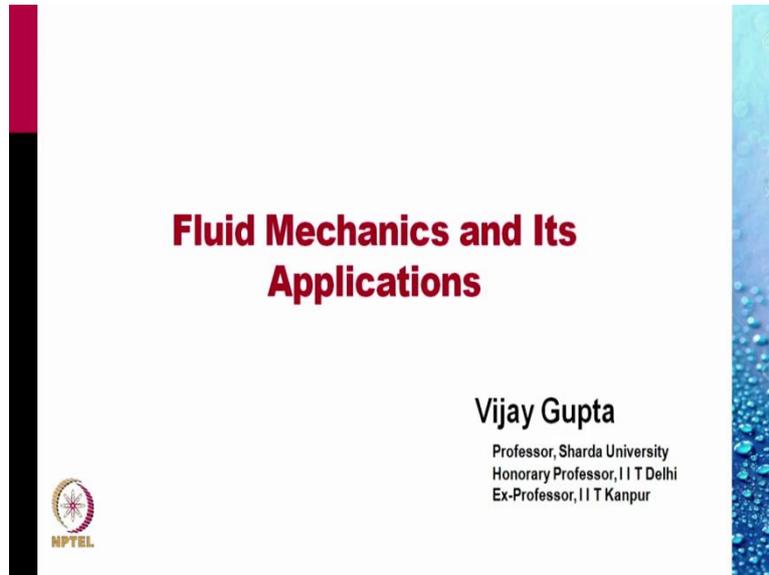


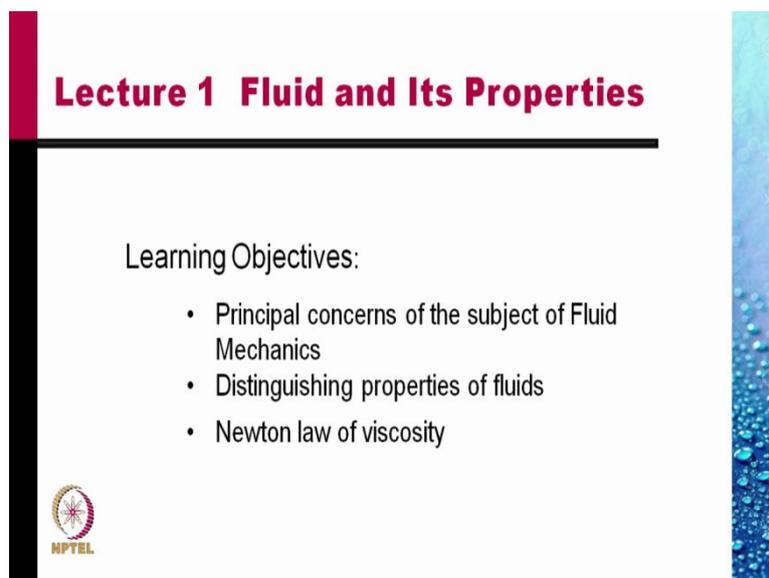
Fluid Mechanics and its Applications
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Lecture 1
Fluid Mechanics and Its Properties

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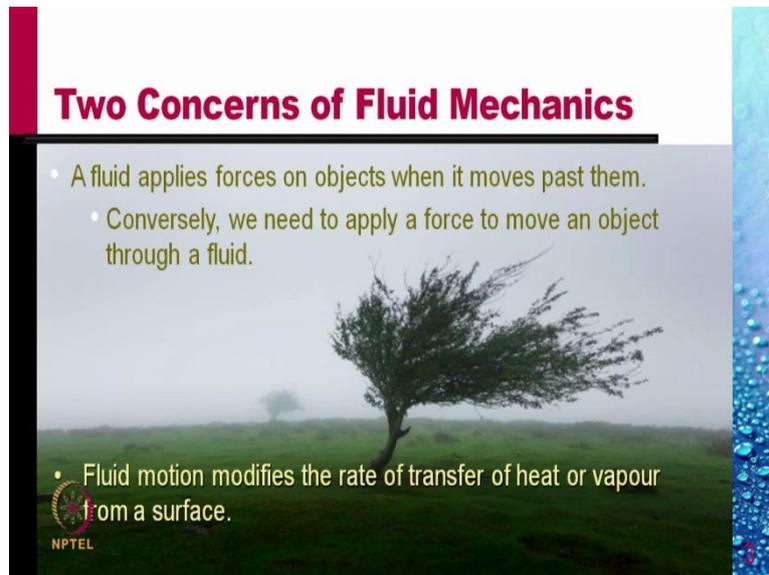
Good day everyone. I am Vijay Gupta. And I will be teaching this course on Fluid Mechanics and Its Applications. This is a very practical course, in which I would do very little mathematics per se, and mostly I will be doing applications. The mathematics related to this course, can be picked up from a book by the same title by Dr. Santosh Gupta and me.

