Enabling Paradigm Change and Agility at NASA's Johnson Space Center –
Interview with Chief Technology Officer, Douglas Terrier

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The Lyndon B. Johnson Space Center (JSC) is based in Houston, Texas and focuses on manned space flight, conducting space research and development, providing mission control, and training of US astronauts. In 1961 the Manned Spacecraft Center grew out of the Space Task Group based in Langley, Virginia, that had been formed in 1958 with an original workforce of 45 people. When President Kennedy in 1961 posed the goal of putting a man on the moon by the end of the decade, NASA realised that a more expanded capability would be needed, at a new site. The Clearlake, Houston site was announced in 1961, selected out of a total of 23 sites under consideration. The organization received its current name in 1973 in honor of US President Lyndon B. Johnson. Gradually JSC grew to its current personnel size of 14,000, 3,000 of which are civil servants and 11,000 contractors. Over the years JSC has had primary responsibility for the Mercury, Gemini, Apollo and Space Shuttle programs, as well as the International Space Station and Orion[1].

Ellen Ochoa, the 11th Director of JSC took office in 2012. She presented JSC's mission and strategies to the NASA Advisory Council's Commercial Space Committee in May 2012[2]. In accordance with the overall NASA vision "to reach new heights and reveal the unknown, so that what we do and learn will benefit all humankind", JSC's mission is to "lead a global enterprise in human space exploration that is sustainable, affordable and benefits all humankind." JSC has posed four primary strategies to achieve that mission. First, to "lead human exploration" through such capabilities and assets as the International Space Station and commercialization of, and reaching beyond, Low Earth Orbit. Second, to "lead internationally" in human space exploration by leveraging the collaborative experience gained at the International Space Station and by championing international initiatives. Third, to "excel in leadership, management and innovation" in terms of technical and

business management practices, and by engaging the human spaceflight team. Fourth, to "expand relevance to life on earth" through partnerships with economic and social impact, engaging society, and communicating with stakeholders.

In that presentation, Director Ochoa explicitly noted the need for "paradigm change" within JSC in pursuit of effective commercial partnerships. This entails the development of relationships with industry, academia and government, establishing non-profit partnerships, creating higher customer focus, and adopting industry best practices such as lean development and rapid prototyping. One key challenge has been to transform "JSC's culture to one that's reliable, progressive, innovation-centered and easy to work with."[3]

In 2013, Director Ochoa unveiled an organization change program labelled JSC 2.0. She explained it as follows: "My concept of JSC 2.0 asks a fundamental question: If we were starting JSC today, how would we build a space center to reach our vision of leading a global enterprise in human space exploration that is sustainable, affordable and benefits humankind? What expertise would need to be resident at JSC? What facilities would be required? Where else can we find expertise and facilities that could be used, and how would we collaborate? How would we be organized to most efficiently and effectively carry out our work? What tools and processes would we use? How can we be more nimble and adaptable to change, and stay that way in the future? I hope everyone at JSC will engage in 're-inventing' JSC so that both our current programs and projects, as well as ones we hope to carry out in the future, will be successful."[4]

The themes of leanness, adaptability and agility were featured in internal publications over the next few

years. A re-organization of JSC initiated in 2014 for example had as its chief goal to accomplish "a structure and governance that is more lean, agile, and adaptive to change."[5] The internal publication Roundup repeated these themes in 2015 and 2016. In 2016, the evolving change program labeled JSC 2.016 included enabling change as one of four overarching themes (in addition to connecting to the mission, making programs successful and removing obstacles).

It was in this organizational change context that in August 2016 we spoke with Douglas Terrier, who took on the role of Chief Technology Officer at the Johnson Space Center in April 2013.[6] In this role, Terrier is responsible for JSC's technology investment strategy and integration of JSC's technology portfolio. Before joining NASA in 2003 to take up engineering and strategy roles, Terrier had worked for 23 years in commercial aerospace with Lockheed Martin, General Dynamics and General Electric Aircraft Engines. This wide-ranging experience, in both the commercial as well as government domains, and in both technical and business-oriented roles, gave Terrier a broad perspective not only in terms of technology but also in terms of organizational change at JSC and the agency as a whole.

