**Fluid Mechanics and Its Applications**
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**Lecture: 3A**
**Pressure and Machinery**

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Pressure is used in lot of machineries that we operate.

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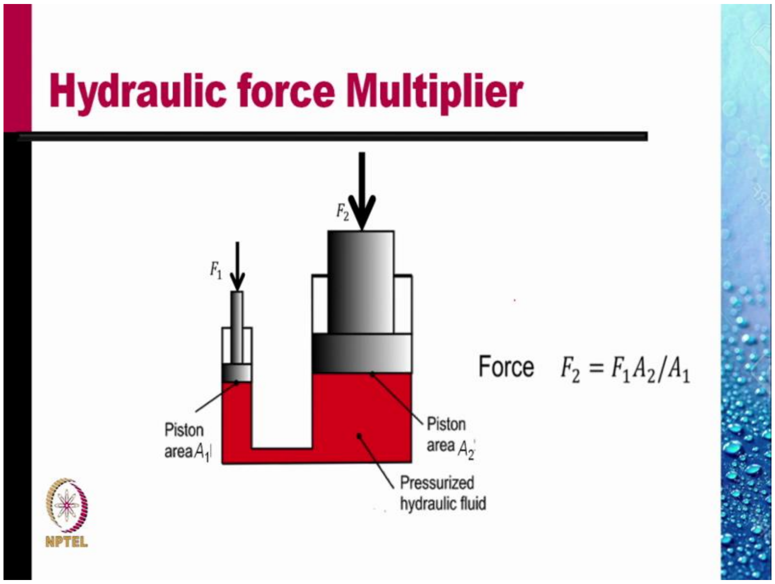

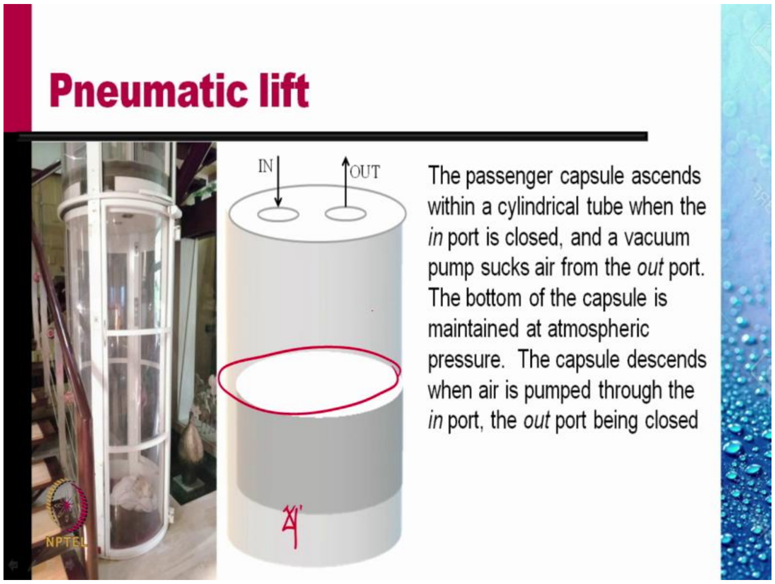


And these machineries are based on the principle of hydraulic force multiplier. Consider two cylinders connected and carrying a fluid. In one cylinder there is a piston of area $A_1$. In the other one, there is a piston area $A_2$. If we apply additional force $F_1$ on this piston, this will create an additional pressure $F_1 / A_1$ in the fluid. This additional pressure would be transmitted everywhere within the fluid.

So, this same additional pressure $F_1 / A_1$ would appear at all points, even at the face of the second piston. And so, the force developed in the second piston would be $F_2$ equal to $F_1 / A_1$ multiplied by $A_2$. And as $A_2$ is large compared to $A_1$, force $F_2$ would be large. This is the principle of force multiplier which is used in the various devices.

Shown here is a fancy pneumatic lift. This lift is nothing but a cylinder within which a capsule carrying the passengers travel. This cylinder is connected to the inlet and outlet ports of an air pump. a compressed air would then press the capsule down, and the capsule carrying the passengers would come down.

But if we connect the output to the input of the compressor, then it will suck air out from the top and then decrease the pressure below the atmospheric pressure. The atmospheric pressure is acting below the capsule and so, the pressure difference multiplied with a large area of the capsule results in a large force that carries the capsule up.

