House of Commons

Business, Energy and Industrial Strategy Committee

Oral evidence: OneWeb, HC 806

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Watch the meeting

Members present: Darren Jones (Chair); Judith Cummins; Richard Fuller; Ms Nusrat Ghani; Paul Howell; Alexander Stafford.

Questions 1 - 26

Witnesses

I: Carissa Christensen, Chief Executive Officer and Founder, Bryce Space and Technology; Professor Marek Ziebart, Professor of Space Geodesy, Department of Civil, Environmental and Geomatic Engineering, UCL; Dr Mark Dickinson, Deputy CTO & VP Space Segment, Inmarsat.

Examination of witnesses

Witnesses: Carissa Christensen, Professor Marek Ziebart and Dr Mark Dickinson.

Q1 **Chair:** Welcome to this morning's session of the Business, Energy and Industrial Strategy Committee. Today's hearing is in respect of the OneWeb satellite purchase by the Government, which was announced on 3 July this year. At the time, the acting permanent secretary felt unable to authorise the purchase without what is called a ministerial direction, due to the speed at which the Government acted in putting forward their offer. We launched an inquiry to try to understand the background of the purchase, and also the technical aspects of the OneWeb satellite system and what that means for the UK post Brexit when we lose access to European satellites such as Galileo and Copernicus.

This session is therefore a technical session with our witnesses on the panel. Colleagues will note that we are one witness down. Tim Farrar was due to join us today, specifically to advise us on space spectrum and the value of that. Unfortunately, yesterday afternoon the Government said that they were unable to support Tim attending the Committee today because of his involvement in advising the Government on the OneWeb purchase. Clearly, from our perspective as a Committee, that is entirely unsatisfactory. It is not for the Government to interfere with witnesses appearing before this Committee, but we understand why Tim has therefore felt unable to appear before us today, and we look forward to calling him in due course.

That to one side, I am delighted to have three excellent witnesses with us today. We have Professor Marek Ziebart, who is Professor of Space from UCL, Dr Mark Dickinson, who is the Deputy Chief Technology Officer at Inmarsat, and Carissa Christensen, who is the CEO of Bryce Space and Technology. We are delighted to have you all with us this morning.

Before we get into some of the technical questions on OneWeb specifically, I just wonder whether you might help us with a 101 before we get into those questions. It would be useful for the Committee and the House to understand from a Government perspective and from a state perspective what it is that we currently have access to as members of the European Union—what we are therefore losing at the end of this year—and why we are therefore interested in buying new satellite companies. Then we will get into some of the detail of OneWeb. I wonder if, Professor Ziebart, I might come to you on that, given that you lecture people on the 101. You might be able to help us understand that starter for 10, please.

Professor Ziebart: Let me try not to lecture you or hector you at least. For Brexit, wherever you stand on that, it means that we have lost access to our role in the Galileo system. Galileo is a satellite navigation system much like GPS, but it does have some features to which we have privileged access, because we were one of the system developers. Not least of those is the technology development, running the facilities to operate the system and being deeply involved in the actual technical aspects of research and development. It also meant there were jobs for very high-tech people working in British industry and we built up considerable expertise in that area.

The 101 in terms of what we lost is, first of all, opportunities for development of our space sector and access to certain classes of signal of the system that are hard to jam. Let us just bring that up as an issue. Many criminals and certain states would like to interfere with satellite navigation systems and make it difficult to use them. You can fight against that by having very advanced signals that are resistant to jamming and by having military-grade complex signals that are stronger and more reliable under various circumstances. We have lost access to those and that makes us vulnerable. I was one of the authors of the Blackett review for the Government on resilience of position, navigation and timing, so these were issues we did discuss. Is that sufficient for now?

Q2 **Chair:** Yes. Thank you for that. In the post-Brexit world, we have lost access to these particular signals that we use for secure—or military, presumably—requirements. That was why the previous Prime Minister had announced sovereign capabilities to be invested in so that we had something that was not reliant on the American GPS system, because we did not have access to the European system and for obvious reasons we would not be able to collaborate with other systems from countries such as Russia or China. We wanted to build our own. Before we get into the detail, I wonder if I could bring Carissa in on this point. What is OneWeb in relation to those sets of requirements? Is that going to solve everything for us, or do we still need to build some more things?

Carissa Christensen: Generally speaking, again just in that 101 context, satellites are usually focused on a particular purpose. Satellites provide communication services and the UK has a number of major communications providers, including Inmarsat and Avanti. Satellites provide imagery. They take pictures of the Earth and provide insight, and there are multiple commercial imagery providers, although there are no major providers based in the UK. Satellites provide GPS signals and those have mostly, although not entirely, been dedicated systems purpose built to provide navigation and timing information.

There are systems that provide multiple services. For example, there is a communication system called Iridium, which now works with a company called Satelles to provide a certain kind of navigation system. There is a pathway toward hybrid satellite activities, but it is not typical because of the complexity of satellite systems and the need to optimise the equipment and design of the system for a particular purpose. I would say, again having not conducted an engineering study on OneWeb, so I am speaking very generally, that it is an open question and an important question as to the extent to which that system design in the near term is suitable for navigation, whether it could evolve to be suitable in the long term, and how that affects the economics of the system from a commercial standpoint.

Q3 **Chair:** Thank you for that. Dr Dickinson, the Secretary of State did say to our Committee before the summer recess that the main intention of OneWeb was to provide rural and maritime broadband connectivity, and he focused on that as opposed to the positioning requirements that we might need as state. Clearly, Inmarsat has been involved in this business for a long time in providing services from your own satellite capacity. From your perspective, how would the Government buying OneWeb and having a state ownership in OneWeb complement or add value to what we already have access to, for example through Inmarsat and other providers?

Dr Dickinson: Thank you for that question. Maybe I will make just one comment initially by just thanking the Committee for inviting Inmarsat on to this panel to give evidence. We really welcome the opportunity to engage with the Committee and this is a pivotal moment, I believe, for UK space and how we can make decisions going forward to make space strategic and a very important part of the UK economy.

You are correct that a wide range of services can be provided by space. Inmarsat has been around for 40 years providing mobile global communication, initially mandated for the safety of live services, and that has evolved over time. We still provide that service for all maritime vessels, but now we have a wide range of users and Inmarsat itself is addressing those market sectors. That has dictated the Inmarsat system design.

As you have highlighted, the public statements are around the OneWeb system serving broadband needs and maybe backhaul needs, which are quite different market sectors than Inmarsat has been serving and will serve in the future. There are different systems and different designs for different markets and for different services, so this could be seen as a complementary addition to the UK's suite of capabilities.

Q4 **Chair:** Thank you for that. To summarise the 101, OneWeb does not provide a kind of secure positioning or military requirements, so we have to think about that in addition to this, but the OneWeb system could be seen to be complementary to the access we currently have to services on the connectivity requirements that the Secretary of State referred to. This is probably why in the ministerial direction it was discussed as a commercial opportunity for the UK state to buy OneWeb out of its bankruptcy situation in the United States, and I just want to start to dive into some of those commercial considerations.

OneWeb, we understand, built satellites in a different way. Traditionally, as I understand it, you build a satellite; you have it in the middle of your factory, people come to it and build it up. They used to be quite big and they are a bit smaller now. OneWeb had been working to try to speed up the process to reduce the cost, so that you could get more of the things up into your allocated space after launch. I just wonder whether we could have a bit of a conversation around some of these key technology innovations to understand that and perhaps to challenge me if I have just inaccurately made that assessment. Professor Ziebart, you are nodding. I do not know if it is in a positive or a negative way, but I will come to you first on that.