Heracleous	Thank you for making the time to speak with us about JSC's and NASA's journey towards agility.
Terrier	One thing that I wanted to talk about that's been on my mind, and this is from the chief technologist perspective; the idea that for most of the period since the industrial revolution, the time frame between the refresh rate on any technology has been around a decade, or a couple of decades. Our time frame of our NASA processes, certification, all that, is also about a decade. Unfortunately, we've now found ourselves in a period where the refresh rate on certainly anything that has to do with computers or artificial intelligence, all the things that are going to be pivotal to the new space technology, is completely out of phase with our own processes. So I think this is a forcing function that we're not really paying attention to. Our processes, by definition, produce products that are out of phase with the rapid pace of technology. So it's out of our control that this 18-month

doubling [Moore's law] is a reality in many industries, and it's not just in computers. In advanced manufacturing, certainly in biomedicine, anything to do with synthetic DNA, all this stuff. These are all the things that are going to have huge impact on the way we conduct every industry, including ours. And yet our systems, all of our certification, all of our design reviews, all these, they're fairly fixed - phase A, phase B, so on, and so on. And there is no way they can possibly take advantage of this new technology, the speed of technology.

Heracleous	Will this be one of your goals in your new role? [referring to Terrier's impending move to Washington to take on the Chief Technology Officer role agency-wide]
Terrier	I think this is one of the things that I have to push on, because we have a whole institution that is not only just invested in the traditional program management model, but it is a cornerstone in policy, hard-coded into how we do business. And it spells out the phases that you necessarily have to go through to get anything into flight, safety being the paramount concern. But given today's accelerating pace of technology it's a recipe for being obsolescent. Because of the traditional way we conduct these gated milestones; preliminary design review, CDR (Critical Design Review), all the regular things that we do; there is no fuzz, you have to follow this process, if you're a vendor doing business with NASA. Let's say you start with design requirements and so on. Now, the technology that you base-lined is upgraded. It's a 386 processor on station problem, right? We also don't have an efficient way for the design to incorporate that refresh. So, again, you don't have the right time-phasing to really keep up with the technology, and you don't have a mechanism for introducing the technology as it modifies.

So this JSC2.0 idea of being agile and adaptive, I think, there's of course cultural and organizational things, but if you even look at just the engineering systems, engineering process, it tends to preclude that agility and is a fundamental limitation. So we say we're going to incorporate more private sector, right? But a condition of doing business with the government or

NASA – DoD (Department of Defence), same thing - is you're required to follow this process, right? You're required to follow these steps and go through these gates. And so, by definition, that, again, doesn't really allow you to really take full advantage of technology. So I think, bottom line is - we can talk about our process and our culture needed to become more agile, but I think talking about that, sort of in the mindset of 20th century technology is not very helpful. And you know, we can go, we can extrapolate that and talk about singularity and when machines are designing machines so that refresh rate becomes exponentially more rapid. So how do you make the process agile enough to accommodate this? I think that's, to me, that is the biggest opportunity-cost, if you want to call it that.

Heracleous   Do you have support for this thinking in Washington? I was just wondering, whether you talked about this and they said "great" and...

Terrier   Of course. I think by definition, the way this agency works allows the Chief Technologist's Office to be the champion of these kind of radical ideas, right? So yes, is the short answer to your question. I think it's probably fair that yeah, there was some resonance with that. I have to say that the organization is set up, both here at JSC and in D.C., to be tolerant of the Chief Technologist sort of being the far-out voice. And we'll listen, but then we've got our process, and that has to be balanced against that far-out voice. This is a pretty rigid process, and, though we're listening to that voice, there's often no place in the process to insert that voice.

Heracleous   We can take the discussion wherever you would like. What I was thinking was maybe we can start with JSC 2.0 and what does agility mean for JSC? What have been the challenges up to now? And then move maybe to your role in the whole agency, and maybe do you have any thoughts about how you might approach helping NASA become more agile? In our workshop today we talked about dimensions of agility. So we said one is leadership, being able to sense the environment outside - not only sense but engage, think about what it means, and take action. Then we talked about agility at the organization level, experimenting,

reallocating resources and actively looking at outdated processes and saying, "this doesn't serve us anymore" and changing it. And then finally, the strategic dimension where we say, "do you need to change your business model, the way you do things?" Do you engage with networks, and do you balance speed and stability?

Terrier   I'll give you my view of it, I have to start at the beginning since we're talking about JSC 2.0. So you've got an organization that is absolutely invested in cultural beliefs, norms, that what we do in human space flight is unique, and that it is completely different from what the rest of the world does - going back to Apollo. These things don't exist anywhere, these challenges, so we have to invent everything. We have to do everything internally because we're facing extreme requirements that haven't been faced before. And that was true, actually. I think one of the hardest things about - any cultural norms - is that when they're based on reality, it becomes very hard to change them. However, over time the reality has changed. So you've got an organization that very much values that internal reliance on doing everything, self-inventiveness, based on the premise that there's nobody outside that's doing this, and you get that embedded in the organization. And you find that that's been a very successful model, actually. And then you bring that all the way forward through Apollo and Shuttle and the International Space Station, and largely that model remains effective.