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The learning objectives of this first lecture in which we will discuss fluids and its properties is to talk about the principal concerns of the subject of fluid mechanics, the distinguished properties of fluids, and the Newton law of viscosity, most of which you would have covered in your high school.

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Two Concerns of Fluid Mechanics

- A fluid applies forces on objects when it moves past them.
 - Conversely, we need to apply a force to move an object through a fluid.
- Fluid motion modifies the rate of transfer of heat or vapour from a surface.

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There are two concerns of the subject of fluid mechanics. First is, a fluid applies forces on objects, when it moves past them. Conversely, we need to apply a force to move an object through a fluid. The subject of fluid mechanics is largely concerned with calculating these forces.

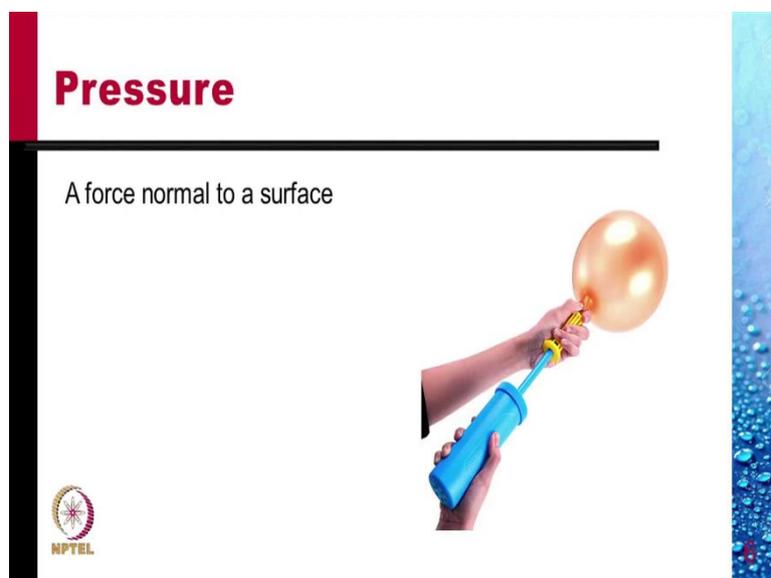
The second concern of the fluid mechanics is that the fluid motion modifies the rate of transfer of heat and vapor from a surface and this rate of transfer of heat and vapor is required for designing heat transfer equipment and the diffusion equipment, largely an engineering concern. So, we need to study how the fluid motion modifies those rates of transfer. This is what we are going to do in this subject.

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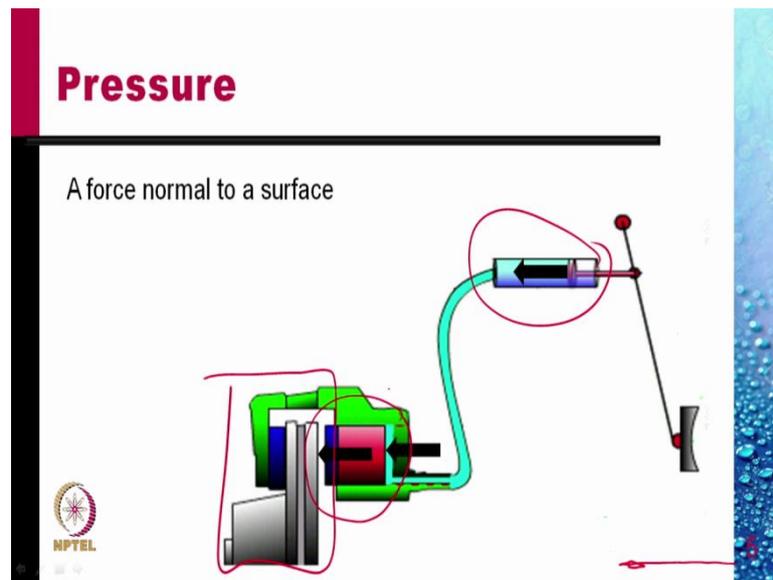
But first, let us talk about the various kinds of forces in the fluid. All of you know that a fluid exerts buoyancy forces on objects which are submerged or partially submerged in it. A boat, a paper boat floats on water, because its weight is being balanced by the vertical force of buoyancy that it experiences. You had learned in your high school that this buoyancy force was first studied by the Greek scientists Archimedes.

