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. Can you guess what this sound is? Its simulated Martian sand bouncing off the wheels of a Mars Rover. I didn't say it was going to be easy. I'll be walking on Mars with Airbus engineer Abbie Hutty a little later on, but since it's the 50th anniversary year of the first human footsteps on the lunar surface, this episode is going to start with the Moon and a personal view of some of the engineering highlights behind one of the world's most iconic moments. This is how Lord Browne, engineer and chairman of the Queen Elizabeth Prize for Engineering Foundation views the success of the Apollo project: "It's an outrageous idea to take a human and put them on in another world - that's the main point of it, it was a challenge which had not been met, with a finite time scale to get there, with the resources needed and attracted the best people from all walks of life because they said we can do something which is different, we need to do more of that". My first guest is an engineer who worked on the Apollo program and has enjoyed a career since then that has spanned the Space Shuttle, writing books and continues with his current position as editor of Spaceflight magazine, David Baker welcome to 'Create the Future'.

David Baker
Thank you very much indeed.

Sue Nelson
What were you doing when Neil Armstrong first set foot on the Moon?

David Baker
Well I was very closely involved in looking at the data that was coming in, in building 31 outside Mission Control - the familiar location for TV audiences watching this dramatic event. There was a whole range of us in a series of different departments surrounding Mission Control which were looking at the data as it was coming in. My particular job was to see if any funnies were coming in.

Sue Nelson
Funnies?

David Baker
Yes funnies of data, things that were not going as well as they should. We had this template that we'd written that could propagate for later missions, but of course with the Apollo 11 mission this was the first time that we were taking the lunar module, right down to the surface of the Moon, so we had to monitor to see if there were any conditions which would dramatically alter the flight profiles for landings in later missions.

Sue Nelson
So you're in Houston, you're looking out for funnies, how did you get from living in Britain to suddenly being there when history was made?

David Baker
Well obviously the bottom of the barrel was being scraped horrendously. I was fortunate in receiving a scholarship from the school that I attended in Hertfordshire which was connected to a number of American universities and was a NATO program at the time - the inspiration of Senator Clinton Anderson who was the senior senator of New Mexico and was in fact presiding over a state which had a lot of research on nuclear propulsion for upper stages of rockets. Because this was an intense period of the Cold War, opportunities existed among all NATO countries for schools and universities to put up potential candidates to go and work on these various programs and for me it was the ultimate go-to job.

Sue Nelson
What aspect of it were you most interested in when you saw that launch - did you witness the launch from the inside of the control room?

David Baker
No, I saw it like several million other people on television, but it was very interesting that we were, what I like to say we were cerebrally immersed in it with the data that was flowing back. In that pre -digital age and a time of pretty scratchy television it was actually the natural human emotion to want to look at the screen, but the real information was streaming down through all the data channels. Really my work began at the start of the countdown because we were looking to see if there was something that we would need to alter for later missions.

Sue Nelson
So what data were you specifically interested in?

David Baker
My particular responsibility was looking at the performance of the command service modules and the lunar module. We were concerned with looking for any delays in prosecuting various actions such as lunar module separation. Lives were at risk. I guess it's counter intuitive to reflect that the attitude we have was not that this was the culmination and after it would be job done, Apollo 11 was essentially the last of the development flights we thought, because this was the final piece of the jigsaw going right down to the surface and conducting operations on the Moon and coming back up. We needed to know that all of those steps and procedures were fine for building upon to keep the crew longer on later missions.

Sue Nelson
How did it feel at the time for you because must have been young?

David Baker
Well I went in my late teens and by my early twenties I was quite involved in the Gemini program. I felt that the opportunities in the United States were far greater than they were in the UK. We were just emerging from a period of real intense austerity and rationing, there were limitations on government work in aerospace projects, on the inertia from developments in the Second World War. By the early 1950s Britain was actually ahead of the United States in a number of aircraft performance capabilities and that inspired me as a boy growing up, and then it all began to grind to a halt when I reached my later teens. I was actually supposed to become an airline pilot but I had a problem with my ears, which later cleared up. Nevertheless, I felt that in the US everything was on a constant level, there weren't the ivory towers that existed in Britain in the 1950s. I loved that. I loved the fact that you could rub shoulders with test pilots and astronauts. You were all treated as equal members of a team. I think one of the greatest motivational lessons I learned was not to achieve self-pride or self-fulfilment, but to not let your team members down. There was that pseudo military approach toward a sense of responsibility - we were all doing it for a cause we all believed in. We were nascent rocketeers in the making and it was just so absolutely thrilling!

