Episode_91-Quantum_Technology_and_Defense-Understanding_the_...

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SPEAKERS

Heather "Lucky" Penney, John "Slick" Baum, Dr. Andrei Shkel, Dr. Max Perez

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J John "Slick" Baum 00:01

Welcome to the Aerospace Advantage podcast. I'm your host, John "Slick" Baum. Imagine being able to navigate precisely without a GPS or having a clock that can keep perfect time for maneuvering without a reference timekeeper, having a radar that was able to detect very low observable aircraft or even see through any kind of noise or deception, jamming, or even being able to transmit and receive on radio frequencies well above where we can transmit now, this week, we're going to talk about what might seem to be a pretty abstract subject, quantum science and technologies. We've all heard the buzzwords about quantum computing, and it is really mind bending stuff. But what a lot of folks don't realize is that quantum is so much more than computation and encryption. And as a matter of fact, some of those other quantum technologies are much more than computation, and they have the potential to really alter how our traditional capabilities like stealth, precision navigation and timing and communication function on the battlespace. So today we're going to talk quantum, what it is how engineers and technologists are developing it, and how those capabilities might be important to the warfighter. So today I have our very own Heather Penny from the Mitchell Institute team. Hey, Slick, it's great to be back. Thank you. Thanks for being here, Heather, as always. And we also have Dr. Max Perez, who works at ColdQuanta. And Max is an engineer at ColdQuanta, a company that is working on developing a lot of these technologies. Max, welcome.

D Dr. Max Perez 01:28

Thank you for having me.

J John "Slick" Baum 01:29

And finally, we have Dr. Andrei Shkel, who is a Professor of Engineering at the University of California, Irvine, and a former DARPA program manager.

D Dr. Andrei Shkel 01:37

Thank you, I'm excited to participate in the discussion. Well, we are very happy to have you all here. So to kick this off, Heather, what the heck is quantum? I think it's really, it's really important for us to define these terms up front.

H Heather "Lucky" Penney 01:49

Well, you know, we in the defense community have been hearing the word quantum for quite some time. And people are treating it like it's a pixie dust and but they don't really understand what quantum is and the science behind it. So when we're talking quantum, we're talking about the unique properties that we can exploit by cooling atoms to near absolute zero. And for those of those of us who remember high school physics, that's when all movement, all of all atoms completely stops. And we begin to get some really unique properties that we can exploit. They're kind of counterintuitive. So there's different ways to cool atoms. And there are different properties of those atoms, we can that we can exploit once we've cooled them. And then there are different technologies that we can use to exploit all of those different unique properties. So when we've been hearing about quantum in the defense space, we often hear about it in terms of computation, right quantum computing, and this is all going to be about encryption. But I think it's important for warfighters to know that this is so much more than just that. As a matter of fact, there's a lot of technologies that are nearer to the horizon than quantum computing and actually can have a greater impact for the warfighter in the battlespace. And finally, our listeners should be aware of what a qubit is, it's really just the quantum equivalent of a traditional bit, a classical information, which is really a one or a zero. And this was based off of the physical transistors back in the day. So a quantum bit of information is a qubit, only it's not a one or a zero, it's one zero, or both, it holds that ambiguity in it. So it's not just that bit of information, but it's also a physical thing, just like that transistor is.

J John "Slick" Baum 03:27

Now Heather, I do appreciate that. And we're going to set some context with Max. So China had the Sputnik moment four years ago, when it's Micius satellite demonstrated intercontinental quantum key distribution. So first off, what the heck is that? And why does it matter to us?

D Dr. Max Perez 03:43

Sure, Micius, was a large Chinese effort, which was essentially the first national effort to demonstrate a defense or security application using quantum technology, it was about $100 million effort. And it was while it was known it was going on when it was announced to the general public, it was the first major demonstration that quantum was a player in defense and security and that the Chinese were making a major effort in this area. What it was fundamentally was to demonstrate secure communications using a technique known as quantum key distribution and it did it remotely from a space satellite. So those two things were major and quantum, most quantum technologies are done in a laboratory environment. They're not remotely deployed, and they're not really focused on applications. A really good one in the

US is the CAL mission, the Cold Atom Lab that NASA put up around the same time scale four or five years ago, but that was focused differently was focused on fundamental science as opposed to a defense and security application.

