Constellations Podcast

Episode 195 – Old Versus New, Plug and Play and Responsive Satellites

Speaker: Dr. David Hardy, Consultant, TC Space Consulting – 40 minutes

John Gilroy: Welcome to Constellations, the podcast from Kratos. My name is John Gilroy and I will be your moderator. Today, we'll examine the fast-paced changes across the complex space and satellite industry, both on the military and commercial sides.

This exciting conversation will highlight what some of the challenges were 15 to 20 years ago and what they are now through the lens of our guest, Dr. David Hardy. Dr. Hardy works as a consultant at TC Space Consulting. Before this role, he had a long career with the Air Force as senior space researcher and leader.

His last government position was in the Pentagon as the Associate Deputy Under Secretary of the Air Force for Space, and the Deputy Director, the Office of the Principal Department of Defense Space Advisor. Dr. Hardy, you sure are qualified for this interview, aren't you?

Dr. David Hardy: I'd like to think so.

John Gilroy: Oh, more than qualified. We're going to hit maybe one 10th of 1% of what your background has taught you about this whole field. Okay. Let's jump right in here. Dr. Hardy, you served for the United States Air Force for more than 41 years, flew over 60 payloads into space, developed payloads for the space shuttle and numerous satellites. Wow. What a resume. Tell us about your journey and what got you started and what kept you in this industry.

Dr. David Hardy: Well, I mean, first of all, my dad was an eminent chemist and I have a grandfather who was an eminent engineer, so there's a technical strain in our family genetics, I guess. But I was always interested in science since a very early age. And I grew up in the '50s and '60s and I read lots of science fiction. I just loved the whole idea of space.

So, I went and did my undergraduate degree in physics and then went to Rice University to study space physics and astronomy. At that time, Rice was deeply involved with NASA. In fact, I worked on payloads. They were left on the moon by the Apollo astronauts. So, that's where I got started.

I actually went to Rice on extended delay from active duty, because I was in ROTC at the time, Air Force ROTC. So, when I finished, I entered the Air Force laboratory system as a space researcher. And then over my career, I filled lots of different roles. First of all, as a bench scientist, as a basic researcher. But then progressively in charge of larger groups.

I ended up as the chief space experimentalist for the Air Force on the research side. And then I was the Associate Director for Space Vehicles, which did much of their space research. I then took a bit of a detour to head directed energy research for the Air Force. Then I went to my Pentagon job.

So, I've always loved the idea of space. I entered it at a time in which space was very exciting, the end of the Apollo era. I find now across the arc of my career, back at a really interesting time in space, perhaps the most interesting time and most transformational time we've seen in, oh, 30 or 40 years. So, it's just lots of fun.

John Gilroy: Good, good. Let's talk about the arc of your career. I guess if you look at it from 40,000 feet, which you're familiar with that phrase. So, what was the initial spark that shifted focus from large complex satellites to small satellites in modularity? How did early perceptions of small satellite capabilities influence this transition?

Dr. David Hardy: Yeah. I started my career, the first satellite I developed a payload for was B78-1, which launched in the early '80s. Back then, satellites were basically gold watches. Every one was designed uniquely for its role. You designed the bus. You designed all the payloads. It took you a year to just do the wiring harness for one of those big satellites. It took you a year simply to do the thermal model to make sure it didn't burn up from heat overload.

And that was simply driven by the level of technology we had. I remember for that first payload, you actually had to have a test rig to test your box when it's on the satellite. It was all analog. It had dials and meters. And so, that's what you had to do to build a satellite. I mean, it was so specialized. The technology, while able to put something interesting into space was still very primitive by modern standards.

But what happened a little bit is because they were so complicated and they were one of a kind, the tendency was to load up everything you possibly could onto a single launch. Because the satellite was expensive because they were one of a kind and the launch was expensive because launch was intrinsically expensive back then.

So, it drove us to a architecture where all the satellites tended to be big, complex and expensive. Well, that's an interesting element of the trade space, but it's a very confined area of the trade space. So, we end up building military systems that take 10 or 15 years to build or longer because they're so complicated and they cost many billions of dollars because they're so complicated.