Professor Ziebart: I would not want to show my hand too quickly. In terms of mass production of satellites, that is what we are looking at. It is rather like the step from conventional car manufacture to Model T and the Ford car. Historically, you would design a satellite, you would put a lot of very complicated, often novel instruments into satellites and then spend months in a very carefully constructed environment called a clean room, where you would test all the instruments to make sure the thing is going to work properly in space.

If, on the other hand, you are actually building your constellation of satellites from many satellites that are very similar to each other, you can build one and then carry out extensive tests on it, and then mass produce the others and just carry out routine unit tests on a sampling of those satellites, with some associated risk. That is a new paradigm in the construction of satellite technology and OneWeb had done well in terms of solving many of those problems. They have a production line where they can turn off, say, one to two satellites per day, much as SpaceX do. Contrast that with one satellite every few months. That is a complete paradigm shift, so for the UK to get a slice of that action of understanding those processes is going to be a good thing.

Q5 **Chair:** Thank you for that. Carissa, I wonder if you could help us understand the same question in respect of launch costs, because of course you might be able to speed up the production of these in the factory, but you still have to get them up into space. Have we seen similar efficiencies and reductions in cost in doing that as well?

Carissa Christensen: To frame that, let me speak for a moment about the architecture of OneWeb. The smaller satellite size of a tenth or less of the size of large communication satellites is part of the innovative architecture that has been proposed. This is not a brand-new concept, but its implementation in a constellation of hundreds or even thousands of small satellites in low Earth orbit is really part of what is viewed as innovative about OneWeb and other broadband LEO systems. By contrast, large communication satellites in geosynchronous or geostationary orbit are 22,300 miles up, can see about a third of the Earth and can serve a large population as an individual satellite, although they are often part of a system.

The OneWeb system, by contrast, is many small satellites orbiting very close to the Earth, hundreds of miles up. That has some advantages, in particular the idea that this system is resilient to the failure of an individual satellite. It also has an advantage in terms of communication efficiency. There is less distance to the satellite, and so, therefore, you do not get the same kind of lag that you do with a satellite that is further away, again all things being optimal. On the other hand, there are some disadvantages to that architecture. It is more at risk for certain kinds of disruption, intentional disruption or debris and it is more at risk of creating debris that can be a problem for other space activity.

To then get to the question of specifically launch, the deployment of a system of many hundreds or thousands of satellites is not likely to happen satellite by satellite. It will happen for the most part in large groups of satellites, so those satellites are using essentially the same launch vehicles that larger satellites are for the majority of their deployment. There may be small test excursions or missions that would use very small launchers, but generally speaking it is using larger launchers. The benefit that you get, if any, is really around the number of launches you are conducting. More launches equals more cost, but a higher launch pace equals lower cost per launch and more launch efficiencies. Generally speaking, a priori you cannot say that it would be dramatically lower in launch cost, but it does change the trade space somewhat.

Chair: You can shoot up more in one go, so you do not have to pay so often to launch.

Carissa Christensen: On larger vehicles.

Chair: Understood. Sorry, Professor Ziebart, you wanted to come in.

Professor Ziebart: Let me just add a point. We should from a 101 perspective establish some numbers here. Here is the Earth. These low Earth orbit satellites we are talking about are operating about 1,000 kilometres off the surface of the Earth. It is about here. The conventional navigation satellites used for GPS operate at about 20,000 kilometres and the GEO satellites that Inmarsat, for example, has specialised in for many years operate out here at GEO. We are going to deal with these three terms: LEO, low Earth orbit; MEO, medium Earth orbit; and GEO, geostationary or geosynchronous orbit out here.

On the launch, I would set out one thing, which is the capability to launch multiple satellites off a single launch vehicle and the associated costs. Mass is the main problem, but it is also how high you want the thing to go. Launching into LEO is an awful lot cheaper than launching into GEO. It is just to do with the amount of energy required to get the thing out here. Both OneWeb and Elon Musk’s SpaceX have developed the capability to launch multiple satellites, as many as 30 to 60, off a single launch vehicle. That does have some economies of scale.

Q6 **Chair:** Thank you for that. I had a note to say that it is very hard for Hansard to record props, but I enjoyed it nonetheless, so thank you for doing that. Dr Dickinson, did you want to add anything in addition to my questions before I move on to colleagues?

Dr Dickinson: I will make a comment, particularly around the technology being developed, and the innovation around the new capability for designing constellations. It was not that long ago since space was really the preserve of Governments and very large organisations, and that has really changed very radically over the last 10 years or so. There are many more space actors. There are many different technologies that have come in that are allowing satellites to be deployed for various applications. You saw an Indian launch last year launching 70 different satellites in one go. Things are changing radically.

To follow on from Carissa's points, the technology and the manufacturing capability that the mega-constellations require, simply due to the number of spacecraft they have to produce, does percolate through the whole space ecosystem. Inmarsat is purchasing large, very sophisticated technical geostationary spacecraft, but we are seeing in our latest spacecraft we are taking advantage of some of the manufacturing concepts that have been evolving over the last 10 years for these constellations and been applied to more traditional spacecraft. In terms of manufacturing, we are not producing a satellite a day. We do not need to for those GEO spacecraft, but we are seeing the cost advantages, the techniques and skills being developed, and the innovation being applied more broadly across the whole space sector.

On launch there are a lot of satellites to be deployed on these systems and the ability to launch many tens of spacecraft at any one time is a great enabler for that. Maybe in the future they will be looking to add additional spacecraft to be able to complement the fleet or be able to replace any spacecraft that need to be removed from the fleet or that may have to be reorbited. The ability to launch by small numbers in the future will probably be important for them, and getting the number up quickly and in the right orbits.

We can maybe discuss later on about the different orbital architectures they have and what the most efficient ways of deploying those assets are. OneWeb is in something called polar orbit and that means you have a certain number of planes around the Earth with satellites in each plane. The message is that innovation that happens for constellations actually does pass through to the whole of the space sector.

Chair: Thank you for that. We certainly will be coming back to some of that detail shortly.

Q7 **Richard Fuller:** Thank you, witnesses, for joining us today. I want to talk about the numbers of satellites. Ms Christensen, you have said previously that the start-up satellite companies are targeting more than 20,000 of these small satellites in the next 10 years, which sounds like an awfully large number, certainly compared to history. I wonder if you might just help the Committee by stepping us through the challenges with doing that, both from a CEO perspective looking at the operational difficulties within their own company to doing that, and then from a board perspective with an eye over, collectively, with all these companies trying to do it, what it might mean. You have said that a small fraction of these are actually going to be deployed. Then I would be interested in other comments. Ms Christensen, if you could start, that would be helpful.

Carissa Christensen: I am more than pleased to, Mr Fuller. There has been a change in the space sector over the last decade—really visible since about 2015. That change has been driven by external investment from venture capital firms and from a group of billionaire advocate investors who are deeply invested in space. That has resulted in a significant increase in start-up space companies, far more than historically we would have seen. Many of those companies are built around small sats to try to take some of the technology and innovation that we have been talking about and apply it to new business concepts.

