NASA JOHNSON SPACE CENTER ORAL HISTORY PROJECT
COMMERCIAL CREW & CARGO PROGRAM OFFICE
ORAL HISTORY TRANSCRIPT

JOHN COULURIS
INTERVIEWED BY REBECCA HACKLER
HAWTHORNE, CALIFORNIA – 15 JANUARY 2013

[The opinions given in this transcript are the opinions of the person interviewed and do not necessarily reflect the official opinions of SpaceX.]

HACKLER: Today is January 15, 2013. This oral history interview is being conducted with John Couluris at the Headquarters of the Space Exploration Technologies Corp., or SpaceX, in Hawthorne, California for the Commercial Crew & Cargo Program Office History Project. Interviewer is Rebecca Hackler, assisted by Rebecca Wright.

Thank you for squeezing us into your schedule today, we know it's very last minute. We'd like to start by asking you a little bit about your background before you joined SpaceX, and then how you got involved in this venture.

COULURIS: Let's see, I started off in college studying undergrad [undergraduate] in mechanical engineering. Then a graduate degree in aeronautical engineering, and then went to Grumman Aerospace [Corporation] briefly. I always wanted to get into spaceflight, and actually into designing and building and flying spacecraft. After that though I went into the Navy, and I was a pilot in the Navy for a little over nine years.

Becoming a pilot was a way to become a better engineer, to actually have flying experience for the vehicles I designed. You have that practical experience. From there, I went to

JetBlue [Airways Corporation]. I joined JetBlue when we had 28 or 29 aircraft, and we built that up to about 150 aircraft. I was a pilot there and also worked operations.

I really wanted to get into spaceflight, and I'd been following SpaceX. Through some back and forth, Elon [Musk, SpaceX founder and CEO (Chief Executive Officer)] contacted me, and he was very interested in changing the paradigm of spaceflight to be more like airline operations. He'll quote a lot that no airline would be successful if they threw away every [Boeing] 737 [aircraft] after its first flight, and so that's what he was going for, that kind of repeatable operations in spaceflight.

We talked, I came out to L.A. [Los Angeles], and I loved it. I love SpaceX. We had about 280 people I think, at the time when I came out. COTS [Commercial Orbital Transportation Services] was just awarded maybe three weeks prior, and I'd been talking to them right before that. I decided to take the plunge, move from New York [City, New York] to L.A., and I've loved it since. I was the first person in Mission Operations.

What was great about SpaceX—because everything's in-house, operations for the spacecraft grew up at the same time that the design did. We were able to influence the design when needed, and we could tailor our operations for what the design required. That allowed us to really fast track a lot of the effort to be able to go from contract award in [August] 2006 to our [International Space Station (ISS)] berthing mission in May of 2012.

After long mission ops [operations], we built the Dragon [capsule] capability up. I worked for Tim Buzza—awesome guy, I think he's employee [number] five—and he's given us more responsibilities. We now do launch operations as well. We're always charging forward to the next efficiency in spaceflight operations. That's my quick background.

HACKLER: Thank you. How was it different working at SpaceX, as opposed to some of the aerospace corporations, or being in the Navy or with JetBlue?

COULURIS: I was used to having a lot of responsibility in all my roles, but what really impressed me with SpaceX is that they trusted people with responsibility very low in the organizational structure. A lot of decisions didn't have to go all the way up to a director, to a vice president, to Elon. Elon had a very excellent hiring process, I think, where he went for top people in multiple industries, and he trusts them. You earn your trust, but then you trust them to make the right decisions.

That's what I'd say was one of the main reasons why we are able to move as quickly as we do. You can assemble small groups together, and you can make decisions at as low a level as possible. That really impressed me from the first few weeks I was here. There is a method for configuration control and that kind of thing, so that's the balance. I think that's what happens with large organizations. It's very important to have configuration control, and to make sure engineering change orders are properly vetted. Finding that balance—it starts to get very bloated very quickly I think.

HACKLER: How did your responsibilities evolve within SpaceX, and when did you first start working with the COTS office?

COULURIS: I actually started working with the COTS office pretty much right away when I was hired. I think part of it was they identified that SpaceX's proposal is more of an engineering proposal, and that it was light on the operations itself. I started working with them as soon as I

started taking them through what we wanted to do, conceptually speaking. I remember my first meeting with the Mission Operations Director [Paul S. Hill], it was great.