J

John "Slick" Baum 04:48

Well, Max, I really appreciate that. And that goes back to what Heather said. I mean, this is not just quantum computing that the layman would think I mean, now you're instantly talking secure communication. So that's really, really important for the warfighter. So Lucky, what are your thoughts on this? And why do you see the Micius issue as so important? And what does it represent?

H

Heather "Lucky" Penney 05:06

Well, it's like you hit it right on the noggin, when you've described me ces as a Sputnik moment. I mean, this should really be a wake up call for the entire defense community because China's demonstrating a commitment to move quantum physics and quantum technologies out of the laboratory and into the real world with real defense applications. So they're not just doing theoretical math and lab experiments. This is real world stuff. And it's important too, that listeners understand that this is just one of the many applications that China's pursuing, and why we should be concerned about the investments and actions that China is taking. So yes, we you know, we've got a cold lab. And yes, we're beginning to make more investments. But we need to make have some really robust investment investments that allow us to take that technology out of the lab, and really productize it. When I say productize it, it sounds really commercial. And you know, to a certain extent it is but it's really about making it practical and pragmatic for the warfighter to integrate onto their weapon systems, and use in real combat, use in real employment. That's what's important. And right now, the United States doesn't have any program that's nearly as ambitious, integrated, or well resourced.

J

John "Slick" Baum 06:18

Yeah, Heather, I couldn't agree more, I want to go back to Max quickly, because I have to admit, you know, when we use and, you know, I'm using air quotes here, you know, it's a podcast, but you can imagine what when I say "quantum", you know, sounds like magic. So Max, can you give us a better understanding of the science that's going on here?

D

Dr. Max Perez 06:33

So basically, it's the combination of the properties of quantum mechanics that enabled devices that have a performance or a sensitivity, much, much better than any device has been demonstrated previously. The three main principles that we take advantage of in quantum technology, are superposition, entanglement, and the wave particle duality of matter. Superposition is the basic idea that a particle can have multiple states at the same time. So it's a non-binary state, and it can be used to form some of the most powerful computers in the world. Entanglement is the idea that atoms or particles that are made in the same quantum function are fundamentally connected no matter how far apart they are and that's actually the basis of quantum communication devices. And wave particle duality, which is the idea that particles or atoms can be thought of as both particles or waves is the basis of some of the sensors that we are looking at today for potential upgrading of positioning systems so that they don't require GPS,

J John "Slick" Baum 07:41

I want to bring in Dr. Shkel on this just just to add anything that you'd like.

