The Future of Manufacturing Business: Role of Additive Manufacturing

Krishna Kashyap Singh
Process Expert - LPBF
Wipro 3D

Lecture – 31
Design for LPBF – Case Studies

Hello participants and welcome to my third session of design for LPBF. During my previous sessions, we went over various design considerations and various type of value addition which can be done in form of part consolidation or in form of simulation driven design that is called design for additive manufacturing or how we can design conformal cooling channels in a tooling application, how we can make prototypes without using any tool.

These things were discussed in the last session and in this current session, I will be talking about few case studies which come from the industrial background which we have done in the past 8 years and for a few projects it has also taken a certification and validation time of more than 2 years which is exactly this one. This particular component what you see here. This component took certification time or validation time of 2 years.

The reason behind that is that this component belongs to a satellite application and this has been designed for 10 years of mission life. That means the component has to undergo critical cryogenic conditions in the outer space by say for 10 years continuously. That is why the functionality of the component remains critical and a lot of considerations need to be given if you want to produce an economic component, if you want to produce a component with minimum cost involved in the additive manufacturing process.

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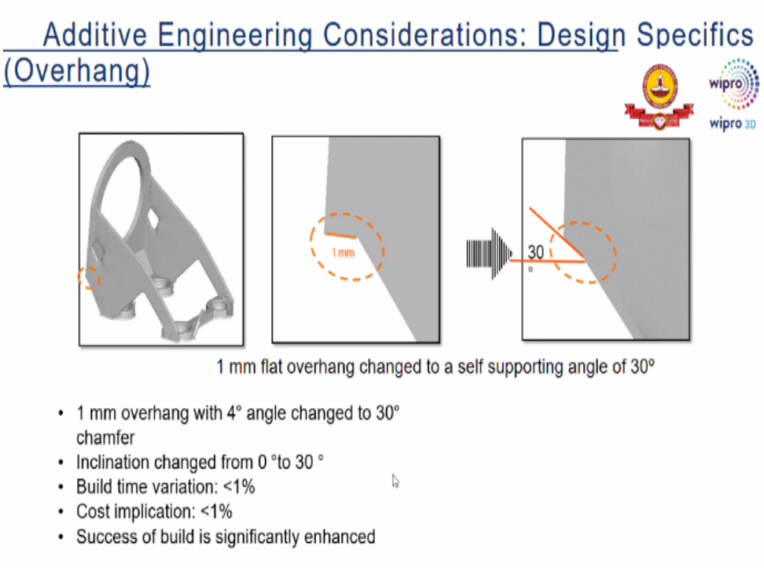

So, moving ahead this is the example of an aerospace bracket that was manufactured in LSI 10 mg. Now there are certain features here which features cannot be produced without adding support structures and the thickness of this wall is only 2 mm. So, if I make a support structures for supporting this, the support in itself will be very weak and it may hinder my build or it may cause a build failure.

So, instead of adding support structure here what we do we add some material and we make this 4-degree angle of overhang into a 30-degree angle because for aluminum my 30 degree is the critical angle. Any surface above 30 degree can be built without adding a support structure. Now this was necessary in order to make the build feasible whereas the consequence of making this design change was negligible in terms of the build cost and the material that was added.

The build time variation was less than 1% and the cost implication as well was less than 1%. So, this is like without adding any extra cost you have changed design in such a way that you can achieve the component in the required condition in one build itself. You do not have to do an iterative process to understand the nature of the part, the support structures which will ultimately add to the final cost of your component.

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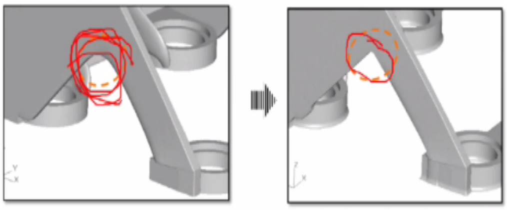
Additive Engineering Considerations: Design Specifics (Fillets)



Overhang with 8 mm radii changed to 1 mm radius

- 8 mm fillet changed to 1mm fillet
- SCF remains the same as there is no tensile load applicable across
- Reducing the requirement of support structures
- Build time variation: <2%
- Cost implication: <1%
- Build success is significantly enhanced

Another such feature in this same component was the fillet. If I am using an 8 mm fillet, then I need to add certain support structures in order to support the overhang which is being made here this particular area. So, what I need to do? I need to change my fillet from 8 mm to 2 mm so that I do not require the support at all. So, fillet is one of the considerations that you need to pay a lot of attention.

