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REVIEW

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High-Payoff/High-Risk Research Enables Full-Spectrum Dominance in the Battlespace

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As the vice president of Advanced Concepts & Technology for Raytheon Intelligence & Space, Bradford Tousley leads an innovative technology incubator inside Raytheon Technologies, which focusses on high-reward/high-risk disruptive technologies for the defense industry. In this interview he discusses the history of Raytheon Technologies and some of the advancements, including quantum computing, ARAKNID, DyNAMO, directed energy weapons, digital engineering, and synthetic biology, which will enable US forces and allies to maintain full-spectrum dominance in the battlespace in the near future. See video at https://youtu.be/8BGtJSISKUs.

Introduction

Samuele Lilliu (**SL**). Thank you very much for doing this and thanks to your colleagues for making this possible. You were recently appointed Vice President at the Advanced Concepts & Technology for Raytheon Intelligence and Space, which is part of Raytheon Technologies.[1]

In the past, you've worked on really fascinating projects, you spent quite a lot of time at DARPA, as the Director of the Tactical Technology Officers. Really interesting stuff. I'm a big fan. I've seen lots of videos on some of the programs we've been running. And now because this is relevant now, I was wondering if you saw the recent crewed flight test a few days ago,[2] I guess that was the result of the DARPA's Airborne Launch Assist Space Access. Right?[3]

Bradford Tousley (**BT**). The DARPA Airborne Launch Assist Space Access, I think it was called ALASA.

SL. The other project I saw was the DARPA Robotics Challenge.[4] I saw a couple of videos showcasing the competition. That was amazing. I've seen there's been a huge evolution with these robots. If you consider, for example, Atlas,[5] it started with those hooks and things and cables, and then there was a video last year where it was doing jumps and really crazy stuff.[6] So are these robots ready to be deployed for applications or they're still too loud and bulky to be used for real applications? What's the situation now?

BT. Well, I think there's two or three things you can consider there. One is, is the development of robotics capability, it's going to be fundamentally enhanced by power capabilities, because the systems are all limited by power. We humans, we are a marvel of biomechanics and integration of biological energy into muscles and tissue. So the robotic systems are going to be limited for now in terms of their power capability. That is the fundamental limit. In terms of autonomy and in terms of the connection of them to humans and human-machine teaming, that's coming along quite well.

You brought up the Robotics Challenge. I would say that, over the last 21 years, DARPA and others have worked on robotics challenges of various forms, whether it was the Grand Challenge[7] or the Robotics Challenge,[4] there was the Red Balloon[8] challenge, which is about sharing of information. But all these challenges were meant to inspire and innovate, and get the next step going forward in certain areas. And I think the Robotics Challenge that you talked about, was focused on bipeds, it was focused on disaster relief, and there's a lot of progress made in there. I know that.

During the run up of the DRC, the DARPA Robotics Challenge, I was afforded the opportunity to go to Japan and see Fukushima, where many of the tasks for the DRC were established as a result of considering how could humans employ robots in disaster relief situations. So I think you'll see it there. But the rest of it is going to be quite a bit manned-unmanned teaming, human-machine teaming for the foreseeable future. And many of these systems are simply going to be limited by the power and the mechanics of them for some period of time.

Figure 2 | Dr. Bradford Tousley, vice president of Advanced Concepts & Technology for Raytheon Intelligence & Space.

SL. So they're not ready to be deployed in warfare scenarios yet? We're not going to see any Terminator anytime soon, right?

BT. I don't believe so. I can't speak for all countries, but I can say, at least within the United States, the sense I'm getting is that we have a strong sense of ethics of how we employ autonomous systems in support of our warfighters. And for the foreseeable future, they're going to be involved in teemed operations only.

SL. Yeah. I saw that you worked, long time ago, you worked on GaAs photodetectors[9-11] during and after your PhD in electrical engineering at Rochester. So what kind of impact did a background in electronics and nuclear engineering have on your career?

BT. Well, yeah, nuclear engineering was way back then, during my undergraduate degree. It was insightful to teach me all about thermodynamics and nuclear reactor theory, large structures.

When I went to graduate school for electrical engineering, my dissertation was on what's called III-V semiconductors,[12] the class of semiconductors I worked on [was] In-Ga-As,[13]. I was basically doing Applied Physics, trying to understand the carrier dynamics of that particular material, which is used today and phodetectors and high-speed electronics.

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The real essence, though, of what I achieved from that or learn from that, was that research and pioneering something is a very difficult process, has a lot of trial and error, you have to have perseverance. Some of the results of the ideas you have coming into pioneering research isn't necessarily the way it comes out. What I learned from all that was just the difficulty of advanced research and you have to be prepared to stick with it for the long term and persevere through tough challenges.

Raytheon Technologies

SL. Raytheon is one of the largest aerospace intelligence service providers and service manufacturers in the world. You joined the company in late 2019. How would you describe Raytheon? What's Raytheon for you? How do you see the company?

BT. Raytheon today is a very large aerospace, commercial and defense company. I think we're about 180,000 people. There's four major businesses, of which I'm part of one, the four major businesses are Raytheon Intelligence & Space, Raytheon Missile Defense, Collins aerospace, and Pratt & Whitney.

