Episode_89-Hypersonic_Strike

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SPEAKERS

Arlen Kostival, Eric Knutson, John "Slick" Baum, Brian Schappacher

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John "Slick" Baum 00:01

Welcome to the Aerospace Advantage podcast. I'm your host, John "Slick" Baum. This week, we're going to talk about one of the most exciting developments in combat air power: hypersonics, the ability to fly at over five times the speed of sound. Now, we've known how to do this for decades. I mean, think about the X-15 at the National Air and Space Museum here in DC, and the Air Force Museum in Dayton. They flew in the 1960s and were beyond incredible. But that was a long time ago. And the reality is that America took its eye off of that hypersonics ball for way too long. The 1970s, 80s, 90s, and even the 2000s saw a random set of programs that failed out, had irregular funding and inconsistent objectives. This was a lethal combination that ravaged our hypersonic talent pool, burned through time and saw us barely tread water. And the advantages of flying so fast are obvious from a military perspective. It allows commanders to rapidly strike targets, and traditional defenses really don't work against things that are flying that fast. Our adversaries, especially China, get this and that's why they've invested so much to develop their own hypersonic technology. And it's worked. The lead we used to have doesn't exist anymore. So that's the crux of today's episode. We're in a hypersonic race with countries like China. The focus is on weapons. And we don't want to come in second because if you think developing hypersonic tech is tough, inventing defenses against something so fast is even harder. Our assets in the Pacific like our bases, ships, space downlink stations and logistic lines would be incredibly vulnerable. There's no good plan B for losing this race. Now, we covered this earlier in the spring with hypersonics experts, Dr. Mark Lewis and Dr. Dick Hallion. But we wanted to continue the conversation and learn more from some folks who are directly involved with working the program. So with that, let me introduce Eric Knutson. He is the director at Skunk Works Advanced Systems.

Eric Knutson 02:01

Thank you much. It's a it's an honor to be with you today.

John "Slick" Baum 02:04

We also have Brian Schappacher. Brian is the Air Launch Rapid Response Weapon's deputy program manager.

B

Brian Schappacher 02:10

Yeah, I really appreciate being on here, you know, in this industry you usually don't get to talk about your work. So this is super exciting for me.

J

John "Slick" Baum 02:16

And also Arlen Kostival, vehicle systems engineer.

A

Arlen Kostival 02:19

Yeah, thanks Slick. Excited to be here, and looking forward to the opportunity to have this conversation.

J

John "Slick" Baum 02:23

They're part of Lockheed Martin's team developing hypersonic technology, including the hypersonic Air Launch Rapid Response Weapon, or ARRW for short. That missile has made a lot of news lately. It's launched off of a B-52. It has executed two successful flights and is in line for a bunch more testing on the way to hopefully join its operational inventory. And we're really excited about the recent wins here with the latest test flights. But it's also important to emphasize the program has experienced its fair share of challenges. So the bottom line here is, this tech is really tough. And we're asking a lot of people to rapidly innovate on some of the hardest airborne applications we've looked at in decades. So, I'm talking about everything from aerodynamics to materials and propulsion. So everything is on the line here, the high, ultra high varsity level. So again, gentlemen, thank you for being here. So let's kick this thing off and put your project into context. I've got to ask this question. Why should we care about hypersonics? I know that I tried to explain this in the introduction. But why do you think it's so important that we win this race? And Brian, we'll get started with you.

B

Brian Schappacher 03:25

Sure. I mean, you know, the technological advantage that America and our allies have enjoyed for many, many decades is being eroded at an alarming rate. Really, hypersonics is the game changer there, they really decrease our response time and strike scenarios. That reduces the time our adversaries have to counter and react, you know, it gives a bigger element of surprise, I think the biggest thing that it provides is a significant deterrence, you're less likely to, your adversaries are less likely to engage when you know that, you know, we have these capabilities.

A

Arlen Kostival 03:53

Arlen Kostival

Yeah, I'll just jump in on that. I think Brian made some good points, I want to highlight two important factors that I think makes this capability an important tool in our warfighters' toolbox. One is the speed, right? And so when you're talking about hypersonics, you're talking velocities in the miles per second range. And that's very, very hard to defend against. So you know that that is a core component of this capability. But speed alone is not enough. And I think you also have to factor in the maneuverability of these types of systems. So I like to think about it like I'm playing baseball. Traditional ballistic missile type systems, that's a bit like hitting the high fly ball to center field. You know, it's gonna pop way up, there are plenty of time to track the trajectory and start to plan your catch for when it's come back down, a little bit easier to defend against even if they're traveling very, very quickly. But hypersonic is a little bit more like smashing a line drive to center field, with a ball that's capable of making a hard left turn once it clears that second baseman, and go and find some open space out there in that field. That's that's what we're really talking about when we call these capabilities game changers, if they really start to change how you interact with the system and make it very hard to defend against. So I think Dr. Lewis and Dr. Hallion hit the nail on the head in your podcast earlier in the year, one of the quotes that I took away from that was, you know, this is a tactical capability that can produce strategic results, kind of like Brian was mentioning.

John "Slick" Baum 05:22

So Brian, I've got to ask you, frankly, what is at stake regarding being the hypersonic leader or the victim of hypersonic strike. I mean, it ties to our core security issues in a way that we have not considered in decades.

Brian Schappacher 05:35

It's really important to be first and to be ahead of this, you know, we have to have the technological advantage. So that isn't, so we aren't a victim, right, we need to be ahead and have the deterrence capabilities.