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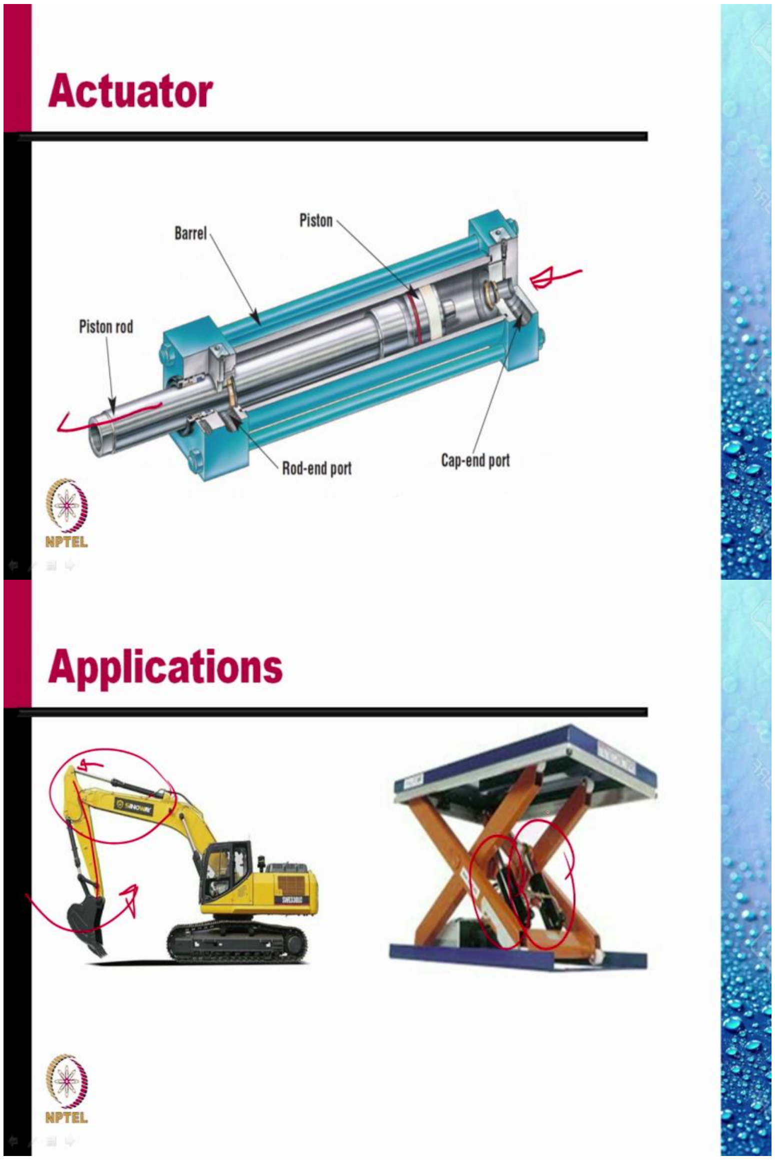


This picture shows a pressure actuator used in all kinds of hydraulic machinery. What it does is that a pressure if fluid at a large pressure is pumped into it and as it pumps this acts on this piston and this piston moves in that direction applying a force in whatever equipment that we want to apply force at. Example of this is this earth mover. This is a pressure actuator. Applying hydraulic pressures at this end would extend this rod and would make this arm turn in that direction. We can apply very large forces through these actuators. These actuators are also used in controlling the control surfaces of an aircraft. This hydraulic table for lifting loads also uses two actuators in a similar manner.

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Let us now consider forces and pressure in fluids which are moving as a Rigid Body.