In April [3rd] 2020, all four of those businesses came together. That was heritage Raytheon [Corporation], and heritage United Technologies [Corporation].[14] It's a really interesting combination of commercial, aerospace and defense. It's got a long history. I think United Technologies started back in the 1930s, I believe. Raytheon started in 1922. Raytheon particularly grew out of essential leadership of Vannevar Bush, who was instrumental in the United States and research development in WWII. United technology has always been involved in propulsion and power. Raytheon Technology got it started working on radar systems. So it's got a long history, and then the merger on April [3rd] 2020, brings forward these four businesses to really do great things in research and development and science and technology and providing capabilities for the population and for our warfighters.

SL. Yeah, because you mentioned the history. I mean, Raytheon [Corporation] was founded in 1922, I believe, and the company evolved from, let's say, manufacturing electrical appliances, and then it became one of the largest players in the defense industry. What happened there? When did you decide to change direction? Was it during WWII?

BT. Well, they were involved in electronics. But one way to think about Raytheon's early pioneering achievement had to do with radar systems. In the United States and the United Kingdom, during WWII, there was quite a bit of advancement made in early warning radar for detection of aircraft, threating aircraft.

Raytheon was involved in that with the development of microwave tubes. An example of how that defense application migrated into the commercial sector, back in the mid-40s was there were some Raytheon engineers after the war that were looking at microwave tube performance in a laboratory and one of the scientists noticed that he had a candy bar in his pocket, it was getting hot, starting to melt when he was working with these radar tubes, microwave tubes... today, we will use solid state power amplifiers, but back in the day, engineers were looking at essentially, these electronic tubes to generate the energy to power the radar system. Well, the heating of that candy bar was really the first idea that an engineer had that, "hey, we might be able to harness this into some sort of an encased Steel Cage or electrical cage". And that was the basis of the microwave oven.[15] Yeah, that's used today in kitchens around the world.

So it's interesting how defense technology becomes commercial technology. But it all comes from innovation, because who would have known that a heated up candy bar would become the basis of converting radar technology into something that could be used in the kitchen.

SL. Because we mentioned DARPA, people are probably familiar with DARPA, it's a public organization, but [they would be] also familiar with Skunk Works (Lockheed Martin),[16] a private organization, when it comes to advanced military technology. I guess, Raytheon Advanced Concepts & Technology, the ACT unit,[17] is a relatively new entry this space. Can you provide some background on the ACT unit? How old is it? What's the story behind it? And why was it established?

BT. Yes, ACT began as a part of the business of Raytheon in 2007 and it was stood up essentially to focus on prototyping capabilities, largely under sponsorship from DARPA, and IARPA and the US Air Force, organizations like that.

But it was stood up in order to explore the bounds of sensors and subsystems, radars, electro-optical instruments, infrared instruments, manned-unmanned teaming, cyber, things like that. And it was stood up in 2007 to focus on those early customers that are focused on solving hard technical problems. So the way to think about it, and I relate this back to what I learned in my graduate schooling, was you have to persevere through successes and failures and research and development because the path is not always linear. ACT was stood up to focus on prototyping those systems, what's called 6.1 to 6.3 funding or the prototype funding for the US military and for our warfighters.

SL. What's 6.1 to 6.3? What's that?

BT. Yeah, 6.1 is a category funding in the United States. 6.1 funding is what we call basic research. So if the US government is going to fund somebody to do the most basic research, the most exploratory, the most nascent, that's what they call 6.1. And then when you get into what's called 6.2 and 6.3, you're starting to take those technologies and combine them together to develop a new prototype, and to wring it out and to see if it's going to work. Within the US military establishment, 6.1 to 6.3 funding is often done well before requirement is even established, because it's not clear that the US military is going to establish a requirement for anything until they know that technology fundamentally works. So ACT's job is to help prove that point. Sometimes we succeed, sometimes we fail. But either way, we're going to persevere through that challenge and try and solve that prototype for Raytheon and for the warfighter.

SL. That links a little bit to the concept of "high payoff and high-risk". Does that apply to ACT as it applies to DARPA or there's a slightly different mind-set because [Raytheon] is a private company?

BT. No, it's absolutely the same. It's a great term "high payoff, high risk". A lot of people would like to say, well, it's "high risk, high payoff". The point is, we're after the maximum payoff we can get in the development of new technology or a prototype. We accept the risk that goes along with it and we understand that our goal was to be successful, but sometimes we will not be and so we go on to the next challenge. But you're absolutely right. It's the highest payoff we can get. And then we'll accept the risk along the way. And that that's fundamentally what goes on in what I said, 6.1 to 6.3 research.

Once you start getting into 6.4 full blown prototypes, or experimentation in the field with the US military, with a warfighter, at that point, the risk has been reduced substantially. And it's then about experimenting with the concepts to make sure that the military understands them and then they can derive a formal requirement from that, having the confidence that in this case Raytheon can deliver the systems needed.

Josephson Junction Microwave Bolometer

SL. Probably the recent papers that were published in collaboration with Raytheon are part of this type of research, right? There were some high profile publications that Raytheon published in Nature[18,19] and Science,[20,21] in collaboration with groups worldwide top groups in Spain, Korea, Japan and so on. So there was one publication in Nature [titled] "Graphene-based Josephson Junction Microwave Bolometer",[18,19] where basically you published a paper that details a bolometer that is 100,000 times more sensitive than the current commercial sensors. Can you tell me a little bit about that work? What was that about?

