Sue Nelson
Hello, I'm Sue Nelson and welcome to the Create the Future podcast, brought to you by the Queen Elizabeth Prize for Engineering. Celebrating engineering visionaries and inspiring creative minds.
[Music]
The James Webb Space Telescope has been making headlines around the world since the release of its images began in July. That first deep-field image covered a tiny section of the universe, yet revealed thousands of galaxies using infrared astronomy. It was taken by combining images from two of the telescopes' instruments at different wavelengths, and one of them is MIRI, the mid-infrared instrument, and our guest today played a key role in building it. Paul Eccleston is Chief Engineer at RAL, the Rutherford Appleton Laboratory in Oxfordshire, him after a degree in aerospace engineering at the University of Southampton, he worked in industry building aeroplane electronics before joining RAL to start work on MIRI. So how did he feel on seeing those first stunning images from the James Webb Space Telescope?

Paul Eccleston
It was a real special moment, because although we knew that everything was working properly, and all the telemetry that we were getting seemed to indicate that things were all as they were meant to be. The proof of the pudding is in the eating. And so when those first images came back, there was a combination of relief, that everything had gone well, and things were working perfectly, and a sense of pride that actually, so many hours and years of hard work that had gone into that had actually been really worthwhile. Because they're such beautiful, stunning images, never mind the science and the new knowledge that's hidden inside them.

Sue Nelson
And the years that went into this from just from one instrument point of view for and from your point of view, when did you start work on MIRI, what year was it?

Paul Eccleston
I started work on MIRI back in 2003, when I first joined the Rutherford Appleton Laboratory, where I am now. But people had been working on the concept and the idea for a few years before that since the late 1990s. When realisation that such an instrument would actually really enhance what James Webb was going to be able to do.

Sue Nelson
And explain your role in it, because obviously, it involved engineers and scientists from all corners of the UK.

Paul Eccleston
Well, I started off my work as a thermal engineer and thermal analyst, analysing temperature flows and heat fluxes to make sure that the instrument was gonna get as cold as it needs to because it operates at a deep cryogenic temperature. But then as the project progressed, and I gained experience, I then took on the role of AIV manager. So I was then in charge of the integration and verification. So that's the testing of the instrument to make sure that it was all going to work perfectly when it got up into orbit, and it would survive the ride to get there. And it was properly calibrated to make sure that we understood when the data comes down, what it really means

Sue Nelson
Now this keeping MIRI cold, what sort of equipment did you need to ensure and test that the instrument would be at the right temperatures?

Paul Eccleston

MIRI operates at six Kelvin, so that's minus 267 degrees Celsius, and in an environment, the rest of the spacecraft around it is about 40 degrees warmer. So we have to be well insulated and well isolated. And we have our own dedicated cryocooler which works like a fridge, but using helium as the as the working fluid. But that's on flight. On ground, we have to be able to test it to make sure that it's going to operate perfectly and that we understand where the heat is flowing and how it moves around the instrument. And to do that we have to simulate it. So we use a really large thermal vacuum chamber. So this is a big cylindrical chamber that's about three metres in diameter and five metres long, that we can pump all of the air out of to get it down to a deep vacuum, so, simulating space, which also removes one of the methods of heat transfer so it means that the convection goes away. And then we had to build inside of that chamber, a smaller shroud and test rig that would give us a 40 Kelvin environment and hook that up to dedicated coolers that could pull all of the heat out of that bench and mounted with MIRI on that bench was a light source or telescope simulator that we could use to shine a very well calibrated, well known light into the instrument and scan it around and move it to different points on the detector to simulate different stars and galaxies that it would be looking at.

Sue Nelson
Now, I must admit, every sort of stage of what you were describing just then, each bit sounded a challenge. So I'm sort of dreading asking you which was the most challenging because it did all sound like a challenge?

Paul Eccleston
It was, the whole project was a series of incremental challenges. And the only way to get through something this big is to break it down into those component parts and tackle things, logically, one at a time. There were some really big challenging issues to deal with, particularly in the thermal design and understanding, getting the isolation that we needed. And in actually building the test rig and the simulators that could actually simulate the environment that it's going to see in space, because it's so different to the day-to-day environment that we have on the earth that it's quite a challenge to get down to these temperatures, these pressures on something of this size and scale.

Sue Nelson
And what's the leeway that you have in terms of your parameters, like your temperature, for whether MIRI works, or MIRI doesn't?