D Dr. Andrei Shkel 07:46

Let me just put a little bit in context, the use of sensors, and PNT (position, navigation and timing) and how this all come together and quantum on top of it. So PNT is, is positioning navigation and timing and this is a core service for the Department of Defense. Every single platform, every single person uses this in the battlefield to find where they are and what time it is. And they do this to synchronize different platforms. People in DoD say, "Well, it's like oxygen, you, you take it for granted when it's there, and it's fatal when it's disappears". And this is really true and PNT technology has used this technology, when Department of Defense released it to the public has doubled. The use has doubled every five years since 1960 and this is mostly due to GPS and miniaturization of electromechanical components and the future PNT usage is expected to double every two years as a result of telecommunication, autonomous navigation, robotics, other commercial markets and searching small and precision technologies. And as a modern PNT paradigm is based on the assumption that space-based GPS, or more broadly GNSS (Global Navigation Satellite System), is accessible most of the time of the provide position velocity and timing information, enabling every user to operate on the same reference system and time extender. And today's military system increasingly rely on GPS creating potential vulnerability for US and allied fighters and if GPS suddenly becomes degraded or denied, it is actually a very real. The GPS signal, it's a very specific frequency, but it's a very big frequency. The strength of a GPS signal is a billion times smaller than the cellular, cellular phone signal. So it is easier to overpower GPS signals and the spoofing is another part of the electronic warfare. So, when GPS is inaccessible, not available, the critical information with respect to position orientation and timing can only be gathered through self-contained onboard instruments. The ideal solution would be a self sufficient instrument not relying on any external information, like GPS relying on signals coming from the satellite. So, precision microscale clocks and inertial sensors are required to address this paradigm of self contained PNT or what is also frequently used as assured PNT, PNT, which is always available, regardless in what environment you are. And a preferable military solution is to completely eliminate dependence on GPS or any other signals during a mission. We can accomplish this today...this is very intriguing opportunity to use atoms as sensors, and it is a very attractive option. So atoms...and this is the reason atoms are perfect and they are identical. When we are fabricating something, it's imperfect, and these imperfections, result in a drift in sensors and in noise. If we can manage to make sensors using atoms and using batch manufacturing techniques, we will solve the problem of self assured PNT.

J John "Slick" Baum 11:30

Well, it is so massively interesting to me, for both and we're into the first question here and there's, there's so much application from the military standpoint, but also a civilian standpoint.

And for me, as an F-16, pilot, you know I'll date myself, having flown the airplane 20 years ago, but we didn't have GPS in the airplane. So you knew your current coordinate, when you started the jet, and you type that in to tell the airplane, this is where you are. And when you're going 600 knots, you know that that platform would drift as you were pulling G's and making turns. So you knew that you were going to fly on a certain route and fly across an intersection and or over a mountain or something like that and you would do a position update to pull that drift back in. And you know, obviously, to your point, doctor, it was small enough to fit in the jet, but because of that the reliability might have a drift rate of you know, so many miles per minute, you know, is how we were measuring that. But this technology, just to quickly talk the evolution, you know, we brought the GPS signal into the cockpit and it was bringing those real time updates every time the internal navigation unit would drift, the GPS would bring it back and say "No, no, no you're back over here. You didn't drift, you know, a half a mile or whatever". But your point is so applicable to the warfighter, especially as we get things smaller, but I really want to go back to one of the things that you said. Now how do we use quantum to act like the old INS (Inertial Navigation System) system, I had my F-16. If we aren't going to use GPS to update my navigation system.

D

Dr. Andrei Shkel 12:58

Pulling is used to sort of create sort of this is a cloud of atoms and sort of by dispensing the atoms if nothing happens, if motion for example, doesn't happen, this cloud of atoms will move in a straight line. But if there is a rotation, this cloud of atoms will start deviating from the straight line. And this deviation is proportional to the rate of rotation or proportional to the acceleration. And what we use is a technique of optical or quantum ruler, which allows us to measure how much deviation happens. Due to a perfect structure of atoms, atomic sensors made however, smaller sensors are will have no drifts during operation or will have extremely small drift during operation due to cooling. Atomic sensor can have an exceptionally low noise floor, a combination of perfect structure of atoms, and low noise floor of quantum sensors would allow to extend the duration of missions for very long time and without the use of GPS and any GNSS signal. So this is really a combination of the perfect structure of the atom and ability to achieve a very low noise due to the cooling effects for example.

J

John "Slick" Baum 14:18

Right, and Max, I just want to ask you quickly, how do you physically get that atom cooled?

