HOUSE OF COMMONS

Science and Technology Committee

Oral evidence: UK Space Strategy And UK Satellite Infrastructure, HC 98

Wednesday 3 November 2021

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Watch the meeting

Members present: Greg Clark (Chair); Aaron Bell; Dawn Butler; Mark Logan; Carol Monaghan; Graham Stringer.

Questions 1 - 47

Witnesses

I: Professor Washington Yotto Ochieng, Chair in Positioning and Navigation Systems, Imperial College London; and Lucy Edge, Chief Operating Officer, Satellite Applications Catapult.

II: Professor Anu Ojha, Director, National Space Academy; and Professor David Southwood, Senior Research Investigator, Imperial College London.

Examination of witnesses

Witnesses: Professor Ochieng and Lucy Edge.

Q1 **Chair:** The Science and Technology Committee today begins taking oral evidence in our inquiry into the UK's space strategy and satellite infrastructure. During the weeks ahead, we will consider the opportunities to design, manufacture and contribute to these systems and the analysis of data obtained by satellites. We will also consider the UK's launch capability and assess the UK's strategy, and those of other countries, for the future of space and satellites.

I am very pleased to welcome our first two witnesses: Professor Washington Yotto Ochieng, Professor of Positioning and Navigation Systems at Imperial College London, and Lucy Edge, who is the chief operating officer at the Satellite Applications Catapult. Thank you for helping the Committee to kick off our inquiries.

Professor Ochieng, many of the activities and services that satellites provide will be known to the Committee and to viewers among the public, but will you give us an overview of the full range of services that satellites are providing to the UK at the moment?

Professor Ochieng: Thank you for inviting me. My expertise is in positioning, navigation and timing. People will have heard about GPS and so on. These are space-based platforms that provide positioning, navigation and timing.

I tend to explain it in this way. I cannot think of anything, either terrestrially—on Earth—or beyond that does not require positioning, navigation or timing and their derivatives, such as speed, heading and attitude. The challenge we normally face is the performance, or stringency, of the quality of the information. Overall, positioning, navigation and timing underpin life as we know it.

If you think about the challenges relating to the quality of the information, that brings up new applications, some of which are to do with national security. Some of them are to do with increasing levels of automation. People have heard about autonomous mobility—autonomous vehicles, smart cities and so on. All those applications require positioning, navigation and timing. Therefore, at least from a PNT perspective, the relevance of space is clear, as we have seen with GPS, the Chinese BeiDou system, Russia's GLONASS system and the Europeans' Galileo and EGNOS systems.

In summary, PNT—and therefore space—is relevant to life as we know it.

Q2 **Chair:** That is a suitably grand introduction, contributing to an understanding of life as we know it. I should say to viewers watching on TV or online that the ringing bell is not a fire alarm that we are ignoring but the testing of the Division bell, so no action is required from us.

I will put the same question to Lucy Edge. What are the principal current

applications and uses of satellites in the UK?

Lucy Edge: It divides up into three or four main areas, depending on how you look at it. Washington has already mentioned positioning, navigation and timing. We also have communications and connectivity for all the different kinds of data transfer: voice transfer, wi-fi systems, major delivery of streaming technology and so on.

There are two parts of Earth observation: our standard Earth observation imaging—we might think of something like Google Maps—and observation of weather systems, which are viewed from space, looking down through and into our atmosphere and down to Earth. The latter group is extremely exciting. As the technology improves, the number of things we can see increases and the resolution we can see things at keeps improving. It also gets cheaper to develop and to deliver as a service and as data.

By that, I mean the perhaps more obvious point that images of our Earth become better resolution—we can see more information. We can also look at very specific particulates—finding molecules, finding pollution in the atmosphere and finding particular layers of particles that are interesting. We can do all sorts of fantastic diagnostics, where we use proxies of particular molecules to evidence that something else is present, even though you cannot see the "something else" on its own. That latter category, which is broadly called Earth observation, has so much exciting opportunity in it. We have barely scratched the surface of it yet.

Q3 **Chair:** In the next 10 years, is it principally the case that, as you put it, the resolution will become more finely grained and we will be able to see more clearly and in more detail? Will that be the principal development that will change our lives, or will we be able to do new and different things with satellite technology?

Lucy Edge: Definitely the latter. There are a few different reasons why I give that answer. One is that those three or four different services from space are not three or four independent services any more. The positioning, navigation and timing, the communications, which transmit the data, and the gathering of the data in the Earth observation are becoming more and more integrated. Really powerful applications will be a combination of all that technology from space.

We are also looking at a move now towards truly ubiquitous connectivity. We have all been in places where we do not have connectivity with our phone at exactly the moment when we most need it. The technology that is a combination of terrestrial and space technology is becoming much more capable. The resilience is increasing all the time. That means we can really rely on that. The combination of that reliable connectivity with improved positioning, navigation and timing and the improved Earth observation capability that I described at the start means the power behind that is much greater. The accessibility that comes from the cost

reduction means that more and more organisations, start-ups, universities and individuals can really access this and start using it, in ways I have probably not thought of yet. That is what is happening in the next five to 10 years.

Q4 **Chair:** That is very clear. Professor Ochieng, thinking about positioning and navigation, will we get incrementally better over the next 10 years at what we are already doing, or are there new developments that will change how we do things in this space, in which you are an expert?

Professor Ochieng: That is a very good question. To me, the key word is "resilience". Increasing the resilience of PNT will be key.

Chair: For people who do not know, PNT is positioning, navigation and timing.

Professor Ochieng: Yes. It is about increasing that resilience. There are also institutional issues associated with it, to do with things like ownership—owning a system. The way things are structured at the moment, particularly with respect to GNSS, is that nations—the United States and so on—own the particular platforms. If you do not own or, at least, part-own the system, there is the potential for denial of service. That is why it was interesting when the UK was part of the European space-based navigation programme—EGNOS and Galileo. Resilience is linked to that, in the sense that you want a system that is actually available and operating in the presence of disruptions, if you can. You want a resilient and robust system.

As we move to the future, particularly thinking about the mission-critical applications—safety and security-critical applications such as autonomous vehicles, smart cities and so on—there will be an interesting question for the United Kingdom, in particular, as a sovereign country. It will have to decide one way or the other whether it is going to own its own PNT capability or to work with others to ensure that mission-critical applications, including those associated with national security, are covered.

Very highly resilient PNT is where we should be going. With all the development associated with integration of space, terrestrial systems and so on, increasing the level of resilience is what we need, but there is that political, sovereign issue that we need to tackle.

Q5 **Chair:** That is fascinating. I am sure we will go into more detail on that this morning and later in our sessions.

On the question of resilience and denial of access, is it your view that this is essentially something that national Governments have to provide on a sovereign basis, or do you see resilience coming from a future diversity of commercial providers?

Professor Ochieng: There is a very interesting question about the role of Government and the role of industry and academia in all of this. I think

the Government have been very good in classifying space as a critical national infrastructure and, therefore, one that underpins public services. From my perspective, the Government should lead with regard to their own responsibility to ensure that public services are provided.

There is then a role for industry in how that is delivered. It will not be the first time that we have acquired infrastructure using this kind of model, where the Government lead and industry comes in and takes over. I do not think it is one or the other; I think it is both, but with the Government providing leadership.

The UK leads the technology with its industry and academia. When we were in EGNOS and Galileo, the UK was quite expert, particularly on the safety-critical aspects of these systems, so I have no doubt that the UK has the capability, industrially and academically, if we work together. It calls for leadership at Government level, as this is a critical infrastructure that underpins almost all public services. I was a member of the Blackett review, which looked at how we depend on GNSS—global navigation satellite systems—and it is very clear. I recommend that report to the Committee, and there was also a previous one, from the Royal Academy of Engineering. Of late, the national security adviser has been looking into this.

The worry is that we are over-reliant on GNSS and that GNSS is not protected to the level at which it should be, particularly where it underpins mission-critical applications. That calls for leadership, because it is a critical public service. Obviously, industry has a role to play, under the leadership of Government.

Q6 **Graham Stringer:** I think this is a natural continuation of your answer, Professor Ochieng. If there is a continuing improvement in positioning, navigation and timing, what problems will we be able to solve that we cannot solve now?

Professor Ochieng: That is linked to the point I was making, which is that life requires PNT. The challenge is the level of performance or quality that that information should have to underpin the applications we are looking at.

I will give you some examples. Obviously, PNT would be required for driverless cars. Positioning, navigation and timing are pretty important if you are sitting in the back of a car that is driving itself.

Telecommunication networks are synchronised using GNSS time, which is the cheapest source of very accurate time. We have smart cities, or smart city contexts, increasing levels of automation in society and robotics. All that has very stringent requirements for PNT. You are looking at accuracies at the centimetre or even the millimetre level. You are looking at something called integrity, which is how we guarantee the level of confidence that you have in the information provided and is very much linked to safety and security. This is where I was bringing in resilience.