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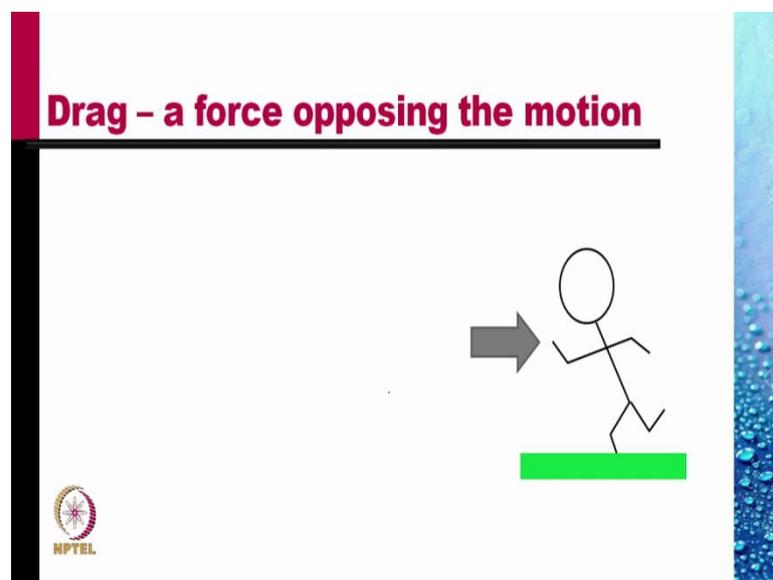
Then, there is a force normal to a surface, which is termed as pressure. Pressure is an abiding concern of fluid mechanics. And we will deal with it throughout this course, we will see various applications of this force of pressure.

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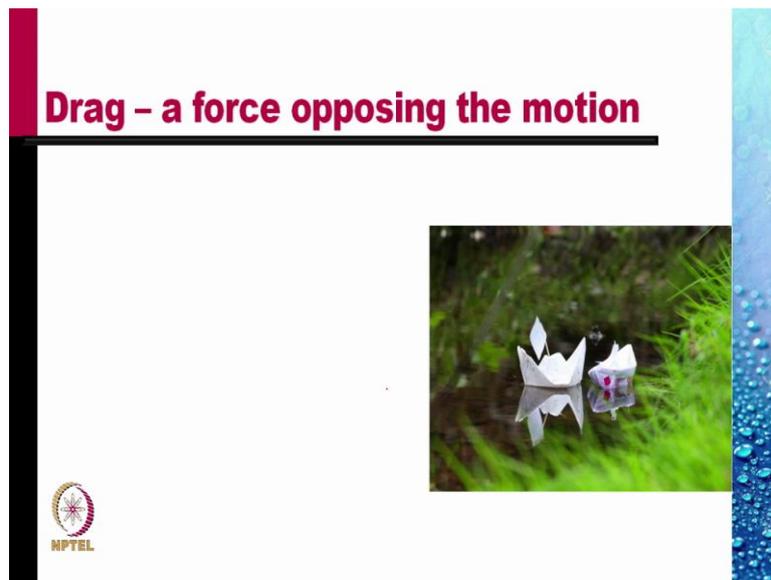
One of the application of this pressure is shown in this sketch of a basic hydraulic system for a car. This here is the wheel of a car which is, in which this is a pad. There is a hydraulic fluid in this cylinder. And as you press the brake pedal, the fluid goes and presses this cylinder against this causing friction to apply a torque on the wheel to make it stop. This is the basic mechanism of the hydraulic brakes of a car.

