Sue Nelson
Hello, I'm Sue Nelson and thanks for joining me on Create the Future, a podcast brought to you by the Queen Elizabeth Prize for Engineering. Many engineering designs begin on paper. In Mark Schenks' case, he's taken that expression quite literally. He's a lecturer in aerospace engineering at the University of Bristol and one of his research interests covers origami, the Japanese art of paper folding. How did you get into origami?

Mark Schenk
My mother did origami when we were children, so I was always aware of origami as a plaything, as a pastime. I never pursued it very much, but it was more when I then got into my PhD phase when origami became an option for a research topic. I knew the concept and then it made sense to continue on with that.

Sue Nelson
I can't help noticing that there's a box here with some paper designs...

Mark Schenk
So these are kind of demonstration models I use during public lectures to demonstrate the various features of how you could use origami for engineering basically.

Sue Nelson
This one is lovely, it's bright red. It's not, you know, when I think of origami, I think of some little bird or, a little frog or something. Whereas, this is like a concertina that we can push it in, and then pull it out and it expands in a sort of zigzag fashion.

Mark Schenk
Yes, I think when engineering origami is much more geometric than the bird or the crane that you're probably used to. One of the main reasons is that you tend to repeat a pattern. So in engineering, it's easy to take one simple pattern and repeat it over and over again. In this particular pattern, you take one kind of fold, which you move in two directions to make a large sheet, and that makes it easier to design and analyse, basically.

Sue Nelson
Let's have a look at some of the other ones in here as well. Are these exactly the same shapes because they look them to me again. It looks like a zigzag.

Mark Schenk
They are, they are the same shape but then formed into a tube. The previous one was a flat sheet. So it's a flat sheet of paper that's folded up into a 3D shape. This one is a tube of origami basically. This is the most common pattern you will find; it's named after a Japanese physicist called Koryo Miura and this is the fold that most engineers tend to use for their applications.

Sue Nelson
And what applications would that have? That folding side of zigzags and, in fact, I've just noticed you've got a wonderful one here in metal. It's absolutely gorgeous.

Mark Schenk
Yes, it's gorgeous once you've made it. Making it took quite a lot of effort. So this is the same pattern made from stainless steel and, again, folded from a single sheet of stainless steel. It's very nice, but it does become less foldable. So because it's made from steel, you can't easily fold it. The paper ones are very easy to expand and contract whereas the metal ones tend to be more of a fixed shape.

Sue Nelson

And then there's this shape here in your box that is not like the others in that it looks more like a flower, a two-dimensional flower, which you've now just pulled out. So, it looks more like something that would go into the flexible tube that would go into your washing machine or something. Is it foil?

Mark Schenk

It is exactly the same, exact same pattern as before, but rather than being flat it's now in a circle. So this is made from a foil so this is this is three layers of a very thin material. This material is about twice the thickness of a human hair in total. But it's aluminium and then mylar, which is kind of like PET – like a shopping bag material – and then aluminium again. This is a prototype for inflatable deployable structure we launched in orbit a couple of years ago. It's an origami cylinder. So when it folds up, it's a really compact shape. You then inflate it once it gets into space, and then it deploys from something which is about six centimeters tall to something about a meter in length. It forms a very smooth cylinder. We launched this a couple of years ago on a small CubeSat satellite – a really small satellite the size of a whiskey box. It's 10 by 10 by about 30 centimeters, but it's about the size of a good, good bottle of whiskey. And we launched this kind of this inflatable boom on the satellite, so it was launched in orbit, then inflated and deployed to full length.

Sue Nelson

That's great to see that this tiny, small prototype then has an application on a spacecraft. When you see it like this, you can totally get that because weight is important, and volume is important on a spacecraft. So, you then have something that is very lightweight but, once folded up – which is where the origami comes in – takes up hardly any space at all.

Mark Schenk

Yes, that's one of the motivating reasons for exploring origami in engineering. Classically, you start with a flat piece of paper and you make it into 3D. But the other way around, if you need something which is 3D and you want to fold up small, origami is a technique for doing that. So this particular case, a project at University of Surrey when I was there, I was thinking of how to design one of these inflatable booms and origami was the last thing on my list because it was really hard. It's quite hard to make. That's the downside. But this turned out to be an application where we're given we want to achieve, and origami became the only real option for this particular application. So I tried my best to avoid using origami with this particular mission, but it ended up being the being an origami pattern that worked best.

Sue Nelson

And what other structures – I can think of one, for starters: a spacecraft – will benefit from this folding? The most obvious being solar arrays.

Mark Schenk

Yes. Well, again, like I hinted at before, making them in an origami pattern can be quite challenging. Solar arrays are designed to fold up because there's only so much space, you know, in rocket faring. When you get to orbit, you want to unfold them because you want a large surface area to get more power. And origami has been proposed for this and actually, the Miura pattern I pointed out before, has actually flown in orbit. In 1995. JAXA, the Japanese space agency launched this particular pattern.