And now you come to today. And what we have is many of the same cultural biases, I will call it, in the organization. When in fact, the premise, the assumption, that people outside aren't dealing with some of these challenges is just no longer true, because of the Dot Com revolution, because of everything that's going on in Silicon Valley, in some cases far more innovative. Also, now you have a commercial space industry that's operating without the same constraints. So they have a different speed of invention and agility. Because they're not constrained by these processes that worked so well for decades. That self-reliant culture made sense, but now we have an organization that's really, by nature of its very culture, not that curious about outside,

because it's convinced that it's not that relevant; it's different out there. They're doing oil and gas, they're doing different things. We're doing space.

Heracleous   Is this still the case?

Terrier   I would say you can find it broadly, not just inside NASA. You can look in the broad culture and people say, "It's not rocket science." Which means it's not hard, so why would I ask them? We're doing the hard stuff. We know the hard stuff, right? It's an interesting thing. People don't walk around with that consciously, but subconsciously the implication is, I'm doing the rocket science. Why would I ask somebody who's not doing rocket science? So I think it's entirely across the whole culture. The corollary is that people outside would say, "I never knew I was invited to participate, because I'm not a rocket scientist. That's hard stuff, man, I don't know what I could contribute," which is not true anymore. So in response our leadership have taken a bold step by saying, "I'm going to have a JSC 2.0 initiative. I'm going to reinvent the culture. I'm going to draw the control volume around the human space community," including headquarters, the contractor community, so on, "and I'm going to reinvent that community, move the pieces around within that chess board." But we're still not challenging ourselves enough to look outside, right? Because all the rocket scientists are inside this control volume. So why would we even ask outside?

Heracleous   Was this explicit, or...?

Terrier   No, not at all, but it gets back to our cultural biases. If you look at the implementation, we read the words and you say, "I want to be more agile. I'm going to be responsive to change." We should say "responsive to change" means we've got to look outside to see what the change is, but that's not what is happening in practice in many cases – a lot of our effort is concentrated internally. So I would say, to come to the question, when you look at the challenges - or the difficulty we've had with really realizing the full potential of JSC 2.0 - it's fundamentally that, on that point, that you can't actually be agile and be responsive if you don't fully understand the change outside. And the change is the new space

companies, the public-private partnership opportunities with other industries, with people like yourself. People are doing good work all around us, and if you don't know what that is - and we're very sincere by the way about wanting to embrace change. We're very sincere, but we haven't yet fully understood the changes outside our own ecosystem here.

Heracleous   Because of the embedded culture?

Terrier   Because of the embedded bias around that. And also remember that the people that were told 20 years ago, "Look, you don't want to be distracted by going to the opera, or going to the art show, or other industries, because we have hard work to do. It's hard engineering. It' i rocket science," they grew up reinforced, and they came up and got certified in a very rigorous process. These people are at the top of their game. They are very invested in this path that they've taken, a path that has largely proved to be very effective. So they've learned for 20 years not to look outside. Whether they meant to or not, that entire certification process was totally internal. None of that certification asked, "How good are you at looking at trends around you? How good are you at organizationally responding to them?" None of that was asked in their roles, and they've been very effective at the most challenging environment and rewarded for that. So of course they're going to perpetuate that, right?

Heracleous   And when you tried to raise these points, what happened? Because you're very elaborate about them, and you can explain them...

Terrier   So I have the very good fortune to be on the senior council here. And again, I'm sort of the one voice on the extreme. I'm the progressive voice in the conservative room. Everybody is very respectful and very willing to listen, but what happens is you tend to have one person saying, "Hey, this environment around us is changing very fast." And you have ten very credible, very valued voices, saying, "No, no, no. That's just PowerPoint engineering. They're making that up. They have overly optimistic views. They haven't been at this for 40 years and don't know how hard it is, how dangerous it

is. They don't know how much rocket science this is."

