March 26, 2018.

>>Dr. Garrison: I want to introduce our speaker today. This is Tim Crane. He's an aerospace engineer and Vice President of research and development at intuitive machines. Proud alumni of Texas A&M university.

>>Dr. Crane: It's the other university, the orange one.

>>Dr. Garrison: So he has degrees in aerospace engineering. After graduation he worked at NASA Johnson Space Center where he worked on (inaudible) involved (indiscernible). This involves navigation systems, proposed human robotics, spacecrafts entry and landing (indiscernible) proximity missions. There's design used in 2009 (indiscernible) science laboratory. At AR CAM flying inspection vehicle, Hubble robotic servicing vehicle and provide (indiscernible) for the Orion exploration vehicle. In addition to that you may know he worked as an adjunct here in the UH physics program teaching astrodynamics course. So some people who have been around may remember that. So I guess five years ago he helped founded a company intuitive machines,

which is doing some really fascinating stuff. He will tell you about it. And again last week I want to remind you this is both the company internship opportunity so this is somebody who you may want to ask a lot of questions to.

>>Dr. Crane: Thanks, David. We will talk about it intuitive machines as we get into this. Very excited to be here. Seminars are my favorite to talk to; more or less you want to be here and I get to talk about whatever I want. So that's a good combination. As we go through I have time for Q and A at the end if you want to debate or go deeper into something. If something is not clear don't hesitate to raise your hand and I'll clarify. I'll provide an overview of the URV. We will talk about intuitive machines. Talk about the motivation that URT used to be the TRV. Terrestrial return vehicle. NASA DNA that I like my three letter acronyms and I can't escape them. TRV became URV. Technology People with GAD and design overview concept of operations bell talk about and what we are trying to achieve and where that program is and we will have time for Q and A. Intuitive machines is Dr. Garrison