To unlock all those applications and to underpin some of the developments that are very useful for the globe as regards climate change, sustainability and so on, which are very much PNT-linked, we have to ensure that the level of performance improves to meet the stringent requirements for those applications.

Q7 **Graham Stringer:** Lucy Edge, if communications improve, what problems will that enable us to tackle that we could not tackle previously?

Lucy Edge: It is a similar answer, in some ways. We have talked about resilience already in the positioning, navigation and timing context. Of course, the same autonomous or driverless vehicles, whether on the ground or in the air, need to be able to communicate. They need an absolutely guaranteed route of communication. You do not want one that could drop out at exactly the wrong moment; that resilience is critical. If we are building businesses and investment environments off the back of communications, it really needs to be known that they are reliable and that it is worth the investment to use the technology. That is one part of it.

The other part of it is confidence, both across the whole country and globally, in access to the same quality of information, and the same quality of access to the same quality of information. We have been talking for a really long time about the digital divide and the damage that can be caused by some people having better connectivity to information, services and support than others. By improving communications, we tackle that very serious challenge, which is still prevalent in this country as well as in many other places. It also allows us really to bring a different preventive approach to a lot of global challenges. Professor Ochieng talked about climate issues; there are preventive activities around climate issues. There is also the need to resolve the really damaging events that occur, which requires high-quality comms as well. It normally requires high-quality communications in an environment where any terrestrial network has been damaged.

Q8 **Graham Stringer:** Professor, how much will our changed relationship with the Galileo project delay our progress?

Professor Ochieng: Do you mean in terms of impact?

Graham Stringer: We are going to be locked out of part of the Galileo project, aren't we?

Professor Ochieng: Yes.

Graham Stringer: How will that affect the progress of improvement in positioning, navigation and timing?

Professor Ochieng: I was one of the designers of EGNOS, which was the system that came before Galileo. I then moved on seamlessly to designing—or at least co-designing—the Galileo system, so I know them fairly well. I also know that the Galileo system, GPS and so on are under

constant modernisation, to improve them, by their respective owners—the respective states. A lot of research is going on. I do not know whether people are aware of this, but a lot of the improvements associated with increasing accuracy, integrity, resilience and so on are undertaken by industry and academia. Some of the discoveries—people talk about millimetres from space—came as a result of research. They are constantly improving.

These systems are available to everyone, including the United Kingdom. I am referring to the open services. There will be some commercial services from Galileo, for example. There is an element of Galileo that is called the PRS—the public regulated service. That is available only to authorised people. The United Kingdom is out of that.

The reason why I talked about denial of service is that these particular states, or the owners of these systems, do not guarantee the availability of the services—even the open services—because that could be affected by national security issues. That is one of the problems we have. Until there is denial of service, those open and commercial services will be available to all in the UK.

The worry associated with these systems is really from two standpoints: one is denial of service; the other is to do with national security. From that perspective, as I said earlier, the United Kingdom, having left EGNOS and Galileo, has a choice to make. I think that choice should be made pretty quickly with regard to what it does, as a sovereign state, to address both the potential for denial of service and the very serious and significant national security issues associated with owning the service or, at least, having a guarantee that the service will be there to support or to underpin national security-type applications.

Q9 **Graham Stringer:** My final question is the science-fiction question, really. You both paint a picture of the future where we can sit in cars and they drive us to where we want to go. What happens if the system breaks down? Most systems have vulnerabilities and break down, however well they are planned.

Professor Ochieng: My area of expertise is resilience, so maybe I should define resilience, at least as I understand it. A system is operating normally. Then there is a period of disruption and it goes down for a bit. Then, if you are lucky, it comes back. When it comes back, it could be to the old normal or it could be to a new normal.

What I am trying to do with resilience is to ensure that the period and depth of disruption equate to zero. That is what I call a robust system. In other words, it continues to operate in the presence of a failure. Inevitably, that will call upon addressing the vulnerabilities, as you call them—that is the right term—to the extent that we would then have integration of synergistic and complementary systems. That is how you do it. You do not combine systems with what you might call the same failure modes. That is the problem we have with GNSS. You have four or

five of them—however many you have. They are operating in the L band frequency so, by definition, in general they constitute a single point of failure, even when you integrate them, depending on certain vulnerabilities.

As was said earlier, we will have to have some kind of harmonious co-existence between the Earth and space, in terms of the integration of sensing technologies and so on, to provide us with this robustness, which is equivalent to resilience in the presence of disruption. That is really where industry and academia come in. The UK calls it resilient PNT. That is the right way to do it. The issue is how to achieve resilience. As you say, the key is addressing vulnerabilities.

Lucy Edge: I will build on the same point. In any high-risk working environment—the space sector launching things into space is one of those, and another would be nuclear—you must have lots of different alternative routes to success, so that you can always ensure that you do not have what we call single points of failure. That is how you design these complex systems, especially when they have a human in the loop, as an automated vehicle would probably have.

By looking to the space sector for these designs, you are looking to a sector that has decades of experience of designing something and then never again being able to get to it, but having to rely on its being able to work for long periods of time. It is a sector that understands these kinds of challenges and has worked through them for a really long time.

Q10 **Chair:** Professor Ochieng, in the context of our being excluded from certain parts of Galileo, you said there was a choice that the UK had to make, and to do so quite quickly. Can you characterise what that choice is? What are the options that make up the choice?

Professor Ochieng: Obviously, some of these are political issues. I suppose it is possible to come to some agreement with the current owners of Galileo. Let us call it the European space-based navigation programme, because that also includes EGNOS. EGNOS is the European geostationary navigation overlay service. That is the system that we developed first, before we moved on to Galileo. I suppose there could be an agreement between the United Kingdom and the Europeans to access the PRS or, at least, to co-own or partake in the project—that is, the European space-based navigation programme. There could be a similar thing with the United States vis-à-vis GPS. That is the working-with-others idea.

The other option is to go it alone as a sovereign state, just as the United States, Russia and China have done. I have one point to make on this. I will not say that the United States, Russia and China are adversaries, but I think you understand what I mean. Let us say that this was arranged in a way that was antagonistic in nature. If I exclude Galileo, which belongs to 27 countries, I think there is a need for a fourth dimension—a level-

headed intervention, in the form of the United Kingdom, which, to me, is by capability a world power in space.

It is really a question of exploiting that capability, because it is there. SSTL, for example, is a leading spacecraft manufacturer in the UK. We are very good in data and analytics—all the things to do with artificial intelligence, machine learning and so on. We are very good at command and control—the ground segment and so on. The UK as a country has that capability.

I think we could be the fourth dimension in all of this, particularly working with the Commonwealth. I have always wondered about the Commonwealth, because you have big players like Australia, South Africa and so on. Perhaps there is something there for the United Kingdom with respect to space that is about galvanising that access and being the fourth dimension in all of this. Those are the options that I see with regard to that question.

Q11 **Chair:** You talk about the UK having the capabilities. It is evident that we do, but the fact that the other players are the US, China and the 27 members of the European Union—Russia is obviously smaller than those economically—indicates that economic weight, as well as scientific ingenuity, is important. Are we of a size that we can credibly aspire to having an alternative to the Chinese system, Galileo and the US system?

Professor Ochieng: Economically, the UK is quite capable. As with everything else, you do a cost-benefit analysis, don't you? I go back to my opening statement that PNT underpins everything. There was a study by London Economics that said we would lose £1 billion a day if we lost GPS, for example—£5 billion in five days. If you think about the cost of putting up these systems, which can now be a lot cheaper than what it took to do GPS and so on, I think the UK could do it.

I go back to the point I made about the rest of the world, particularly the Commonwealth. It would be very nice for states like South Africa and other African states to co-own a space infrastructure. I think you could get them together. Perhaps you could have a UK-led, Commonwealth-type system. It is just an idea.

Q12 **Chair:** Lucy Edge, you were nodding your head vigorously at one point.

Lucy Edge: Yes. You are spot on when you say that the size of a nation's space success is clearly linked to its Government investment. We are never going to compete with some of these really big-budget countries from that angle.

I think we have to look at it in a different way. There are other things that we can do. We have less of the heritage infrastructure—we have brand-new launch sites, for example. We can look at a different, agile approach to space. We are world leaders in small-satellite technology. The Government's interesting investment in the OneWeb company has demonstrated a different way of working between Government and

industry. We will see how that plays out, but it is a very interesting and positive opportunity to see the way in which these kinds of things can progress.

What it means is that we have room for innovation to take a different approach to a challenge. As Professor Ochieng described earlier, when we are talking about resilience and different kinds of services, the key thing is to have a different approach—a different solution to the problem. That is how you get really high-quality availability, because then you do not get the single-point failures that knock out a whole capability.