BT. Absolutely. That is what I would call 6.1 or fundamental research. And that particular research was attempted in order to validate an extremely sensitive infrared detector, you call that out correctly, it's called a microwave bolometer. In this particular case, one of the researchers at ACT, I think they partnered up with MIT, developed essentially a single layer of graphite, we call it a graphene detector, in between two niobium electrodes on what's called a Josephson Junction. That particular detector is, as you said, extremely sensitive for microwave infrared radiation. We've already sold one of those sensors to a university in Germany that's using it for Dark Matter detection in deep space. But that's an example of where some researchers attempted something for the first time to see how well that detector would work. That is 6.1 research and we're going to carry it forward and see what other system and prototype applications that we can achieve with that.

SL. Do you think it's an issue of the fact that these detectors need to operate at very low temperatures or near zero Kelvin?

BT. When those detectors are operating at those extremely low temperatures, what's called the noise floor drops, and the sensitivity gets much, much better. That was one of the reasons it was attempted with graphene. Graphene as the material is something that's being worked on for the last 5 to 10 years. But what's novel here is the fact that it was embedded in between two niobium junctions in an extremely sensitive framework that can be used for deep space astronomy, or it can be used for switching and potentially quantum computers. There's a variety of applications that we see it can be employed in. But in this particular case, the first implementation is for Dark Matter detection and for essentially extremely sensitive infrared astronomy.

SL. Because you mentioned that they are very small, then it's going to be easier to assemble them into a matrix to build up a full size detector for imaging purposes.

BT. Those are the next sets of applications we're looking at with that particular technology is "how do I scale up with many detectors?" In the case of quantum computing, if I want to use them as extremely sensitive photon detector, inside of a quantum computer in a very cold chamber, "how can I scale up with those as well?" But the first step along the way, in terms of this high payoff high risk approach, the first step along the way, was to validate that the single detectors work extremely effectively by themselves. And that's what we've done.

SL. You guys work a lot with the universities and I guess you do lots of partnerships with universities. Do you have any research grants available for scientists where they can go and apply? Is there anything like that?

BT. We do. Well, across Raytheon Intelligence & Space, number one, we work with a lot of universities, on joint proposals. We do a lot of work from the standpoint of internships across Raytheon Intelligence & Space. Frankly one way that we're able to find great young talent to join Raytheon Intelligence & Space is by the collaborative work and the internships we do with universities.

In terms of specific grants, I know universities will pursue specific grants on their own. [At] Raytheon Intelligence & Space (ACT), most of our work is what I call CRAD [Customer Research and Development], we do a lot of work with universities in that, where we'll be on the receiving end of crowdfunding from the US government and then we'll have grants or some sort of fixed price work that we'll do with universities.

I know, particularly on the 6.1 and 6.2, where across Advanced Concepts & Technology we do a lot of work with US universities today and it's a key part of some of the advancements we make and it's also a key part of our recruiting good talent for the future. That's, that's a critical part of the technology ecosystem.

Quantum Computing

SL. Now, in terms of quantum computing, I believe you're working on quantum computers as well, have you built one at Raytheon?

BT. Yeah, so ACT is working on what I would call systems engineering of quantum computing. What I mean by that is, there's a substantial amount of money in the United States and around the world, being dedicated into what I'll call large number of qubits, a qubit is a quantum bit, large number of qubits, for scaling up quantum computers and applications, commercial and otherwise.

In the particular case of ACT and Raytheon Intelligence & Space, we're focused on the system engineering applications to understand the algorithms, to understand the applications such as optimization of aerospace structures, and systems, and we're focused on understanding the systems engineering and the noise floor limits of the quantum computers.

It's one thing to simply say, "Well, I can build a quantum computer with 50 or 100 qubits". The real question is, "Can I build them and understand what their performance is? What their noise floor is? How well they perform with error correction and with error rates and understanding it. It's simply not enough to just have a large number of qubits in operation, you have to understand from a systems engineering framework, and how they work not just in theory, but an operation in order to know what are the potential applications we can really use them in. So at Advanced Concepts & Technology, we're focused on that systems engineering question.

SL. What can be done right now with quantum computers?

BT. They are still in the research stage, there are many press releases every year that come out about "well, we have 20 cubits or 30, or 40, we scaled all these up". I think most people understand that in the near term the applications for quantum computers are in signal processing and optimization problems. And what I mean by that is, when I want to scale up and do a large number of qubits in parallel, and I understand how to characterize each one of them, then I can solve signal processing or mathematical problems we call optimization, which are problems in which I need to scale a number of parameters in parallel, and process them and then come out with a solution. That's fundamentally different than our canonical pipeline processors that we have in large scale today. So we think those are the near term applications.

Longer term, there's obviously desires to use quantum computers from the standpoint of encryption, understanding encryption, and what the fundamental limits are. There's something called Shor's algorithm it was done many years ago, which postulated that a highly performing quantum computer would be able to break even the most demanding encryption.[22] So we do see those and those potential applications coming down the pike.

But today, what we're focused on is two things. Number one, the system engineering question and understandings out exactly how well they work with the noise, what the noise sources are, and how to characterize them. In the near term, applications we see are in mathematical optimization.

International Arms Trade

SL. In terms of international business, I would imagine that you're only allowed to sell non state-of-the-art technology outside the USA. I would imagine the USA would keep the most advanced devices and things. So if you want to sell something overseas, do you need approval from the US government for each contract you might need to sign? What you're allowed to sell overseas?