John "Slick" Baum 05:47

Yeah. And that makes total sense. And, you know, that has to provide you and your team with a lot of motivation as you lean into this effort. So let's wind back the clock, I've got to ask the question of where were you when you first started hearing about the United States' desire to get back in hypersonics? And what were your first impressions? Eric, we'll get started with you.

Eric Knutson 06:06

So for me, it wasn't so much of a case of the United States getting back into hypersonics. It was really the turning point, when the technology to support hypersonics became a reality, we had the opportunity to work with some luminaries out there that were key to make that happen. People like Steve Walker, Dave Walker, Chris Clay, and James Weber that kept the fire alive, so that we could create these technologies. Those technologies and tests began to work. And that's what inspired AFRL and DARPA to go ahead and release some demonstration contracts, so we could prove them in flight.

B

Brian Schappacher 06:40

Yeah, and I can, I can remember, when I really first kind of started to hear about hypersonics, it was probably 2017 or 2018. And I was on an airplane headed out to a flight test for the conventional cruise missile program I was on at the time. And I typically would buy kind of both Popular Science and Popular Mechanics just to have something to read on the airplane. But I remember seeing this article, it had this really exaggerated picture of, you know, this vehicle that it looked like it was halfway to the moon, you know, flying way above the Earth, but it's all about hypersonics. And I remember, you know, reading through the article and thinking, Man, this is, this is really cool. The US, we absolutely have to lead in this. But I'm also an engineer, and very quickly, my thoughts switch. You know, the engineering mind came out and you know, heat right? This this thing, you're showing this picture of this thing in space, and then it's going to be, you know, hitting a target on Earth, there's a massive amount of heat that has to be dealt with, there's a thermal protection system, you know, I think to the Space Shuttle, where they have these really heavy tiles on there to protect against heat. You know, that's much too heavy for you know, missile that's gonna go on an aircraft or something. So I kind of became a skeptic. But you know, as you're around the office, you sometimes hear those conversations around the water cooler and people talking about you know, that, hey, they're working on this new hypersonics thing. And when you don't get a lot of details, it started to make it a little bit of a mystery. And I kind of knew that that's something that I wanted to do one day. So when I had the opportunity to come on to a hypersonic program, Air Launched Rapid Response Weapon in particular, I certainly jumped at that opportunity.

A

Arlen Kostival 08:10

Yeah, and then, you know, for me, I was actually in fifth grade, when the DOD set out on a course to develop what they called at the time a prompt global strike capability, just kind of setting the stage there, right. And so you know, if you track through the history books, this was kind of a research project for me, but the Army was flying the the first advanced hypersonic weapon or HW prototype, you know, as I'm graduating high school, and then I started my career at Lockheed Martin working in the FAB ballistic missile defense area and dabbled in strategic ballistic missile defense systems. I really got my first exposure to hypersonics in the 2019 timeframe, when I started supporting some concepts, architecture, trade studies for how we were going to launch one of these hypersonic missiles off of an Army launcher. And at the time, I learned very quickly that that was going to be the same missile that they were deploying on the Navy platforms. So I got really excited about the opportunity to get involved in a very fast paced and intense development effort. And right from the start, because of that commonality with deploying the same missile on two different platforms for two different services. I knew that we were getting into something really special here.

J

John "Slick" Baum 09:25

Yeah, no. And I just want to point out for our audience, if they didn't realize it already, I mean, we have folks that have spent, that have been thinking about this problem since before they started their adult professional lives. So I mean, obviously, we've got some really dedicated professionals, and I really appreciate you all sharing your thoughts. And you know, one of the things that I was thinking about is what really differentiated our nation's approach to hypersonics this time was a willingness to pursue multiple programs concurrently, you know, to basically develop a number of pathways and see which way works best. So can you help people understand that there really isn't a single or one way to create a hypersonic weapon? Eric, we'll get started with you.

E

Eric Knutson 09:58

Yeah, sure. So we've mentioned before, we're talking about the Falcon series that Brian, I think was talking about growing up upon, but it was always single tracked, even going back to the '60s when we're first doing hypersonics in flight. Because the importance of hypersonics is a differentiator, it became obvious that we really needed to make sure that we didn't have a single point failure. So there were two paths that were established early on, one being a boost glide, the other being an air breather. The difference between the two was really the complexity, and the initial thought was boost glide is something that you just really have to accelerate really fast, and then let it cruise. How hard can that be? The alternative is can we actually get a ramjet, scramjet to perform, to give us that sustained performance and acceleration as we go to our endpoint. And the conventional thinking was a ramjet or scramjet, that's gonna be really hard. We'll keep that in the wings. But let's go primarily after a boost glide. It was probably about one month after that decision was made that the scramjet was proven out in a free jet wind tunnel. And now we had two real viabilities. And so that's what was carried forward by the Air Force and by DARPA, and continues to this day successfully.

B

Brian Schappacher 11:21

And I can probably jump on that a little bit to to even say, work in ARRW, which is a boost glide hypersonic, you know, I know a little more about the boost glide side of things. But even then, the US has invested in a whole portfolio across there. You have air launched and ship launched, you have the Navy pursuing a hypersonic boost glide, you have the Army, you have the Air Force. So you know, we've made sure as a country that we are covering all of our bases with hypersonics. I guess would be one good way to put it.