This area now will be built without any support structures and again by making this small change here kindly pay attention to the fact that material has been added. While making the design change, material has been added, it has not been removed. So, my build time variation plus my material addition plus my cost implication does not go more than 2% in this particular scenario.

This is an ideal case where I can make a design change, yes of course application based FE analysis is required in order to validate the design changes. There should not be because by reducing the fillet radius, what we are doing we are intentionally incorporating stress concentration there. We need to check whether the stress concentration is within the allowable limit or not or whether it is affecting the fatigue life of the component or not.

An application-based simulation is mandatory once you have made this design changes. If your application-based changes are telling you that the design changes are good to go with, then you can go for the final build. Again, why we are doing application-based simulation? Because I do not want the part to fail in less than the part cycle.

The part cycle has been designated for 10 years or 5 years or these million numbers of fatigue cycles, a certain number of fatigue cycles, then we have to take these things into consideration.

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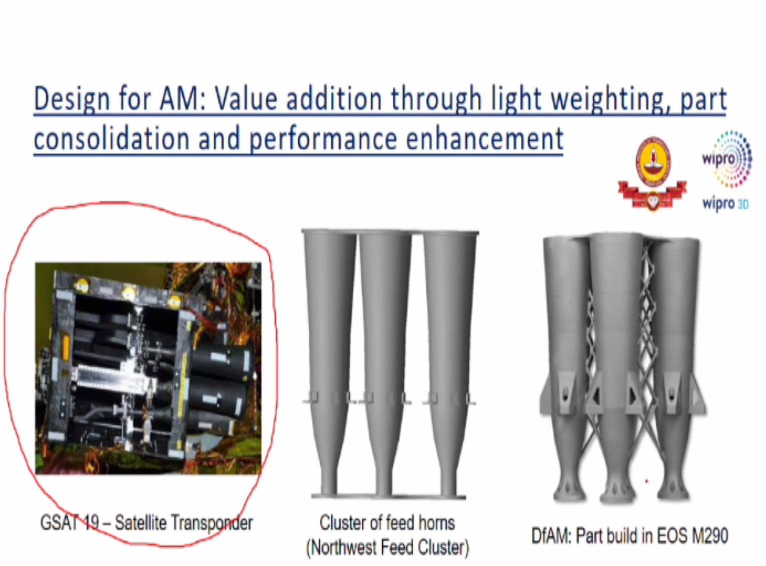

Moving forward this is one of the brilliant case study as you can see this is the component. What you see on the left-hand side here this particular portion this is showing you the actual use and application of the component. So basically, the unit that you see this is a transponder of a satellite. This is a communication satellite and this is a transponder of the satellite.

The transponder is basically responsible for receiving the input and sending the output after making certain modification to the RF waves. Now the component that you see here in the center this is a component that was initially being used as the conventional design, this is a conventional design of the component. The component what you see on the right is the component that was redesigned by the engineers of Wipro 3D.

We added a lot of value in this component in form of part consolidation, in form of functional integration which was improving the structural stiffness of the component and in terms of a faster manufacturing cycle. Conventionally, the component used to take around 2 to 3 months to be manufactured, but now the component is manufactured in around 2 weeks, machined in 3 days and then delivered to the customer in 3 weeks.

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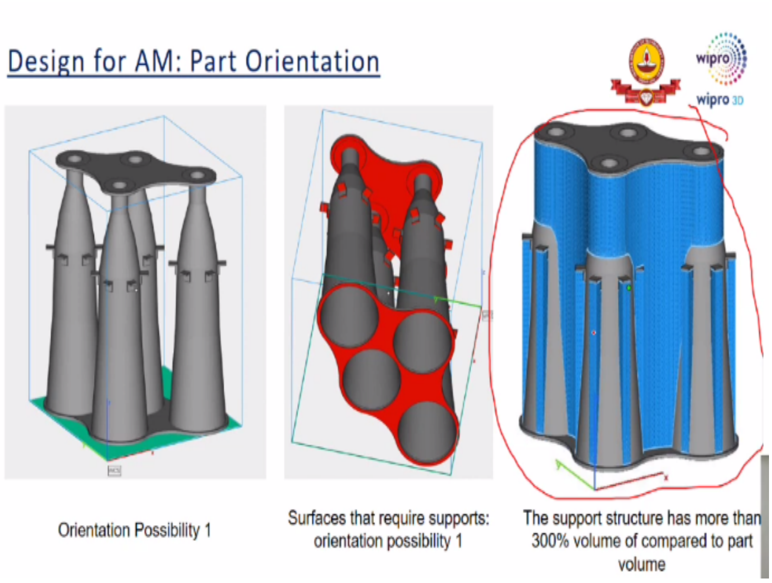