BT. Raytheon Intelligence & Space is obviously a US-based defense contractor, commercial, and aerospace and defense. And we develop quite a bit of advanced technology. From a business standpoint, and from a United States government regulation standpoint, we do carefully evaluate and adhere to regulations in terms of what we're able to sell internationally. It's not that we desire not to, but from a business standpoint, and from a proper regulation standpoint, we adhere to all the regulations as we're supposed to. There's ITAR [International Traffic in Arms Regulations] rules and EAR

[Export Administration Regulations] rules. But between both of those, we carefully follow those rules.

Having said that, there are systems that we have sold internationally, and we do you know, every year, one example of what ACT has sold internationally was there was a counter sniper shot detection system that was prototyped and developed by Advanced Concepts & Technology back in the early 2000s.[23] And then, at the time, it was it was developed and sold by BBN, which is a part of ACT today. Those systems were provided to US warfighters. In the 2005-2006 timeframe is when they started to be fielded. And they're sold internationally today in full authorization with ITAR and EAR regulation.

So, no, in fact, we do sell internationally, but we're going to properly follow the US regulations and laws as we do so.

SL. What's your approach towards preventing reverse engineering because I mean, software can be reverse engineered, you just need to disassemble it and reassemble it. Hardware can be reverse engineered, it's tougher, it's difficult to disassemble the microprocessor and a chip. But larger parts like aircrafts and other things are probably easier to reverse engineer as long as you can maybe replicate what was done with the materials. How do you protect your systems from being reverse engineered?

BT. An active area research that we are involved in is trusted computing, trusted distributed systems. The United States government is interested in having micro electronic systems that are trusted, so that we provide them to the warfighters for operational systems, that they have the utmost confidence that they can trust those systems. And that's an active area of research that we're working on today. I know the United States government has funded, different institutions, Raytheon's involved in that, and yeah, that that is the way I would, I would answer that questions that were focused on trusted systems in operation.

SL. I don't know maybe this is a silly question. But let's say that you are flying some drone in the air in the sky and another drone falls in some country in some area with insurgents. Do you have any mechanism to like destroy it so that nobody can go and check what's going on there?

BT. I think the question you bring up is something in the nature of operational military units. Certainly, any military equipment, when it's employed in an operation, there's a risk that it's going to fall into the hands of the threat. That's something that the US military will consider in the course of their operations. From a technology standpoint, yeah, we'll do everything we can to develop systems that are trusted so that if those sorts of situations do happen, we'll have procedures in place to consider how those systems are protected in the future.

ARAKNID and DyNAMO

SL. Now talking about warfighting and strategy, I saw your 2016 plenary talk at SPIE Defense where you spoke about advanced platforms for sensing in the air, space, sea, undersea and ground domains.[24] My understanding is that the Joint All Domain Command and Control (JADC2) is a DoD initiative to connect networks from different domains into a single network to enable faster decisions and actions. So in essence, speed is the best weapon probably.[25] So what's the role played by Raytheon in JADC2?[26]

BT. Let me start by highlighting that the JADC2 is one element under a US military doctrine, I believe that the Vice Chair of the Joint Chiefs of Staff highlighted recently, it was General Hinote, highlighted Joint All Domain Operations (JADO). Joint All Domain Command Control is a piece of the implementation under that doctrine. I know there's ABMS (Advanced Battle Management System), there's Project Convergence, Project Overmatch. Those are all pieces underneath Joint All Domain Operations.

Within Joint All Domain Command and Control, one thing that that ACT Raytheon Intelligence & Space is working on is advanced software that can be enablers. So there's two specific elements that we're working on, one is software and one is communications. I would phrase these as enablers for JADC2.

In the case of software, we have a piece of software we've developed called ARAKNID [Anytime Reasoning and Analysis for Kill-Web Negotiation and Instantiation across Domains],[27] which is essentially software that enables multiple units in a warfighting domain to bid and subscribe to the resources available to conduct combat operations. One of the most difficult challenges in JADC2 is how do you allocate the resources available, the sensors, the platforms? How do you allocate those to support the mission given that the mission is always dynamic, it's always changing in real time? You may have an operation or at the start of the conflict, you begun, but then very quickly, the situation changes. And so within those changing situations, a piece of software that ACT is providing to the military, an experimentation, we'll see how they ultimately acquire it. But under experimentation, what we're validating with the ARAKNID software is that you can bid and subscribe in terms of sensor and resource allocation dynamically, as the operation unfolds in a very efficient fashion. That's one piece of JADC2 two that we're supporting.

Another piece has to do with communications in all these operations, you have multiple security levels with multiple military units with multiple services. They have different protocols, they have different hardware, they have different security levels. And so within that we've developed software that can be implemented on various radio systems, we call it DyNAMO [Defense Advanced Research Projects Agency's Dynamic Network Adaptation for Mission Optimization].[28] And in essence, what it a multi-level, multi secure mesh networking that can support these dynamic operations in real time.

So both DyNAMO and ARKNID are currently being used in an experimentation today that can support the development of JADC2 in support of Join All Domain Operations. We'll see ultimately, where the US military goes from an acquisition standpoint, but at least from an experimentation and prototyping standpoint, that's where we're focused today.

SL. So and basically, this also links to the concept of mosaic warfare. We discussed this concept with Dr. Grayson from DARPA.[29] He spoke about mosaic warfare and this is part of it, I guess.