A

Arlen Kostival 11:51

Yeah, and another key element of diversifying your portfolio is not just boost glide versus air breather, like like Eric mentioned. You know, certainly we're doing a lot to get those boost type systems into the hands of the warfighter as fast as we can. But you also have to look at different gliding body technologies, which is kind of the pointy bit on the front end, right. And you know, one of the really cool things when you look back through the history of experimenting and developing this technology, you know, we actually saw the second flight of the hypersonic test vehicle, or HTV, that came out of the Falcon study, you know, so that's what happened the same year that we had the first Army hypersonic advanced hypersonic weapon, HW, so we're actually seeing two different viability technologies tested at the same time there, and those who've continued on different trajectories for their development. So yeah, it's not just the platform, or the missile, but also, you know, the end effector, or the glide body that you differentiate capabilities in.

J John "Slick" Baum 12:47

And I really do appreciate that background, gentlemen, we're making a lot of people really smart on hypersonics with this podcast, so thanks for that background. So Brian, what's the genesis of ARRW, your program? What's the actual requirement? Who created it? And when did the effort kick off?

B Brian Schappacher 13:01

Sure. So as Eric kind of mentioned, you know, Lockheed Martin, as a company has really been in hypersonics, for at least 60 years in various, or at least in areas that help develop technologies that support hypersonics. So if you think about it, you know, launching a satellite into space that requires hypersonic speeds to break, you know, to break the Earth's gravitational pull, so you can get into space. So there's experiences from launching satellites that we can take even into the hypersonic realm, to understand you know, especially thermal and some of those issues that you have to deal with. But for a more recent example, from the ARRW program, and where they came from, they can really trace their history back to Tactical Boost Glide around the 2016 timeframe, that was a joint effort with Lockheed Martin and DARPA really to develop a hypersonic boost glide technology. So once that, you know, really started to look to be viable, that's where the Air Force jumped in and said, hey, you know, this is this is a good launching point for us to have a hypersonic missile for ourselves. So they used TBG, basically, as a launching point for ARRW. ARRW's goal as a program here was to put all the pieces together. So we needed the glider, a payload, algorithms to fly it a booster, and a factory to build it all to make it be the first production hypersonics product that we have out there.

A Arlen Kostival 14:24

And then, so I just want to jump in here with a little bit of background about the Conventional Prompt Strike, or CPS and Long Range Hypersonic Weapon or LRHW programs that I support, which were, you know, part of that portfolio of boost glide systems that Brian talked about earlier. So for us, the trade studies really began in the 2014 timeframe with the government and starting to, you know, assess the viability of different design approaches, and balancing those with, you know, schedules for operational readiness and elements like that. And then, you know, we really turned into the program of record with a development contract awarded in 2018, that gave us the opportunity to start operationalizing this capability for both the Army and the Navy, which we're very excited about.

J John "Slick" Baum 15:09

Yeah, no, I appreciate that. And it's made me think about, you know, how many other efforts were launched around this timeframe. I mean, you guys are just one of many, right?

B Brian Schappacher 15:17

Absolutely. And the US, you know, really invested in hypersonic technologies for all the armed forces simultaneously. So you have ground launched and air launched and sea launch, short range, long range, medium range, boost glide, air breathing, but it goes further than that, as well. It's not just entire weapon systems. It's also an investment in technologies that will enable you know, this and future generations of hypersonic products that, you know. Things like advanced materials, sensors, engines, boosters, all the things that you would need to continue moving hypersonics forward to go, you know, continuously, faster and higher and better.

J John "Slick" Baum 15:52

So speaking as a former requirements officer, I can tell you that I know one of the keys for a program's success is clear, having consistent requirements. So do you feel like you have that from the government?

E Eric Knutson 16:01

I would say we definitely have had clear and consistent requirements. For these technology demonstrators, they start off really with a few key pillars of what they want to attain. And they stuck to that. And you know, the tough part is really, as engineers, technologists, hypersonic nerds is the desire is always more and more data. We want to get all that stuff that we can get on the ground. So it's really having the ability to contain oneself to the data stream that one has available to them, so that you only get the data that you can use rather than going overboard, but requirements wise, it's been consistent.

B Brian Schappacher 16:39

Yeah, I'll second that as well. From the ARRW perspective, you know, our customer understood, the only way that we were going to move as fast as we work to develop this product was to have those clear requirements upfront. So they did a very good job of establishing what they called key performance parameters. And that's basically, this is what a hypersonic missile, a tactical hypersonic system, has to do. And here they are, and they were laid out up front and haven't changed, so we've been able to really move with the speed that we need to, to get to early operational capability, which is, which is the goal here.

A Arlen Kostival 17:13

And then first, CPS and LRHW, I talked about that trade study phase that we went through from 2014 to 2018. And I think we had a fantastic partnership with the government there to study the trade offs between requirements and how that affected schedule for operational readiness, right. So I think we've had a fantastic partnership with the Army and the Navy, and very clear requirements. I also want to highlight that I think it's important not just to have a clear set of requirements, but also a good tone and culture around the urgency, right. And so what that has looked like for us, is that our customers have been very understanding of risks associated with going fast. And we see that, you know, in our day to day lives working on these development programs, and in terms of you know, needing to take some smart risks to get things going concurrently, because we have fallen behind a little bit. And we're now working very hard to catch up.

J

John "Slick" Baum 18:08

Yeah, and I want to jump on some of that you said Arlen is, you know, tone and culture. And really what that boils down to is people right, which is obviously the key component here, because you all have been given one of the hardest tech problems that you know, the United States has seen in a long time. So on the human level, even, how do you begin? I mean, this just seems overwhelming. And how did you break it down into a manageable set of tasks, and you each have a unique perspective on this. So Eric, let's get started with you.

