Future of Manufacturing Business: Role of Additive Manufacturing

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Lecture-23
Design for Additive Manufacturing (DFAM) for Metal Printing

Hello, good morning. Good afternoon, everybody. This is Vaman Kulkarni and right now a consultant. But before this last 2 months back, I retired as director from Honeywell technology solutions. I was with Honeywell for last 14 years as responsible for all the mechanical systems and before that I was with the gas turbine such establishment DRDO for 21 years. So, that has been my quick background.

So, today's topic is on the design for additive manufacturing, popularly known as DfAM. This is very relevant, because additive manufacturing is becoming more relevant in the current situation and scenarios, it can bring a lot of benefits. So, we will see some of that, and then mainly concentrate on the approach which we need to follow and the tools which are available for the DfAM.

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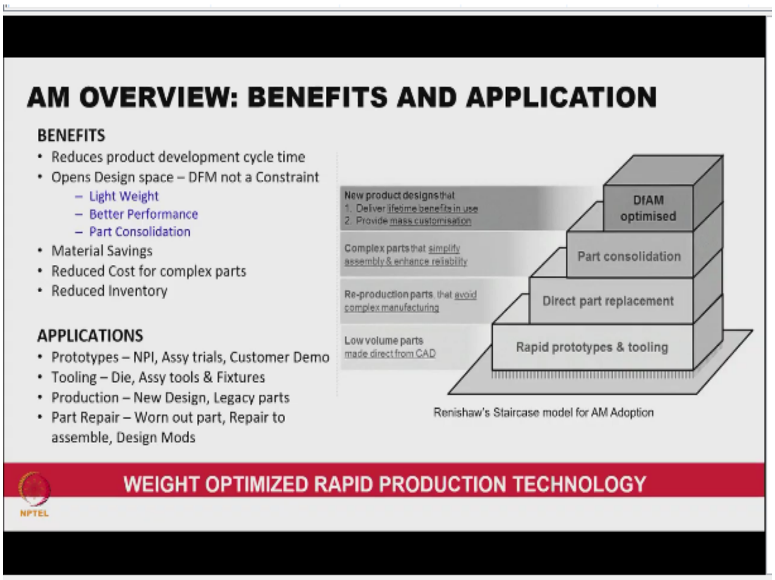

Quickly looking at the benefits of additive manufacturing overall. It definitely reduces the cycle time for product development. So, we can quickly make the prototypes and test it, validate it, and then make quick design changes and then finalize the design. So, that is a big benefit of additive. In addition to that, because of the process itself, it enables wider design space. It opens up the design space, because the way it is done is we are building the part layer by layer using the CAD model.

So, we do not have as such any manufacturing constraint which used to be a bigger need to be considered earlier when reducing doing the design and because of that, we can design a lightweight part, we can get a better performance and then we also can consolidate the part. So, that it reduces the assembly related challenges as well as the time involved in the part in the assemblies.

Definitely it is almost like 100% of the material is used to build a part, there is we are not going to take out any metal material except for the some of the finishing things, it could be as high as 95 to 98%. The complex parts, which used to have a lot of tooling requirement or the casting and forging things. So, that is disabled as and hence we get a better cost advantage through the additive manufacturing.

We can reduce the inventory because we can build the part on demand. So, the inventory related cost can definitely come down. That there are quite a few applications I talked about the prototype earlier, we can also build quickly the toolings which are required, either for the casting or the forging related dye tools, as well as the assembly and fixture tools. So, those are the additional benefits we get, we can quickly take advantage of additive manufacturing.

New designs that is where we are going to concentrate today and converting that into a production thing both for the legacy parts as well as the new product designs. We can take advantage even for the production of these things. It is also been used today for many of the part repair activities for both worn-out parts, as well as some deviations would have happened during the regular manufacturing and then we can address that as part of the part repair activities.

The right side, I would like this chart, which is from Renishaw’s Staircase model, which clearly talks about the applications. On the top you can see the design for additive manufacturing. So, that is where we will concentrate to more today. It can really open up the design the benefits of additive manufacturing, rather than just taking the existing part and then re-manufacturing.

There are advantages of that which you can see in the bottom today. That is without any constraint that is being deployed. We need to address some of the replacing the direct part replacements. That is due to the sum of the supply chain related challenges, which we have and then which we can overcome by using additive manufacturing, and there could be a lot of issues in the today's assembly related challenges.

So, without changing much of that design, we can consolidate and then come up with a design. There are some good examples of those applications.

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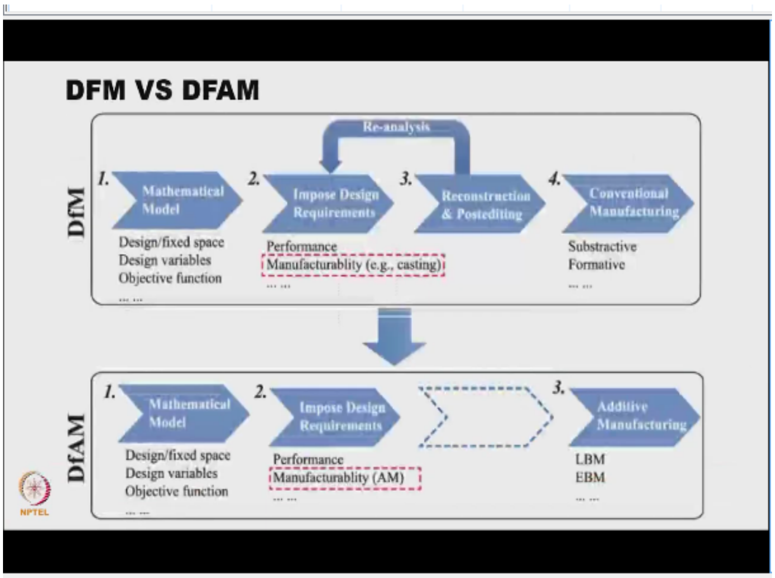

So, we have been familiar with design for manufacturing for the conventional things. And now, we are talking about the design for additive manufacturing. This chart shows the basic difference between DFM and DfAM. Typically, while designing itself we consider the manufacturing related inputs and the constraints and then come out with the design, but when it is reviewed by a manufacturing expert. He might again give some more additional input saying that we need to simplify certain things.

Because it is difficult to manufacture all the yield could be very low when you do it using a conventional subtractive way of manufacturing. So, in the DfAM many of those things are removed. In fact, you can see that the step 3 is totally removed from the DfAM and in the design itself, we have to unlearn some of the constraints which we put for ourselves as designers while coming out with the design. So, that is the major difference between the DFM and the DfAM.

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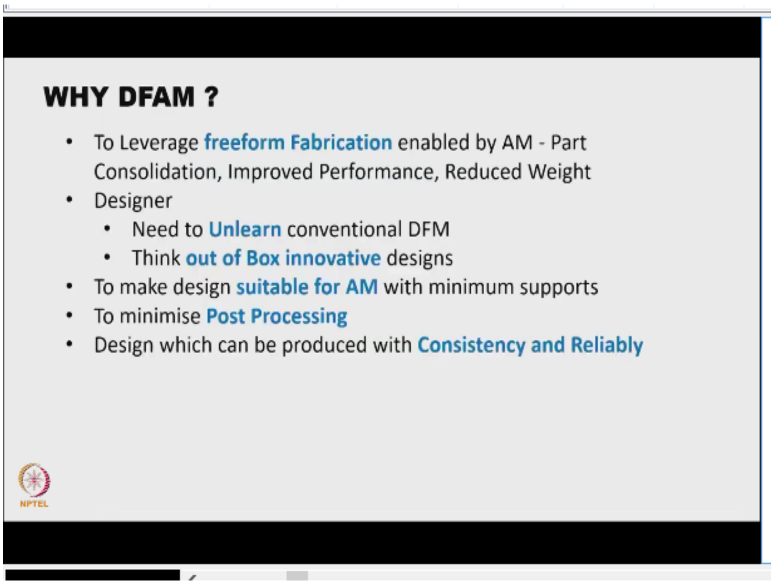

Why DfAM? As I told there are quite a few benefits of additive manufacturing, if you really want to make best use of additive manufacturing a DfAM plays a big role. The basic advantage is it is a free form of fabrication, which AM allows. So, we can leverage that to make either a part consolidation or come out with a design which gives an improved performance, it could be in terms of the losses or the efficiencies, which you can provide.