Paul Eccleston
We've got margins built into the system that enable us to have reasonable confidence or pretty good confidence that everything is going to work as planned. So we design for a particular temperature point, that in this case, we're designing about half of Kelvin below the limit for where the detectors start to get too noisy. But then there would be a gradual degradation as you go above that point. And but we're designing to get the very best science on a mission like this, where so much time and money is being invested into it, you want to be absolutely certain that that things are going to work properly. So you do build in that extra margin. On other types of missions that we also work on, in some cases you would compromise on that because you're doing something quickly and cheaply to experiment and find out whether something works more than engineering development or a proof-of-concept mission, and in those cases, you can compromise a bit. But on something like Webb, that's not possible, so you build in all of that safety margin into your temperatures, but also into everything else. Into the level that you shake it to for vibration testing for example. You build in an extra few G compared to what you think it's really going to see.

Sue Nelson
You started working on it almost 20 years ago, when did you get to the point where MIRI, from your point of view, was completed?

Paul Eccleston
We delivered and shipped the flight model, the one that's actually up there, out to NASA Goddard in 2012. So May 2012. We packed it up into a dedicated bespoke transport container, took it down to Heathrow and flew with it out on a British Airways flight out to the US drove it around to the NASA site. And then in the period, after that, it went through a series of integration steps to put it together with the other instruments, put those instruments onto the back of the telescope. And then to put all of those sort of separate stages went through yet more environmental testing, more vibration tests, more acoustic tests, more thermal vacuum tests, to make sure that it all works properly. And then the telescope component went out to California and met up with the rest of the spacecraft and the sunshield and was mated there before going down to Kurú. So that whole process took about nine years. The incremental steps and testing that took place at each at each stage.

Sue Nelson
How did you feel on seeing the instrument sort of in situ in a way because you know, you're so used, you spend all that time working on it in isolation and then suddenly realising and seeing it as part of a whole?

Paul Eccleston
It was a really interesting feeling, because the scale changed, at that point. We went from worrying about things inside MIRI. And most of the difficult challenging bits inside MIRI, a small, most of the stuff is small enough that you can fit in your hand, and almost everything is small enough that you can lift it up in terms of component parts. And MIRI as a whole is a slightly smaller than a washing machine, and weighs about 80 kilos, so it's about the same as an adult person. But then when we get to NASA Goddard, and we start integrating with the other instruments, it becomes something that's more the size of a minibus, and then that goes onto the back of the telescope, which is six and a half metres wide. So that's then the size of a full-size bus. And the scale change and the complexity change in how long everything takes increases accordingly, as well. So operations that we know that we could do and on instrument level that would take us a few hours, suddenly take whole days or multiple days. Because that additional size requires things to take much longer.

Sue Nelson
And what for you was the sort of biggest engineering lesson that you took away from that project. Because, you know, that's an amazing, amazingly successful process from thermal engineer going right the way through on an instrument that now and let's face it, it wasn't always that mission, considered it was going to be a success, or even get off the ground.

Paul Eccleston
Yeah, so the main lessons, I think, aren't really technical. It's about how teams work, and how the sum of lots and lots of parts can become so much greater. Because the real challenges for Webb are complexity, and scale, and the need to be relatively risk averse. And those things drove in a lot of the time and a lot of the cost into the programme. So I guess from that I've sort of seen, I've seen how that side or that type of project works, and have been able to pick the really valuable bits about making sure that teams are built with redundancy and resilience in them. And that communication is the absolute key. Making sure that people are regularly talking to one another. And not just talking to one another, but really understanding what each other are saying, both on technical level, but also on a personal level. Because those personal relationships that you build in a project and in project teams, are the things that you fall back on. When did things get difficult, because every project and programme will have moments where things don't go to plan. And how you deal with those is really the thing that sets apart success and failure. Because to be successful, you deal with the setbacks, you overcome them. And you do so quickly and sensibly.

Sue Nelson
You mentioned difficulties, it must have been difficult when, you know that you've delivered an instrument on time. In fact, you were early, weren't you?

Paul Eccleston
We were certainly earlier than the other instruments.

Sue Nelson
And then you have this period where yes, you're working on the integration, everything but you've got all the politics that were going around at the time. How do you cope with something that's out of your control? You know, you open a newspaper and you see all the, you know, is this worth it? Is it going ahead? Will it be cancelled? Will it work, you know, all the other technical difficulties with the main spacecraft as well, which means your instrument potentially couldn't have even got off the ground?