People forget that we would load all the requirements we could onto a satellite because it was expensive. Well, unfortunately, complexity goes more than linearly with requirements. If you double the requirements and try to squeeze them into a satellite, the system is much more than twice as complex. Risk and costs, unfortunately, go much higher than linear with complexity.

So, we ended up with these very big, very expensive, incredible by the way, they were remarkable satellites. I mean for the time the things we could do from space. But that's a very restricted trade space and therefore, only countries that were very expensive, very technologically advanced, had lots of money, were really space players.

Well, we certainly didn't like that. I mean, there was a lot of desire for a less expensive option to produce space capabilities. And by the way, it was only 20 years ago where the idea that only big satellites made sense was still the ingrained consensus. In 2001, I was the technical advisor to Air Force Space Command up in Colorado Springs.

And at that time, the perception of the future for space, the military perception was only big satellites, only small numbers. They would always cost a lot. We would only use expendable launch. Heaven forbid, we use reusable launch. Small satellites made no sense, because you couldn't put enough capabilities on them. And by the way, those weren't completely irrational positions.

If you actually looked at the technology at the time, you could make the case for it, but it didn't project what the arc of technology would be, which is basically you could start condensing all of the critical capabilities for the subsystems into smaller and smaller volumes. You could put huge amounts of computation on board. Everything becomes more energy efficient.

So, leadership really didn't project that. Well, at least not all of leadership. So, back in the mid-aughts of this, there was some thought now, "Okay. Maybe we should look at small satellites to see what they do." By the way, against great resistance. So, go ahead.

John Gilroy: I just want to take maybe an aspect of this transition. So, what were the biggest challenges in designing satellites in the early 2000s, the aughts as you say, particularly in terms of wiring and thermal management, and how just has that aspect, how has that evolved?

Dr. David Hardy: Well, again, the problem is that if you build a big satellite and you want to squeeze all the capabilities you can on it, then the internals of the satellite are complicated. And again, you only have radiative, conductive cooling. So, just keeping the thing cool gets complicated. And we worked on all sorts of technologies to try to get around that. But it's the problem that surface area and volume, I mean, if I increase the volume and I only have the surface area to radiate, it gets progressively more difficult, because volume goes as a cube and surface area goes as a square.

So, that was always an issue. You could figure it out, but it would take a great deal of time. So, it was thermal and what was the other one you were interested in?

John Gilroy: Wiring.

Dr. David Hardy: Oh, yeah. Same thing applies. If you have a myriad of boxes and they're all independent subsystems that you have to hook all of them together, it gets very complicated just to wire the whole thing because every box was ... You had no flexibility in the interface. All the interfaces were sort of designed. You'd write an ICD where you define each pin to make sure it fit with theirs. And so, no. That was the limitation of the technologies you were applying.

And then the fact that we were stuck in this portion of the trade space where we convinced ourselves the most economic thing was to make them really big, which is why it took us typically decades or longer to build a new military satellite, which if those are the parameters you put on, it's going to be hard and slow.

John Gilroy: You probably remember the mid-1990s where personal computers introduced a concept called plug and play. You can just put that little card right in your computer to figure it out and let's apply this to your world. So, can you explain the concept of plug and play satellites and how embedding functionality into the satellite structure. That's became revolutionary, didn't it?

Dr. David Hardy: Right. But on a satellite, it requires the same convergence of technologies. In order to make it work on a computer as it will on a satellite. You have to have common protocols. You need a lot more computational power. You need a lot smarter interfaces that are able to analyze. When you plug something in, it can analyze the interface and it can produce protocols to talk back and forth to identify what is it that's being plugged in.

It took a while. It took longer to do that in space because space is a somewhat harsh environment, got radiation problems, you got single event upsets. Things tend to get hotter. By the way, back then, we wanted them to last a lot longer. We really want to build a satellite on a three-year cycle. So, you had to wait a couple more generations for the fundamental electronics and subsystems to reach your maturity where you could even think about plug and play.

And even when we thought about it, oftentimes what would happen is that we loaded on so many requirements and made it so complicated that standard interfaces that are the heart of plug and play wouldn't work. So, we ended up redesigning it. Contractor gives you a plug and play bus. But then you say, "Well, but I need 18 different additional things that aren't consistent with it." So, that's really why it took a while. Plug and play is intrinsically attractive and has become more attractive.

