Maj. Gen. Heather L. Pringle:

All right. Can you hear me? Oh, good afternoon, everyone. How are we doing? Yeah. I know you've been waiting with baited breath for today's panel. We have a very exciting group of panelists with me up here. We've been waiting all week to come to you and tell you about the future of propulsion. I'm the Air Force Research Lab Commander and Technical Executive Officer. It's one lab for two services, and we're really proud to be a part of telling you about the future of propulsion. It's often an unsung technology, but it's really helped us achieve the air power and space power that we see today. In the air domain, for example, propulsion is a critical component of our quest to attain faster speeds, greater range, higher altitudes, and improved power and thermal management capabilities.

Propulsion, of course, is also important to our space domain operations, as it takes extreme speed to escape the earth's gravity and to get to those far reaching orbits beyond geo in cis-lunar, but it also helps us efficiently manage space operations once we're on orbit. So really, all this is to say is that engines, rackets, propulsions, they're really here to stay. And so today, I'm really honored to have with me three experts to join us in this very important discussion, strategically chosen to represent the programs of today, as well as the potential technologies of tomorrow. I have with me, Dr. Mike Gregg, who's the Air Force Research Lab aerospace systems director out in Dayton, Ohio.

And to his left, we have Dr. Shawn Phillips, who's the chief of the Rocket Propulsion Division out at Edwards Air Force Base. And to his left, we also have Mr. John Sneden, who's the Air Force Lifecycle Management Center Director from the Propulsion Directorate. Unfortunately, Dr. Howard Meyer, who represents Air Force Futures, was unable to join us today, but I'd like each of our panelists, starting with Mike, to give us a quick intro and tell us about yourself.

Dr. Michael Gregg:

Thank you, ma'am. As general Pringle noted, I'm the director of aerospace systems. So, what does that mean? In the portfolio, there's hypersonics, there's traditional turbo machinery and propulsion. We have the Rocket Lab folks out at Edwards. We have autonomy, power and thermal management, and we have the air vehicle. So, one of the big things we're working on right there is the CCA type vehicles, and leaping ahead. A little bit about myself, spent 25 years in uniform, really covered the whole life cycle. I started life at the Rome Air Development Center way back, 30, 40 years ago. And then I got involved in missile defense, in acquisitions, C-17, and then I did some space work for a while, and then I ended up in sustainment of C-5 and C-17. So, seen it soup to nuts, and I'm really excited to be back in AFRL right now.

Dr. Shawn Phillips:

All right. Hello. As General Pringle said, I'm Shawn Phillips. And maybe you caught that I have two level of bosses right here, so I will stay in line the entire time during the presentation.

Maj. Gen. Heather L. Pringle:

And it's going to be hard for him. I'll just tell you.

Dr. Shawn Phillips:

Yes, it will be hard. So, a little bit about the Rocket Lab out at Edwards, which is part of AFRL. And what I want to say is we really embody the one lab, two services. I got the pleasure of being assigned, voluntold to be part of developing the CONOPS for AFRL during that time. And our division has about a 60/40 mix of Space Force Guardians and Air Force Airmen, which has really been an, I think, an exciting thing for us to take on in the areas of rockets that we have. So, a bit about myself, I'm a lifer out at the Rocket Lab.

Usually when you go there, people don't want you to come back, so I've really enjoyed that 25 years of actually being out in the desert, the Mojave Desert, where we don't have this thing called humidity. And today hopefully, we'll talk a little more about the technology and stuff that we have.

Mr. John Sneden:

Great. Well, good afternoon. I'm John Sneden. I'm the Air Force Director of Propulsion, and I'm also a member of the Senior Executive Service. It's an honor to be here with you today. And I think as General Pringle indicated, this is a very important forum, so I'm glad we're getting some airtime to discuss this key technology. I've been doing lifecycle weapon system management for well over 20 years now, encompassing space systems, aircraft systems, propulsion systems. And I will tell you that being in the propulsion directorate has been one of the most challenging and rewarding jobs I've ever had. This team really enables the propulsion center of excellence for the Air Force. They support ready, affordable, safe, and effective propulsion systems for 10 major commands, and over 50 international partners.