So, when we receive the component, when we have to fabricate the component in AM without making any design changes then this is how it looks like. This is how it looks like when we do not have to do any design change and we have to build the component as it is. So, the build chamber that you see here this build chamber belongs to EOS M290 where we are having a build volume of 250 into 250 into 330 mm.

Basically, it is 350 mm, but certain space is occupied by the thickness of the build plate at the bottom in the z end. Now in red what you see are the features of the surfaces which are mandatory to have support structures if we want to build them successfully in EOS M290 machine using atrium fiber solid state 400-watt laser.

So, as we have discussed in the previous sections that for LPBF process support is one of the mandatory things we want to build flat overhang structures. So, there is a lot of support requirement here and when we look at the support design in this particular image, we can see that a lot of support has been added, in fact the volume of the support is 300%, that means three times the part volume itself.

So, that is my major of the machine time would be going in printing the support structures, then my major of the material will be used in making the support structures and my most of the post processing effort would be going in removing the support structures. So, the cost, the basic major fraction of the cost that is added to in fabrication of the component is due to the requirement of support structures.

So, we thought of changing the orientation and we wanted to see is there any other orientation where we can save some cost, save some time and at the same time we can save some of the post processing effort.

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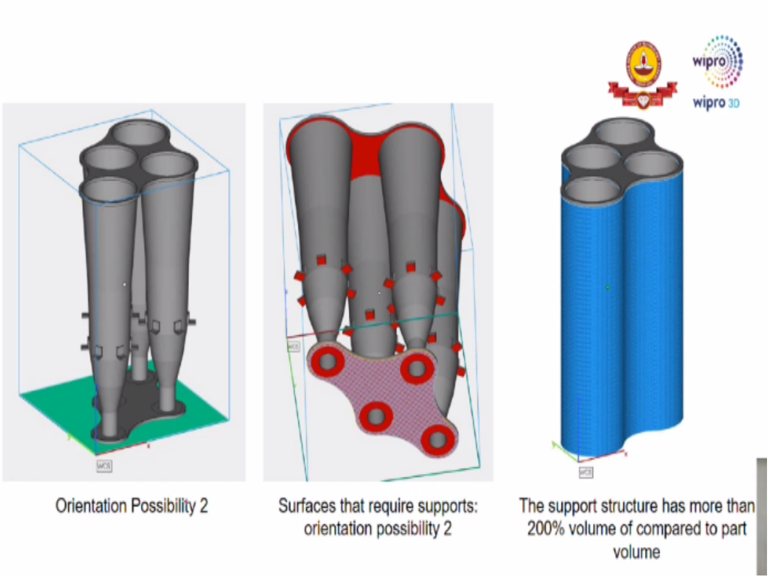

So, we rotated the component along x axis by 180 degree. Now the surfaces which require to be supported by support structures have reduced by 100%. So, earlier the requirement of support volume was 200%. In this particular orientation, the requirement is 200% of the part volume. So, this orientation is actually the only orientation I am having because as you can see the component is just fitting in the build space.

The component is having a z height of 322 mm which is not allowing me to have any other orientation than these particular two orientations. But in this case the best part is that there are certain other problems as well. In order to understand those problems and in order to understand how to eliminate these problems by using design for LPBF, we need to understand the working of the component, why?