And at JSC we find ourselves - not intentionally, but because of our paradigm, in the camp that will defend the traditional model, for good reasons because we believe it's safer, it's well understood. We know the process. We're following all the lengthy process through all the gates. "I don't know what's going on over here, but it doesn't look like this thing that I know produces safe, reliable results. I don't trust it, it is unproven so I'm going to defend this." It may be difficult to be completely objective, because we're fully involved and invested in the model we know and understand. The contractor community I'm used to is involved, my friends, my relatives, jobs are involved. This is big. And if you wake up one morning and make radical changes, it's not just a matter of academically saying, "Oh, this is a better model." You're talking about laying people off. You're talking about families losing their homes. It's a big deal. You're talking about congressional support that's invested in these jobs and these districts and so on. This is a big thing. And so, it would be naive of us to say, "nobody wants to listen to a different voice," because it has huge implications and we have to make balanced decisions. You're well aware of this, it's a big thing. So I don't think it would be fair to be too critical of people that are very cautious to look at a different model.

Heracleous   Any other challenges that come to mind? From our discussion, I could see that, the sensing of environmental signals, evaluating them and taking initiative, driving forward, has been a big challenge. One is maybe people don't actively sense what's happening outside or even if they do, they don't really critically evaluate and say, "So what does it mean for us?" And even less taking initiative and driving forward. And I also guess from our discussion that unless the leadership bit happens, the reallocating of resources, experimenting and actively removing inertia and bureaucracy may not take place because it depends on leaders taking action. Is this also what you find?

Terrier   Yeah, and we're trying to do those things. But I think this is one of those classic challenges, the Kodak case study is a good

one, right? This idea of paradigms and I'm going to double down on film and all this. But you have the same forces at work, if 90% of my revenue is coming from film processing and kiosks in every country, you go on vacation, you take your film, that's the revenue of the company, right? So fine to say digital is the way of the future, but now the entire revenue model of the corporation and the work, the decades of infrastructure, the people staffing the kiosk and the processing, they're at risk. Inside our organization is a somewhat similar case. It's fine to say there may be a different model that may be more public-private, but remember, this process, that's very rigorous, involves civil servants and NASA people every step of the way holding your hand through each gate to assure safety. If I say let me let go of that, and I'm going to let people outside have more of a role with less oversight, what are these people doing? All of a sudden you question the value of this oversight. So you realize that each of the people in the decision making roles own part of those processes. Literally their staff is part of this process. How do you objectively evaluate a different model? Do we just give a contract to SpaceX for example and accept the product once it is demonstrated? And then we have to understand how we have the visibility to assure safety in these new models. What does that mean for the leader who's responsible for the hundreds of talented people who job is rooted in the traditional model, in assuring all these steps? So I think this also involves the human nature, loyalty thing even more. That's at a personal level, it makes objectivity very challenging

Heracleous   And with Kodak, I think the most interesting part of that story is that Kodak invented the digital camera. It came from them. And we see also with NASA a lot of the technologies that are used in commercial space come from here.

Terrier   Yes. I think that's to me the most interesting. And the second interesting aspect is that in the late 1990s the Kodak board made a conscious decision to invest ... they actually had a choice between digital and film, and, even though they saw the trends, they took a conscious decision to invest in professional film, a new formulation. Because they thought they

could persuade the market to come back, buy a better product. This is what's going on. We see the trend, but we think if we just do the traditional model better we can bring the whole market forces back. A lot of people don't realize they had the money to invest in digital. They made a conscious decision that, "Yeah, I see the market's going there, but man if I come out with a better formulation." Why? Because everybody on the board grew up as chemists, grew up in chemistry. They weren't electronics people. This is their passion, and so on, and they personally believed that everybody would see that in fact it's a better product. Our people really believe that if I just do my traditional model better, everybody will see it's a better product, and their opinions will be changed. Our value proposition is based predominantly on maybe .999 safety posture. It's not balanced on cost, reusability, supply chain, things that drive decisions.

Heracleous   Which are all the things that I think the government is interested in, to make the public sector more efficient.

Terrier   Exactly. And there again we are calibrated by the value proposition in the '70s, which is "the government, my boss, is interested in beating the Russians, no matter the cost. So if I just do the technical part well I'm good." We haven't fully embraced the new paradigm that the government's interested in operating more like the private sector and its efficiencies, right? But we have few people who are fully fluent in those values. Most of our leadership are not fluent in business terms, because we've never had to be.

So what we do, which is true for a lot of industries, is we take the best rocket designer, and make them managers. We are not trained as CEOs. We often have little business training. We're not fluent with this language. We're very fluent with the technical language, and we can make a very good case why this 99.999 solution is better than a commercial company's 99.99 solution, because we have one more nine behind it. We can make a very good case for it, and we often believe that that's the entirety of the trade.

Heracleous   Do you feel lonely having this understanding, when not many other people view it that way?