And the technology spread that they have is just immense. It goes from the 1950s, systems that were developed and produced in the 1950s, all the way to the most cutting edge technology that we have out today. So, truly a tremendous spectrum of activities going on today. And our focus overall is to innovate, it's to drive effective solutions, and it's to ensure ready, affordable, safe, and effective propulsion systems across the life cycle. And the team that supports that is just absolutely fantastic, and I'm honored to be a part of it.

Maj. Gen. Heather L. Pringle:

Well, thank you all for joining us here today on stage. I really appreciate you taking the time to be here. So, we're going to start with Mike. And as you said, your career has spanned the entire acquisition life cycle, but now you're leading the future of research and development in the propulsion area. So, what are the major developments that AFRL is working on, or any new areas that are exciting to you?

Dr. Michael Gregg:

This is really a very exciting time to be in the propulsion world, and that's no hyperbole. And when I talk about propulsion, it's across the whole spectrum. It's not just fighter jet engines. It's rocket engines, it's solid rocket motors, it's some small at triable engines, it's rotating detonation engines. So, we're really covering the whole spectrum of what it means to propel something in air and space. Shawn is going to be talking much more about our end space and to space propulsion work, but that is really just an exciting frontier to think about multi-mode propulsion and how we can use green fuels in space and how we can enable maneuver without regret. So, it's a really exciting time and we are trying to make the right investments based on the demand signals we are hearing. How do we support the OIs? How do we support what the war fighter needs today? Which is different from historical norms.

So when you hear that the lab in particular is drawing down some investments in the larger engines, that's true, but it's still a very exciting portfolio, and we are innovating truly at the edge. If you think about just the small at triable engines, there's a tremendous amount of work and research that needs to be done working in the lab and working with our industry partners. Hopefully, I'll have a chance later to expand a little bit, but it's really exciting to be looking at and investigating rotating detonation engines. Once again, we are doing some research in the lab, but we also have great partnerships across the spectrum of looking at this really interesting technology space.

Maj. Gen. Heather L. Pringle:

Hey, thanks Mike. All right, Dr. Phillips. So, you've an Air Force Guardian civilian. You've been out at the Rocket Lab for some time now. And the Rocket Lab has been an important part of our nation's development in rocket propulsion and been truly a part of some of the major developments that we've seen over the years, whether it's missile development, but particularly with the space launch areas. And in fact, I don't know if this audience knows, but the vice CSO, General Thompson, started his career out at the Rocket Lab out at Edwards. So as the director of this really amazing lab that we have, how have you adjusted propulsion investments to align with what they're doing in the commercial industry, which has really seen an uptick in activity, and it's really pointing us to some new and exciting directions?

Dr. Shawn Phillips:

So that was great. And the General Thompson thing is awesome. We got to see him the other day again, to mention that. And he still talks about that was the highlight of his career, at least that's what he tells us, going out and testing at the Rocket Lab. So, when you ask that question, General Pringle, the first thing I'd like to do is go back, and you mentioned the history, and I [inaudible 00:09:26] two sentences on that because we have so much history there over 60 years of it. And I think the pride that everybody can take in this room is that we know the aircraft side and all the history there, but every large liquid rocket engine ever developed or tested the United States has its footprint at the AFRL Rocket Lab. That is great, but the development at times were eight to 12 years, sometimes 15.

The other thing in commercial space, we had... We're looking at things, we were leaders. We were doing all this. We talk about the space access and in space. So, stepping forward to what you're saying now is how we changed. We had to change. It was almost like the other... This morning I woke up and said, think about everything that's happened in quantum computers. The Air Force couldn't step and say, "We're going to lead this." They had to say, "How can we leverage this?" So, what we had to do is stop being that lead that's trying to push the engine technology, when you have a multibillion dollar a year commercial space market, and say, "How can we go to the next phase of what the Air Force and Space Force needs?" And that was rapid capabilities. I know that's preaching to the choir. Rapid capabilities development, but also architect enablers.

