David Carroll (00:14):

Okay. So, I am David Carroll, I'm president of Champaign-Urbana Aerospace, or CU Aerospace. Today, I'm going to be talking about propellantless propulsion, in particular Solar and Drag Sail Technologies. First, let's start with some principles behind solar sails. As you probably are aware, the sun emits over a very broad range of wavelengths. And the solar pressure exerted by those photons that are emitted is the integral under the curve here in the outside of the atmosphere. And that solar pressure constant amounts to 1,366 watts per square meter.

With solar sails, the photons themselves are a free propellant. And what you have is a situation where incident photons can reflect off of a surface and impart momentum to the reflector. In this case, what happens is the photons exert two times the photon momentum. For a perfect reflector, this creates a change in momentum, which gives you a force imparted on the sails. So, photons come in from one side and push the sail the other direction. Now, each photon has just a tiny amount of momentum itself, but lots and lots of photons end up adding up to a significant force.

So now, let's talk a little bit about different solar sail technologies. The technology that we started working on about 20 years ago was called UltraSail for ultra large solar sail. It's based on an older concept called Heliogyro, which is a deployed sale spinning concept. Our version, Ultrasail, has the advantage of having tip satellites on the end that can provide stability and control. The large blades here, let me point out, these end up being on the order of five kilometers or a couple of miles, two, three miles.

And it enables large mass fractions of the scientific payload to travel to interplanetary missions. And in this case, our belief is that UltraSail is really the future for solar sails in the long term. So, this is a little video we put together on UltraSail. And this, as it says here, was done on a NASA program. And what you have is a deployed satellite. And there's a hub with these tip sets. And each of the tip sets has its own spool of sail material. The blue panels here are solar panels for power. And these tip satellites have their own little thrusters on them that pull the sail material outwards from the hub itself. As I mentioned before, these sail blades, when fully deployed, are on the order of, say, five kilometers.

Then, you can twist the blades in a fashion similar to a windmill. And that allows the whole spacecraft to spin up and provide centrifugal stabilization. So, we started work on a much, much smaller scale project. The full ultrasound concept is billions of dollars of project to actually build and fly. So, NASA requested we look at something smaller as a demonstrator. And we started the cube sale program. Now, cube sale is a... Let's call it a three U cube set that's broken in two. So, we've got one 1.5 U cube, and a second 1.5 U cube here. The panels are off here in this zero G demonstration. You can sort of see the two sail spools in there. Each spool is 120 meters of sail materials. So, that deploys to 240 meters overall, once deployed. This is myself holding cube sail. This was put onto a rocket lab electron launcher and launched in December of 2018, to an altitude of 500 kilometers. Right now, we are waiting for the satellite to decay in its orbit so that it is below the international space station before we deploy. And that is scheduled for around early 2022.

So, here is a little movie on cube sail to give you a better understanding of what it is doing. So, it is ejected from a deployer, once it's in space. Antennas deploy. It reorients itself so that one of the satellites is facing downwards and one of the satellites is facing out to space. And then, there's little cameras on the inside. And you can see one is the showing the deployment towards the earth and one out towards space. And you can see that the aspect ratio gets pretty long here because 240 meters is quite a bit of sail material.

The system deploys using gravity gradient stabilization. The solar photon pressure that I mentioned before actually billows the sail. And then, once the mission is complete, you can rotate the space crafts to maximize aerodynamic drag. And then, the satellite ultimately burns up in the atmosphere. So, the next step that we think is the right step is something that we have proposed called the I-Sail demonstrator, which is 3,800 square meters of sail material. These blades end up being about three kilometers long each, and you can see little tip satellites and the hub satellite. So, the other thing... I've already sort of mentioned, in a sense, that solar sails can be used as drag sails. The Earth's atmosphere itself extends into lower earth orbit sort of wispy at that altitude, but there is some aerodynamic drag. So, drag sail concepts use the deployed solar sail as sort of a drag shoot. And that allows it to more rapidly de-orbit at the end of its life.

And this happens... This works very well up to about 700 kilometers or so. And then, the atmosphere slowly decreases in density, and gets so low in it density that, above 700 kilometers, you really can't utilize the drag so well for de-orbiting. So, one of our concepts is called CubeSail-D, where the D is for drag or de-orbit. And this uses a mix of both solar sailing concepts and drag sail, where the solar sailing concepts you use to decelerate the orbit from a higher altitude down to about 700 kilometers. And then, from there, the drag effect takes over. Another technology that's being evolved is called electromagnetic tethered. de-orbiting. This is being pioneered by a company called Tethers Unlimited. They have a technology called terminator tape. And this can...

The electromagnetic effects can result in additional drag. And on the right here, you see a chart that... I'd mentioned 700 kilometers before as being sort of the limit for aerodynamic, but the electromagnetic effects can help up for another couple of hundred kilometers. But above 900 kilometers, then the time it takes to decay, it starts getting very large over 25 years. So still, above 900 kilometers, you need to have some other type of technology to help de-orbit these satellites. But I guess a final comment here is that the drag sail technologies, such as CubeSail-D, would sort of inherently take advantage of this electromagnetic drag effect. Then, the further out more advanced concept for sails is the electric or E sale.

Illustrated here is what's called the Heliopause Electrostatic Rapid Transit System, or HERTS concept. And in this concept, you are taking... You're utilizing solar wind protons that can create an electric dynamic pressure on deployed tether wires, so that what you see here is these sort of lightning bolts or discharges along the tether wires. And this technology looks to have some real advantages for deep interplanetary, or maybe even inter stellar travel. The disadvantage would be close into planets that have magnetospheres, such as the earth or Jupiter, that would block the solar wind and minimize the effect of this E sail. But still, for interplanetary travel, this looks quite interesting.

Sail type missions to date? There has been IKAROS, which was launched in 2010. That was a very successful mission, demonstrated solar sailing to Venus, and also attitude control. NanoSail-D was launched in 2010, which demonstrated drag de-orbiting. Similarly, LightSail-1, 2015. And let me note that IKAROS, NanoSail-D, and LightSail were all this sort of square sail configuration, as opposed to the long deployed ribbon that we have been looking at. CubeSail, which I talked about earlier, was launched in late 2018 with mission operations scheduled for 2022. LightSail-2 launched last year, and is scheduled to de-orbit in 2021. The Terminator Tape, Prox-1, launched in 2019 successfully. A new one just launched called Dragracer, where you have two fairly identical satellites, but one of them has this terminator tape. And so, these are... were launched at the same time.

And so, one will deploy this terminator tape. And the hope is that it will demonstrate much more rapid de-orbiting than the other one. And then, not the last mission that is... There's other missions planned, but NEA Scout is fabricated and assembled, and is estimated for launch next year. And that will do a mission to a near earth asteroid. So in summary, solar sails are technology that achieve this propellantless propulsion category, where you're using solar photons to push a sail, much like the wind pushes a boat sail. And sails can be used also to increase drag for faster de-orbiting. Electromagnetic effects can also help this de-orbiting. And then lastly, there's this advanced electric sale or E sale technology that shows promise for interplanetary travel. And so, if you have any questions, my email is at the bottom here. Thank you.