This we are not able to do it the conventional things because of the manufacturing constraints. We can also reduce the weight considerably by having topology optimized parts as well as lattice structure. So, these are the things which can is possible when we deploy the DfAM. The key thing as a designer is we have to unlearn some of the things which has been taught to us as part of the DFM activities.

Because additive manufacturing, we can come up with the out of box innovative designs. There are additive manufacturing related inputs which the designer needs to consider especially when he is designing gait, he needs to ensure that there are minimal supports, especially in the overhang regions where we need to give the support, how we can minimize that, because those are the supports which we need to take it out.

And also, it is a wastage of material and we may have to do some post finishing operations where we provide the supports. So, keeping that in mind, we have to ensure the design itself. So, that we can have the design with minimum supports and we need to ensure that there is a minimum post processing needed to finish the product. We need to ensure that when we come out with the design, the part should be manufacturable consistently using the additive and it should be reliable.

So, this is one of the questions which is being repeatedly asked for additive manufactured parts, but if we have a design addressing that, then we will be able to address most of the questions which comes out for the additive manufacturing.

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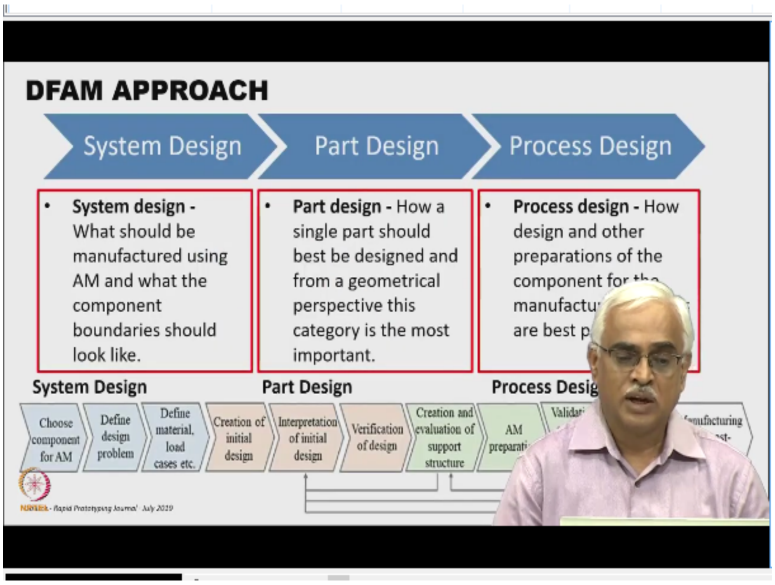

So, let us get into the details of the typical DfAM approach. The way I have classified this DFAM approach is the first one is the system design. The second one is the part design itself and the third one is the AM process design. In the system design, it is basically we choose a part which can be produced through AM and what are those component boundaries for this component.

So, the problem sort of gets defined as part of the system design. We also look at the interfaces, and then the bigger assembly where it goes in. So, that we can consider the consolidating the parts and the material what could be used. So, it is more like identifying the part defining the boundaries, that is what is done out of the first step, which is a system design.

In the part design, we start actually creating the initial design. This includes the conceptual designs, and then carrying out some of the analysis for either for the flow thermal or temperature related or the structural related analysis to make sure that it meets all those requirements. And then we also verify that design, and before we start looking at the additive manufacturing, way of producing these parts.

So, that is all part of the part design. In the process design, we take this design, and then we evaluate it for making it out of additive manufacturing. Then we also start looking at what is the best way to produce this part a what is the ideal orientation, which will ensure that it will have some minimum supports and then we also optimize in terms of the build time and the cost, what is ideal.

And maybe AM simulation will help us to make sure that the part can be produced with quality and without any failures as you move along. So, there are same simulation tools, which helps us. After doing all that, then we start producing the parts. So, that is typically the overall approach.

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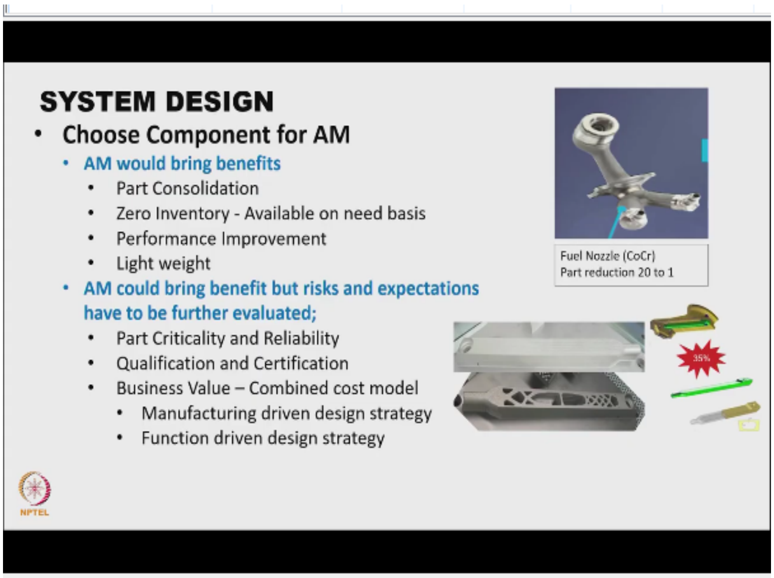

We will get to the little more details of these things. I will talk about few pointers as well as with an example here and then at the end, we have some couple of case studies, which we can quickly run through. As I told you, the first thing is we have to choose a component for AM, keeping in mind what benefits AM would bring, if we make this part as an AM produced part. We talked about the advantages earlier.

So, we need to ensure that some of these things we can incorporate in the design, then we say that as this is the good part to be printed. In some cases, we may select a part, but there could be some risk which will be involved in this. Basically because of the criticality of the part and then we may have some questions regarding reliably producing this part. Finally, in especially in the aerospace is scenarios, the part needs to be qualified and then certified, there could be more effort and testing involved to validate some of those things. It also should be aligned to the organization's business value.

That is where we come up with the cost model and then see that it is aligned with our manufacturing and manufacturing strategies as well as the function driven strategies where it brings in some of the differentiators to provide a better performance compared to the competitor products.

