March 19, 2018.

>>Dr. Garrison: Let's get started today. I want to introduce our speaker, Steven Fitzgerald. He's from intuitive machines. I didn't really know a lot about intuitive machines but one of our former adjuncts, Tim prey(ph), who worked at NASA and US physics department for quite a while, he worked with intuitive machines. If any of you know he's over there, they are doing interesting stuff. And so there was one person, can't remember his name off the top of my head, who was here last customers as part of our college seminar series about the stuff they dominant I found it pretty fascinating. So for the next three weeks we have got three different talks, each is going to be from somebody from that company, and they are all going to talk about some of the things they are doing. You will notice that as a group they are actually doing some very different work but it's all fascinating stuff. So with that I want to keep in mind this is a local company, one of the situations if you have questions they are here to answer and if you want to learn more about what they are

doing, we have the speakers right here. Thank you, Dave. I was asking David about the course, what the course is, and I love the framework. How many undergrads waits are here? Excellent. I expect hard questions from you. Graduate students. Y'all can't ask questions. (LAUGHTER). I'll tell you about intuitive machines and myself first. Actually graduated just across the street back in 1980 -- (indiscernible). I left here and had a bachelors in masters in aerospace engineer of Texas A&M and through a co-op worked at NASA Johnson space center. Retired after 30 years in my technical background and specialty really qualified as physics. It's built on that and in particular aero thermic dynamics, which react the flows for vehicles. So reacting chemistry and reacting aero thermic chemistry. In addition I moved my career every three years I did a specialty. Started with the jets and went to space shuttle with the space station which is basic kinetic theory and statistical mechanics. And came back from that and during that time had a couple of space flight experiments where I was a JC plume expert, which is basically space shuttle fire and you get long plumes and they go every where including the space station. So we got involved and modified the models for the space station. And then from there I went on to other things. I worked Columbia (indiscernible) investigation team. I was a branch chief and moved up to the constellation program where I was in charge of technical integration. We put together a grand plan to go back to the moon that's the on again off again plan that we are working towards right now. And then essentially I retired as senior technical advisers for (indiscernible) division. In addition to that about that time I joined the aerospace advisory panel and I had a huge interest in the education and the growth of: Students in college. I contributed to that at A&M. And i have a real soapbox here about appropriate utilization of tools. You guys as undergrads and graduate students of the university, we have companies throwing software at you. Engineering program you get thrown software for 3-D CAD and analysis and stress, fluids, and you can use it. My soapbox if you will is just because you have a ham mar doesn't mean everything is a nail. One of the things an engineer which scientist and (indiscernible). But the key thing is understanding the problem, what level of fidelity, what level of rigor is required to give you a useful answer to the problem being asked. So you don't always have to go to the Nth degree. I'll show a lot of Nth degree stuff but more basic fundamental engineering that goes into answering the questions. Because that's ultimately my job. My job is and the job of intuitive machines is to gauge for the customers and solve the most difficulty challenges with the framework division, the approach we learned at NASA. We have 40 engineers. The idea was we come out and take our years of experience and lessons learned and apply it to aerospace and medicine in the Houston area. Employee number five in the company, I've been there a while. I brought one of my customers with me and we have been doing work in really chasing interesting problems. I made my career solving problems that other people think are impossible or intractable and I love doing that because it's high expectations. It's an impossible problem. And two we have to be creative. So that's what this is about. The level of work we are doing in the oil and gas industry is ground breaking. On the NASA side I grew up with the development of CFD. It's the solution of governing equations of fluid. In the Euler, viscous, Navier-Stokes equations, you have the boundary stokes equations and thermal chemical equations that are difficult to solve. Those are the equations we solve on super computers and have gotten good at it. The statement I made earlier about you getting thrown tools is you can go right now out to the Internet and identify your search for CFD codes and type in source. Download and see cases all day long. If you have access to commercial tools they are designed to give you an answer. Even if you give it garbage. The challenge of doing this type of work is knowing is it right. How do you know your solution is correct when no one ever solved that problem before. That's one of the challenges we face. What we do these cases you are seeing you will hear a lot about, some of these, the idea is these are full scale real world problems being attacked with high fidelity engineering tools and being applied by people dedicating themselves to understanding the tools and the assumptions that go into the tool and how to use the tool and validate to get a correct answer. Within our scope, within our ability. So everything we do is full scale. On the NASA side we have (indiscernible) facilities, wind tunnels, but we don't call it done until we got the flight data, which gets me to my favorite quote of all times. We are talking about models. Challenging problems. George Box who was on the faculty of Wisconsin, all models are wrong but some are useful. This is important for physics. For students to understand. This is important for engineers to understand and pair rents. We think we are right all the time but sometimes we are not. From an engineering standpoint I can sit and solve a problem with a Navier-Stokes equations if people think I'm using a high fidelity tool I'll get the right answer. However, the Navier-Stokes equations are an approximation. Turbulence, closer, models are an approximation. Breakdown you get more into verified flow. They no longer apply because the assumes they were built upon which is the stress strain relationship breakdown. So what is key we do an analysis, we get handed a challenging problem you first have to understand the problem and then pick your tool. You have to understand what assumptions you can safely make about solving your problem, which variables are well known, which ones are unknown and choose wisely. That's my soapbox. But I love Einstein's quote and I believe he quoted this as simple as possible but no simpler. In other words, have a model if you know was wrong, it's good enough when you simplify it down to the critical fundamental thing that has to be modeled and no simpler. You can go too far on both sides, you want the sweet spot in the middle. Our young guys hear from me all the time. Just because you have a (indiscernible) code doesn't mean you have a solution or the tool that it's a right way. So the problem we are talking about is hydrocarbon. Back in 2010 we were familiar with on the news everyday BP blowout and