Q13 **Aaron Bell:** Thank you, Chair, and thank you both. I have questions on the future applications of satellites, so I suspect they are mostly for Lucy, but if you want to come in, Professor Ochieng, just indicate and I will bring you in.

Ms Edge, what are the most exciting space technologies being developed at the moment that we have not already discussed, and what benefits could they bring to society?

Lucy Edge: We have already discussed Earth observation in general, but there is enormous potential there. In bringing value to society, I really want to highlight that this is not about "Star Wars", space-style thinking about space. They can bring value in transport systems, in the national health service, in solving issues around loneliness and being on the edges of society. There are so many challenges that we can solve with some of the existing technologies that are not yet being fully exposed and utilised. That is a key point.

It is critical that the UK always has something going in really exciting future technology. I will use our astronaut as an example; doing something really exciting brings attention around it in a very special way that inspires children and adults and everyone in between, and that is absolutely critical.

The piece that is super exciting at the moment is the drive towards in-orbit servicing and manufacturing. The UK is already on this journey. We are operating from Harwell. A company called Astroscale is operating a debris removal service, which is demonstrating how you can attach and separate from another spacecraft in space. Robotics and automation are being tested in that process.

That is the servicing and debris removal side of it, which is absolutely critical in itself, but I like to think of it also as a journey towards something even more exciting where we start moving into building things in space.

Q14 **Aaron Bell:** What are the specific benefits? We have a limit on the size of things that we can get into space. Some things can be opened up in space, but you are talking about manufacturing in space.

Lucy Edge: Yes.

Aaron Bell: What projects will we be able to complete that to date we have not been able to, off the back of that?

Lucy Edge: That is the really exciting part of this. We can start by thinking about optimising that volume inside a launch vehicle. As you have described, there are limitations there. If we think about a flat-pack-furniture-style of spacecraft that can open out in space, that is already the beginning of an improvement. When we do that—start that manufacturing, building things, really creating things in space—we start to be able to think about huge structures. Huge structures can be valuable for things like Earth observation and comms and larger antennas, for example.

They start to get really interesting if we think about space-based solar power. If we start linking this now to climate solutions and net zero, this is future activity but it is building on things we are already doing in the UK. If we move ourselves into a position where we can create the large structures that are required for space-based solar power, we start to do some very exciting things. It addresses our challenges around energy generation in part, but also, for me, it is that wow factor of space that makes people stop and get involved and think, "How can I study maths at school?"

Q15 **Aaron Bell:** What you are setting out is very exciting. Where specifically are these technologies being developed? Which UK organisations, either industrial or academic, are carrying out the most ground-breaking space and satellite research, and which of those is the Catapult supporting?

Lucy Edge: This is always a risky situation because I will forget somebody, and it will not be deliberate. Internationally, a number of countries are looking at in-orbit servicing and in-orbit manufacturing, but nobody has succeeded yet and nobody has really moved into this space in any meaningful way, and we are certainly alongside.

With space-based solar power, you have to start looking at how you transfer power wirelessly, and Japan is leading in that area. We are leading in the approach to debris removal and close approach and attaching in space and separating again and inspecting.

There are bits that we are doing that are really critical. The Catapult is working alongside a number of different companies, including ones focusing on the debris such as Astroscale and ClearSpace, which is based out of mainland Europe but has a presence in the UK as well.

Q16 **Aaron Bell:** You have brought up the debris point a couple of times. How big a challenge is it? It is obviously a global problem. If we do all the work, are other countries free-riding off the back of that? How do we co-ordinate this internationally if it is a big problem? I can see that Professor Ochieng wants to come in as well.

Lucy Edge: Everything about space has to be handled internationally. We have talked about, this morning, the importance of national

capability, and I fundamentally agree with that, but space does not have borders—it does not respect national boundaries. It is an international environment, and we have to work together in that international environment. Debris is a key area.

Another part of the space chain where the UK leads is around regulation and law. We have a really strong voice in that area, and the country is well respected for the people in the UK who work on that. We have a number of universities that work on space law and space regulation in this country. That is a huge part of it.

With debris, there are two sides to the challenge. One is handling what is already there that was launched at a time before people were discussing the importance of removing it, and that is going to come down to national Governments in many cases. The second is the future-proofing of the environment, and that is the commercial side of it. If you are launching a constellation of low-Earth-orbit satellites as a commercial opportunity, these days you should have an obligation to think about how you handle the end of life of that mission or the individual spacecraft in that mission. It is not fully clear on a global level that everyone will abide by the same regulations or even best practice, but we should definitely be pushing for it. Numerous organisations with a UK presence work on that.

Professor Ochieng: It is an excellent question. You have heard of new space, deep space and all these things. The way that I like to look at it is what I call global challenges, whether that is about food or health and so on. Because space is different from here, how can we benefit, let us say, from the space environment? You hear a lot about space weather being a nuisance, but the space environment with its zero gravity and so on can be quite good in helping us to tackle even some of our health challenges by looking at how we create medicine in space and so on.

One way to look at it is to ask what the global challenges are. The other relevant point is sustainability, which we have talked about. We do not want to export all the problems we have created on Earth into space. We have to make sure that we are sustainable. Reference was made to in-orbit servicing and so on; I also want to mention additive manufacturing. You have heard of 3D printing, for example.

Aaron Bell: Yes.

Professor Ochieng: There is a company in the United States—a start-up—called Relativity Space that is at this moment testing the world's first fully 3D-printed rocket-propulsion system. That is a way of reducing costs considerably associated with launches and the types of platforms and so on.

With respect to debris, different technologies have been tested, including zapping, using tethers and things like that. It is quite a difficult problem tracking a piece of debris in terms of a projectile. We are looking at some very heavy mathematical models to enable us to track them. The United

Kingdom is very good, or has been very good, in its regulation, which is now bestowed upon the UK's Civil Aviation Authority to regulate.

The UK is also a signatory to the Artemis accords, which try to bring all the different countries together in the regulation of space. That is going to be quite a challenge given some of the security and defence aspects of all this. The UK is in a very strong position to be able to influence the world in that respect.

In response to the question about exciting things in space, Professor Southwood, who will come after me, will probably tell you quite a few things about what we are doing at Imperial College London.

Q17 **Aaron Bell:** I look forward to that. I will go back to Lucy for the last couple of questions. We are in the middle of COP26. What potential space technologies, including ones that your Catapult is developing, can contribute to our and the world's ambitions to reach net zero?

Lucy Edge: A lot of the Catapult projects that we work on, normally in partnership with Government, universities and industry, have a climate focus. Our first very spin-out was an organisation called OceanMind. The short version is that they track and identify illegal fishing to protect the oceans in multiple different ways.

We have been working on a project with the European Space Agency called ForestMind, which is a development of this theme, and it is largely about supply chains and deforestation caused to service a food supply chain. Using some very complicated techniques that are terrestrial in combination with some space-based technology, we can start to identify where beef has come from, for example, and therefore whether deforestation would have occurred in order to service that supply chain. That is an example. You could use it for soy or numerous other products.

We have been working with the coffee industries and the chocolate industries on the same kind of concept. One of my favourite projects that we are working on at the moment is through the international partnership programme with the UK Space Agency, and that is at COP26 this week and is working with the Commonwealth of Nations, the United Nations, Fiji, the Solomon Islands and Vanuatu—three nations that have really high-risk situations upcoming with global warming and very different existing infrastructures—on three bespoke solutions for three nations that have completely different existing capabilities in the comms to their island groups and how they can have resilience against the climate changes that are occurring that are nothing to do with them. If you need to relocate an entire town, you only want to do that once. That is an emotionally very challenging situation for everyone involved. When you go through that process, you really want to know as a Government that you have taken every possible step you can take to make the right decisions for your people.

There are also examples as in the past couple of days. We know that deforestation and methane emissions have been at the top of the agenda coming out of COP26. Measuring those from space is the only really meaningful way that is available to us. If we want to monitor that, put regulation around it and make sure we are sticking to targets and organisations are doing the right thing—especially, for example, with methane emissions—we have to have space technology in the system, because otherwise we are not going to be able to monitor it. The only commercial company that has a solution that is affordable at the moment is a Canadian company called GHGSat. They have a presence in east London and they are trying to grow that out there.

There are things that have happened very well in the UK that have attracted organisations here to set up. We must celebrate that some good things have happened as well.

Q18 **Aaron Bell:** Finally, I think Professor Ochieng mentioned it to us already, but to some extent what your Catapult is working on is public health. Is monitoring and auditing where we are going to see the biggest benefits to public health from space technology?

Lucy Edge: There are two very current areas. The future possibilities are massive, but I will stick to the two current areas right now. Pollution is a huge issue that is going to become much more present in our way of understanding illnesses and preventing certain illnesses, and that can be monitored from space in a very meaningful and helpful way.