E

Eric Knutson 18:35

Yeah, excellent observation. It really does come down to the people. We're creating something that doesn't exist. There's no manual, there's no education that you can get. You're creating afresh. And it's not something new, we've all had opportunity in the past to work X-7, -117, the U-2, SR-71. These were daunting problems. The key to success in all these is to keep it simple. What are the few things that you're really trying to achieve? Don't try and boil the ocean, don't try invent everything here. If something exists that solves the problem, let that be part of the system. Focus on the key elements. And that's truly what we've done in hypersonics or whether it was material for a boost glide, how can we heal that heat? Whether it was how do we get the airflow down the inlet per scramjet and keep that inlet started? Let's focus on that. Keep it simple.

B

Brian Schappacher 19:31

Yeah, and this this is something Lockheed Martin, I mean, not even specific to the ARRW program, but but it predates us in fact. But Lockheed Martin recognized many years ago that you know, it's very hard to have all of the experts you need co located in one place for development. So they started as, or we started as a as a corporation, rolling out tools that would allow you know, if you have an expert in one part of the country and another expert on the complete opposite end of the country, they wanted rollout tools. So those those folks could collaborate together and work together and not have to go and colocate. So those were in place. When we started to work on the ARRW program, I learned very quickly that there's just no way that you're going to get all the experts on to one Lockheed Martin campus to go and work this problem. But because we had those tools in place, we didn't have to, we just, you know, we had somebody, we have folks, you know, spread all across the country, I think we have seven different Lockheed Martin sites that are that are working this program all together collaboratively, because we have all of those tools in place. And really, that was one interesting thing with COVID. You know, before COVID even made it popular to work in these distributed virtual teams, ARRW was already doing it because we had to, we had no other choice. That was the only way we were going to get there.

A Arlen Kostival 20:49

And it's a really good question in terms of how you break down a complex problem like this. Being a systems engineer, I like to think about it in terms of just following our standard development cycle. We often call that the systems engineering V, where you start at requirements and you break it down into architecture, trade studies, and you go do some design, and work your way back up and implementation and operations. What makes this challenge particularly unique, though, is the pace, right. We're trying to do something that would typically take us five to 10 years to mature to operational readiness. We're trying to solve that problem in less than half that time. So I think there's a few keys to success to doing that, effectively. One, we're using a lot of model based engineering tools. So I'm trying to work more in that, in the digital world, to take advantage of that speed that comes with digital communications and digital engineering. I mentioned already, partnering very closely with your government counterparts to establish clear requirements that are consistent upfront has been huge. And then for Lockheed Martin, you know, we've invested in a 65,000 square foot factory in Cortland, Alabama, it's becoming our production center for these vehicles. And, you know, getting that started early, I think has been really effective for us to think about, you know, delivering vehicles before we've ever even finished the design for them.

J John "Slick" Baum 22:03

Sure, again, you're just continuing to make me think about this problem. And I do want to keep focusing on people. And I don't want to sound crass, but I'm a fighter pilot, so I'll try to try to come off as cleanly as I can here. But you know, the folks that delivered the X-15, I'm talking about the engineers in the workforce, I mean, they're obviously largely dead. And the government's on again, off again, approach to hypersonics was really brutal on the experts in this workforce, you know, over the decades after that. So how did you cultivate a new bench of talent to to take this this project on?

E Eric Knutson 22:34

So Slick, like a like a fighter pilot, although at some point, they may not exist, what they touched and did lives on. And that's very much the case with the hypersonic community of the 1960s. They provided those little puzzle pieces that would form the entire picture eventually. What it took was the computing resources, the modeling and simulation, to stitch those all together. But ultimately, you're absolutely right, it comes back to the people. This is not a case where you can bring folks in that are miles deep in their specialty, and they stay within that box. This takes a unique set of individuals that can go beyond their their comfort zone, they can operate without a safety net, that can cross into all the disciplines that they affect, to a great risk, take on that challenge, and put forth a solution that we can go and test.

A Arlen Kostival 23:25

I'm kind of the younger side of the workforce here. Right. And certainly this experience has been way outside of my comfort zone, but has been a great learning opportunity for me in terms of cultivating a new bench of talent. You know, a couple of things they were doing on the CPS and other HW programs that have been pretty effective. One, we're pairing younger employees with folks from more established heritage programs that are doing ballistics and ballistic missile defense to try and train those skills for how you do missile development, not just for hypersonic technology, but booster platforms as well. We've also got some really good partnerships with like local high schools and universities. And you know, in particular, it's not just the design talent, but it's also manufacturing and operations. We're trying to cultivate a good bench of folks who are able to actually manufacture and test these because they're not simple systems to manufacture either. And then, you know, another element that's been really important for us is the partnership that we've had, like I've talked about, with our customers. We've had a lot of Navy and Army and OSD senior leaders come down and visit our factory, talk to our workforce and really inspire them and motivate them to want to face this challenge. I think that's been really effective.

B

Brian Schappacher 24:36

And just to add on to that, you know, as a corporation, really Lockheed Martin has invested like well over $100 million in not just internally but in suppliers and universities as Arlen said. So we've been investing all over the place and developing that bench that is needed to continue to move tech hypersonic technology forward.

J

John "Slick" Baum 24:57

Awesome. Well, okay, so now you you all have your team, you've got your requirements, and you've broken down the initial task. What's next?

E

Eric Knutson 25:03

Yeah, the next step is really how you approach the problem, we tend to approach it in the scientific approach, we will look at the systematic observations and measurements, the experiments and formulation testing and modification of our hypothesis. And as we go through all of that, there's no doubt that something's not going to work the way we expect it to. We're not going to have all the data, and having the wherewithal and the readiness to lay out the alternative approaches, and re-attack and modify our hypothesis so that we can ultimately get to something that works. But really it's just focusing on a scientific approach.

