

**MICHAEL  
SPELLMAN:**

Good morning, everybody. OK. I'm going to kick things off. I'm Michael Spellman, Director of Composite Manufacturing and Cutting at Autodesk, under the Digital Manufacturing Group. Just to give you some background on my history, I've been in the composite industry for over 24 years, for the past 24 years. I was formerly co-founder of Majestic Systems, where I acted as the CTO of the company, where I developed, designed, and architect solutions for nesting, laser projection, automatic fiber placement, and tape laying for composites.

Just kind of looking at the history of how we've progressed with the products, back for instance in 2010, we actually won the very first Innovation Award for Composites Excellence at the JEC show. That was the first award given for software. The next year, we actually won the same award for TruPlan, and then finally in 2012, we actually won the award for TruFiber. If you take a look at some of the companies, just about every major aerospace company in the world is actually using our technology for composites. And of course, we also use it in other industries like construction, transportation, and energy.

And so today in this class, what we're going to be talking about is composite materials, particularly carbon fiber. And as you know, they are some of the hottest materials today. And they're renowned for their high strength and weight ratio. Carbon fiber parts are becoming more popular in traditional fields as automotive and construction. And this class will introduce Autodesk's new composite manufacturing platform.

So some of the things that you're going to learn during this class are the steps needed to do the hand layup process, how to actually create manufacturing strategies for composites, how to analyze material defects, and how to create fiber paths. So just to start off with, I'm going to do a quick introduction on what composite manufacturing is.

Just with a show of hands, how many know about composites today? How many use composites? OK. Are there any people in the audience who are not familiar with composites? No. So I think there are a couple of parts that are being passed around. So just some sample parts. You may just want to pass it around. This is a composite board, a composite laminate board. And I think there's another part, Matt, that you've got passing around that's actually been laid up with fiber placement. So you could pass it around. You get an idea of what the strength of composites are and why they're so widely used.

So when you think about composite materials, composites could be anything. It could be something like as simple as plywood. Composite is having something that's made out of more than one material. And so typically when we talk about composites, we talk about it being based off of two different types of constituents, that being the fibers and the actual matrix that actually holds it together.

And then when we talk about what are composites, when people are doing composite design, typically what we're looking at, to get better strength, what we typically do is we're going to use several layers of material. And what you're doing by using the different layers of material, you're adding the strength by changing the direction of the fibers. That's going to give it strength, of course, by having more layers and having them go in more directions.

And if you take a look at some of the charts, why do we use composites versus other materials? And really looking at why that's being used, you could just see the strength and weight ratio, it's just a much larger area when you have composites. And so with composites, because we can use multiple layers, we can actually tailor how we want the performance of the material to be, at the same time being able to lightweight it.

And when we talk about where composites are used, I'm just going to show you two quick videos in terms of what are the typical uses for composite materials? In this video, you're seeing the typical hand layup process. Parts get cut on the cutting table first. They then get kitted together, where they have to build up a particular part.

Now they're doing the hand layup process, which is actually guided by laser projection to help them layup that part. A lot of times they'll have to vacuum bag that material down and do some other things. And then they'll actually put it in the autoclave to actually cook the part. And that's the whole hand layup process. That's the whole cycle that you would do for hand layup.

If you take a look at one of the other processes that maybe you didn't see in that video, during that hand layup process, how did they know exactly where to place that particular part or how to place that particular ply?

Typically today, what they use is laser projection. And what laser projection does is it guides the person how to actually align that piece. And that's really important, because you want to locate that ply in the exact location in order to get the proper performance of it, because for instance, if you turn those fibers in the wrong direction when you lay it up, you're not going to get the performance that you want for the part. And that would be a really bad thing. For

instance, if you're going to build a part that's going to be flying on an airplane and it's a structural part, if you don't have that proper performance, something bad could possibly happen. And so that's really the worst situation.

So with laser projection, it's going to show you exactly where to align that piece, but it's also going to show you where the direction of fibers are supposed to be. And so laser projection is now a standard in the industry when you're building composite parts, especially for hand layup. It's like augmented reality.

And in fact, one of the other courses that we have-- I believe it's on Thursday-- is going to be a course on part of the platform that I'm going to be showing today. I believe in the room, we'll actually have a laser projection on site. And that way you get a better idea of what laser projection is actually all about.

So laser projection is just one of those processes that you saw on that earlier video. And so hand layup is one process. Another process that's very similar to hand layup would be forming. There are probably some courses here at AU as well this week. A course on RTM, Resin and Transfer Mechanism.

So with that process, you're using dry fibers. You're actually not using the resin already impregnated in the material. And so for that process, very similar process. You still have to cut those dry fibers out. And then typically those dry fibers are either hand layup or laid up by a machine that would place them in. And then you would put those into a mold where you would inject the resins to pressurize that component. So those are the two kind of hand lay up processes.

Another process, of course, that's really interesting is automatic fiber placement. And this is some of the software that we have developed to drive this equipment. Of course, this machine is a multi-million dollar machine. The parts that they're working on are extremely expensive as well, because there are a lot of materials that get put on the parts. The tools that have to hold that part and support that part also extremely expensive. You could see there's a lot going on in terms of driving this machine, because on this machine it has a lot of different fibers. It has a lot of different tows on this machine.

And what we're actually doing is we're controlling which tows are actually being deposited on the machine as it rolls across those surfaces. We're also controlling how much compaction we're putting on that surface. We're also controlling how much heat is being turned on when

we run that process. And so this is an example of an automatic fiber placement machine, which is run on a piece of gantry equipment.

A similar type of process-- again, this is also automatic fiber placement. The difference with this is this is with robotics. And today you take a look at this technology, this technology obviously very expensive. And in terms of the number of machines that are out there, you're not going to find thousands and thousands of these machines out there. And that's why even today hand layup is still very popular.

In fact, when these machines first came to the market, a lot of people in the industry saying, you know what? It's going to be the end of hand layup. It's never going to be used anymore, because you're going to be able to automate this process and everybody's going to use that process. But there's still room for all of these different processes that you're going to do with composites.

And I believe over time the price on this equipment is going to come down substantially. You're already seeing the prices go down. And you're starting to see this become much more popular. In fact, especially with the robotic machines, because they can get into smaller areas and have a little bit more control.

When you take a look at the different target markets that we talk about for composites, again, at the top of the chart, you're seeing the automatic fiber placement and tape layup, and those are being used in industries, of course, like aerospace. Believe it or not, it's starting to be used and very popular in construction.

Why is it being used in construction? You're hearing all kinds of stories where bridges have fallen down, because they're using metal and they're corroding or using some other structures. With composites, it doesn't corrode. So it has a lot of properties that give it better performance. It's also used quite often in the creation of the wind turbine blades.