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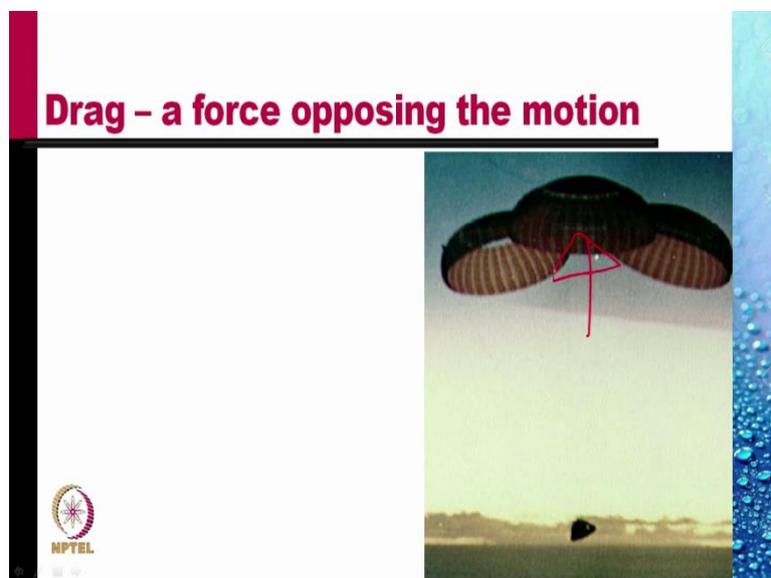
Then the other force, the drag force opposes the motion. If you run against the wind, you experience a force, that tends to stop you, this is a force which every moving vehicles experiences. And, we have to expend energy to overcome this drag force.

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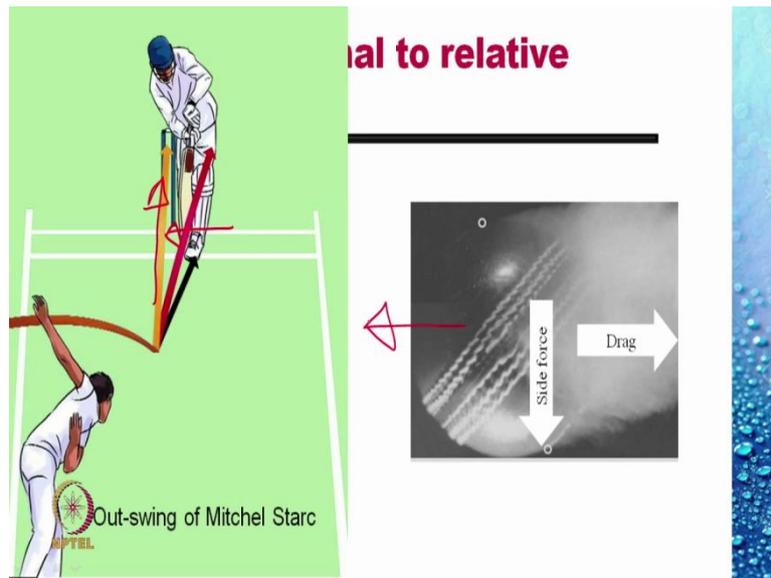
These boats, paper boats, floating on the river. Are they floating with the speed of the stream? If there was a difference in the speed of the flowing water and the boat, a drag force would result which would either accelerate or decelerate the boat till there is no relative motion between the water and the boat.

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One positive application of this drag force is in the parachutes. This payload is being delivered with this parachute. The payload in this case is a space capsule is being delivered by the parachutes. The parachutes while coming down move against the air and the air applies a force on these parachutes in the upward direction, thus decelerating the downward velocity of the payload.

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On the other hand, the force that is relatively normal velocity is called a lift. The Australian bowler Mitchel Starc here is bowling his fast-paced ball, a swinger. The ball, if it was going straight would have followed the red line, but because of out-swing, it moves in the direction of the yellow arrow. This arrow. It is the out-swing ball. How is it possible? This is possible only if there is a force on the ball in that direction: a direction normal to the direction of motion of the ball. We would, later on in this course, explain how that side force comes in on the ball.

This ball that is shown is moving in that direction. There is a force of air: drag force which is trying to decelerate it, and there is a side force that results because of the inclined seam, and this side force results in an out-swing.