Sue Nelson
I can imagine! For you as an engineer looking back on Apollo, what do you think was the greatest challenge? Bearing in mind that there were so many of them.

David Baker

There have been many people who have spoken about the enormous technical and direct engineering challenges of inventing things that were needed for the job, the prosecution of which was still a big unknown when Kennedy laid down the gauntlet. In looking back I think one of the most important enabling influences was the way the whole management structure came together after 1963. I pitched right in at the beginning on the cusp of a massive transformation in NASA, which had originally been a metamorphosis from the National Advisory Committee for Aeronautics. Here was an organization that suddenly had to manage operational activities as well as build and contract out hardware. They'd never done that before. So for two and a half years after the Kennedy challenge it was devolving into an unholy mess. We would never have been on the Moon had there not been a massive transformation in bringing in the engineering examples of Bernard Schriever, who pioneered in the Second World War systems engineering as a concept. Wernher von Braun was the architect of the V-2 and Saturn launch vehicles, but he still brought the waterfall chart method of looking at project management and it couldn't encompass the vast array of 20,000 companies and 350,000 people working for a common goal. So a new concept was needed and it was essentially from the Manhattan Project through to the big development projects for ICBMs and big missiles in the 1950s, that Bernard Shriver applied World War two systems engineering methods to the missile programs. Jim Webb, the NASA administrator, then realised that he needed that in NASA. Suddenly there was a transformation.

Sue Nelson
It's interesting actually because that's what engineering is also about, it's not just providing the solutions, it's putting the framework in place so that you get the best of your component parts. It's a lot of project management effectively too.

David Baker
Yes and I think two messages went out when George E. Miller came in as head of manned-spaceflight operations in 1963 and really shook the whole establishment right up and tipped it on his head and rewrote the rule book. He brought what are now known as the 'GEM' boxes - which were the beginning of a series of adaptations of a US Navy program called 'PERT' (Program Evaluation and Review Technique). Essentially it created an environment in which we could all embrace the war footing, not in combative or necessarily military terms, but most of the people that I was rubbing shoulders with, and I have to admit that I subscribe to, were very committed to championing the ideological cause of what we defined as democracy and freedom against what we perceived to be a totalitarian autocracy that was essentially threatening the world order. We did not want the structures of an extreme Stalin-esque societal structure being imposed upon free-thinking people and that was what drove us, it's one of the most important aspects of Apollo.

Sue Nelson
How did engineers pull it off though when it's often been cited that they were using technology that had less computing power than a modern smartphone? Was it purely ingenuity based on existing technology or was there any sort of leap forward in a specific aspect of the technology that was required?

David Baker
Innovation is the child of challenge and the challenge we faced required innovation, discovery and invention in order to make it happen. It is often said that the computing power of the Apollo guidance computer in the mothership and in the lunar module would be incapable today of powering a digital wristwatch for instance. But in fact, the important thing to remember is that they were not controlling all of the mission operations and computational activities. That was buried in the serried ranks of freezer size computers down in the Real-Time Computer Complex 'RTCC' on the ground. Indeed, one of the things that was decided very early on by Charles Stark Draper who had the responsibility for all the guidance and navigation systems in the program, was that you're not going to be able to delegate total command authority on navigation guidance and control of the

spacecraft to the crew - you're going to have to base it on the ground and find a means of having all that information transmitted to the crew in very small batches to then input into various computer programs for the next set of activities. So the mission wasn't run from the spacecraft. Even in the landing we had three separate computer programs – so you would switch from one, to the second, to the third.

Sue Nelson
How did you do your calculations?

David Baker
There was an awful lot of mental work going on. In those days slide rules were essential. I was at Annapolis a few years ago and apparently the US Navy still requires its pilots to learn how to operate slide rules. There was an astronaut who only made it back to his carrier when all the onboard displays in a very modern combat fighter just a few years ago using a slide ruler. Slide rules were essential.

Sue Nelson
I have no idea how to use a slide rule, I suspect many people listening have never seen a slide rule so that's something to Google! How did you end up working on the Space Shuttle, what was your job?