BT. Yeah, so DyNAMO and ARAKNID were both funded by the Strategic Technology Office out of DARPA, led by Dr. Tim Grayson. Within the framework of DyNAMO and ARAKNID, indeed, Tim had explained on behalf of DARPA, the mosaic warfare construct, which was, you're stitching or you're integrating together different pieces of technology. They weren't necessarily architected upfront, but you put them together after the fact in a mosaic like framework. I believe that's the way the Dr. Grayson was explaining it.

SL. Are ARAKNID and DyNAMO systems any way related to DARPA's STITCHES [System-of-systems Technology Integration Tool Chain for Heterogeneous Electronic Systems]?[30] So DARPA's STITCHES is a way to connect systems that weren't meant to be connected. So it's a sort of middleware...

BT. Yeah, STITCHES is a part of one of the programs that was developed at a Strategic Technology Office of which Arachnids is a part, so you're exactly correct. That is a piece of the overall thrust of technology that was being funded by the Strategic Technology Office.

Directed Energy Weapons

SL. Now talking about the directed energy systems. These are this basically weapons that can hit and damage a target by focusing a high energy electromagnetic or sonic wave and even charged particles on it. So the ACT unit developed a system called High Energy Laser Weapon System [HELWS], which uses a multispectral targeting system [MTS] pod to perform surveillance and counter drone attack missions from a lightweight vehicle; basically a dune buggy, a desert car.[31,32] So what are the components of this system and how does it work?

BT. Yeah, the HELWS that you referred, it was basically a rapid prototyping effort [partially] funded by the US Air Force for Advanced Concepts & Technology to prove, in a prototype configuration, that a directed energy capability could be put on a small... you call it a dune buggy... it was actually an MRZR, which is an all-terrain vehicle, I believe, developed by Polaris Corporation. In this particular case, the HELWS was employed in a prototype configuration on an MRZR to validate that that direct energy capability could be used to neutralize small drones on the battlefield. The way to think about it is you might have a radar system in a tactical situation that could detect these drones or these small quads, which can be threats to the worldwide US military forces and others. The direct energy capability can be used to neutralize those threats in flight once they've been cued up by a radar system.

The advancement here these are these are essentially fiber coupled systems with solid state power amplification. So from a power added efficiency standpoint and an end-point standpoint, when it's embedded inside of an MTS [multispectral targeting system], a small turret and put on one of these small all-terrain vehicles, it shows a capability that could be useful to the US military in the future when dealing with these small drone threats.

The part that I'm proudest about is that the team from ACT pulled this together and in 24 months under [partial] Air Force sponsorship, and showed what can be done. And now it's up to US military to decide requirement and acquisition standpoint, what they want to do next, but at least from the standpoint of taking the technical question off the table, we've shown that this can be done.

SL. And so this was adapted from the system that was mounted on the Reaper drone, right?

BT. Yeah, so the MTS platform, the MTS ball, turret, which is used for electro optical and infrared sensors, has been put on a variety of US military aircraft.

SL. So there are two main components, there is the sensing part, and there is the laser part that attacks the drones basically. In terms of sensing, you have a hyperspectral camera I guess. I used once a hyperspectral camera; we were looking at some materials. The most surprising thing is that it generates a huge amount of data because you don't just have an image. But for each pixel, you would have a spectrum. So if you have an image, like let's say 4k images, maybe 25 megabytes, but if you multiply that by the number of [elements] that you have in a spectrogram, that becomes like, I don't know, if the vector is 1000 elements, that becomes 1000 times larger, so 25 gigabytes. And if you have 30 frames per second, then you start getting terabytes. So how do you handle complexity with these systems? And what do you get from different frequencies when you sense?

BT. So if we transition now and talk about just hyperspectral imagery, Raytheon and others, obviously have developed hyperspectral instruments in short-wave, mid-wave, long-wave bands. You're absolutely right, when you use a hyperspectral instrument in a look-down mode, from air or other places, you generate what's called a hyper dimensional space. In other words, each of those, each of those spectrum that you've divided up from the imaging sensor generates a huge amount of data, whether it's high frame rate or low frame rate, and depending upon the number of spectral channels. You're absolutely right, that that has been one of the... you can call it… an opportunity and you call it challenge of employing hyperspectral instruments over the last 25 years has been in fact the amount of data it generates. But from that data, you can look for match filters, match signatures, you can do atmospheric correction, you can often segment a military target that employs you know, Camouflage, Concealment and Deception (CCD), you know, detect decoys from a real target. But you're absolutely right, hyperspectral imagery is a very powerful enabler and something that that ACT works often.

SL. What do you get from different frequencies? What's the range of frequencies they are using?

BT. Yeah, I think you can think of a being used all the way from, you know, 0.4 microns up to 10, or 11 microns. So all the way from the visible, near infrared, up to the long wave infrared. There's all kinds of different things you can use it to segment, manmade materials from otherwise, you can use it to segment different types of vegetation. In the commercial sector, there's lots of employment of hyperspectral imagery for crop detection to look for healthy crops versus, unhealthy crops, farmers are looking at that. The US military is interested in looking at long wave signatures for detection of effluence and signatures in that area. There's been some use by the military to look for camouflage versus non camouflage targets. There's a whole range of capabilities that can be analyzed from the visible all the way to the long wave infrared, but as you said, one of the big challenges coming out of it is just the amount of data it generates is enormous, which I believe it's an opportunity.

SL. Now talking about the laser system, how long would it take to take down a drone like Phantom 4 and old Phantom four a DJI Phantom four, like a drone, like the size more or less, how long would it take?