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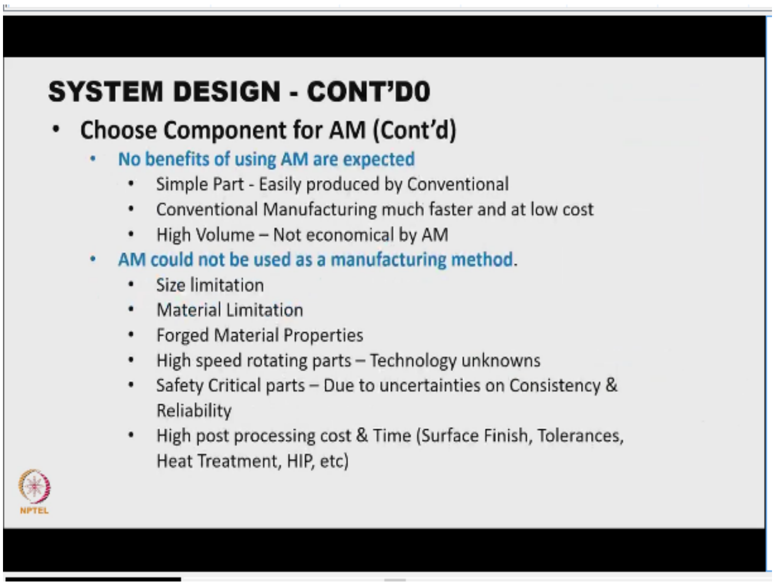

So, in some cases, we see that there is no benefit of using additive manufacturing. It could be a very simple part and it can be done very easily with conventional manufacturing. It may not be cost effective to go through the additive approach and if we go through additive it could take more time compared to the conventional things and especially if it is a high-volume simple part, then it may not be economical to produce it by AM.

So, in that case, we may say that additive is not suited for that component. In some cases, we see that the part itself may be very difficult to produce it out of additive manufacturing. It could be because of the today's size limitations what we have the build volume typically what we can do today is about 400 millimeters by 400-millimeters by about 500-millimeter height.

Of course, there are new machines which are coming up which can handle up to 1000 millimeters also, but still to be established. There could be a material limitation also, today materials are limited to nickel alloys or titanium alloys, aluminum alloys, stainless steel, anything which is related to the magnetic alloys and hardened steel could be difficult to do it out of additive manufacturing and because of the strength related things, conventionally it is done through a forging.

We may not be able to match the material properties with additive manufacturing or high speed rotating parts that are still technology needs to be established, especially in terms of the centrifugal forces and then**,** how it works out on the additively build parts, keeping some of these things, we may say that, they could be very difficult to produce these part out of additive manufacturing.

We also have to keep in mind the post processing which are involved. If there is lot of post processing to be done on an AM build part to meet the final product requirements, then also it is not worth pursuing out of additive manufacturing.

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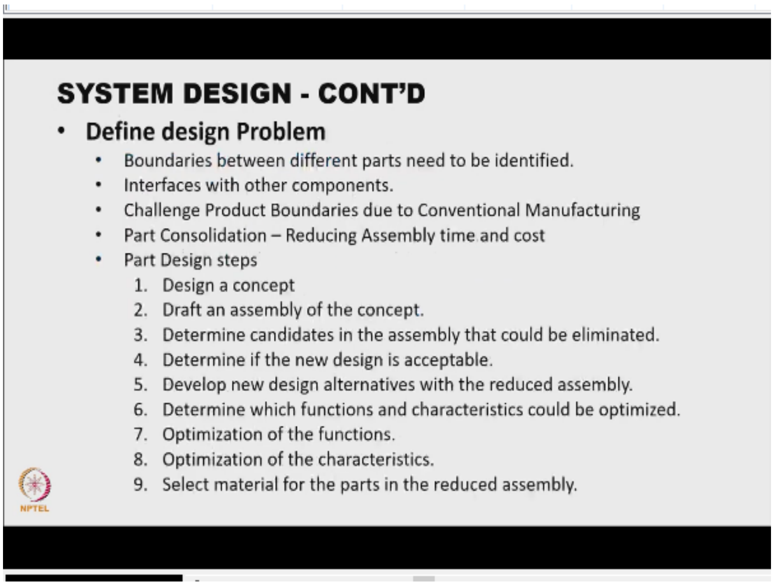

Once we select a part, then we start defining the design problem. When we say defining the problem, it is sort of defining the boundaries in terms of the interfaces with the adjacent parts, where it should fit in. So, it also defines the interfaces with the adjacent components or we also have to understand what current challenges are if it is done out of the conventional. So, that we can address those things when you are designing it out of additive manufacturing.

Once we have an understanding of the bigger assembly, we can also look into the part consolidations. So, typical design steps are indicated here. We come up with the concept and then we look at the assembly with that concept and then we look into see whether any parts can be eliminated any fasteners or joints or even the adjacent parts can it be included as part of this design.

Then we see whether that new design is acceptable with the reduced parts and then we start looking at which are those functions which we can further optimize to get a better performance. If it is a heat exchanger for example, we can see how we can improve the heat exchanger efficiency by coming out with the AM designs or if it is a duct where the pressure loss is to be minimum.

So, how we can make care habited designed to minimize those pressure losses. So, those are the things what we will look at and then we finalize on the optimization function. Then, we also see that what is the best material which we can produce this, keeping in mind what it can offer.

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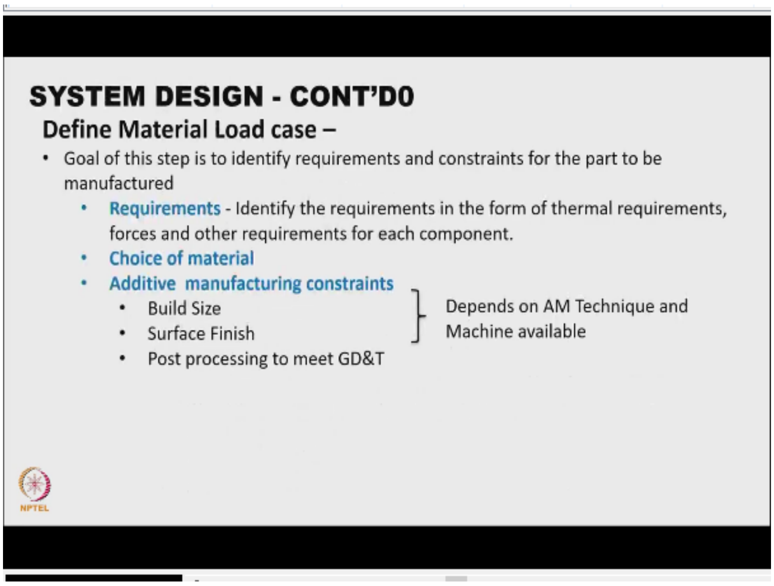

So, once we do those sort of defining the problem, we also have to define the load cases and the material load cases. Typically, we may have some of the thermal requirements, structural requirements, floor requirements. So, those are the things which we have to finalize, before we start doing the detailed design. As I told we also have to finally decide on the possible materials what we will be using.

We need to make sure that the other constraints which we have for this AM which can produce to the AM in terms of build size or surface finish those are the things which we sort of define as part of the load cases.

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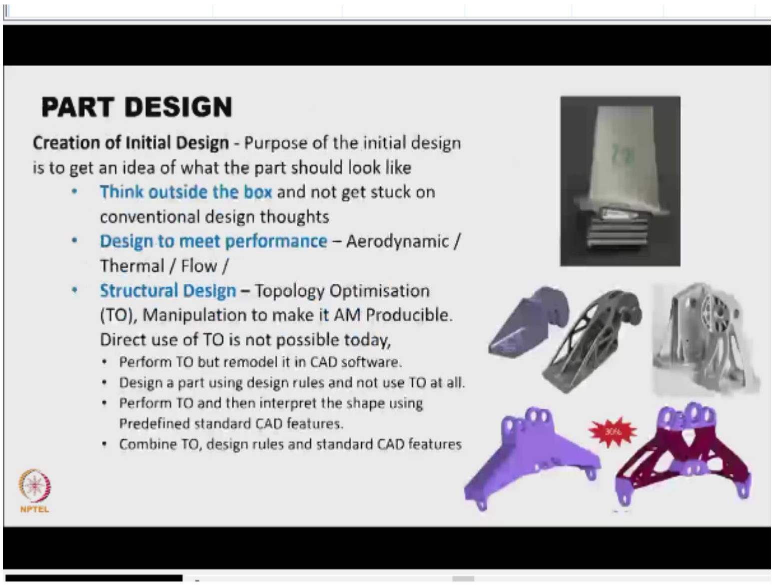

So, then we start looking at the part design where detailed part designers as part of the additive manufacturing DfAM approach. So, in the part design, as I indicated, we come out with the initial design which is more like a conceptual. So, in addition to the conceptual design, it will also have form fit and function things incorporated as part of initial design. We need to think out of the box when we make this initial design.