The other part of the story is building out these smart environments where we can help people who need medical support more rapidly, effectively and cost-effectively. One way of looking at that is turning ambulances into a mobile hospital instead of them just being vehicles. Not only can you transmit images back and forth between the hospital and the expert who may be quite some distance away in a big traffic jam, but you could also, as we move forward over time, be thinking about robotic support from the expert who is remote and can support the person in the ambulance. We are doing a lot of work on that with many partners, including the NHS at Westcott where we have our future networks facility. This is all about communications that cross over between 5G, 6G and satellites.

There are other examples that are quite simple on the face of it but can be life changing for people who live remotely. For example, for colonoscopies, you can swallow a pill that is a camera and you are wearing a little belt that looks a bit like a seatbelt, and the camera, as it travels through your system, takes all that video imagery, bluetooths it to a machine that you are wearing on the seatbelt device, and then that can be sent to experts who can look at the video. You may live on a small island off Scotland or somewhere else extremely remote. It takes away those emotional challenges of having to get to a hospital. Although we do not like to talk about it too much with health, it costs a lot. Being able to do that in a lower-cost way means it can help more people.

Aaron Bell: Thank you very much. That is very exciting to hear.

Professor Ochieng: Can I say a quick word on this? I have a couple of examples. We have not mentioned Covid—the pandemic that we are still in—which has been spread very much by our capability to be mobile across countries and so on. Space obviously offers that observation platform where we can look at how people move about and correlate that to the infection rate so and on. I have been involved in a project trying to do that.

Another example is in Australia, where there is no form of communications for health workers in the outback. Space allows us to monitor where they are and to use Iridium satellites to send alarms and alerts.

Those are a few examples of where we are. Space is going to be important in our being prepared for the next pandemic. We were caught unprepared. The question for us now is how we get ready for the next one. Space has a significant role to play.

Q19 **Carol Monaghan:** I thank both of you for your comments so far. You have painted a very positive picture of the space industry in the UK, which is of great benefit to us all.

At the end of September, we saw the publication of the long-awaited space strategy. Professor Ochieng, what did you take as the positives from the strategy, and what was missing?

Professor Ochieng: Let me start with the positives. All the right words are there—what we should be and what we should be doing as a country. What is missing is how we do it and how we actualise it. That is what I cannot find.

Q20 **Carol Monaghan:** A press release last week said that the UK would launch a rocket into orbit in 2022. I found that surprising. Obviously, it is a target, and there is the technology, but 2022 seemed pretty soon.

Professor Ochieng: Yes. I take it as it is written. I have been involved, as I said, with EGNOS and Galileo and so on. I cannot remember how many times we revised the full operational capability dates. It could be that it is a little bit too soon, but I do not have all the details of that happening.

I gave you a short answer for a reason. The strategy contains good words. For example, it mentions the UK playing a leading role. It mentions the comms, the Earth observation, the PNT and all that. I do not see a joined-up approach. If you go back to sustainability, we should at least be considering things like multifunctional platforms so that we have a really joined-up space strategy accounting for all the different facets and components of what space offers.

For example, in aviation we have something called communication navigation and surveillance, and we treat them as one, at least when we are considering how to provide it. I do not see direct references to skills—the talent pipeline. I do not see very clear roles for Government, for industry and for academia. In fact, coming from an academic background and knowing what is present in the UK, I do not see it emphasised enough, particularly from the perspective of PNT.

We talked about the economics. I do not see direct reference to the funding that would be needed, let us say, to pump-prime and then to let industry take over and so on. The right words are there, but I struggle a little with the actualisation of things.

Q21 **Carol Monaghan:** I do not know whether you are aware of the Scottish Government's strategy for space in Scotland, which does talk about skills. Should there be more collaboration with the devolved nations in drawing up the space strategy?

Professor Ochieng: Absolutely. It is the United Kingdom and therefore you would expect that.

There was something I wanted to say about levelling up and trying to bring the different parts of the UK together with respect to the capabilities of space. I gave a lecture in Kenya a while ago. They do not own space infrastructure, but given that the space infrastructure is there I was talking about how the Kenyan youth could be empowered to exploit the power of space to build Africa, because the signals are there. As I said, they are open. There is a lot that these particular technologies can underpin in offering development in different regions of the United Kingdom.

Q22 **Carol Monaghan:** We are talking now about launch capability—not necessarily in 2022—within the UK probably in the north of Scotland somewhere.

Professor Ochieng: Yes.

Carol Monaghan: A number of sites have been detailed for that. You have mentioned skills already; do you see having launch capability as driving skills, or should it be the other way round—do we need to have the skills to drive the launch capability?

Professor Ochieng: It is skills that will empower and underpin the development of space.

Q23 **Carol Monaghan:** We need to be doing that now, essentially.

Professor Ochieng: Yes. Launch capability is a demonstration of technological prowess—being the first country in Europe to launch from its own soil as opposed to doing it from Guiana. There are technical issues associated with that depending on where you want the satellites to be—above the equator and so on. I see them as a demonstration of

technical prowess. If you do that without the skills and the talent pipeline, it comes to a halt at some point.

Q24 **Carol Monaghan:** Surely, it is more than just a demonstration of prowess. Surely, if we have launch capability, we will see what has happened in the States, for example, where you see different industry operators and different people coming to base themselves around that. That would be the ambition, surely.

Professor Ochieng: I take the point you are making about it. In the general scheme of the space industry and its benefits, I would not count launch capability as something terribly significant.

Q25 **Carol Monaghan:** Thank you. Lucy Edge, I think you were about to come in on that. I would like to ask you about space strategy, but maybe you could come in on those questions first.

Lucy Edge: I hope it has come across today that I am hugely passionate about the space industry. I have been in the space industry my whole career. I have looked around peers and friends over the years and thought how lucky I am to be in an environment where I truly love the job that I do every single day of my life—

Carol Monaghan: Just like us politicians.

Lucy Edge: I have been very lucky that I have been able to run a number of launch campaigns in my career. However much you know that the day of the launch is the day when you have literally nothing to do apart from sitting in front of a TV screen, it is somehow the most exciting day—the one where you get the goosebumps; the one where everybody tells you how amazing you are; and the one where everything matters all of a sudden based on one thing.

We need to drive skills now to support what we want to achieve in the future, but having launch sites in the UK is an enormous advantage for our young people—to see something that exciting on their doorstep. Even if they are not from Cornwall or from Scotland, they are not that far away from either of them in the UK, and to have that on their doorstep and to see them launching—I think we can launch in 2022 if people put their minds to it—is going to really change the way young people look at space opportunities in the UK.

It does not have to be technology. I am a physicist and an engineer. That is no longer what the space sector needs only; it needs really clever, creative thinkers. It needs people who understand user-centred design. It needs great marketeers. It needs fantastic business entrepreneurs. All of that is required in the space sector now in a way that we did not recognise when I started my career.

Q26 **Carol Monaghan:** To take you back to the space strategy, what are its pros and cons, or strengths and weaknesses, or however we put it?

Lucy Edge: The absolutely overwhelming pro is that we have a space strategy nationally now, and the devolved nations have all been launching theirs over the last number of months. That is an extremely important moment in time for us. That is absolutely the positive.

It is also really good to see that applications of space are called out independently in there, whether it is about improving public services or the specifics around climate or transport. That is really powerful, and it gives us something to all stand behind, which is really meaningful.

As for the weaknesses, Professor Ochieng has already mentioned the lack of next steps to turn it into a deliverable plan, which are key. From the sector, we are looking to try to create the picture and the jigsaw at the moment, and we can see that Government Departments have seen an uplift through the CSR. We have a National Space Council. Is it all going to link together and help us to take forward, Department by Department, the use of space across Government? That would be really powerful.

Q27 **Carol Monaghan:** Do you see it more as a vision of what we want to achieve rather than the detailed plan and how we are getting there?

Lucy Edge: It is not a plan, but it is more of a vision because it is not a wish list. It focuses on areas where we have strengths in the UK and it focuses on things where we can meaningfully effect change, like in the climate world. We have world-leading universities in that space, and we have really high-quality space technology as well. There are areas where we can make a huge difference.

Professor Ochieng: The actual governance structure of delivering this thing is key, and that needs to be clarified.

The second thing is creating ecosystems that account for all the stakeholders—call them centres of excellence. Galvanisation around a governance structure that delivers is key, and I could not quite find that in the strategy. In terms of vision, yes; in terms of the actual reality of delivering, it is a little bit lacking. That could be developed further to give stakeholders the confidence that coming together would actualise something practical.

Q28 **Carol Monaghan:** You will be pleased to know that your colleagues behind you are nodding away.

Lucy, we are hearing about vision and ambition. How is the Satellite Applications Catapult feeding into the ambition and vision?

Lucy Edge: We really work to de-risk the innovation. That means that what we need to do is bring the risk exposure of the innovative idea down and bring the opportunity and that market up. You never get rid of the gap, but you close the gap. That is a really woolly answer, and the reason it is a really woolly answer is that case by case it is a different challenge. Sometimes, organisations do not know anything about space, and all they really need to do is to be partnered up, and we effectively create a

networking environment or a dating agency. In many other spaces, it is about providing the infrastructure that small companies—start-ups—can get access to that they could not otherwise afford.