said we founded in 2013. We felt like a lot of the engineering processes and techniques we have in NASA could also be gainfully employed in the industry so we said we are in Houston let's do aerospace and reach out with some of the same techniques and do energy and medicine. I'm happy to report that we have done very well in energy. Medical sector is harder to crack. Their business model is challenging. They want you to stick with an invention for years and years and it's a different model than a young start up who isn't focused on a single device which is what they like to do. We like to go over challenging projects. Same that drew us: To Nasa those momental challenges we seek out in our commercial endeavor. 75 percent of the work is aerospace, half government and half commercial and 25 oil and gas. We specialize in autonomous systems. The core of our company is guidance navigation and control. Taking sensor information, making sense of sensor information, calculating what changes your vehicle or robotic or RV or anything the number for needs to change its course to take action. So we take that smarts that's the part of intuitive machines we replay into other industries. So, if you look at our website and search the Internet you might come across mention of the TRV. That was the original design idea. The original product we were trying to put forward to develop the priority small payload return capsule. Right now the International Space Station services the big boats. A dragon or Cygnus coming upper three to six months. If you are doing an experiment or send something back you have to wait for a dragon in particular to come up and you reload it because it does re-order. When the dragon comes down it plunks into the ocean and everybody does the navy SEAL thing and unpacks it and ships it. On the logistics of getting payloads back from the space station are challenging. You can imagine the compression of resources and time once that cargo return vehicle becomes a space station to get everything done that has to be done and back onto the ride home. One idea was what if we had an ability to return payloads from space station independent of the big boats coming back. And now that decouples your experiment from the scheduled constraints or delays even launch delays of when the dragon gets between (indiscernible) might be able to bring some of your cargo back. The Cygnus doesn't bring cargo back that just burns on re-entry. So you have a limited number of options. We wrote a proposal to casis(ph) which is the office for advancement of science and space chartered with basically utilization of space stations and national lab, we got a grant to be the preliminary design. We found a customer interested in funding it and able to take that design all the way through pre CDR, critical design review. CDR is an airspace industry NASA term. You have done some analysis on the design and basically ready to build it. So we are actually a little further than ready to build it in some areas and just right there including some drop tests. I'll show you some pictures in a little bit. So we hit a pause we were sending TRVs and begun looking at what we can do other than coming back from the International Space Station, turns out that the technology we are using for the TRV could be applied in a broader sense and that's why we get to the universal return vehicle. Whether we can return from the universe is a matter of scale. The technology came from NASA in particular a lot of engineers Johnson Space Center had been studying a lift to drag ellipsoid entry, entry bodied design for over 20 years. If you seen Apollo, the Orion spacecraft have that standard capsule design blunt air shell. Those are called a low lift to drag. Low over D design. Might get a lift to drag ratio of .2. They can banking and turn but limited to when they hit the atmosphere. The ellipsoid is .3 and .4 on the ratio to lift and drag which means two things. One it means you have a lot more cross range. The reentry problem is like a severe coming down a slope. Not straight down but S turns to bleed off energy as they come in. Also modulate those S turns to correct for dispersions when you hit the atmosphere to land where you want to land. Now the width of those S turns from a standard reentry problem directly relates to the lift to drag ratio. The higher you lift to drag ratio the broader those S turns can be and cross range is the term we use in aerospace engineering. If you go above this ellipsoid design and to lifting both Sierra Nevada -- dream chaser has more than .3, .4 something in that area. I'm getting a head nod. There's a variety of designs. The reason NASA is looking at it they envision a 10-meter diameter that looks lift to drag entry vehicle for Mars for putting down metric tons of human cargo. Human habitats, nuclear reactors, hydroponic base. The whole thing you need to set up an outpost on Mars. One of the trades they use this design. This is an excerpt from a paper by Chris Cermillie(ph) about the Cobra Mars reentry vehicle which shows a shape similar to what we are using in the URV for Mars entry. So we formed a partnership with NASA in 2015 with a space agreement that said if you will help us with the design and analysis of the shape we will do all the propulsion and operations, and give them the reentry data to validate the analysis they are doing for Mars and other designations. The reason we are calling it a universal reentry vehicle, is this shape will scale so it can be used for this International Space Station cargo return. You can send it to the moon and do a lunar sample return with it. Or you can enter at Mars. Actually you can do everything coming back from Mars all at the same shape. I think that's it. Middle lift to drag ratio also means you can pull only about 3Gs. So instead OF slamming to the atmosphere at six, SEVEN, EIGHT gravitational accelerations, this