We need to understand the challenges which we have with the conventional approach and how we can work on through the AM design. We also have to ensure that in terms of performance, we are getting a better performance. It could be aerodynamic, you can see a turbine blade which I have shown there, the airfoil as well as the cooling passages inside the internal cooling passages. How those things can be optimized so that we get a better performance and as well as we are able to meet what the temperature what the material can withstand.

So, those design optimization for the performance are carried out and then we look at it from the structural design point of view. The key thing when you look at the structural design point of view, which is different from the conventional way is, we can take a lot of weight from the part through additive manufacturing. We can make it lightweight.

So, that is the big advantage of additive. This is enabled by topology optimization. Topology optimization has been used for more than 10 years now, but whatever design comes out from topology optimization, which are not able to produce it using the conventional approach and again, we had to do a lot of compromise, but today with whatever design which we come out using the topology optimization. It can be produced through the additive manufacturing which still we may have to do some small refinement to make it suitable for additive manufacturing.

So, the design which comes out on topology optimization. In the today's limitations, we cannot directly take it to a CAD software like NX, Catia or Pro-E. So, that is the we had to build a remodel it in the CAD software which again is little time consuming, but the other option is we can build in some certain rules inside those CAD tools. So, that we can convert that model into the CAD software.

So, those are the things what we can do and maybe once we define those rules, we can automate it and then we can take the model into the CAD tool. So, some work needs to be still done in that but topology optimization is definitely the way to go about few parts I have shown here few brackets, in fact, these the middle ones are the brackets which are used in A320 and then the A380 aircrafts and then the bottom is one of the engine mount bracket, which we can typically optimize it to reduce the weight by more than 30%.

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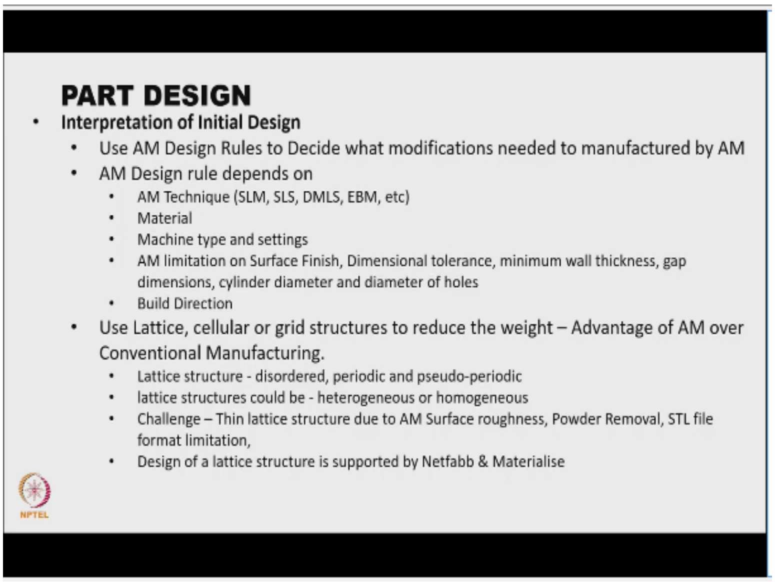

So, once we have the initial design, we have to interpret the design, so that it is compatible for manufacturing by AM. So, there are a lot of design rules which we can come out. In fact a lot of work have happened in this direction, but it is still very specific to the organizations which has spent a lot of time and effort, it is not openly shared. Also, these design rules are arrived at keeping the infrastructure what organizations have.

When I mean infrastructure, it is the machine what they have been using the material what they have been using. So, keeping those into consideration the design rules have been developed. We can use those design rules and then see whether the initial design can be produced out of AM. We also have to keep in mind the limitations of the AM in terms of tolerances, the surface finish, the minimum wall thicknesses, what can be done.

The diameters what can be produced to the accuracies? So, we need to keep those things in mind and maybe the initial design may need to be fine tuned from those considerations. The other big thing which we have to keep in mind is to take a big advantage of additive manufacturing is to reduce the weight by incorporating the lattice structure or the grid structure, that are the lattice structure design has been there for quite some time.

But the question is how to produce the parts? Now with AM since we can produce these parts. We can have the lattice structure which is either periodic or pseudo periodic or completely random, since it can definitely be produced through the AM. The lattice structures could be homogeneous or it could be heterogeneous. The challenge of producing these lattice structures in the additive manufacturing is the thin lattice structures.

Especially the ultimately this the CAD model has to be converted into an STL format, which is the format the AM machines will use it and there are some constraints in translating these models and we may lose some of the geometries as part of that. We need to keep that in mind especially, when we have the thin lattice structures. The typical software's which are available for lattice design is Netfabb and materialize.

In fact, those many people are having using these software's to come up with the latest designs which can be produced with the additive manufacturing.

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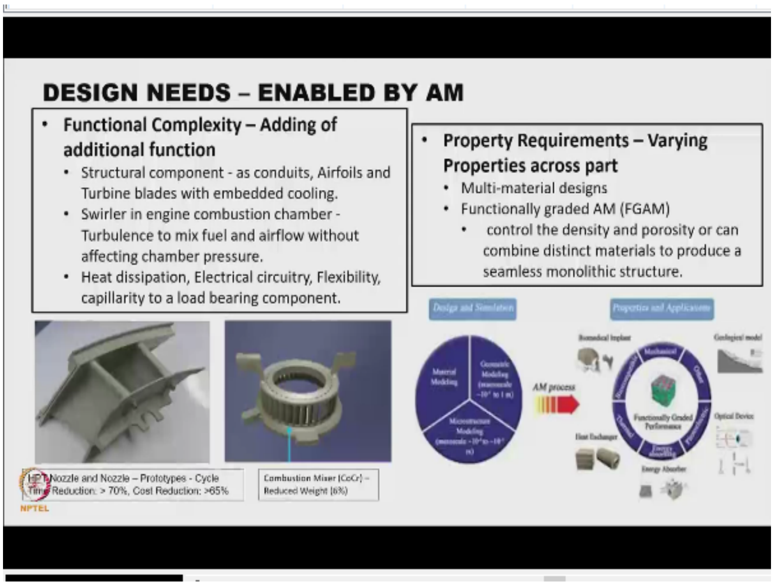

As part of the design for additive manufacturing one is the functional complexities which we can incorporate. You can add some additional functions to get the additional benefits of additive manufacturing. A simple example is a structural component can also be used as a conduit or an airfoil. So, that we can do those additional functions. Similarly, the swirler in the combustion chamber, which helps in improving the mixing efficiencies.

So, that is the other example of adding additional functions. So, those are the things also we need to keep in mind while producing the part. There are some examples you can see the combustion mixer as which is a GE9X part which GE has come out and it is going to be a production part. In addition to this, we can also think of having a varying property across the material length and breadth of it.

It can be done either having a multi material designs or it can be done by intentionally incorporating the porosities through which we can address can change the density of the materials. So, this is a new area which is been explored and a lot of work is happening in this area to take advantage of additive manufacturing through which it is possible to produce these varying properties in the same designs. So, the functionally graded AM is a big area which a lot of work is happening today.