We went from doing point designs, which really meant that you have a mission set, and you need to go from this point to here. We went to same... We have to be capability developers, and we need to use what's out there with commercial market. So, things like responsive space access, which are first launch with SSU, October 11th with ABL. So, we just got the word today. We looked and said, how do we actually get this responsive market happening at the S&T front and bring these companies that turn their eye towards the DOD? And we did that. Rocket Cargo, which I know you're very familiar with, we helped out with TCO on that area, the first start [inaudible 00:11:00]. So, that was how we had to change our portfolios. We went from these large engines to the space access capability. And in space, just real quick, what we had to look at was the same thing.

We did point designs for how do you get from A to B? But as we know from the talks yesterday about the Space Force, space operations is a different regime now. It's not about what's that mission right there. It's our operation aperture is open to the point of, what can we do and what do we need to do? So our job, as Dr. Gregg mentioned with multi-mode propulsion, is we have to enable an architect out there that can be resilient in space, but maneuver without regret, give you the tools, that propulsion capability that allows you to go where you need to go without saying, "I just lost three years of my satellite life."

It's part of your RV director. I know that that's the architect for that, and the propulsion enablers come from where we are right now with our scent fuel, which is in-house, and then moving on to combining electric and chemical propulsion to move forward. So, we've had to change really to a capability and

architecture enabler, if you want to say it, and move away from that point design, which I think has been an incredible thing to do. Hopefully, that answered it completely.

Maj. Gen. Heather L. Pringle:

No, thank you John. That was absolutely great. So, no worries there. So, John, you mentioned you have one of the toughest jobs that you've had in your career. And of course when you look at your portfolio, it's soup to nuts. It's propulsion development, acquisition fielding, sustainment, as well as modernization. And you're doing all that to ensure that the war fighters needs are met today, but also in the future. So from your perspective, why do we continue to invest in propulsion, and what more is needed?

Mr. John Sneden:

Yeah, that's a great question. So, I'll just open and say it's all ties back to what the SEC have laid out in the operational imperatives. The reason we invest in propulsion is to do exactly that type of thing for a war fighter, ensure that we have next generation air dominance, ensure that we have a family of systems capability to be able to support the fight, ensure that we're ready to drive to a readiness posture that meets a wartime footing. And there's multiple factors that pour into why you should invest, but at the end of the day, they all support those operational imperatives. And I'll offer you a few thoughts in terms of what I think is key. The first reason you want to invest is because it drives capability out for the war fighter. It's capability that the war fighter deserves. And what does that look like?

Well, typically, it looks like fuel efficiency, which drives range, which means that there's more time on station. It means that you can start your operations from further out. It means that you have less tanker dependency. It means survivability, because we have better acceleration capability to get in and out of the fight, and it means that you have better power and thermal management capacity to be able to feed those advanced mission systems that all the next generation weapon systems seem to have. So, it is a game changing technology that we have to continue to invest in to make sure that the war fighter has a cutting edge. The other key thing here is that this investment allows us to stay ahead of China. And China has a very specific focus of catching up to the US, getting to propulsion parity, and exceeding our capacity.

In order to be able to move further, we have to be able to transition our next generation technology, we have to be able to update the performance capability of our legacy systems, and ensure that the war fighter has the readiness, has the capability to be able to go fly, fight, and win. Another reason that you want to invest is quite simply that it gives us a place to practice. Practice what? Practice digital transformation. Some of those tools that allow us to move faster, drive costs down. And this is an area that needs vast improvement in the propulsion world. So, an ability to move in that realm is critical for us. And finally, what I'd offer is that investment propulsion means that you're helping maintain a viable propulsion industrial base. And I want to be real clear on this point. Our engine OEMs, they're not going anywhere.