A lot of times they'll be using what's called tape layup instead of fiber placement. And the difference between tape layup and fiber placement, using very similar type of equipment, but there it's a big piece of tape. So it's putting out one big piece of tape along that wing blade. And usually they use that type of material when they want to deposit a huge amount of material. When you take a look at those wind turbine blades, they're tremendous. They're almost the size of an aircraft. You can actually walk inside of one of those.

At the next level, you have what we call the traditional hand layup. And of course, that's used quite often in things like automotive. But the other areas that hand layup is also being used in these areas is, as I was talking about that RTM process, where you're going to be doing forming for the parts. And so today we're really going to talk more about the hand layup process and the AFP process itself.

In addition to that, there are other processes that are coming onto the market. Well, actually filament winding has been on the market for quite some time but now you're actually seeing some new applications like braiding where you're actually using robots to actually push the part through a spool of threads that are actually braiding the parts. So that's something that's becoming a much more widely used technology.

If you take a look at the different steps that actually get created to do what I would call a full end-to-end solution for composites, where do things start from? First, you start with the design of the composite part. So at the design of that composite part, you have conceptual design, you've got the applied design and the structural simulation that's going on. And usually this is in a loop that's happening at the design stage. This is really where we're actually starting this process. And that's what I'm going to be talking about from this line forward.

Here, we're talking about a design for a process. So here's where we're using manufacturing design and manufacturing simulation. That's one of the things I'm going to be showing you today, which is called true plan. That's going to show us how the material performs for a particular process. And so what we're going to be talking about is two different processes there. We're going to be talking about doing the simulation for fiber placement, but we're also going to be talking about doing the simulation for hand layup.

And then depending on what your process is, you may go down a couple of different paths. When you talk about automatic fiber placement and ATL, one of the first things that you have to do after you do the simulation of the manufacturing process, you're actually going to need to generate the tool path. How do you drive that machine that we were just shown on the video?

And then once you generate that tool path, the next thing that you actually have to do is you have to do some manufacturing simulation. And why do you have to do the manufacturing simulation? Well, when you look at the expense of that machine that we just showed up there before, it's extremely expensive. And the tools that you're building it on are also extremely

expensive. And so if there's any point of failure that goes on, it's really critical that you catch it.

So any time a part like that actually gets generated by a tool path algorithm, you have to have a simulation process to validate that it's actually going to work perfectly. Then after that process, of course, is you actually have to drive the machine tool itself. And that's where you actually have to generate an NC code for that process.

So generating the NC code for the process is not necessarily the same as generating the tool path. And the reason for that is, just as I showed you before, you can have two different types of machine tools that are running that. One could be a robotic arm. Another could be a gantry machine. So you then have to generate the inverse kinematics to actually drive the equipment that generates the NC code for that.

If we take a different track, and we actually go down the track of the hand layup, here's where we have to do some nesting, because these composite materials are typically coming on rolls of material. You're going to put that on a cutting machine just like you saw in the very first video. That's where you're going to optimize that material and get the best efficiency out of it. Then you're going to, of course, send it down to the cutting machine itself that's going to cut that process up.

On the cutting machines, they may have a whole bunch of other devices on it, like labelers, or sometimes they will even have pick-and-place machines to help you do the kitting process. That's something that will be generated. And then once you come off the cutting machine, you could then branch off into two different areas.

One area is where you're going to do the hand layup, and that's where you're going to be guided by the laser projection to help you lay up that part. But another track that you could take is you could do a forming process, where maybe you did the lay up inside the mold. And then you're going to do an RTM processor or some other forming process that's going to go on.

Now, eventually all of these are going to meet up at the end, whether you go through the automated process or the more traditional draping and nesting process. And it's at that point, after that part gets cooked, you're typically going to run some kind of inspection on that part to validate did it actually-- did the part actually come out correct, the way that you thought it was going to be?

There's a lot of variability that goes on in composites. Just the material itself, there's some variability in terms of what that thickness is. So sometimes you actually have to inspect that part to even check if the thickness is proper, because it may not be something that you can actually control.

You could control it as much as you want, but as you build that part up, because of that variability, in terms of just the thickness of the material and the whole autoclave process itself of cooking that part, it could be a slight tolerance off. And then we actually have a very special process where what we can do is after we inspect that part, we could kind of run an adaptive process on that part to actually build it back up into tolerance.

Now, once you get past the point where you know that the part is valid and it's secure, then that part can go off to a bunch of other processes. Maybe at that point, you could run some of the Delcam operations where you're going to go ahead and doing some trimming and drilling on the part. And then maybe it's going to go to some other processes, maybe where you're painting it in the shop and so on. So this, in general, is kind of an introduction of, as I said, of what composites is all about. Any questions on that so far? Good.

So the next thing I want to talk about is something that I call the composite data model. Before we can actually start to manufacture the part, how do we know what it is that we need to do? And so to do that, what we have actually built is just this year we've launched the TruPlan product under Autodesk. Prior to this, this product was actually running on top of CATIA.

And so what does the composite data model look like? So the composite data model allows us to define the recipe of what this part looks like. Here, what we see is we see all the sequences that are actually going to build the parts up. And what does the sequence mean? The sequence is basically those steps.

Remember that first slide that we saw where we saw all those materials stacking up at the different directions? So that's what the sequence is. It's the first step. It's the first layer of material that you're laying down. And then when you go on to the next sequence, it's the next layer. Now, underneath each of those sequences, you then have plies. The plies are actually the boundaries that are making up that particular shape. And that's what you're going to be laying up.

Now, when we take a look at this, each of those sequences are actually based off of-- they're actually based off of a layup. And what the layup is, is the layup is the surface of the material.

So that dictates what the surface of the material. Typically today, when composites are designed, when you design a surface that you're going to be building something off of, you actually design it all on top of that surface. You don't actually design each of the surfaces independently.

And there are actually two reasons for that. The first reason is a composite design could in some cases have hundreds of plies and hundreds of sequences on top of that surface. And rather than building up every single surface in the design, that could take a lot of horsepower on the computer. That can make the design extremely heavy. And so for that, that's one reason why it's better practice to design it off of that surface and just have the understanding that it's going to be built up by a particular material thickness.

But the other important thing is, even if you did do that-- let's say we had infinite compute power, and we could do all of that, and that wasn't an issue. What happens if you make a change? If you make one little change on the material thickness or some of the other properties, all of those surfaces have to be recalculated all over again. So the typical way that we've designed these things are off of a particular surface.

So for instance, in this particular one, what we're actually looking at is we actually have two surfaces. There's a flat surface on the bottom, where we have four plies that are being stacked up. Then there's some core that's being put on top of that surface. And then we have what's actually the over-core surface, which is the next surface. And then there are a couple of other laminates that are on top of that. In fact, that little floor board that we passed around, that actually has three different components. You've got some composite laminate on the bottom. You've got some core between it and then another composite laminate on top of that part.