B

Brian Schappacher 25:36

And from ARRW standpoint, we've really, really had to leverage digital transformation and digital simulation models to move this move this forward, you know. We develop these super complex simulation models. So we were able to take a digital design of the ARRW missile and stick it on a digital model of a B-52, and fly missions all over the world, before we ever even built our first component, You know, from those simulation models, you start with scale, you know, scaled models that you would bring to a wind tunnel, and actually collect some real data on your, you know, your potential design that you are going to move forward with. That includes hypersonic wind tunnel strength as those exist as well. So you can collect hypersonic data while you're sitting on the ground, then, you know, the next step is really to start building hardware and developing software that's going to control that hardware. We have very high levels of simulation that we call our hardware in the loop, that's kind of our graduation exercise where you actually bring the real missile hardware and you set it up on a bench and you make everything work together. And then you know, we're, as we move into the flight test stage of the program, you're constantly collecting that data that would improve your simulation models, because it is way cheaper to simulate, to simulate your flight or simulate your missile than it is to go ahead and actually do a flight test. So we rely very, very heavily on those digital models.

J John "Slick" Baum 26:58

Now, obviously, this all sounds like you've got a plan, but I'm sure that there were some challenges along the way. So can you highlight what maybe some of your biggest challenges were during this period and how you tackle them?

E Eric Knutson 27:11

The challenges were constant and unrelenting. It'd be really easy to complain about, well, I can't get wind tunnels, I can't get funds, I can't get people, all these things are common challenges. But the real challenge that we face is moving on, We cannot sit here and expect to have 110% answers to every question. But we need to be comfortable with saying, Okay, I've got my 80 or 90%. Let's move on. That's probably the biggest challenge we face.

B Brian Schappacher 27:40

Yeah, and I don't know that we as ARRW that we have, you know, we have the secret formula. But I know the dedicated team is is a huge part of how we could tackle these. And I'll just give one quick example. You know, COVID, obviously has impacted everybody. But in particular, when we were going out to do a wind tunnel test, we had a whole team of engineers going out to do that test. But COVID struck, and everybody except for one person was was either infected with COVID or had to go into isolation and was not able to work. But instead of taking the massive schedule hit that that would have been the one remaining engineer, he said, You know what, I'm just gonna do it and pulled double and triple duty, double shifts, triple shifts, whatever it took to get it done. So we didn't have to cancel that test. And I think if we didn't have people that were dedicated like that, we just, we just couldn't get there.

A Arlen Kostival 28:31

You know, communication, I think is one of the hardest challenges that we face in trying to establish a really complicated system like this very quickly. Brian mentioned that COVID obviously made that a whole different ballgame. And I want to give a shout out to kind of the unsung heroes of of that consequence, right? So there were days for me and for a lot of folks on our program where we would start some of our meetings at 7am. And, you know, we're working from home, and we're just tied to our computers and our phones until nine o'clock at night. Meanwhile, you know, for me, my wife was bringing meals and taking care of the house chores. And you know, can't thank her enough for that support. And I know for a fact that there are tons of examples like that all across my program of folks who are extremely dedicated to this mission working very hard. But the pace of communications makes it really challenging to make sure that you're keeping in sync with everybody as you're as you're moving fast.

J John "Slick" Baum 29:21

Yeah, no, and I really appreciate that that point, Arlen and, you know, brings me to to another thought that you know, obviously the missile itself isn't just one thing. So let's talk about integration. It's the sum of many components and independent systems. So how did you guys bring all that these different pieces together?

E Eric Knutson 29:36

And that is definitely a challenge. Hypersonics is a strange beast in that everything, absolutely everything, affects everything else. So we early on had to create our analysis tools that considered thermodynamics, aerodynamic structures and stresses, all as one, as one closed loop. In many ways, what we created soon became known as digital engineering. is something that had to be created long before digital engineering was possible in order for hypersonics to work. So it's all about the entirety, you can't have an engine developed independent of an inlet, independent of an airframe, because they all affect the airflow. And this just runs throughout hypersonics.

B Brian Schappacher 30:19

And I mentioned previously about our distributed workforce and grabbing experts, wherever they are. Well, that also means you're developing the subsystems and major subsystems and different parts of the country. So we took the approach on on ARRW to really divide the missile up into three major subsystems. So you do all that integration from the minor subsystems into one major subsystem. And then you bring, once you once you get all those fully integrated, you can bring all three pieces together, and really test how the whole system works.

A Arlen Kostival 30:49

And Slick, I think you touched on a really important point there, right, it's more than just the missile system. We like to think about hypersonics as being, you know, the vehicles themselves, but there's a whole lot of other infrastructure you have to develop to make these systems tactically capable. Weapon control system, launcher platforms, canister systems, logistics, training, readiness, all of these need to come together and mesh perfectly as you integrate at the system level for customers to be able to take these capabilities and actually deploy them. And you know, there again, communication to ensure that everybody is passing clean requirements across interfaces is really, really important.

J John "Slick" Baum 31:29

Yeah, absolutely. And I do want to focus on one thing I mean, you know, I know I'm a knuckle dragger fighter pilot here. But you know, the propulsion piece is so interesting to me. And it's obviously a huge element in, you know, the successful piece of a hypersonic missile. So how did you approach the challenge? And it because I think it's really important for our listeners to understand that there's such a huge difference between propulsion for subsonic and supersonic flight versus what's required for your challenge of hypersonic flight.

