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SHAPING THE FUTURE OF AEROSPACE

MATT ONDLER

POSITIONS: Chief technology officer at Axiom Space since January 2020; president and CEO of robotic engineering firm Houston Mechatronics, 2014-2019; at NASA's Johnson Space Center, chief of the Software, Robotics, and Simulation Division, 2007-2011.

NOTABLE: Oversees hardware and technology development at Axiom Space, which last year received a $140 million contract from NASA to build the first privately owned module for ISS; co-founder of Houston Mechatronics, which builds undersea robots for installation and repair of underwater oil and gas pipes; worked at NASA Johnson for 28 years, including a two-year stint as project manager for Project Morpheus, an initiative to quickly build and fly a low-cost lander that concluded in 2014 after handful of test flights, including a 2012 flight in which a prototype crashed and caught fire.

AGE: 57

RESIDENCE: Houston

EDUCATION: Bachelor of Science in aerospace engineering, University of Colorado at Boulder, 1986; Master of Business Administration, University of Houston, 1993.

Tomorrow's station operator

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"If you build it, they will come" — that's what Matt Ondler and his colleagues at Axiom Space are betting in their plan to erect the first privately owned space station. Assembly will start in 2024 when the International Space Station's robotic arm attaches the first of four planned Axiom modules to the Node 2 port to begin a couple years of confidence building before the modules separate to form a free-flying station. As chief technology officer of the roughly 100-person Houston company, Ondler oversees the construction of these and future modules that Axiom plans to build for in-space manufacturing, welcoming space tourists and other needs. I spoke with him via video call ahead of AIAA's virtual ASCEND conference in November. Here is our conversation, compressed and lightly edited. — *Cat Hofacker*

Q: The International Space Station celebrated 20 years of continuous human presence in November, but both NASA and U.S. lawmakers agree the U.S. modules are nearing their end of life. Why is a commercially owned station the next step?
A: There's a lot of advantages for NASA, of course, but also for commercial space. The advantage for NASA is that of the $3.5 billion a year or so that NASA spends on the International Space Station, only a fraction of that, about $500 million or so, is used for science and technology development. So there's a big overhead in maintaining the station, and by having a commercial alternative where NASA can still go procure those kind of services in terms of research and technology development, it frees up a bunch of money for NASA to do something else, to go do the next big thing — to go the moon or on to Mars. NASA has shown and proven over the last 20 years how to keep humans healthy in space and how to do real work in space, and so it's a good time to try to exploit those and move the industry beyond to start manufacturing in microgravity and create a new commercial enterprise.

Q: Paint me a picture of Axiom Station. Besides being privately owned, how will this station be fundamentally different from ISS?
A: The first and most important is that our space station is completely funded through investment, through revenue that we generate from our business, and so it will be owned by Axiom Space and wholly operated by Axiom Space.

> Ondler later got back to me and clarified that Axiom's $140 million firm-fixed price contract is for the company to provide NASA with data and lessons learned from designing and building the initial modules. Axiom plans to cover the cost of designing and building the modules through a combination of investor funding and revenue from other parts of the company including private spaceflight missions to ISS. — *CH*

Fundamental business needs will drive how we operate the station, how we build the station, how we maintain it. We have to be able to build and maintain and operate a station at a cost that is much lower than the ISS, but we can do that by leveraging the technology and the capability that ISS has proven over the years. The first two Axiom modules will have the ability to house crew, to house payloads, lots of equipment, storage and things like that. Then the third module is dedicated to research and manufacturing. We want to accommodate heritage NASA experiments as well, so take a payload from the ISS and bring it across the hatch and install it into the research manufacturing module. The fourth module is a power thermal module, so it has large solar arrays, it has a three-person airlock that'll be more capable than the one on the ISS. From there, which modules we build depends on the market. If there's a market for flying crew, then we'll build another habitation module. If there's a huge market for research, manufacturing, we'll build a research and manufacturing module next.