And so when you take a look at the properties of what the layup has defined in it, the layup has the actual surface that we're referencing. It has a direction of what we're defining is the build-up area, because if I have a surface, how do I know if I'm building it up this way or if I'm building it up coming down below? So that's what's defining that direction.

And of course, it also has a rosette. The rosette is the coordinate system that dictates what the origin of that is. So whenever we reference a ply to that surface, it's off of that base origin. And then when we take a look at what the definition of the ply looks like, the ply actually has a boundary that we're representing.

The ply also has the orientation that we're going to do for that particular ply. And then there's

some other information that we could put on there, in other words, to tell us how much do we want to do a thickness update as we're actually building up this process or do we want to actually generate-- do we want to displace some out of boundaries for a particular ply, just to make sure that we're in tolerance to generate some of the results that we're looking for?

So in a few minutes, I'm going to show you a slide on what that process actually looks like. And we're going to be talking about what we call strategies. So at this point, we talked about how do you design a composite part? What does that composite data model look like? But one of the things that's going to happen is as you start to build up your composite data model, you're going to start to create a bunch of these things that we call strategies. Inside a TruPlan, what we've built is an infrastructure that actually allows you to create manufacturability for a particular process.

And so today what we've done inside of TruPlan is we've created manufacturability for many of the different strategies for automatic fiber placement and automatic tape laying. And in fact, this afternoon there's a class-- I believe it's, what, 3:00, Matt? So at 3:00 is a hands-on training class, where you can actually do some hands-on training to go through this process. It'll take you through all of those different strategies on how you could go ahead and perform it. And what that's going to do is it's going to give you the feedback as to show you is this material going to work on that surface or is this strategy going to be proper for that? So that's one type of strategy for fiber placement.

Another strategy would be hand layup. How does that strategy work for hand layup? How is the material warping when we drape it over the material? But the reality is, you could have many composite strategies. Every day, there are new techniques that come up in manufacturing. And so who knows? Tomorrow there could become another strategy that comes online. And guess what? What we've created here on this platform is an infrastructure that allows us to add in new strategies on top of this platform.

And so when we do these strategies, you can actually have multiple strategies for building this part up. What if I want to go ahead and I want to simulate what is it going to take and what's it going to cost to do this in a hand layup process versus putting this on an automated piece of equipment? You can actually put both of those strategies in the data model. And what you could come up with is we come up with things that we call manufacturing configurations.

And so within TruPlan, you could set up these manufacturing configurations that allow you to

track which strategies do you want to do for hand layup? What strategies do you want to do for automatic fiber placement? And you could come up with as many configurations as you want. And that makes it easier for you as designer or the manufacturer to actually compare these different strategies versus trying one and deleting it and then adding another one.

And so the next thing I'm going to talk about is just the hand layup process itself. This is some technology that was actually built in conjunction with the OCTO team with the offices, the CTO, that's the research and development part of Autodesk, they developed the draping algorithm. And what we've done is we actually have that built into TruPlan at this point. And so what it's actually doing is it's figuring out how that material is going to drape over that particular part. It's also doing the math that's actually going to do the flattening for that particular part as well. And we'll see some solutions for that in a moment.

So this is just a video on the draping. So inside of TruPlan, you're seeing that we're going ahead, we're selecting a part. The very first thing that we're doing is we're going ahead, and we're adding a strategy. At this point, we're going ahead, and we're actually selecting what type of material that we're using. We're specifying what is the cell size when we're doing the draping itself? That's referred to as warp and weft. That's actually the size that we want to actually do the simulation for.

In addition to that, we actually want to place what we call a seed point or seed curve. This is going to dictate how we're going to do that strategy when this lays up, because when you're laying something up by hand or even if you're laying it up in fiber placement, it will make a difference where you actually start something from.

So for instance, if I try to drape something on this table, and I start at the corner over here and work my way to the end of that, it's obviously going to be more accurate over here in the corner, by the time I get to the end of that table. And vice versa, if I started on that corner and come this way, it'll be more accurate over there.

So depending on where you do that seed point with that seed curve where you guide the draping path, it's going to make a difference in terms of the draping algorithm. And this is showing you how it's going ahead and it's doing that draping in that 0-degree orientation across this part. I'm going to let those slides go just a little bit longer, because within the slide we'll actually start to see where we're going to run the flattening. So any questions on this so far?

**AUDIENCE:** When you're designing [INAUDIBLE] off a single service and then stacking a picture like a window [INAUDIBLE] were going up and you can see that doesn't it grow out?

**MICHAEL SPELLMAN:** Absolutely. Absolutely. And that's really important. When we first started TruPlan, because TruPlan has actually been on the market for some time now, but before we were actually providing the manufacturability for fiber placement and tape layup. But we were actually using another platform. That other platform already had this composite data model. They actually had built the infrastructure to support that.

And so one of the things that you have to do when you're building off of that surface is you have to have an understanding of knowing how thick the material is. And then what you actually need is you need an engine that's actually going to do what we call the thickness update.

And so what it's actually doing is it's actually offsetting those surfaces automatically for you, based on the thickness of that one layer. And then it places the next layer on top of that and so on and so on and so on. So it understands that composite data model. It also has the information, and it has the knowledge of how to build up that material.

So at any point, you can actually do what we call a core sample, where you can actually look at any location on that design that you've made. And you can actually test how thick it is at a certain location. Because when you're laying these plies down, you may not actually lay these plies down across the whole surface. They may just be laid down off of a partial portion of the surface. And so that was one of the challenges for us when we actually created this new platform at Autodesk is we had to build this new data model. We had to build this new infrastructure that provided the thickness update to achieve that. And so here you could kind of see we're producing the flat pattern as well as the draping simulation. And you'll notice that if we do the same kind of draping at 0 degrees versus, let's say 45 degrees, that solution is going to look quite different.

**AUDIENCE:** Is it going to save any [INAUDIBLE]

**MICHAEL SPELLMAN:** So yes, certainly. So the draping is definitely going to give you information that's going to tell you where the distortion is. So right now what we're doing is we're running the strategies. So the strategies are just the approach that you want to try. It doesn't mean it's a good approach. It doesn't mean it's a bad approach.

To understand if it's good or bad, what you actually then have to do is you have to run some analysis on those strategies. And so that's the next piece that would come out of that. And so the analysis will tell you all different types of information. We're going to actually get to that in a moment. You'll start to see what some of the analysis looks like. So for instance, where this left off, you could see that 45 was a little bit different than what the 0-degree orientation was.

So now that we've really gone through what I would call the design of the hand layup, we've produce some flats. We have that in the system. We've got all of these flats in the system. What's the next thing that you have to do? So we just did this draping strategy for hand layup. Well, the next thing that we actually have to do is we have to go ahead and do a nesting process to run it on the-- sorry. We need to run a nesting process to drive it on the cutting machine.