Paul Eccleston
Yes, it's a bit of a challenge in this case. I always had a lot of faith that it would, I guess, partly recognising that the that the sunk cost fallacy is at play. And there was a very strong psychological incentive to continue with the programme even though things were running late running behind and massively over budget in the US. But I think the main thing was that being close enough to the programme meant that we always understood what those real challenges were, and understood that in themselves they weren't insurmountable, and the teams that were investigating these problems were doing so sensibly and logically. And some of them were what you'd call sort of silly little faults or silly little problems that with hindsight, you go, “Oh, no, we should have thought of that”. But, of course, a lot of very clever people have been involved in this design and had been involved in looking at it through the years. And hadn’t spotted these things. And so that was exactly why you go and do testing. And so what it really showed was the value of doing that testing and validation so that these things happened on ground when they could be fixed rather than in flight.

Sue Nelson
And that sounds as well, this lesson of teamwork and communication, that obviously you all communicated well with each other in terms of what their delays were, and why?

Paul Eccleston
Yes and that's something that I've then taken on in in other programmes, since were being entirely open with the team all the way through, right the way from the top level, the political customers, as it were, through the science community, who are going to be the ultimate users, throughout the engineering teams and all your supply chain, is by far the best thing to do. If you try and hide problems, if you try and fix things before you tell other people that there's been a problem, then ultimately, one of those things will catch you out.

Sue Nelson
And it feels odd even talking about the difficulties and challenges of the James Webb mission and producing an instrument when now we know it's been an astounding success. Beyond all imaginings, really just even the test images were stunning. And the images we've now got are just, you know, mind blowing. Do you take an interest in the astronomy part of the mission as well, just as a matter of interest?

Paul Eccleston
Yes, absolutely. That's one of the main motivators for me is, through my time on the project, coming into contact with so many folks who were professional astronomers and had a real passion for it. I've picked up, not a deep understanding, but at least a reasonable idea of what Webb is trying to discover and why that's exciting

and important. And so actually now seeing those things coming back and still talking to the team about what is being seen and what that shows us is really interesting, because it's not just showing that the images are beautiful, but inside those beautiful images, there's so much scientific data that's hidden inside them when people know what they're looking at and know how to interpret it.

Sue Nelson
And since then, what have you been working on?

Paul Eccleston
Since we delivered Webb back in 2012, I then started working on a mission called Solar Orbiter, and was an instrument manager there for the SPICE instrument, which is an extreme ultraviolet spectrometer.

Sue Nelson
And this is a mission that's looking at the Sun in in unprecedented detail?

Paul Eccleston
Yes, that's right. So that launched in February 2020, and is now going around the Sun and taking images and in situ data from really up close, it's inside the orbit of Mercury at closest approach, and orbits around out to the orbits of Venus. And every once in every three orbits, it flies past Venus and gets a bit of a gravitational kick. And we'll eventually end up going around the sun sideways out of the ecliptic plane so that it will be able to see the poles of the sun and take images of those and understand what happens at the top and the bottom of the Sun which most of the time we can't see because we never see those from the earth and we never see them from any of our other missions.

Sue Nelson
And was it after solar orbiter then that you started work on Aerial.

Paul Eccleston
Actually in parallel with Solar Orbiter. I was also working on a mission study for a mission called Eco. This was a concept to do the study of atmospheres of planets around other stars which call exoplanets. And that went through a four-year design, study and competitive process against five other missions for launch lots called M-3 three of the third medium class mission in the ESA Cosmic Vision Programme. That was unfortunately then not successful. We didn't win that back in 2014. But that then evolved and we reformed the team and refocused the site have different goals of the mission and refocus the way that we would build the mission, and proposed again, under a new name called Aerial for the M4 slot, which will launch a couple of years later. And that, thankfully, was successful. And so since 2016, I've been running the Aerial mission consortium, which is putting together the payload and the science ground segment for that mission.

Sue Nelson
And you must be taking a huge number of lessons from MIRI, working on that, with this mission. Now, I mean, you've outlined some of them already, in terms of your teamwork?

Paul Eccleston
Yeah, so we're taking both technical lessons, and managerial structural lessons for how to run projects successfully across. And indeed, a lot of the same people and organisations are involved because again, it's an infrared payload, operating at cryogenic temperatures. So a lot of the technical challenges are quite similar. And so we're building for example, MIRI was made out of a single type of aluminium alloy, including all of the reflective components, all of the mechanisms, all of the structures were all made out of this particular

aluminium alloy, so that when it calls from room temperature, where you've aligned it and made sure that the mirrors all properly work, down to cold temperature, everything shrinks together, and so it stays well aligned. We're using exactly the same design philosophy for Aerial but at this case, we're scaling that up to include the telescope, as well as the instruments that we're building, all out of this aluminium alloy.