I tried to use the example, what SpaceX wants to be is like the FedEx [Corp., shipping service] of the space industry, where in essence you give us your packages and we'll deliver them there. You don't have to worry about the operations of the truck, you don't have to worry about those kind of things. It's just what are the interfaces we need, and how do we prove ourselves safe to go to a critically important asset like the International Space Station? From a human life aspect, as well as a $100 billion asset.

HACKLER: In going to the Space Station, NASA also levied a lot of requirements. How did you work with those, and how did you work with the ISS Program Office?

COULURIS: I'd say first off, the COTS office was absolutely a phenomenal idea, and I wish that would translate into more programs beyond NASA. A takeaway that you can have is perhaps the Air Force, commercial customers could take some examples. The COTS office worked hard to have a minimal set of requirements. First of all, what is NASA trying to accomplish? That's regular resupply of the ISS. Therefore, what are the requirements that allow that to safely occur?

They took those requirements even down a level where they said, "We're not levying requirements for mission success. We're only levying them for safety." What that means is we have to design to make sure we're always safe to ISS and to astronauts. As far as if we have to abort the mission and we can't fulfill it, well that's our responsibility. And then, in essence, we don't get paid. That helps set a minimum level of requirements that the COTS office really scrubbed.

The COTS office worked kind of like a liaison between us and getting NASA used to this concept of commercial space, and also getting us a better understanding of what NASA needs. We were at pretty far ends of the spectrum I think when we first started, and the COTS office gave a little bit of credibility when we would say to regular NASA, that had worked larger programs in the past, that SpaceX is taking responsibility for that and you don't have to worry about it.

On the other side of the coin, they helped explain to us this is truly important, and here are the reasons why, "This is why this requirement is important." They went beyond just safety requirements and so forth. They also went to the customers that eventually will be flying cargo, and made sure we had the minimum requirements. Not only did we build a safe spacecraft, but we built one that was functionally usable. I think the first meetings I had with Mike [Michael J.] Horkachuck [NASA COTS Project Executive], and then with Alan [J. Lindenmoyer, Commercial Crew and Cargo Program Manager], were great from the start. We had a really strong working relationship.

Another really good thing is that the teams were small. You knew who to contact, and who needed to be made aware of something when designs change, or a proposed change is coming down the road. Mike and Alan and Warren [P.] Ruemmele [Assistant Project Executive] as well were not only always there for that kind of communication, but they could then get the support that we needed on the NASA side spun up quickly. If, for example, we needed additional verification on a requirement, or we wanted engineering help—that small but talented COTS office really is what made now commercial crew a reality, because they were so successful.

HACKLER: Talk about the milestones that you had to prove. Were you also part of the verification process to prove to NASA that you had successfully completed them?

COULURIS: Yes. ISS integration is part of Mission Operations. A really cool thing about SpaceX is you are not pigeonholed. If you're in Mission Operations, you sit console and that's it; if you're on avionics, you design boxes and that's it. We float throughout. I work a little bit on the RF [Radio Frequency] system with the avionics folks, avionics people sit console in Mission Operations. It makes their roles as engineers better because they have operational experience. Just like what I was talking about being a pilot and an engineer. They've flown Dragon, so when they take back that experience to a design they make a more robust, more operationally responsible design.

I worked on every milestone that we had to deliver, as well as the verification process. That was, as I was saying, part of Mission Operations. The milestone-based, fixed-price contracts that we operated under, the Space Act Agreement, gave us the freedom that we could really design a robust system that would fulfill NASA's needs. Not only in the short amount of time we had, but for the small amount of federal dollars that we did it for. We're talking at least an order of magnitude, if not more, less expensive than any other attempts at this.

Part of that was there had to be a little bit of faith in American engineering, in the commercial sector, that NASA could provide us a set of requirements—[SSP (Space Station Program)] 50808 was a well-written document for that, and worked with us as to determining the verification plan. "How do we verify that we've fulfilled each one of these requirements?" Then, we went out and fulfilled them.

A good example—for the cargo layout inside the capsule, you could do a lot of computer modeling. You could do a lot of adjusting within a computer. You could put for example a UG [µg (microgravity)] model of a human for their reach, to get all the percentiles of anthropometric categories that you have to fulfill. What we did instead is we built an actual capsule that had the cargo racks in it, and then we had two people who worked at SpaceX—one that fit the 5 percent female anthropometric, and the other fit the 95 percent male—and we put them both in the capsule, and let them show that they could reach and do these things. We were even going to go to a casting office here in L.A. if we couldn't find them, but we were fortunate enough there.