And so inside the same platform, you can essentially export all those flats that we've developed and designed inside of this part-- inside the design of this part. It will export it to any format that could then drive the cutters. And at that point, you could use any solution that's on the market to produce the nest and cut it. Or built into the application itself, you could just use the nesting technology that's in there already.

And one of the things that we've done is we've recently created a forge micro surface for nesting. And this is using that forge microsurface inside this platform. If you notice this platform, by the way, all of the things I'm going to be talking about today are all built on top of Inventor. One of the things that's kind of nice about this is every piece that I'm going to be showing you, it's all coming together in the same application.

So we're going to go through some other laser projection stuff, and you'll see that. So we had generated the nest, and then we're generating the reports that get generated from that. Those reports tell us how much time it's going to take to cut that, how much material is going to be used for that. And so you're doing that all from that same process.

And as I was saying before, this is that same microsurface that we built this on. In fact, we've built some prototypes of that same microsurface working inside of Inventor as well as working inside of Fusion.

Now, the next thing that you do after you do the nesting process within this platform is you want to do the laser projection. And there too, for the laser projection, you can do this all inside of this application. And the thing about it is this-- I'm going to be talking about two different

types of laser projection. One type of laser projection is what I call composite laser projection.

And the other type of laser projection is what I would call laser projection simulation, a little bit different. For instance, a lot of laser vendors on the market today will say, hey, I can take your composite part, I can project it on the laser. Not true. Not true. Why? Because they don't have the composite data model. If all they have is the plies that were built on that surface, guess what? They just have the geometry on the plies on that surface. They're not going to get the thickness updates that they need to actually offset all the plies off of that surface to the right height in the right areas.

And that's really, really important. Because, as I said, composites, especially building in aerospace parts, something that's going to be flying, if you get these plies projected in the wrong area just by a little bit, it's going to be off, and the part's going to be out of tolerance. So within this application, we're doing the laser projection for composites. We had already just generated it.

But now what we're actually doing is within the same platform, we're using something called Autodesk TruLaser. That, by the way, has been in the market for over a year now at Autodesk. We're going to take that composite laser projection, and we're going to push it into the simulation.

So what does the simulation do for us? The simulation actually gives us kind of a virtual world. It gives us this environment where we can actually see how the laser is going to perform on that particular part.

Why is that important? Because I don't want to take my part out to the shop floor and waste time on my equipment to figure out where should I position the laser so that it's in the proper location. Because then I'm not making the most out of my machine tool. I want my machine tool to do what it's supposed to do. In this case, I want it to project. I want them to use it for production. I would rather use a simulation to help me position things and to see what the performance of that part is going to look like.

So within here, what I could do with the laser simulation, you could see I could kind of go through things like I could show where the volume of the coverage of the laser is going to be. Can it cover that whole thing? Or maybe I need to make my stand a little bit higher so it can project, because these laser projectors, what you'll see if you go to the course on Thursday, it

has a certain range that it can actually project to.

And what you're seeing there is that's something that we call Parallax. That's showing you how good the projection is going to be. What the laser projection is going to do, the best thing-- it's all through line of sight, because it's actually using lasers to project on any 3D surface.

And so the thing is this-- if it's projecting normal to the surface, that's perfect. That's going to show up green. But if it starts to come at a sharper angle and approach a sharper angle, it's going to turn up yellow. Now, in the red areas, that's what we call Parallax. That's where you're trying to project down, that's on something so sharp that if you're just off by a little bit, actually the light's going to fall off.

And those are the areas that you could worry about. And so what could you do to fix something like that? One, if you have an understanding that, OK, that's going to happen there, you may just deal with it in this situation. Or you may actually get two laser projections coming at different angles to give you a better presentation of that part. So once again, just through the same platform, what we're able to see is we can do both of those things. We could do the composite laser projection at the same time as we do the laser simulation.

So now we're going to talk a little bit more about laser simulation. The application and everything that we do, whether we're driving cutting machines or we're driving laser projectors, we support all different vendors. It doesn't matter who the vendor is. So if there's a laser projector on the market, we support it. These are just a couple of examples of the different vendors that are out there.

This is what a simulation environment would look like inside of a TruLaser. This is where you can actually virtually simulate what's happening on the shop floor. Where do you put your lasers? This is what they do in a clean room. This is actually what it looks like. Where do you place your tools? You could see there could be a lot of different activity going on.

As I was saying before, sometimes you actually have to use more than one laser, because on a barrel like this, because of line of sight, this laser would never have been able to reach to the other side, because the surface of that part is going to block it. And so that's one of the things that Autodesk TruLaser will do for you.

This video clip will just give you a better idea of something like that. This is a situation where we've got a big wing skin. Here, within this platform, you could use any factory asset that you

have built up. You could build things like stands and projectors. You can actually even build what we call the target points.

The simulation process will actually test and make sure that the targets are located in the right location. Again, it's going to show you the proper coverage of all of this stuff. And then, of course, it's going to show us what the quality of the laser is going to look like. And again, all of this is in an effort so that you can do the manufacturing process the smart way. Do the simulation up front before you bring it down to the machine.

I see so many times that machine tools are coming out with a CAD package and some other tool on top of the machine tool. And the machine tool vendors think that's so fantastic. I look at them, and I think they're crazy. Why would you want to put an engineer on a million-dollar piece of equipment and let that machine tool stay there for five or six hours without doing anything? That machine tool should be cutting. It should be projecting.

The engineer should be on another computer somewhere else. And so, again, these are other types of simulations that you could kind of see. Based on where the position of that laser is, you're going to see that we're going to start to get extreme Parallax in certain areas that it's not going to be able to get. And I'm just going to go through this video just a little bit faster so we don't run out of some time.

So the next thing I'm going to talk about is what we're looking for when we talk about automatic fiber placement, when we talk about what kind of simulations do we want to do? These are some of the things that happen in real life. You want to take a look at what the fiber angle is going to look like.

When you're laying down this automatic fiber, you want to see are you generating any gaps or overlaps between the material itself? Do you want to make sure that you're getting the proper compaction when you're going over a ramp or a different type of surface? That's really important, because if that material doesn't adhere to the surface, what's going to happen? You're going to get some delamination that's going to go on on that part. And it's going to be a really bad thing.

You can also experience things like wrinkling, where the material is going to fall on top of itself. And you could also run into some kind of other steering distortions that are going on. So these are some of the physical phenomena that are going to go on. And these are some of the simulations that you're going to actually see that are going to be inside of TruPlan.

And so if we kind of take a look at the next slide, we can see how TruPlan is going about building up these strategies that are going to give us the analysis of how this material works on the surface that we're putting it on, along with the machine process itself. And that's what we call design for process. That's the manufacturability. That's that manufacturability infrastructure that we've built on top of TruPlan.