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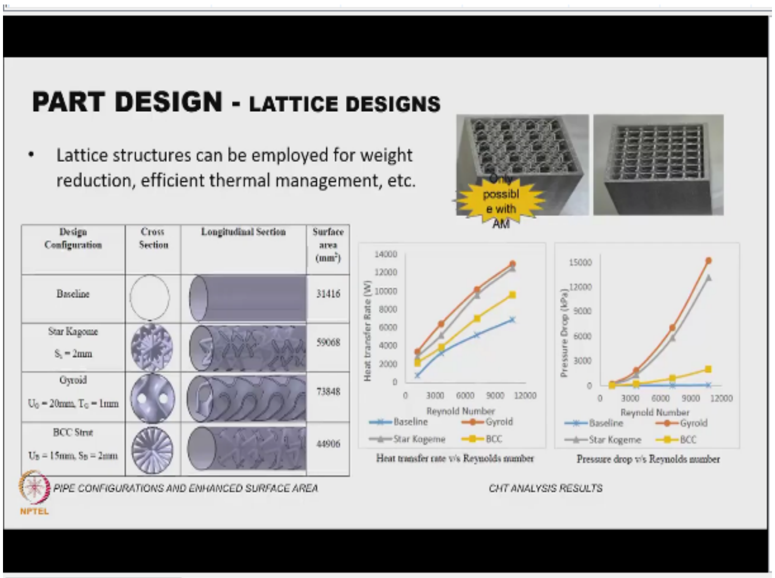

The lattice designs, we talked about a typical example here. This is for a conduit which is also acting as a sort of heat exchanger. So, the conventional design is the baseline is the one which is on the top where it is just a smooth hollow design. There are 3 designs which have been considered can see the how we can increase the surface area by incorporating the lattice designs.

We also have to keep in mind the pressure losses. The CFD design shows in terms of the heat transfer rate as well as the pressure drop and then based on this we can select the designs which definitely gives advantage here both in terms of improving the thermal efficiencies, but within the pressure drop what we can allow for.

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So, there are in the design we also get some of the manufacturing related benefits what we have especially we talked about the part consolidation. An example there what you can see is the heat exchanger which is made out of aluminum, this is 163 parts is converted into one single assembly. So, lot of part consolidation reducing the weight by 40% and then the cost by 25%.

So, once we have this part consolidation it also helps in reducing the inventory because we just have a complete assembly as one part. The other benefit of additive is in terms of reducing the material wastage. The wastage of material could be as low as less than 5% just for the supports which we are talking about. In some cases, additive manufacturing is an ideal case when we have to have a quicker turnaround time and small production.

This is ideally suited for aerospace industry which has a lifetime of more than 30 years. You may have issues with the current supplier and he is not able to produce or he has closed the shop. Whereas, we can quickly take the design and reproduce it, in fact recently there was a part Honeywell got FAA certified. This is the critical part; this is a bearing support which is the design is almost more than 40 years old.

But then there was an issue with to the current supplier and then quickly we can reproduce this part through the additive manufacturing and we did not look at the defect much bought it, but we ensured that it can be produced through the additive manufacturing the consistence in the reliable way and this part has been certified. So, those are the typical scenarios where you can take advantage of additive manufacturing.

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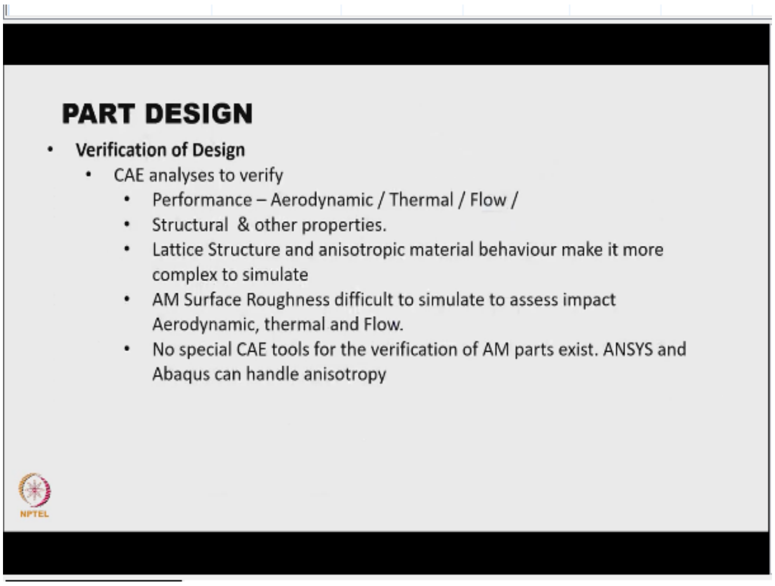

So, once we have this design, which is locally into from the manufacturing point also, we go back and then we re-verify make sure that it is meeting the original design intent. So, that is where we do the aerodynamic analysis, the thermal analysis and ensure that we meet the performance and structurally the party is able to withstand the structural loads the thermal loads, it is able to withstand.

We also ensure that the surface finish what we get out of additive manufacturing either it is good enough or what post processing needs to be incorporated. When we do the CFD analysis, some of those effects of surface finish on the performance could be difficult to simulate and have a quantifiable impact. So, those are some challenges of course, the CAE tools have been rapidly developing.

It where we can almost the final details can be simulated and then the impact can be analyzed, we do not need to have any special tools for this verification, we do the conventional answers Nastran, Abacus.

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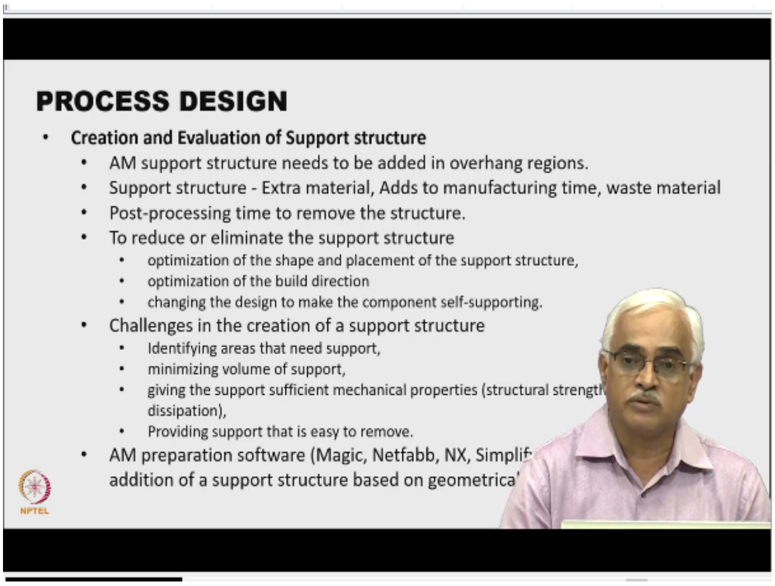

Those other tools which we use it for all the analysis. So, coming to the last part, which is the process design, which is more related to the additive manufacturing related things. The first thing which immediately had to be done is the evaluation of the support structure. So, we have to ensure that the design is reviewed by AM expert who will ensure that the supports which have been thought about is good enough to withstand the structural notes.

At the same time the support should not be too strong. It is difficult to take out those parts and there is a lot of wastage of materials. So, we also look at the AM the design and what post processing needs to be done subsequently after the part is produced by AM to meet the final part requirements. So, that the challenge in terms of creating the support structure today is it is typically today is based on the experience.