Then things like lighting requirements—we could take a light meter to each label, and there were some labels where you know what, it wasn't light enough. Well there are multiple solutions. You could either A) add more light, which hits your power and it's difficult to mount. B) You could remove the label, which actually is not helping the crew, but at least now you're not below the lighting requirement. Or C) what we did, we got an astronaut, [K.] Megan McArthur. She went through all of this and said, "No, that's light enough. I can see it, the font is big enough, therefore I'm good to go." She said, "The Astronaut Office, we're good with this." That helped us take care of that verification.

Having the astronauts involved in the process also was critical. They were fantastic, because we gave them actual hardware that they could bounce around—open hatches, close lockers, play with our straps, for example—and give us pointers. We could rapidly turn around those fixes. A good example was the MPLM, the Multi-Purpose Logistics Module that NASA uses, has these straps that have a very specific harness mechanism, locking mechanism, and adjust. We went out and bought those same straps.

They're very expensive, space rated. We had a better design that actually came from NASCAR [National Association for Stock Car Auto Racing]—higher g [gravity] loads, easier to actuate, but this is our first interaction with the astronauts so we want to make sure they had something familiar. They were telling us they actually don't like those straps. We said, "Well, how about these?" And it turned out they loved the NASCAR straps.

Another example is the latches for the lockers. We tried to get the exact latches that are used on ISS from another aerospace vendor. Each locker requires two of these latches. They cost $1,500, and consist of about 20 to 25 parts. SpaceX, we weren't going to build that. One engineer was inspired—I think it was honestly in the men's room—where he saw the latch on a stall, and we were able to make a locking mechanism out of that. Costs $30 in parts, it's more reliable, and it's easier to replace if it ever goes bad. Again, the astronauts—not only did they love it, but they loved the story behind it because that shows the ingenuity.

They helped us with that, and it's that kind of stuff that helped us with verification. There are four methods of verification, and we like the test. We like the ability to get hands on to verify. I think that's where you get above and beyond the computer model, because sometimes people may be a little bit hesitant because they don't have hands-on [experience] to truly say, "This will work for me in orbit." It was Milestone 20, where we built out the cargo model in Dragon.

That was great even for the public, because we released a press statement that here the astronauts are in the first Dragon. It shows the public that they are getting a return for their money, there is real hardware out there. At the time there was this perception, "Who's SpaceX? What are they doing?" When you see real hardware, and you see real astronauts using that hardware, it goes a long way.

HACKLER: Yes, those are really neat stories. How did NASA react when you proposed those changes? What sort of negotiations did you have to go through for them to accept that?

COULURIS: Different changes required different levels of concern, and it really was very interesting that it almost depended on the department. I would say on that level, because we had such a great working relationship with MOD [Mission Operations Directorate] from the start, and the fact that we had a great relationship with the astronauts, and with the crew interface office, basically the engineers who help the astronauts determine this is, from a human factor standpoint, completely acceptable.

We involved them from the start, we called them when we had a different design. It was funny—it was from those groups that they told us, "Well, we definitely want to see that design, because we don't like what we currently have." The designs for both the straps and the latches evolved slightly from feedback from those groups.

I'd say that was really important to us, because NASA actually moved very quickly in responding. Sometimes there's a perception that it's a bureaucratic organization, but when you get those small groups together, and they feel like there's something tangible coming out from their efforts, they really worked hard, gave us great feedback. I'd say they were impressed as well with how quickly we could turn around prototypes, let them test it, and then get it on the spacecraft.

Other areas like GNC [Guidance, Navigation, and Control] we had to make a lot of modifications as the design evolved, as the approach evolved. We combined the two missions, the original C2 and C3 mission into the single mission [C2+ COTS demonstration mission].

Again, that just had to prove to our NASA counterparts that we could do that. That was an involved process, but ultimately successful.

HACKLER: We understand that the COTS office was sort of disruptive within the NASA culture because they were proposing this new way of doing business. Was there ever any conflict working with the ISS office with their more traditional set of requirements?

COULURIS: It's funny, I would've expected there to be more. There wasn't, and I'd say that's the good job not only the COTS office did, but we brought MOD into the fray right off the bat. What we were doing, should we change things, and getting them on board with our concept. I think they acted well as our representatives to the rest of NASA. I understand there are decades of experience, and that's why some of these different methods evolved, but the concept of a different way of doing business—I would look to other industries, and stress that NASA should deeply consider using Space Act Agreements and milestone-based contracts a lot more than they do.

