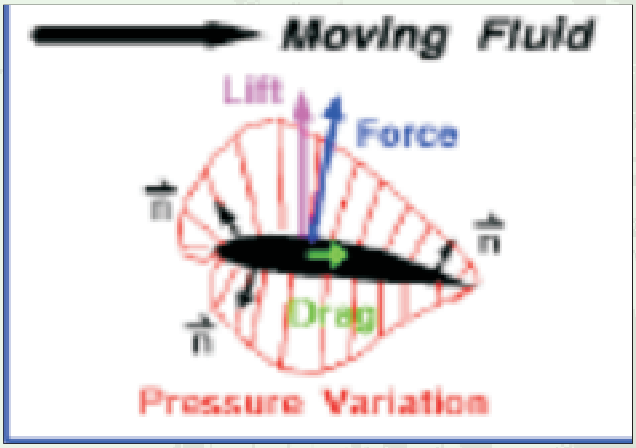


Fig. 4

Although an airfoil is designed for lift, it also experiences drag so airfoils are streamlined to minimize drag forces. The influence of angle of attack on lift and drag coefficients has been shown in fig. 5.

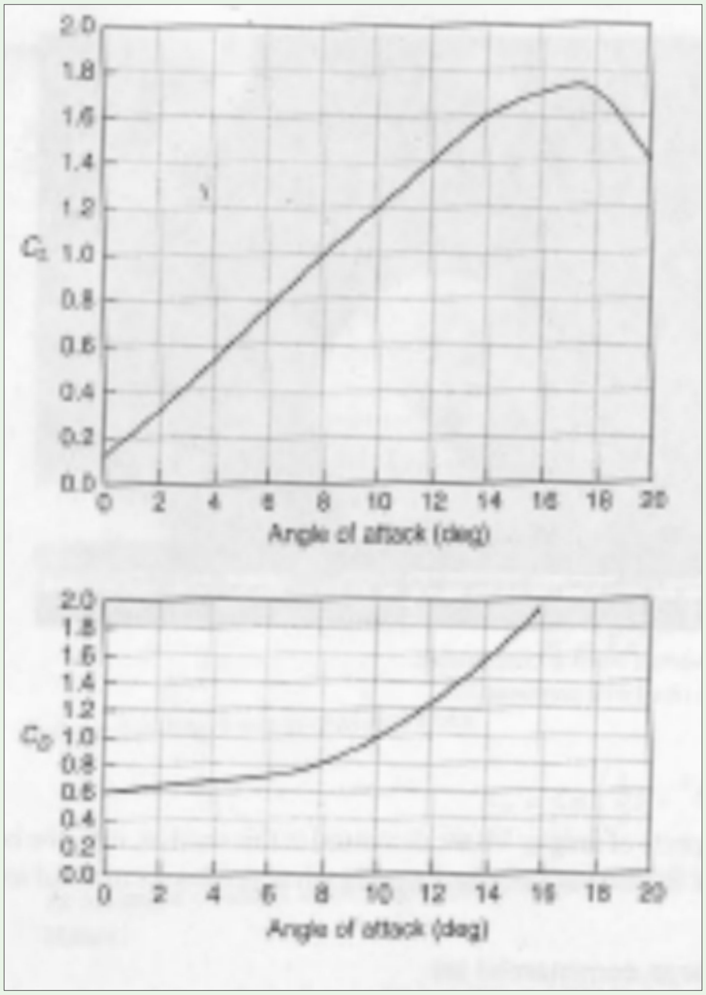


Fig. 5

Three characteristics are involved in airfoils. Firstly, typical airfoils have a positive lift coefficient at zero angle of attack, because airfoils are not symmetric. Secondly, the lift coefficient is approximately linear with angle of attack; in addition, the drag coefficient also increases with angle of attack, but not as dramatically as lift coefficient. Thirdly, if the angle of attack becomes large enough, the lift coefficient reaches a peak, then decreases abruptly; the drag coefficient increases just as rapidly. The airfoil then stalls. The stalling phenomenon has been shown in fig. 6.

As angle of attack increases, boundary layer separation occurs on the top surface near the trailing edge. Again if the angle of attack increases, it causes the point of separation to move forward, but the lift coefficient still increases. At some critical angle of attack, characteristic of the particular airfoil, the forward movement of the separation point no longer produces an increase in lift, and above this critical angle the lift decreases significantly.