D

Dr. Max Perez 14:22

So there's three basic approaches to cooling atoms. So cold atom technologies are generally the most sensitive of the quantum technologies that are available. The most intuitive way is the direct way you can use extremely large refrigerators, called dilution refrigerators, to directly cool atoms down to just a hair above absolute zero. Those are called dilution refrigerators, they tend to be extremely large and complex and hard to deploy. Another way, a technique for cold atoms is using ions. They have an electrical charge so you can hold them using electrodes. They're very,very stable, but then you also use lasers in order to actually cool the individual ions. And one of the challenges with ion technology is it relies on a manufactured ion chip trap, which can introduce errors into your sensor signal. The third way is the way we do it a

ColdQuanta as we use a lasers that impinge upon clouds of atoms from all directions, in order to actually remove the energy and cool down the atoms themselves. And this is somewhat intuitively similar to how a noise cancelling headset might work, you simply your laser is out of phase or off resonance with the individual atoms. So when the atom is moving in one direction, the laser is pulling in a sense, and when the atom is moving in the other direction, the the laser is pushing exactly out of phase with the motion of those atoms and on on the whole, the energy of the population of atoms is reduced down to just a hair above absolute zero down to the millikelvin, the microkelvin in some cases, the picokelvin regime of of atom population. So these are extremely cold atoms that are somewhat counter intuitively cooled by using lasers.

H

Heather "Lucky" Penney 14:23

Slick, what's important is that the methods used to cool the atoms, it comes down to swap C and noise, the direct dilution refrigerator method, big Frigidaire, it takes a ton of space and a ton of power. We're not going to get that onto any aircraft. It's more warehouse size and it needs massive amounts of energy. The ion method is really useful for some applications. But again, the ion trap chip makes it less precise. So it's a graceful solution for some things, but we have to understand its constraints. The laser cooling method, I believe, has the most potential for miniaturization, for integration on to weapon systems. It's far more precise, because it's using that perfect noiseless atom that Dr. Shkel discussed. And I've seen these qubits in cold quantities facilities. They're actually smaller than your coffee cup.

J

John "Slick" Baum 17:04

Yeah, it's absolutely fascinating. And again, I know the challenge is going to be getting those those mass produced and small enough to be utilized. Now we've kind of focused on this PNT mindset. But Lucky, I know that we've heard that quantum is used in many other respects with computing and encryption. So do you want to hop in on that and how that's relevant.

H

Heather "Lucky" Penney 17:21

So folks need to understand that quantum has much wider applications than simply computing and encryption. And as you mentioned, select we've talked a lot about PNT, right? But we can basically break down the quantum technologies into three broad categories. The computing piece, which is probably further in the horizon and of course, that's really interesting, because the potential of the power of the processing when you exploit that superposition, or the non-binary element of the qubit. So we all know classical computing is binary, it's either ones or zeros. What's really exciting about quantum computing is it can it's non-binary, it's one zero, both, either you don't, you know. So it's really it's really fascinate. But it's further off communication, which we've talked about, which is either you know, you've got encryption and secure communication, we might even be able to expand the the frequency range that we can communicate on by exploiting qubits as well. And then sensing. If you ask me, I think the sensing the quantum sensing will have the greatest impact on our national security. It can cover anything from quantum radars, clocks, we've talked about the PNT navigation, the magnetometers, gravitometers, which can be other ways of sensing the environment, and even more, and I think what's really fascinating and super important is that these sensors are much closer to reality and fielding than we realized. You know, Max talked about, one of the ways of cooling these atoms is using these lasers. And that's actually allowed technologists to be able to start to miniaturize these qubits and that's key to making feasible and practical sensors and technologies. The other thing that's really fascinating is that as they continue to improve this capability for quantum sensing, they're moving the foundational technologies for the communications and computing forward. So there's a synergistic benefit by focusing on quantum sensing.

J

John "Slick" Baum 19:12

So Max, you're working in a company that's trying to bridge the laboratory science to real and practical hardware that can be integrated into a weapons system. So can you describe one of the capabilities you think you're getting close to for the warfighter?