provides a smoother ride. Biological like (indiscernible) sample from International Space Station. So that's the technology backgrounds. So we first look at this for ISS. Saying what can we do. The idea was that we would use the Japanese modules air locks called the GM air lock which is built with a mechanism called the Cyclopes tray or table. Basically what happens is you can use the Cyclopes to eject payloads into space from the (indiscernible). You mark what you want to eject it has a spring mechanism you close the door and the outer hatch opens reach into the Japanese arm hold it in the direction you want and release the spring mechanism. So the first design concept we had was let's scale this down and send it up as a payload on one of the cargo missions to space station store it and when the time is right load it and pick it up. It's fully capable of maneuvering in space and landing on a soft target. We will show you examples of that. It could also be a free flier. So no reason why it can't fly on it's own but the initial idea was to put it in the space station. How many people work or have aspirations in working in space? Couple. About a third. Half, maybe. Here's an example. Taking a direct flight from Los Angeles to New York and you have an aunt in St. Louis and you are supposed to return her baggage to her and you were not able to do it. Imagine a bag as you flew over St. Louis the airplane would kick out and it would automatically fly to your aunt in St. Louis. That's what the TRV is. If your aunt was a scientist you would stay in orbit. So there's your terrestrial example. We tried to sell this to a shipping company originally for advertising purposes. You can imagine the parachute coming out and you have that shipping company, logo and advertising on it. It doesn't quite work out. This liability issue brings bringing it back from orbit. So the idea is you would first load up the TRV or the URV, at the processing facility. The guys get in and make sure it's ready to get loaded. It goes up on either falcon or an Aires rocket so it's Cygnus or a dragon mission. Once it's up on ISS it gets stowed with other baggage. Something THAT lookS like a golf bag, the vehicle is about this big. It goes up and it will bestowed and wait for the scientist on board to perform the experiment. That could take a view shames. It could be the completely experiment or if you had a big enough experiment, experiment that required calibration, you can envision doing a small sample of that experiment and sends those results home to get them calibrated and updating, the protocols you are going to run on board so you don't run the whole series without confirming the protocols. So the astronauts run the experiment and this is, this is the (indiscernible), the Cyclopes tray fits in here, the arm comes out and ejects it. It's completely autonomous. In fact the original design didn't even have a radio. Completely autonomous. So the vehicle is stowed away on the space station. That's called IVA. Internal vehicular activity. This is important because that means that our propulsion system has to be compatible with humans in an enclosed area which is an inert blow down propulsion system. Like taking a balloon -- a lot like taking a balloon and not tying it off and releasing it and the pressure blows out. We have to make sure what blows out of the engine is nonflammable and nontoxic. In the event the whole thing released, we can't put the crew in jeopardy. So the design for the universal return vehicle which never has to go in the space station went to higher orbit or to the moon. We can use a different propulsion systems that use a combustible type of design. It wakes up, sees the sky, looks at the stars and adjusts for altitude and orientation GPS. And we have (indiscernible) most advanced FNpeg, fully numeric predictive entry guidance. FNPEG. With my engineers we call it F'g peg. So actually we will complete all the maneuvers and banking angles until we get to a parachute. It deploys. In the end it lands on a surface area smaller than this room, about a 15-meter land footprint, six hours from the time you close the air lock. So same day delivery. You can prove the experiment. Put it in the air, lock, kick it out, and that day you have it back on earth. Let me run through a quick video. This is a general lock you can see the Japanese flag there. This is the external experiment area. That air lock is where the Japanese arm pulls it out and the bottom is covered -- there's the TRV. I'll point at it. Let's look at -- this video is actually an animation run with the actual software with a high simulation. We have trick which runs a package called geo. It's aerodynamic. We modeled the sensors and took the flight software for the TRV and dropped it in a simulation. You see an animation driven by the results with the actual flight software executed a complete mission ejected from the ISS. So when we leave the Cyclopes tens, pull the timer, power source, basically, the vehicle runs on double A batteries, and it powers up and it begins a countdown. The reason it does that is we will have enough change in velocity, thrust authority, or Delta V, as we call it in aerospace world, to leave the orbit and hit the atmosphere, which means we have enough Delta V to point in the wrong direction we can intercept with the International Space Station. So we have to get a sufficient separation so that all the systems are optimal. We are able to orient and do a separation maneuver first and do a (indiscernible) maneuver. But if we don't make that, if the systems are not optimal and can't execute the -- we go away. Right there is a little spec that's the International Space Station. There's a red line coming down and forward. This is what is called a rotating reference frame, a local V, vertical and horizontal. Your frame of reference is stuck on the space station and moving with it as