Boeing, for example, when they built the Dreamliner 787 [aircraft], did not have a huge subsidy or a cost-plus contract. They got with their customers—in this case it was ANA [All Nippon Airways Company, Ltd.] and Japan Airlines [Company, Ltd.], but even on the 777 with United Airlines [Inc.]—got the requirements set, what United Airlines needs, designed to that, and had them throughout the design process, iterating.

That's where the milestones were really important. Both PDRs [Preliminary Design Reviews], CDRs [Critical Design Reviews], and then individual milestones throughout, which involved payment from NASA to SpaceX, were critical. Not only did they first set for NASA,

"This is where SpaceX is, and this is the progress they've made, and here are some areas that we feel they're deficient in and they need to work up to," but those also set milestones for SpaceX.

"Hey, we've got to get moving to hit PDR in June, to hit CDR in December." Schedule and scope creep can just continue if you don't have these milestones. The way they were spaced apart, it was appropriate. We didn't hit schedule on everything, but you look at the sum total of what we did, I'd say we exceeded most programs anyway, with an incredibly aggressive schedule.

That was the great thing between Elon and Gwynne [E. Shotwell, SpaceX President and COO (Chief Operating Officer)], setting tough schedule goals internally, though knowing technically what we're capable of. Not setting a goal of beyond Mars in three months, but setting appropriate goals for us to step forward. Gwynne's relationship with the COTS office, and with Kathy [Kathryn L.] Lueders [ISS Transportation Integration Office], Angela [T.] Hart [ISS Program Office], and even the Cargo Resupply Services [CRS] group really helped make the transition from COTS, which at the end of the day was only a demonstration mission, into CRS, which is an operational mission. First flight of the airliner versus now the New York to Miami flight, that kind of model.

One important point with SpaceX—we are very lucky with the iterative basis. We started off with Falcon 1 [rocket], learned a lot of lessons from Falcon 1 [one Merlin engine]. Falcon 1's design went right into Falcon 9 [nine Merlin engines] 1.0. The three anomalies we had on the first three Falcon 1 flights allowed us to learn to not only have successful flights four and five, but to ensure—knock on wood—that every Falcon 9 mission to date has been successful. It's directly because of what we learned from those anomalies on Falcon 1.

Falcon 9's heritage went into Dragon C1, the first Dragon vehicle we flew two orbits. Fantastic mission, that was a lot of fun. That experience then helped grow into Dragon C2 and the operational Dragons, which are now triple-string avionics, greater fault tolerance, meeting the safety requirements of NASA. Then all of those lessons we learned from Dragon C2 and that design architecture are now going into Falcon 9 1.1. Now the rocket itself will be triple string, it will be rated for human flight, that kind of thing. NASA's milestones have allowed us to follow our own progression internally, as well. That's what really worked out well.

HACKLER: How much do you feel that working with NASA has influenced how SpaceX does business?

COULURIS: I'd say it's been tremendous, and it's been very positive. We always have the resistance to bureaucratic oversight, and NASA knows that, so NASA is always very conscious of it when they look to provide oversight. When they need it, they tell a compelling story, and that's why we're able to accommodate. I'd say sometimes it was more than we felt needed. NASA in general, though, was willing to hear us out and work with us. Sometimes we felt, "Why is this needed," and then we were grateful for it.

It was a good relationship. The success that we had makes it easy to say that it was a good relationship, because it did work out, but it really was. I'd say even if we weren't as successful, that relationship would allow us to dust ourselves off, get up, and go again. I'd say the COTS office facilitated that. What I think is important for the future is to have that small COTS representative, and to have clearly-defined points of contact and system experts on the NASA side who communicate directly with the SpaceX side.

What you see a little bit now, because we've been very fortunate to be successful, more people are now getting involved on both sides. It's working out, you just have to be careful that eventually you don't get this huge organization that's almost as much effort to keep the machine oiled on the organizational side as it is to fly rockets.

HACKLER: Can you think of any particular examples of a change NASA suggested that at first you were resistant to, but then it ended up working out for the best?

COULURIS: There are a few out there. I can say some very operationally-specific changes that they recommended that were good. One that comes to mind, an actual change on the spacecraft itself, regarded something as simple as a strobe light position. SpaceX wanted to put it on the trunk, which is a throwaway portion of the vehicle currently. It wasn't as good for astronaut visibility, and they recommended moving the location of that strobe. When we looked at it, we could actually move it to the front of the capsule, which does reenter, does provide the crew better location of that light relative to the spacecraft, and allows us to now use that light for recovery. If for whatever reason we splash down off target, there at least is something actively flashing, so at nighttime you can see it. Also, it's not a hazard to maritime operations for others.