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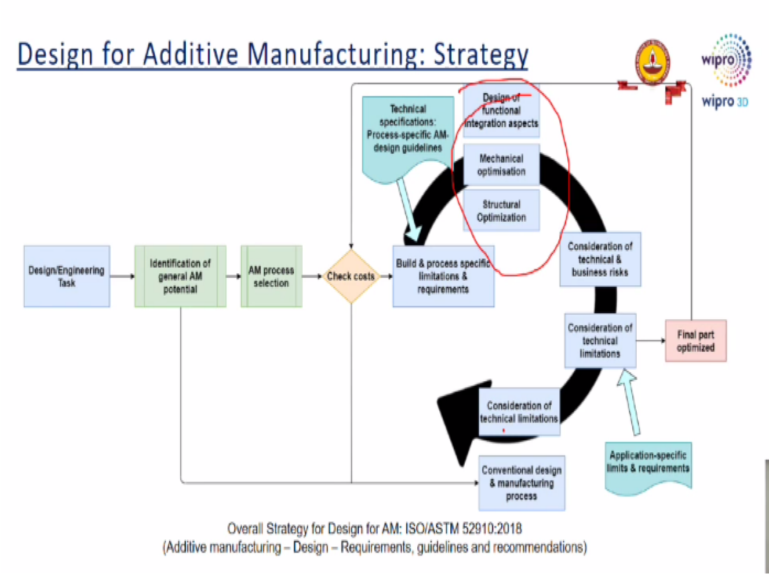

Because if we want to go for design for additive manufacturing; there is a certain strategy devised by ASTM which we have to follow if we want to produce an industry grade component. Especially when we are talking about a component this critical for a space mission, then definitely we need to follow a strategy in order to redesign our component.

In order to minimize the cost associated and in order to provide numerous process benefits and lifetime benefits and performance benefits to the users of the component. So, how do we do? We start with the engineering task and in order to define the engineering task we need to identify the general AM potentials first and in order to identify the general AM potentials we need to completely understand our design goal like; where the competent is being used?

What is the purpose of the component? What is the design space? What is the non-design space? What are the areas which are being used for bolting and what are the areas which are only being used to provide some stiffness to the component? All these things we need to understand and then we need to identify whether I need to use conformal cooling, whether I need to use some change in the critical dimensions which will require support structure or can I do a part consolidation here.

Can I combine three four parts together and make it happen? In order to do so, what will be my design area? What will be my non-design space? All these things we need to identify. Then once we are clear what we are going to do what is our general AM potential, our design objective based on my general AM potential, then I will go for my process selection.

Now process selection is dependent on various things such as the build space, which machine you want to use? What is the space available? What is the laser you are using? What is the recoater blade? The blade that is being used to spread the powder what is the material of that blade? It is a ceramic blade it is a hard recoater, soft recoater. Once I am good with the process, I know the machine, I know the material specifications, I have selected my process.

Then I go to a rough check or a random check of the cost that what is the estimate, budgetary estimate that I am getting in order to make a new design of the component through this part. So, a rough estimation is taken then we give considerations to the design process specific design guidelines which we have discussed in the earlier section of the part and how we are doing that I will show that to you using the case study for this particular component.

Once we are clear with that, we go and design the functional as integration aspects. In this case what is the functional integration aspects that this particular struts they are the part of their design, but they are also providing structural integrity and they are helping in maintaining the relative position of each of these cones. They are doing multiple job. We have integrated two functions in a single design.

Then there is mechanical optimization, so where is from where I can remove material and then we do structural optimization. Structural optimization means in few cases where we are trying to do topology optimization that comes under structural optimization. We are trying to optimize the structure for minimum use of material. So, my design, this particular block is taking care of all the aspects of value addition, all the engineering aspects of value addition.

Then we take into consideration the build failure, here we do the simulation, the process-based simulation and then we take into account the business risk. How much cost is associated to a build failure? or how much cost is associated if the part is not confirming to the actual end requirements? or If the part is meeting the technical that means the mechanical strength requirements or not?

After taking all this risk into consideration, we create we understand our limitations based on the consideration and the nature of the process and then we reach the final optimized part. Once we have made the final optimization of the part after doing the simulation, process-based simulation we go back and check the cost and this particular variation between the final optimized cost and between the initial design cost should not be more than 10 to 20% that is what we have observed.

Once I have taken care into my process limitations, my application limitations and requirements, then what we do. We go for building the part where my post processing is also taken into consideration why because I might not be able to produce the required surface roughness. So, I have to go for a post processing activity and that will be largely based on the conventional design and manufacturing process as well.