Terrier   There are others in the organization who are championing change. And you only have to step out to talk to people like you, or you only have to step out to talk to people in OSTP (Office of Science and Technology Policy), OMB (Office of Management and Budget). You don't have to look very far to find a lot of resonance with these ideas.

Heracleous   And just to look at the strategic aspect, that is, changing the business model. As you mentioned, from inward looking to kind of a network model working with industry, getting value through networks et cetera, so what's interesting is that JSC has been experimenting with open innovation. It has had industry collaborations. So if some of these things have been happening, why is it still so difficult to say we are going to take this model and sort of expand it and slowly change the agency?

Terrier   I think that that speaks to the culture we have, which is a culture that is tolerant of different views, but it's not the same as saying I hold that new opinion on the same level as the traditional views that have been demonstrated to work. So we can tolerate both, experiment with new ideas provided this does not interfere with the traditional role.

Heracleous   Okay, so it's a bit like I'm doing a small experiment that shouldn't threaten the way we do things?

Terrier   Exactly. And the moment you start to threaten this, you'll find that you'll get a different response. First rule - first, do no harm. And by the way, just to be clear, the thought behind that is routed in hard earned experience. Nobody comes right out and says it, but it's implied. Look, these lofty new ideas are great. That's fine. But we're not a research center that has the luxury of trying untested ideas. We're an operational center. We have six crew on orbit right now. We're flying spacecraft. Our paramount principle has to be safety. Any mistake, the slightest mistake, can cost lives. And oh by the way, as people are fond of saying, if JSC gets a cold, the agency gets pneumonia. If

JSC and human space flight has a problem, the agency's done. That's actually true.

Heracleous   Because of the human involvement...

Terrier   Because of the human aspect, and the public interest. So you can fly a probe and crash it into Mars all day long. That's a bad day, but, it's not in the papers, we can recover. If you lose a national hero, that's a very big problem. Now, with that in mind, people say, "Look, this is my job, and if I am distracted in any way, somebody may get hurt." I'm a pilot, and there's a lot of truth to this. This is very, very critical stuff. Steven was a flight director. You are making split-second decisions. So I will tolerate you exploring new ideas, but the moment you interfere and get my eye off the ball, I'm done playing. Because now you're going to put people at risk. And that's how we tend frame these questions. There's a compelling argument there, right? So the question is, how can you find a way to have an absolutely bulletproof operational scenario that can continue while you concurrently make gradual change that's not disruptive? There's a lot of fear that change will be disruptive.

I'm going to give you one last example on the last point. If you go in the old control room over here, the Apollo control room, with the ancient technology. We used that up to 1996. So you'll see the new control room with the computers and so on, and you see the old one, with analog technology and tubes. They used it to 1996. So you'd say, "Why would you do that?" And the organization would respond, "Because even though I know - not that I'm stupid and I didn't know there's much better technology - but I have known for 20 years, every fault, every possible scenario, every possible mistake, every possible anomaly, and I know how to deal with it, so I can never be surprised. The moment I introduce the new technology, man, now I've got a learning curve". Who wants to be the guy that's the flight director on that learning curve when these lives are at stake? Even when I'm aware that there's a better system, I'm not taking the risk, right? We delayed that as long as humanly possible. We just couldn't keep that thing operating anymore. Once we put the next one in place, we've had that

one for another 20 years, basically till MCC-21 now. For the very same reason.

So how do you inject change into that, right? I think that the good thing is, on the positive side, these are the brightest people in the world who absolutely, passionately want to do the best for their country. Nobody's here because they're going to make a fortune. People are here because they're truly, personally, invested, so it's incredibly sincere. I think this is a case where you have to show people with small, unthreatening examples where this can work. And when they see that model, they're smart, they will see that. I think we're actually doing that very well with the Commercial Crew Program. If you go talk to people in the Commercial Crew Program they won't say, "This is PowerPoint. This is just nonsense, it's just media hype." They'll say, "This is great. And I'm absolutely invested in this being successful."

Heracleous   What is the Commercial Crew program?

Terrier   So this is a program where we basically said, "We're gonna pay Elon and Boeing to provide the transportation to the station."

Heracleous   Instead of the Russians?