That's a small example. There are much deeper—for example, our flight software verification process. The amount of verification and testing that NASA required ensured that we were ready for rendezvous operations. If we were going to our own station, let's say, we would've definitely done testing and verification, but I think they allowed us to be ready for more contingency cases. That's what made C2 so successful.

HACKLER: How did you work with the astronauts to train them to grab the capsule when it arrived, and unload the cargo?

COULURIS: That's a great question. Now I'm working the crew side of Dragon, and training is always this evolving concept. They're the commercial aspect of the new model, whereas NASA is responsible for crew training regarding the ISS and grapple operations. We would provide a model of Dragon, and when it came to actual Dragon systems and Dragon familiarity, we hosted that here in Hawthorne for the C2 mission and CRS-1 mission, where the astronaut crews would come out and get familiar with Dragon. We'd take them through a training regimen that familiarized them with hatch operations, cargo operations, systems knowledge.

Don [Donald R.] Pettit and André Kuipers [ISS astronauts] for C2—they were awesome. I mean, they were unbelievably awesome. They came out here for training originally, along with other crews, but I remember them because we were thinking these could be our first crew members. Very excited about the training. They really got into it. CUCU operations, our COTS UHF [Ultra High Frequency] Communications Unit.

While they were on Station, Don was up till 2:00 a.m. his time practicing on the onboard trainer to grapple Dragon. I have to tell you, it felt like an eternity at the time, but now that I look at it, that's the fastest grapple operation I'd ever seen in any simulation, or any other vehicle getting grappled from free drift. It was really quite impressive. Maybe that's skewed a little bit, but that was my perception, is that it was incredibly short.

Because we had already worked together, not only with them, but they had such a great relationship with the CapCom [Capsule Communicator]—which in this case was Megan McArthur and the Flight Director, Holly [E.] Ridings. Then her groups, like on the I

[integration] side, Paul [M.] Brower, also Sarah and Jeff, and then on the VVO [Visiting Vehicle Office] side, Sean [K.] O'Rourke and Paul [S.] Lane—we got to the point where training—not only crew training, but operator training—we'd done so much that we could tell from the inflection in each others' voices, "Where are we," "What do we need to do," "This is important."

That was a thing, going back to being a pilot, that I wanted to instill into our crews. To watch it happen for real—and Holly knew it, she knew it would come to this, that we'd eventually get there. It was great. Even little things like Megan sending a friendly reminder right before they grappled us that we're only on one LIDAR [Light Detection and Ranging]. We lost one LIDAR, and had we lost the second one we'd abort.

She didn't quite say it, but Don's worked with her as much as he has that, "Hey, just a reminder that you got to get this fast." That was great, and that's the thing about train like you fly, and then fly like you train. I didn't come up with that of course, but it's true, and it works. It allows you to deal with the unexpected. That's what everyone on the group did, from the astronauts on the ISS, to the Mission Operations director of crew, and to our group here at SpaceX.

HACKLER: What a great feeling when all that work culminated in a successful mission.

COULURIS: Yes, it definitely was. Definitely was a relief too.

HACKLER: Did NASA or any of the other federal agencies you may have worked with, like the FAA [Federal Aviation Administration], ever express specific safety concerns that you had to address?

COULURIS: Yes. First of all, SSP 50808—the requirements document of what visiting vehicles have to fulfill to go to ISS is based on safety. Right off the bat we have a list of, "We have to do this for safety." Sometimes we could horse trade, "Why is that truly for safety? Can we fulfill this requirement by doing something different?" They would work back and forth, because the requirements were not so in the weeds that they tied your hands.

A good example with the FAA from a safety point of view—certain trajectories we fly over the United States, and so we had some additional requirements during that portion of flight while we're over the United States. The FAA was fantastic as well, they really were. Not being in the industry, you hear these horror stories of government organizations not being able to move fast. Again, the FAA organization was small and a sharp group of people. We were able to show them, "Will this fulfill your concern?" We even had them sitting with us during simulations, and they're like "Yes, that's great. Okay, you guys are certified."

Not safety-related necessarily, but an operational requirement the FAA had on certain other trajectories—we discovered that Dragon lands in a very specific spot in the ocean. As we gain more experience we'll be able to get this down, but we have to cover a wide swath of ocean in case we have off-nominal reentries. That kind of landing ellipse that we have to cover takes out most, if not all, of the transpacific routes coming out of Los Angeles.