Across venture-funded businesses, not simply in space, the typical success rate is about 25%. About 25% of firms succeed and, anecdotally, about one in 10 generate really significant investment returns. This is also somewhat different culturally from the historical space sector, which had large industrial players as well as government actors very much involved in the risk tolerance associated with these start-ups. Certainly, simply based on the structure of that emergent element of the industry, one would expect a relatively high degree of mortality from start-up companies. That is, as I say, normal.

There are certainly technical challenges associated with space systems; it is a remote and hostile environment. More significantly, generally, from a business standpoint, challenges are around capital and financing, and around customers and revenue. Capital and financing requires investors, banks and insurers that are comfortable with the technology and supportive of what is typically a longer period before returns are generated. The challenge on the customer and revenue side is often either competing with terrestrial alternatives, which can be lower cost, or building a market where the space service is offering something entirely new. We are seeing that, for example, in certain kinds of analytics products. We would expect to see that in pay-for-service navigation. Navigation signals are globally largely free at this time. That building of a market also adds to the timeline and the risk.

Q8 **Richard Fuller:** Thank you, Ms Christensen. I would like to just broaden it out to the other two witnesses, if I may, Chair, and come to Dr Dickinson. What Ms Christensen was focusing on was non-operational risks specifically and highlighting, to my mind, first, venture capital mind-set. Secondly, that is associated with a higher degree of financing risk than has normally been the case in the industry. Thirdly, innovation risk from either competitors within the sector or general innovation in other sectors has a significant impact on the commercial viability.

Dr Dickinson, on the actual operational challenges for the chief executives of these various companies trying to launch 25,000 satellites collectively into space, what is going to go through their minds about the major challenges they need to overcome to win in such a competitive space market?

Dr Dickinson: People often focus on the space segment. They like satellites. They like to see launches. The complexity on these systems is not just the satellites in orbit and making sure that they stay in the right place and that they do not have any collisions. To have a service is a far more complex aspect than just the space segment. You have a whole complex ground segment to manage and you have regulatory issues to manage around market access to allow you to make sure that you can provide services into regions of the world where you want to develop a market and achieve revenue. From a top-level operations point, you have a number of areas that you need to focus on.

You are quite right that the satellites need to work and be able to be kept in their correct positions. All that sort of stuff from a technology point of view can be achieved, and that is clear, although it is a challenge. A lot of it has to be automated because you are dealing with the sorts of numbers where we are seeing proposed systems of hundreds or even thousands of satellites. That has to be coupled with the whole end-to-end system architecture, in terms of ensuring that you can get data from the satellites to the ground, to where it needs to go to, and you need to have the regulatory environment to allow you to serve those markets that you want to.

These are complex systems to manage. Technology will be needed. Automation will be needed to make that work, but that does not mean to say that it is not possible. As Carissa highlighted, there are LEO constellations around today, albeit not in the same sorts of numbers—Iridium is a good example—that are providing services today and have done so for many years with quite a complex LEO type of constellation.

Q9 **Richard Fuller:** Just to ask a bit more detail on that, compare the risk on the operational side to maybe some of the other issues that Governments are wrestling with at the moment. They just do not know the answer to a new virus and how it works, and it all has to be discovered. However, do we kind of know what the operational risks are likely to be? They are in manufacturing, in launch capacity and making sure that you can deliver a satellite a day rather than a satellite a month. We just need to get better at it, so making the pins quicker in the Adam Smith factory example. Is it more towards the latter of those or is it more undiscovered territory in terms of what the obstacles are going to be for winners in this particular market?

Dr Dickinson: The technology is there and it is more the execution of the system. There are satellites launched today, of which OneWeb is an example, where they have a partially deployed system today. SpaceX has an equivalent system with Starlink. They are prototyping. They are finding new technical opportunities, but fundamentally, from the system design point of view, there is not really a big unknown there. They are complex systems to manage and that will require sophisticated capability to be able to ensure that they operate successfully, and I am sure that is what those companies are focusing on developing.

Q10 **Richard Fuller:** Finally, for Professor Ziebart or Dr Dickinson, out of that 20,000 for one operator, what is the number of satellites they are going to need to reach some level of commercial viability, either as a single purpose or multipurpose system in this new competitive space?

Professor Ziebart: We should put some numbers into this. The OneWeb constellation design aimed for about 700 satellites operating in low Earth orbit to provide global coverage. Roughly speaking at the moment, in near Earth space there are about 2,000 active operational satellites. There are lots of bits of debris and there are quite a few dead satellites as well. If we look at the plans that Elon Musk has filed with the frequency control commission, he plans to launch 10,000 to 12,000 satellites. Jeff Bezos's company, Blue Origin, also wants to launch many, many satellites. We are looking at, potentially, over the next decade, 20,000 satellites operating in low Earth orbit.

I find some anxiety about that because that is a space traffic management problem and my group at UCL, under contract of DSTL, simulated what that environment will look like, in terms of the number of satellites operating. Nobody has ever done that before. Anecdotally, something happened a few weeks ago that is pertinent to bring up. There was a potential collision between a European Space Agency Earth observation satellite and one of the Starlink satellites. That is a problem of prediction. You are trying to predict, "My satellite is going to come close to your satellite," and if you pass a certain threshold, somebody has to change their trajectory. That is expensive and affects your operation.

ESA contacted SpaceX saying, "We think there is going to be a collision. What should we do about this?" They heard nothing. Then a week goes by. They try again. "Hey guys, look, we are going to crash. One of us should do something about this". Still nothing from SpaceX. Then in the end ESA had to unilaterally decide to change the orbit of their spacecraft to make sure there was not a collision. That is even with the numbers we have now. I am sure, as Dr Dickinson would say, that these problems will be overcome, but at the moment we do not have good evidence that that is going to happen anytime soon.

The second thing that is pertinent to your question is that this is a gold rush going on in space right now. These actors want to deploy their satellites in orbit as quickly as possible, because that is like capturing that real estate and it is like the Wild West. There is no law out there or at least no law that can be enforced, so people are just rushing to do this very quickly. There are implications around space traffic management and if collisions occur, that debris will hang around in those operational orbital shells and that will make it harder and harder to operate.

We are not looking at something called the Kessler syndrome here, but it is worth bringing up the term because historically there was this study done by a man called Kessler, who said if these satellites smash into each other they create clouds of debris. That debris might disable other satellites, then they cannot be controlled and they smash into other satellites, and we get a tragedy of the commons. The entire environment becomes inoperable because of the way in which we are behaving in space. Like I said, the risks are because it is the Wild West; people are not really listening to each other and they are just rushing ahead.

Richard Fuller: It is a mixture of the Wild West without regulations and the gold rush, where we will probably end up with more panhandlers than millionaires.

Professor Ziebart: That is beautifully summarised, Mr Fuller. I hope that goes some way to answering your question.

Q11 **Paul Howell:** Just moving back on to a slightly more specific subject on broadband, the Secretary of State had said that this was one of the primary areas to be going into. What is the broadband market like at the moment when you are talking about the terrestrial capacity versus the satellite capacity? Will terrestrial get too much taken up before satellite gets there? Is there such a growth that it does not matter and there is plenty to go to everyone? Can you just give us a scale as to where the marketplaces are going that we are supposed to be investing in here?