Q: What do you envision that the customer breakdown for the future Axiom Station will be?
A: It's really a multipronged business approach and customer base, one of which is private astronauts. Those will come in a couple different flavors: Some are wealthy individuals that people like to call tourist astronauts. We think there's also a big market for professional astronauts that are from countries that may already participate in the ISS, but they don't get the opportunity to fly their astronauts as often as they would like. There's another group from that category that don't necessarily participate in the ISS or don't have a way to really participate in the space program, but want to for their own countries' interest, for their own countries' prestige, to stimulate the STEM fields in their countries. And then we hope at some point to be able to fly individuals that might be working at companies that are interested in doing manufacturing in space, for example. Another big piece of the business model that I think will end up being the largest and most profoundly world changing is on-orbit manufacturing, the ability to leverage microgravity and to build things you just can't build on Earth. It has the promise of being a game-changer, to overuse the phase, but to really create entire new industries where we hope to be building space station modules specific for customers so that they can scale up their manufacturing. Another market segment that's interesting is people who want to create media in space, whether it's movies or commercials, and that's something NASA can't really do. NASA can't really be seen as promoting a particular company, and by

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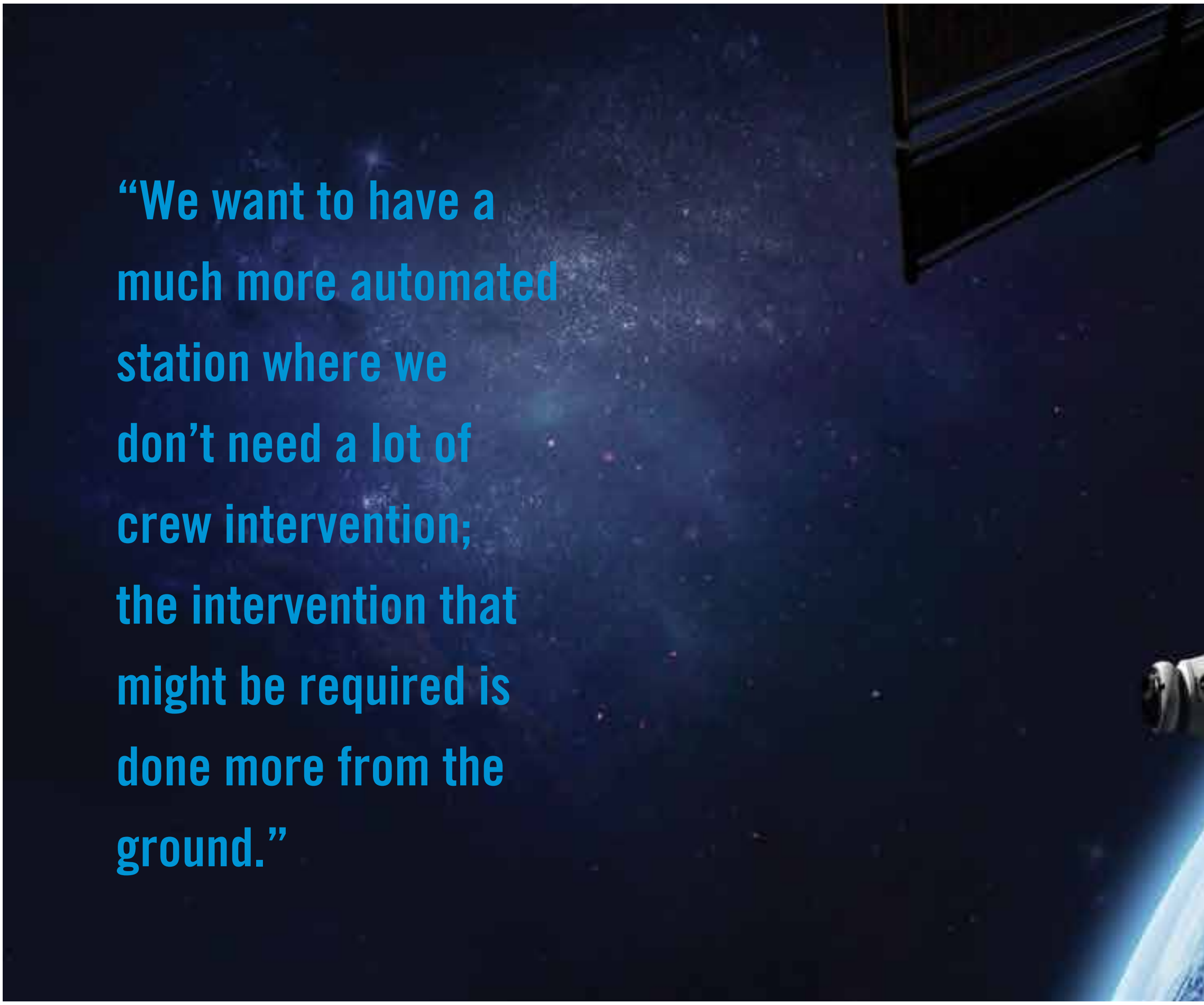