And so one of the things that you'll see inside of TruPlan is it has an understanding of what that material is. And when we talk about materials, there are two different things that we actually will talk about. So inside of TruPlan, you have what's called a material catalog. That material catalog is going to tell us what the thickness of that material is and what some of the other properties are for that material so we can do the proper analysis.

But then there's something else that we call the packaging. The packaging actually tells us what's the size of that material? What's it being used for? I can have some carbon fiber, and I may be doing a fiber placement process or I could be doing a hand layup process. If it's a hand layup process, it's probably a fabric or something. And so that's how that packaging would be defined. It would be defined as a fabric. And that way I would know it's a larger size for that.

But if it was a tape, I would know that it's a tape when I chose that material. So here's where I'm actually picking the strategy that I want to go ahead and use. And after I do that strategy, I could then go ahead and do the analysis on what kind of mesh did it make? What did the fiber path actually look like? So it had generated-- just from doing the strategy, it's going to generate that fiber path for this process.

The next thing that you could do is you can actually go ahead, and you could run all the analyses on it. And there are quite a few different analyses on it. There's a gap analysis. You'll see this angular analysis, this compaction analysis, total length analysis, wrinkle analysis, and steering analysis. A bunch of different things that you can actually look at, a bunch of different phenomena that you can actually look at when you analyze this particular part.

And so with that feedback, that's where you're going to see, if we were doing this hand layup process, when you said, do I need to cut this piece or do I need to put a dart in this piece? That's where the analysis is going to give you the feedback to tell you, yeah, maybe you do need to do that.

And when it comes to hand layup, I know right now we're on fiber placement-- you might actually have to cut that part out for two different reasons. One might be because the analysis told you that that part was no good, that that strategy was no good. So therefore you had to break it up. But other times, you may actually have to break that part up, because you don't have the material that's wide enough. We'll talk about that one in a minute. Any questions on this so far? OK.

**AUDIENCE:** So if you're simulating say ply 100, doesn't this software have to do all those calculations to build up the surface before it does that analysis? And does that take an inordinate amount of time or is that pretty quick?

**MICHAEL SPELLMAN:** Yeah, so you definitely have to do that build up. You absolutely have to do the build up. One of the things that's special about this platform is the way that we do the thickness update. We're able to achieve these calculations extremely fast. So it doesn't take an inordinate amount of time. Obviously, if you have thousands and thousands of plies, it can take some time. But this process is actually really, really fast.

When we've done benchmarks against some of our competitors, where maybe they're taking five minutes, we're doing some of these calculations in seconds. And it has to do with some of the math that we're doing. We're actually doing some processes using discrete math versus using NURBS or something like that. So we're able to achieve those things really quick.

One of the other things that's really important within this process too, you'll notice that there's a little icon up there that says Automatic Update. Just as you said, that 100th ply, you're going to calculate, well, what if I go ahead and I make a change to the 10th ply or the 11th ply or I change something in the geometry?

The way the platform has been built, it automatically knows that you've made an engineering change or a design change on any of the parameters that are going to affect that calculation. And it will automatically do an automatic update for you. So it's not as if, if you make that change, you have to repeat it on all of those other plies. It will just do it all instantaneously for you.

And so one of the last things is, you can imagine if you do have hundreds of plies, how do you make all the changes to the stuff? Does that mean you actually have to drill down to each additional ply and make those parameter changes? So one of the things that we've built into the platform is something that we call a strategy table. It's a pretty cool tool, because what it

allows you to do is you can do a mass edit on any one of those plys. And you could change any one of those properties. And what it could allow you to do is you could do also advanced filtering on the ones that you're selecting.

So for instance, let's say you want to change some of the strategies on all the plys that are running at 0 degrees. You go ahead and do a filter on all the plys that are 0 degrees and then just change those particular properties to it. Well, let's say you want to swap out something that has a particular material? You could go ahead and select that particular material to filter by, and you could go ahead and change that. And so that's a really good tool to allow you to do that.

The next thing I'm going to show you is TruFiber. So TruFiber is what's actually generating the tool path for the automatic fiber placement. And so then the first thing that we have to do is we actually have to build up the equipment itself. We have to define all the different devices that we have that build up the equipment, like what are the parameters that are happening on the roller? It's

Also going to build up, if we have any probing operations, if there's a head on the machine, it's going to go ahead and it's going to allow us to build that up as well. So maybe the machine has got a probe operation. Now, once you go ahead and you define all the equipment, that can be stored away and that can be reused. But that is something that's important to build up. So you're going to end up building a library of these things. And then you can reuse them at any particular time.

So here you see we're just kind of building that up. And so here we're assigning that to a machine. We assigned the head and the roller to the machine. And then once we finally get through that process, that's when we'll be able to start to actually assign it to a particular process or a particular part. Any questions so far?

**AUDIENCE:** Can you do that as a consultant [INAUDIBLE]?

**MICHAEL SPELLMAN:** These pieces of equipment are very sophisticated. So in terms of this type of stuff, believe it or not, that type of stuff is fairly easy, because the building up of the parameters of that is pretty straightforward. The thing that you obviously need to have, though, is you need to have the geometry of the equipment itself. And you certainly need to have the kinematics of the machine. So you do need a good starting point.

So in many cases, the machine tool providers will give you that. They need to kind of give you that information or if they don't give you that information, you've got to figure out how you can go ahead and calculate that information. So actually building that stuff up is not that difficult. What's much more difficult is building up things like the post-processor, things like building up the inverse post-processor or the reverse post-processor where we're going to do the simulation. That's more difficult. And so certainly on occasion, we can do that as a consulting effort to build that up.

And the thing is too, even if you had two of these same machines-- supposedly same machines-- they would never be the same. There's going to be something that's going to be slightly different from one of them. So you would definitely want to check all of those values that you have on those things to make sure that that's correct.

Here, once we've assigned the machine to a particular process, what we're doing is we're doing a fiber operation right now. This is a very, very complex operation, a lot of different parameters that are going in as part of this operation, a lot of different things that we could do here. And we'll talk about that a little bit further. In fact, you'll be able to get a little bit more detail on that in the class that we have this afternoon, where you'll go through some of that stuff hands on. But once you do that, then you've actually generated the tool path for it.

And then once you've generated the tool path, you can also do what we call tool path editing. So within the application, there are quite a number of tools that will actually let you edit that tool path itself. So you could go ahead and you could actually start taking a look at what you've generated, and then you could kind of go to town, like doing things like reversing the courses, maybe changing the compaction on something. So this is just going to show you some of those tools that you can use to achieve the editing process for that.

And within here too, of course, you could-- as we're building the tool path, we can do kind of-- I wouldn't call it a full simulation, but what we're actually doing is a simulation of the head. So inside of TruFiber, we're not actually building the full kinematics of the machine. We're actually just building the head itself, the head and the roller itself. And that's what we're checking right now for collision.