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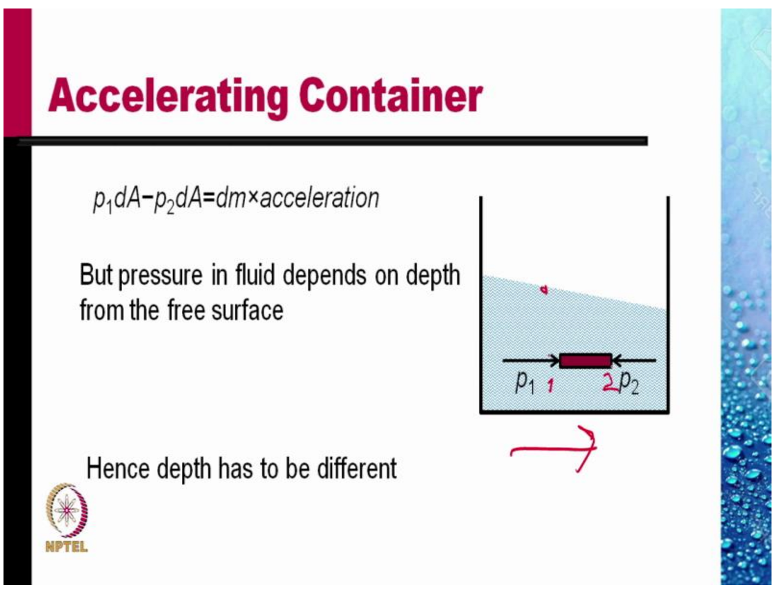


Let us consider a container which is accelerating in the horizontal direction. Consider a horizontal fluid element or cross-sectional area dA. The net force on this fluid element in the horizontal direction is $p_1 dA$, where $p_1$ is the pressure on the left face *minus* $p_2 dA$, where $p_2$ is the pressure on the right face and this should be equal to the mass of the fluid element times the acceleration.

But the pressure in the fluids depends upon the depth from the free surface. If the fluid is accelerating the horizontal direction the fluid pressure variation in the vertical direction would not change. So, the pressure at this point would be the atmospheric pressure plus $\rho gh$. If the fluid is accelerating, $p_1$ must be greater than $p_2$. So, pressure $p_1$ must be greater than $p_2$. So, the depth of this face from the free surface should be more than the depth of this face from the free surface. This means, the free surface cannot be horizontal. The depths have to be different: more above point 1, and less above point 2.

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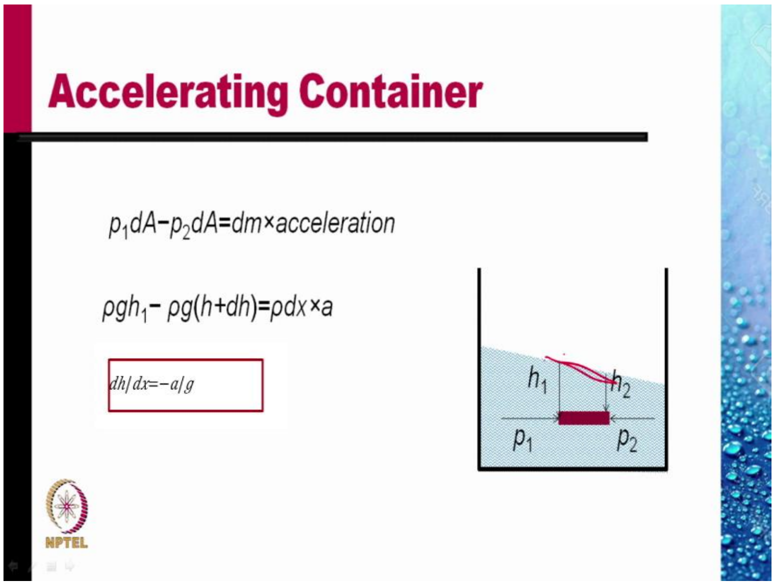


Here we have shown this. The depth is $h_1$ above point 1, and $h_2$ above point 2. Clearly, *dm* the mass of the fluid element would be the density ρ times *dx*, the length of the fluid element times a cross sectional area *dA*. Acceleration $a$. If I plug in this for *dm*, I get a simplified equation $\frac{dh}{dx} = -\frac{a}{g}$. $\frac{dh}{dx}$ is a slope of this line and $a/g$ is acceleration divide by the gravity.

