

Hello and welcome to Engineering Earth. In this video we're going to discuss the concept of relative velocity and how our choice of a reference frame in a problem can lead us to different velocity descriptions.

First let's take a look at the Reynolds transport theorem that we derived earlier and that we've so far applied to conservation laws governing fluid flow through control volumes. We've already applied the RTT to describe mass and energy fluxes and soon we're also going to apply the same theorem to analyze momentum, and that's why we have this variable B appearing in the Reynolds transport theorem. It's because Reynolds transport theorem can be flexibly applied to describe any extensive property of a flowing fluid system which could be mass, energy, or momentum. So, this little b could stand for any of those. And then on the right-hand side we've got that same thing B per unit mass. So, today's topic is going to deal with the velocity term in the RTT and you're going to notice that there's a little subscript r on the velocity term. What does it mean? So, this little r tells us that the velocity we're concerned with is the velocity of the fluid relative to the control volume. So, remember that the control volume can be fixed in place, it can be stationary, or it could be moving. And if the control volume is moving, then the velocity of matter that's crossing the control surface to go in or out of the control volume could potentially be moving at a speed that's different from the speed of the fluid relative to a fixed reference point, like the ground. The speed of the fluid relative to the control volume is the one we want to use in our analyses. And we just reminded ourselves of this by putting this little r on the velocity term. The relative velocity is described by a simple equation. So, on the left-hand side we have the thing that we're concerned with right, this is the velocity of the fluid relative to the control volume. And then on the right-hand side we see another velocity of the fluid. But this time this is the velocity of the fluid relative to some fixed reference point like the ground. And then our final term is the velocity of the control volume and the speed that it's moving relative to the ground. So, on the right-hand side, both of these terms are velocities relative to a fixed reference frame. So how fast is the fluid moving relative to the ground and how fast is the control volume moving relative to the ground? And then over here on the left-hand side the combination of how fast the fluids moving relative to the ground minus how fast the control volume's moving relative to ground is what's able to express the thing that we want to know, how fast is the fluid moving relative to the control volume. So, if we have a stationary control volume, then the velocity of the control volume relative to the ground this last term over here becomes zero and our velocity of the fluid relative to the ground or relative to the control volume are the same thing.

Let's consider the example of water that's being flushed from a fire hydrant. So, in this problem my control volume is not moving, right? My, my uh fire hydrant is stuck here in the ground and the water is coming out of the fire hydrant and has to pass through my control surface. You know right here here's where my water is exiting my control surface. And so if I want to express the velocity of water relative to the control volume. I can see that's going to be equal to the velocity of water um relative to the ground minus the velocity of the control volume. And so, the velocity of the control volume, I know, is zero because my fire hydrant isn't moving. So let's say that my velocity of the fluid is moving at a rate of 2 meters per second relative to the ground, then I know that my water relative to the control volume is the 2 meters per second that the water is moving relative to the ground, minus the speed of my control volume. And my relative velocity in this case is the same as the velocity relative to the ground, 2 meters per second.

So now in this, in this example we've got a moving control volume. We're going to take the same exact approach, the governing equation is exactly the same, the only difference now is that the velocity of our control volume is going to be something other than zero. So, in this example I have a toy remote control car and I'm playing with it with a hose. So, I'm moving the remote control car at a constant speed, and then I'm hitting the toy car with a jet from the hose. So, if I'm directing the car toward the right, like you can see in this uh schematic at a constant speed of 1 foot per second. And then I hit uh my car with a jet of water that is moving at a constant speed of 8 feet per second. What is going to be the relative velocity of the fluid relative to this moving control volume? Right so I just take my governing equation, and I can find that the velocity that water's moving relative to this moving control volume is going to be the velocity of my jet, the 8 feet per second, minus the velocity that my control volume is moving, the 1 feet per second. So, the relative velocity that I'd want to use in my analyses would be 7 feet per second. So, the particles of water are actually entering my control volume at a rate of 7 feet per second even though my jet is moving faster than that because I'm concerned with how fast the, the water particles are moving relative to the control volume not relative to the ground.

Let's do one more example with a moving control volume. In this example I have an airplane that's flying in the sky and I'm analyzing the exhaust that's coming out of the back of the plane. And so, my airplane is the moving control volume so my control surface is going to be around my airplane like this. And right back here I've got the exhaust that's passing through the control surface at some rate that I want to know. So, let's say that the gases are exhausting out of the control volume moving towards the right at a constant rate of 800

kilometers per hour. And you'll notice that that my exhaust is moving towards the right, which is my positive direction, so this is a positive 800 kilometers per hour. Meanwhile, my plane is moving towards the left at a constant rate of 500 kilometers per hour. And since it's moving in my negative x direction, that's going to be a 500 kilometers per hour. So now if I want to know the velocity of this exhaust relative to the control volume then I take my velocity of the exhaust, my positive 800 kilometers per hour, and I have to subtract the velocity of my control volume, my negative 500 kilometers per hour. And so, my relative velocity of the exhaust relative to the plane is 1300 kilometers per hour.

Thank you to the National Science Foundation for supporting this work.

Great job reaching the end of this video. Please reward yourself with a quick 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.