5,000 feet of water. Basically had a kick they lost mud flow and essentially they lost the platform lives were lost and last account was $57 billion it cost them. Oil flowed for about 70 days. Last number I calculated it cost BP $30 million for every hour the oil was flowing in the Gulf of Mexico. What I want to do is saying with some engineering analysis on the front end, if I save you one week, a day that's three quarters of a billion dollars. If I save you a week I save you a billion. It's about understanding the value of the work we do. In order to get that kind of funds they have not yet given me my billion or I wouldn't be giving my talk. But it's not just a big BPs or blowout you see everyday. One of my customers had an ongoing response in the Gulf of Mexico for decades. There's sheens everyday and he gets hammered by the government. The resource center receives 20,000 calls a day which is reporting of environmental releases. A guy at the gas stations could be pouring gas and spilling out that's a release. Or it could be a pipeline in the gulf of Mexico had a failure of a valve and it's leaking and the customer knows it and they can't shut it down. Or maybe they have shut is done but there's oil out there. If you take a vote and you see a sheen on the surface and you report it, it gets reported. The challenge is how do you attribute these releases. Who is responsible? That's one of the things that I'll get to when I talk about my customer. This is an example and I'm going to make sure this is (indiscernible). Hydrocarbons can be oil, gas, and basically mixtures of solutions in between, typically multi-phase. Reservoir liquid form and it comes up to the surface pressure drop gas come out of solution. And in this case this is (indiscernible), in this -- this is basically 600 million cubic feet of gas per day flowing from a depth of 800 feet and getting to the surface. Edge to edge that's about 600 yards. The hydrodynamic jump from the middle is this high. Enough momentum in the fluid coming up it raised the sea level. I have tools for doing this Texas A&M oil spill calculator, it's open source and you can download it. If you are interested it come talk to me about a job. Here's a simulated release. Gas velocity, gets to the top of the surface and per second if you do Rho GH you get the appropriate hydraulic jump. For main core plume rising at the surface, that sphere, that's right in here. This little area right here surfacing, that's 80 meters. That's why this is so large. What are those other rings. What else is happening? Because they are not part of the simple model. So the model I choose to model this problem with was too simple. So I understand it. So I went to another methodology and got this solution here on the left. All this is, is me trying to understand what those rings are and what they represent, what's going on. A fluid coming to the surface and then also (indiscernible). If I'm watching this what happens is fluid which has a mixture of the gas methane and water because when it comes out it's (indiscernible). You get a mixture of gas and water. When it breaks the surface most of the gas is released. So now the fluid that falls back is less fluid than the fluid coming up. So it dives under and sea water is more buoyant and it comes up and releases more gas again.