Sue Nelson
And as you'll be aware, the most recent Queen Elizabeth Prize for Engineering was awarded to the engineer who was involved in producing really high-performance permanent magnets. Are they used at all within any of your missions?

Paul Eccleston
We certainly do use permanent magnets, we use them within mechanisms. So for Aerial we have a cryogenic cooler that operates as a fridge. But that requires a pump that sits in the spacecraft and pressurises the Neon is a working fluid up to 20 bar. And that contains both permanent magnets, and then electric coils to pump and generate the pressure in the gas. We also use magnets for position sensing of mechanisms where you'll have a magnetic field sensor, and a very small permanent magnet on a on a wheel or something and you're trying to gauge the distance away that can be very accurately calibrated using magnetic sensors.

Sue Nelson
And when you were younger, did you always know that you were going to be an engineer?

Paul Eccleston
Yes, I guess I probably did from a relatively young age other than the, the boyhood fantasy of being an astronaut, which I eventually grew out of. I was sort of surrounded by it to a large extent because my father's an engineer, worked at Rolls Royce Aero Engines for his career. And so I was often around air shows and airports and went into work with him. And so, that sort of aeronautical engineering and things runs in the family. My uncle was also in the industry, but I also had a fascination with space and astronomy stuff. So by the time I was thinking about careers and going to university and things I was pretty clear in my mind that I wanted to do engineering, but I would quite like to do it with a space flavour, in some way.

Sue Nelson
And now I know because I've, I have heard you play your trombone for a short film made about you about your work on the James Webb Space Telescope, that you're very musical and you play in a number of forms, don't you, in various bands?

Paul Eccleston
Yes. So I play in both Symphony Orchestra and in a jazz band, a big band, yes, played the trombone for many years since I was a kid. But find, even now it's a good way to do something completely different. And I think it is important to have some outside non-technical things to do because it broadens sort of how you think. And it allows your brain to turn off into a different way. But also the people as well. A lot of my close friends through university were met through the music side of things, either with music students or other students with an interest in music as well.

Sue Nelson
And there must be that, you know, similarity as well, is that effectively whether you're in an orchestra, or with engineers working on an instrument or scientific instrument, it's about teamwork.

Paul Eccleston

Yes, definitely in the dynamic that you have with teams, be it an orchestra where you have a conductor and a leader, but you also have the direct interactions between different players, who may be playing in harmony or in parallel for a short section, and you're working closely with them for a period. And then you drift apart, and one of you will be playing a different part or whatever, that has some quite close analogies to how project teams form and then evolve, and they have a director or someone equivalent to a conductor. But that person's job isn't to do the project. That person's job isn't to play the music, that person's job is to facilitate and make sure everyone else is doing their job, but the right time in the right place. And so that, yeah, there are definite parallels between project management and projects in an engineering sense, and how music groups, or indeed sports teams, how they operate and run. And so having those sort of outside parallel interests does develop skills that are of relevance in an engineering workplace.

Sue Nelson
And if you could give advice or encouragement to anyone listening who's considering engineering, as a career, what would it be?

Paul Eccleston
It would be to absolutely go for it and go for engineering, because there's so much diversity of things that you can do. A lot of the folks that I was friends with at university, doing engineering, they're now doing a very wide variety of things from folks who are working in the automotive industry and Formula One, through people in aviation, through folks who are building bridges, or working in telecommunications, or working in space, and astronomy research. All of those things have basically come from the same background and the same education, because engineering teaches you how to think how to analyse and gives you the skill sets, but then how you apply that is completely up to you. And it is a career where you're not working in isolation. Some people who that suits, there are roles where that is absolutely valuable people who are really good analysts to want to sit down and solve the most tricky problems on their own and concentrate for days and weeks on end to solve something that's absolutely valuable. That's really needed other people who are sociable and want to communicate and facilitate things between different people, that's perfect as well. And teams need to be made up of a mix of things. So engineering really is a career that anyone can find their place in and find their way and find something that's really fulfilling because they can be doing something that they think is really worthwhile and valuable to themselves or to society.

Sue Nelson
If that's not an advert for getting people into engineering. I don't know what is. That made me want to go back in time. Paul Eccleston, thank you very much for joining me on the Create the Future podcast.

Paul Eccleston
Thanks Sue.

Sue Nelson
Find out more about the Queen Elizabeth Prize for Engineering by following @qeprize on Twitter and Instagram or visit qeprize.org. Thanks for listening and join me again next time.