Sue Nelson

How appropriate!

Mark Schenk

Yes, it was actually designed by Professor Miura, whose name is attached this pattern. He designed it. But it's always been a prototype. If you look the ISS, for example, the International Space Station, the solar arrays there are much simpler. They are literally constantia folds, just back and forth. But these are a bit more complicated to launch in orbit. But yeah, that's the obvious application for origami, solar arrays. But also solar sails, this is where you don't use sunlight for power, but for propulsion. So literally the photons hitting your spacecraft, push your spacecraft along. So, it needs to be very large and very light, because there's not much force coming from sunlight. Again, the Japanese space agency has explored using origami patterns for these kind of solar sails. It makes more sense as these are very large and very thin membranes that have to be unfolded once in orbit.

Sue Nelson

Where do you see this extending further, perhaps into the future with other parts of a spacecraft? I mean, you've mentioned booms, could be antenna as well. Booms are often used with the instruments hanging from them. Are there other applications that could benefit from this?

Mark Schenk

So, people have looked at antennas for small satellites, again, these things tend to be designed for very small satellites for larger satellites there's less and less of a push for compacting it as much. So, people have looked at origami patterns for small antennas, for cube sats, reflectors, so having a large surface area to receive a signal from the ground, solar arrays again. But again, these tend to be quite simple fold patterns. The ones you see in front of you are quite intricate. They tend to be a bit simpler once you once you launch them. But those are the main applications, antennas, reflectors, booms and sails.

Sue Nelson

It's lovely the way a childhood interest has sort of ended up as part of your professional life. So we know that you were interested in origami as a child and obviously it came in useful later. When did the interest in engineering start?

Mark Schenk

Actually, quite late in a way. I was one of those classic students who was very good at A-Level maths and physics. And if you're good at math and physics, one of the options is engineering. So for me, it wasn't a really conscious choice at the time whereas now looking back, I'm an engineer through and through. I couldn't pick better, but at the time I picked it because it was the best fit to my skills. It's only once I was really in the field and discovered what engineering actually is, that I became a real engineer. We get a lot of students coming into aerospace engineering who are really fascinated by space or aircraft - that's one route into engineering. But for me, I was always good at problem solving, maths and physics, and it got me into engineering. So, there's no deep inspiration there other than once you started engineering, you'll probably learn to love it.

Sue Nelson

And it was a good fit.

Mark Schenk

It was yeah, absolutely. I couldn't have picked better. But you don't know that until you look back and go "Yeah, this was exactly what I needed".

Sue Nelson

You sound British, but there's just a touch of an accent there because you're from the Netherlands.

Mark Schenk
Yes.

Sue Nelson
It's funny you like foldable, compact structures when you're from a flat, fairly compact country. I don't know whether there's any psychological interest there?

Mark Schenk
Not that I can think of I'm afraid, no.

Sue Nelson
So where did you study? What did you study?

Mark Schenk
So I did my degrees in Delft, which is one the three big engineering universities and Netherlands. So I did my degree in mechanical engineering there and then my Masters I picked biomedical engineering, still within mechanical engineering, but it's more biomedically focused. That was about 5-6 years at Delft. Then I moved to Cambridge for my PhD and then I moved from mechanical into more civil structural engineering, where these origami structures were part of that research group. They'd been looking at deployable structures in the past and the sort of a logical next step was to further explore origami and deployable structures. That was kind of the motivation at the time.

Sue Nelson
I was at Delt, actually the Technical University last year, looking at their research on robotic flying insects which were really interesting. And you mentioned this biomedical specialism, did the origami have any application with biomedicine there? Or was it something totally different that you were working on?

Mark Schenk
Completely different, but actually linking back to what you said about the flight robotics. So, one really interesting area about origami is being used to understand how nature works for flying insects, where you can imagine having a ladybird for example, they've got these hard scales under which they fold up their wings. So the scales kind of pop up the wings, fold up and fit underneath the scales. That folding pattern is it something that's currently being studied using origami techniques and it's not really designing but more understanding how the folded up. So it's a bit of a diversion.

Sue Nelson
It's an interesting one!

Mark Schenk
Linking back to your flying robotics, origami is actually being used in that area to understand how insects like Lady birds, like earwigs fold up their wings. But no, so there was no direct link for me personally between the biomedical side of things and origami. There are links nowadays, there's quite a lot of work happening in applications of origami, which have biomedical links. So for example people looked at using origami for stents. So these are little deployable structures that you place inside somebody's artery to expand it to get the blood flowing again. Some people in Oxford have explored that. People are using origami for small kind of robots that you can ingest and crawl through your digestive system. So there's quite a few applications being explored for origami in biomedical. But for me, it was, in that sense, a bit of a fluke that I ended up doing origami afterwards, there was no direct link for me at least.