it goes around the earth. Now you have the spirogyra motion plots that rendezvous analyst are used to looking at. We come back up and swoop and come up. And if nothing happened different, that goes on and on until differential drag causes it to separate from the International Space Station. Each one of these scallops is an orbital revolution. So if you go back to your fundamentals of kinetic and potential energy, we have come down and come back up. So the orbit of the TRV or URV in this case is slightly more elliptical than the orbit of the space station, because it has that push so it's falling down and comes back up later. The and that will repeat except for once we are out here we do a maneuver. That wasn't the maneuver. There it is. See how that it is formed in the orbit. If we didn't do that separation maneuver this bow tie pattern would repeat indefinitely. Okay. Once it's sufficiently far from the ISS we do the actual (indiscernible) maneuver. This is not realtime of course. A couple of different shots. This is the same view on the bottom left. You have a top down view on the top right and then the top left and bottom right is both different perspectives centered on the vehicle. So you might be able to make out the thruster (indiscernible). There's no moving surfaces on this vehicle. So there's no rudder or flaps or elevators. It's completely steered by jets. The vehicle itself is statistically stable and trims out at a certainly angle we use the jets to steer is like a surfer. So begin to enter the atmosphere and S turns one way, and coming around and back, get to 25-mile altitude and we will deploy a supersonic parachute. Those of you in California extra, that's Vandenberg Air Force Base, a nice space to land. It jets out into the ocean so we come in a reentry path, if we run short we splash in the owner ocean. On the first shoot this point the vehicle itself is inert; it's not under control. Aerodynamics stability and the parafoil comes out. It's an adaptation of military technology where it drops these big pallets and has a GPS system of its own sphere able and that's what brings it into an area of this size. So to give you an example of what that looks like. One of the things we were worried about with the URV shape was it's aerodynamic, .4, .3 lift to drag ratio means it has flying properties. So we were talking to the suppliers of thigh parafoiled systems. They had systems before which were not aerodynamic. So the military put a pallet and wrapped it up as a brick that falls underneath the parafoil. For this application, the parafoil folks we were working with were concerned for this parafoil system, so we did a series of drop tests out in the desert since 2015. The idea is we are going to go up in the series of altitudes under this helicopter and drop the vehicle and test the release mechanism on the back of the vehicle, bell test the winching on the motors to bring in the parafoil, and test for aerodynamics stability. So the drug(ph) chute helps stabilize the vehicle and the door will release, there goes the door. We did a total of four tests in this sequence. Three were great. One the door didn't release. But we built these for test affordably. So this is not built to strike aerospace tolerances and multi-million test articles. These were built to be tested and destroyed as part of that test. So we learned a lot about the door mechanism interaction under load with that drug shoot that would potentially help us save a vehicle later on. And it's always fun to go out in the field and do rockettee stuff. So back to this guy. A little detail on the system. This is our operational timeline. What you see everybody laid in this timeline, the circular bubbles. Those are the software flight modes. So later on I'll show you a software schematic. These circles relate back to the software modes of the vehicle goes through sequences autonomous for the reentry. So we have a deploy window, all the mechanics you can't kick this out on the wrong side of the planet you have to be lined up or you will fly over Vandenberg and kick the vehicle out. Another deploy window we release and exit the keep out sphere. That's the first distance. The space station has a series of defined boundaries. They have a keep out sphere and approach ellipsoid. These are marks that you restrict motion of participating vehicles within these different keep out zones. So we have that keep out sphere. If the Cyclopes fails that is what this represents. We have gone from idle to a warm initialization, turn the navigation system on, and it is tracking as far as -- and GPS at this time -- just observing where it is. Once the timer reaches a certain set point, prop inhibits propulsion was inhibited this whole time to prevent inadvertent firing. The ISS application means we have applied power to the valves. No power technologic system involved. Point the vehicle, so basically we get a pre-entry configuration. We maneuver to point the vehicle in the opposite direction of its velocity vector to execute the maneuvers and separation. Any time you see a scientific movie and shuttle and space spacecraft thrust toward the earth it's completely wrong. It's always the other way. You accelerate away to come back. So we do the burn. First maneuver the one we separated from space station lift is a meter per second. That first swoop down and away. And then the big burn the one we do later for reentry is 170 meters per second. This is important because what we get when we get kicked out in space station is a third of a meter per second. So even our small maneuvers more Delta V than we are imparted. We did a lot of safety reviews with the ISS to make sure we had the right protocols in place that we would not execute this maneuver until we were well away from space station and had confirmed all the systems on board operated (indiscernible). That gets back to the risks because (indiscernible) is a human vehicle the way we protect the human risks if we didn't pass all the checks for on board operation. We just lose the payload. So that was the tradeoff we had to make for safety. Another diagram, the keep out sphere, the little red circle is the approach ellipsoid. This reference frame is down. This is the velocity direction of the space station, moving around the earth in this direction. We swoop. We swoop. Get a separation and there we go. Because the vehicle is on a timer an analysis we had to do is what happens if we don't get the full push. So we look at the worse case, this green line where we have barely any separation at all, and some minimal value. Well, we proved even that was less desirable. It could safely execute the maneuver. The approach we were talking about before, this is the California coast. Baha and this jet of land is Vandenberg. As you come in from the space station, 51 inclination, we have a nice spot if we go short. No habitated areas. If we go long, theoretically we can hit baha, but the deal of it conditions are if you went long we won't go that far. So we did an analysis. The FAA required us to do the analysis if the probability of failure were 100 percent. So we looked at every second from the time we separated down to the atmosphere what would happen if the vehicle totally stopped responding from thereon and we convinced ourselves we had an acceptable air footprint. In fact, operationally we target an entry point that short of the (indiscernible) point, so if the system goes offline we go into the drink. And then the control guidance system kicks on, recognizes it doesn't have the range to meet the final target. Some of those S turns does a lift up to lost and end point and hit the end point. So this is an operational trick we did. This is some of our nominal analysis. This is a dispersion same simulation we used to create the animation. Has all the aerodynamics. We ran our Monte-Carlo analysis. Thousands of entry cases to evaluate the probability of our dispersions. So this red is the first parachute and (indiscernible) this 5-kilometer -- we would be able to fly down and hit that 5-kilometer target. We are inert under that, so we are flying a parachute. We got to a more uncertainty then the parafoil comes out. And when that drops it takes that uncertainty back out because we are in control again. So the ellipse of uncertainty comes down and comes down, and because we are divided the parachute comes out and expands again. And the parafoil comes out and drives us down to the 15-meter type landing accuracy the size of this room. We did sonic boom analysis. Turns out this is something you have to do for the FAA for reentry vehicles. We can land at Vandenberg because the sonic boom would be too much for areas around Houston. To give you an example, this is called a MO3 bag. It looks like a box or yeti cooler. This is a standard stow bag. The design we had for space station is it will fit in that standard cargo. So when the drag inCygnus arrives at ISS and taking the cargo through the hatch, this is another white bag they are stowing away in the storage space on ISS. And it sits there until the time the crew comes around to doing whatever experiments you might be doing, which is a point of interest. What kind of experiments would you be doing? We can return up to 20 kilograms in 30 meters back to the earth surface. So micro gravity crystal (indiscernible) rodent enclosures, (indiscernible) cultures, busted parts. If something broke and you need a forensic, why did that break and you have that equipment, those are the things we would bring back. So that's the shape because this green area is the published volume of the Cyclopes ejection mechanism. We couldn't make it bigger because it won't fit inside the safe operating volume. The last thing you want is wedge locked on a multi-billion dollars orbital facility. The top of the vehicle here, this little purple contraption is what locks into the Cyclopes with its spring loading mechanism. It is a complete vehicle even though it doesn't fly up like the space shuttle. All the subsystems you would expect. We have structures. We came up with a design which is an all carbon composite frame with no fasteners. It has a zipper type design and pieces come together. And we want to carbon ride and it locks it into place. Takes about 15Gs. Entry is for 3 Gs. Thermal protection, and we will be using shuttle tile material. There's a surplus of that. We are working with NASA to use that. Payloads. GNAC control systems. Measuring units which measures change in altitude and acceleration. Really change of velocity acceleration. GPS. There's a new generation of star trackers. The way you determine your altitude and orbit, if you take a picture of a field of stars there's a (indiscernible). You can do triangle math and identify as long as you can see them five stars. By the time you identify five stars in a 4,000 star catalog, the odds are you have a misidentified what those five are. There's something like one in 15 trillion. So it's a great algorithm for these five stars once you know them. That's what your altitude goes to the (indiscernible) exploded view, because the propulsion system was a blowdown system we use (indiscernible) tanks and they take up some volume of the vehicle. Its original design had smaller tanks than these. What happens in a thermodynamic system when you release the pressure on a pressurized volume? Anybody? Starts to cool. So if you took an aerosol can and -- any scuba divers? The tanks get frosty. If you go back and look at the equations, one of the problems we ran into, we blew this down to the 107-meter per second engine burn and the propellant turned to liquid. It cooled to the point we got liquid. It's no good for gas. So we had to expand the volume slightly so the proportional effect of that blow down didn't liquefy the propellant.