E

Eric Knutson 31:54

Oh, absolutely. It's all about energy and energy management, whether it's a boost glide, or an air breathing system, it all starts off with getting boosted up to an incredible velocity. So a lot of similarity there. And it comes down to how do I create that energy and somehow deal with all the heat, and the shock and vibration of that much energy being expended in a short period of time. For the air breathing, it gets additionally, more complicated, in that I need to have an inlet, and they talk about the inlet in terms of being started. Air has to be able to flow down that inlet and get to a ramjet, or scramjet. If you go back to something like the SR-71, they saw that by having kind of a probe that would move almost three feet, aft and forward, so that they could keep the shockwaves where they need to be. That was over a couple Mach speed range. Now you're getting up into hypersonics. So huge ranges that you have to cover. And you need to be able to do that without having all sorts of moving parts. So it became much more of a challenge. I don't know, Brian, tell us a little bit about how it affected the boost glide.

B

Brian Schappacher 33:00

Well, I think about it from just the size of the booster too. You hit on it. From a boost glide, that's where all the energy is coming from is from the booster to get there, to get to your target. But then you think of an ARRW, that's got to go on an airplane, well, you know, an airplane can't carry an unlimited amount of weight. So you really have to balance that booster and how much thrust and how much you need to get out of a booster, versus what the airplane can carry as well to ensure that you're still able to meet your mission, and obviously, you know, do it at hypersonic speeds.

J

John "Slick" Baum 33:31

Well, yeah, I mean, you talked about obviously, energy management and building up energy and dissipating energy, obviously a huge challenge. And I know I'm not spoiling anything for our listeners, because I'm sure everybody has seen Top Gun 2 now, I'm just, you know, excited that Maverick can punch out at Mach 10 and still walk into a bar and get a drink. So, but back on focus here, I want to ask you what else is really unique to a hypersonic system that we might not know about.

B

Brian Schappacher 33:55

So one area that comes to my mind is all of your subsystem, we talked about the system being made up of a bunch of subsystems, well, each of those have a specific job to do, but when it comes to hypersonics, they have to do it so much faster. You know, you may, in a more traditional cruise missile, you may not worry so much about the time it takes for a subsystem to initialize or be ready to do its job. But in hypersonics you don't. Time is really not a luxury that you have because everything happens so fast. Something else that that's unique is the plasma layer. So when you're going that fast and you're heating the air around and creating these massive amounts of pressure and heat as you're flying through the atmosphere, you're actually super heating it and creating plasma. And understanding you know, your control strategy and how you're actually going to fly through that or how your electronic systems are going to operate through that, those are those are definitely challenges that your your design has to handle for sure. Something else that's probably unique to is is Paschen's law, or Paschen's curve. This is something Freidrich Paschen discovered, that as you reduce the pressure on a gas, the voltage required for electricity to actually arc between two conductors, that voltage decreases as well. And when you start getting into the hypersonic realm where we know that we're flying higher, where the atmosphere, there's less pressure, that voltage starts to come down. And depending on how you design your system, or choose your components, you may start to be affected by that, where you know, everything, everything in the world today is smaller and closer together, you think of your cell phones are getting smaller and smaller. Well, that means the little electrical components inside of there are getting more compact, and your pins are getting closer together. Well, that may not work if you're in an area where where Paschens Lawn comes into play. So you just have to be very careful with your design and just understand all of those effects as you're as you're going through.

A

Arlen Kostival 35:49

And Slick, I think it's really important that you mentioned the hypersonic system, right? So I think when you look outside of just the missiles, and the launchers and control stuff, it's also really important to pay attention to the fact that you need a very robust intelligence infrastructure to be able to make good use of these systems. And in a tactical scenario, you need really fast, credible, reliable info on potential targets. And that's, you know, I think, impact outside of just the Army, Air Force, Navy environment that that we're seeing with the creation of this capability from an operational standpoint as well.

J

John "Slick" Baum 36:25

I really appreciate it because, you know, again, these are the experts that we're discussing this stuff with, and you all have, we've really been talking up to this point about the concept and getting to the phase of having something real. So when did you really think you were turning the corner from a science project to something that was really going to be able to be built and flown? And I don't mean, as you know, to sound insulting would say, but, you know, I have to think that there's a window where you're literally, you know, studying how you'll overcome some of these challenges, and then you'll start, you start to see it come together into real physical being.

E

Eric Knutson 36:56

It's interesting, you know, as a pilot, one of the monitors that we wear is, it's hours of sheer boredom interrupted by moments of absolute terror. In hypersonics, if something goes wrong, it goes wrong really, really fast. So it's a little bit opposite. It's every moment is sheer terror. Everything has to be done just properly. And it's when you can get everything to work together as design, that you start to see that that turn. And for me, that kind of happened, as we were going through numerous tunneltests and various ground tests, where we proved out, yes, we can actually predict what's going to happen. And as the these became a majority, and then everything was predicted, just as it turned out, it kind of gave us that satisfaction that you know what, even though we cannot do everything on the ground, our predictive capabilities are now such that I think we can go and fly and fly successfully.

B

Brian Schappacher 37:51

And I remember this pretty specifically as well, you know, I talked about computer models, and we spent so much of the early days of the program in the computer models and making it work on a computer screen. Well, as you mentioned, you know, Tom Cruise went Mach 10 in a manned jet on a on a computer screen. But that's a whole different ballgame when you bring it off the screen and you actually bring the hardware together. So the first time I witnessed a hardware in the loop test, this is where we actually take all of the missile subsystems that really make up an ARRW missile, we stick them on a bench and plug them all in together. And we actually have them work together to complete a simulated mission where every every subsystem has to do its job, with its precise timing, seeing that all come together and work you know, all these things that are coming from all these various parts of the country all coming together to one and actually working. That's when that's when I knew that this is, Yep, this is gonna work.