simply having a commercial space station, we can foster some of those markets as well. The last big piece, too, is to be able to be a place where NASA can continue to do fundamental research and do experimentation, technology development for, say, going to the moon or Mars and also a place to train their own astronauts for future missions. All those things together create what we think is a pretty robust business model.

Q: Take us inside the design process for Axiom Station and how these emerging markets are influencing those plans. For example, does the prospect of having humans onboard who are not professional astronauts require Axiom Station to have more creature comforts?

A: Each of our initial modules is being designed and developed to be either launched on a SpaceX Falcon Heavy or a Blue Origin New Glenn, and that ultimately does constrain the size of the module. We have a partnership with Thales Alenia to build the first two modules. They’ve built about 40% of the modules on ISS, so they have a lot of expertise. More importantly, they have all the tooling and friction stir welding machines and all the industrial capability to build the module. That really allows us to get a good start on our station, but subsequent modules may be very different. There may be large inflatables, we may do some construction in space, and that allows us to build things that aren’t necessarily constrained by the launch vehicle itself. So the future will end up being a little different, but to get that foothold you have to launch those first modules on a launch vehicle, right? On the overall design, some attention was paid to the aesthetic and the comfort and the ease at which

people can integrate, to be able to have them bring their own phones and iPads and plug into the network, easily be able to share their experience with their family and friends and with Instagram, for instance. The other part is taking advantage of advances in computing and processing power. We want to have a much more automated station where we don't need a lot of crew intervention; the intervention that might be required is done more from the ground. And then we hope to have some pretty interesting robots in the future on the station. Maybe a robot internally that helps prepare for the next crew or moves cargo around. This trend toward more automation means less requirement to have professional, trained astronauts to operate the station, but we will always have professional Axiom astronauts onboard as well to handle off-nominal situations.

▲ **In this rendering of** Axiom Station, the station has been assembled into a collection of crew and cargo modules that supports private spaceflight visits and activities, including onboard research and manufacturing.
Axiom Space

Q: And how is Axiom making sure it can accommodate companies or government agencies who might want to build and attach their own module to Axiom Station?

A: We want to be positioned where we're a logical choice to build that module for them as well, but if there was someone else who built a module and it met our interface requirements, they would certainly be allowed to come and attach to our station. We're designing all the modules to have what are called the common berthing mechanisms that are the same as on ISS, and so having that common berthing element or having a standard NASA docking system means the ability for all vehicles to dock with us, as well as being berthed. Those are the primary interface requirements, and then it just depends on what they want to do with that module: It's dedicated to manufacturing, it's dedicated to a movie studio.

Whatever it happens to be, we would have to work through that. We're really trying to build with our station an infrastructure and a capability that's very, very flexible to allow lots of different customers. For example, we want our payload accommodations to be as close to a terrestrial laboratory as possible. So if there's a researcher at a Johnson & Johnson or a DuPont who has some equipment they're running in their lab on Earth, we want to be able to take that experiment and almost identically fly it on our station and plug it in. We want to have those kinds of services that are very common on Earth and have them on our station as well: the ability to plug in the same kind of power that you plug in in the lab or they get on the Wi-Fi just as easily as in the lab. That's the goal for our payload customers. We think the path is that we fly experiments and prototypes for customers to prove out a particular technology, and then we find ways to scale that manufacturing. That could be in our existing modules; it could be that the scale of the manufacturing that's required would require an additional module that's dedicated to that. We have the flexibility to accommodate all those things.

Q: There's a long way to go from where we're talking in 2020 to that vision becoming a reality. What absolutely has to happen for all this to come together?