Now we make a comparison between both of these and then we prepare a build plan. If all the cost is the minimum cost that we can achieve after redesigning, then we go for it.

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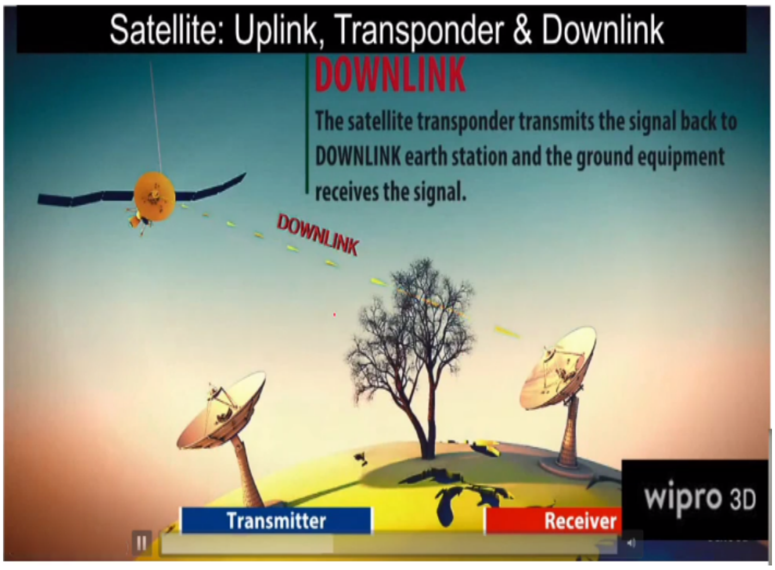

Now in order to understand, what are the design space? What is the non-design space? What is the functional aspect of the component? This particular component that we are seeing and this component belongs to the transponder module of a communication satellite, we will first see that what is the functioning of a satellite? What does a satellite do? So, what a satellite does is that transmitter on the earth. It uplinks a signal to the satellite where the transponder of the satellite receives the signal.

Now the same satellite changes the wavelength and frequency, it amplifies the incoming signal and then it sends back to the receiver on the earth, and the signal that it sends back to the receiver it is called as a downlink. So, there are 3 particular stages. One is the uplink, second is the transponder and then is the downlink. So, this is how a satellite while revolving in the orbit is still keeping into consideration all my factors.

The satellite that we are talking about actually rotates in equatorial orbit over and its focus is largely over India. This is how the satellite is continuously rotating in an orbit which is directly above the equator. Now the satellite that we are concerned about belongs to the equatorial orbit and it has an inclination of 0-degree to the equator that is the reason it is called as an equatorial orbit satellite.

So, we know that the component that we are talking to belongs to a transponder module and it belongs to a communication satellite. Now we understood the working of the satellite.

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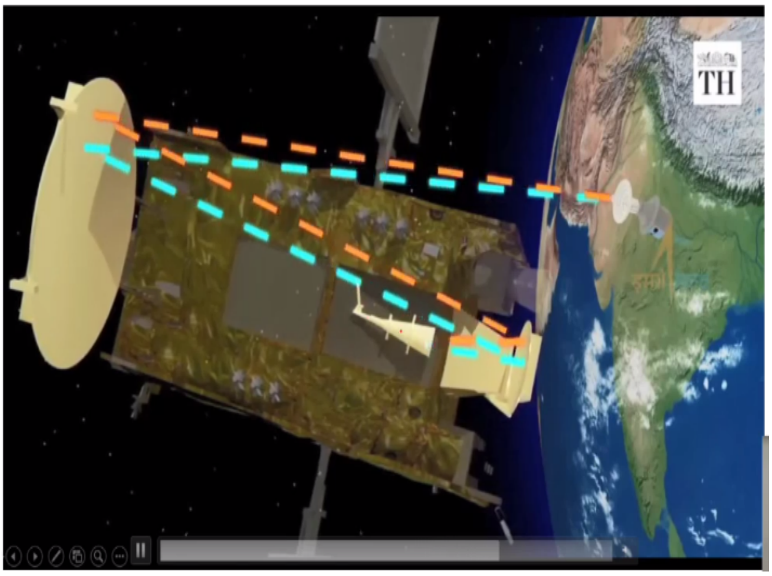

Now let us try to understand what our component is doing. So, there is a single feed horn component, what I have in my hand is a multiple feed horn component, but in the video what we will see is a single feed horn component and we will try to understand how this works. When the say uplink is received, it goes to the reflector of a satellite, it goes to another reflector then it enters the feed horn.

