Hi everyone! In this video we're going to revisit some concepts that we discussed back in chapters 1 and 2 related to a flow phenomenon at solid-fluid interfaces. We're going to be applying these concepts again and again in this course, so this is a good chance to make sure that we're understanding boundary layer physics correctly and especially the mechanisms that cause these characteristic behaviors at solid-fluid interfaces.

So, one property of fluids is that they stick rather than slip when they touch solid matter. Since fluid flows are often interacting with solids, like the solid walls of a pipe confining water or air flowing over the land surface or um a solid channel that is containing a flow; understanding the behavior of fluids at boundaries is important for being able to predict other properties of the flow, like its viscosity, or I'm sorry it's like its velocity. So even before taking this class if we had a fluid that was flowing in a domain where I've got X and Y, like this, and I had a flow moving in the X-Direction so with velocity u like this one and my flow ran into some kind of solid wall, like this. We would know implicitly that right at the wall the velocity locally would become zero. We know that a fluid can't flow through a solid so it's got to go kind of around that solid and the flow would not be able to pass through it would have to go around. But if the wall is oriented differently so that it's down here at the bottom. And we've still got our velocity moving in u, like this and we've got distance away from our wall Y, like that. Because we've been studying the no slip condition, we now know that the first layer of fluid that is touching our solid at this wall would also be moving at the same velocity as the solid, which in this case would be zero. So right down here at Y is equal to zero our flow velocity also locally is going to be zero and then the next layer of fluid above that first layer that's sticking to the solid would be able to move a little bit faster. But it would still be held back by that layer of zero velocity fluid that's touching the solid so you could think of it being slowed down but it's not sticking to that low velocity or zero velocity layer of fluid so the no slip condition really only applies between uh the interface of a solid and a fluid, so fluid-fluid layers that are moving at different speeds are going to affect each other but in a different way, through the creation of shear stress, which we'll discuss in another video. But each fluid layer that moves further and further from that solid wall, um will be able to move faster and faster so my next fluid layer can move a little bit faster and the next after that a bit faster still. Until eventually my fluid is moving at the free stream velocity where it's no longer feeling the effects of the boundary below it. So down here where the velocity is changing with distance away from my solid this is known as the boundary layer. Whereas up here in this region where the velocity is not changing with distance away from the wall we refer to this as the free stream. So, once a fluid reaches the free stream you can think of it as no longer feeling the boundary below it. So, we've effectively divided our flow into two different flow domains: the free stream above and the boundary layer below. Now in the free stream, the magnitude of velocity is u and the change of velocity with distance from the wall is now zero. Right, I can move as far away from the wall as I like to and my free stream velocity, u, isn't going to change. So, I could write this like du/dy, my velocity gradient, at this point is equal to zero. Now down here in the boundary layer we have a different story. So in the boundary layer the magnitude of flow is zero at the boundary and my velocity gradient, du/dy, it's not equal to zero like it is in the free stream. Instead, it's some finite number that corresponds to the slope of the velocity gradient moving away from the boundary.

So now let's consider another example where I've got two plates, two solids that are bounding a fluid, so in between my two plates is a fluid, and the distance between my two plates will say is y and so my top plate is moving at a velocity u is equal to big U and my bottom plate is stationary. So velocity of my bottom plate is zero and then I've got my fluid that's in here, I'll make my fluid yellow. Okay so just like before, both of the first layers of fluid that are touching either of my solid plates either the bottom or the top plate are moving at the same velocity as the plate. So down here at the bottom my velocity locally is zero because my bottom plate is moving at velocity zero and then up here at the top my local velocity is big U because my, my top plate is moving at big U. Right, so if this is the magnitude of big U, what I'm going to see is that my magnitude of velocity is going to decrease as I move through the fluid towards the bottom plate each layer is being slowed down by the layer below it, or sped up by the layer above it. Until I get down here really close to my plate and I've got a really low velocity and then the very last layer of fluid is moving at the same velocity as the bottom plate, zero and I have a distribution of my velocity du/dy that looks something like this.

Okay, next example in this one I've got internal flow moving through a pipe. So, here's my pipe section and I've got a flow moving through uh my pipe and my pipe isn't moving, none of the walls of my pipe are moving they're all stationary right. So up here the velocity is zero and down here the velocity is zero, all the way around the circumference of my pipe the velocity of those pipe walls is zero. And so the very first layer of fluid that is touching my pipe walls, all the way around my pipe, is going to be moving at zero velocity right, the same as my pipe and then the next fluid layer next to that can move a little bit faster the next layer can move a little bit faster still and so on. And then I get to the very fastest velocity right in the center of my pipe so in the center of the pipe my velocity is equal to U Max, the maximum flow speed inside of my pipe, and my boundary layer looks something like this. Now I'm drawing it in two dimensions here, but you have to picture this in three dimensions, so all around the outside of my pipe if I look at it in a cross-section like this all the way around that cross-section I've got a slow flow layer. And then all around the next layer is a little bit faster, and then this layer becomes faster, and then here in the middle this is my high speed core where my velocity is maximized because it's as far away from the boundary as I can get.

Okay last example that I'm going to show is, again I've got two solid plates that are bounding a flow between them. This one looks similar to a previous example that we have done, but it's a little bit different now. In this case my top plate is moving to the right at a speed of little u is equal to big U and then my bottom plate is moving to the left at a speed of u is equal to negative big U. So exact same velocities different directions. And then I've got my fluid in between these two plates like that. Okay, so now what's going to happen? Well, my very first layer of fluid on either pipe is going to be moving at the same speed big U, right it has to move at the same speed as the solid that it's touching and down here, I get the same thing happening. Down here my first layer of fluid touching the bottom plate is moving at the same magnitude big U but in an opposite direction, and then my next layer of fluid is moving a little bit slower. Why is this happening, right? Well because as I move further and further away from either of my plates I'm getting closer and closer to the other one of the plates that's moving in the opposite direction, until I get to a place in the middle where the two velocity profiles can meet and this is where U is equal to zero. So now I've got a velocity profile you know something like this which should be identical on both sides.

So, thank you to the National Science Foundation for supporting this work under Grant 2335802.

Great job reaching the end of this boundary layer uh video and please reward yourself with a Moment of Zen. I study fluid mechanics because I love water and healthy aquatic ecosystems. Whatever your passion is, I hope that it motivates you to continue your study of fluid mechanics.