Sue Nelson
Now, we're in your office at the University of Bristol in the engineering department in something called the Bristol composites Institute. So, what goes on at this institute here?

Mark Schenk
So this is a large group of researchers all working on composite materials. The classic example is carbon fibre composites. So, most people would associate that with racing cars, but also modern aircraft are largely being made from composite materials. So for example, the Airbus A350 is at least 50% weight, is composite materials. Basically you are making material by having these very, very small thin fibres, so these are a fraction of the thickness of a human hair but you put thousands upon thousands of them side by side and very thin layers, you can build a material by putting these layers at different angles on top of each other. And the reason we like them is because they are very light, or they're very stiff and strong for how light they are. So they're comparatively very stiff and strong. So for the aerospace industry, it's interesting for weight saving primarily, so a lot of the work happening in our group is around making lighter structures, how do you manufacture using composites, but quite a few people including myself also use composites for shape adaptive structures, so using composites to make a structure which can change shape very easily. And this is where the fibres come in, because you, lets say, if you have a sheet of aluminium, for example, the stiffness or how hard it is to stretch the material is the same in any direction basically, if you make a composite, you can make it more stiff in one direction, less stiff in other way, you can really choose how you can use the material. So we make the shape changing structures using these kind of composite materials.

Sue Nelson
And is why I noticed on your research pages, it says zero stiffness structures. So does that relate to something that is not so stiff in one direction, as you said, but is a bit more flexible in the other?

Mark Schenk
Yes, that's a very niche research area but yes, it is exactly that. It's making structures which have no stiffness in certain directions. These don't relate strictly to composites, but they are types of structure which are used, for example, in compliant mechanisms. The classic mechanism is one with hinges and links and springs and what people try to do is make mechanisms where you don't have hinges you don't have springs and all that. And what you want is you want to make it out of a single piece of material. So rather than something rotating like a hinge, you'd have something bending. The advantage is that there's no friction because there's no joints moving past each other, the downside is that there is stiffness. You want to move it, it has a stiffness that you can design into structures to then compensate for that stiffness. So, if you make something which has a positive stiffness, something which has a negative stiffness, you add them up, you get zero stiffness and it allows you to make something which can deform shape very easily in some direction. So, we don't use composites for that much yet, but it is the same idea - using materials to design stiffness where you want it to be.

Sue Nelson
And do they have applications other than the aerospace industry?

Mark Schenk
Composites or zero stiffness?

Sue Nelson
Well both (laughs).

Mark Schenk
Well the classic example of a zero-stiffness structure is pretty much on every UK desk, the classic angle poise lamp is zero-stiffness.

Sue Nelson
And there's one behind you.

Mark Schenk
There's one behind me, yes. I bought that one to show in my lectures basically, so the first years get the benefit of hearing me talk about a lamp for 15 minutes and they do wonder why I find it so exciting. But anyway, you can explain why it's so interesting, because the idea behind the angle poise lamp is that you can reposition it in any position you want. So, changing it from one position to another requires no force. So there's no stiffness. And that's done by having these springs, we look at these lamps that has the spring to the bottom. And by moving your lamp around the springs extend and contract. And as a result of that you feel you feel no stiffness. That's a very classic application, other applications are mechanism designed, where you have a compliant mechanism where you don't want that's stiffness, so you can remove it. Those are the main applications for zero stiffness. Composites are much wider. You'll find composites pretty much everywhere around you. Space being one of them as well.

Sue Nelson
And in terms of structures that have this lovely mix of origami and engineering. We've talked about them so far, particularly with use to a spacecraft. Where else could this be applied.

Mark Schenk
You can't go to a shop and buy many origami products just yet. It's not very common in industry yet here. We're exploring them for quite a range of applications, deployable structures is one. So for example, tents or deployable shelters, people have explored origami for that. But also, in more unexpected places like robotics, people like the idea of using origami for robotic actuation. Again, the same idea that you can fold something up and make it small and deploy it. You can also imagine a robot arm which is based around an origami structure. And it's going to fit in the field of soft robotics, where the picture most people have when they see industrial robots are these big, huge, chunky robots. If you picture a factory that makes cars they use these big chunky robots. They move around and pick up huge parts. They're really stiff, so if they hit a person, for example, that is quite dangerous. Whereas if you make robots which are much more flexible, if that robot then hits a person, the robot will just deform. So it's a kind of a field where soft robotics is being explored for human interaction. So robots can attract humans and origami has been explored within that for robotic arms for example. Yeah, that's an area where it's being explored.