The FAA asked us, "Hey, look. We can't shut down all the airlines going to Australia and New Zealand for an hour or for two hours. Can we adjust where you land? Can we adjust the times?" We worked back and forth with them to keep the air traffic control system functioning, and accommodate commercial spaceflight. Having knowledgeable people, and trying to have the same people doing the job—until they need a replacement of course, having an

overlap period where they can be trained—has been what allowed us to get from C1 in December 2010 to this last mission in October [2012].

HACKLER: You said you started at SpaceX right after the first COTS awards. Were you involved in any of the subsequent proposals? SpaceX competed in the COTS Round 2 selection after RpK [Rocketplane Kistler] was terminated, and then the CCDev [Commercial Crew Development] proposal.

COULURIS: Yes, I was in with all of them, especially because we have an important part of that in mission operations. Commercial spaceflight is different than traditional contractors in the past, where they would supply the vehicle and vehicle knowledge. At the end of the day, NASA was responsible for flying it, NASA is responsible for training. SpaceX is responsible for those things. It's kind of like an all-inclusive package that we'd have to put together for these proposals, every COTS proposal after the initial award we worked on, as well as CCDev and then CCiCap [Commercial Crew integrated Capability].

Two different programs, and they both have their advantages. The CCiCap group is again a really good group. They're open minded to what we're doing. The reason I stress a lot the Space Act Agreement and the milestone-based, fixed-price contract as being important is because we proved it worked. I'm not saying necessarily that another method can't work, and others have proved that it can.

I can tell you that we can keep cost down and keep operational reliability up if we follow the COTS model, which so far CCiCap is, but there may be an initiative to go to a cost-plus

[contract]. I'm in operations and engineering, so I can't speak to that other than I know what the contract requirements allowed us to operate under, and I'm not sure about differences.

HACKLER: How did your working relationship with NASA evolve over the time that you've been working with them?

COULURIS: I'd say the biggest thing was trust on both sides, and I'd say that face-to-face contact is critically important. No matter how much you can get done with WebExes [online meetings], and at a distance of every four to six weeks, if we hadn't met face-to-face for those first two years, people would start branching off again into different thoughts. NASA's thinking, "Okay, what's SpaceX doing now?" and SpaceX thinking, "Why is NASA asking this of us?" Then you get everyone back together again, you get it fleshed out.

You work long enough with a group of people, they know how you operate and they can help you before it even gets to your level. A lot of that is putting in long hours, eating together, getting to know one another outside the work environment as well. You could be putting in a 12-hour shift, and you need to have a good knowledge of the people you're working with. I'd say again, that was important. That's what made it so successful for us, and all the things we had to deal with on C2. CRS-1 is a good example of us being able to take the lessons learned from C2, and in five months apply most of them that we could apply on the schedule allowed, and have a completely successful mission.

There's a funny poster that somebody had on their wall. We had the Engine 1 anomaly on ascent on Falcon 9 [on CRS-1], and their poster was, "Lost an engine and still got to Space Station 30 minutes early." The reason we were able to get to Station 30 minute early—it wasn't

only the hard work of the SpaceX side, but the trust in NASA that they knew we scar out a lot of time as margin, because we don't know what to predict. Then when it's truly at that time, and you know everything's good, you can go, go, go. You don't have to sit there and wait for no reason, other than burning propellant and waiting for a malfunction. That's what made that mission so operationally successful. I think many don't realize that mission is proving that kind of airliner operations that we're going for.

That's what the COTS office has allowed. I equate it in the past to airmail contracts—you've probably heard this. The government helped the aviation industry, which certainly would never be profitable in the '20s, even in the '30s. Subsidizing and helping development, they built the industry that exists today. Now people can travel around the globe in a matter of hours, and it allows people to travel for far less cost. That's what we're looking to do. That's why we're serious about going to Mars. We want NASA to be the pathfinder, and we will be there with them in continuing on, beyond.

HACKLER: What new markets or opportunities have you seen for SpaceX as a result of this partnership with NASA?

COULURIS: The great thing about Dragon is that at the end of the day, Dragon is still SpaceX's. We've come up with this alternative called DragonLab. It's basically a free flyer, and we make some modifications. For example, we don't need the berthing adapter that goes to Space Station, we don't need some of the proximity sensors we use for Station, but we do need things like longer-life solar arrays, perhaps CMGs [Control Moment Gyroscopes]. Basically, the ability to fly as a free flyer for about two years in orbit.