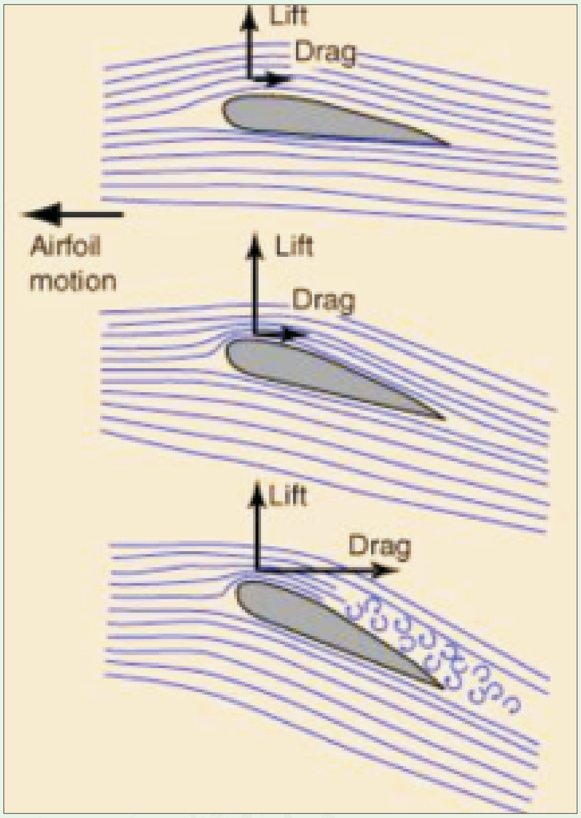


Fig. 6

3.0 LANCHESTER – BETZ – JOUKOWSKY LIMIT

Assumptions & Physical Conditions:

- The rotor has been assumed as infinitesimally thin disk
- Fluid velocity falls gradually before and after the disk
- Pressure difference builds up across the disk
- Fluid velocity right across the disk does not change
- Pressure far upstream the disk & the pressure far downstream are equal to the static pressure of the undisturbed flow.

Power Coefficient, Cp:

The power coefficient has been derived from the Law of Conservation of Momentum. First postulated and established the limit in 1915 by the British Aerodynamicist Lanchester. Russian Aerodynamicist Joukowsky carried out the similar studies and established the same limit in 1920. Simultaneously, Betz, the German Scientist established and published the limit in 1920 and became the first person to publish the result. Hence the limit is known as Lanchester – Betz – Joukowsky Limit, commonly known as Betz limit (Reference 6).

Cp = Rotor Power / Power available in the wind = Pout / 0.5* $\rho A v_1^3$

Maximum or optimum Cp, Cp,max = 16/27 = 0.5926

3.1 Losses:

The different losses attributed to the maximum power coefficient are:

a) Wake Losses

b) Profile Losses

Some of the methods to reduce the losses are as follows:

In order to reduce wake losses, vortex generators (VG) can be used on the rotor blade. In order to reduce profile losses, winglets are used. Winglets are the curved profile at the blade tip. By reducing the losses, Cp can be attained more close to the maximum limit.

4.0. Conclusion:

Theory underlying the Aerodynamics of Wind Turbines has been introduced alongwith the phenomenon of lift and drag. Maximum power coefficient, losses and remedies to reduce the losses have been addressed.

Reference:

1. Fundamentals of Aerodynamics – John D Anderson
2. Wind energy handbook – Tony Burton et al., - Wiley
3. Theory of wing sections – Ira H. Abbot et al., - Dover publications
4. Guidelines for design of wind turbines – 2nd Edition – DNV/Risoe
5. Wind turbines – Fundamentals, Technologies, Applications, Economics – Erich Hau – Springer publications
6. Wind Energy, 2007;10: pp 289-291

Gireesh Kumar V.R.
Standards & Certification Unit,
Centre for Wind Energy Technology, Chennai, India.

Published by :
CENTRE FOR WIND ENERGY TECHNOLOGY (C-WET)
An autonomous R&D institution established by the Ministry of New and Renewable Energy (MNRE), Government of India
To serve as a technical focal point of excellence to foster the development of wind energy in the country
Velachery - Tambaram Main Road, Pallikaranai, Chennai - 600 100
Phone : +91-44-2246 3982, 2246 3983, 2246 3984 Fax : +91-44-2246 3980
E-mail : info@cwet.res.in, pavan@cwet.res.in Web : www.cwet.tn.nic.in