David Baker
Well after the initial Apollo landings, once the dream had evaporated that we weren't going to be installing a permanent human presence on the Moon, the next project the focus for NASA was to try and reduce the cost of spaceflight. The Shuttle had already been determined to be the next program for NASA even before Apollo 11 landed on the lunar surface. I was very much of the view that no matter what we dreamed up and what we commissioned in terms of studies, nothing was going to happen unless we got it past the legislators and the bean counters in Washington who essentially controlled the destiny of not only NASA but many space operations in the United States. I chose an opportunity to go up to Washington in order to support NASA's bid for budgets in various congressional hearings and so became very involved in the development of the Shuttle and had to step aside from NASA for a while because I was employed by the Department of Transportation to do an analysis of the econometrics of the Shuttle. So I became quite familiar with all of the economic studies. From there I went around the world representing NASA to recruit organizations, governments, and companies to invest in payloads that could be flown on the Shuttle. So my job on the Shuttle program was to examine the capabilities that that vehicle could fulfil - much as on Apollo.

Sue Nelson
When it first started launching it was considered a huge success, for the first time we had something that was reusable, unlike Saturn V. But after Challenger and Columbia questions were made about its design. I've previously interviewed the first woman to command the Space Shuttle, Eileen Collins, who said it was a bad design, do you believe that?

David Baker
Yes I think it was a very bad design and I think that became apparent long before it began flying. It was designed down to a congressional limit on the amount of money we could spend each year and in total on the Shuttle program. It came in at the end closer to the budget estimate, it was still over budget when it was completed in its development phase, but it was flawed. We promised too much to too many. In order to get the Air Force onboard the huge payload capability was to satisfy a military requirement for spy satellites. It also had a huge cross range because the Air Force wanted to be able to go up and come down within one orbit and deploy a satellite before the payload could be tracked by Russian radar stations - that required a huge wing area which drove up the amount of pressure on the thermal insulation that then put us toward vulnerable tiles

that brought down both Challenger and Columbia. Now retrospectively applying the rationales for risk analysis and failure propagation looking at the system now, the first flight had only a 50/50 chance of getting the crew back alive yet at the time it was believed to have a 99.99%.

Sue Nelson
One of my regrets is that I never saw a Shuttle launch, I've seen other launches but not the Space Shuttle. Did you ever get to see one yourself?

David Baker
Oh yes I used to take people down from the business community in London and Wall Street who were backing commercial payloads - we'd brief them at Cocoa Beach in the Crossways Motel the night before the flight because a lot of these people didn't know which end was up bless them and they were going to be investing millions in the payload. We got VIP tickets for them so I've seen quite a lot of Shuttle launches. They were very different to the Saturn V.

Sue Nelson
Today we're talking about going back to the Moon. NASA's made its pledge to go back to the Moon by 2024 including the first woman and there are also plans for a Moon base. Do you think it's as big an engineering leap now considering the technology?

David Baker
It's certainly not a leap of any kind, it's merely an application of existing capabilities - none of which really came out of the Apollo program because it was a closed loop solution to an open-ended challenge. What that means is that the past solutions that solved the problems in getting to the Moon then were of their time, but the consistency of technology development to date through the International Space Station and the burgeoning commercial environment - an application of these new capabilities is the way that we'll go back to the Moon.

Sue Nelson
Well NASA has always seen the return to the Moon as a stepping stone to Mars, so it seemed an appropriate time for me to go and meet Abbie Hutty, an engineer at Airbus Defence and Space in Stevenage at their very own Mars yard, where Abbie has been instrumental as an engineer building Europe's first rover that is going to Mars on the ExoMars mission next year.

Abbie Hutty
This is a Mars analogous terrain - it's a warehouse full of sand and rocks, we've got the right colour of lighting for a Martian day and there's a backdrop which is actually a panorama from Mars taken by Curiosity. It gives you a really good idea of what the actual terrain on Mars looks like. We've picked the sands to be the right kind of colour.

Sue Nelson
It's a sort of terracotta brown!

Abbie Hutty
Yes, it's all about making it look like Mars so that we can develop our autonomy systems. We have to have something that looks like Mars so that the cameras get realistic kind of terrains to then be able to do their algorithms and calculate our routes.

Sue Nelson

Which is why these rocks actually do look very similar in shape and size to the ones in the in the panorama?

Abbie Hutty
Absolutely, we know roughly what the size of obstacles and rocks are on Mars so we've picked them to be among the most challenging that we're likely to experience as we're driving around. We need to know that there will be some that are going to be too big for our rover to drive over - it has to be able to recognize that and drive around them accordingly. We need some that are navigable and some that are slightly outside of its capabilities so we can make sure that it makes the right decisions as it's driving through the terrain.

Sue Nelson
Now I know that you have several prototypes of the ExoMars Rover, this one is a predominantly silver one, a bare one. If it was a car we're just looking at the chassis effectively?