BT. I'm not going to get to the specifics of the employment, how long it takes, but suffice to say within that 24 month prototype program, we validated that, you know, in the case of HELWS, a 10 kilowatt system can bring down a quad, quad drone, a small drone. And we validated that within that program.

SL. Have you tried it with this swarm drones?

BT. I'm not going to get into specifics. This is something that's [partially] funded by the US Air Force, you can evaluate its effectiveness against these emerging classes of threats. You can imagine that, as these systems proliferate, it's going to be a threat to military forces all over the world.

SL. And also, well, things like stadiums, things like airports. So there are plenty of commercial applications as well.

BT. I imagine the commercial sector and the private security business, they're going to be every bit as interested in how they can defend against potential threats from the small drones.

SL. Yeah, and power plants and things like that. And I'm going to ask you something silly. I don't remember if it was one year ago or something, there was an incident at a nuclear power plant in Palo Verde that was attacked… not attacked… but there were drones.[33] And they said, those are UFOs. Would you use that system against UFOs?

BT. Well, I yeah, I'm not going to speculate...but there is no doubt that small drones have proliferated World-wide. If somebody saw them over Palo Verde [?], or somebody saw them over a military installation, it's something that I think we've all come to expect, based on the fact that they're affordable, and they're deployed worldwide. So it's not to me unusual that people are going to find these small drones in places that you probably wouldn't want them. It's something as a society, we're going to have to come to grips with and that's why we have regulations. That's why hopefully, the FAA [Federal Aviation Administration] is working on those sorts of things. But from a military standpoint, that's what I'm going to focus on, as part of Advanced Concepts & Technology is what can we do to defend the warfighter against those potential threats and give them the best chance for success.

SL. Yeah, because I mean… I don't remember where it was, maybe it was somewhere in the Middle East, they were equipping these drones with explosives, and then they were launching them. Commercial drones. I mean, you just mount some explosive, and then you send them to targets and civilians…

BT. You just pointed out the prime example of why it's of concern to the US military, because we're interested in protecting our warfighters or peacekeepers in harm's way, then we've got to give them the best capabilities to defend against the threat. And you're right, the proliferation of those lower cost systems, even though the payload is not that great, it's enough that it can provide a threat with a capability against the US military. So that's why we're interested in this direct energy capability that could be put onto a small all-terrain vehicle with forward deployed forces to protect themselves.

One of the reasons that we were interested in this 24 month prototype effort was that directed energy capability provides, quote, unquote, an unlimited magazine. If I had to use a bullet or some sort of projectile to try and bring down that small drone, I've got to worry about number one, where do those projectiles, how do I logistically provide them. Depending upon my accuracy can actually hit the threat system for anything that I miss, where those projectiles come down. And having a direct energy capability provides notionally unlimited magazine to deal with these lower cost threats.

SL. So you don't need to reload the laser system. As long as you have power, you can still send pulses and pulses and pulses.

BT. Exactly.

Digital Engineering

SL. Talking about systems engineering... this is an interdisciplinary field of engineering and engineering management that focuses on how to design, integrate and manage systems over the life cycles. These concepts have been around since many years, but maybe what was missing was computational power, able to support complex simulations and maybe usable digital twins. What's digital engineering and how was it used to speed up the design and prototyping of things like, for example, sixth generation fighter jets or other systems?

BT. From a sixth generation sensor standpoint, we are using the digital engineering thread to validate the entire prototype development of a sensor from concept formulation all the way to the final testing. As opposed to thinking only about digital prototyping for the standpoint of computer aided design of a mechanical system, the digital engineering thread means you record and you digitize everything in the process along the way from the standpoint of initial concept formulation, to the software development to the actual mechanical hardware, to the supply chain. All of that gets digitized as a portion of the record of the development of the capability. And it's done for two main reasons.

One is, from a standpoint of prototype formulation it minimizes the number of mistakes and iterations that you have to do because you got a good digital record right off the bat.

And then the second aspect is, once you complete the prototype project successfully, for example, that high energy laser weapon system, we've got a full digital record now. So if there's another part of Raytheon that is going to go in and produce the system in response to the US military saying, "Hey, we want to acquire multiples of those not just that first prototype", then we've got a complete digital archive of the entire system and the process by which we used to develop it that enables the production to be just much better.

From a sensor standpoint, it means that the number of iterations in the design cycle, you can actually do more iterations digitally. If I had to do all that in an analog framework with teams of people developing a new sensor, developing a new concept, if I'm going to use evolution from the multispectral targeting system you're talking about, I don't, but if I use something like that, if I did that analog, I would have to use engineering teams multiple times to cycle through the design. Once I do it digitally, I can do it much more rapidly and much more accurately. So then once I finally bend the metal the first time, then the odds that I'm going to get it right the first time are much higher. And that's another reason to the digital thread is it just allows me to cycle through the design process much more rapidly.

Within the software framework, there's a term within Agile software development, called Continuous Integration and Test. And what that means is once I developed some software within the digital thread that might be as the sixth Gen sensor programs once I go into a testing framework 10-15 years ago, I might have to have a software developer spend day and night, pressing the Return button to keep running the software to validate whether it works or not. In a digital thread, that continuous integration and test that regression testing, as we call it, is done automated. And it can run 24/7 without any humans at all, that entire process means I'll reduce the number of errors, I'll find my bugs faster. And that that just speeds up the accuracy and the performance of the entire system in a much better way.

SL. So this is hardware development taking suggestions from the best practices from software development, basically.