John Gilroy: Well, let's go from plug and play to CubeSats. So, how did CubeSats and miniaturization transform the way satellites are designed, built, and deployed today?

Dr. David Hardy: CubeSats really evolved simultaneously with what we call the small-size satellite revolution. They both relied on the same convergence of technologies. Basically, the ability to miniaturize the subsystems that are required to build a bus in a CubeSat is simply a very small bus. Same thing applied to smallsats. In fact, a good friend of mine, one of the things they did was to actually fly a cell phone as the ... No, as basically the core of CubeSat because you have almost all the functionality you need for it.

I remember, I was in graduate school when the first HP calculators came out. Again, we just forget how far we've come in the ability to miniaturize computational systems and to make them more versatile. We thought it was cool that you had a calculator that could do logarithms. I mean, that was 1972. I mean, admittedly it was 50 years ago almost. But that all had to mature. So, it was interesting.

Much of the innovation started from people just wanting to play with these new toys. As I said, I was responsible for the TacSat program, which was one of the first Air Force sanctioned programs to look at small satellites and their functionality for military use. But we had to battle against a pretty entrenched belief that we were just hobby shopping, that these small satellites were never going to give anything of real military utility.

And then CubeSats were one level further down in terms of, "Oh, those are really toys." Whereas now, no. I mean Mr. Musk has 5,500 smallsats in orbit, which all of which he's launched since 2019. He's launched 5,500 satellites in five years. In the early aughts, nobody thought you could do that, because it would cost too much or that it would have any good function.

John Gilroy: Let's delve into these concepts, the buses and interfaces. So, why are standardized interfaces critical for responsive satellite launches and how do they compare to the challenges of building large custom satellites? You got a big comparison there, don't you?

Dr. David Hardy: Yeah. There are two reasons, at least from a DoD perspective that we like flexible interfaces. The first, it can just simply drive down cost. The Space Development Agency is all for trying to figure out how to do these tranches of proliferated satellites to fulfill important military functions. Well, proliferating a capability across many small buses, it's not obvious that that's a good solution, because you have to replicate all of the bus structure for each one of your satellites.

So, the argument between a giant monolithic system and distributed functionality across a lot of small satellites, again, it's not at first case obvious that the smallsat thing is going to work. It will work, however, if you can make each of the buses pretty much a commodity. Not like in the '80s and '90s where they were gold watches. I believe Mr. Musk produces three satellites a day off his assembly line.

I mean, 20 years ago, nobody would've thought that was ... So, first of all, smallsats and this interchangeability almost commoditizing them, not only the satellite, but at the subsystems, allows you to simply build a factory and build them like Ford Model Ts. The second thing is, so we like it for cost. We like it for the fact that if you build proliferated constellations of small satellites and you build them for shorter lifetimes, you allow to update your technology more frequently.

One of the problems with the old big satellite model is if it takes you 15 or 20 years to build a new constellation, the first one is out of date by the time the last one. So, you're always buying the technological role. So, we like that. But the other reason we like it is that space has become a contested domain. Chinese saber-rattle about crazy things they like to do. The Chinese have a stated policy of seeking to deny their adversaries the use of their space facilities.

So, if it's contested, then you have to deal with the potential for attrition. So, you want to be able to use small satellites to quickly replace or augment, which would be very big with 20,000-pound satellites.

John Gilroy: Yeah. I guess the conclusion is the military is using modularity and responsiveness in satellite systems to address these contested domains. And maybe the word I wrote down, resiliency is really the big factor here. I mean, if one satellite goes down, you just plug in another one. Where if the big monster gold one goes down, that's trouble. So, resiliency seems to be the word here, huh?

Dr. David Hardy: Yeah. And military parlance, it's mission performance and mission assurance. What does your system do for you and how well will it survive across the phases of conflict? So, resilience is actually considered to be part of overall mission assurance. Mission assurance is defensive things to protect yourself. Resilience, which means, they could do stuff to you, but you survive it. And then it's augmentation and replenishment.