D

Dr. Max Perez 19:26

Of course, so the first quantum technology that we're applying for specific application is atomic clocks. And it's a specific flavor of an atomic clock called an optical clock. Optical clocks are extremely interesting because, as and Andrei mentioned, clocks are the basis of essentially all PNT. Positioning, navigation and timing technologies all depend on clocks, other technologies that also depend on precision timing, are communication systems, data network systems, and any number of ...any system that require wires synchronization between two different nodes. Our technology that we're pushing out today will have 100x improvement over currently deployed technologies. It is potentially much more robust than any similar atomic clock that's available on the research market. And because it is fundamentally quantum, it has a stability, because it's based on these perfect atoms that is significantly better than any other commercial clock today, and will allow warfighters in particular, to operate in conditions in which GPS is not available to provide that timing reference.

H

Heather "Lucky" Penney 20:40

Slick let me jump in here and explain again, why clocks are so important why that precision timing is so important. As Dr. Shkel mentioned, it's kind of like oxygen, you know, when it's gone, that's when you realize you really, really need it. I think a lot of people don't realize how we've exploited timing in the battlespace, right, so we're all familiar with fifth generation aircraft and the information fusion. That all relies on advanced electronic countermeasures and being able to see through electronic warfare that largely relies upon timing. So there's a lot of things that we do on a daily basis in the battlespace to be effective, and to counter our adversaries attacks against us, again, that rely on timing. So this is just really exciting to know that this is closer to the warfighter than we thought,

J

John "Slick" Baum 21:23

Yeah, and, you know, Heather, I wanted to add on one of the things that when I was mentioning how the F-16, for example, INS, you know, added GPS to bring in that drift rate, but then we really exploited GPS to do so many other things like be miniaturized and help, of course, the timing for communications. But then also, you know, things like the JDAM (Joint Direct Attack

Munitions) weapons, so all of these things really became dependent on GPS. And then now the vulnerability is you just attack GPS, and that you've wiped out the timing, you've wiped out the communications, you've wiped out the accuracy of smart weapons and things like that. So you know, having this capability that's depend on GPS is obviously, such a vulnerability. And now having another solution path is essential. So I say, sign me up for this kind of technology. And and that said, you know, I'd like to ask what are some of the biggest challenges in the quantum community that you're facing as you mature these kinds of sensors? So I'd like to quickly start with Andrei and then go to Max.

D Dr. Andrei Shkel 22:19

There are a number of challenges of course, with quantum it's super exciting technology, but it's a sort of challenging technology as well. Again, I was, I remember, I was visiting one of the physics lab, and there was a monitor on the wall with training atoms, and this group that has been working on a quantum sensors, it's quantum atoms are perfect, and they can produce perfect information, perfect timing, but they are agree, we need to manipulate them, we need to move them from place to place and very small volume, they are subject to environmental imperfections and our changes to the magnetic fields or temperature variations, and so on. So there are a number of challenges on components technologies that need to be ensure(?) is that there are a number of challenges how to isolate this atoms from the environment, how to manipulate these atoms perfectly so that we don't sort of distract this perfect structure of atoms. There are a number of other very interesting multidisciplinary challenges that we need to address is to develop for example, combinatorial algorithms, a combinatorial. Meaning to use a combination of senses, not just quantum, but combine it with a solid state, miniaturize a sensor because they have complementary characteristic. So this requires to develop combinatorial algorithms and architectures that can seamlessly, can integrate quantum and solid state components with dissimilar physics in a single ensemble and on a single microchip. So this is a lot of manufacturing and quantum engineering challenges.

J John "Slick" Baum 24:03

Well, gentlemen, I really appreciate the background and understanding and I also have to say quickly, Andrei, I love your passion for the atoms. I mean, you're down at that level and you can tell that you just love exploring this technology. But is it fair to say that the DOD is making an effort to coordinate quantum efforts? You know, there is a quantum.gov website with, you know, this quantum initiative that's supposed to be coordinating quantum R&D across the government. So how is that going from your viewpoint?