Carissa Christensen: Perhaps I could offer some thoughts on that. There is significant ongoing growth in demand for broadband connectivity. That is observable every day in every industry and in every country. One of the challenges is the price competitiveness of broadband providers and there are two layers to that. In any business, price competitiveness is a part of the competitive landscape. For space systems to achieve services that are comparable with terrestrial and to be able to offer them at a competitive price is a significant business challenge.

There have been efforts in the past. There are currently satellite operators that offer broadband services with a different architecture and a different type of system from what is contemplated by OneWeb, Starlink, Kuiper and perhaps Telesat. Those systems serve, for example, individuals who cannot get a terrestrial alternative, but can be costly and can have challenges in performing at the speeds that would be expected from a terrestrial alternative.

Then the second layer of complexity with the broadband market is the degree to which broadband access is increasingly viewed by consumers more along the lines of a utility than as an item for which they are willing to pay significant amounts that grow meaningfully over time. It is certainly a robust market, but it is a market with complexities and limitations that create challenges.

Professor Ziebart: It is worth just adding in one factor, which is the number of people in the world who currently do not have internet connectivity. That is seen as a market opportunity by the likes of Elon Musk. Elon Musk will tell us that 4 billion people around the world currently do not have straightforward access to the internet and that is much of his driver for launching the Starlink constellation. By the way, Ms Christensen mentioned Kuiper, which is the constellation being built and designed by Jeff Bezos from Amazon. They see this as an enormous market opportunity, because they think they can sell internet services to a huge fraction of the population of the Earth who currently do not have it. Whether or not they would be willing to pay for it is a moot point in that respect, but there is a market opportunity there and to a certain extent OneWeb should be seen in that context as well, being as they were actually ahead of that race at one time.

Carissa Christensen: If I could add to that excellent point, the International Telecommunication Union publishes quite good data that speaks to what is affordable for telecoms services for populations around the globe. Many underserved populations are looking at an affordable monthly charge of tens of pounds as opposed to hundreds. There certainly is a great uncertainty about the ability of those populations to pay. Also. to speak to that very relevant point of access, at least a significant proportion of those under-served billions do potentially have access to some service, but it is not affordable to them, so it is not a matter that there is zero infrastructure. It is that there is a mismatch between the cost of the service and the ability to pay.

Dr Dickinson: Maybe I can just add one point as well to those excellent points made—I agree with them. There is certainly an under-served market and affordability is absolutely key. With OneWeb specifically, we have seen the Indian partners come in. They must see a market in their core areas that they can serve their potential customers with such a system.

I do not know the details of the UK terrestrial market in detail and what percentage of folks are unconnected today or have poor service, but there probably is a demand there. Affordability is key, but these partners see the global opportunity also. I assume that there is a pent-up demand for broadband for those regions. It is about finding the ability to serve that market at the right cost and with the right user terminal technology that allows it to be affordable to the many.

Q12 **Chair:** Thank you for that. Given I have constituents in Bristol who would be desperate for good broadband connectivity, I am sure they will be thrilled that the UK Government are now in the business of providing internet to the world.

Before we get into questions on spectrum, I just want to ask one thing about the debris question and the number of satellites. We have already concluded that OneWeb does not fulfil the military or security satellite requirements that we have as a country, and so presumably the Government will make further announcements on that in due course. If you have all these satellites at low Earth orbit and potential debris, what is the risk associated with that in terms of your own military and security satellites, which presumably are in those outer orbit zones that you have talked about earlier? Who would like to comment on that question just shortly?

Dr Dickinson: I can try to give a comment on that. Space situational awareness is a fundamental capability that is required. As was being pointed out previously, if you have a collision in LEO or in fact at any orbit, the debris population from that can affect everyone. This is not a regional problem. It is not like you have an oil spill and it affects one country. With a debris event in orbit, all that debris will spread around and will become everyone's problem.

I chaired something called the Space Data Association for a number of years. This was a partnership of operators around the world sharing operational data in essentially real time to allow us to try to mitigate those events. Space situational awareness is fundamentally important. What it requires is highly accurate, timely and transparent data. Creating the framework to be able to share that data and requiring satellite operators to share data in that way is a fundamental aspect of allowing successful co-ordination to make sure that events like potential collisions are managed effectively. You cannot do that without good data and that is fundamental. What we need is a framework globally to allow all operators to have the same sort of responsibilities and act in the same sort of way.

Today there are 65 nations that have some regulatory capability for satellite operations, but we need to make sure that everyone plays in common rules and understands what operational best practice is. How do you share data? What data do you need to obtain from the ground to augment the data that comes from the operators? How would we be able to facilitate sharing of information?

When we set up the Space Data Association 10 years ago, the first thing we actually did was to create a phonebook so we knew who to call and when. Something as easy as that was stage one. Then you get on to sharing where your satellite is now and what your plans are in the next week or so, because it is no good knowing now. If you are going to move your spacecraft tomorrow and you do not tell anyone then how can you expect anyone to stay out the way? It is that method of sharing data in a transparent way, engaging with the entities that are monitoring the space environment today and augmenting that with commercial capability. There are a number of companies today that provide SSA type of services, whether they are optical or radar.

It is about fusing that data together to ensure that the collisions do not happen. What we do not want is a large amount of debris being produced, because that actually makes difficulty in accessing other orbital regimes. You have to go through LEO to get to GEO and MEO, so it is vital that those assets are operated in a secure and transparent manner.

Chair: Understood. Thank you. It is manageable, but we have some work to do.

Q13 **Ms Ghani:** I was going to talk about the spectrum, but before I get to that, I want to refer back to a comment that Professor Ziebart made on a question that was asked about broadband. You said that OneWeb was "ahead of the race". I wanted to draw out if you think the UK Government buying into this is good value for money. In particular, the previous permanent secretary at BEIS made a comment about the commercial case for investing as, "I cannot satisfy myself that this investment meets the requirements for value for money as set out in *Managing public money*". It is important, as Ms Christensen said, that the success rate of these companies is only 25%. I wonder if we can have a quick conversation about that first.

Professor Ziebart: First of all, from the point of view of return on investment, I am personally not convinced. I have not seen any evidence to say that that has been considered carefully, but it may have been. It does depend on what you are buying and what you think you are going to get in return for your money. We are going to come upon those issues as we go through.

In terms of being ahead of the race, indeed, OneWeb at one time was doing very well in terms of its launches and its mass production of satellites. I would say at one point it was ahead of the game, but now you have someone like Elon Musk who has entered into that race. Characterising it as a gold rush is a good way to think of it now, because people are rushing to go and make this happen. Elon Musk's launch technology is now superior. He has demonstrated launching 60 satellites very reliably in one go and returning the launch vehicle to Earth, so it can be reusable.

The industrial and technological might that is represented by SpaceX is very hard to compete against if you are OneWeb, but that is not to say that the race is over. It is a costly race. The initial investment by the UK is £0.4 billion. There was some reporting that the OneWeb consortium then sought an additional £1 billion in funding in the last few weeks and if the UK Government and the Indian company are the major funders of this operation, those costs are going to carry on rising and rising. I am personally not yet convinced of the value of the return on investment. Let me pass over to Ms Christensen.

Ms Ghani: It is very definitely a crowded market. What do you wish to add, Ms Christensen?

Chair: Sorry, Ms Christensen, could I just interject one second? We are trying to be careful not to interfere with ongoing commercial negotiations around further funding for OneWeb, so if we could just keep our answers focused on the technical aspects, we would be appreciative. Thanks.

