Hi, welcome to Engineering Earth. In this video, we're going to review how properties of fluids and flows influence our analysis of conservation of mass.
Let's consider a steady flow of mass through a control volume. In this example, my control volume is a solid device. It has solid physical walls, and there are only a couple of places, inlets and outlets, where mass can enter into my control volume from the outside.
So I'm drawing my physical walls in this black color, and then, of course, I've got a control surface that covers my entire control volume and separates any mass
that's inside of my control volume from anything that is in the surroundings outside.
My little red dashed line of control surface you'll see is going to cover up my inlets and outlets too, but it's just imaginary, right? It's not like I'm making a solid wall, so I can have mass that comes through my control surface. It can't go through the control surface anywhere that the black line is solid, of course, because that's a physical wall. Okay, so again, we're looking at a steady flow of mass, and of course, we know that a steady flow of mass means that the mass isn't changing with respect to time. So let's say that in this example, I've got mass flowing in through these two inlets on the left like this, and then I've got mass leaving my control volume through one outlet over here on the right. How would I calculate the mass coming in or out through these inlets or outlets? Um, so I would first think about the density of the fluid that's coming in, rho, and how fast it's coming in or out through these inlets, so the velocity, and then I would think about the flow area that that mass is flowing in or out through. So I've got a rho, a velocity, and an area: density, velocity, area. Um, and if I look at the dimensions of each of these variables, I know that rho is a mass per cubic length, I know that a velocity, oops, I know that a velocity is a length per unit time, and I know that a cross-sectional area is a length squared. Um, so all of my length terms are going to cancel, leaving me with a mass per unit time, which, of course, we have defined as a mass flux. We've given it the variable of little m with a dot over it, so a mass flux rate. So let's say that I've got a steady mass flux of 3 pounds of mass per second coming in through inlet one, and then I have a steady mass flux of 5 pounds of mass per second coming in through inlet two. So because it's a steady flow through my control volume, I know that anything that's coming into my control volume also has to go out at the same rate. So therefore, I already know that the mass that's leaving my control volume over here on the right-hand side is my 3 plus 5, 8 pounds of mass per second. That's my mass going out. So what you'll notice is that in a steady mass flow, the mass inside of my control volume doesn't change over time. I've got some mass coming in at a rate of 3 plus 5 pounds of mass per second on the left, and that same mass rate of 8 pounds per second is going out on the right, and the amount of mass inside of my control volume stays the same over time. It's similar to our example of the bathtub control volume. It's like if we had the faucet and the drain flowing at exactly the same rate, and then the water level in the tub doesn't change over time. There's no storage in the control volume over the time we're considering.

Now let's consider another example of a steady mass flow through a control volume. Um, again, I'm going to draw my control volume with solid boundaries except for just a couple of fixed inlets and outlets like this. And once again, my control surface covers all of these physical walls, and also it goes over my inlets and outlets as well. And so my mass can move into or out of my control volume at these inlets or outlets. It can't move through the physical walls. And so let's say I've got my mass coming in from the left again like this and going out over here on the right. And again, we're considering a steady mass flow. This time we know something about our fluid. Let's say that our fluid in this example is air, and our control volume is a device called an air compressor. So because this is a steady flow, again, I know that anything that's coming into my control volume also has to go out. So again, if I've got 3 pounds of mass per second coming into my control volume through the right-hand side, I know I have to have 3 pounds of mass per second flowing out on the right-hand side to conserve mass. Since it's a steady flow, anything that comes in has to go out, and the mass inside of my control volume again isn't changing over time, there's no storage. But since this is an air compressor and my fluid is air, a compressible fluid, I also can know something about the density of the fluid. So when the air comes into my air compressor, its density, which I'll call rho, is that mass that's contained per unit volume, right? And then when it's leaving, that same mass is now being contained in a smaller volume, and so therefore I know that the density has to have increased in my air compressor. So in this example, my flow through the control volume was steady. The same mass went in that came out, but the mass was contained in different volumes, and that's what an air compressor is designed to do, right? To fit the same amount of air mass into a smaller volume so that it's faster, for instance, to inflate my car tires. The point being that even though the mass is conserved, I've got 3 pounds of mass per second coming in and 3 pounds of mass per second going out, the volume is not necessarily being conserved. So that depends on the property of the fluid mass. In this case of a compressible fluid, the volume was different when it was coming in and out because that mass was compressed, creating different density.

Final example. In this case, again, I have another steady mass flow through a control volume. And again, in this example, I've got a fixed inlet and a fixed outlet that mass can come through. And in this case, I know my fluid, and it is water. So water is a liquid, basically an incompressible fluid. And again, since I know that my mass is steady, um, my flow is steady, I know that the mass coming in on this side, I'll call this my m dot in, um, has to be the same as my m dot out. And if I calculate my mass flux rate again by the fluid density, the velocity, and the flow area. Right, so I can set this up in a balance so that I've got the product of my fluid density, my fluid velocity coming in, and the cross-sectional area of that inlet, and it has to be equal to the product of my fluid density going out, my velocity out, and the cross-sectional area going out. Because it's a steady flow, mass in equals mass out. And so I can notice something else: the rho in and the rho out, these have to be the same, right? So if the fluid is incompressible, that means that the density can't change inside of the control volume the way that the density of air changed in the air compressor. Since the fluid is incompressible, this density has to stay the same, and so I can get rid of my density term, it's going to cancel out on either side of this equation. So then I look at the combination of velocity and the flow area, and I notice that if I look at the dimensions, my velocity again is going to be a length per unit time, my area, oops, my area is going to be a length squared, and so their product is going to be a cubic length per unit time. Right, a volume per time, which we've defined as the volumetric flow rate, Q. So in this example, the flow of mass through the control volume was steady, m dot in equals m dot out, mass in is equal to mass out, but also my volumetric flow rate in was equal to my volumetric flow rate out. In this example, the flow of mass through the control volume was steady, and the same mass that went in came out. And because the fluid was incompressible, that mass was contained in the same volume. So in this case of an incompressible steady flow, the volume was conserved along with the mass.

Thank you to the National Science Foundation for supporting this work.
Great job reaching the end of this 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 it motivates you to continue your study of fluid mechanics.