They're all well maintained by the commercial market, by fourth generation military workload that they have, and we're applicable to fifth generation workload. But what we're keenly focused on is that advanced propulsion space, that advanced propulsion technology space, and how do we maintain it? And I'll offer to you that there are more countries that can produce a nuclear weapon than can produce an advanced propulsion system. So, it's very key that we keep that very thin sector of the marketplace alive. And there's a variety of ways that you do that. So, when you talk about what more is needed, one of the key things that you have to do is you have to focus on investment, tech transition, and speed. And that means that from a laboratory perspective, we have S&T efforts that cover large, mid, small, and

that we have this constant pipeline that's moving, we're transitioning the technology we have from the labs to the war fighter, and to make sure that we have the engineering development, manufacturing production capability to be able to move forward.

And frankly, we need to be able to do that with more than one propulsion OEM. We need two, at least two propulsion OEMs to be able to make that maneuver, so we can keep innovation and we can keep cost where they need to be. And then the final thing is that we have to continue to sustain. That means investing in programs like our component improvement program that drive safety, reliability, maintainability, looking at our digital transformation type of activities, whether it's using big data, big data analytics, advanced manufacturer repair capabilities, that whole ecosystem to lower cost, pick up speed, and drive the readiness that the war fighter deserves. So there's a lot of maneuvers that have to happen here, but again, the aggregate team is capable of yielding that outcome.

Maj. Gen. Heather L. Pringle:

Well, that's really helpful, John. And I'd like to go just a little bit deeper on how we can maintain our advantage in propulsion. And of course, you've overseen eight different systems with 30 different propulsion variants, so you've kind of seen it all. But based on your experience, let's talk about more from the industrial base perspective and technical technology transition. So, how do we maintain our advantage?

Mr. John Sneden:

Yeah, that's perfect. Thank you for that. The first thing I'll offer to you is that the US has the propulsion advantage over China, and we have long head propulsion dominance. And I'll offer that our intent is to maintain that propulsion dominance. And it's not just in performance capability. It's also in system reliability, which drives time on wing and readiness, and it's also in safety. And I don't want anybody walking out if you're thinking anything other than the US has the world's most capable, reliable, and safe propulsion fleet in the world. And with that, we have all the capabilities that go along with that. But I will tell you that anytime you have an advantage, it's important to check your six. How fast is your adversary coming up behind you? What's going on? We can't keep living off the advantage. We have to always be innovating, always be moving forward.

So, I will offer to this crowd that China's catching up. They're catching up at a rapid pace, and they're leveraging multiple things to get there, including their commercial market, their partnerships with other nations, intellectual property, theft, frankly, and investments and propulsion technology, manufacturing capability, materials, infrastructure that outpace our own. All right? So, if we were to stand still, which, again, is not our intent to go do so, then we would see China reach propulsion parity from a performance based perspective within about a decade. Obviously, it's not our intent. And then we also have to look at not only what China's doing, but what's happening within our own environment? What are we doing that's contributing to the degradation of some of that lead? And I would offer to you that it's... You look in our labs, we don't have any large engine S&T efforts, haven't had those in a couple years.

When we start talking about fielding capability, we don't do that at the same pace that we used to. Sixties, seventies, eighties, nineties, all had rapid capability moving, always moving propulsion technology for. Our last fighter engine, derivative fighter engine that was fielded, was done a couple decades ago, the F135. So, we're not moving at the same pace that we used to. And then frankly, we don't focus as much as we used to on performance updates. We're very safety and reliability focused, but don't put as much emphasis into that particular portion of the world. And then finally, I'd offer here that from our engine technology, our next generation engine technology, we're still working the

transition pathways of how we move ATP forward, how we move in gap forward. So, there's still a lot of work to do. But with that said, again, what I'll offer to you all is that we have no intention letting China catch up with us.