Carissa Christensen: This is appropriate and it is important in the context of this gold rush conversation. There are not very many companies in a position to deploy such a system. It is complex and it is capital intensive, so we will not likely see another three or four potential operators emerge. We have a good understanding of the LEO broadband companies that we will see in the next several years.

With regard to OneWeb generally, I will say that there is a widespread view that large LEO constellations have the potential to be transformative and there is, as we have talked about, business and operational uncertainty and risk associated with this business area, not speaking to any particular operator. There is also opportunity for innovation and connection with the broader UK space ecosystem. The question does come down to what the intent is. Is the intent a predictable commercial investment or is the intent access to transformative technology with a recognition that there will be evolution and change in the future?

Q14 **Ms Ghani:** Thank you. I know that we are limited to what we can say, so I will move on to questions on the spectrum and I will turn my attention to Dr Dickinson. OneWeb currently holds Q band priority status. Is there an intrinsic value to this spectrum?

Dr Dickinson: There is intrinsic value to all spectrum. Spectrum is a really precious resource and the UK has a long history of managing spectrum and the spectrum assets that we have. Absolutely, there is intrinsic value to spectrum holdings. Spectrum comes in many different forms, in terms of different frequencies with different capabilities ranging from where things like navigation signals sit and where Inmarsat's legacy L band business sits, right down at 1.5 gigahertz or so, all the way up to much higher frequencies, those Q/V band ones you mentioned.

Each type of frequency has its own types of properties and what it is good for and what it is no so good for. For example, L band is a wavelength where, actually, you do not suffer from things like atmospheric issues. That is why it has been used traditionally for things like safety services. If you are in a boat sinking in the middle of a storm, you do not want things like the rain that surrounds you causing you issues sending your distress signal. Up at higher frequencies, at Ku and Ka, you can have higher data rates because there is more spectrum available, but they come with some sort of limitations. Each spectrum band is good for some purposes and not good for other purposes and that is part of the system design and the spectrum rights that you have.

You have two communication links with a satellite. You have the one from the user, the person who is accessing broadband, to the satellite and then you have to get that data from the satellite back down into the terrestrial network, so you have things called gateways. You can use different frequencies with different applications, whether it is a user link or down to the gateway link. Those spectrum allocations all have value, but the value will be determined by what part of the system they allow to happen.

Q15 **Ms Ghani:** If a company wanted to register second or third on the spectrum, what control or what challenges would a company face from OneWeb, for example, if they were the primary owners of that spectrum space if they had priority status?

Dr Dickinson: I am sorry. The audio was dropping out there. I could not hear the question. Maybe if one of the other panellists heard they could respond best.

Chair: Are there any takers?

Carissa Christensen: Yes, if you could repeat it.

Ms Ghani: Professor Ziebart can probably take it. If OneWeb has priority status, what challenges would another company have to try to have second or third status on that spectrum to try to register?

Professor Ziebart: Let me throw in something it is worth saying. We talked earlier about the idea of there being no law in space or at least no law that is enforceable or one that anybody is willing to try to enforce. Spectrum is the one place where people will co-operate, and so having made the grab and having got hold of that part of the spectrum, that is then a golden opportunity. That does not mean that people will not do some nefarious things and there are some historical precedents around satellite navigation, where there was competition within the L band around signal design and use of spectrum. Arguments resulted between major international players in that respect.

Having said that, if you are developing a system, you are investing a huge amount of money. As Ms Christensen said, there is a lot of risk associated with that. If you try to use the same spectrum as somebody else or try to get close to their spectrum, you run the risk of your system failing or degrading, and everybody falling out because it will not work. Spectrum issues are taken very seriously.

Having said that, spectrum issues are not purely about space alone though, because terrestrial communication systems can interfere with space services. For example, there has been a big argument in the United States around provision of broadband operating at certain frequencies and interfering with the GPS signal. President Obama himself ran into trouble where he had made certain guarantees about providing broadband services and then the technical solutions to that started to potentially degrade GPS provision of precise services. That went all the way up to the US State Department, and I was one of the people who testified in that debate. At least that is some flesh on the bone of the question. I will pass over to Ms Christensen.

Carissa Christensen: I wanted to speak particularly to the topic, which is quite related, of the legal and regulatory structure around space activity. Certainly, we would all agree that there is not a sufficient integrated regulatory system that operates nationally and internationally in a predictable way to achieve the goals of a space commons available for everyone.

It is important, however, to highlight that there are multiple levels of regulatory and process oversight, particularly in launching nations. Taking the US as an example, in addition to the spectrum licensing that we are speaking of by the FCC, imagery satellites are also licensed, launchers are licensed and while there is a limited amount of official authority, there certainly is some review of the payloads on the launch vehicle in terms of their operations and consequences. There is a significant degree of military interest in space activities to ensure the operability of multiple systems. NASA, while not a regulatory agency, has insight and often provides input. There is a community of actors that do interact and that do shape outcomes.

Issues of conflict across spectrum issues of conjunction, satellites or debris hitting each other are not new issues. They are worsening potentially with significantly more activity and require a more structured environment, but there has been successful management and mitigation of those issues in the past, just to provide some framing on that.

Q16 **Chair:** Thank you. Just a follow-up question from me on that, just so that I am clear. In order to get ownership or rights over spectrum, it is not like for mobile spectrum where the Government auction it and then you have rights that are regulated by Ofcom. You have to get some satellites up there, you plant your flag and you have ownership of it. There are two parts to my question.

The first part is that OneWeb has done that, because it has shot up a load of satellites and claimed ownership to that spectrum, which we now partly own as a Government here. Does the spectrum that OneWeb operates in give us a particular advantage compared to other spectrum allocations that are available? What does it mean in terms of OneWeb's relationship with, for example, SpaceX or other companies operating in that space? Do we now just own that or are there ways for that to be challenged? Is there a risk around continued ownership of that? Professor Ziebart, do you want to have a go at answering that for me?

Professor Ziebart: I cannot speak to historical precedent in low Earth orbit and maybe my colleagues, if I may refer to them in that way, might be able to answer that question. I can say that just because you have an FCC licence, you launch your satellite and you start broadcasting on that frequency, it does not mean that somebody else will not try to do something similar and that is an issue of risk. I did make reference to what happened between the Chinese satellite navigation system and Galileo, which was a perfect example of that and people essentially fighting over that spectrum. One person has to back down in the end because they cannot be interoperable.

Having said that, it is not just as simple as, "Am I transmitting on a certain frequency?" because there is a signal structure as well. You can try to stop things interfering with each other by having clever algorithms that encode the information that sits on top of the carrier wave that comes down to the Earth. I would say that I am not a specialist in that area, so I must refer to my colleagues for a more informed comment.

Chair: Carissa, did you want to comment on that?

Carissa Christensen: I am actually, given his experience with SDA, hoping that Dr Dickinson will wade in on the nuances of spectrum allocation, because it is complex.

Chair: I have to say this is one of the reasons we did invite some additional colleagues, who unfortunately could not be with us, but, Dr Dickinson, do you have something to add?