>>Audience Member: (inaudible).

>>Dr. Crane: We have to have limits. But we took a simple analysis first and the point mass of the total CG allocation and moved it from the center of the payload to the outer (indiscernible) line, and that was within acceptable control tolerances. So that was good. Speaking of that, this is the control payload area here. You can see access port there. This is the hatch covering the parafoil. The way we design the primary heat shield is separable. We didn't design it for reviews but it's possible we can pull it apart and reuse the top half. Our entry conditions are such that the shuttle tile will deform. So better hotter than the shuttle is on reentry

but still looking at it on design wise. I had to pull all will numbers off this to make sure it was presentable. A lot of the CG analysis trim line considerations we did 50 degrees depending on Mac number. That's what these lines represent. We had to be aware of where our CG was with respect to that ejection mechanism out of alignment and you can get a torque and come back and impact the Cyclopes mechanism.

>>Audience Member: (inaudible).

>>Dr. Crane: Mach number 25. Twenty-five. It trims with mach number. It's stable at high-end of the tack. So 50 degrees sounds scary, but it's actually quite stable. That was the benefit of taking the design and analyzing for 20 years and bringing it in. These are the kind of things NASA helped us with the heating analysis. So this is the snapshot of an aero thermal analysis, similar to fluid dynamics, but taking a flight condition at that mach number, number that density, and the constituent components of the atmosphere of that altitude and did an analysis of what the heating looks like on the vehicle.

So from that we came back and began designing how much of the vehicle needs to be shuttle tile, in the red how much frizzy, which is that white spacey type suit cloth material. That's what we used to do these on these 1301-degree foot lines. So a whole series was done. If you look in the literature a lot of the designs NASA looked at for these ellipsoidal reentry vehicles. They look like bullets. We went through 12 design iterations with NASA because we found out the first we had was uncontrollable at mach number five. One pound jets couldn't control the vehicle and move on a flat spin at mach number five. So we added an original on the bottom side, kind of a keel almost. But a mach number five you need they are very subtle so it doesn't look like a straight line. It's a very small rise in the shape. That got us down to mach number three. Then we did iterations on the vehicle. So what we were able to do was take this academic trade study design that NASA refined and moved to the next level.

>>Audience Member: (inaudible).

>>Dr. Crane: Bobby brown, he's been in

the guided entry community at Nasa and academia for quite a while. I worked with him when I first worked at Nasa. He's doing more of the chron calibration tick(ph) reentry where it hits the atmosphere and -- but same field. This is a view of how the Cyclopes mechanism, that gripping mechanism, you see the spring load? So that whole thing locks back and ejects and gives us that .3 meters per second when we came off. Two parachutes. This is my baby. So we developed an approach for very efficient software development and reuse on a project called (indiscernible), four years ago, five years ago. You may have seen a rocket being tested out. We set the field on fire. That was me. So we found a way to reuse a lot of the software NASA developed and got an 85 reuse out of the code. So there's open source core flight software spacecraft operating system that NASA developed. That provided a lot of your basic services and you can host your specify applications within that your guidance and navigation and control. So we use that for an architecture. Open source trick simulation also, that's a framework you can tie simulation into atmosphere, engines, gravity, torque, all of that stuff. We were using a program called ITOS. Something NASA used over and over and we thought this approach we kind of prototyped and stumbled. Turns out half the company we were doing the URV development (indiscernible) we hired them away from NASA (indiscernible). So this is an approach we are familiar with.

>>Audience Member: (inaudible).

>>Dr. Crane: So it's an open source software and you might know 23 you do computer programming their many shades of what open source can mean from it's yours if you do something bad with you it's on you not me to if you attach any other software not only you have to give back the software you borrowed but give the (indiscernible) back. If you modify CFE those modifications you have to give back. But the application code you host is not CFE. So it's just in that right spot. An example of what that looks like. Say you were developing a heart surgery simulation and you went to a great biomedical research institution, say Mayo Clinic and get their cardiovascular simulation

environment. If you make changes for that, you have to give it back. But you write your own heart model that the simulation talks to as a separate process and application, you didn't change what they gave you to wrap around it but wrote your own piece within it, so that's kind of that area. Now -- great question -- oil and gas customers we have to be careful. A lot of open source codes we use and if you are not careful you can deliver something to the customer they share with their competitors.

>>Audience Member: (inaudible).

>>Dr. Crane: Yeah. All of that stuff you have to make sure you manage in your configuration process for sure. Just another example I mentioned that core flight software comes with built in capability. This green and blue. Processes and software, limit checking, data storage, cable services, timing services. All the things you might need from an operating system. This comes with CPA and CFS. Automated flight, IME processing all the applications we wrote to compliment we were able to get from NASA to make that full flight software build. GN&C symmetric. Fairly