You get a ring of concentric -- basically dives and dips and rises. Each time it's more gas. The shape is influenced by the seascape. You get a trailing out at the edge which when I take this we see this in the field. What I've done is used three tools, neither which are highest fidelity to understand the problem. Because the application is where can I safely position ships on the surface to do an intercession with that well. They need to know where to safely position people, how far away. This is that key to understanding the problem, this is not numerically correct but represents enough of the physics to allow me to understand the fundamentals and now I can take it to engineering. And so the interesting thing is, if you are a company drilling a well in the Gulf of Mexico, they assume they can do a BP type intervention. Big ship directly overhead and I can lower my (indiscernible) -- cap my intervention of flow and drill pipe straight down. Maybe, maybe not. It depends on ocean conditions, currents. One of the things our tools did is went into predictions for the ocean. High fidelity Gulf of Mexico model around the world I can extract predictions and simulate this case six years of a release from one location and every dot you see is a simulation. That's the same release. The difference left, right, north, south, is the whole function of the current and the salinity and the temperatures of the environment. If I'm a customer and I'm trying to get that well and look at this picture in the right very seldom I'll be directly over the well because that's where the plume is. Again informing our customers without having to go to great length to pull the highest fidelity tool this tool is ow useful for making decision. If I have a customer like this one, if you thought three and a half billion, this is a simulation of three and a quarter billion cubic feet being released. Difference is 5,000-foot depth. This is compressed at those depths. Has a density lower than oil but it's still liquid. When it comes out it screams. Because it's giving out so quickly it's turbulent. It generates terabytes of data for one second simulation in order to capture the fluid dynamics we have to have a high resolution grid. It takes a long time to run. But if we need to do engineering analysis with this, how much force if I put a stack, a piece of hardware in this flow how much force is generated on average? Well, this is not the one that's going to directly give me the answer. I can put a piece of hardware and you will see one later, if you are trying to design an operation, make decisions about how to do it, you make decisions quickly. Out there in the field you need to know if tomorrow is better than today. This hardware the right one to apply today. You make quicker decisions. So we develop case specify engineering models. When I say that it sounds like it's less than the complete physics model which it is. All models are wrong but some are useful. Engineering models we develop for fidelity that useful for us and the problem. This case we are focused where the force is the highest and so we do high fidelity fits to the flow field. This is two, three equations that I can put into a program to do simulations very easily. That's great for the high velocity gas, but I have to adjust my model because one of my customers had this flow field. Whereas the other one was forty meters per second. This is 1.5. The challenge is when you look at the simulation you see the blue stringers, that's water going backwards and down. That water is drawn in and down into the flow so this is mixing with the flow in the pipe before it comes out. That invalidates for my approach on the left. So a chance to get creative. So what we did in this case is looked at the exit plane of the blowout. On the right you see clear areas where water is going down. So it pushes the oil off to one side. And it's dynamic as all get out. Let's go play this. So this is a 10 second simulation we did. The dot is the average velocity. The placement is the velocity centroid being. That's where the blowout where the forces are coming from. So now I have got an unsteady solution I can track those things and take, identify what frequencies of the flow are. Evaluate that against engineering, what the natural frequency of the system is and calculate. In this case these are different levels of engineering models we apply. Again, appropriate to the question at hand and the timeframe you need the answer. All of these are valid models and applications. So back to the fluid structure interaction. Depending on the velocity and the question being asked, I can use an engineering model or go high fidelity. The one on your left, my right, is that gas case you saw surfacing. This is a flow field going over and around and through a capping apparatus. This case they built it for land based staff. Most of the hardware they built has tiny, nicely laid out machinist love, these lines with hydrodynamic lines about a quarter inch in diameter, 10, 12 in a row come out and they flow together. It looks nice. But you have got a thin critical piece of hardware hydraulic lines you can count on that a can't lever in a flow field high frequency oscillation is 100PSI change in pressure. The challenge is you will fatigue your hydraulic lines and they will break. This is critical information to decide how do I design a piece of hardware. Without this information they go with the standard and they -- it doesn't work. Because all of this aerodynamic flutter has fatigued the lines.

