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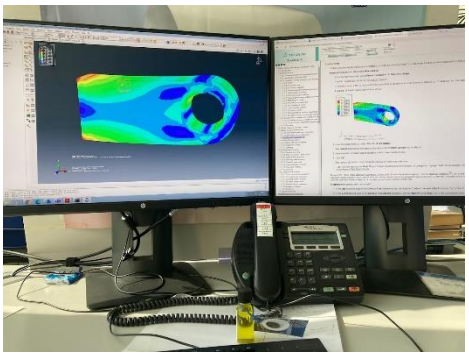
Non-technical report

The past ten weeks have been many things – exhilarating, exhausting, and fascinating, all at the same time. But above all, they've been a learning experience. Not just about materials science - that was a given - but also about myself, the world of work, and the beautiful city of Berlin. I arrived in July with a suitcase, my bike, and no idea what to expect, and I left in September with a summer of amazing memories and experiences.

One of the first things I learned is that jet engines are *really, really cool*. I knew that already – it's why I applied to the placement at Rolls Royce in the first place! But something about seeing them put together in person evoked a certain childlike wonder in me. In my first week, I spent an afternoon touring the shop floor at Rolls Royce, where, every day, thousands of moving parts are assembled in just the right way to make each engine. It felt miraculous that such a complex thing could even work. And yet, they're some of the safest machines humanity has ever built – they have to be, because the consequences of failure mid-flight are catastrophic. That I could go, in just a couple of months, from learning the basics of fracture mechanics at university to applying it in safety-relevant situations at Rolls Royce was surreal.

My project area was the development of a new method to conduct 'overspeed assessments' for turbine disks. These assessments are to prove that the disk can briefly survive spinning too fast, e.g. due to a control system failure, and are a regulatory requirement for every new engine. Currently, they're done via a 'rig test' in which a production disk is spun up until it destroys itself. But such tests are dangerous and expensive, at over €500k per run. Our project aimed to replace this with a simple tensile test of a fracture-mechanics specimen, as standard in laboratories over the world.

The difficulty comes in matching the loading conditions between the disk and the specimen. Turbine disks are subject to complex, multiaxial loading, caused by the combination of thermal gradients and centrifugal forces. Modelling this is not possible by hand, and required me to learn the finite-element software '*ABAQUS*'.



Learning ABAQUS

Learning the software occupied my first few weeks at RRD. My colleagues would give me little problems to model in ABAQUS from the various projects they were working on, which let me get an insight into the other work going on in the office. Talking to them was also a great chance to practice my German, which was more than a little rusty after being unused since my GCSEs! Unsurprisingly, the technical vocabulary was a pretty difficult for me, but it was good to at least get to a point where I could ask people how their

weekend had been or have some light chat over lunch. And, of course, everyone spoke excellent English when it was (often) needed.

In parallel with all this, I had to read up on fracture mechanics, since the level needed would go far beyond what I'd covered so far at uni. In particular, I had to research ways of modelling elastic-plastic fracture, since the alloys involved are significantly ductile. I took advantage of the huge library of reports and papers Rolls Royce had on the subject in their internal network. It was all a little overwhelming at first, with everything being new, but slowly things fit in to place and it, much like the German, became a language I could speak.

In my free time, I started doing some sport to keep me busy. On the weekends I took to the local countryside on my bike. I'd brought it over on the plane – it was extremely useful to have with me, since I could get around Berlin for much less than a monthly train pass. I often cycled to work, and even convinced my supervisor, Hartmut, to make the 22km commute with me once! A little later, I also found a group at RRD who met every week to play badminton. – it was great to join them while I was there, and I met some lovely new people through it.

RRD Badminton Club

By week three, I'd learned enough to begin working on the overspeed project properly. One of the key challenges was to insert surface cracks into our disk models in ABAQUS – below a certain size limit we cannot rule out their existence on the real disk, and so overspeed assessments have to take them into account. The process of "meshing" (creating the network of small elements) around these cracks was tedious, since the detail needs to be very fine to capture the large stress gradients around the crack tip. I then had to extract J-integral and stress triaxiality data from the cracks during loading, so these could be matched on the tensile specimen.

In week five, disaster struck: Hartmut was on holiday, and the other project lead, Michael, got Covid at the same time. For possibly the first time in my life, I was left with nobody telling me what to do, and had to figure out my own way to be useful. I decided I would put my programming skills to good use and try and automate the tedious meshing process described earlier. Over the next couple of weeks, I developed a script using Python that would interface with *ABAQUS* and insert a crack at the desired location. Making the script was laborious, since you had to define the exact location of each line mathematically rather than just clicking something in a GUI. But eventually, it paid off, and my script meant that the crack meshing process was easily repeatable by any engineer in the future.

While nobody was in the office, I also got the chance to do some much-needed tourism. A long weekend visiting a friend in Augsburg showed me the stark contrasts between north and south Germany – inflections in the dialect, the importance of religion, and even the

different kind of Aldi there. There was much to do – lakes, cathedrals, museums and we even caught the end of the World Kayak Championships! It was a completely different atmosphere to the hustle and bustle of Berlin, and showed me just how varied Germany can really be.

Swimming in a lake near Augsburg

In my last few weeks in the office, we were determined to make up for the lost time whilst Michael was ill. We set about including temperature data into our model, which would have a critical effect on the end result. A major sticking point was the conversion of data between SCO3, Rolls Royce's in-house FEM software, and *ABAQUS* – a problem that would take up the rest of my time in Berlin. I started making another script to do this, but unfortunately the ten weeks came to an abrupt end before it could be finalised. The project itself is not due to complete until April and I'll be following the final results eagerly!

But now I'm back in Cambridge, reminiscing on the incredible summer I've had. The experience will prove invaluable in the year to come, providing some much-needed context to the things we'll cover in lectures. And some things will stay with me for much longer – the friends I met, the language I picked up, and the memories I made. Thanks must of course go to the Amourers and Brasiers company for their generous support, the Materials Department at Cambridge for organising everything, and to Rolls Royce for taking me in. In particular, I'd like to thank Lianne for her dedication to the programme and helping everything to run so smoothly, and to Hartmut, who made my time in Germany so wonderful and guided me every step of the way. At the start of the summer I was a little unsure about my decision to pick materials science over chemistry for third year, but now, after everything I've learned, I'm certain I made the right choice.