Enters the feed horn, by the feed horn it enters the transponder. Now the transponder changes the frequency. It amplifies the waves and then it sends back to earth. My component which I am talking about one single cone one single cone here this particular cone is responsible for performing the action that you see in the video, that is receiving the uplink and then sending the uplink back.

Now you must be wondering why we have four cones here. The purpose of having multiple feed horns is that we will have multiple beam spots and the operational efficiency of the satellite will be increased. In this video we will see that how we are able to increase the operational efficiency of the satellite. Now earlier in the previous video we were watching with a single beam, now since in the video that you see there are multiple feed horns like this.

This is a set of 4 feed horns. There are 4 by 4 such setups and if we have so many setups each horn is responsible for projecting a certain area. Now that area how much projects depends on the altitude of the satellite, on the diameter, bigger diameter, on the input diameter and the slant. So, this becomes my design constraint. This video clearly explains me that how using this particular satellite component we are able to project, to transmit the waves to the projected area on the ground.

Now what I cannot change in this component is the input diameter, the output diameter, and the slant of the cone because my z height of the cone is fixed and the satellite height where the altitude of the satellite with the satellite is going to operate is also fixed. So, I know what is my non-design space where I cannot make any change.

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So, moving forward, we understood the application, now we need to understand the conventional way of manufacturing the component so that we are able to understand the pain points. What are the pain points that we are going to solve through design for additive manufacturing? So, this component this was earlier being made in aluminium 6061 material alloy and it was heat treated by a T6 heat treatment method.

The dimensions are actually very large when we talk about additive manufacturing. Earlier the component how it was being manufactured? It was manufactured through CNC turning, laser cutting and TIG welding. We will try to understand where the turning, laser cutting and TIG welding was taking place which are the areas, but since welding is involved and you can see here that we have multiple areas which are being joined.

Like this area there will be welding, this area there will be welding, then these clamps will be welded to this thing this bottom, all the bottom areas will be welded, this will be welded, this will be welded. So, there are multiple welded joints. Now the welded joints are not very much favorable for an RF application because the more the welded joints are there more chances of RF leakages.

So, there is one thing I can provide the customer right now that is that I can consolidate all these parts together and I can eliminate the need of welding. I can eliminate the need of welding which will help me in reducing the RF leakages.

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What was happening earlier that this particular component is being manufactured using a CNC billet. Now a complete CNC billet offers diameter slightly bigger than this one. CNC billet was taken in a CNC turning machine and then it is made into this shape and then all 4 such mandrels are manufactured with wall thickness of 1 mm in earlier manufacturing method. Then all those 4 are placed together in the relative positions and then they are welded together.

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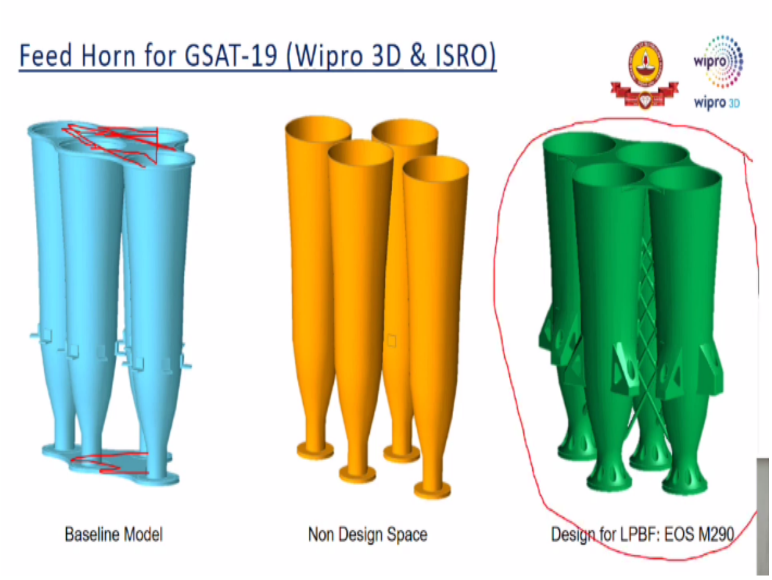

They are welded together using these end plates. These end plates what they do? They are providing rigidity in terms of maintaining the relative position of each and every center of the feet horn and also these end plates are providing stiffness, but at the time of welding we need to be really careful about the relative positions of each and every feed horn. That means that this distance to this distance to this distance to this distance shall be maintained.