We'll take university experiments, we'll take government experiments, whatever people want. Put them together, fly a Dragon on orbit as a free flyer for that amount of time, and then have the ability to bring their cargo back to them. That's a direct application of the COTS program with Dragon. This vehicle is very spacious, has great power that it can give to other payloads, so that's an application.

Without the COTS office, without government help, Falcon 9 would have taken longer to develop. From Falcon 9 1.0, we've been able to develop 1.1, which will hopefully fly later this year, with vastly improved capabilities. We'll have the ability to put three stages of Falcon 9 together and make Falcon Heavy, so now launch the most capable rocket in the current inventory from the United States. At prices that even the Chinese and the Russians have said they can't compete with, and here we are building in California. It's American ingenuity, and it's something to be proud of on the NASA side, that they helped us develop this.

Then Grasshopper—we're going to evolve Falcon 1.1 into a landing, reusable rocket. You can see it on YouTube, that's going to be the future. That's that reusable flight, and it all started with the COTS program.

HACKLER: Thank you. At this point, I'd like to ask if Rebecca Wright has any questions.

WRIGHT: Just a couple. So much has worked out well, but what do you feel like has been the biggest challenge?

COULURIS: First, there are some good things about SpaceX that I absolutely love. We all work long hours, but because we love what we're doing—we truly do and truly believe in it—you

don't really notice that. Like you'd probably know, especially in your careers, you love reading about the history of spaceflight, right? You probably go home and read about it. Well, that's what we do. It's great when you're in a job that you love.

I'd say some of the challenging items that I see—we are a little bit of a victim of our own success. Now others want to get involved, and that's not a bad thing, but they're having difficulty letting go of their legacy requirements. A great example of this is in the avionics world. Aerospace avionics have a very rigid set of requirements they have to fulfill, just because of the decades of experience we have. But there's a lot out there in the consumer world that's actually overtaken them. There are other ways to satisfy the original requirement, why aerospace-grade avionics are the way they are.

They definitely fulfill a very needed niche, but that's getting smaller and smaller. Instead of, for example, designing a box that can take every radiation hit you think possible, can take vibe up to whatever, we look at commercial grades and say, "We can take care of vibe, we can't take care of all the radiation hits. Can we put three of these boxes together, and have them vote and reset when one of them takes a hit?" By the way, that one aerospace box from 20 years ago costs $3 million. That's the kind of thing that's convincing people.

I'd say on the NASA side, I am so impressed with how they've come around with it. The [NASA Office of] Safety and Mission Assurance—we just met in [Washington] DC. They want to learn what are we doing for our part selection, and how can they apply it back to NASA? That's great, because if they're practicing it, then they understand it when we do it. It's time now for other government agencies to understand that.

I think the Air Force is coming along as well, but the Air Force is a major customer and we're very new to working with them. We had these discussion with the COTS office, with

NASA, five, six years ago when we proposed this, and they were a little hesitant. Now they're onboard with it. Now we just have to relive that again. We also have to relive that again a little bit with the crew, with the CCiCap, only because it's being run out of a different Center [NASA Kennedy Space Center, Florida].

Again, all these organizations are very open minded. We're especially lucky now that we have some spaceflight experience and heritage to build off of and show them, whereas the COTS office had to trust in analysis. They had to trust in analysis and kind of go with it. A great example of how NASA helped us is we would have, just through analysis, said for example, "We can take this many radiation hits." Mike Horkachuck and Alan Lindenmoyer insisted we use part of some plus-up money that was awarded [COTS fiscal year 2011 budget augmentation] for radiation testing.

We were able to come up with a very innovative way of exposing our avionics to radiation hits to see, "Probability says we will take a hit x times for 1 out of 180 days," something like that. Then from the ops side, I could see those numbers and say, "Okay, that's all right, and I'm triple string. GPS [global positioning system], we can expect one hit maybe every day? All right, that one I need to concentrate on and have an operational workaround ready to go." And sure enough, when it happened we were ready to go.

The first time it happened during a simulation, we worked with the Mission Operations director in the program group. It took maybe 36 hours to resolve it. That experience, from simulation, training like we fly—for CRS-1 we took a hit, we were reset and done within 20 minutes. First of all, COTS office funding the ability for us to run this test—they also funded T-VAC, thermal vacuum, which only proved that Dragon was able to fly in space.

Again, something we wouldn't have normally paid to do because it was so expensive, they helped us with. Take actual results, apply it to operations, train to that, so that way when it happens in the real world you can just keep going. That was a great example of their help.

WRIGHT: Speaking of Mission Operations, it's a directorate that's been entrenched in mission flight rules, and documents that are based on simulations. Did you fall into building that same type of culture, or were you able to optimize a more efficient way to share that knowledge and have that document as well?