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Lift – a force normal to relative velocity



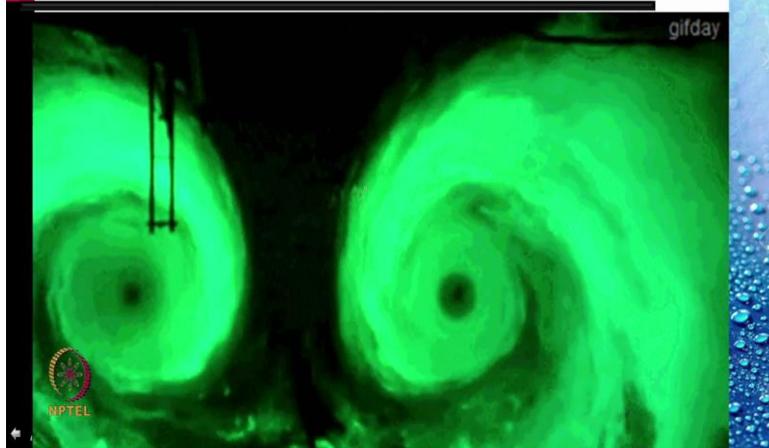
The lift is also responsible to keep an airplane flying in the air. It is the lift generated by the relative motion of the airplane with respect to surrounding air that exerts a vertical force on the wing, normal to the direction of motion of the aircraft. It is this lift which is upwards that balances the weight of the aeroplane.

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Lift – a force normal to relative velocity

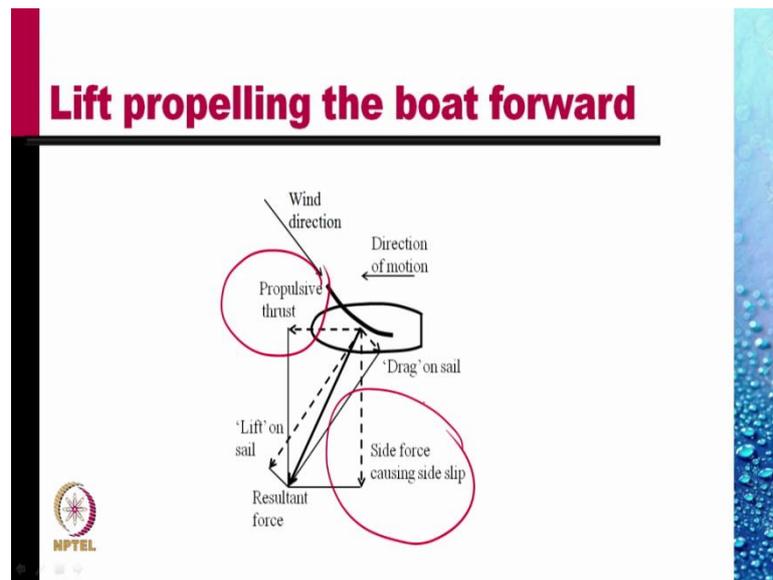


Lift - a force normal to relative velocity



We will see later on that this is the result of these vortices that develop in the flow and they are moving down. And while there are moving down, that means there is a force that is applied on them downwards. And the reaction to these forces is the force which is applied vertically upwards on the aircraft.

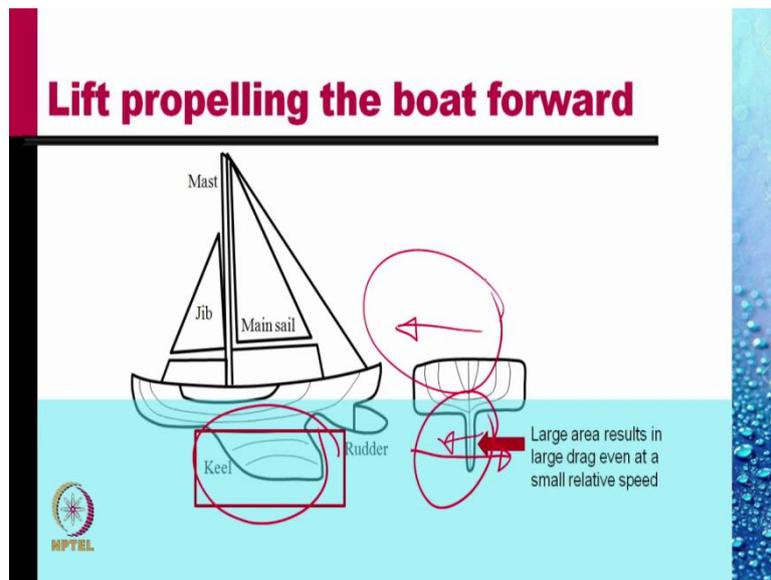
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The lift is also responsible for propelling a boat forward. The direction of wind is shown here. The direction of wind. The sail on the boat is so arranged that the wind comes tangentially on to the sail. Because of the sail, because of the wind flowing over the sail, there is a lift force on the sail. Lift force is perpendicular to the direction of the wind and a drag force in the direction of the wind itself.