Abbie Hutty
So this one's Brian, it's our current most realistic autonomous navigation prototype and that means that we've got the right cameras onboard, it's got the right processors to do the algorithms and calculate the path and it's got all of the right locomotion systems and actuators so that we can actually perform that drive. Everything else isn't representative of the rover. One of the big things that we have differently here in our Mars yard is that we have much more gravity. Mars is smaller than Earth, it only has about 0.38 of the gravity of Earth - so to make our rover sink and slide down slopes in a representative way the rover that only weighs 0.38 of the mass of the flight rover.

Sue Nelson
Well shall we walk up to it? Both of us are wearing sandals - I'm sinking into the sand, it is just like being on the beach.

Abbie Hutty
It is exactly like being on the beach yep! So this is Brian - up close you can see we've got six flexible wheels and they're fully metallic because we don't want to contaminate Mars with earth life. Rubber tires come from trees so we don't want that but we still need that kind of flexibility in our wheels to get traction so we've come up with these spring wheels that actually provide all of that with a metal wheel. Each of the six wheels is joined to another – in pairs they're on a rocker system which actually keeps all of the wheels in contact with the ground no matter what terrain you're driving over. You can see that we've got this tall mast on the top which holds the cameras so we can see where we're going to drive. You need a little bit more height to be able to see over dunes, craters or rocks.

Sue Nelson
Let's get it started then. I should explain, that little tinny sound are the grains of sand hitting the inside of the wheels as it flies off.

Abbie Hutty
Yeah because it's an electric vehicle the motors themselves are really quite quiet so we can't hear any kind of engine running but actually yes as you drive across the sand you get these little pings as the sand grains flick out of the wheels because they do compress and they squeeze those sand grains. You get this interesting kind of crackling noise.

Sue Nelson

How challenging of an engineering project has this been for you? And I know you've gone through several roles of an engineer through the whole process of this rover.

Abbie Hutty
The thing that I've really loved about working on the rover is that nothing is straightforward, nothing is normal, there is no normal - it's a Mars rover. This is the first time that Europe has ever built a Mars rover. You have to really start from a blank sheet of paper and just see what will work. There's been a lot of trial and error, there's been a lot of things that we've tested and then found that they didn't work as we'd hoped. We've had to take alternative paths so there's been a lot of lateral thinking, brainstorming, going back to the drawing board and learning about Mars. We've also had to learn about whether the dust storms would erode the surface of our structure, the temperature fluctuations on Mars and all of these really interesting things just to make sure that the solution we come up with will work for this other planet.

Sue Nelson
That's sort of what an engineer does though isn't it - nothing is ever as planned normally. You have to work things out?

Abbie Hutty
Yeah, a lot of the time engineering is about trial and error. It's about incrementally improving things, trying one solution and then modifying and evolving that solution until you come up with something that works for all situations as you designed it.

Sue Nelson
Was there any particular aspect of this that you are most proud of or that you thought as an engineer “yeah that was that was good, I'm really proud of that”?

Abbie Hutty
I was in the structures engineering team so - it's going to be the first carbon fibre structure of a Mars rover, which to be able to say that I've helped design the first carbon fibre vehicle on Mars is pretty cool. The actual chassis is a bit like a Formula One racing car, with a similar carbon fibre monocoque. Also some of the bracketry that we've put into the rover, I mean it doesn't sound very exciting if you're not a mechanical engineer but having to build something that will have flexibility as you go through the day to night temperature ranges, carry high loads through launch and landing and then have enough stiffness to be able to withstand all of the forces when driving over rocks. We've come up with some very exotic titanium machinings which just look beautiful. They're works of art. Not because we've made them beautiful out of any aesthetic reason, but because that's the way the laws of physics require us to do it. I really love that combination of beauty and functionality you get with something that has had to be pushed to the extremes like this.

Sue Nelson
Could you see yourself and Airbus designing a lunar rover at some stage in the future, particularly with everybody wanting to return to the Moon?

Abbie Hutty
Absolutely, I think there's a lot technology on this rover that would be transferable to that kind of a project. You have many of the same challenges on the Moon, you've still got issues with dust and whether that gets into your motors, how sharp the dust can be and whether that damages parts of your structure, you've got very cold temperatures because there's effectively no atmosphere on the Moon where...

Sue Nelson
Ooh it's gone over a bit of a bump there on the rocks!

Abbie Hutty
And all of the same autonomous navigation systems could be applied equally well on the Moon. I'd love to work on the lunar rover, I think that would be a great next challenge.

Sue Nelson
So what are your final stages then for this rover before it goes to Mars?