D Dr. Max Perez 24:31

So the coordination from the DOD is going well, they've injected a lot of interest into quantum technologies in particular, but there's a number of things that they could be doing better. Following up from what Andrei just said, I think the system level approach for deploying quantum technologies is not being focused on as much as it could at the upper levels of the DOD. I spent a lot of time working with the UK quantum initiative and I noticed very different approach in the UK when they're bringing in companies at the very early stage to work at system-level projects, what are known as demonstrators that demonstrate quantum technologies being used with other conventional technologies together to solve an applied problem. And there's a very specific example that I might note in that, you know, when Andrei when he was at DARPA, he initiated a combinatorial program that combined quantum technologies with more conventional sensing technologies to really attack the problem straight on producing full initial instrumentation that can provide navigation without access to GPS. That's been, that was rolled into a number of programs that were very successful in the UK in which they demonstrated these types of technologies, which provided a lot of excitement, and a lot of push in the quantum industry in the UK. And what I'd really like to see in the US, at both the DOD level and across all of the quantum initiatives in the government, is bringing together defense companies, government laboratories, and private companies in order to demonstrate these technologies can really solve some real world problems. I think that's the next step in quantum in the US and I think that's the direction we're headed in.

H

Heather "Lucky" Penney 26:19

Slick, I need to inject here that while the Quantum Coordination Office is a start, is just a start. Quantum is not going to be easy, quick or cheap. Which means that we can't rely upon investments from venture capital alone to mature these technologies. It's just not going to happen at the speed that private equity needs to make money. So it will require government commitment, and government investment to mature and integrate and bring quantum in pragmatic ways to the warfighter. And this means more than coordination, we need a Manhattan Project-style private public partnership.

J

John "Slick" Baum 26:51

Yeah, that is a great point, Heather, I know that, as always, we could keep this conversation going. But we are getting tight on time here, I want to ask and I'm going to go in order of Max, Andrei, and then Heather, if you could just give us what you want the audience to take away as your key takeaway from this a quantum science and technology.

D

Dr. Max Perez 27:09

So the key takeaway is that quantum technologies are here and now. The science is well demonstrated, but what we need is very focused, nearing efforts in order to combine quantum technologies with conventional approaches in order to solve real world problems. And the problem of most importance to solve today is the challenge of fallibility of GPS-based position navigation and timing systems.

D

Dr. Andrei Shkel 27:36

To make a dent we need a very serious effort, and was already highlighted, let me just emphasize this, and we need a very serious effort to start breeding the next generation of engineers and I would call them quantum engineers. We need to invest in engineering research on quantum and atomic sensors, really focused research, not just on quantum in general, on quantum and atomic sensor, because it's very specialized application area of quantum. This needs to be a coordinated effort on new materials, highly specialized fabrication technologies, hands on test and evaluation culture, I think it's very critical. We need to promote the full cycle of developments in academic labs from design modeling, publication, packaging, control, tests and evaluation, all done by the same group of engineers. So engineers need to look into the entire cycle of this development and I think it's, it's super critical.

H Heather "Lucky" Penney 28:40

Slick, what I would say is, I want our listeners to understand that this is a must-win strategic race with China. We cannot lose. We've talked about some of the technologies but we we need the listeners to understand that when we begin to deploy these quantum technologies, and more than just, you know, our F-16s, and hopefully, super, you know, future weapon systems, and again, so forth, this is actually going to impact our lives writ large. And so we cannot lose this race to China. And what we need, is we need the government to commit to Manhattan project-type of effort, level of effort, to ensure that we're making the right investments, and we're building the right technologists and engineers and manufacturing capabilities to be able to bring quantum to our everyday life.

J John "Slick" Baum 29:27

Okay, I'd like to do the same thing with this question. We'll go Max, Dr. Andrei, and then Heather. But I really want to understand where you all think we're going to be in the future in the near future in the distant future when it comes to quantum?