A

Arlen Kostival 38:45

And just real quick, the the moment for me was the first time I walked out into our factory in Cortland, Alabama, and I saw, you know, major components of our first vehicles being worked on and assembled by these incredibly dedicated people, you know, just getting a chance to meet with with those technicians and manufacturing engineers who had been bringing this stuff to life while I've been sitting in Denver working on CAD models, it was a really important moment. And that's what I knew when I saw the passion in their faces as they were working on all this stuff. That's when I knew that we were we were doing something pretty big and we were on a pretty exciting mission.

J

John "Slick" Baum 39:18

Alright, so I've got to ask what's next? It sounds like you have an article. Do you just hanging on a B-52 and go launch it? Or is there a big regiment of ground testing that has to be done first?

B

Brian Schappacher 39:27

You're a pilot, you know that. No, it's definitely not that simple. Maybe it is in the movies, but not in real life. You know, from from our standpoint, safety of the aircrew is paramount. So it's not just you know, Lockheed Martin obviously is very concerned about safety. So our the range safety officers and so are the aircraft community and so are the pilots. So we're, there's all these different safety boards that want to review your design, review your testing data, so you can prove to them that this thing is safe to hang on an aircraft. And that includes, you know, we have to do integration testing with an aircraft, right, software and hardware integration testing with the aircraft itself to check out how the two systems interact. We have to do compatibility tests where we make sure that that all the electrical systems on the aircraft are not interfering with the missile, but also that the missile isn't interfering with the aircraft. And once you clear all of those hurdles, you are granted a limited flight clearance, which really is you're okay to go ahead and test at this point. I appreciate all of that to the discussion. And it really cuts to the important part of innovation, that's learning through failure. You know, obviously, Congress and others want to see immaculate results from day one. But I think most of us would argue that it's pretty unrealistic, especially for such a tough program, as our listeners know, that you guys have an incredible feat in front of you. So if your batting average is too high, it may be safe to say that you're not pushing up hard enough. And leaders need to give programs top cover to allow for this learning. And that's a hard task. So can you walk us through your thoughts on that? Yeah, I mean, you know, we're maturing technology, really quickly. And sometimes challenges arise there. I think, I think SpaceX is a really good example of a company that that does a lot of learning from, from failure. I mean, if you, if you look at them in the beginning, they, they were going to launch a payload into space, and then land they're boosters back on a barge either in the Atlantic or back on the launch pad that they they left from or right next to it. So that can be reused. And, you know, they're very, very well covered. They had some mishaps in the beginning of their program as well, but look where they are now. I mean, it's almost second nature. And I myself, as somebody that lives in Central Florida, I mean, it's almost, you see so many launches, all the time, it's almost second nature now with how well they're doing, you don't even consider all of the challenges that they had to go through in the beginning. And hypersonics is definitely like that, you know, where we really are pushing the envelope of what's possible at an extremely rapid pace. So yeah, that opens yourself up to the possibility that sometimes things aren't going to go exactly as you planned them. I think from ARRW's standpoint, our customer has been extremely supportive here. You know, obviously, everybody, including our customer would have preferred that we'd meet all of our objectives during every single flight test. But you know, when we did have a less than desired results, the approach from our customer really was, you know, they come into the room and say, Okay, what did we learn? How fast can we recover, and go try this again. So the focus has been on learning from from day one. And that's why, you know, a lot of these test missiles are very highly instrumented, so we can collect as much data as possible. So even if we don't get quite all of our objectives complete, there is a ton of of data, and a ton of learning to come out of that. Yeah, I

J John "Slick" Baum 42:37

couldn't agree more. And you know, one of the things that's a lot tougher for you is you have those requirements, I mean, that if a company you were mentioning before, they had no requirements to land something on a barge. They just did it, because it made sense for their business model. And, you know, obviously, you know, they can fail and keep failing, as long as they have the bankroll to do it. And it's just a totally different scenario. So you guys are really crushing it with the fact that you do have stringent requirements, you know, for the taxpayer, and you're being great stewards of all of that. So, you know, I do want to fast forward to, you know, some main factors that we'll be tracking, you know, as ARRW is meeting its design objectives and thinking about launching potentially next spring, right.

B Brian Schappacher 43:13

Yeah, I mean, we still have upcoming flight tests, we've completed our booster test series, which was really all about, you know, mainly focused on validating the performance of the booster. So now we're moving into what we call the all up round test series, which is which is end to end, right. We're still going to focus on booster performance, of course, but we're going to shift some focus on to the, some additional focus on to the glider performance. So yep, there are flight tests upcoming for the for all up rounds, and you know, just keep an eye out in the news. And as you see, you know, in the way that we've structured our flight test program, you can think of each subsequent flight tests being a little harder than the previous one. So there are a lot of test points very early on in the program, we worked with the customer and said, alright, you have, here's all these things you have to do, you know, the key performance parameters we talked about. And here's all of the different flight tests and test points and test objectives that you're going to have to go through to prove to us that ARRW works and ARRW is ready for the warfighter. So as we said, we've successfully completed the booster test series. And we're about to move on to the all up round test series and just continue to build off of everything that we learned in the booster test series. Awesome. So I'm going to shake things up on the Aerospace Advantage here because I have a few questions that I really want to answer. So we're gonna go a lightning round here. What are the things that keep you up at night at this stage? You know, it's not necessarily the hypersonic elements that keep me up at night. It's all the basic stuff that you're including in the system, that's off the shelf, that we know works, that fails. It's overlooking the obvious that keeps me up at night. Yeah, and for ARRW, you know, we have more more missiles to build and more flight tests to get through and complete than we've had at any other time in this program with the goal of reaching the early operational capability in 2023. So there's, there's just a lot going on. And it's an extremely aggressive schedule. So you know, that that keeps me up at night, just making sure that we can meet all of those commitments. But as I mentioned, the ARRW team that we have, we still have that team. So we still have all those dedicated people that want to see this through. So I'm confident that we're gonna be able to get there.