A: There's a few long poles. One is we certainly need continued support from NASA. It is very helpful and important for us to have the opportunity to start our station attached to the ISS. The ISS provides some services to us that we don't have right away, such as power and communications with the ground. And then the ISS becomes, we hope, an early customer for research, exploration technology maturity and hosting NASA astronauts, similar to how NASA became a customer for the SpaceX Dragon capsules. The government being able to be a future customer and provide some funding to help private companies is important, and so that continued commitment certainly plays a big part in it. But we also have an interesting challenge in that we have a short window of opportunity. There will be a day in which ISS is no longer viable and too expensive to maintain and it will be at some end of life, and it doesn't do us any good to show up the day before that. We have to get there relatively early. Our goal is to launch the first module in September 2024. The second element is launched about nine months later and then the third element about six to eight months after that. And then there's a bit of a gap to launch our fourth element because it's quite different than the others and so will require some design work in addition to what we've already done for the first three modules. That's a relatively short time in the aerospace business when you're building such a complex thing, so I think that's going to be one of the challenges: to continue to move fast. Everything else is generally an engineering problem. We pretty much understand how to build a space station, how to keep humans healthy and alive on the station, how to accommodate payloads. We just have to go solve some engineering work to do it right.

Q: In your mind, what are some of those biggest engineering challenges?

A: One is the Common Berthing Mechanism, or CBM, through which vehicles visit ISS and that will also be our approach to connect modules and dock vehicles with Axiom Station. The CBM is made up of a passive and active side that are on each module that are being put together. The passive side is just hardware, while the active side has mechanisms and electronics and powered bolts that pull the modules together and then bolt them together. When vehicles such as the Japanese HTV visit the ISS, they are captured by the ISS robot arm and then berthed. The ISS will have the active side and the HTV will have the passive side. Since the completion of ISS, every vehicle that comes to visit that is not docking carries the passive side, therefore people only build the passive CBM these days. It's been at least 10 years since anyone has built an active CBM, and even then the electronics were likely obsolete. We need to solve that problem very quickly because we're going to have a lot of active berthing mechanisms to accommodate our ability to add modules. So that's one problem solved. Another is when we are a free flyer, we will be using control moment gyros on the order of the size of the ones on ISS. It's been a long time since someone built those, and they are a bit of an engineering marvel so there's a long lead to develop those. We're also flying a pretty unique propulsion system: oxygen methane. One of the reasons we're doing that is it's a green propellant, so it's relatively easy to test on the ground because there's no toxic chemicals. The other big reason is that we can take the carbon dioxide that's exhaled by the crew and turn that into methane. Our studies show that with the crew of six onboard, we can create all the propellant that we need just from the crew producing $C0_2$. That makes a very compelling business case because you reduce your resupply propellant greatly, but no one's flown a methane oxygen system yet, so there's some development work there. We plan to test some of that hardware while the initial modules are still docked to ISS.

Q: What lessons have you taken from the early years of ISS?

A: The list is probably very, very long. One interesting one that we're working pretty hard right now is the whole idea of stowage, which not a lot of attention was paid to in the early days of ISS. It ends up being a big problem: not only stowing the stuff that you want to use, but the stuff that you've already used or

▲ **The Axiom Station** habitation module created by French product designer Philippe Starck in 2018 is shown in an early rendering. Axiom envisions a rotating roster of professional astronauts and space tourists living aboard the future station and enlisted Starck's help in "paying attention to the aesthetics," Ondler says.
Axiom Space

need to throw away and how do you manage all that? When you talk to crew members, they still tell horror stories about how they spent an entire afternoon trying to find a seven-sixteenths Allen wrench. The other is trying to build for replaceability. So, for example, there is our networking and computer infrastructure we're designing so that swapping out should be as easy as replacing your laptop every five years. We're also looking at innovative sources for those kinds of processors — automotive parts, for example. If you look at a modern automobile today, it's pretty much a computer marvel where there's millions of lines of code and all kinds of sensors being addressed and fused together. Those are parts that are available that we want to try and see if we can use for an aerospace application because they're much cheaper, there's more suppliers available, and we have the ability to upgrade in the future.