If he blows up stuff, I can put up new stuff. I mean, that's what we do in every other domain. You always have reserves. And as the battle develops, you figure out where you want to put your reserves.

John Gilroy: I'm taking down notes here. Three satellites a day, it's pretty impressive. That's really was maybe back in your science fiction days, you would've thought of that, but no one thought of that until we actually see it doing it. Let's talk about hours here. Let's switch the sequence here. So, what technological and logistical advances are needed to achieve a truly responsive space program capable of launching satellites within hours? That is a crazy question. Really?

Dr. David Hardy: Again, if you really want to address the problem of space as a contested domain, present and future warfare will take place not on months or days. They will take place on hours. So, you need your ability to shape your Space Force and respond to adversary actions on the order of hours. Well, that's complicated. We know how to do it in the air domain.

One of my favorite analogies, if you look at F-35, and there's a lovely picture, unclassified picture, which shows all the weapons payloads you can put on an F-35. So, it's a standard flight aircraft, the standard, but then it can be configured in any number of ways. So, depending upon what you need for that phase of the conflict, they configure the F-35 with it.

Okay. You want to be able to do exactly the same thing for space systems. And by the way, F-35 achieves that by basically having a flexible interface, the place where you attach them or all the weapons can accommodate on the same attachment points, they all hook into the same fire control system. So, we want to do that.

Now, the air guys have been doing that for 100 years. We're still figuring out how to do that, and it's a bit more complicated. So, it breaks down in one thing is you want to be able to put your payloads, you want to be able to configure a small satellite quickly for it to take whatever payloads you need to replace what you're doing. Then you have to be able to mate it to the rocket. And rockets are more complicated in that regard than an aircraft would be.

Then you have to be able to actually check out the whole configured system together quickly. Then you have to be able to launch it. And then without a human up there, you have to be able for it to quickly check itself out and become operational, because it's not like an aircraft, though we're moving away from that, too. We're going to have drone aircraft, too.

So, it'd have to semi-autonomously configure itself. So, we have to figure all of this out, and we've actually made a lot of progress. Mr. Musk is not actually building a rocket for that ... His is still launched on schedule. But there are a whole series of small companies who are looking at what one would call responsive small satellite launch, where within a day you can configure it, get it on the launch pad and launch it, and then it can check out an orbit within hours. And again, the advance of technology is such that we should be able to achieve that.

John Gilroy: Back in the aughts, you mentioned earlier I had a friend named Rob Pegararo, he flew to Florida to see a launch. Now, I think there's two a week. It's like, "Yeah. It's just another thing. It's like another bus coming by or something." It says, "So, maybe this whole concept of hours isn't pushing it too much."

Earlier in the interview here, you very trippingly in the tongue used the word expendable, and that's normally in the space world contrasted with the word reusable. And so, how have the economics of reusable launch systems like those enabling high launch rates reshape the satellite industry?

Dr. David Hardy: It's interesting. It's one of my minor claims to fame. I actually ran the study for the Air Force Space Command in 2001, which looked at our options for responsive launch. And there are basically three launches, it's first stage expendable, second stage are fully reusable. This was in 2001. And even in 2001, we could make the case that it was technologically feasible to do what Mr. Musk has done with his Falcons, which is reusable first stage, expendable second stage.

And again, good technical analysis, and we took it up to the leadership of the Air Force, the Under Secretary of the Air Force at the time, and he said, "Yeah. The analysis is good." But he says, "Dr. Hardy, you realize we're never going to launch more than eight rockets in a given year." Now, this is true. If I look at your estimate of the development cost and how many launches it would take to amortize the cost, he says, "It would take you 20 years."

So, he said, "No. We don't want to do that." So, it took somebody like Mr. Musk, and also by the way, continued advances in technology. What's really made reusable launch, if you go down into it, is a convergence of a series of different technologies. So, yeah, it took Mr. Musk to believe that there was elasticity of demand. So, yeah. He'll launch 120, 130 satellites, rocket launches this year.

John Gilroy: Amazing.

Dr. David Hardy: It's quite interesting that in some areas there was a long plateau in launch for decades where not much advance was made and then a convergence of different technologies and Mr. Musk's willingness to take the risk, there was suddenly a breakthrough. And now, launch costs are down by 20, and eventually it'll probably go down by 100.