The one on the right is the slow case, that's supposed to play and it's not. In this case it's moving around and this was where it was coupled to, the fluid surrounded ho the lowering system frequency so we have to look for other options. The forces were low enough that the damping was there for the motion so it doesn't excite anything. But you have to look and understand the problem within the scope of basic first order physics. The natural frequency of the spring mass amper(ph) system is one equation. You can analyze and look at basic frequency that's first order and accurate to evaluate whether or not you need to look for second-order impacts or not. It's all about what level of fidelity is required to solve the problem. Now the customer that had a release in the Gulf of Mexico. Basically he's being asked about it and what are you going to do about it. It's daily overflight, flights they fly over and everyday is a different place and it looks different. They calculate different volumes. Today we observe 3-barrels of oil on the surface. Two days from now they might observe 100-barrels. The next day it might be a different place, another mile away and barely be visible. The challenge of this is we are only getting a piece of the picture. So what we are to do is utilize our expertise and simulations and evaluate all of these observations. In this case they went out into the field deployed sensors to measure the environments. Took samples on the surface. Total of 51 observations. We were to say look at all of these observations. So you will see something that looks like this. Simulated release condition and all of these dots which represent different methodology and assumptions using that text oil spill model I used earlier plus another we developed. And in general you will see observation. So this case the observation is the green cycles at the center and then uncertainty with the pilot to be able to locate it. Basically six to four millimeter droplets within this thing and that's great. But we come here now and this is another example, different day. We have different sets of data. ADCP field that's velocity with the flow. CDP is salinity to temperature to density type of information.