And there's a lot of things that we can do to yield that outcome. And a lot of those things are already in work. So, if you look from a lab perspective, we can continue to bolster our labs, and that means not just small and mid-size engines, but also putting large engines back in there, transitioning our key to engine technology, like ATP, which yields a 30% range improvement, 18% acceleration and double the power thermal management capability out there, moving in gap forward to ensure that we have next generation air dominance through a next generation propulsion program, all those small and mid-sized engines that are in the lab today, getting those fielded to be able to address our munition and CCA capabilities of tomorrow, updating our modernization programs for our legacy systems. All of those things are either in work or can easily be moved forward. And again, it's our intent to do so. And I would offer that, at the end of the day, we will continue to maintain our propulsion advantage, but it will be through an investment and transition and deliberate action.

Maj. Gen. Heather L. Pringle:

So, there's a lot that we can and are doing to maintain that technological edge. And so on that note, I guess I'd like to go back to the racket lab, and Shawn, have you tell us about how you've made that transition from large liquid racket engines to the responsive launch systems to really take advantage of all the innovation that is out there. Shawn?

Dr. Shawn Phillips:

So, thanks. Oops. I'll be the first one not to put [inaudible 00:22:58] mic. So, that was probably the funnest challenge with my career, and I really loved it, because I always like... When people say they don't have enough money, they don't have enough stuff, you have resources like you wouldn't believe, like the AFRL rocket lab, 10 billion of facilities. And we're sitting there looking at this commercial space market, new space, and all the other existing companies say, you have tens of billions of dollars going into this, if not more right now. It's crazy how much is there. How are you going to leverage that? We didn't want to let one contract to say go this way.. As to mentioned, we're doing capabilities. So, the challenge is how do we bring the entire commercial space market, both on the space access and in space, to the DOD? How do we turn their eye towards us?

And we looked and said, what are their needs? And it really came down to two things. The first one was resources. We had a facility that's been there since the 1950s, up and growing over 1960s. And these companies can't just build these facilities, get the air permits, get the environmental factors. And then we have, and I'm proud of this, the Department of Air Force, the top subject matter experts in the field, and the companies don't have all that. So, we start engaging in public-private partnerships. And those partnerships, we brought the companies in as true partners. Not saying here's a GOCO, saying, "We're going to work with you to develop the technology." As we work with them, we start showing the DOD requirements. What's the needs? And they started changing towards that. So, the biggest challenge was getting that part. And there's a second part or the second challenge. How do we change our culture at the site where we were always the leaders?

We were always the ones that were saying, "Here's our contract. Here's what the Air Force needs. Here's now what the Space Force needs." Now, it's, "How do we work with that company and we help leverage what they're doing to the DOD?" And the results have been phenomenal. I smile when I think about this, just over the three years, when I can look and say how many companies we have on site. How many are doing things for pennies on the dollars for launch services, for in space, the companies

that are invested in our multi mode propulsion for the nation, the modular propulsion, so we can actually do a quick form fifth change of things in space, as opposed to everybody having a different propulsion system? And the space access area, that whole thing I mentioned with the public-private partnerships, when I say it's a collaboration, we're talking about companies sign up have to live onsite, well, not their people live onsite, because we are in the middle of the desert, but the company's onsite for 10 to 20 years. And they're there, hand in hand, doing work with our researchers, which we've never seen before.

And our researchers have a sense of value that they've never had before, where they get excited. I had one person I've seen for 20 years. I know this is anecdotal. And he's walking and he's smiling. And I was like, "Jacob, why are you smiling?" He goes, "I'm going to work on this new rocket factory in a box, and I'm right there in the box with the people that are doing this." He said, "We never going to see this part." And so when you look at it, we've changed that hardest part. The two parts was the companies are looking at the DOD needs and they see the investment, not just looking saying, "Let's do this launch. Let's do this for commercial." And we're seeing our research culture change to that we can leverage and have great impacts and do it in the shorter timeframe. So, I think those are the two biggest challenges that we've turned the quarter on, and it's really exciting to see.

Maj. Gen. Heather L. Pringle:

Well, that gives us a lot of hope about the things that we can do to maintain our advantage in propulsion. I was going to keep this story to myself, but I was recently out at Edwards, and I met one of their newest aerospace engineers. And he actually came to Edwards, the middle of the desert, and he's top in his field for propulsion. And he left Stanford to come work in the research lab. And I said, "Why? Why would you leave Stanford to go to Edwards?" And he said, "Because rockets are here to stay." And it's really an exciting time.