COULURIS: That's a great question. I would say NASA would say we provide the absolute minimum amount of documents. They may want to see a little more, and on my side I'd say we provide still a little too much in joint documentation. But then again, sometimes when you say, "Why do I need to have a document for this?," you sim [simulate] it out and say, "Okay, it's good to have it written down."

All our documentation is actually electronic. Not only is it electronic, but it's interactive. We keep documentation to a minimum, we really do. Really all we have is our procedures and our flight rules. NASA required some more documentation. Some of it was helpful to us, some of it we're able to push back on, and others MOD would say, "Look, we really need it. This is why," and we'd say, "Okay, we'll do it."

From the NASA side, I hope Holly would say they learned as well, that perhaps they don't need as much documentation in certain areas. The biggest problem you have when you get too much documentation is that starts to conflict with itself as you're trying to upkeep all these docs. I would say in MOD—Holly, Paul, Sean, and Pauline as well—pushed back on the

document requirements before they even got to SpaceX. They had already taken care of some of this.

If you look at [Space] Shuttle, for example—it was 30 years of flight history, it didn't start off that way—but a ton of documentation. We looked at, "How can we get around some of this documentation? Can we automate some of this where you don't even need a document to describe it?" You, in essence, press a button and it gets executed, and then you train to that.

WRIGHT: I just have one more, and it has to do with International Partners. How did SpaceX work with them as well, because they're all on the International Space Station. Did you have to provide information so that the partners were satisfied, or did NASA take care of part of that?

COULURIS: We did. NASA was a fantastic go between, between us and the International Partners. It was a very delicate situation. First, because we're a commercial provider it's a little bit different than others working on ISS. Second, there are ITAR [International Traffic in Arms Regulations] restrictions that NASA has to deal with, as well as SpaceX. There's also competitive concerns that we have.

We're in this as a business, we're providing a service. If an International Partner that also has a visiting vehicle sees how we're doing something, it could influence their design. They could even say, "Hey NASA, you're letting them do that, what's going on?" NASA itself, through the IMMT, the ISS Mission Management Team, really provided a strong go between, between us and the International Partners [IPs].

We would brief the IPs every so often, both during the mission and even before the mission, on our vehicle. The support we got from the Mission Ops Director and from all of

NASA made that a lot less painful, I think, than we were expecting it to be. They really did. I'd say the Europeans use the Russians in a similar model for ATV [Automated Transfer Vehicle], where we had to prove Dragon was safe to NASA, and then NASA would vouch for us if you're with the IPs, as per your agreements.

WRIGHT: Again, emphasizing the trust factor.

COULURIS: Exactly, yes. We had to earn that trust with NASA. In fact, that's a great point. Here NASA would be beating us up making sure they got all this stuff, and then when you hear them speak to the IPs, they're representing SpaceX. All of a sudden you're like, "They do get it! What do you know?" But the purpose was well served. Because they did that, they were ready to present and represent us well.

WRIGHT: Thanks.

HACKLER: Thank you, that was a very interesting perspective from the SpaceX side.

WRIGHT: Is there anything else you want to offer, working in this experience? Especially since you've had industry, and military, and now commercial experience. Do you have any more thoughts of any lessons, or anything you want to share with us before we close?

COULURIS: It's really cool. I really look forward to reading this 20, 30 years from now, and I truly feel like this is the start of something historical. SpaceX is about more people getting mass

and humans to orbit and beyond. It's not just about SpaceX going. We want to see that competition, because that keeps us lean and keeps us moving forward, and I'm looking forward to launching humans on Dragon. I really hope all the good we learned from COTS does translate, that it's not thought of as a one off.

We were fortunate when COTS was started, because [the NASA] Constellation [Program] was still being worked so there was a lot of focus on Constellation [Ares rocket and Orion Crew Exploration Vehicle]. COTS was able to establish itself, get nurtured into a real entity. So when Constellation did go away [cancelled February 2010], it was able to stand on its own, and it was able to represent itself well. I'd really like that the advantages of that program aren't forgotten.

NASA, I think, will be bigger because of commercial space than anyone gives it credit for. People who aren't as informed think NASA's going away, but it's just the opposite. We'll be orbiting Jupiter someday, and NASA will be the first to be there, and we'll be supporting.

WRIGHT: That's a nice thought. Well, thank you.

HACKLER: Thank you.

COULURIS: Thank you, I appreciate it.

[End of interview]