John Gilroy: Amazing. I know you spent some time in the Pentagon. And I'm sure when you're in the Pentagon, you heard the phrase, "Contested domain." You used it earlier in the interview. So, how has the recognition of space as a contested domain where satellites and other space assets are vulnerable to deliberate interference, damage or destruction by adversaries? How has that influenced satellite design and your replenishment strategy?

Dr. David Hardy: For a long time, the consensus was that space was the ultimate high ground and therefore couldn't be attacked. That was always wishful thinking. I'm a history buff. And there has never been a military advantage that was gained by one country that the other side didn't eventually figure out how to contest and put at risk. I mean, just the nature of any revolution in military affairs, as they call them, always prompts a response.

So, the Russians even were way back when talked about anti-satellite. So, if it becomes less expensive to launch ... There are two trends. First of all, the overall cost of being a space power has gone down. And second, the technology that drives that is diffusing incredibly rapidly around the globe. There used to be two and a half great space powers, United States, Russia and Europe. They're sort of a half.

So, they were always with us. But now it's not true. There are, what, 60, 80 space-varying nations, India and China are producing. And we live in a world where the rate of global diffusion of technology is just so fast. So, again, they're just going to be more countries that are capable within their national budget to do things in space and put things in threat. So, that's what we're going to live with, I mean.

John Gilroy: We started talking about highly customized solutions, size of refrigerator in space and everything else. Now, let's look about for small constellations and niche applications, how does this modularity concept and standardization create value compared to the big ones, to the highly customized solutions?

Dr. David Hardy: Well, first of all, it opens up the competitive space. If there are cheap buses and you come up with a really cool new sensor and can figure out how to distribute that capability across a small constellation, you can compete with guys who were building big expensive systems. So, first of all, it democratizes somewhat.

What's been exciting over the last decade is that for many decades we participated in a progressively smaller set of aerospace companies that could provide space capabilities. They shrank and they shrank. We ended up with basically one launch provider. But look what happened with United Launch Alliance, it's up for sale. What's been brooded about is maybe $3 billion.

Do you know what the implied market capitalization of SpaceX is? $180 billion. And by the way, Blue Origin, who might buy them, is the same way. So, it allows so much greater diversity. And the venture capitalists are all over it. I mean, the number of small satellite companies around who are doing interesting things is just amazing. I mean, as I say, we're down to a handful of aerospace companies. Now, there's 100, and a bunch of them in Europe. And India has a bunch of them, and Chinese.

After such a constrained era in which there were lots of smart people working on it, but it was really pretty small, boy, just a number of different folks looking at different ideas. Some of them are crazy. But by the way, all my rocket friends said that Elon was crazy when he started SpaceX. They joked that the only way he was going to make a small fortune in rocketry was by starting with his large one. But he now has the most dominant rocket company on the planet. Even the poor Europeans are having to come to him to launch their stuff because they're way behind.

John Gilroy: I think if you read the Walter Isaacson biography, you have to get up and walk away every few minutes, because you don't even believe. There's some pages in that, I go, "No. I'm not going to believe this page." And the stuff that he did is just incredible. And let's talk about the commercial success, too. How do commercial needs for satellite monetization differ from the military's need for flexibility and rapid augmentation? Real similar or are they completely different?

Dr. David Hardy: You have to split it up. First of commercial use of space, the biggest use is for communication and internet. And for the longest time, the comp portion of it was just big GEO birds, squeeze as many transponders as you can on it. You optimize it, and we did that for decades. And again, we tried actually a couple of times to figure out an alternative to the big COMSAT birds. And most of those fail, interestingly enough. It's an interesting history.

But now it's quite clear that the geo comm birds are being hugely competed by these proliferations of huge constellations of lower earth and all sorts of orbits. I mean, people are just looking at all the trade space of size and orbit and power. It's just really amazing. So, that's been the biggest driver has been common internet, and part of that is bandwidth and latency.

I mean, GEO is cool, but it takes a while to get up to GEO and back down. And modern comms instance don't want those huge latencies. So, that's one of Elon's big selling boards. So, comm, it's interesting. The military is always primarily for most of its needs, actually uses commercial comm. So, the military actually loves the idea that you have this proliferation of different architectures for commercial comm, because it can allow them what we call path diversity.