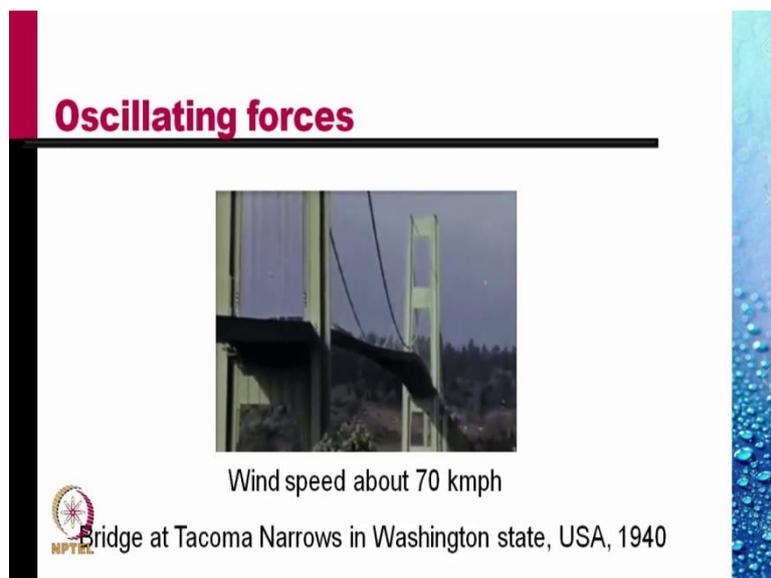
The resultant of these two forces is this, by law of parallelogram of forces. We break this force up, the resultant force up, into two components. One, as shown here, in the forward direction, which we have termed here as the propulsive thrust, and the other, perpendicular to the direction of motion which we call the side force. We have to overcome this side force, and if you can overcome the side force, the boat would move in the forward direction, quite a bit into the wind itself.

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Here, we are showing what generates the side force. The keel of the boat, the portion of the boat below the waterline. As the wind applies a sideways force on the boat, the boat tends to move in that direction, causing a relative motion and so, the water applies a drag on this boat. Since, water is much more dense, this force is a large force. So, with very small velocity, we can overcome this side force. And so, the boat drifts to the side only slightly. Most of the motion is forward. Large area of the keel results in large drag even at a small relative speed.