As a start-up, you do not want to raise your first million and spend all of it on an additive manufacturing machine because you need one to develop your technology. We purchase those kinds of things, put them into supported facility environments and create access models to them that are very different from what industry would find anywhere else, so that they can have short-term or longer-term access to really high-cost, high-tech equipment, and they can have the business support that goes around that. We run the machines for them, if that is what is needed. We have been developing those facilities, which we call DISC—disruptive innovation for space capability—facilities and we have been developing them in different places across the UK depending on the appetite and the need. That is an example of something physical that we provide to help people to overcome challenges.

Q29 **Carol Monaghan:** Do the Government support this properly?

Lucy Edge: One more thing I was going to say about the space strategy is that both it and the innovation strategy talk about a different approach to funding from Government that is about being a procurer of commercial services, and that is very interesting. If you look at our map of funding, if you are a start-up or an SME in the space sector, there is quite often a lot of capital investment, and there is a grant piece at the start. In the UK, we are getting better and better, through organisations like Seraphim, at funding the investment into the businesses, but there is still quite a big gap in the middle, which is that high-risk space. If we can start to narrow that gap, not by filling it up with lots of extra grant funding but by looking at new and innovative models for funding like Government being a procurer of services, we start to challenge exactly that point that you make.

It is the key message with everything, really. Nothing in this is perfect. The national space strategy is not perfect, but it never would be. We have to look at where the opportunities are and how we can get involved and all lean into this. We know that the Government are showing extremely strong signs of wanting to, so let us all work together and see what the opportunities are to fill the little holes we have so that we have a nice smooth-running, well-oiled, end-to-end sector. There are a few little gaps in it at the moment.

Chair: I thank Lucy Edge and Professor Ochieng for lifting the curtain very enticingly on the sessions that we have to follow. I am very grateful for your work and for advising the Committee on the areas that we will pursue.

Examination of witnesses

Witnesses: Professor Southwood and Professor Ojha.

Q30 **Chair:** I will invite our next panel of witnesses to join us at the table. Professor Ochieng and Lucy Edge are welcome to stay and observe.

We have as our second pair of witnesses this morning Professor Anu Ojha, who is the director of the UK National Space Centre, and Professor Southwood, who is, like Professor Ochieng, at Imperial College, where he is a senior research investigator. Thank you very much indeed for joining us.

Perhaps I may start with similar questions to the witnesses in our previous panel. What are the areas that are most interesting and exciting on the horizon that space and satellites might give us access to during the next 10 years?

Professor Southwood: In the next 10 years, we are going to be living in a slightly different world—different partly because of space. Space is going through a revolution at the moment with the growth of constellations. Our country has taken a rather decisive jump ahead by investing in a constellation. How we use it is up to us. Investing is only the first step; it is exploiting that really matters.

At the same time, we are clearly going to have to move towards a different nature in how our society works. We are going to have to have electric cars. Every evening, you are going to come home and plug your car in when you have finished work. That changes our power system in this country; it becomes much more distributed. What does that have to do with space? The more complex your power distribution, the more vulnerable it could be to the impact of solar disturbances and so on. You have to think through where our society is going and then come back and see where space fits into it. I chose that last example because I am sure you would not know it.

There are lots of things that we can see coming. We are going to move towards a greener world, I trust, and space will be utilised in a large part of that. I hope what comes out of COP26 will lead us globally towards a greener world. Space is the only way you can look at our world and monitor what is going on. It is the only way you can keep up with the health of the planet.

There is an economic question that, increasingly, we are going to have to think about: how we persuade the laggards and how we internationally charge for pollution or modifying the climate. I do not know quite how that is to be done. It is the way, I would say, if I saw the world perhaps not in 2030 but 2040, that I feel we will have come to terms with in some way. It is an economic issue, so there is a very clear need for the Governments involved, and for the Government to persuade other Governments how we should behave.

Equally, to take perhaps something that is a little less worrying, I am pretty sure we are going to be exploring in deep space and we are going to have exciting events like landing on the moon again, going to Mars and

sending robots around the solar system. That is also part of space, and it is something we will see.

I am sure we are going to have exciting events, but we have to bring home the technology that we use to get there. I am sure all of you have mobile phones. Many of the protocols that are used for switching systems for your messages came out of deep space exploration—the requirement to be able to communicate and to manage data from far away. There is a lot of spin-off as well. Focusing on what the world will be like is where we should start.

Q31 **Chair:** Thank you very much, Professor Southwood. You have huge experience in this area. We first met when you were president of the Royal Astronomical Society. You have also served at the European Space Agency.

Sometimes, I wonder whether the term "space", covering the sector as it does, can lead people who perhaps do not follow it is as closely as some of us do to think that this is wonderfully exciting and very stimulating intellectually and in other ways, but it may not be as practical in difficult times and an economic priority.

In government, when I was responsible for these things, I used to talk about space and satellites, too, because people understand that satellites have an almost infinite range of applications in everyday life. You have given an example of how some of the protocols in mobile phone technology come out of deep space exploration. Given your long experience of leadership in the sector, is there a tension and a difficulty there?

Professor Southwood: You put your finger on something that I felt throughout my career. When you are on a train and you talk to the person next to you and you say that you are in space, immediately, they leap to the wonderful things of exploring the solar system, but they regard you as somewhere else, whereas, for me, space is everyday life. As Professor Ochieng mentioned, it is part of our critical national infrastructure. Whether we like it or not, we depend on space systems, and our nation needs to be aware of that. Does the general public need to be aware? They are taxpayers, so they need to know that this is an important thing that the Government need to be paying attention to and funding.

There is a dichotomy. The minute I say I am a space scientist, people want to talk about going to Jupiter, which is fine. It is very exciting, but it is not what everyday space is, and it is not, if you look at what this country spends on space, the biggest item.

You are absolutely right to pick up that dichotomy. We must somehow harness the enthusiasm and interest in the exciting final frontier aspects and bring it back home because there are some really fascinating problems that we can deal with having been on the final frontier, if you see what I mean.

Q32 **Chair:** Thank you. Hopefully, our inquiry will make a contribution to that.

Professor Southwood: Yes.

Q33 **Chair:** Professor Ojha, give us a glimpse into the future. We have talked about some of the applications now. What over the next 10 years might members of the public in the UK expect to see and experience that is attributable to space and satellites?

Professor Ojha: I will follow on from the point Professor Southwood made to help to frame the answer. My answer to, "What do you mean by space science?" is to say that it is three things: it is looking out there, which is astronomy; it is going out there, which is exploration with robots and humans; and then there is the part that very often the general public overlooks, which is the satellites that are not looking out there but are looking back here, and that is space-for-the-benefit-of-life-on-Earth satellite applications. Those three ecosystems, as such, are linked together much closer than people realise.

Right now, in terms of where we are in the UK and globally, the space sector is undergoing change at a more exciting rate than we have seen since the 1960s. What are we going to see in the future? The previous panellists talked about the importance of space capabilities for a critical national space infrastructure, and they gave some really great examples—navigation, monitoring and so on.

What are we going to see? COP26 is on at the moment. We will be able to monitor and get the solutions and look at the progress only through this network of infrastructure that we have in space monitoring the Earth. I liken it to having a patient in an intensive care unit. You can have all the medicines that you would want to trial, but unless you are monitoring the health of your patient in real time at a really high level of resolution, you are going to be held back massively. Space gives us those capabilities and platforms that we need to answer those issues, in terms not just of climate but of the drivers of potential future conflict and geopolitical tensions, such as the challenge of feeding the world's population and the challenge of resource.

The previous panellists referred to megaconstellations—hundreds or thousands of networked satellites in orbit in a way that was not possible 10 years ago. That gives us new capabilities for the future in the next 10 years. Exploration, which is one of my areas of focus, is not just driven by science; there is a geopolitical aspect to it, of course. When we look at the exploration agenda now, it is being highlighted as it never was since the 1960s—a return of humans to the moon and the ambition of humans on the surface of Mars within the next 15 years. It is being translated into reality. It is important because many of the technologies we will need have a direct relevance, here in the UK as well as globally, to what we need to achieve in terms of net zero, such as our issues of power generation and of recycling the materials we will need.

We are trialling technologies on the ISS, and they are directly applicable to solutions on Earth that, at first glance from the public, are completely removed from space. It is an inflection time at the moment with really exciting changes and possibilities. We need space as part of the solutions; this is not a bolt-on.

To be honest, we need to do a better job of telling the general public and policy makers about this. People will have heard HRH Prince William a couple of weeks ago: why are we focusing on space when we are looking at the carbon footprint and the problems on Earth? We will not be able to solve the challenges that we face on Earth sustainably at the resolution and data rates necessary without that space infrastructure and without those space capabilities.