Terrier   Instead of the Russians. So, out of necessity frankly, because the shuttle's retired. Now we have to say, "Man, we gotta find another way." By the way, the assumption was, "there's a community that wants to adopt a new model. Let me give that a shot. Okay, lets start with the flights to station, a near Earth flight. We'll continue in our traditional way to attack the very hard problem of going to Mars and the Moon and so on. But we'll let try this new model on this lower risk mission". We said: "We believe you can manage that. We'll help you to manage that, it's fairly well understood, Low Earth Orbit." As we're executing that, as you see on TV, you're starting to see, that doesn't look like a joke. That looked like these guys are really operating a spacecraft, right? And the people who are in that community, who are the part of NASA supporting them, are now very much embracing and invested and this does work very well. We like this model. We still have some concerns about too many shortcuts from the model that we're used to, but now our attitude isn't, 'Oh,

that's never going to work. It's nonsense.' Our attitude is 'how can we help that more agile model be more safe and work?' Maybe there's something in-between, right?". So how can we bring our knowledge to make it even safer, but take advantage of that agility and that cost saving? And the reusability and all those things. So now you're seeing a lot of the agency invested, the people involved in that.

Now, you go one step out from that and look at the International Space Station (ISS) –also a traditional model. But we can't continue to operate the International Space Station unless we have the transportation for the crews. So now we are depending on this commercial model being successful, and now you get the International Space Station going, "hold on, slow down everybody at the table. No, we need that to be successful; that's not PowerPoint engineering, because if that's PowerPoint engineering, we can't support and resupply this $billion space station program, because we don't have any other way to make it work, right?" Now the ISS program is invested. So here, the Space Station program is now starting to change its voice, right? So, I think that's a good example of where you have to introduce new ideas in a way that's non-threatening. It's the lower risk, low Earth Orbit solution and we're still using the proven traditional approach in the high risk game. But we will, through experience, get more comfortable with the new model as it proves itself over time and we learn how to safely incorporate it.

Heracleous   So it's kind of an incremental change?

Terrier   Incremental, exactly. And for this reason, I'm actually very optimistic, because I think we're on an irreversible path. I worry about the speed of that progress, but I think - and this is really, really important, it's about how do you accelerate that through the system? How do you increase the speed of that change? Right now, in that arena, because SpaceX is in that arena, because we, the government, have introduced a new model that allows them to compete. They wouldn't follow the whole process, right? We've allowed a little deviation, essentially. Now you find that the Boeings and the Lockheeds, and so on of the world are saying, "Wow. If I want to be in that market,

I have to find a way to also make my process more agile." Today, we're largely maintaining the old process in deep-space exploration - more challenging, more expensive missions. It's like everything in the private sector, if there's competition and I have to compete, then I figure it out if I want to stay in business, right? On the other hand, if there's a government contract that continues to subsidize an old, expensive model, why would I ever change? And so, in my opinion, keeping the traditional model of contracting in place too long may actually slow the progress of the industry. Does that make sense?

Heracleous   Yes. Is that why the government has been tightening the budget?

Terrier   I think some people in the government are trying to force that discussion. That's exactly right. What's been happening over the past few years is that the white house tends to propose a very aggressive budget that seeks to encourage new models, and the Congress comes back with appropriation language that maintains much of the proven traditional model and moves more cautiously. I think it has been a healthy tension but each iteration is putting more and more pressure on the traditional model.

Heracleous   So you mentioned a couple of very interesting points, and what you said reminded me of this idea of positive deviance. So you said you allowed a bit of a deviation, and then it kind of helps to change the understanding of people and, ideally, move the system forward. So the positive deviance could explain part of the process of the commercial space, kind of bringing some learning to NASA.

Terrier   I'm one of those who would probably be comfortable on the more aggressive end of the change spectrum So I would say, what if we expanded that model? But what happens is if you try to do that too quickly is you get, as we were saying before, a lot of resistance because of the safety concerns. However, if you open it and say, "Let me just do the space station transport." Open that as the beginning, right? But the deep space exploration and Mars missions, that continues with a more traditional system for now. Now nobody feels threatened while