Abbie Hutty
So we're building the actual flight rover at the moment in our clean rooms here in Stevenage. We're coming to the end of the build now, very nearly everything is together. Once everything is finally integrated together onto the rover it goes out to France and we do what we call environmental testing - that's things like making sure it will survive the acoustic pressures during launch and the extreme temperatures on Mars. Then we do some communications testing to make sure the rover is working as expected. That's really it for us, we deliver it on and it gets integrated into the descent module, which gets integrated into the cruise module, which gets integrated into the rocket. All of those integrations take a little bit of time. It's due to launch in August of 2020, so that's where we are heading towards at the moment.

Sue Nelson
Abbie Hutty there. So David, what's different do you think between getting us to the Moon and getting to Mars - apart from the distance?

David Baker
Survival. We have not yet been able to demonstrate the ability to keep people alive outside the Earth's magnetosphere for any period longer than about eight or nine days. I think as well as the engineering challenges, the biophysiological problems that we know we will face have to be evaluated first at permanent bases on the lunar surface where for most of the time they will be living in the full exposure of the solar wind and of cosmic radiation and cosmic rays, which of course are deflected by the magnetosphere - that's a great unsolved area. While there's good PR we're really not yet tackling that issue. The challenges of going from here to Mars are less than those we faced than going to the Moon with Apollo. I think the biophysiological challenges are going to be immense and we'd better be prepared for those.

Sue Nelson
You're right, as many people pointed out with Andy Weir's magnificent book 'The Martian' which was later turned into a film, if that was done totally without creative license the Martian would be dead from radiation.

David Baker
Yes indeed.

Sue Nelson
Now we have some questions on Twitter here we go. Jeffrey Matthews wants to know "Whatever happened to the documentation for the Saturn V IMU? The software is lost".

David Baker
Well I'm not sure that it is lost. There were four computers that were provided for the Apollo program and it was the Saturn V computer which was arguably the most important. It was after all the one computer system which

saved Apollo 12 when all of the systems on the command and service module went out after it was struck by lightning. I'm not aware that the software for that is lost. I certainly have all the computer books and the code books for the Apollo guidance computer. I didn't think it was lost.

Sue Nelson
Maybe we'll find out - We also have a question from Libby Jackson who works at the UK Space Agency “What was the best or the most satisfying problem you personally had to solve?”.

David Baker
I think the fact that tasked with stretching a vehicle that was designed to spend 30 hours on the Moon, making it capable of spending theoretically up to 80 hours on the Moon. In demonstrating that you can build in, intrinsically, to a system a capability that will allow it to extend it beyond its reach. That's what we did with the Apollo hardware with the command and service module and with the lunar module.

Sue Nelson
Another one from John Tursees “Would you like to see the Apollo Moon landing sites preserved untouched or recover components to learn how they have lasted 50 years in space?”.

David Baker
That's a very interesting question. I would like to have them preserved. I think that that is a very important set of iconic representations of the great achievements of the Space Age. I think as well there is great good purpose to retrieving. Samples were retrieved of the Surveyor 3 by Apollo 12 that had been on the Moon for just two and a half years but for 50 and more years I think, yes, the forensic separation of certain pieces of equipment - but then to leave them alone and respect them as iconic sites for what we can achieve if we put our minds to it.

Sue Nelson
I would quite like to go back to Beagle 2 and find out why one of its solar arrays didn't open, that would be very interesting. We've got Amanda Groombridge as well “If Apollo 10 had landed on the Moon would they ever have been able to leave due to the amount of fuel versus the module weight?”.

David Baker
No they would not because of course it carried only the propellant - the fuel and the oxidizer - which was sufficient to get back up into orbit and it could not fire its engine for the 7 minutes that it would coming up from the surface. So the weight it had when getting back to the mothership would have been far too heavy compared to the offloaded discounted propellant it had just going down and then using say a small propulsive burn to get back up again.

Sue Nelson
And David Payne “What was the most bizarre source of inspiration in solving an Apollo engineering problem that you are aware of?”.

David Baker
Well I think one of the most bizarre and one of the most simplest, which brings you down to earth if it's not an oxymoron talking about rocket launches and Moon flights, was the fact that a number of us had to go to the top of a Saturn V, lie on our backs on mattresses with feet against the sides of the rocket stage and rock the thing back and forwards just to prove that all the integrated strain gauges were in place in recording that we were actually trying to kick a Saturn V over.

Sue Nelson
Well that's a brilliant place to end our episode of ‘Create the Future’. Thank you once again to those people who tweeted in some questions there and a huge big thank you to David Baker and Abbie Hutty. Join us again next month on the ‘Create the Future’ podcast.