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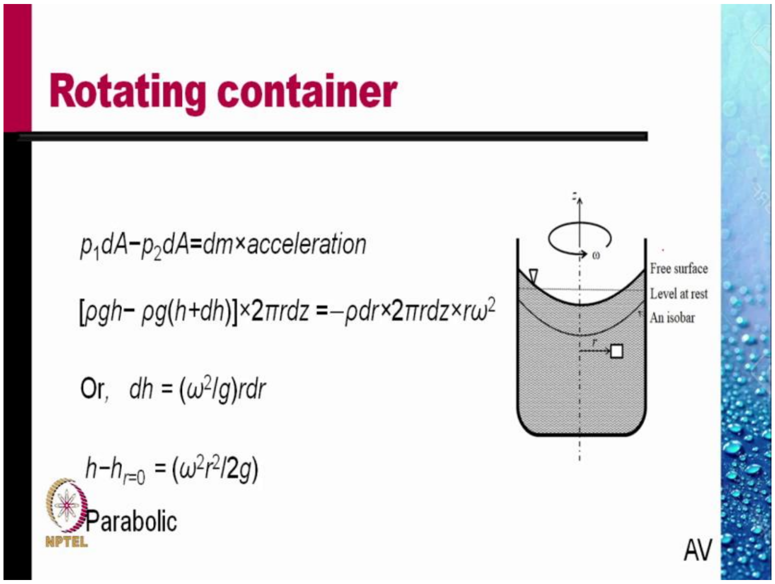


Next, we consider a rotating container. A container of a liquid which is rotating about x-axis at an angular speed ω. We see that the free surface of this is curved. If this was the level at rest, then when it is rotating with omega, this curved line becomes the free surface. Again, we consider this small element shown as white at the radius r from the axis.

Consider the force balance. At the left face of this white element, the force is $\rho gh$ multiplied by $dA$. The force on the right face is $\rho g(h+dh)$ multiplied by the area which is $2\pi rdz$. And this should be equal to mass *times* acceleration. And acceleration is the centripetal acceleration $r\omega^2$. And so, on simplifying this we get $dh=(\omega^2r^2/2g)$. And so, by integrating this and using that at $r=0$, the depth is $h_{r=0}$, we get this equation for the free surface. This clearly is parabolic.

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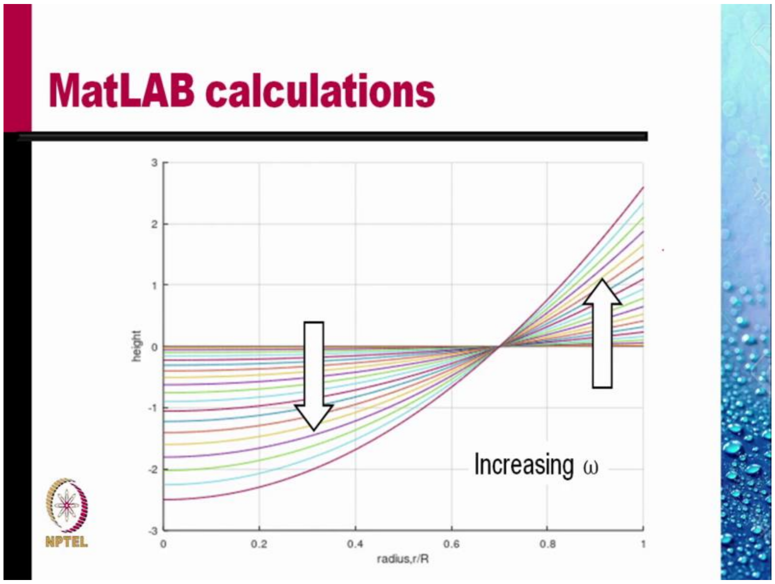


Here I have done/ calculated the free surface for various values of omega. The horizontal line is for zero speed. And as omega increases, at the center the free surface dips and near the wall it climbs up.