Dr Dickinson: I will try to make a couple of comments. Technically, you do not really own spectrum. It is not yours for all eternity if you do not use it. You have rights to it and then you can utilise that spectrum for your system. If you do not use it, eventually it can be used by someone else, so it is really a matter more of co-ordination. You have the right to use a spectrum and then you have to co-ordinate with other operators. In the UK, Ofcom assists Inmarsat in that coordination process and, in fact, it is very good at it and helps us a lot.

It is really how you have access to that spectrum. You can utilise it for your system. You have to use it, otherwise it eventually can be passed to someone else in the queue. As Carissa mentioned, it is about how you work with systems of systems and how you can make sure that you can work alongside different orbital regimes and different frequencies to make sure that your system is viable.

Chair: Thank you. So you have to just basically keep your activity going in the bit you are already in and then you keep hold of it, to use some simple language. Okay, thank you for that.

Dr Dickinson: The filing is not owned by a particular company. It is actually managed at a nation level, in the UK's case by Ofcom.

Chair: Maybe we can call them in the future. That is helpful. Thank you for that.

Q17 **Alexander Stafford:** It has been an interesting discussion so far. This is to Professor Ziebart. I know you have already discussed some of the LEO satellites, but can you tell us a bit more about the technical challenges of LEO satellites delivering GPS-style functionality? What are the challenges about this technology?

Professor Ziebart: There are multiple challenges. I am sorry, it is rather complicated, but I will try to hit the main things. The first thing to understand is that if you are doing communications, you are on the Earth and you want to use a service, you just need to see one satellite to do communications. If you want to do positioning, navigation and timing—

PNT, as we call it—you have to be able to see four satellites simultaneously. That means that your visibility to the satellite becomes much more demanding to carry out PNT.

The design for repurposing a subset of the OneWeb satellites for a GNSS delivering PNT capability looked at 70 or satellites. That was the design. Let us contrast that with operating in medium Earth orbit with a conventional GNSS, which is well-proven. It works. It has been done four times very successfully. That is the way to do it, to a certain extent. You can use maybe 24 satellites in orbit instead of having 70 satellites in orbit. Also, on satellite lifetime, the satellites operating out of medium Earth orbit can last 10 or 15 years; the low Earth orbit satellites last about three years and that means you have to replace them much more frequently, so with additional cost.

The next thing up is that in order to carry out positioning, navigation and timing you have to measure ranges from, say, your user equipment to the satellite in orbit and that ranging depends upon having clocks in your user equipment and very expensive atomic clocks in the satellite in space. They are very expensive at $1 million to $2 million a throw. If you have 70 satellites in your constellation instead of, say, 24, you have an awful lot more clocks that you are going to need in orbit to do that and if your satellites are having to be replenished, then you are losing satellites and you are having to buy more and more clocks all the time, so that makes it expensive.

Then there is the issue of how fast these things move. A satellite moving in low Earth orbit moves at about 7.5 kilometres per second. A satellite in medium Earth orbit moves at about 4 kilometres per second. The practical outcome is if you are on the surface of the Earth, at best you would see a OneWeb satellite for about 16 minutes but in reality more like about 10 minutes, whereas you can see a GPS satellite or a Galileo satellite for hours. This means that the satellites are popping up over the horizon more frequently with a low Earth orbit system and that means that your user equipment has to lock on to and acquire these signals much more frequently. That is power intensive and it is more complicated.

The next thing perhaps worth mentioning is if we can introduce the idea of a Doppler shift, which is the way in which the signal frequency is shifted based on how fast the satellite is moving relative to the user on the ground. The OneWeb satellite is zipping across the sky very rapidly. The Doppler shift is changing the frequency, and so the user equipment has to work much harder to basically retune. It is rather like having to continually retune your radio to keep track of the signal.

There are other technical problems to do with the performance. Maybe the easiest thing is to make reference to something Ms Christensen said earlier about the Iridium system. Iridium tried to develop a low Earth orbit GNSS system and essentially failed. It technically got the thing working, but it was five to 10 times worse than GPS. Given we have four existing systems that all work pretty well, and someone has had a go at doing in low Earth orbit and it did not work very well, that sets some kind of precedent.

The next thing is to do with incentivisation of the user base. Somebody has to manufacture equipment on the ground that is going to pick up these signals and use them. You already have four existing systems: Galileo, GPS, BeiDou and GLONASS. Given that there is already a new front end or a new bit of equipment, shall we say, sitting on the chipset, what is the incentive for somebody to actually develop that technology?

There are other issues, but essentially the technical case and the challenges are substantive. Let me at least wrap it up in this. One time Xerox designed a photocopier and they bore the R&D costs of doing that. Once they had done that, you could have this big machine in the office and everybody goes to that thing, uses it and gets photocopies. Once that has been established, loads of other companies then developed similar machines. Where we are with GNSS is you have four existing systems operating in medium Earth orbit. There are roughly 24 satellites moving 4 kilometres per second and it works really well, so it is no surprise that when China and Europe developed their systems they essentially copied the design of the Russian and American systems. It has not been done successfully at low Earth orbit. It is not to say it could not be done. Perhaps it could be done, but it is not a case of "buy this thing off the shelf". It is essentially an R&D project and that means money, that means time and it means risk.

If we are really serious about having our own system because we have strong technical and security reasons to do so, we are not well served in treating it as a research and development project. It will take time and money and even then, at the end of all that, maybe it will not be fit for purpose.

Q18 **Alexander Stafford:** Thank you for that. You are clearly putting quite a negative view about the LEO aspect of it. Is there another way of looking at it? Could a LEO system actually complement or augment the mid-Earth systems? Could it work together to improve the system as a whole and is there an opportunity there?

Professor Ziebart: Absolutely. As a standalone system I would say no, but as an adjunct there are many things that would be useful for that. It depends on what we want this thing to do. If we want to actually help everyone around the world improve their PNT services, having a low Earth orbit system would be a good idea and it would add simple things. The satellites are much closer to the Earth, and so, therefore, the signal power is much higher. Typically, a GPS satellite transmits only about 100 watts. These things are 20,000 kilometres away and they are pumping something like the size of a light bulb. You can use it, but it is very easy to jam that signal. Jamming is a real problem for us, so having a low

Earth orbit signal that augments the overall architecture is definitely good.

There are also arguments around timing and if we were to design an adjunct system where it does not have to do all the things that the medium Earth orbit systems can do, it gives us additional technical opportunities for innovation and so on. I am not completely against the idea, but if we are going to have it as the thing that we rely upon for PNT then it is very risky.

Q19 **Alexander Stafford:** Thank you for that. In the context of us no longer having access to Galileo, is there another alternative now or likely future alternatives to GNSS PNT in the near future?

Professor Ziebart: When the UK Government committed to developing its own GNSS a number of architectures were proposed, so there are lots of things one could do. One could even, actually, rely upon some form of terrestrial system to do it or completely do without having a space segment and develop some kind of quantum-based accelerometer that somehow works miraculously. Thinking about it from a financial perspective, if we really need it I would buy a system that already works, but should we be open from an R&D perspective to alternative architectures and concepts? Absolutely.

Q20 **Alexander Stafford:** I guess that belies the question for you or for anyone: do we actually need a sovereign GNSS system? Is there actually a point of this? I appreciate that is an opinion, but do we need one still, despite all these difficulties?