Q34 **Chair:** Thank you. That is very compelling. In terms of people on the moon and on other planets, why is it necessary, given what we can do remotely now? Is it necessary or desirable to put people there rather than machines?

Professor Ojha: It is a really good question. Lord Rees has made that point very clearly: why send humans when robots can do the job?

One of the challenges we talked about previously was building hardware to go into space, because we are launching in an incredibly violent launch regime in terms of vibrations and so on. Once it is in space, it has to operate in the harshest regime you can imagine—far more challenging than anything on the surface of the Earth. When we are looking at instrumentation going elsewhere in the solar system, we are talking of a journey time of months or years. By the time you design your instrumentation, flight test it, qualify it, launch it and it gets to its destination, it is obsolete compared to technology on Earth. With a human, that is not the case. Humans have a flexibility that is unparalleled.

My colleague, Professor Ian Crawford, did an analysis of the science conducted during the last Apollo lunar landings—15, 16 and 17. The science output from those trained astronauts was off the scale compared with their geologist colleagues on Earth. We talk about having humans and robotics systems working together. There is a benefit for Earth, ultimately. Many people ask, "Why do we want to understand the moon? Why do we want to understand Mars? Why do we want to understand Venus?" It is what I call comparative planetology.

By looking at the history, development, geology and atmospheres of other planets in the solar system and how they developed, we have, fundamentally, a better insight into the history, the evolution and possibly the future trajectory of our own home planet. Studying the Earth in isolation is fine, but doing comparative planetology is not only intrinsic knowledge for its own sake but gives us a better understanding of our home planet. We have seen this specifically in terms of carbon dioxide in

our own planet's atmosphere as well as other processes within the atmosphere.

Chair: Thank you very much indeed.

Q35 **Carol Monaghan:** That message probably does not get out enough or widely enough—there is that lack of tying up between what can be done in space and the impacts here on Earth.

I am going to come back to the question I asked the last panel about space strategy: what was positive about it and what was missing?

Professor Southwood: I am really pleased that the strategy is there. It gives you a reference point. You can refer back to it and show that this is what the country is trying to do. You can even use it to co-operate with other countries. However, from the point of view of the needs of our country, as Professor Ochieng said, it is a strategy that gives us a vision more than how we get there and how we deliver the targets. I recognised my own country when I was reading the strategy. In other words, it is right in that sense; it is something we can sensibly chase.

Then there is the question of how we do it. We are in a different world now. Until we decided to leave the European Union, in a way lots of issues were carried for us by our policies with the European Space Agency and the European Union. Now, we can think for ourselves. That does not mean we have to be antagonistic to anything. It means we can put an emphasis on the things we feel are very important for our country, and we can leave aside issues that are not so important to our national needs. In other words, we can focus back on ourselves. There is an element missing, which is the joined-upness. We need to make sure we know how we do things.

Q36 **Carol Monaghan:** Do you know who will do that joining up?

Professor Southwood: Not entirely. The UK Space Agency has a new CEO, and he has certainly been charged with delivery. What I am talking about could be called delivery. It is taking the goals given by the strategy, which I would sign up to, and finding out how to do them. We have to do some of them, such as elements of national security and sovereignty, ourselves. It is as simple as that. At the other end, there are things that clearly matter globally. The obvious thing would be dealing with space safety and space traffic management. We will have to negotiate that with other countries, and we will have to somehow find a way to do it, but we will not do it on our own. We cannot manage space traffic when we are a single nation.

We have certain tools. We have had long-term collaborations both in the civil and the military area. We should build on those where they are appropriate and where our national interest is not supreme. There, you can pull out things quite straightforwardly, but you need then to make sure that it does not become an interdepartmental battle as to who is in

charge, which is what is so important about having a National Space Council.

With all due respect to our civil service system, there is a tendency for silos to form. I honestly think space goes across. One of the great things is to see the change in attitudes in the Ministry of Defence. There is much more recognition in our Ministry of Defence that civil systems may be cheaper, more effective and made secure, to be used in a way that they probably were not 30 years ago. Things are changing, and it is time to make sure we have this joined-up thinking across our Administration in this country.

There is a new CEO in the UK Space Agency, and as I said, he has to deliver. This is one of the things he is going to have to work at because he has to look at what he is delivering to as well as how he delivers it, using the European Space Agency, national facilities and national industry, or negotiating at the truly global level in the UN. Those are all things where some of the problems we will face in future need solutions, but you have to choose the right way to go, and we have to look after our own independence, remembering that we are different.

We are, I hope, going be the first nation in western Europe to launch rockets into space from its territory next year, as you have picked up. That makes us different. It gives different interests. We are the first western European nation to have our Government invest in a constellation for communications and potentially other uses. That makes us different. That means we have to look after our interests. I have probably said enough.

Q37 **Carol Monaghan:** Thank you. Professor Ojha, could you come in as well? I am aware of the time. The Chair is probably eyeballing me.

Professor Ojha: The forcing function of the integrated review for the formation of the national space strategy and the defence space strategy, which is soon to be released, have really done the job in focusing minds on the need for change in structures. As a vision document, I agree with my fellow panellist that it is great, but we need a strategic delivery plan. Succinctly, the challenges are funding, governance, sustainability and people.

On governance, we have different entities working together. We have a National Space Council. We need to make sure we are getting the right advice from industry, from academia and from all the stakeholders directly to the highest level. My understanding is that our space council was modelled on the US model chaired by the Vice-President. It is very successful because of the advisory structures to make sure we are getting maximal intelligence input in forming the decisions from, as Professor Southwood says, the MOD and the UK Space Agency. Do not forget the role of the research councils. I have to declare an interest in the STFC. We are the entities together that will deliver that strategy, and roles and responsibilities need to be outlined very clearly—we do not

need coherence, perhaps there is an element of top-down command and control—and we are not quite at that balance yet.

Thirdly, on sustainability, in terms of small satellite launching, that will be great next year. Looking at what Virgin Orbit can do with a launch system under a 747, I am confident that is going to happen in Cornwall in 2022. That will be a great moment for the UK. Going forward, in 10 years, if we want to have sustainability, we need to make the UK an attractive investment opportunity for those people wishing to build small satellites here and launch them from here. We need to look at that sustainability across all of those aspects that are highlighted in the strategy.

Finally, where the strategy, unfortunately, is really lacking, is not because of our lack of expertise but because of skills. Underpinning us teching our way out of the challenges we face now using space, people are key. There is a broad spectrum on skills development, from the inspiration programme—a really overused word in my opinion—all the way up to the really focused skills development programmes. Some of them are broad, for millions of people. Some of them are for smaller numbers of people and much deeper in depth. You need to have a graded, supported and strategically championed approach for all those different levels. We have the elements in the UK that have been developed and supported with the UK Space Agency and the research councils. They need to be ramped up at scale because we can have all the ambition and even a delivery plan but, for our next generation who are going to implement this and develop our new capabilities, we as a sector are competing against other sectors that will be trying to attract them. That is where I found, unfortunately, the strategy really lacking, but the solutions are there. I would hope that is looked at again in giving a much higher strategic and operational prioritisation.

Q38 **Aaron Bell:** Thank you both for your time.

Following on from what I was asking Lucy Edge earlier, what would you pick out as the most exciting space technology—you have already spoken a little bit about this, Professor Ojha—currently being developed above and beyond the ones we already know about like PNT and communications?

Professor Ojha: In terms of satellite applications—I will take a step back—it is capabilities. It is the capabilities and the potential for megaconstellations. Megaconstellations are thousands of satellites in low-Earth orbit. Two years ago, there were 2,000 satellites; today, there are 4,500 active satellites. In 10 years, there will be 20,000 to 40,000. I have concerns. I am an astronomer. I look at the night sky. I still use my telescopes, and there are light pollution issues. The potential benefits, if it is done right, are not just in monitoring the environment.

The biggest challenge we face globally is access to data. Three billion people are unconnected at the moment, and we know that access to data now is a key part of a gold standard. It is not just about energy supply.

These space capabilities and technologies that we have, and that we will develop further, are transformative, and that is really exciting.

In terms of astronomy and exploration—those other sides—getting humans to the moon and moving on to Mars, our capabilities to understand the universe, the new capabilities we are having and the technologies that we need to develop have, in some cases, direct relevance to the use of data here on Earth. I have talked about going to the moon and Mars. Energy production and generation lends itself, potentially, to small modular reactors and the way they can be used to help to address net zero.

If we want to understand having 10 to 50 times more satellites in Earth orbit, we need to understand what we call space weather, because 160 years ago the sun ejected a huge cloud of material. It was a solar flare. It is called the Carrington Event, and it made these aurorae that we saw a couple of weeks ago appear globally. In 1859, that did not really have an effect on us. If it happened now, it would wipe out most of our orbiting satellite infrastructure, on which we are critically dependent. It is exciting, but we also need to look at the resilience that we are building in.