So this is a nice feature that's kind of inside of TruFiber, where we have the graph, which is actually telling us how much the head actually has to tilt. Because on these heads, one of the things that's going to happen is they could have a heater on the back of the head. And as the

head is rolling over that surface, you may have to avoid that heater or some other components that are off the head.

So typically when we're generating the tool path at this point, it's doing automatic collision detection as it generates the tool path. A lot of other packages on the market will actually generate the tool path, and they won't do collision [? SEAM ?] avoidance until the simulation process. This will do this collision avoidance on the fly and check that for you. But it's only looking at it from the perspective of what you've got built into the head model that you've built in here. It's not necessarily the same as a full-blown simulation, which we're going to see next.

**AUDIENCE:** So you could have a [INAUDIBLE]

**MICHAEL SPELLMAN:** Because we're actually just placing the roller over the machine. We don't necessarily need to know what machine is actually driving that. I can take this tool path, if I want I could put that head on a robotic piece of equipment. I could take that head, and I could put it on a gantry machine. If all I'm doing is I'm making sure that that head is not interfering with that surface, then I can check for all the collisions, and I could do the maneuvering of the heads over that surface.

So I don't necessarily need to know what's happening up here, because that's not coming into contact with the machine. Believe it or not, that's one of the benefits of this, because if you go through this process of programming the part, and theoretically you had machines that I would call compatible, you could theoretically take that same thing that you've generated out of TruFiber and just write a post that goes to one machine and write a post to another machine.

And look, that would be the holy grail in terms of fiber placement. And that would be to be able to drive it on multiple machines without having to modify anything, because it takes an enormous amount of work to qualify and certify that a program is absolutely correct. And so that's the advantage of what TruFiber offers. It gives you that potential to be able to drive it on other pieces of equipment that, as I said, are compatible.

Why do I say compatible? If I've got one machine that's putting out eight tows and another machine that's putting out 16 tows, I can't take a course that's been generated for one and use it on the other. OK? Or if I've got some other different types of hardware in process that I'm doing in the driving of that tool path on one versus the other, they wouldn't be compatible. I would have to actually do a different type of tool path. But if they were, even though they're different machines, different robot, different gantry, I can actually drive the same program

through the same thing.

And when we generate the post-processes, we do them in two ways. We can generate an aft output, which actually gives all the information that's necessary to drive that piece of equipment. A lot of times machine vendors want to write that stuff themselves, because they want to protect maybe some of their own IP. And they just take the source that we generate, and they write the post themselves. Or we'll actually write the post to the machine tool itself. And that's when we need to know a little bit more information about the machine.

One of the other things that's really important inside of TruFiber as well is we have a unique thing that we call process zones. So as we're defining the tool path, we can also define these process zones. The process zones are going to be areas where maybe we have a ramp that's going on. Maybe we want to do something special as the head approaches that area.

Maybe we want to give it some extra compaction or maybe we want to slow down the feed of the material or speed up the feed of the material that's going across the roller so that we get the proper compaction in that area. And so there's a process that we could go ahead and we could define the process zones and associate that with the ply. And then we could do that operation. Any other questions so far? Go ahead, Martin.

**AUDIENCE:** The graph that you showed before, you have it saying sort of reported for steering and post course [INAUDIBLE] you could see graphically what your steering is for a particular course [INAUDIBLE].

**MICHAEL SPELLMAN:** I don't believe we have anything like that at this point, no. I think it's more right now that graph is for tilting, but I don't see why we couldn't have a graph of that, where you could see if there's some steering that's going on. And that way you could see if you have more-- wow.

[HIGH-PITCHED TONE]

Not me. OK. But that could be another good use of that. And you'll see more naturally in the simulation, though. In the simulation, we do have a way to show that, a neat way to actually show you what's going on there. And that may make a little bit more sense.

So this is TruFiber simulation. Inside a TruFiber simulation, this is actually something that right now is inside of a different platform. Our goal is at some point to put it within the same platform. But what's really cool about TruFiber simulation, it has all the capabilities to set up all

the different types of connections that you may want to go ahead and connect up, things like rigid connections, rotational connect joints, translational joints, tripod kinematics, and two-column kinematics.

So this is what we're doing here, is we're actually defining the kinematics of the machine. All you have to do is bring in the assembly of your machine tool. As long as those components are built up as subassemblies, they will actually come into TruFiber simulation as one unit. And then what you could do is you can independently set up the kinematics of each of the axes. And then you can actually test them out. You could kind of jog the machine around and see how it's actually running. And this is the process that you do to actually build up the kinematics inside the simulation engine.

And just like the same question you asked before, is this something that you would do as a consulting? This one maybe is a little bit more difficult than the other one that we did because this is more Before, we were just doing the head model, a couple of parameters here and there, and you have overall sizes, where this takes a little bit more effort in terms of doing it.

But the ultimate goal is, at some point, if we actually have tie-ins to-- in fact, Inventor actually does a really good job of actually allowing you to actually build the tools inside of Inventor. And we could actually read that directly in, and we would have the kinematics automatically, if it originally came from there.

So here we're, as I said, we're just kind of building up the full kinematics of that machine. And just, again, an example of what some of these things look like. These are the different types of connections that you may have in real life. This kind of demonstrates a different kind of kinematics that are part of this engine. So those are the connection types.

This is an example of the two-column kinematics. Here is another example of what I call the tripod kinematics. All of these are all capable inside of TruFiber simulation. And then this is where we're actually-- now what we're doing is we're actually bringing this in along with the work piece, and we're driving this inside the NC code. So here you can actually lay out your work piece on side that equipment.

So all that machine set up that we've done in that previous slide, we just refer to that machine, and we bring in our work piece, and we bring in the NC code. And actually what we're bringing in, is we're not just bringing in the NC code, we're actually bringing in what we've gone through our reverse post-processor.

That's really important, because what we're doing there is we're actually generating-- we're actually parsing that NC code, actually turning that back into tool path inside of our fiber data model that describes the tool path. And we're actually doing all the timing calculations, because that's where we have information on the accelerations, the decelerations of machine. And that's what gets actually brought into the simulator.

Once you've brought that in, we then have different ways that we can actually show the tool path. So this is where we can kind of set up the different time intervals. And we've got something called a look ahead. If you're looking at it right now, you're seeing the full tool path. So essentially, what you could do is when you drive that tool path, you could space out how far you want that tool path to actually be. You could say, hey, I want it to be 100 inches forward from where I'm placing it down or I want it just 10 inches from where I'm placing it down.

And as we're actually displaying that tool path, we've got a couple of other interesting things that we can do in terms of displaying that information. We can actually show a colored ribbon of that tool path. And that, Martin, that's where, when you asked about the steering or stuff like that on that ribbon, is through a visual effect we can actually show you some of the effects of that tool path. What's the acceleration? What's the velocity? Maybe what's the steering direction that's going across those areas? That's where you could get more of a visual effect and see where things are going to thrash.