Professor Ziebart: Let me kick that off and maybe bring in the others on that point. It is a moot point as to whether we really need it. There is a socioeconomic argument, which is that the UK's involvement in Galileo meant we had a whole generation of engineers who became very skilled in the UK. Let us look at one thing. The atomic clock was invented at the National Physical Laboratory in Teddington and all these GNSS systems rely upon atomic clocks, so having a vested interest in keeping up that kind of development is good. Also, if we do not have our own system we fall behind technologically from everybody else. Everybody else will be running along solving the technical problems that you have to deal with and learning as they go along. The UK space industry is a very important part of our overall GDP, and so we should foster that. There is a socioeconomic argument to it.

There are also resilience issues. There is the fact that we have four independent systems. If GPS goes down, GLONASS will still operate. If GLONASS goes down, it will not collapse the Chinese system. We do have a certain amount of resilience and lots of scientists and engineers over the years developed very clever ways of exploiting the signals from those systems without the co-operation of the signal providers. However, for certain things, like financial transactions, control of the power grid and certain military applications, they are fundamental things that we rely upon and they are a pervasive and embedded part of our infrastructure. There is a risk in not having a service that we can rely upon in that respect, but it is a question to debate. Let me pass over to my colleagues.

Dr Dickinson: To follow on from the real expert here on that topic, the idea of an augmentation service to an existing GNSS system is certainly interesting. Inmarsat has been providing that service since 1996 for both augmentation to GPS on the WAAS in the US and the EGNOS system in Europe. Essentially, what those augmentation systems are doing is improving the accuracy from, say, tens of metres down to single metres or so by transmitting corrections. This augmentation type of concept is not new. It is important for particular users. In fact, the spectrum that we use to provide the services today is UK-held spectrum. The idea that there could be an evolution of augmentation systems providing maybe some extra layer of resilience is important. As has been commented, maybe the additional power that could be available from LEO systems allows some jamming or unintentional interference events to be managed.

These capabilities are already around. It is important that for the UK, as already has been highlighted, the loss of a GPS service, as highlighted in the Blackett report, is a £1 billion a day loss. You would find people noticing very quickly if the service stopped, probably as soon their satnav stopped working or the train stopped working. It is a really vital thing and lots of our critical national infrastructure relies upon these services. It is about finding the right balance of the services we need, both from a security point of view and to a CNI point of view, and how we can provide a full system or, if not a full system, how we can best augment the systems that are available today.

Q21 **Alexander Stafford:** Thank you. Carissa, do you have a view, especially about the sovereignty of it and whether we need this, despite all the difficulty?

Carissa Christensen: I do have a view. My view is really very much around how that question is framed and how the Government answer that question, "Do we need a GPS system?" I would say that it is critically important to view that question through the lens of the broader space strategy, which is certainly evolving, and consider it in an integrated fashion across Government. That means not specifying a particular architecture or a particular technical solution, but focusing on capability and doing so in a very sophisticated way that considers economic security, military needs in the near term, prosperity goals in the long term, the synergy of technology and supply chain enhancement across launch, satellite manufacturing and other services areas. It is really to fully leverage commercial innovation to have the ability to make decisions that accept a partial solution that is dramatically less costly or an innovative solution that is somewhat more costly to really define that trade space and make decisions within it within layers of complexity.

The UK has an opportunity to really become a global leader in the ability to make agile, integrated decisions about space across Government. As a proud UK migrant and as someone who has operated in the US system for many years, I do see the opportunity for much more integration and the benefits that come with that. This is an extraordinarily good case study of how that could play out.

Q22 **Chair:** Can I just follow up on that very briefly? My assumption before this session today was that on issues of military security and critical national infrastructure we needed a sovereign satellite capacity, which is not OneWeb and is probably going to have to be something else, because of our loss of access to those systems through Galileo, but presumably there are lots of countries that do not have their own sovereign satellite capacities for those services. Just to be clear, what you are saying is it is not that black and white that for security, military and CNI purposes we must have sovereign capability. We could just rely, for example, on other networks. Is that what you are saying?

Carissa Christensen: It is unambiguously necessary to have reliable and predictable GNSS navigation services, whether the correct answer is a dedicated independent national system, a regional system or an augmentation system. Japan has built an augmentation system that works with a major national system. That is a critical part of the trade space and it is in the broader context of post-Brexit military relationships and alliances.

A part of that might be the consideration of what the UK would want to be able to offer to its allies, both in terms of providing resilience to their GPS systems or capabilities, or as an opportunity for them to participate in the development of such a system. That kind of integrated decision making in that complex trade space is so important for space activities because every aspect of the space economy in the UK affects the other aspects of the space economy in the UK. Military affects civil; civil affects commercial. There is so much interplay and there is so much opportunity to leverage the benefits across those sectors with thoughtful decision making that is not programme specific.

Chair: Understood. That is really helpful. Thank you.

Q23 **Paul Howell:** This follows on from the sort of discussion we have just been taking, in that what we are seeing here is the Government moving from being a customer in this market to being a real participator, and that changes the dynamics. I have spent many years in business, where if you move from being a customer to being one of the suppliers, you change the dynamics of interaction with the different people who you are participating alongside. Are there things the Government should be making sure they are aware of in terms of changing their perspective on everything here in the way that it is going to relate to other players in this space?

Carissa Christensen: I am so sorry. I had a little bit of audio difficulty. If I could ask you to repeat, Mr Howell.

Paul Howell: It is about the change in mind-set, if you like, of a Government that is moving from being just a customer in this space to being a player in this space, and how that changes the dynamics of things that they would be able to do or not able to do, and just the different relationship changes that will go on that we should be very cognisant of.

Carissa Christensen: I would say that the most important viewpoint change is to recognise that each Government action, whether it is acting as a regulator, whether it is acting as a funder of R&D or whether it is acting as a user of systems, has an effect on the health of the space economy in the UK. A relatively straightforward decision to buy routine communication services can actually be folded into that broader space strategy and used to drive future outcomes around technology and around the industrial base. Certainly, one of the really important perspectives is an investment perspective that, first, becoming a global space power for the future requires ongoing investment and, secondly, that every Government action that affects space is part of that investment strategy and should be viewed through that lens.

Q24 **Paul Howell:** Are there any particular risks? You have talked about the strengths there and the opportunities that are there, but are there risks that we should be making sure we are aware of as well?

Carissa Christensen: There are absolutely risks. There are business risks that we have talked about associated with new products and services, and the ability of companies to compete in new markets, whether that is compete with terrestrial alternatives or compete with companies from other countries. There are military and intelligence risks because of the extent to which military and intelligence requirements are linked to space systems. Certainly, ensuring national security is a critical objective and it needs to be considered in that context. We have talked about what I will call environmental risks and the question of maintaining and sustaining the space commons in a way that is accessible and usable.

A future in space is a fundamentally international future and I will not necessarily put that in the risk category, but I will highlight that from the point of view of the UK's position in the world, its diplomatic influence and its relationships with close and distant allies. Its space activities are going to affect those relationships.

Q25 **Paul Howell:** I just wonder whether either yourself or one of the other panellists would just like to draw out whether any of the risks you have listed would be top of the list in terms of concerns.

Professor Ziebart: Let me speak to that. We touched upon the idea of what is going to happen to that part of space in the next few years and we touched upon the idea of debris. There is one thing it is worthwhile the Committee knowing. I am going to hold up the Earth. For the sake of Hansard, Ziebart held up a model of the Earth at this point.