All they want to do is get a message from point A to point B to the extent that it's ambiguous what you're using to get from point A to point B, commercial or you're on military makes it much more complicated for the bad guys. Commercial and military use of comm have great convergence of interest. And the other big area is ISR looking down at the earth. Well, same thing sort of applies.

Commercially, you want to monitor crops or you want to monitor the level of truck traffic in China as a measure of GDP or economic growth. Those are all cool. Well, if you can measure a truck, you can measure things of military significant. So, again, for a significant portion of the things the military would like to, there's a big convergence between what commercial can produce a commercial product for and what the military would like to exploit.

So, the Air Force has its own office of commercial space. I think it was only in the last year they set it up, which is just to do that, figure out what you can do in commercial. And the last advantage is with all this proliferation of commercial space in many areas, they're going to innovate faster than we ever could with a military bird.

If you have 50 companies trying to build different ISR things for commercial products, that's probably a deeper innovation web than we would have if we went to our three aerospace, three big aerospace companies and asked them to tell us what to do. So, it just offers us that, too. So, now, it's very exciting. I mean, military loves the proliferation, mostly. The other side of that is it just feeds the diffusion of the technology globally though. So, okay, you get to do all sorts of cool stuff, but potentially send it to this bad guy.

John Gilroy: Yeah. Good, good, good. You talked about being interested in science fiction to get you involved in space and satellites. And so, now, I'm going to ask you a science fiction type question here. So, we talked about modular approaches and new technology. So, what do you foresee modularly playing in future space exploration like space stations and multi-use satellite buses? I mean project out a few years. Can you? Can anybody?

Dr. David Hardy: I'm not sure anybody has fully come to grips with the transformation that will take place when you routinely can launch 150 tons on a given launch with a starship. That's one-third of the entire weight of the Space Station. And I forget it's 30 or 40 shuttle launches we required in order to build the Space Station. So, you can build an equivalent size structure with three launches. And that's just with Mr. Musk's new Raptor. That's what he claims.

Most people have actually looked at the existing Raptor, and since the 100-ton thing is, you know,100 tons is two to three times larger than the biggest satellite we have ever launched. It's bigger than Hubble. It's bigger than Webb. But if you're going to launch these big structures and there are companies that are working on building the next space station, you're going to want the whole thing to be modular.

You want space to operate just like we do on the ground where things are easily ... Sierra Space along with Blue Origin, they're going to build a commercial space station. In fact, Lockheed Martin is, I think, proposing. NASA's approach is we're not going to build another space station. We're going to simply buy services on a commercial one. Mr. Musk's goal is 100 tons for $120 million. That is getting me the cost per pound of sending a package airmail around the planet.

John Gilroy: It's going to be fascinating just to put on your seatbelt and watch the next few years a price for a kilo, what's it called? A dollar per kilo ratio is just ...

Dr. David Hardy: Yeah. It's $10,000 a pound back in ancient days when I was first living. And it's below 1,000 now. So, it's been down a ... It's hard to know because Elon won't reveal his actual, though people say, I mean, it's been speculated that his in-house cost for a Falcon 9 launch is $20 to $30 million. He charges 100. So, he has a big margin. He has a really nice margin on this. But $20 to $30 million, again, I have to go look up the number again. That's always already down in the hundreds of dollars per pound. And if you do Starship, you're getting down below 100, down into the tens of dollars per pound.

John Gilroy: Hey, that's science fiction for me. We have to end it with that. Where does science fiction start and end with these numbers? I mean, it's too much.

Dr. David Hardy: What is it? The famous quote, "the future is not only stranger than you think. It's stranger than you can imagine."

John Gilroy: That's what's happening with this conversation. Well, we've covered, I think, everything in the world or outside this world as well in this conversation. I really appreciate you helping our listeners put a lot of these concepts into perspective because you're wide and varied background. It's really been a fun interview here. I would like to thank our guest, Dr. David Hardy, consultant at TC Space Consulting. Thanks, David.

Dr. David Hardy: Sure. My pleasure.