A Arlen Kostival 45:25

Yes, like, it's a funny question to ask engineers, because they kind of pay us to worry about all the things that are gonna go wrong, right. But for me, it's the integration of the big elements of this system that need to go together, right, to take a missile and put it on a truck, or put it on a boat or put it on an airplane, have it talk effectively to those systems have the fire control, you know, algorithms working properly. So it's that little voice that's in the back of your head, that's, you know, just kind of wondering, What if one of those little details got missed and what what could the consequences be? But I will say that from all the ground testing that we've done on CPS and LRHW, so far, I've been very impressed with a demonstration of the the pieces of this system coming together. And I have full faith in the technical strength of our engineering team to solve these problems quickly. So very excited to look, looking forward to an upcoming integrated system test for LRHW, where we're going to be clicking all those pieces together and watching them all work. Hey, you know, I do appreciate the transparency answering that question. Okay, so next lightning question is looking back on everything that you've accomplished so far? What are the biggest surprises and lessons learned?

E Eric Knutson 46:31

Short answer, there's no limit to what you can achieve, if you don't know that it's impossible.

B

Brian Schappacher 46:38

I like that, Eric. I think for me, you know, we haven't really talked about ARRW being designated a Section 804 rapid development program, but that basically, as part of the contract award was, hey, you're agreeing that you're going to go really fast. So I mean, we, Lockheed Martin had to learn how to do that. But beyond that the industry did as well. I mean, I can think of times where, you know, there may be a, I don't know, environmental test, or some tests that you want to do, where the facility you're gonna go to would say, hey, I need this information, 30 days ahead of when you're going to test well, on a Section 804 rapid development, that information may not be available until 15 days before you need to test. So you know, going back to that organization and saying, hey, well, can we give it to you in 15 days? And having them, Well, I don't know, yes, actually, you can. Let's work with you and make this happen. But that whole world that had to be navigated as well was was was a bit of a surprise to me.

A

Arlen Kostival 47:35

Yeah. And then I think for me, I've got three main lessons learned out of the experience I've had for the last few years working on hypersonics. One is that communication is extremely important. And the pace and quality of your communication tends to drive the pace and quality of your development. So in general, areas that we've seen some challenges have been areas where we can kind of see communication breakdowns. And that's been very interesting to correlate. Taking risks is something that I think, is a little uncomfortable for, I'll say, the traditional aerospace development approach. And I think we're learning that kind of a build, test, learn and iterate approach can be very effective. And you can never discount a very dedicated, very motivated team to solve some of those late breaking problems very quickly with creative solutions. And then the last main takeaway from me out of this experience is on the personal side, I think I speak for everybody on my program, in just saying that we've learned how incredible our friends and family have been in supporting us through some of the very long, very intense days that it's taken to get towards milestones like flight tests, and certainly want to give a shout out and thank you to all of them.

J

John "Slick" Baum 48:45

Absolutely. I can't even imagine some of the long days and weeks that you all have pulled as these milestones have come together. Alright, so my last question, I'm going to ask you to pull out your crystal ball here. So give our listeners an idea of of the future of this program. So where do you want to be in a year, two years, or even five years from now with this technology?

E

Eric Knutson 49:05

I'll go ahead and start. You know, the United States has waited long enough. We spent a decade trying to get to where we're at. It's time to get this into the warfighters hands, give them the tools that gives them the advantage.

Arlen Kostival 49:17

I'm just going to play off of what Eric just said, right, like on that thread. You know, the CPS and LRHW programs are excited to move towards fielding of this capability for the Army in FY23 and for the Navy in the mid to late 2020s. So, you know, the guiding light for us is getting this capability into the hands of our customers as fast as possible so that they can deploy these tools and defend our nation.

Brian Schappacher 49:44

And I think looking at hypersonics, you know, from a little more macro level, I think for every every hypersonic product, the goal is to go faster and be more capable and even more affordable. So I think you know, as you look one year, two years, five years down the road. You know, I mentioned before that it's not it's not just the specific weapons systems that we're working on. There are other hypersonic, you know, technologies that enable these current systems to go faster or be more capable or be more affordable, that are also being worked. And I can see, you know, in the one to two to five years, we're going to start rolling those in and have you know, even better hypersonics than we have today.

John "Slick" Baum 50:24

Okay, well, gentlemen, I can't thank you enough for being here. There are those that talk about history. And then there are those that make history, and you and your team are definitely in that latter camp. And, you know, as we've talked about today, hypersonics is such a tough challenge. And it's so important and this is a race we must win compared to our adversaries and those that are out there seeking this technology as well. And one last thing I want to say is I can't thank you enough, just as an American, for your personal efforts as Arlen you know, clearly shared with us as well, and all the hard work and late nights you guys put into this. So all thank you so much for being here.

Eric Knutson 50:57

Thanks Slick.

Arlen Kostival 50:57

Thank you for having us.

Brian Schappacher 50:58

This was a great time, it really was.

John "Slick" Baum 51:02

With that, I'd like to extend a big thank you to our guests for joining in today's discussion. I'd

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