D Dr. Max Perez 29:39

The immediate future is going to, you're gonna start seeing field demonstration of individual quantum technologies in the the following years, you're going to start seeing integrated system demonstrations on on specific platforms in parallel with that the manufacturing and the skills development is going to ramp up very, very rapidly across the quantum field such that in the five year time span, we're going to be able to see a robust supply chain from the quantum industry that can support the Department of Defense's needs, along with the defense primes in order to get these technologies out to the warfighters. In a reliable, and quick way.

D Dr. Andrei Shkel 30:22

So first of all in one year, and I don't know where to start, but I will be short. In one year, I would really like to see examples in academia, for training quantum engineers, I would like to see that at least one school in the nation has sort of a role model on how this needs to be done. There are no examples of this, to my knowledge, in one year, I also would like to see a focus in the DARPA program on development of quantum sensing, as well-thought metrics for achieving painty objectives, which we discussed of this self-contained navigation. I really would like to see it through DARPA-style with with the roadmap and quantitative milestones, sort of to energize the community to jump into this and solve these challenges. In two years, I would really like to see a national roadmap on quantum sensing. I don't know what it really take. But I think this is absolutely unnecessary. There needs to be a quantitative a very well thought a quantum sensing roadmap and it will take a while. So this is why I put it as a two years target. And in five years, I would like to echo what Max was saying, so all this effort will happen in DARPA programs and other agency programs and a roadmap to have a first production, or quantum single chip timing, and the inertial measurement unit which will demonstrate this prolonged GPS-free navigation is what I would like to see in five years.

H Heather "Lucky" Penney 31:58

Slick, I love that really pragmatic, focused a recommendation from Dr. Shkel. I would reframe this as what should the US government do over the near, mid, and long-term so that policymakers can have an action plan. First, I would give the quantum office more responsibility and budget. Coordination is not going to be sufficient to regain and maintain the advantage against China in quantum. So this quantum office should be supporting the foundation that Dr. Shkel mentioned, like training quantum engineers, and also investing in manufacturing facilities. Because like chip foundries these facilities will be specialized and require massive investment. We have such a national security interest at stake that this infrastructure demands a public private partnership. I would then urge the DOD to create programs beyond research and development, RDT&E is not enough. We need to create programs of record to catch this technology on the other side of the valley of death. We know now that we need an alternative to GPS, and quantum is going to be our best option. Conveniently, it's also the closest of the quantum technologies to maturation. So we've got to create a poll for a minimum viable product that we can integrate into weapon systems. This will accelerate the maturation of quantum PNT, the combinatorial engineering that Dr. Shkel discussed and provide quantum companies a target to design to and a belief that there'll be a program of record to catch them on the other side of that leap of faith.

J John "Slick" Baum 33:26

Yeah, I couldn't agree with you more there Heather. And you know, one of the things that I just want to sign off by saying is you know, when I first heard of quantum of course, it just sounds like magic, something that the warfighter might be able to see operational at some point but but who knows when you know, and how long it's going to take to mature the field. So I really appreciate having everybody on the podcast today to shed some light on this. And you know, one thing that we didn't talk about, which I'm sure will tee us up for a future episode, is the application of quantum in space for the Space Force. So with that, I just want to thank everybody for being here.

H Heather "Lucky" Penney 33:56

Hey Slick, as always, thanks so much.

D Dr. Max Perez 33:58

Thanks for having me. I'd be happy to join on the next podcast on applications to the Space Force.

D Dr. Andrei Shkel 34:04

Thank you very much, it was a total pleasure to participate in the discussion.

J John "Slick" Baum 34:10

With that, I'd like to extend a big thank you to our guests for joining in today's discussion. I'd also like to extend a big thank you to our listeners for your continued support, and for tuning into today's show. If you liked what you've heard today, don't forget to hit that like button and follow or subscribe to the Aerospace Advantage. You can also leave a comment to let us know what you think about our show or areas you think we should explore further. As always, you can join in on the conversation by following the Mitchell Institute on Twitter, Instagram, Facebook or LinkedIn. And you can always find us at Mitchellaerospacepower.org. Thanks again for joining us and we'll see you next time. Stay safe and check six!