Now in order to maintain this, we need to weld it using very high precision fixtures. So, making fixtures is mandatory in this case for my component. Now making fixture is adding time and adding cost to the manufacturing process. So, now by clearly understanding the application, I know what is the design space. When we manipulate it in the non-design space and try to solve all the problems.

The first one was to give stiffness, the second one was to make self-supporting structures and the third one was to do part consolidation and remove all the joints. We were able to do all this and this is the resultant of that particular design.

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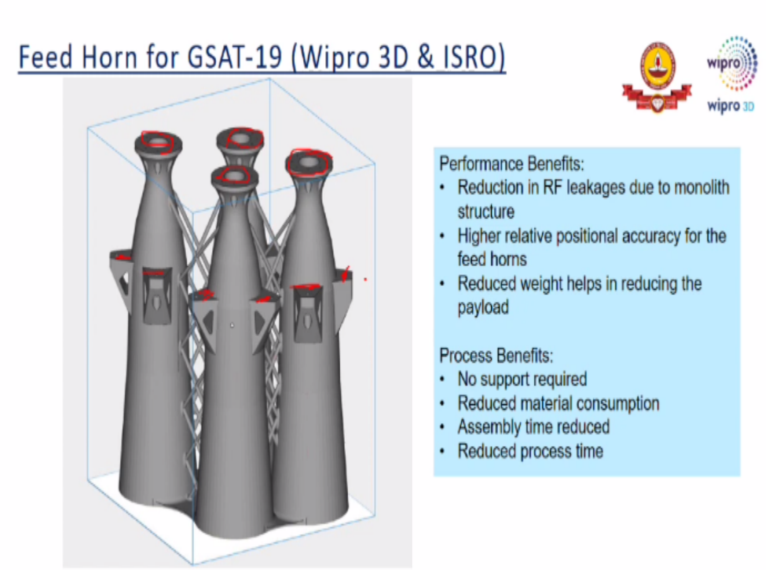

This is the design that we produced. The design was produced with zero support structures. There was not a single welded joint. Hence there was a tremendous reduction in the RF leakages due to the monolith structure that we produced. The relative position increased because there was no need of fixtures and there was no welding, all of us know that welding leads to distortion.

Since we have eliminated welding, we have eliminated distortion and we are manufacturing all the 4 cones in a single structure, so the relative positioning is relatively better as compared to the conventional manufacturing method. Now what are the process benefits that we are getting here? Earlier the volume that we were using the material that was estimated to build this component has reduced by two times and the assembly time has reduced.

Why the assembly time is reduced because we have eliminated welding. We are making the component in one single process and now only these surfaces which are required for mating these surfaces will be machined and they will be tapped and then all these surfaces where there is going to be bolting happening, this will be machined and tapped and then this component will be ready to use.

So, this component we are making in 3 weeks and the conventional component we were making in around 3 months.

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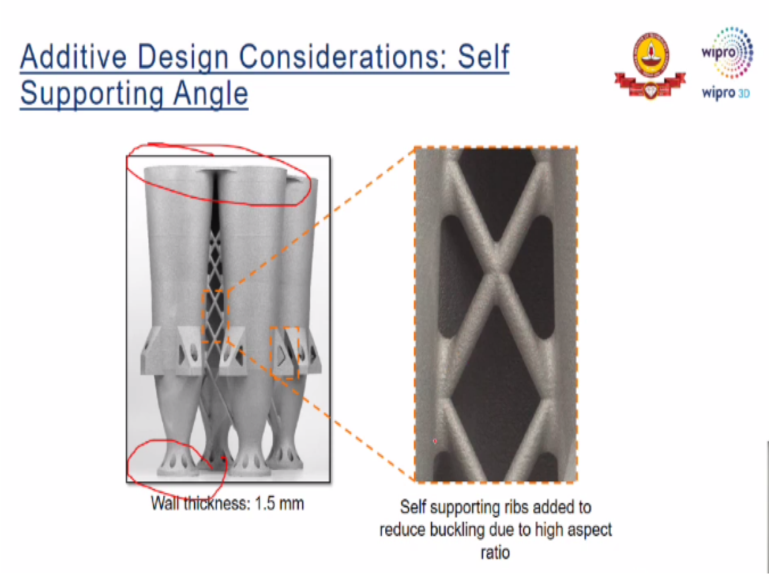