The CDT, that extra information didn't change our answer. We didn't need that for the simulation. Currents definitely do. So this is nominal for us. We did a good job with this model. when we used the measured data. NGOFS is the Northern Gulf of Mexico operation forecast highest resolution they have high fidelity simulation. It has the highest density and considered the most accurate. It got 45 percent match with the observation. Whereas my tool got 96 percent with the new data. But look at this, one of the things at understanding the problem is sometimes not just physics aspects. My customers problem was not does he have a release. It was not that he did everything he could to solve it, not that oil was showing up on the surface. It was that people were reacting to the oil showing up on the surface. Because it's an emotional topic. People should care about the environment and should be concerned about whether or not release in the environment will harm life or vegetation and impact our standard of living. So those are emotional answers. People react to what they see. So look at this, in this case, you might assume that the oil slick is going in that direction. I did initially. But you can measure data and simulate it and it does this. So it comes up and initially goes down south and then takes a right turn. That was something they not observed before. So sometimes it's here, here, but all of it flows. What is happening? Why is it important? So to address that we did the volumetric release. You saw the surface from that. All right we said particles and oil droplets are different sizes therefore they get carried farther away or closer to the source. Currents move every where so it's green in the full current data. This case we simulated 250,000 trajectories at 100^{th} of a second over hours. It opened a lot of eyes. This is an and makings regions. Notice how dynamic it is. The fluid (indiscernible) is the red of the larger ones. This we did not expect. The current at that location of the Gulf of Mexico are so dynamic they change minute to minute. 180 degrees they will change or in the case you saw 90 degrees in a matter of minutes. They will change at the bottom, at the top, you can have flow going different directions bottom and top and it was eye opening. But is it good enough? The observation we saw, it's hard to see I tried to get as much contrast. Essentially here's the release point or the source and you see these oscillations. If I recount those I have four, in my simulation I get four and then up here it's hard to see but it takes a right hand turn. So this is 20 minutes after the observation. So with the actual location and now I match the shape and the direction. Here's another example. Our observation simulated prediction. In this it's a very simple model. I had three or four knobs I was are ready to turn to get a better answer but I don't need a better answer. I can explain what we see. And that was the emotional answer that people needed. There was active sonars and they were taking samples, four lines of attribution all released the same conclusion. But the nail on the head is one they have never seen. They have never seen anyone match it. More examples. This is a picture in the announcement. This is the observation and here's the sheen. This case I was able to adjust the size to march the pattern. Now I have an idea of what size droplets are coming up. This one, same thing but much shorter. A different dynamic. All of these are exactly the same volumes from exactly the same place just different times. All the same depth as well. That is about 460 meters, call it 1800 feet, a little more, maybe 2,000. It's got a lot of water coming up. (indiscernible) winds are a phenomenon. They are called Langer(ph) cells. It's an interaction between the low velocity cross wind and perpendicular to current. So it sets up this counter vortices at the surface. I didn't model that in my data or methodology These last are my favorites. Lots of times people will see multiple droplets coming together and never understood it. This looks like a piece of taffy that is twisted. It's moving back and forth like this. And then you can see the same spiral patterns in the observation. In this case it was high wind so it didn't give it much clarity. This case is another one if you look at the observation it has shear and shifts and the edge goes on. In the observation I go this. But when I plugged in the simulation, minutes, actually an hour past when the pilot said he took the data I got this. So the pilot observation he marked down wrong. So score card, essentially we were the first to match everything the pilots observed. Everyone else cared about location. So we evaluated location, shape, direction, size and compare all of those things and added it with a simplified model. We were able to match 96 percent of the observations which I was very satisfied with. Simple, simple model. Simple as possible. Now, this has been out there for decades. We only took data for February 27th until march 15th. They have years of observations. So what can we do, how can we take what we have learn and apply it. Depends on understanding the currents at the site, and understanding what variables you prepare against. And in this case here's the observed sheen and you have the cyclic pattern where it gets longer in the summers. If you understand the Gulf of Mexico if you take the wind speeds in the Gulf of Mexico they get lesser in the summers. Winters are more dynamic. If you look at the annual flow of the Gulf of Mexico it has a cyclic behavior so we can expect a connection between all of those variables. The thing is if we took just the horizontal velocity at the surface, pick a direction north, turns out the Mississippi River empties close to this site. And if we take within an hour measured window, the Mississippi River outflow volume and we plug it into nothing more than a momentum equation where you say I have a northern velocity 59 my site reacting to the head pressure for the Mississippi River flow, and the Mississippi River flow a 2-D release will spread at a certainly angle, and within the factor of 50 percent theoretically it should be 10,000, that scale factor if you will. If I apply a scale factor of 15,000 I get all of these peaks lining up on the predominant shape. All of the vacations in between are fluid dynamic interactions that happen and create vortices when two fluids mix you saw it with cream acknowledge coffee. It may give it dynamics but in general it scales. So that says I can take, Gulf of Mexico and -- my Mississippi River flow, make an estimate of velocity, which direction they are headed at the surface and predictions. So five years of predictions gave me this. This is what the actual possible spread of the observation appeared was. And the color of those dots is by time of year. It's not unreasonable to expect that you have predominantly seasonal currents that are at play. So within the simple model you are able to track all of those releases. Over all of those years to a single point. And we got to within 6 meters of the location on the sea floor what they thought the regions was coming from with simple physics. And that's the end of that presentation. Let me give you a quick -- thank you. (APPLAUSE). So all of my customers have unique and challenging problems. They are not all good stories yet. This one particular customer the government is holding three quarters of a billion dollars of his money and the conclusion we reached from the team any intervention will make it worse. So he's trying to work with the government. In that case every bit of money returned will go to the City of New Orleans to fund inner city programs because that's what the company dedicated itself to. Other customers more business related drilling in the Gulf of Mexico and put together a model. The government spent $2.5 million trying to prove it wrong. Peer reviews got good answers and he's still trying to get the government approval to drill. So in all of those cases I know that I have done everything I needed to do. I've given my customer the best answer I can. I've given him understanding for problems he didn't have initially. It helps him with his discussion with the interested parties and all we did is apply physics. That's it. That's all I got. Now, questions. Undergrads waits, come on.

>>Audience Member: (inaudible).