BT. Oh, absolutely. The Agile software development cycle predated the digital thread by probably 10 years. And that was really a recognition… the Agile software development cycle came out of the commercial industry. And now it's gone into the defense industry and we're gradually shifting our programs to be Agile DevOps. And within ACT, we're threading that now to be as well, our hardware development programs and that the way we're leading the way.

SL. Would you be able to explain what's Agile programming and development for the audience? Because that's very important.

BT. Absolutely, yeah. So Agile software development is fundamentally a construct where the evaluation metric for software development is fundamentally a unit of time. What it means by that is, I'll set up a particular thread or a sprin, it's typically what's called a 30 day sprint. Within that 30 day sprint of software development, you'll have a set of stories, or touch points from a software development standpoint, and you'll iterate them very rapidly within a period of time, so that over a 30 day period, you may cycle through three or four elements of software development.

In the older type approach what was called a Waterfall, you'll set up a whole set of requirements, and then you'll lay out an 18 month plan to accomplish it. And then you'll work like crazy to accomplish all those goals. And in many cases, you'll be successful. But the commercial world 15 years ago identified that if the unit of measure within software developments focused on time, they could adopt a more Agile approach that was efficient in the employment of the use per hour of a software developer. And so in that particular case, software led the way and now hardware is folding in nicely working on developing hardware in an Agile framework, which is exactly what the digital engineering thread is.

Millimeter-Wave Digital Array Phase 2 Contract

SL. Now, talking about sensors, transmitters, and receivers… There was an article that said that "Raytheon Unit wins DARPA Millimeter-Wave Digital Array Phase 2 Contract".[34] So my understanding is that there is an interest in developing more capabilities in terms of millimeter wave communication between different units because, essentially, the radio frequency spectrum is very crowded. Can you explain what the situation is? Why is it crowded? And why there is a need to move to let's say 5G bands?

BT. Millimeter wave is of utility to US military, because as you go higher in frequency, if you go from S band up to X band, and then you go up to K_a and beyond, you know, 35 GHz and beyond. As long as I maintained an effective fractional bandwidth, I have more capabilities, because of the directionality and the total bandwidth capability within that frequency range. Now, as you go higher and higher frequency, you have water vapor, and so you have atmospheric attenuation that kicks in. But nonethelessthe US military in many ways is migrating capabilities up into the millimeter wave. So that's one reason that Raytheon within the MIDAS program, were pursuing it.

But let me take a step back for a second. Raytheon technology has been working on radio frequency systems for many years and for many years those systems were segmented. So on an aircraft you might have a communication subsystem and then you might have an electronic attack subsystem, and then you might have a radar subsystem. But those were all three different systems. In the MIDAS program, what we're validating is that I can combine all three of those together into what's called a multifunction system. The US military ultimately wants that because they'd like to have one aperture on a notional aircraft that has all those functions combined together, because from a real estate perspective, on that vehicle, I combined it all into one piece of real estate, which is very valuable for the US military, the real estate on these platforms.

So developing a multifunction system in the millimeter wave is extremely capable and extremely effective.

The US military — and that's what the MIDAS program is all about — is showing that within the millimeter wave frequency I can do radar, EA [Electronic Attack], and comms all out of the same aperture, all in a way that's highly directional as a function of essentially a phased array. And so within that program, we're developing all the subsystems, and TR [Transmit/Receive] modules, how you do the three dimensional stacking, it's all a very demanding, technical application.

Referring back to what I said at the start. It's a high payoff application, not without its risks, but it's a high payoff application for the US military to develop a millimeter wave multifunction system, and that's what we're pursuing.

SL. So when you work with frequencies, I don't know exactly what frequency frequencies you're using, I guess, from 30 to 300 GHz...

BT. 55:41 Well, millimiter waves... when you're getting up to 300 GHz that's much higher, that's what's called THz, sub-THz. But, you know, the standard millimeter wave is I think most people consider it to be in what's called a K_a band.

SL. Is distance an issue? Because I mean, if you're working with radio waves distances is not really an issue, but when you get shorter wavelengths, maybe distance is an issue, and you need to increase power. Is there any drawback with these frequencies?

BT. Well, no, I think that from a system engineering and an architecture scaling standpoint, it ends up being what's called a power aperture issue, which is "Do I have the aperture necessary within the power and the transmitter-receiver elements in behind to generate the power necessary to accomplish the mission, taking into account the atmospheric?" That's something we account for within the whole system engineering design process, back to that digital engineering thread. Now, that's all accounted for.

Another reason it's not just because the radio frequency spectrum is crowded below it, but there's also reasons you want to go higher in frequency, because in some cases the application gives you better resolution. In terms of going higher power, higher frequency, it's more demanding technologically, which is one reason that Raytheon's being paid to do this in the MIDAS program.

SL. Is there any link with the Starlink constellation or that's totally unrelated? Because Starlink is beaming 5G? I don't know if that can be used for communication with your systems.

BT. That's slightly different, but at Advanced Concepts & Technology, we are being paid by the US Air Force on a program called Global Lightning, to demonstrate that we can communicate from a US military aircraft to the Starlink constellation. And the way to think about it is there are a variety of what we call P-LEO, a proliferate LEO [Low Earth Orbit], constellations. Starlink, Telesat, One Web, Kuiper, they're all examples of emerging proliferate LEO constellations. The US military is interested in seeing, can their aircraft communicate directly with these emerging constellations for military purposes. Within the "Global Lightning" program we are in fact being paid to validate that we can demonstrate connectivity between the US military aircraft and Starlink. And that that program is well underway.