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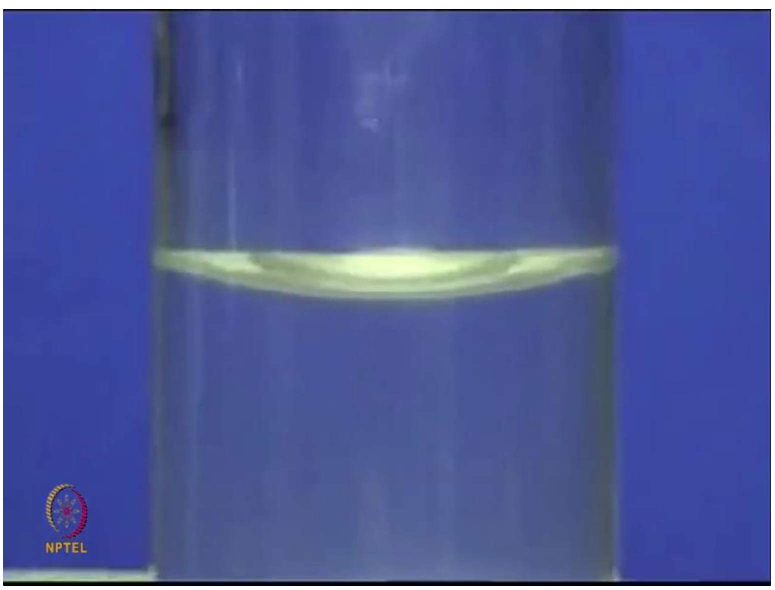

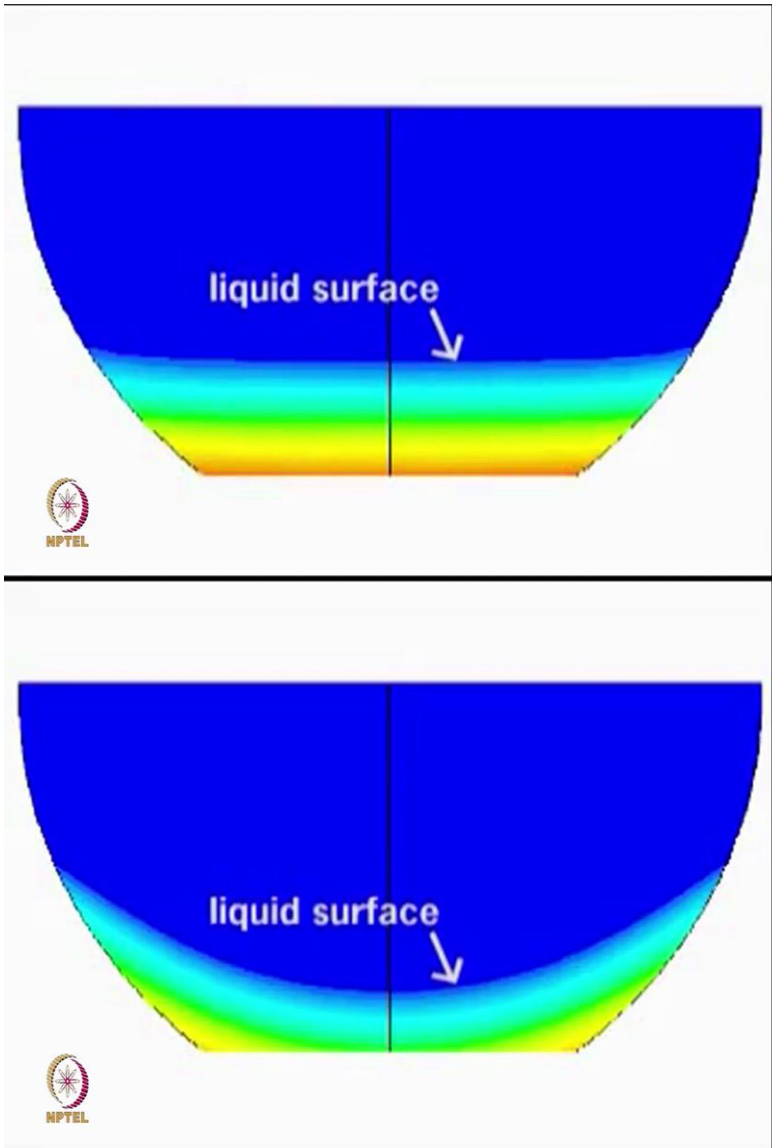


Speaker 2: When only gravity is at play, liquid surfaces in the laboratory are flat and horizontal. However, when we spin this container of water, it rotates as a solid body and centrifugal acceleration distorts the free surface into a parabolic shape. And accompanying CFD simulation shows colored pressure contours, revealing that the pressure indeed rises linearly downward from any point on the surface, just like the case for motionless body of water, according to the principle of hydrostatic pressure.