Dr. Shawn Phillips:

Completely agree with him.

Maj. Gen. Heather L. Pringle:

Well, we're a little bit of a biased panel up here, so what can you say? But given what we're learning about how we can better partner or leverage what's going out there in industry, Mike, I'm going to turn to you. And you've been in this research ecosystem for... We won't count how many years, except you already told us, but how do you see our ability to maintain our advantage in propulsion? Are there some things that are exciting to you? I've heard you say already, twice, rotating detonation engine. So, you want to make it three?

Dr. Michael Gregg:

So, first let me say, working with Shawn for a number of years now, one of the hardest things about working with this guy is keeping him motivated. So, if I could feed off at some of his enthusiasm, there are two things I really want to highlight, and one Shawn mentioned, and that's what we're calling Rocket factory In-A-Box. And why is this important? Because we've been working with industry, we've been using true digital engineering to design a new manufacturing way of doing business with a digital way of doing the propellant, and new ways of doing the solid rocket motor cases. And it's the size of... A little bit bigger than this front area up here. Why should I be excited about that? That is changing. That has opportunity to change an industry that's been using the same methodology for 50 years. That's significant on how we do business.

And if we think, going forward, we need to be rapid in our ability to manufacture, that's what we need. If we need to be rapid in how we design new solid rocket motors, that's exactly what we need. And we're able to do that precisely because we have those digital models that help us design the layout. It's completely automated, and we can rapidly change. That's the power of digital transformation. That's a concrete example of why this is so exciting to be in this space right now. The other example, and actually I think the other directors and General Pringle, they play RDE bingo with me. Every time I say it, they get another chip on their card because I say it a lot, because this is so leap ahead in what we're trying to accomplish here. And for those of you who don't know what RDEs are, it's called a rocket detonation engine, rotating detonation engine. You can apply it to air and rockets. And so instead of a traditional turbo fan engine that has a configuration in the combustion chamber, it's really a detonation.

That's not what you want in a car. But for something like a propulsion system, it's great. And why is it great? Well, you can achieve anywhere from five to 25% levels of efficiency and no moving parts in the combustion part of that, which means you have a smaller form factor. Or if you want to keep the same form factor, you can double your range. I mean, this is a significant leap ahead, especially where we want to go with things like long range strike. And ultimately, it will have applications to potentially an afterburner or an augmenter or potentially even to a jet aircraft. It is so significant. But we know there's a long way to go, and it's really based... What we're pushing really hard on is, once again, this digital environment. And an example that we're working with industry on is...

One of the key things that we're developing is how do you inject the fuel and air into this rotating, into this cylinder? And instead of... Historically, we may have done 12 different designs that took a long time and took a lot of very expensive material. Now, we can use digital modeling to help us focus that cone of uncertainty on, here's where we really want to experiment on. Now, maybe we can only do threes nozzles. And we can shrink the time, we can shrink the cost, and we can drive in on exactly what we need to do that much faster. So. This is a perfect example of how, once again, we're using digital to really focus in on something that's really exciting.

Maj. Gen. Heather L. Pringle:

So, I think we're up to seven times that you've said rotating detonation engine, but it's all right, we can keep going. It's a great topic. But I'm really glad that you brought up the digital transformation, the digital thread that we can use for our propulsion systems. And so since John is responsible for the whole life cycle of propulsion, what can you tell us about how we can use these kinds of agile tools to drive a responsive industrial base and build a better partnership?

Mr. John Sneden:

Thanks for the question. I'd actually like to talk about rotating detonating engines, if that's okay.

Maj. Gen. Heather L. Pringle:

Eight.