simple. De orbit targetter and guidance. A very high speed navigation processer. Entry guidance control 25-hertz, Kalman filters. Fairly standard AFM. A schematic of our operating modes and software. Remember I showed you the graphic of the vehicle leaving the space station and called them bubbles? These are the same modes. Software model, idle from (indiscernible). This shows the sequencing of our machine through the different modes of flight. One thing we did we genericisized(ph) the maneuver sequence so that we did this de orbit burn and maneuver to EI altitude. This was an earlier version. We maneuver the -- separation maneuver or re host that software on a different vehicle and do trans -- or whatever the vehicle called for. We test whenever we can so we develop techniques for initially hosting our flight software and simulated environment. That's what drove the animation you saw earlier. As far as the flight software and the degree in the blue bubble, it ran on a flight processors but running in a simulation environment. But then we can move that to a standalone application simulation over process that begins to separate the simulation from the flight software. And then we become more advanced we move the flight software to its own processer and communicates over a realtime protocol so you get more flight like. By the time we were at pre CDR we had the software running and it can figures to a -- simulation running realtime overnight we get the report next day of the status of the (indiscernible). Not original. We got that from Space X. But it's a great idea so flattery and comments and all of that. So engineers, especially GNC, love our Monte-Carlo simulations. Take the fist Sigma of the universe and wrap it around the software running on the vehicle and make it think it's the vehicle itself. And we run thousands of trajectory cases. That's the keep out sphere the circle in the right is the approach ellipsoid. Each of these colored lines is a different Monte-Carlo realization of (indiscernible) and the values listed on the left are the things we have changed. We changed the initial pitch angle. We changed the CG location. We had changed the inertia property. Thrust to force magnitude. Properties of the star tracker and GPS. Thrust level of the main engine. Percent of the burn we got, and not one at a time. We changed them all together. So each value is a statistical distribution based upon our best understanding of how the system performed and you sum those up and this is the kin of performance you get. If you take these trajectories down to parachute deploy you get the plot that I showed earlier with the 5-kilometer ellipse. And this is the way we validate our design.

>>Audience Member: (inaudible).

>>Dr. Crane: We had a risk managed approach. We were trying to do the whole design in 24 months and we got about 12 months into it. So we were designing for minimal failure. But we didn't have a standard NASA prove to me your three sigma (indiscernible). So that's what a thousand trajectories looks like. Very interested in how long it took for us to cross that keep out sphere. This is a histogram of how many cases took what amount of time. You want to make sure we used this to set our timer for activating the system

appropriately. If I set my timer to 1200 seconds, I capture so many cases. Similarly looking at the velocity at parachute deploy, these are all the kind of things once you have the simulation set up and running you will begin to pull apart and understand what the design performance margin in the system is.

>>Audience Member: (inaudible).

>>Dr. Crane: The supersonic drill comes out about mach number three. The exciting region mach number three and five. Hypersonic region you get toward the end of your control authority but you have not got the parachute out yet. So did a lot of work between mach number three and five. And we get subsonic the parafoil comes out. So that's the design in a nutshell. Free to take any questions. I will mention one other thing we did. That I don't have a chart for but it's kind of a, I think it's interesting. I mentioned we had problems at mach number five. The vehicle run a flat spin and the thrusters we had two on the back of the vehicle. Somewhere back here we had two pods of thrusters. Someone used to working on Mars entry vehicles a one pound thrust sounds

small. This whole vehicle weighs up to 300 pounds. So once you do the torque that pressure is about what you need for this vehicle. We started getting Millie cycle. We made a design change recommendation, send it to NASA. Takes them a week or two. This is intense computations to get these analyses out. Give it back to us and update the aerodynamics and we find out if we did better or worse. We 3-D presented a couple of versions of the TRV. Something about the size of a cup, a small shoe size (indiscernible). And we can configured it to change the CG and broke a subsonic wind tunnel. It used a shot fan and 10,000 straws and (indiscernible). Probably cost 250 bucks. Clearly not a certified wind tunnel facility but we got insight of the trim, spin, damping conditions. We provided feedback and -- didn't claim we were validating a hypersonic design with a 250 wind tunnel. Rather we used to gain insight and intuition we can interact with and we use that to make recommendations to NASA to put it in their design tools. And they come back and say turns out those recommendations are valid and it accelerated the conversion of our design. Sometimes you can go with the super high fidelity large facility validated approach, but that can be an end point opposed to a starting point. We save time and money by using simpler techniques for starting points and submit those for consideration of those end point analysis tools that are more sophisticated than expensive to run. That's it. Any questions?

>>Audience Member: (inaudible).