Synthetic Biology

SL. So the last thing I wanted to discuss about was synthetic biology. So you guys are working on synthetic biology, according to your website... I mean, it's a big field, I didn't know it existed, I just found that there is an entire section on the Nature magazine. So synthetic biology is that convergence of biology and computer science, basically. What's the philosophy behind this approach and what projects are you working on right now?

BT. Sure. Well, let me back up for one second, within Advanced Concepts & Technology we'll work on kind of what I'd call two different types of technology categories, we're going to work on things that are just completely disruptive, there's no requirement whatsoever for it, and in other cases we'll work on emerging areas of technology or maturing or technologies that integrate in concepts that the US military can only think about. So MIDAS and Global Lightning are examples of things they can already see a path to.

Synthetic biology is what I call a disruptive area. There's no requirement yet. And yet, as you pointed out, there is in fact, a merging of biology and computer science that's unfolded over the last 10 years and within ACT, we're looking at that area to try and understand what are the US military capabilities that might come out of it.

One example is, we have a group of scientists that understood that the technologies necessary to conduct deep packet inspection of high data rate networks, that the ability to understand those packets of information, that same algorithmic approach can be used to look through DNA sequences. And so we had a bunch of scientists that said "Hmm, if I can look at deep packet inspection to understand if there's a nefarious Cyber traffic on a data rate of a network, could I use that same approach to look for pathogens that somebody might put digitally in the sequence of DNA?" And they've been working on that for the last 10 years. In fact, we've successfully completed that under an IARPA program. And we've been able to complete the licensing of what we call our FAST-NA algorithm.[35] Because there are there are DNA manufacturers in the United States today and they'd like to know, if somebody gives them a DNA sequence to manufacture the material, they want to make sure nothing pathogenic is in there, they want to make sure nothing nefarious is in there. So they're employing an algorithm that ACT has developed to check the data sequence in the DNA digitally to make sure there's nothing nefarious before they go produce it. So that's one example.

Another example of synthetic biology that we're working on is the utilization of essentially sequences of material that will penetrate down into the soil, try and detect if [there's] explosive materials below the soil like an IED. And then it will propagate back up to the surface and fluoresce at the surface so that a warfighter might be able to say, "Hey, don't go near that region or that area of the ground, there's something underneath that". And we're essentially going to use propagating algae back to the surface to fluoresce up and give off the light so you can see it. So that's the second example of biology that's being used synthetically.

A third example is we have some scientists that are working on a program sponsored out of DARPA to understand if naturally occurring shrimp that actually snap when they when they snap their claws together, if the sonic signature that they emit underwater can be used as a signal of opportunity to detect maritime threats underwater.

So the point is all three of those that fast DNA algorithm, the explosive detection subsurface, and snapping shrimp, not one of those is a requirement. But all three of those or any of the three, depending upon if they ultimately turned out to be successful, may be very effective in the merging of biology and engineering, computer science and the US military to provide capabilities and that's an example of disruptive technology that we'll pursue and sometimes ACT we may pursue that for 10 years before we decide whether to stop working on it or to or to transition it because sometimes it takes many years for a disruptive area of technology to really come to fruition.

SL. When it comes to synthetic biology there seems to be a convergence between bio warfare and cyber warfare. So does it imply that maybe — this is a big perspective — maybe the only way to survive bio warfare is to upgrade humans, as if they were machines with the next available antivirus upgrade?

BT. Well, I think the way I would phrase that, Sam, is that we're focused on in the case of the synthetic biology, the work that we're doing, we're focused on, in the case of the pathogenic sequences, finding things in the data and taking advantage of the cyber capabilities and the data analytics that we understand, to provide in this particular case capabilities to find pathogenic sequences in the DNA. From the overall biowarfare standpoint, I'm not going to comment on that at all.

You know, from an Advanced Concepts & Technology standpoint, in the case of synthetic biology, we're focused on the maturing area biology and data science and how it can be used in a protective way for our warfighters and also to understand from a disruptive innovation standpoint, where biology is headed as a maturing engineering field.

I made the comment earlier about Agile and Agile operations and DevOps and things like that, in the maturation of the software engineering field, and then we're migrating that into our hardware, the same sort of thing is happening in biology. Biology was for a long, long time, an analog field where a scientist or researcher might work in a laboratory with a beaker and check an experiment one at a time. What we understand now is that with the with the rich capabilities of data analytics, that we can start to bring that maturing field of data analytics into biology and help make advances that might be beneficial for our warfighters, from a defensive standpoint.

SL. Yeah, yeah. All right. Thank you very much. I think we can close it here. Unless we want to add some other points. Would you like to add anything else to this discussion?

BT. Just first I want to thank you for your time today, Sam, but I just want to reiterate that, you know, the Advanced Concepts & technology as part of Raytheon, Intelligence & Space, is really excited to be the prototyping arm and to provide capabilities in the disruption in the emerging area of technology, that's useful to help pioneer Raytheon's Intelligence & Space going forward.

SL. All right. Thank you so much for your time, and hopefully we can chat again when I would be in the USA.

BT. Thanks Sam. I appreciate. it was really great to spend time with you today and to be able to talk about Advanced Concepts & Technology as a pioneering innovator for Raytheon Intelligence & Space.

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There are no conflicts to declare.

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