Mr. John Sneden:

So, I'll just broadly say that our intent is to drive, improve, readiness, affordability, safety and effectiveness through a digital transformation, and we've got a lot of work to go do. And really what we're trying to tie into is the operational imperative of being able to yield readiness at a wartime posture, yield responsiveness that the war fighter requires in a wartime type of a posture. And there is a significant problem across the propulsion community. And I know some of my OEM partners are here in the audience today. We have all had this discussion and we've all to been talking about how we can do

better, but we have to do better. So, when we talk about on the developmental end, it takes about 10 to 15 years to develop a new engine system. And some of that, frankly, is a little bit of the Air Force's requirements piece of it.

Some of it is how we've also been buying in the past, and that we haven't really had a lot of chance to practice in a digital environment. But 10 to 15 years is not moving at a threat relevant cadence. And then when you flip over to sustainment and we start talking about how agile capable, either the engine OEMs are themselves or their supply chain is, it's not very responsive. What we see is there's a lot of out of specification components coming in, and we see lead times that sometimes rival two to three years. Again, not a really responsive type of movement. And then on top of that, you've got the worldwide inflationary aspects that are driving up costs. So, there is a lot of room here to drive costs down, improve speed, and improve readiness for the war fighter. So with that, we have a handful of initiatives that we're really proud of, and my intent is to get these more and more on scale.

So, we started what I think to be kind of small, and we've got some great pathfinder projects, but we've really got to start bolstering this out, and we've got to be able to do it faster, go further faster with this. So, the very first thing is, on the developmental end, is we are designing and validating our next generation adaptive propulsion system that will support our in gap program in a digital environment. And that's a huge transformation. Even our ATP engine wasn't designed in a digital environment, just kind of predated some of that. So to be able to do this, we think will help us get onto on a threat relevant cadence associated with being able to develop new engine technology. And again, 10 to 15 years needs to get brought way in. So, a lot of room to go, but in gap is our start. And on the sustainment end, we have a host of programs that are going on right now, and we keep picking up more.

And I'm really proud of everything that we've done so far. Things like using big data and big data analytics for reliability center maintenance activities, to make sure that we're doing the right things to keep engines on the wing longer and drive readiness. We have adopted a advanced manufacturing and repair ecosystem that's yielded the first airworthiness approved component that is flying in a F16 today and was additively manufactured. And we have a handful of other additively manufactured components in the pipeline of varying complexity, and even recently established the first organic capability for advanced manufacturing, for adaptive... I'm sorry, for additive capability.

So, a lot of activity going on there. We're doing our first digital twin, which helps us validate performance models, helps us simulate performance of a system, and helps us be able to move forward into doing a modification of an engine system. We're even looking at AR, VR, moving that into a digital type of environment as well. So, a lot of activities, but they're all focused on how do we move this enterprise further faster? How do we drive costs down? How do we drive readiness up? And again, a lot of room to go make. But what I'll share with you in closing is that this team is leaning fully into this. They have embraced the digital transformation. And while we still have a lot of room to grow, we are equal to that task, and we look forward to bringing the war fighter more in the future. Thank you.

Maj. Gen. Heather L. Pringle:

Hey, thank you. So, we've really only scratched the surface, but this has been an invaluable discussion. I really appreciate you joining me here up on this stage and talking about this really important topic. You've covered how we've transformed from liquid rocket engines to more tactically responsive space access. And if anyone in the audience is interested in learning more, we have our booth down there on the floor. It's number 703. And you can talk to the second lieutenant who has been on the job for three months, and she would love to regal you with her knowledge of tactically responsive space access, but it's really exciting to learn from her as well. But there's lots more that we can do as well, and I appreciate all that we can be excited about. And I think it's pretty clear that we can't take our foot off

the gas pedal because there's more we need to get after in terms of smart propellants. And I'll say rotating detonation engine just one more time for Dr. Gregg.

But as we see new missions in space, or even in air, we're going to have to adapt our propulsion systems to accommodate that. And as General Brown likes to say, accelerate, change, or lose. So, thank you all for being here today. Thanks for being partners with us. And again, let's give a round of applause to our panelists here on stage.