Q39 **Aaron Bell:** Thank you. Professor Southwood, what is most exciting for you?

Professor Southwood: I always dislike this question. It is like being asked: which of your children is your favourite? What I am going to do is agree with Professor Ojha and then choose something else.

What fascinates me most at the moment is positioning navigation timing—GNSS, or whatever you want to call it. That will be very much part of the future. It is already part of our day-to-day life. Resilience is one aspect. Getting around spoofing is important. The weakness of any space system is that the signals that come down to Earth could be picked up by other people and modified. There are very interesting challenges there. There is the cyber aspect of how you encode and how you really ensure that these systems are not only as resilient as possible but as secure as possible. There are some very interesting technologies there. Our country has some real strengths in that area. Although it is not my own field—I was a mathematician originally; mathematicians are very important in this area—it is where I expect to see interesting challenges to the scientific and engineering community, but also some very interesting answers.

Q40 **Aaron Bell:** You mentioned the UK specifically just now and in your earlier answer. At the risk of giving you an opportunity to blow your trumpet for Imperial, which UK organisations are at the cutting edge, not just academic but industrial? Which organisations are doing the most groundbreaking research at the moment?

Professor Southwood: Now, you have really done it: I am beginning to have problems here. It depends where you start. Obviously, there is the

golden triangle—Imperial, Cambridge, Oxford and University College London. The University of Leicester is a standout case. We are friends. Imperial covers a very large amount of technology and health right across the board. Leicester has focused very much on space. They are doing some very interesting things partly because it is a provincial university that can put up its flag and say, "That's it."

If we move north of the border, clearly there is a great attractor along the Forth-Clyde Valley. There are lots of interesting industries there. They are relatively small industries, but that fits if a relatively small launcher is to be launched from the north of Scotland. There is an attractor that is focused on the Glasgow-Edinburgh axis, which is no doubt enhanced by the fact that further to the north we are going to be launching small spacecraft, so there is a whole industry developing there. It is in applications as well. The University of Edinburgh is very big on applications. It would be really unfair not to mention the University of Strathclyde.

Aaron Bell: I will stop you there before you feel like you have to list them all.

Professor Southwood: I have left out the entire west country, where I come from. I will stop there because you only lose friends by being asked that.

Q41 **Aaron Bell:** That is why I am cutting you off. You can blame me later. Professor Ojha, the same question to you, particularly on the non-academic side as well.

Professor Ojha: That is a really interesting thing. The traditional powerhouses of academic expertise in the United Kingdom—Leicester, Imperial and others—have made their mark in some of the biggest missions. Everyone thinks of NASA. We have what we call principal investigator roles from the UK universities with NASA missions and the European Space Agency that are globally recognised.

What has changed in the last five to 10 years that is crucial for the future is the way in which universities are teaming with industry, not just the traditional big companies, the primes as we call them—this is where the role of the Catapult has been key—but with those key transformational smaller companies that are having a disruptive level of innovative transformation.

We call this the new space era. You have these companies that are small start-ups, very often with people much younger, and they are the true crucibles of creativity. It is not the older generation of academics like me. The opportunity for this synergistic working in a way that has not been done before is what is proving to be transformational. It is part of what is accelerating the commercialisation and the changing role of industry working with academia in space, and we need to grow that further.

When we look at Glasgow, for instance, when we look at what is happening, with my STFC hat on, down at Harwell with the growth of a space cluster, including companies that started off as start-ups—we have more than 100 now, and some of them are growing—the way that academia and industry work together, as we see in the Government's focus for this new way of research and innovation and funding, will be absolutely crucial.

Finally, related to that, with my Leicester hat on, when we look at Space Park Leicester, we are trying to get a co-location of academia, industry and skills development working together, which sounds like an obvious mix. There are hurdles, but if you have clear targets for where you want to get to, it is the right place to start looking at the role of industry—big companies—what we can do to facilitate an acceleration of new technology development, which is where these "new space" smaller companies come in, and how we do this sustainably.

Our skills development needs to look at the vocational route and the academic route, involving multiple partners grounded in the community. It is a really exciting time, but we have to build on that momentum.

Q42 **Aaron Bell:** Finally, on resilience—this is a point Professor Ochieng made in the first session—you referred to the Carrington Event. That is not very long ago in the scheme of things—a century and a half. You described the danger right now. How close are we to resolving the risks that we face from the Carrington Event through the work we are doing in new space technology?

Professor Ojha: We are pushing through with space weather monitoring, as we call it. "Space weather" is that term we use. As for the solutions, one way is to what we call radiation harden. The traditional way is to put a lot of extra material around the outside of your satellite. The problem is it is extra mass to launch into space. If this bottle of water is full, it has a mass of about 1 kg. The lowest cost to launch that from SpaceX is $2,700. You start to see that every bit of extra mass you are putting will have a massive commercial impact.

We need to look at having our technologies radiation hardened not necessarily through materials that are coating the outside of it but in terms of redundancy within the components. This is a challenge that we have not solved yet. There are multiple avenues that we need to push along. Some of them are materials based and some of them are hardware based, but we do not have a magic wand to come up with the solutions for them.

Q43 **Aaron Bell:** What is the best estimate for the risk we are running? What are the chances of another Carrington Event within a given decade? Do we have a good estimate for that, or do we simply not know?

Professor Ojha: We monitor the sun, so we know there is an 11-year cycle of solar activity that is overlaid by a 22-year cycle and an 88-year

cycle, but we still do not fully understand when we have these, in effect, cataclysmic events. I will hand over to my colleague, Professor Southwood, because I think he knows more about this than I do.

Professor Southwood: You cannot tell if the likelihood of another Carrington Event is a 100-year event just because it is more than 100 years ago. It is probably a 1,000-year event, so perhaps we could relax, but remember that it might come up tomorrow. We ought to be thinking about it. In fact, we have had much more regular events that are more like one-in-10-year events, such as flooding events that do not make the newspapers to the same degree but have major impact. Power outages are surprisingly common due to solar activity. I can also reassure you that some things have been sorted out. There are some straightforward mitigations. Once you have found out what the problem is, you can start to solve it.

Nearly 50 years ago, when I was working as a very young man in the United States, a military spacecraft was launched for the US air force. It died almost immediately. Was it action by the Soviet Union or somebody else? It turned out to be what is called a geomagnetic substorm. Never before had a communications spacecraft been behind the Earth at precisely the time when a substorm occurred. It suddenly found itself bathed in thousands of electron-volts, which produced big voltage differences across the spacecraft and killed the electronics. We understood, in the end, what that was. Now, we make sure that we understand how electricity is conducted through spacecraft. We simply build it in as a mitigation in the structure of spacecraft. I am sad to say that that discovery is occasionally remade because technologies move on and knowledge does not always move on with it.

I want to reassure you that we are improving things and there are things that we have still to work on. This country has stepped up to the mark in having a severe space weather strategy that is ahead of most countries on the planet, but it is a very appropriate thing. The impacts are very varied, and we are mitigating them one by one. We have some fundamental problems of physics, raised by my colleague here, of shielding from the very high-energy particles that come not only from the sun but from the galaxy. Those will come, and we will have to figure out how to make sure that, if they do not survive them, at least we mitigate the effect of them on our systems. There are various ways out of a crisis, as you know.

Q44 **Graham Stringer:** The Committee and I have been interested in solar weather and solar storms for some time. We have persuaded the Government, only fairly recently, to put it on the national risk register when it had not been there. In spite of what you say, Professor Southwood, I am still concerned, as we move to a more electricity-based infrastructure, that when it comes to hospitals and power stations we still do not have reserves. Do you believe, with your knowledge of solar storms, that we are putting enough resilience into both Earthbound

systems as well as thinking about space?

Professor Southwood: That is a very good question. It is a very sensitive question, and one that is not thought about elsewhere as much as it should be. Putting it on the national risk register was a very important step, but it means that people responsible for our national infrastructure and the way our society functions need to look at it, and this is one of the problems of the insensitivity to the fact that it can impact electrical systems in particular. It needs to be proselytised. People need to be sensitised.

Q45 **Graham Stringer:** Let me put the question to both of you in a different way. Are you knocking on Government's door and saying, "You should be thinking about this much harder"? Are people from your academic disciplines saying to Government, "Look, there is a vulnerability here"?

Professor Southwood: Yes.

Graham Stringer: Good.

Professor Southwood: I will expand on that a little bit. From the Government's chief scientist down there is a sensitivity to this. Getting it on to the risk register was a very critical step. It is a reference point. If you try to explain to people that this is important, the fact it is there and where it is on the register is very important. People think space is far away, but it is not. It is about 100 km above us. It is really close. It is as close as Leicester.