>>Dr. Fitzgerald: I would like to say it's the dinosaur program I started with. But probably not. Actually we have seen all of this work we have done with tools we created with open source tools. I love the open source environment. The reason is not because someone else did the work but because they give you the source codes to read it and understand how they did the work. And therefore derive the

assumptions that you need to. C plus plus is strongest fastest piece that we have got. A lot of my tools working with GP computing for years. I have got two titan XPs in my work station at work. But I can get ten, 11 para flux(ph) of data if I program correctly on GP. That's great for particle based solutions. Classical; CFD, super computer based, is a genius program using basically GP for what it's good for and CPU processing large grain, small grain parallelism. And much of that is still sea based. But I call it a cancer, Python is every where. Python is a cancer if you are reading someone else's code but a savior if you are writing someone else's code. It's an interpretive language that I like and tweak the parameters and a lot of the open source, particularly in the data analysis if you pick up a version of anaconda data processing is massive on the machine side Python is coming up but can't keep pace with invidia and GPs are killing it. But C plus plus, any structure object oriented programming, please when you write programs don't make them so overly object oriented. I still do blocks of code. One guy hates me because he says if it's more than 20 lines you put too much in it. But that's what I do. Good question by the way. Any others?

>>Audience Member: (inaudible).

>>Dr. Fitzgerald: (inaudible). i talked to (indiscernible) about this. He's my boss. You have a better understanding than me. Beth has moved on to a different country with a facilities contract for GFC. We have people come and go. Beth was part of the originals. I followed close behind. Steve (indiscernible) likes the work we do.

>>Audience Member: (inaudible).

>>Dr. Fitzgerald: If you are into bitcoin, you can buy a machine that had 8GPs. I have an 8GP plus a 96 core computing box we use on site and it gets it done. But we generate terabytes a day. Anything else?

>>Audience Member: (inaudible).

>>Dr. Fitzgerald: We have got the challenge in that the customer paid for us to generate the data so we have to store the data and manage the data. So each customer gets a six terabyte drive and that's enough for four solutions. What's interesting in the way they

are going if you know what you are looking for, it's basically concurrent processing. So if I'm looking for the force on a piece of hardware and a complicated solution, if I don't want to move my terabyte data back and forth and coprocess while I'm doing the computation I take a flow field and process the information I want and save that information. But you have to know what you are after. For example, BTA (PH). Kit wear is a company dedicated to open source and they have a product called VTK which is a graphics programming foundation in C plus plus, and they have basically runs on GP. If you have a GP based solver it doesn't have to transfer data. It just changes the owner of the data. Goes to compute mode, changes to the owner to the VTK base process, and generate the data and change it back and the computer goes (inaudible). A lot of people do PETA(ph), X of scale (PH). So the key is what you want from the solution and get that while it's right. We like to use the facility at the University of Texas before. It is Amazon cloud you can use by getting the data. That's where they charge you. So if you know what you are looking for you build it into your processer.

>>Audience Member: (inaudible).

>>Dr. Fitzgerald: We do. One the my customers we did a blowout simulation and if you light an oil we will on fire was the question how much oil escapes unburned. If it escapes unburned where does it go. Positioning ships on the surface relative to a blowout is the direction of the blowout and most of the models I've used at this point are basically gas and plume models, assume diffusion of a cloud. Basically the national -- they are working with ETA creating tools for large eddy simulations and terrain and depends on the application. Everything we are doing at this point are more simplified models because typically I'll run hundreds of cases. My simplified plume case I ran 150,000 simulations in a matter of three minutes. The volumetric one takes 20 minutes to run because I wrote it in Python because -- I'm still putting it on GP but my boss says let someone else pay for that. A lesson in business right there.

>>Audience Member: (inaudible).

>>Dr. Fitzgerald: Sorry. Say that again.

>>Audience Member: (inaudible).

>>Dr. Fitzgerald: I'll pull up slide three. Slide four. Sometimes you have to build your own sensor. This picture on the right, I went up to Wyoming and there was a drilling pad on fire. It was to me I got a bad reputation because I said it was the most beautiful thing I have seen.

(LAUGHTER).