So, there are some tools for providing some of the guidelines, but it is definitely not the best. The experience plays a big role here in identifying the right place where we need to give the support and what is the minimum support which is required? We have to ensure that a supports do not collapse during the printing process. It is having enough for structural strength and at the same time it can be easily removed.

So, the tools plus the experience is a one which helps in the today's evaluating these. The tools which enables the support structure design is Magics, Netfabb, NX, simplify 3D. These are the tools which automate the support structure but still needs to be vetted by AM expert who would run through this in a lot of cases in the past.

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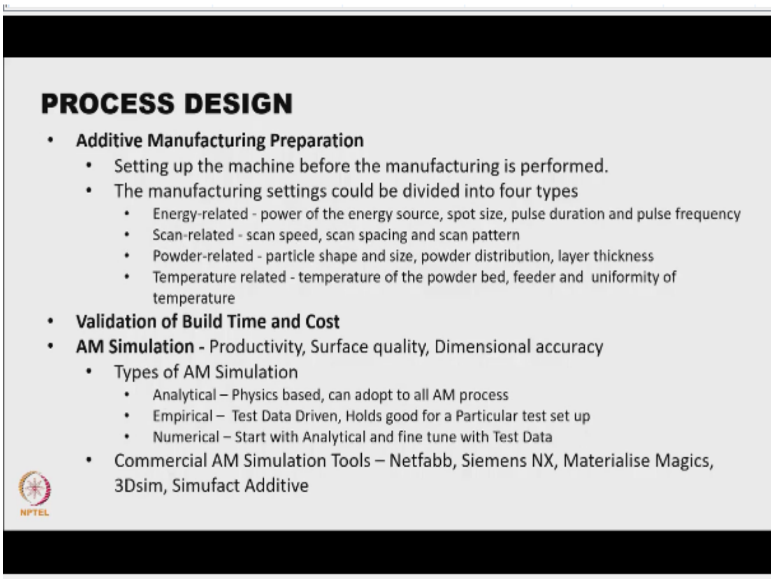

The next thing which you have to keep in mind is the pre preparation to print the part. Most of this is machine related. We need to set up the machine. The machine parameters play big role here. We get lot of guidelines from the machine manufacturers and then that further fine tune to attain the final finished product requirements.

So, typically the machine settings can be divided into four headings which is energy related. Energy related is more like the energy source whether it is the laser beam or the electron beam, the power source, the spot size, the pulse duration which decides on the exposure of the laser to the material, it could be scan related in terms of the scan speed, the scan spacing and the scan pattern itself.

Certain things could be powder related which depends on the powder size, the powder distribution, and then the layer thickness itself and then the temperature later which is the temperature of the powder bed and then the feeder. In some cases, the bed is preheated before we start the processing. So, those are the things which we need to keep in mind while finalizing on the machine settings.

Once we finalize on this typically almost all the air machines, if you run it through a simulation, it indicates what build time it is going to take the build the part. How much it could cost? This cost is purely only for the printing perspective, it does not consider the other part of the cost models, which we have to do it separately to evaluate the business case.

I just want to make it clear that machine just gives the best on the time to build the part what is the cost of that part. So, before we actually print there are a lot of AM simulation tools which are available and then which have been developing last 4 to 5 years especially for the metal printing. They have gone through a lot of validation in the last 4 to 5 years.

AM simulation tool is a very good tool to validate the printing and it almost ensures that there is a 90% or more than 90% success rate when you build the part both in terms of dimensional accuracies, the quality of the part and the success of building that part. Most of these AM simulation tools, it could be analytical where it is completely physics-based things which can simulate the AM process.

There are some limitations of these things when it comes to validation. There are empirical relations, which is based on the test data driven, which is more like the sort of data driven as well as the machine learning type of things. So, but it could hold good for only that type of environment and in the machine setup. The third one is a combination of both you can start with the analytical and then fine tune with the empirical which is more data driven.

That is the one which is giving the better result today in terms of simulations. The simulation tools typically are Netfabb, Siemens, NX, Materialize, Simufact. Those are the good simulation tools which can simulate this process.

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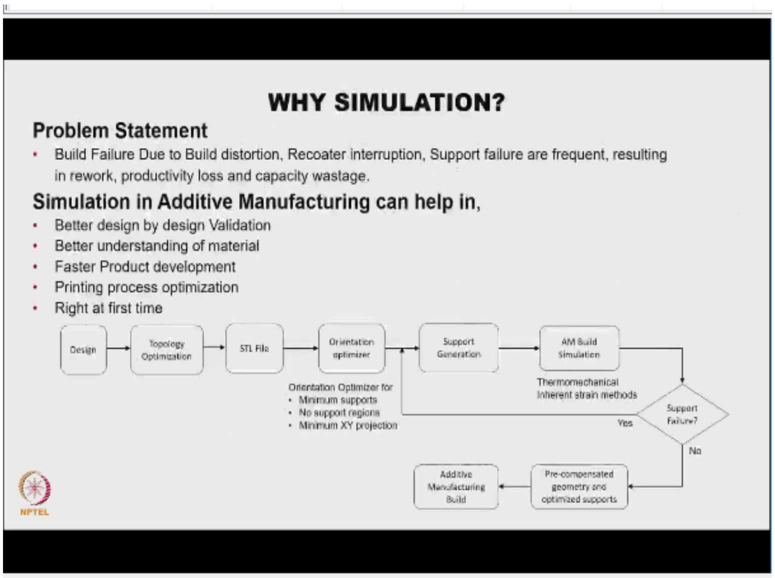

We will look into a little more in detail about the simulation. The benefits, we already talked about it, even though we have a lot of experience in building the part, we still see that when the party is built, there are some distortions or the building itself could be interrupted in between because of the recoater interruptions, there could be support failures. So, these are the things which will cause a lot of productivity loss and then wastage of time.

So, simulation helps to address most of these things. iI you look at the block diagram. So, the first thing is the topology optimization is one part of the simulation which we do it and then we have the orientation optimizer to decide on the minimum supports. Then the printing process itself which simulates the thermo mechanical process which the part undergoes in terms of simulating all the thermal stresses, which that part is subjected to.

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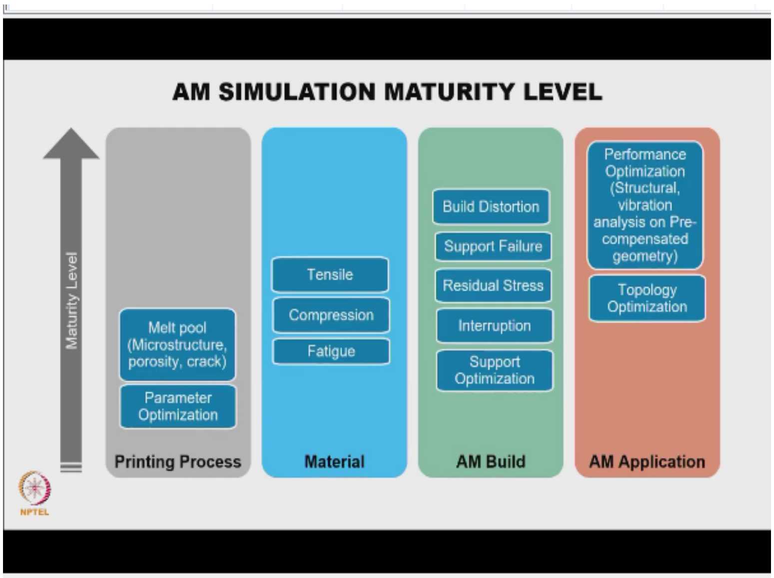

So, if you look the where we are in terms of this tool maturity today. From the AM application point of view, I think tools are fairly matured from the, whether it is on the topology optimization, or it is on the performance using some of the floor tool, CFD tools, quite matured tools what we have. From the preparation for the AM build in terms of supports build distortions.