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Oscillating forces



Bridge at Tacoma Narrows in Washington state, USA, 1940

The Much Stiffer Replacement

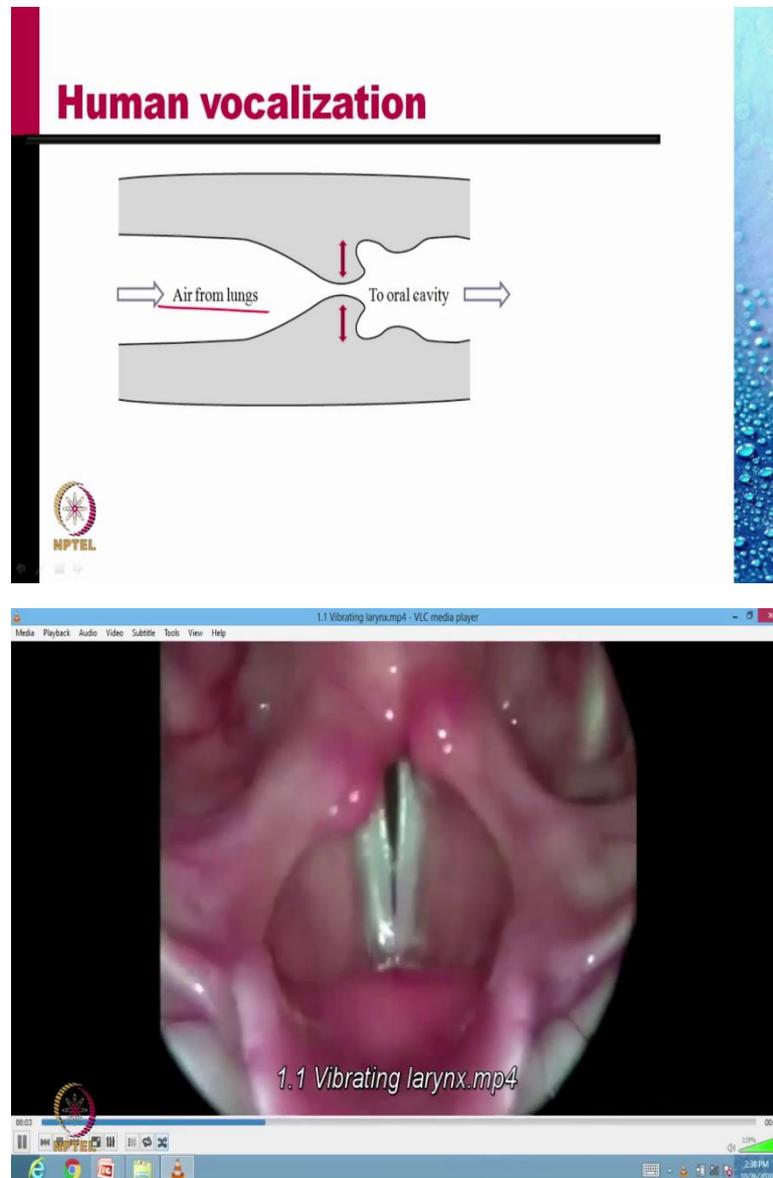


One of the most interesting things is that we can get oscillating forces even when the winds are steady. Perhaps one of the most famous examples is what happened to a bridge at Tacoma Narrows in the Washington State of USA in 1940's. This is an actual picture from that when the bridge was relatively new, only a few months old, there was a windstorm at a very moderate speed of 70 kilometers per hour. And you can see the deck of the wind started oscillating. This oscillation can result only if there is an oscillating force acting on the deck.

Unfortunately, the frequency of these oscillations coincided with the natural frequency of the bridge deck and the bridge collapsed. The bridge was replaced by a new bridge, later on. Note that the bridge has been made much stiffer so that the natural frequency is much higher, and the wind would not set it up into resonant oscillations.

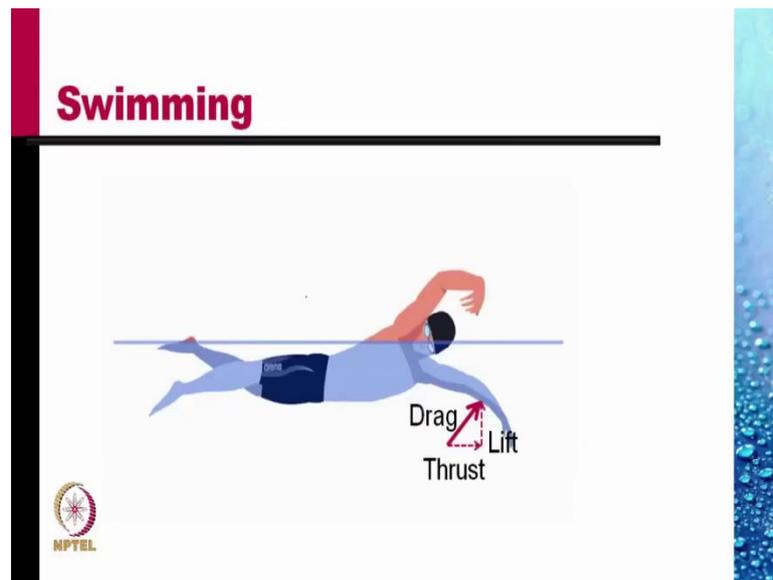
So, a problem for wind engineer, an aerodynamicist, or a fluid mechanist, is to calculate what is the frequency caused by the winds blowing over the deck, and then design a bridge with the natural frequency much higher than that frequency.

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Another example of oscillating forces is what happens in our vocal cords. The air from the lungs is pushed through a narrow opening in our larynx. And though we push the air at a uniform speed, this larynx start vibrating up and down as shown. This is taken with a strobe light, so the vocal cord vibration is slowed down.