	we experiment with and prove out the new models. And that's what's happened.
Heracleous	I wonder if some of these new initiatives - public-private partnerships - maybe remind people of this historical Faster, Better, Cheaper, which had mixed outcomes.
Terrier	I agree. Yes, I think that's exactly right. And I think what we have to balance is there are a lot of very good stories - which everybody around here can tell you - of where those initiatives don't work. However, those stories are based in 1970, 1980, whatever, and it turns out the capability outside the bubble is different today. I liked it, when people tell me that they don't trust that, for example, Elon can take a couple thousand young kids and in so many years build a spacecraft that's going to be safe. I like to point out that's interesting because this place that we're sitting in was built in 1963. And six years later with a bunch of 20something-year-old kids, they were landing on the moon. So explain to me why that can't be done? Oh by the way, they had no prior knowledge, no resources to call on. These guys have the entire database of NASA and experience of the last 60 years to call on. You sure they can't do this in six years? Why is that PowerPoint engineering all of a sudden? So that's a calibration that I keep in mind. Of course you could do that if you're motivated. We have evidence. We have empirical evidence that can be done.
Heracleous	In addition to the incremental way we discussed, do you have any other thoughts of how you're going to try and push the agency towards more agility, particularly in your role as Chief Technology Officer? As you said, you're expected to be a bit of an outlier, in terms of how people see things, and expected to push things forward.
Terrier	I anticipate finding myself in exactly the same position in Washington as I am here, which is, I represent the outlier position at the table. And you have a decision maker, these are smart people, so they're interested in these opinions, but it's very hard for a leader to hear one outlier opinion, among several traditional opinions and just automatically assume that's correct. But in this case you say, "Leader, go look. Go look yourself." So the learning is, my role is to bring these new ideas to the

attention of the leader. In the role of chief technology officer, I'm not required to have vested interest in any one part of the organization. My job, the job of that position, is to bring to the administrator recommendations based on facts. Empirical data. And not to bring any organizational bias or whatever. It's supposed to be an independent adviser on technology trends, and so on. So, I think, making sure that role is truly vetted as being an honest broker, independent voice, and you can only do that by providing correlation evidence. Say "Here's what I've told you. Look for yourself."

Heracleous	So in effect you'll be trying to help them see what's outside. Helping them evaluate. Helping them act.
Terrier	Yes. So of course I can do that by bringing data, empirical data. It's not refutable. Again, by encouraging us to look outside. Some learning, benchmarking, so on. Those techniques would be welcome, because you could do that in a very nonthreatening way. Let's go give a talk here and see what's going on. That's my job. The second thing is, that role does have implicitly the technology policy advisory role. If I present myself as almost an auditor from the outside, with the knowledge of how this thing works in the real world, and let me tell you how it is... of course, people aren't very receptive to that view.
Heracleous	So the system uses its immunity?
Terrier	Yes, the system immunity says, "That's great, but you don't understand how it works in our system. You're not part of the system, you're not part of the team." And maybe because of the way the message is transmitted, "let me tell you what smart people from the outside can tell you". Nobody reacts really well to that. I think the trick is to - whether you do it with this incremental approach, or you come in as, "I'm a member of the team, let me share some ideas. Let me share something I've learned. Let me learn from you, lets learn together?" You know what I mean?
Heracleous	And traditionally, the autonomy of the centers might have been a bit of a barrier.

Terrier   The office of the Chief Technologist, has been fairly independent of the mission directors within the agency in D.C., a fairly independent policy adviser. Similarly, they have not been integral with the centers. So, one of the things that I really want to change, is that I want this office to be seen as part of the team, not an external audit. But people have to believe you have their interest in mind, not really to be an auditor and criticize. I also want to do the same thing where we have a Chief Technologist at each center. I want to treat those Chief Technologists as the staff of the Agency CTO, the arms and legs. Invite them into the conversation, and you take a position for an issue, you say, "Well, we've talked about it among the community and this is what I'm seeing, but here's what the other centers are seeing in their interactions. Here's a position." That's a much more defendable position versus one independent guy who. I think those relationships within the agency and with the centers have to be really worked on, so they become truly a team.

Gonzalez   And if you look at strategy, creating value through networks, that's where the key is for what you're talking about. Number one, doing it from the outside coming in, to try to create those internal networks, never works inside the agency. So already having the networks, and being trusted allows you to bring that up there. But the second part, creating the networks on the outside after you have the trust on the inside is very different than coming with the networks from the outside, and trying to bring them in. And so, I think the power of being able to reach out to OSTP and to OMB and those other organizations when you're a trusted insider is a lot more effective than trying to come from OMB or OSTP into the organization.

Terrier   And I would extend that. I agree completely. I would extend the idea of having an office with a very small staff, and the implementation is done with the center staff so that it is truly a team organization. I would say that's one of the other jobs that office has in addition to technology policy. The other thing is how does NASA technology affect the outside world? That's the office that's going to champion this. To champion the work of the guys who are busy running programs. They don't always have time for that. That CTO has to be the technology champion. Provide feedback to OSTP, congress and other stakeholders, our investment is having this great impact in Houston, is having this great impact in Cleveland, and so on. Well how am I going to do that with a small staff? We have people like Stephen at JSC and at other centers, who are doing great work regionally. Why not involve them in that conversation? As it is, the centers are trying really hard to do regional work - if you can figure out how to get through all the wickets. It's a very different relationship right now. Fair?