Q: How do all these planned innovations contribute to the lifespan of Axiom Station?

A: We think there's a longer life simply because we are building in the ability to upgrade. There are certain things that just wear out, and the unique or different aspect of our station compared to ISS is that every one of our modules is an individual spacecraft. It gets launched by a SpaceX or a Blue Origin rocket, and then it has to approach and rendezvous with ISS, or after ISS it has to approach and rendezvous with our station. Each module is a spacecraft, therefore you could actually deorbit each module individually once it reaches end of life or if it gets damaged from a micrometeoroid strike. That allows us to have essentially unlimited life. When modules wear out, you throw those away and you bring up a new one. Another contributor to this longer lifespan is reduced operating costs. Our philosophy — because we believe we're going to be building space stations or versions of space stations for a long, long time — is we're building all the core infrastructure for the long haul. We'll have engineers that worked on the design that can support operations, and that makes the operations much less expensive. And then you throw in more automation and more capability just because the computing power is advanced, we think the operations cost should be relatively small.

Q: Speaking of lifetime, while ISS has had continuous government funding to slowly build up different kinds of activities onboard over the years, a private station like Axiom's won't have that luxury. So how do you ensure Axiom Station is profitable right away?

A: We have to always be thinking about customers and who will be our first users. We're developing those

▲ **A SpaceX Crew** Dragon capsule onboard a Falcon 9 rocket is moved out of the horizontal integration building at Launch Complex 39A at NASA's Kennedy Space Center in Florida before the Crew-1 mission in November. Along with ferrying NASA astronauts, Crew Dragon capsules are scheduled to carry the first of Axiom's private passengers to the International Space Station.
NASA/Joel Kowsky

now, and where we can, we'll try to fly something early on the ISS. We have to be ready to go on day one, and the same is true with the private astronaut sales and other markets. Private astronaut sales are coming along; Axiom will begin flying private astronauts to ISS next year or early 2022.

Along with building modules, Axiom plans to sell flights to ISS and eventually Axiom Station. The first of these missions, dubbed Ax-1, is scheduled to launch three private citizens and an Axiom astronaut aboard a SpaceX Crew Dragon capsule for an eight-day stay on ISS, where the tourists would sleep aboard station in a location to be determined. — *CH*

In-space manufacturing is another market on the cusp. It's almost like the early days of the internet: You have that capability, but people weren't exactly sure what we'd do on the internet. The same with the smartphone; we weren't exactly sure what kind of apps would be usable, and now you see thousands if not millions of potential applications. I think the same thing will happen with in-space manufacturing. One company will discover a little thing that has a good business case to manufacture, which will lead to other companies and other ideas, and soon it's an explosion of ideas and capability. But those first ones are going to be pretty time-sensitive and we need to try to foster that as much as we can. The big thing is we have to build our station in a very timely manner. We rely on the ISS in the early modules for power and berth, thermal protection and even a comms link, and it's not until our fourth module gets up there that we have true independence capability from the ISS. So we have to make sure we get that done before ISS' end of life.

Q: Say it all goes according to plan: It's 2050 and Axiom Station is operating. What is the long-term future that Axiom envisions in low-Earth orbit — multiple space stations? Crew capsules coming and going?

A: We have a 40-, 50-year vision that in 2050 there's multiple space stations in low-Earth orbit. There's a space station that might be rotating to create some artificial gravity to make it easier to live and work long term, with some maybe counter-rotating parts or some separated parts to still maintain the microgravity environment for manufacturing. Those large space stations might have hundreds if not thousands of people. We think access to space will be much less expensive, and so lots of opportunities for all kinds of people to live and work in space. We also think that in 2050 we will have discovered a number of things that can be manufactured in microgravity to the point that it really has created an entire new industry. And the benefits of those things, whatever they are, will improve everyone's lives — whether it's superhigh-performing fiber optic cable that can only be made in space or perfect retinal implants or other biological things that we figure out how to make in microgravity. Our hope for the future is that there's this incredible manufacturing and capability in low-Earth orbit. And not only in low-Earth orbit, probably in orbit around the moon and other places that we're building stuff and lots and lots of people are living and working in space. ★