Professor Ojha: Related to that point, it is also an example of the critical interplay between those three areas of space science that I have highlighted, because there are some people who say, "Let's concentrate on satellite applications. We do not need to give prioritisation to the other areas." To understand space weather, it is not just monitoring the dynamics of what the sun is doing in its ejections of material and solar flares; it is understanding the processes inside the sun, which are fundamentally about astronomy. In other words, we have this interplay between one area of space science that many people would regard as purely academic and how that will give us greater resilience in our capabilities.

We have been doing that at the University of Leicester. We have been doing that at RAL Space and with other centres. We champion this because we recognise, probably ahead of the curve, just how vulnerable we are potentially and how our vulnerability will increase exponentially as our dependence on these orbital infrastructures is itself going up like this.

Q46 **Graham Stringer:** May I change tack a little? Professor Ojha talked about the three ways of looking at space exploration—satellites, looking down and astronomy. Professor Southwood, it may not come as a surprise to you that we have never had a witness before this Committee who said that their discipline should get less money. It has been my feeling since the PPARC was abolished that astronomy has fallen behind

other areas of science. Is that right? What are the consequences of that if it is right?

Professor Southwood: That is an unexpected question.

Graham Stringer: It was unexpected to me before we started.

Professor Southwood: The UK is still a major astronomical nation. In fact, our astronomy has shifted after the PPARC days, or in the last 20 years, much more towards planetary science than 20 or 30 years ago.

What is my favourite part of astronomy? It is all of astronomy, and it is very hard to pull out favoured parts. If it comes to it, my favourite parts are the places closest to Earth because it is where I live, and it is where most of my friends live, so I work outwards. The UK shift towards much more spending, more effectively, on planetary science, solar science and so on is correct. Whether we have got it right for astronomy overall is an open question. We have this great advantage of the English language, and much of the astronomy is done internationally. We still make our mark there. That is not a reason to think we are getting properly funded. We could do the two things better.

Moreover, it is very important to regard astronomy as terrific training. If you look at some of our leaders in space applications, where did they get educated? They got PhDs in astrophysics at Imperial, Leicester, Cambridge and so on. Intellectually, there are so many technologies you use in astronomy. The challenge to astronomers is to make sure that the rest of the country can use those technologies when they are applicable, and they usually are. That is one of the very interesting things about astronomy: you think it is about something that is over the horizon almost; in fact, very day-to-day things come out.

One does not want to create a country loaded with astronomers. One wants to create a country that uses astronomers, which means funding astronomy academically properly and equally well in our industrial companies. Often, building space astronomy instruments is a very small element of a company's activity. It is one that its staff fight to get on to because it is exciting, inspirational and challenging. If you are going to try to measure some tiny dot in the sky, you have to be very clever, and your technology has to be very clever. I regard astronomy as a national good. I do not have the figures. I will not back you up on that necessarily. You may have the figures and you may be correct.

Graham Stringer: Thank you.

Professor Ojha: On that point, the successor to PPARC was STFC. I am a current member of council and have been for several years. We have looked at this issue. It has become more challenging, but I want to reassure you that, in an uphill battle against—I will come back to funding—pretty much flat funding for the last 10 years and changing prioritisations from Governments, we still try to push, not just to

maintain a status quo but to increase our astronomical activity and what we are supporting. It has been challenging. We are doing this when we look at our role within the Square Kilometre Array. We are doing this when we look at our role with the next generation of large telescopes in Chile in South America and the UK's involvement. It is challenging.

What we have had to do as a research council sometimes is that changes in the exam questions have needed some greater not creativity but thinking of approaches of how we translate the astronomical development of technologies, which Professor Southwood talked about, into areas of more direct relevance. It has been a challenge, but I want to reassure you that we are still committed to not just maintaining but growing our astronomical capabilities, resources and prioritisation in challenging circumstances.

Graham Stringer: I am sorry if I gave unexpected questions, but you answered most of the questions that I was going to ask before, so I had to think a bit harder. The UK is going to have launch capabilities. How will that change the structure of science around it, or industry around it? Could you very briefly explain the financing of launch capabilities? Is it going to be a cost, or are we going to be able to earn income from it? Will it save us money because we do not have to go to Central America? What are the finances?

Professor Southwood: The way we have approached it is to do it as economically efficiently as possible. We are not building the launch sites for the Government in perpetuity; we are bringing in companies to run them, and it will be up to them to exploit them and for us to tax the companies, which I think is the British way of doing things. It is a cost-efficient way to do it.

On the other hand, anything to do with space is capital intensive at the start, so you have to have seed money. My belief is that we should expect the system to be a net earner for us as a country and a profitable activity for the companies and industries involved. If we do not do that, I dislike the idea of having a launch simply for national prestige. There is a new market—a small-spacecraft market and a small-launcher market. We in the UK sitting out in the Atlantic are a great place to launch from. I expect companies to make a profit on this, and I expect my Government to tax them.

Professor Ojha: The commercial business model is what is driving it. To be honest, there are other places in the world where you could launch. What is it that is going to make the UK special? We have the elements. We have extensive expertise in small-satellite manufacturing. Small satellites are great because you replace them every few years, they are not going to be obsolete, you have reduced launch costs, et cetera.

The challenge is whether we are going to support those elements enough—the advantages we have in the UK—so that the commercial entities will have that end-to-end small-satellite design, manufacture and

launch in the UK. That is the vision, but we need to do more to embed that and support it, otherwise in 10 years' time the danger will be that, if we do not get it right, we will have, effectively, the vanity project of small-satellite launch, with the potential for the UK to really establish itself as it has outlined in the strategy, but it fizzles out.

We must better weave together in our delivery plan for the strategy those components that can make the UK so special for small-satellite launch, which is our heritage in small-satellite manufacturing and our skills-development programmes, and marry that to the launch capability we have. It will always be small satellites from the UK. We are talking about the ones that are approximately the size of a washing machine—100 kg to 600 kg. We are not talking about the huge payloads that will always need to launch from French Guiana or from launch sites in Russia or the United States. There are opportunities. The commercial model has to wash its own face.

Q47 **Chair:** We are going through a collective experience of covid, which has affected every part of our lives and science in particular. When we have been through national experiences like this, it has tended to shape the way we do things differently. Do you have any reflections on the impact of covid, not particularly the short-term consequences of how you have operated in the last 18 months—obviously that has been different—but has it changed the way we think about risk and about how we operate in scientific disciplines such as yours?

Professor Ojha: Looking at critical vulnerabilities and our challenging the status quo, sometimes the space sector can be necessarily a very conservative sector. When we look at building what we call the upstream space sector—building hardware, et cetera—we are conservative because we have to test everything to the nth degree. We are going through this incredibly challenging regime of launch operations, so we have a conservative engineering mindset. Sometimes, that can be not orthogonal but pretty much orthogonal to the desire for creativity and innovation.

Covid has forced us at a practical level to take on board innovative approaches when we are looking at the way we conduct meetings and when we look at the way we teach, which many organisations were resistant to until they realised changing the way we do things is not as challenging as we thought. We are an incredibly ingenious species. We can adapt to change. That will translate itself into the way we do things on the space side. I talked about this being the most exciting time since the 1960s in terms of space. It is because of the role of new space and getting new creative approaches, I would say, from a workforce at a younger stage in a disruptive way. They have always gone against the system, so to speak.

Covid has taught us that we need to be much more flexible and adaptive in our response to new ideas that come through. That is what is going to drive the space sector through. It has been a cultural change of focus

from those that are the disbursers of funds and those that are leading large programmes that hopefully will allow the genuine innovators to come through earlier and with fewer barriers to their progress.

Professor Southwood: I am not going to argue with any of that, but I have a rather different aspect. I have realised how much science depends on the social aspect, and also happenstance. When I am working from home, I can talk to the people I am co-operating with. In fact, in that regard it has been even better. I have been working with people in the United States. We communicate—we do not have to fly across the Atlantic: we communicate at home.

What I do not get are the random effects of meeting people who work in a slightly adjacent area. You meet the people you intend to meet. In creative science and creative engineering, something I have missed is learning from people things I did not know—where I think, "Well, perhaps you could do it this way, because I am thinking the way I think and this person is thinking the way they think." That is the social aspect of science and technology that is often underestimated. In my own career, I have moved around in fields, and it has often been due to this aspect of suddenly realising there is something you could do something with that you had not appreciated before. I am sure Anu agrees with me.

Professor Ojha: Absolutely. Fundamentally, it is all about people. We know that those serendipitous conversations you have within academic settings, industry or people generally, really fuel the creativity. I was approaching it more from a governance-and-the-role-of-new-space point of view but, ultimately, it is about getting people together and those serendipitous conversations, which do not really happen on Zoom or virtually.

Chair: Good. Bringing people together of different but hopefully complementary perspectives is absolutely what our inquiry is about. Both sets of witnesses have helped us launch it with great distinction and panache. Thank you very much indeed for giving evidence today.