Gonzalez   Absolutely.

Terrier   And who is your champion at headquarters?

Gonzalez   Nobody.

Terrier   So the Chief Technology Officer can be the champion at headquarters for these initiatives for technology both ways?

Gonzalez   Now you know.

Terrier   Yeah [laughter]

Heracleous   Thank you, Douglas. We very much appreciate your time and your insights.

In his ground breaking book on the history and philosophy of science, The Structure of Scientific Revolutions[7], Thomas Kuhn outlined the tortuous and lengthy process by which established paradigms, that guide normal science, can shift towards new models. He argued that when particular anomalies are regularly identified in scientific findings, scientists initially try to fit these anomalies into the prevailing shared wisdom, or try to extend the boundaries or the paradigm itself to accommodate them. Paradigms get severely challenged and superseded only when there is significant accumulation of evidence to the contrary, evidence that better fits a new paradigm; a paradigm that can provide solutions to pressing problems, together with the necessary new infrastructure of adherents, funding, and belief systems.

NASA is in the midst of paradigm change. The traditional model of large-scale systems engineering imported from the military, together with the belief system of internal self-sufficiency, based on hands-on

experience, and research and testing conducted by exceptional people,[8] has been under pressure by a number of external developments. These include the growth of commercial space accomplishing things never done before such as developing re-usable rockets, continuing budget and political pressure, and robust competition from non-US space organizations[9].

The new model of commercial space however has not subsumed or replaced the traditional model, one of the outcomes Kuhn's theory predicts given the assumption of incommensurability of the two paradigms. Rather, NASA has been interacting with commercial space in the context of public-private partnerships, bringing in the wisdom of the crowds through open innovation projects,[10] and engaging in other initiatives inspired by the private sector such as organization change.

Terrier's interview provides deep insights into the strategic, leadership, organizational and political dimensions of JSC (and NASA's) traditional paradigm, that both challenge as well as facilitate its organization change journey towards agility. He also outlines how change and a new model are being introduced

gradually and in a non-threatening way, through collaboration with the private sector on initiatives such the Commercial Crew program taking crew up to the International Space Station; gradually providing proof of concept for a new paradigm. Beginning from projects associated with Low Earth Orbit, rather than challenging the deep space projects such as the Mars program, these initiatives slowly win converts, and new beliefs and operating models gradually spread through the agency. As Terrier notes, a big bang approach to organization change would produce significant resistance and disrupt current programs. Hence the incremental model of change that introduces a gradually expanding new paradigm that interacts with the traditional paradigm. Terrier's insights indicate that the journey to agility does not simply depend on the implementation of a plan or on a leader proclaiming the goal. Rather it is a complex, multi-dimensional, socio-technical challenge that takes time and commitment to accomplish, particularly for an organization with a long history of ground breaking accomplishments using its particular, traditional modus operandi.

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[1] Information for this section draws from Johnson Space Center fact sheets, http://www.nasa.gov/centers/johnson/about/factsheets.html, accessed on 23 August 2016.

[2] The information in this paragraph draws from a presentation by JSC Director, Ellen Ochoa, to the NASA Advisory Council, Commercial Space Committee, on May 1, 2012. Source: https://www.nasa.gov/sites/default/files/files/Ochoa_NACCommercialSpaceMay2012_508.pdf, accessed on 23 August 2016.

[3] Ibid, slides 25 and 29.

[4] JSC Director, Roundup, Spring 2013, page 2.

[5] Presentation on JSC Reorganization, 12 August 2014, Source: http://science.nasa.gov/media/medialibrary/2014/09/18/JSC_Reorg-fromJSC2.0site_Tagged.pdf, accessed on 23 August 2016.

[6] Biographical information on Douglas Terrier can be found here: http://www.nasa.gov/offices/oct/about_us/bios/oct_cc_terrier_bio.html#.V7xCnZMrJ-U, accessed on 23 August 2016.

[7] Kuhn, T. 1962. The structure of scientific revolutions. Chicago: University of Chicago Press.

[8] As shown for example by McCurdy, H. E., Inside NASA: High technology and organizational change in the US space program, Maryland: Johns Hopkins University Press.

[9] Heracleous, L. & Gonzalez, S. 2014. Two modest proposals for propelling NASA forward. Space Policy, 30: 190-192.

[10] Gustetic, J. L., Crusan, J., Rader, S. & Ortega, S. 2015. Outcome-driven open innovation at NASA. Space Policy, 34: 11-17.