Sue Nelson
It sounds like it's been incredibly useful to look at things slightly differently. I mean, I know engineers always described as problem solvers. And that's true. But whenever something new or different has come along, it's when somebody has looked at something and forgotten what the existing way of doing something is like, so take Dyson and his vacuum cleaners, the shape and style which we're all used to now, just wasn't in existence at that time, they all looked exactly the same and they were always designed in the same way. Is that because of using origami, you get to look at things, taking things that almost feel like two dimensional structures like, you know, a piece of material or a piece of metal or whether it's just cardboard or paper, and then folding it in a way to give yourself a totally different 3D design. It's something, I know that computers do it all the time with CAD, but it's a lovely way of viewing things, isn't it?

Mark Schenk
I'm not sure I can describe anything better than you just did. It does open things up, you have to think in a certain way. And also, origami requires quite a few fields to come together. So there's a lot of mathematics involved, quite pure mathematics, there's mechanism theory, structures, design. You need to be aware of quite a few things, to be able to combine quite a few fields, to be able to study origami because they aren't really like structures or mechanisms, they're somewhere in-between. So you need quite a breadth. So I think that links back a little bit, it does bring together quite a few different fields, which is always good for getting inspiration from different areas.

Sue Nelson
And what about your teaching. Obviously you've got one prop there with the lamp, do you get your origami out for your students.

Mark Schenk
Yeah, pretty much every year or every year I teach. I show origami as an example. Yes. So the first years will for example, when I talk about deployable structures, so I teach mechanics of the first year, so basically, Newton's laws - if I apply force what's the acceleration. And one of the examples at some point is a deployable structure. So we'll talk for quite a while during the lecture about the organic projects I've worked on, in the later years as well, that keep coming back as examples. I think by the third year, they've seen my inflatable origami boom, quite a few times by that point, but it gives a bit of a red thread as there's so many interesting things around that example that keeps coming back over the years. I'm currently teaching a fourth-year unit where I managed to squeeze in origami as an example. And it fit perfectly, but nobody else would have put it in except somebody who works in the field.

Sue Nelson
And so what are you researching yourself on when you're not teaching? What's the project that you're, you know, is really firing you out right now?

Mark Schenk
Well, there's always new origami work continuing. So I've got a PhD student working on that. So that's always in the background continuing. Other things we're working on the moment is linked to these shape changing structures we talked about before. So having a structure that's going to rapidly change shape, so the example we tend to use a lot is an air inlet that can change shape automatically for different air speeds it would open or close. And it's basically the same idea as when you take a ruler, you can press it, at some point it will suddenly snap sideways and that's called buckling. You can use that effect. Normally you see it is as a failure, if it buckles, it's probably failed. So we design buildings, for example, to avoid that. But we can also exploit it because you can imagine that you get a really rapid change in shape. So people use that kind of idea, for example, an air inlet that can open and close automatically as the air speed changes. What we've discovered is that we're pretty good at calculating them, prototyping them, but the testing is actually really quite hard. So we're developing new techniques at the moment because my main topic at the moment is developing techniques to properly test them. Because we know that they work, we can calculate it. We can show that if you want the industry to start using them, you have to really validate them properly. So we're look at looking at techniques to test these buckling structures. That's the main topic area at the moment. So moving away from origami, but shape changing structures is still there.

Sue Nelson

And how do you feel at the moment in terms of the new number of people wanting to study engineering. I know Bristol is an incredibly popular choice

Mark Schenk
We're heavily oversubscribed. It's good. So a lot of people wanted to study engineering. And in a way the main skill of engineer learns is problem solving. And whether you apply it to aerospace engineering, mechanical engineering or, or even banking or finance, it's that mindset, that really is your skill basically. So the fact that we have a lot of students, it's a good thing, but the capacity is now the problem. There's only so much capacity we have to teach students, so we are very oversubscribed because a lot of students want to do engineering, which is good.

Sue Nelson
What would you say to anybody listening who wants to study engineering? What would be your sell, your pitch to, you know, whether it's because of how it's affected your life or the enjoyment. What would you say is the, you know, the big thing. Why study engineering?

Mark Schenk
That's a tough one. I think it is problem solving. It's the ability to solve problems which have not been solved before. So there's plenty of problems that need to be solved, making aircraft lighter and more fuel efficient, to wind turbines, to new renewable energy sources. So all those problems which we need to tackle, we need engineers for, we need we need problem solvers. That's the main motivation you can actually change the future.

Sue Nelson
That's brilliant. And I just want to know, do you ever do origami for pleasure now, and actually do you make cranes or frogs or is it now totally part of work?

Mark Schenk
Unfortunately, it's become entirely work. I was never very good at origami folding. Hence the simple patterns for notes. But no, for me it's work. That said, if you look at some of the biggest names in origami engineering, they tend to be artists as well as mathematicians and engineers. They really like both sides from me, it's my job and I really enjoy it. But I don't come home and fold a crane.

Sue Nelson
Well Mark Schenk, thank you very much for unfolding, sorry for the pun there, your engineering career with me on the Create the Future podcast.