Where you operate where the debris problem is concerned is important. If you are flying your satellites maybe just 100 or 200 kilometres off the surface of the Earth and a collision occurs, the atmosphere acts to deorbit the bits of debris and cleans that part of the space environment. Once you go out to 1,000 or 1,200 kilometres higher up, which is where OneWeb is going to operate and where Elon Musk and Bezos want to launch many satellites, if there is a collision there, there is not enough atmospheric drag. There is not enough atmospheric gas up there to make the debris deorbit and that means the debris will stay there for centuries. That makes it harder to operate in that part of space and that is a genuine risk.

To put it in perspective, think of an objective like this. At this point Ziebart held up something about the size of a hand grenade and said, "Okay. How fast would that be moving in low Earth orbit?" It might be moving about 7.5 kilometres per second. Imagine you get a collision. A satellite breaks up and it showers off bits of metal that stay in that environment for hundreds and hundreds of years. There is nothing to cause those things to deorbit, so that makes operating in that part of space much riskier.

If we are thinking about the risks associated with PNT and we really need a sovereign capability, the operating environment risks are far less out of medium Earth orbit. Some people say that if you have more debris in low Earth orbit, we are just going to have to armour our satellites better and somehow make them more resilient, but the energy of something moving at 7.5 kilometres per second that has the weight of something like a metal pineapple is really frightening and we do not have many ways to control that at the moment, so I see it as a form of uncontrolled risk. As this thing plays out, it might be very hard to operate and it may be even hard to move satellites through that. Dr Dickinson mentioned the problems of launch and deployment. You have to move through low Earth orbit.

We all have a vested interest in having good policies to make that environment safe and for people to act responsibly in space, but we also have to recognise the upcoming risks around space traffic management and collision.

Dr Dickinson: I have maybe just one or two comments. In my opening remarks I mentioned that I felt this was a pivotal moment for the UK to grasp space and the opportunities that it provides. Echoing some of the comments previously, the UK has an ambition in space and that is fundamental. I would strongly encourage that. As Carissa said, investment somewhere allows opportunities elsewhere to happen to help the whole space ecosystem. We can see many new technologies coming down the path and for the UK to be part of that and to help shape them will be fundamentally important.

There is a prediction that the global space economy will be worth $600 billion per year come 2030. How does the UK make sure that it gets the correct share of that and is ambitious in its regime? We have great skills in the country. How do we develop those skills further? How do we develop capabilities that we can export that we can be successful and be world leaders on? Now is the time to look at that and that is why we welcome the setup of the National Space Council, where we have a body where we are bringing together all the stakeholders across the whole of the UK to come up with a coherent plan for delivering on that. The opportunities I feel are really big and it is about using the time now to be able to actually make some forward progress on that.

Professor Ziebart: Could I actually just echo that a little bit because I may seem like a negative voice in this debate? Getting a slice of the mega-constellation action is a really smart move. Those people who try to operate in that part of space and develop services are going to learn how it works and it is an evolving market. It is a moot point that lots of people are trying to launch into that space. If you look at the FCC filings, Boeing had plans, Samsung had plans, Facebook had plans, the Chinese had plans, and there is Elon Musk and Jeff Bezos. A lot of very competitive and developed technologies are vying to have a part in that space and the fact that OneWeb already has a foothold there is a big opportunity.

Dr Dickinson: Maybe just one further comment on that is that one of the things that we probably should do from a UK perspective is to take an inventory of what skills, capability and regulatory spectrum we have, and to take a real, coherent snapshot of where we are now to allow us to see where we want to get to, what that gap is and how we can then build a plan for getting across that gap. We know that space has been a very successful area for the UK economy over the last couple of years and was double digit for many years, but we are still maybe a bit disjointed, so we could take a step where we actually say, "This is what we have today and this is what we can build upon. Where are our key strengths? Where are our key technologies?" and drive those areas forward. Then we can look at the new space world, in terms of constellations and launch, and find the areas that we can deliver significant value on and really push forward on that to try to get as much of that $600 billion per year in 2030 as possible. We should be ambitious.

Q26 **Chair:** Just before we finish, on that point you have just made there, we are doing some other work on this Committee on the UK's industrial strategy. I would just be keen to get your views before we wrap up today as to whether you feel we have a coherent space strategy in the UK. Are all these different things we have been talking about coherently connected in the Government's strategy? Is there a clear vision from Government about what they see the UK's role as in this space, or do you think we need to review that space policy and be a bit better at pulling that together? Professor Ziebart, you are nodding, so I am going to come to you first and then I will come to the rest of your colleagues before wrapping up.

Professor Ziebart: It is a very simple answer to the question. It is obvious to all of us how rapidly space technology is evolving with provision of services, launch capabilities, reusable launch vehicles and enormous deployments of satellites. We had a national space policy document and we do now have a space agency, which was a big step forward, but, as Dr Dickinson said, we also have a huge opportunity to get a slice of that action. I do not know if the Committee is aware of this, but something like 25% of the world's geostationary satellites are built in the United Kingdom. We are an enormous player in that market, but it is rapidly evolving. Therefore, it is certainly true there should be some kind of review, like Blackett, and a process, but it needs to be evolving. It needs to have possibly a Minister for space, or something where somebody has their finger on the pulse for this thing the whole time and they are engaging with people like Carissa and Mark, who really understand the issue from their perspective.

Dr Dickinson: We welcome the formation of the National Space Council. That is a forum that has the ability to deliver on this sort of strategic overview. It should have all the key stakeholders from a UK perspective involved—manufacturing, operations and the Government—bringing together all those stakeholders and coming up with that coherent plan, based upon the solid foundation of what we have today. That is a good forum for being able to develop that strategy.

Carissa Christensen: I will echo the support for the National Space Council. That will be very valuable, in particular if it develops a professional culture that is strongly aligned with evidence-based decision making, if it has leadership support and if it is able to take a cross-sectoral, cross-agency and cross-programme view with an investment frame of reference for the near term to achieve ambitious goals in the long term.

Chair: Thank you very much for that and thank you for all your answers this morning. To briefly summarise, it seems clear that on military and security capacity, this is a question that is separate to the OneWeb purchase. Whether we need our own sovereign capability for those purposes, but also for positioning, is something that we need the Government to answer, and one aspect of that is about Britain's role in the world in terms of military co-operation and security co-operation.

The OneWeb purchase seems to be more about internet connectivity, which aligns with what the Secretary of State told us before the summer recess, in that OneWeb had been particularly innovative in the production and manufacturing of its satellites and being able to launch many of them at the same time has reduced the cost of getting them there. Whilst we are operating in a competitive market, to now have ownership over part of that spectrum seems to be of value in this space. We now just need a bit more of a coherent strategy to understand how this fits with all our other requirements and aspirations as a country, in terms of our industrial strategy, our military requirements and, indeed, how we seek to achieve value for taxpayers' money in the purchase of OneWeb.

As I said at the beginning, the Committee does need to understand all the answers to these questions in its role in holding the Government to account on spending significant amounts of public money in a surprising way when this was announced in July. We will have further hearings in due course with Ministers, the UK Space Agency, hopefully with OneWeb, and with others. Hopefully the Secretary of State has now received my letter and understood that it is not for the Government to interfere with the witnesses we call or the questions that we ask on this Committee. We look forward to further co-operation to ensure that we can hold the Government to account openly and transparently on this issue moving forward. At that point, I will call this session to an end.