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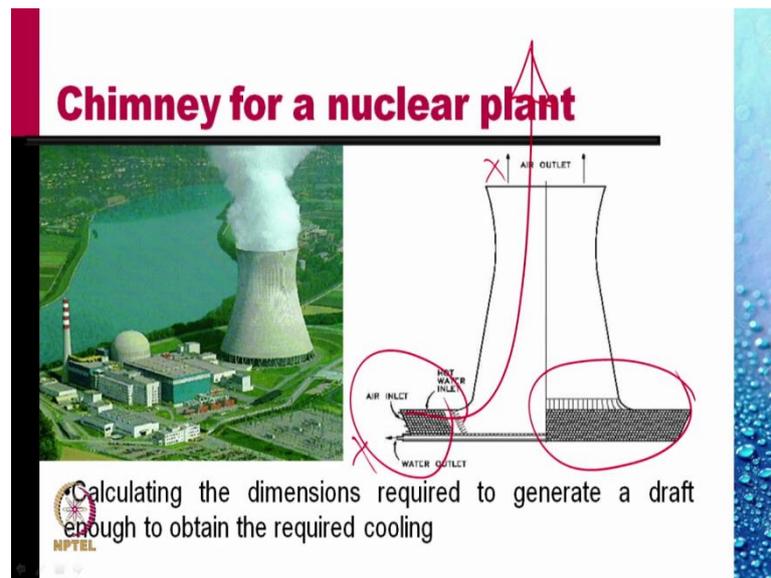


Swimming is again the play of forces between fluid mechanics and bodies, the hand as it goes down, produces a drag normal and opposed to direction of motion on the hand, which is coming down, and this drag force can be broke up into two components: a component in the forward direction which gives you the thrust, which gives you the force because of which the person, the swimmer, accelerates forward, and the lift which keeps him afloat.

There is some new research into motility of sperms. These sperms cannot swim like a swimmer does, because the size of the sperm is very small. We would learn, later on in the course, that the forces or the relative magnitude of forces depends upon a parameter called the Reynolds number, which depends upon the size of the object and the speed.

The speed of a sperm and the size of the sperm are very small, of the order of 50 micrometers, the size of the head of a human sperm, and the speed about 20 micro-meter per second. So, with those speeds, the viscous forces are very large, and with those large viscous forces we can see that nothing can move the way a human swimmer moves. This motion is quite different.

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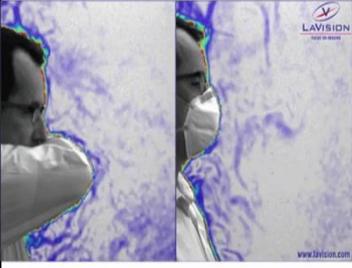


Next, we will discuss a couple of applications where the motion of the fluid results in modifying the transfer rates. In this picture is showing on the left, is shown the chimney at a nuclear power plant. What is the chimney doing in a nuclear power plant? How does a nuclear power plant works? Nuclear power plant works by generating heat in the nuclear core by nuclear reaction that heat heats up a fluid, usually or quite often, a molten metal. This molten metal is taken to a reactor where water is boiled. And the water runs a turbine, a steam turbine. This water needs to be re circulated, but this water is too hot.

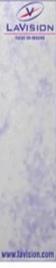
So, before it goes back to the boiler it needs to be cooled. That cooling is done in this chimney that is shown here. The hot water is passed through the tubes shown here and here. Air is lifted up through this chimney, and this moving air sets up convection across the tubes through which the hot water flows, thereby cooling it. What should be the diameter of the tubes? How many tubes should be there? What should be the height of this chimney, are all questions for a fluid dynamicist to answer.

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Efficacy of a face mask



The primary way of person-to-person corona virus transmission is via aerosols or small droplets created by breathing, sneezing or coughing. The reach of exhaled air can be effectively reduced using a face mask. Schlieren imaging technique is applied to visualize the air flow caused by a person breathing and coughing.



This picture shows the efficacy of a facemask. The transmission of corona virus is largely by aerosols or small droplets created by breathing, sneezing or coughing. The reach of the exhaled air can be effectively reduced using a face mask. Schlieren imaging technique is applied to visualize the airflow caused by a person breathing and coughing.