When we're going ahead and, again, we're specifying the tool path. That's where, as I said, we could change that look ahead. And here is where we're showing how the material is laying over. We can see how many tows are being placed down. As we're going through the simulation, we can also do things like look directly at that NC code.

So we could really jump on any line on that NC code. And this is right now with displaying the full tool path, but with just a simple change, I could change that look ahead. So you could see how far ahead it's going. So you don't have to look at the whole entire tool path. That's where you can make some of those changes. And at any point, you can really jump ahead to any portion in that code.

So this has been extremely beneficial to us, this tool patch generator, because really what it does is, not only will it read the NC code that's been generated by anybody else, but it also proves out our own post-processors. It also validates that our post-processors are correct. So if we've made any mistakes when we generate the inverse kinematics to drive that machine on

this piece of equipment, we could see what's going on with it.

Also built inside of here is collision avoidance. So it will do a full collision avoidance at this point with anything on the machine or the work piece or the tool. So you could go ahead, and you can look for any of those things. And that can be done in a couple of different ways. You could stop it at the first collision or you can actually get a report of all the collisions that are going on.

And then finally what we can do within this, we can get full-blown layup statistics, where we could kind of get a report of the various costs that are going on in that piece of equipment. And then finally, just as an example, this is just another simulation that's going on. Some of the things that we can do inside of here, when we display the actual fiber inside the simulation, what's really unique about the simulator is it's we're doing an additive process here.

So we're actually building up the material as we do the simulation. And there are a couple of ways that we could do that. We can actually just show the tool path of where the head is. We call that the ribbon, where the material is laying down. That's where we actually think it is based on the position of where the head is moving. But we know that we're actually giving it more force. We're giving it more compaction when we actually roll that head across the surface.

And believe it or not, the ribbon may actually be going slightly below the surface, because we're trying to actually compress the head up against that surface. So we can actually project that ribbon onto the surface that we're going on. And that's what we could do the simulation on, to show us where it's actually physically contacting that.

And then the third type of operation is we could do the buildup of the material of it as we do that simulation. So it does that same projection down to the surface, but now a projection to the surface plus all the courses that came before it. So any questions on that so far? Go ahead, Martin.

**AUDIENCE:** Can you export inspection data from the composite [INAUDIBLE]?

**MICHAEL** Inspection data. So tell me what you mean by inspection data.

**SPELLMAN:**

**AUDIENCE:** Basically, that XML file and all your tow starts and stops and your core set lines and all that jazz, right? So if you have automated inspections [INAUDIBLE] then you can be able to

validate that [INAUDIBLE].

**MICHAEL** Go ahead, Matt. You go.

**SPELLMAN:**

**MATT THORNE:** So in the simulation, one of the things in the video is there are a bunch of events that are locked. So as you export that file, we do the inverse kinematics into the simulation. It logs all those [INAUDIBLE] events [INAUDIBLE] starts and stops into the simulation. So you then look at that information, jump to those pieces of information [INAUDIBLE].

**AUDIENCE:** Which is fine. I get that. But it's a matter of timing it to the actual shop inspection, right? Because somewhere down the line, someone's going to have to buy off this part at the shop. And since the tools that you're using [INAUDIBLE] program, the simulation program, it needs something down in the shop for them to actually say that everything that we did is good.

**MATT THORNE:** Right. [INAUDIBLE] boundaries for--

**MICHAEL** You want to repeat that. What--

**SPELLMAN:**

**AUDIENCE:** I don't know. It's not [INAUDIBLE] boundaries, but he wants later projection of like the tow direction to see how--

**MATT THORNE:** Essentially just a list of all the data that were keeping internally right now, which is essentially just an export of the information we have, just so you can see it and inspect it on the shop floor.

**AUDIENCE:** Well, it's more-- see, it's more of a-- if you look at it like in relation to [INAUDIBLE], right? You export an XML file, right?

**MICHAEL** Right.

**SPELLMAN:**

**AUDIENCE:** It's all the data that you need, then you can have photogrammetry and all the fancy laser scanners and whatnot actually sitting on the machine while you're laying it up, scanning those individual codes to make sure that we're actually getting [INAUDIBLE].

**MICHAEL** Oh, OK. So what you're asking for is you want to know the location of those things so that  
**SPELLMAN:** maybe some other devices can do some things on that. OK. Gotcha. So one thing I will tell you

this-- is when we were looking at the delays of projection inside of TruPlan, for one thing, we were not just projecting hand layup. We can also project the courses. So that's one of the cool things about it. Because it's all on the same platform, that same laser projection could actually project any of those courses or any of the other information. So that's actually inside of TruPlan. I know that may be--

**AUDIENCE:** It's not exactly the same, because--

**MICHAEL** Right. Understand.

**SPELLMAN:**

**AUDIENCE:** --it's not all laser projected for all the [INAUDIBLE] scanners and stuff.

**MICHAEL** Sure.

**SPELLMAN:**

**AUDIENCE:** So it's basically the source data?

**MICHAEL** Yeah. It sounds to me like what you're looking for is a post-processor for something else or

**SPELLMAN:** something like that. So that's essentially what you could do. We have this data model, and I suppose you could write a post for this other tool that wants similar information.

**AUDIENCE:** Correct. Right.

**MICHAEL** Yeah.

**SPELLMAN:**

**AUDIENCE:** So the theory is, though, that now that you're posting that data for the inspection program, you may have alternate [INAUDIBLE] in the whole [INAUDIBLE].

**MICHAEL** Sure.

**SPELLMAN:**

**AUDIENCE:** But you also, when you're running simulation, also have that exported inspection with data. When you're running the simulation, you want to actually validate the simulation and use that same inspection data that you're sending to the machine. So you're in reality checking exactly what--

**MICHAEL** Yeah.

**SPELLMAN:**

**AUDIENCE:** --[INAUDIBLE]

**MICHAEL**

**SPELLMAN:**

Understand. Yeah. So, again, I think that's-- right now, the generic output is an apt output, which literally has all the information inside of it that you're looking for. It's not necessarily an XML output, but I don't see why we couldn't convert that into an XML format that you could then derive--

**AUDIENCE:**

[INAUDIBLE] the tool center line? It doesn't have all the tows and the--

**MATT THORNE:**

It does.

**MICHAEL**

Actually it does. We embed all of that information in the app.

**SPELLMAN:**

**AUDIENCE:**

OK.

**MICHAEL**

**SPELLMAN:**

Yeah. We provide all of that information in there. So that kind of completes what we're doing inside of TruPlan, TruFiber, the platform. But one of the other things that we're doing as well is we've got a lot of tools that run production. So the nesting that we showed inside of TruPlan, it's kind of basic nesting. It's a tool for the designer to-- in composites, it's very popular to produce a part and generate the NC code, because that's all you're interested in.