>>Dr. Fitzgerald: The guys trying to kill it didn't appreciate at. If Metallica had a pipe organ on stage this is what it would look like. But no one thought to measure a blowout. There's so much unknown about multi-phase in this case supersonic flows when it comes out the atmospheric conditions -- and no one understood what is the momentum at a blowout. So we built a sensor back to take temperature and pressure and it was surprisingly descriptive of the picture on the top is temperature. And you go from here to here, you are going from (indiscernible), which is the liquid. It evaporates. And then goes into (indiscernible). So looking at the temperature and pressure combination you can discriminate

gas, con (indiscernible) and water. Where you have 100 percent water you have a loss of lie frequencies. So in this case we built it, that's an Iphone. For the sensors in the field (indiscernible) are big massive things, sonars, and the data processing is pretty significant. But that can be as simple as pressure (indiscernible) couple. Whatever gets you useful information. How is that for an escape all answer. It's like saying it depends. But whatever you need to get the data. I have gotten as complicated as (indiscernible) velocity measurements that were difficult to take and ease to interpret. So we have to play that balance. That's why university exist to come up with complicated measurement systems to get at the root of what you are trying to measure but you can't always get to that lowest piece you care about. And that's where having the understanding of physics says if I measure temperature here and pressure and I know it's a gas fluid equilibrium system, if I can model that I can make a calculation of what (indiscernible) for example. If the first order physics is correct

I can make measurements and -- you have to go to that higher measuring system. And that's drawing on my NASA experience more than anything else.

>>Audience Member: (inaudible).

>>Dr. Fitzgerald: It's very similar. So one case gravity is delta T, change of temperature, change of density, gravity gives you buoyancy. This case you change, there's a thousand and one density between gas and air. As it goes up the density of the fluid gets mixed and more approaches the density of water. If it stayed gas one bubble coming up it would be, you would have a hole in the ocean the time it gets to the surface. So the viscous forces they are fighting to pull the bubble apart is balanced with surface tension trying to keep it together, so there's a maximum size (indiscernible) stable and can stay there. Everything else breaks up as you go up so you wind up with millions or billions little tiny bubbles -- let hitting a surface, or hitting a roof, it hits it and it's cooler and cools the fluid and transfers and comes down and same thing. Very similar. Good application of

fundamental physics. Similar systems.

>>Audience Member: (inaudible).

>>Dr. Fitzgerald: This media is the actual mixing that takes place in the pipe. So the blue streamers coming in and fluid coming out. Look at the complexity of the mixing. I'm modifying my charts realtime so you can see them better. Flowing in. And the reason is as the gas comes out it only expands at a certain rate. Classical turbulent jet has 22.8-degree angle of spread. That's if it's turbulent and it's a jet. And that cone doesn't fill the full volume and it also doesn't have enough pressure to push all the water out to water streams in. The case in India had a similar problem but higher pressure and that one the water would stream in, but back pressure and the plume, plume would blow it out. So that was like a percolation. Back in the day I woke up to my parent's coffee and percolation, and it generated frequency far apart to that flow that it was just another frequency we had to look at. That was a little more chaotic. But this is, I love this kind of stuff. Mostly I stare at these and looks what is going on and

model it and get the same character of the flow and (indiscernible). That's the fun part for me.

>>Audience Member: (inaudible).

>>Dr. Fitzgerald: It actually has to do with turbulent shear or growth at the edge. If you have for example the water hose fluid density of a thousand air of typical (indiscernible), the density difference is so small that you get this nice steady stream. But if you design it quickly you can get a laminar stream it will stay coherent and go one place to another. Try to do water to water. So now you have got the shear being built up with the differential velocities and tiny vortices that mix. So what you get is two angles. A shear air mixing here and then a sheen air mixing on the inside. So you get these two cones at the same angles and that is the classical turbulent jet. That's easy to model. You get 90 percent there 80 percent of the time by the equation. In this case I can tell everyone based on the conditions what the maximum force is going to be because momentum is conserved. Momentum is basically the mass

of the flux leaving area times the area that's it's force that it's conserved it will never get higher than that. So I can tell someone if they will successfully lower hardware overflow. I don't tell them that I make them write a contract. But first order boundaries. Back in the envelope. Scoping boundary. Huge, huge tool and that's what I lot of engineers can't do. That's what makes old dinosaurs like me useful. I would include him but he looks tougher than me. Any other questions? I wish you all great luck getting through your studies and find work you are passionate and enthusiastic about for the rest of your life. Thank you.

(APPLAUSE).

>> (inaudible).

(End of session)