So, those are the things also which is quite advanced stage. We are able to reproduce, almost like 95% plus of these instances and we can heavily depend on the simulation. In the material properties, we are measuring but any new alloy when we want to develop it. The predictions, still needs to be done validated with lot of testing whether it is tensile, compressive or fatigue will depend a lot on the testing, even today to finalize on this.

The one which is in a nascent stage is the printing process itself, on which decides on the microstructure, porosity, crack and also those are the ones which still needs to be developed.

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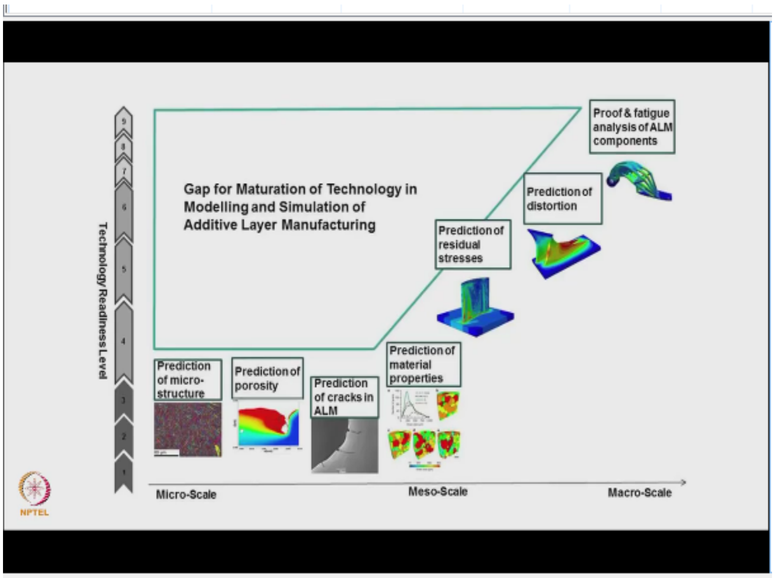

So, this is another way of looking at it only thing is x axis we have a macro scale and then the micro scale of it. So, in the macro side we are fairly good as I, in the last chart also you saw, but in a micro stage is the one where simulation tools still need to be developed and validated, but a lot of development is happening in that direction.

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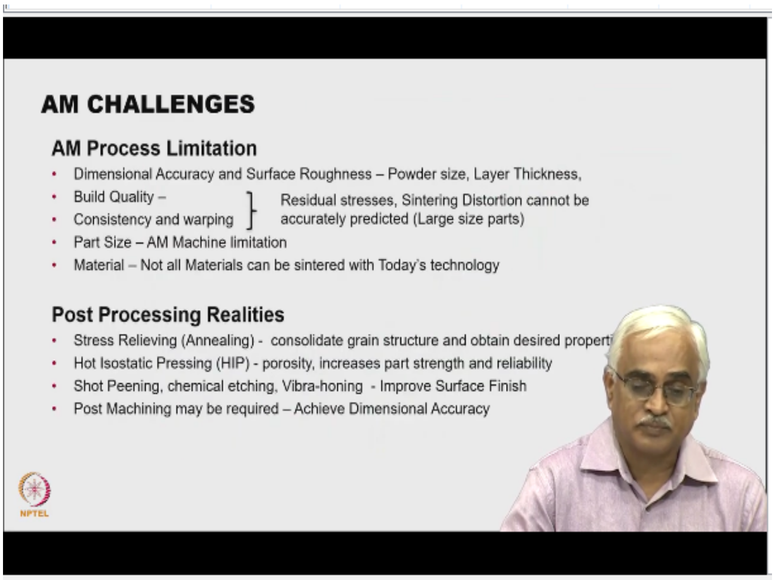

As we went through this, we also looked at some of the challenges. I just wanted to recap the AM challenges today, whether it is process related challenges or additional post processing which could be needed to achieve the final finished part. So, I will not get into those details again. But these are the challenges, which need to be kept in mind when we go through the DfAM.

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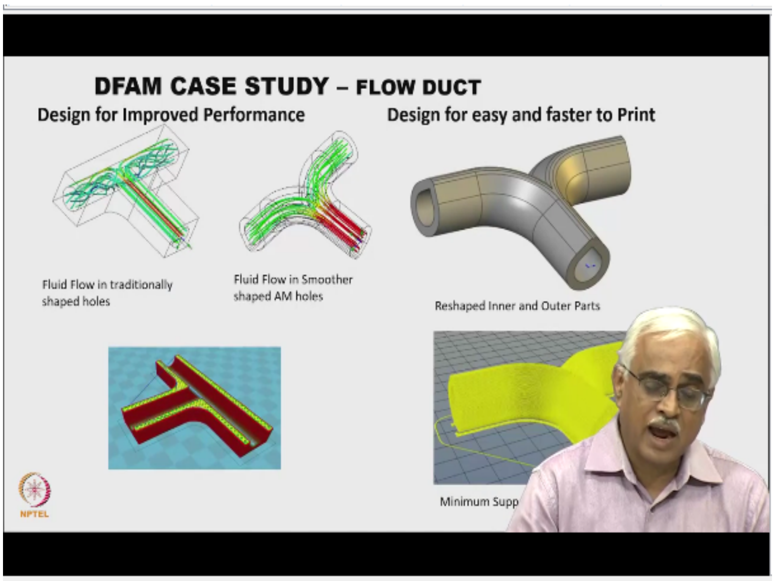

So, next few charts I have a few case studies. This is a simple example, which looks very theoretical without any application but it is very relevant, which can be used in very wide applications. So, if you look at the top left hand is the typically how traditionally we have the duct holes which are drilled because it is easy to drill the straight holes, other than the curved holes using a conventional manufacturing approach.

But with additive manufacturing, we can refine that design to have a smoother hole. So, that we reduce the losses as well as the turbulence associated with that. So, that is the big benefit what we can get with additive manufactured designs and it is very simple flow analysis which helps us to come up with these type of design modifications.

When we look at it, same thing from the structural point of view earlier we need to have some minimum thickness for the ducks and the tubes. But now we can have either the lattice sort of designs or the honeycomb designs which will help us in minimizing the weight. So, both from the performance and weight point of view we look at the designs for the duct and then we come out with their model. And then this model we look at it, how we can produce that part with minimum supports. Again, very good example a simple example how we can enable the DfAM to finalize on the product design.

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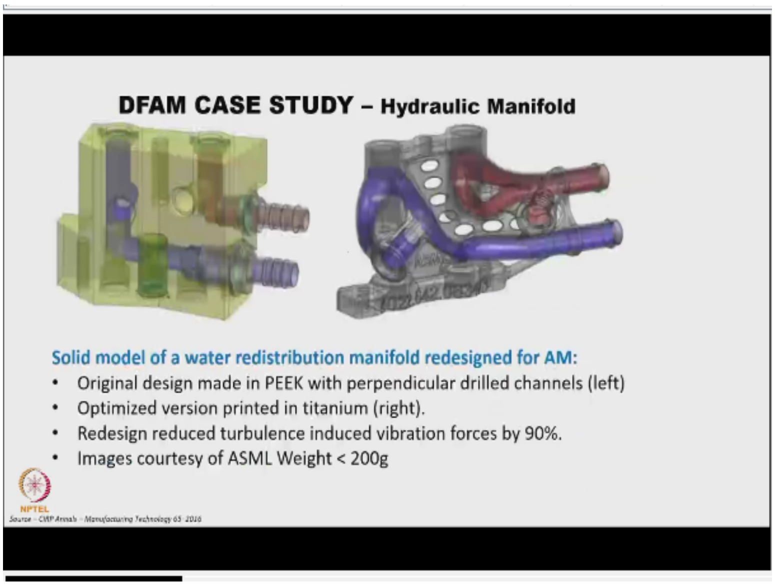

The next one we have is the hydraulic manifold. Again you can see on the left hand part is what is conventionally manufactured. The manifold need to have the multiple drillings to enable the flow passages and all, but again, because of the limitations of the convention manufacturing we need to have either a straight holes we cannot have the curved holes and all. Here in this case the original design was made out of peak.