But what if you're running full-blown production? What if you want to start to mix parts, and you want to drive the shop floor? That's when you may want to use some other production tools, and that's where you would use something like TruNest, which has got its own platform.

Once again, there's another class that's going to be hands-on training on that for the hand layup. It's going to talk all about TruNest, which is going to tell you how to cut all these different types of materials. When we drive TruNest, we're also of course driving all different types of cutting equipment, generating things like labels.

I think somebody asked here before, what about cut pieces? How do you know how to cut the parts up? Remember I said that there may be two reasons to cut a part up. One reason might be that the draping gave you information that said you had to put a dart in, because you were going to get a wrinkle unless you needed to.

But in other cases, you may have material that's just too narrow. The part is just too big. So

one of the things that TruNest does is it can automatically generate the cut pieces and generate the labels on all those individual cut pieces for you on the fly and also manage the fact that it's not going to overlap those cut lines from one layer to the next. And then there are a lot of other capabilities that are built into that logic, like doing common line cutting and, as I said, the labeling and can do things like actually choosing the best material with.

The other thing that we do as well as part of our production solutions is we talked about the kitting process before. When you go through the kitting process, you actually have to pick those parts off the table. And what you want to do is you want to stack them up so that you could then hand it off to a layup process. Well, you could do this kitting process in a number of different ways. You can actually use laser projection to assist you in terms of doing that kitting.

But you can also use devices like pick and place machines where maybe the robot is actually going to pick and place. So here's the hand layup. The laser is guiding the operator to the next part to pick up. It's giving him a tracer line to go to the next part. But here's where a robot is actually picking the parts off the table. And it knows how to pick those parts up and stack them on top of one another, regardless of what the angle is and so forth. Because it knows what the layout is that we did inside of design.

In addition to that, one of the things that we talked about on the very first slide is tracking material. You kind of saw that material tracking that was going on inside that process flow. Composites has a life. If you take a look at that part that we kind of passed around that is the Autodesk A, if you leave that out of the freezer for a certain amount of time, the material is going to go bad. Something like 300 hours outside the freezer, material is going to dry up. It's not going to be useful anymore.

So one of the things that we actually have to do is we have to track the life of the material. So we actually have a special process where, within the TruNest production platform, we can actually use RFIDs to track the material in and out of the freezer. And then we can track it coming to the cutting table. So when we bring the material up to the cutting table, it will only load that nest on that cutting table if it matches the actual material that it's good for.

Then, of course, we generate the optimized nesting. And then we send it over to the layup area where we're also tracking each individual ply. Because once a ply gets removed from that roll, it has a life of its own. And the life of that ply has to be tracked through the life of that part until it gets up to the autoclave. And we keep a history and log of that inside the relational

database, inside of TruNest, so that you will always know the life of any part that's going all the way up to the autoclave.

And then finally, I talked about a process before about how do we go ahead and inspect the parts? How do we check the quality of the part? This is a very interesting process. This is actually a process that I've got a patent on with Autodesk. This is the ply compensation process.

And essentially what we're doing here is when you build up a composite part, a lot of times what will be done is you will overbuild the part, and you'll take that part on a really expensive six-axis machine. And you'll actually mill it down so that you get into the tolerance, and you get the right thicknesses of that particular part.

With this process, what we're actually doing is rather than milling it down and using all of this expensive tooling to support that part and using this really expensive milling machine, is we're using the Mapis laser scanner to scan the actual thickness of the part. We actually scan the thickness of the tool, and we compare it to the theoretical of the part. And then what we do is we pass it through our compensation engine. And without any recurring engineering, it will automatically generate a manufacturing work package to build that part back into tolerance.

Now, why is that important? That's really important, the recurring engineering, because every single part that you build in composites, if you're worried about the thickness, it's going to come out different from one another. They're never going to be the same. It's like a snowflake, OK?

When you go ahead and you make that part, it's going to be a little bit different. And that is because of all the instability that you have through the process. You don't know precisely how thick the material is across that row. You have a tolerance, but it's going to be a little bit different.

And when you put that in the oven as well, all the instability throughout the whole manufacturing process, it's going to lead to a slight difference from one portion of the part to the other. So once you do that process to scan that part, it's going to compare it and, again, it's going to do that non-recurring engineering automatically to generate a work package to drive the cutting device that does the nesting and then to drive the laser projection that's going to help you lay up that part and bring it back into tolerance.

**AUDIENCE:** Go back into the autoclave then?

**MICHAEL SPELLMAN:** You would then have to go back into the autoclave again, yes you would, if you wanted to build that part into tolerance. But what's the-- here's the difference in the choices that you have. You could do that process, and you already have the equipment already on hand. You've got the hand layup, you've got the laser projections, you've got the autoclave.

Take that same process and take that part and have to put it on another expensive piece of tooling on a five-axis machine, that tooling alone is going to cost you an enormous amount of money. And then that six or five-axis machine, that has to be super precise. That's going to be really expensive as well. And this is actually a process that-- this was the process that we won our first innovation award at JEC.

And by the way, that was in conjunction with Lockheed Martin. Lockheed Martin actually has a patent on the manufacturing process. We have a patent on the software. And saved them millions and millions of dollars on that process, because they didn't have to buy that expensive equipment. And they didn't have to buy the expensive tools to build that particular part.

**AUDIENCE:** They're adding more materials [INAUDIBLE]

**MICHAEL SPELLMAN:** Just to put it in tolerance. And this is a situation where they were really concerned about the thickness, because if you're mating parts and you're putting them together, you've got to be concerned about how those parts are going to come together.

Another solution would be you use something like liquid shim, right? No problem. Liquid shim, it solves everything. But guess what happens? It makes the part really heavy. But now, if you just add the tolerance where you have to, the part's much lighter. Much better approach. So any questions on anything that you've seen so far? Any other questions?

So if you guys do come up with no other questions, everybody understands, because I'm going to do a test right after this, you know? You guys got it all? So if you do have some questions throughout the day, we're going to be at the answer bar all week. There's going to be engineers there that can answer your questions.

By the way, this is Matt Thorne. He's the PM for composites. So thanks for answering some questions there, Matt. And Matt also has a class later on today at 3:00. It's actually hands on training for this process. So if you want to get in there and kind of play with the software and see how that process works, I suggest that you go to that. We also have a composite

roundtable that's going on. I believe that class is at 4:00.

**MATT THORNE:** 5:45.

**MICHAEL SPELLMAN:** I'm sorry, 5:45. So do a search on composites, and you'll find the different classes that we have. We also have a final class on Thursday, which is going to go through the hand layup process. And that's where you could get to see some of the nesting technology. And you'll get to see it-- to take a look at the laser projectors right up close as well. So if there are no more questions, thank you very much. Appreciate it.