>>Dr. Crane: Probably not. (LAUGHTER). That would be a bad day. I will say that one of the things we have been looking at. So long story of funding and stop funding and looking at this again and in a sales mode we are out talking to folks about the URV is net capture. So if you go on line Space X captures the shroud, their launch shroud with a boat or basically a trap, lean in the back of it and drive the boat underneath as it comes down in the shutes and usually they grab it. Another approach we have had in order to completely eliminate not completely but mostly the possibility of hitting a populated center is push the (indiscernible) out in the water and

drive underneath it with a speed boat and snag it out of the air is another approach. It actually cool watching it land. When it hits it's just bumps along and it's kin of neat to watch. Any other questions?

>>Audience Member: (inaudible).

>>Dr. Crane: Actually no. We did the analysis and we can pack the payload with ice, ice blocks, and it will maintain that temperature. So the heat is what you are worried about and we don't soak through so you can maintain cold or room temperature down to the surface. If you don't we will get it once it lands eventually that 1300 degrees will work it's way through and melt whatever you did. But we can bring frozen samples still frozen. Yip. For sure. If you take the same design and put it in a lanner land on the moon and put a package on it, a similar design would be able to do a reentry back from the moon. There would be some changes. Not a build to print, and I can go anywhere in the universe, but the design changes would be minimal.

>>Audience Member: (inaudible).

>>Dr. Crane: The X38.

>>Audience Member: (inaudible).

>>Dr. Crane: We have been asked that. The NASA administrator asked us when we presented this can you make it an escape pod and that's something we are looking at to. However this is the caveat our approach to human safety was if all the systems didn't work when we left ISS relevant risk in the re-contact with the space station we would go dark and the vehicle would fade away and renter on it's own. So you lose your business opportunity to payload but preserve the life of human life on the space station. Everything had to work and you know not a whole lot of risk but if you didn't you lose the whole thing. For the escape pod everything is redundant and now the costs would go way up. Except for this. If you built this and you flew ten or 12 of them out of the space station and had a backlog of performance and understood the systems had that flight heritage and said could you make me a (indiscernible) version. I think that's a lot cheaper if you started out with a human rated version from the beginning and layer the requirements of reliability and

triple redundant from the beginning if you know the design basically works and you are scaling up and now adding redundancy it's a better approach. But yeah I would love to build an escape pod. The X38 was a JSC effort that would basically take a crew of six from the ISS. And they were work on that just about the time I started at the Johnson Space Center started winding down. You would be need to make it a single person. The problem you run into. Space station you have two (indiscernible) people up there. So that six people in space station I have two (indiscernible). One of the people gets a kidney stone. They break out the ultra sound and it doesn't go away. Person starts bleeding. Now you have a situation. What do you do. Can't put one person in a (indiscernible). You put three. Flight rules are you can't have more people on board space station than you have the ability to bring them home. So one person gets sick three people come home. An escape pod would be an additional person that one person sick, put the sick person in and this is actually a much nicer ride, that 3Gs is better than you pull on a (indiscernible) so that would be an application. The space station is (indiscernible) in 2025 so we might have missed our window but hopefully commercial space stations will think about that.

>>Audience Member: (inaudible).

>>Dr. Crane: 30 liters and 20 kilograms. I think -- on the bump at the bottom or the reentry? I think it was a shock of less than 6Gs. Not much. Pretty -- one of the things we did avoid the parafoil has the option to a flare at the last minute. But to get that to work you need an altimeter, and that's a layer of complications. So we took the bump and damage the heat shield. That's why it's separable, to get rid of it and throw it away. Now my plug, intuitive machines is located on the first floor of the Boeing building just across the street. We have a vibrant internship program. We just closed our summer internships program nothing for the summer but we are open again in the fall. The way the internship work we look at projects and see what needs support. If you are interested in

doing some work some analysis work for hire outside of the internship program we do too. So if you are a programmer analyst, physicist, don't hesitate to go to our careers page and submit your resume. You can sent it to me my email is Tim at intuitive machines.com nothing but a small company. We get first name emails. And no promises but we don't know we are there unless we have your resume and the things you do and we are excited that (indiscernible) wants closer ties with the student body and faculty here. If you are interested in these kinds of projects or things you see on our website don't hesitate to send me your resume and see if we find a match. I appreciate your time. This was a fun project.

(APPLAUSE).

>>Dr. Garrison: Thank you very much.

(End of seminar)

DISSEMINATED TO ANYONE.