The optimized design is made out of titanium with a lot of shaped holes in the manifold, which will optimize, both on the weight as well as on the performance in terms of the turbulence. The turbulence induced vibrations could be reduced by more than 90%. So, this is an actual example where the additive has been implemented.

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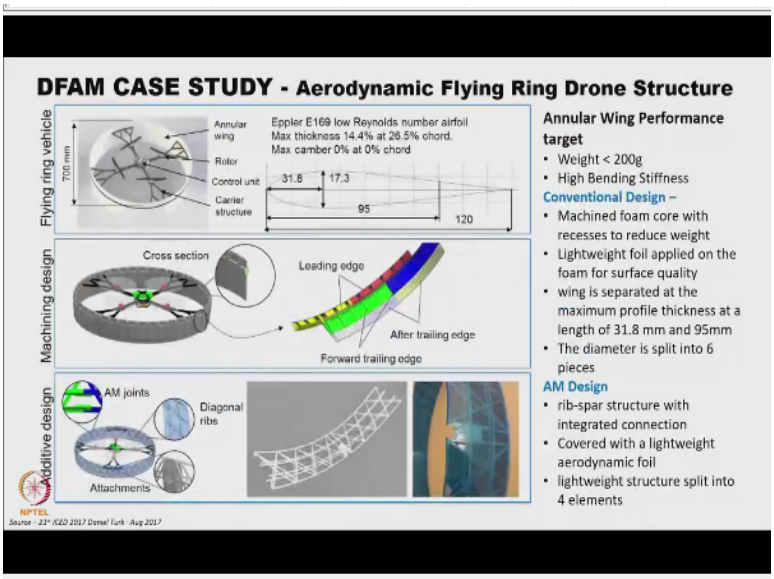

The third case study what we have is this is on the aerodynamic flying ring for the drone structure. The top you can see the airfoil design, which will give the best performance. But, how to produce this design? We wanted to make sure that the design is weight is less than 200 grams. and then it should have a high bending stiffness. So, high bending stiffness helps in maneuverability of the drone vehicle itself.

In the conventional design we have a form core with the recesses, to reduce the weight but it still cannot come. We can meet the less than a 200 grams of weight constraint. But, bending stiffness could be higher. The lightweight foil, we do improve the surface quality we apply the form and the wing is separated at 2 points which is where we have the maximum airfoil thickness and the diameter itself is split into 6 pieces.

So, that is the best design what we can come up with the conventional design, but with the AM design we have the rib-spar with an integrated connection so that it can be easily joined and then assembled. We have a covered lightweight aerodynamic foil. The diameter itself is split in 4 elements, keeping the constant what we have on the AM machine which is used to build this part.

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So, when we compare these two designs the best conventional design and then the AM design. This sort of indicates what is the material usage? you can see that the raw material, what is used in the conventional milling approach is almost like 1.17 kgs whereas the raw material which is the PA 12 powder which is used, which is polyamide, which is 150 grams and then we can see the typical process times from the operator as well as the machine.

So, this sort of a input which helps us to finally arriving at the cost of the part to build through the additive manufacturing.

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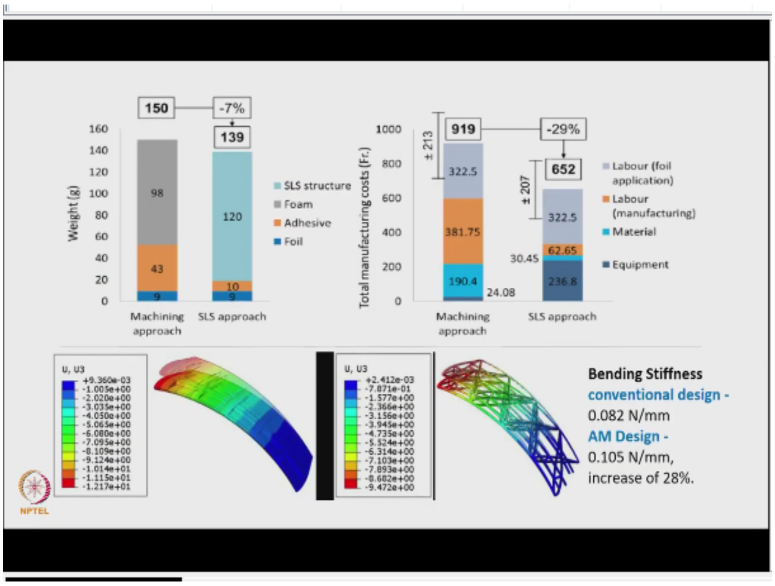

So, those inputs are used here you can see that weight from the additive part is about 139 grams, whereas the conventional manufacturing is about 150 grams. The manufacturing cost is almost 29% less with additive manufacturing and then the bending stiffness, you can see that the additive manufacturing design has the bending stiffness of almost 18% more than the bending stiffness of the conventional manufacturer design.

So, we get advantage in terms of performance which is bending weight, and then the cost. So, that is the design which additive manufacturing is enabling.

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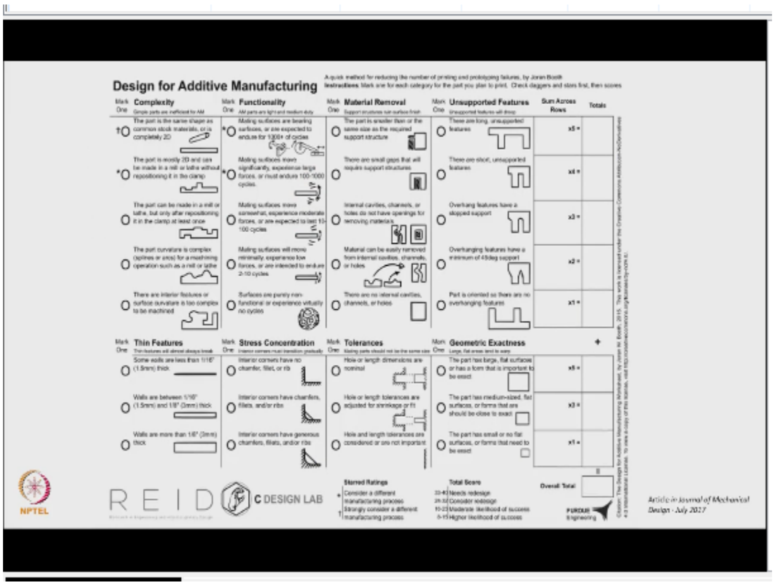

I am not going to go through this chart, there are a few guidelines, which the lead team has come about when you start looking at the DfAM related things, but this is a type of chart typically AM industry will build. And then, that is what is used as the guidelines when you want to go through the design for additive manufacturing. So, with that I conclude this topic on the design for additive manufacturing.

I will say that definitely, if you incorporate the design for additive manufacturing, we can get best benefit out of additive manufacturing in terms of improving the performance, in terms of reducing the weight, and also addressing the cost. So, that is the crux of the whole thing. And this is what every budding engineer should be familiar with, as he starts getting to the additive manufacturing. Thanks a lot.