But again, as I told you we talked about the part consolidation feature which is eliminating welding and adding value, but at the same time there are certain things that I need to take care if I want this part to be structurally integrated during the application and during the manufacturing process. I do not want to put any risk to the structural integrity of the component and to the process as well. So, what we do?

We give certain design considerations from the point of view of LPBF process. First thing that we do we change the wall thickness. We change the wall thickness to 1.5 mm, but while we are changing the wall thickness, we are not changing the internal diameter. We are only changing the external diameter of the end diameter and the output diameter as well because our internal surface of this feed horn is the non-designed space.

That is the surface which is responsible for reflecting the incoming and outgoing signals from the satellite and transponder. The second thing that we did that we provided rib to maintain the relative position as well as to maintain structure integrity but the consideration that is required here is that the ribs have to be on a self-supporting angle that is the reason, they were made at 60-degree angle.

So, as you can see these ribs are self-supporting and there was no support required to manufacture these ribs. Also, what these ribs are doing me, once my build is complete, I have very high chances with such a high aspect ratio that my thin walls may go get buckled up. So, in order to avoid buckling my structural integrity is very important and these ribs are helping me in avoiding that.

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So, based on the printing orientation all the mounting points which were supposed to be flat overhang. We changed the orientation in such a way that all these features become self-supporting angles or you can say in a way that the supports that we have added are a part of the design itself. Hence, we do not need to carve them out during machining and they are adding very minimum weight to my end component.

So, this was the story about the feed cluster a beautiful component which has been spaced for the past 2 years and is performing extraordinary when it comes to performing in cryogenic conditions.

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Moving forward this is another component that we have done for a space satellite. The component that you see on the left-hand side this is a conventional design which was earlier made of sheet metal cutting and then machining, welding, multiple components were made. What we did? We did again part consolidation. We made the design features in such a way that most of the features, what we can say 90% of the features are self-supporting in the nature and this is the outcome that we received. Again, this was amazed on an EOS M290 using LSI 10 mg material.

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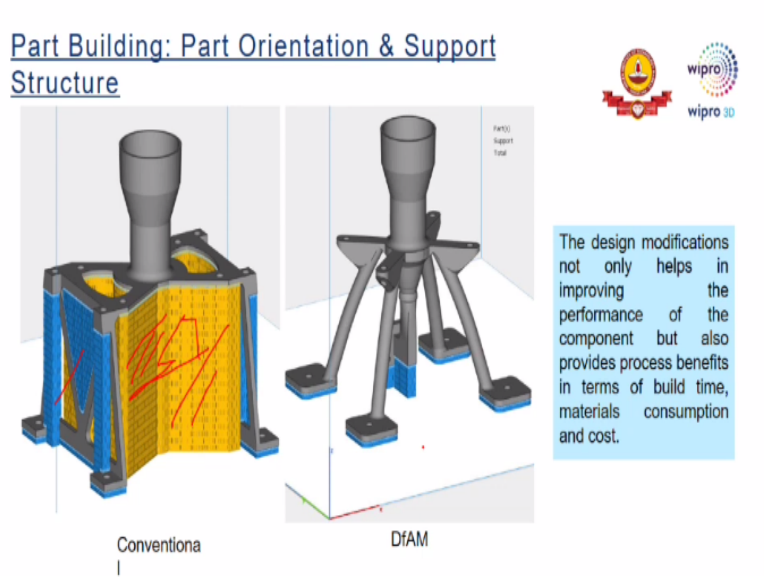

Now this is what I am talking about if you do through conventional and if you do through DfAM. There are a lot of support structures, all these are wastage. These are wasting my time; this is wasting my material and they are adding to the cost. So, a component like this will be most economic to produce through AM. This is where design for additive manufacturing is governing the cost. These two are brilliant examples where design for additive manufacturing is actually governing the cost of my process.

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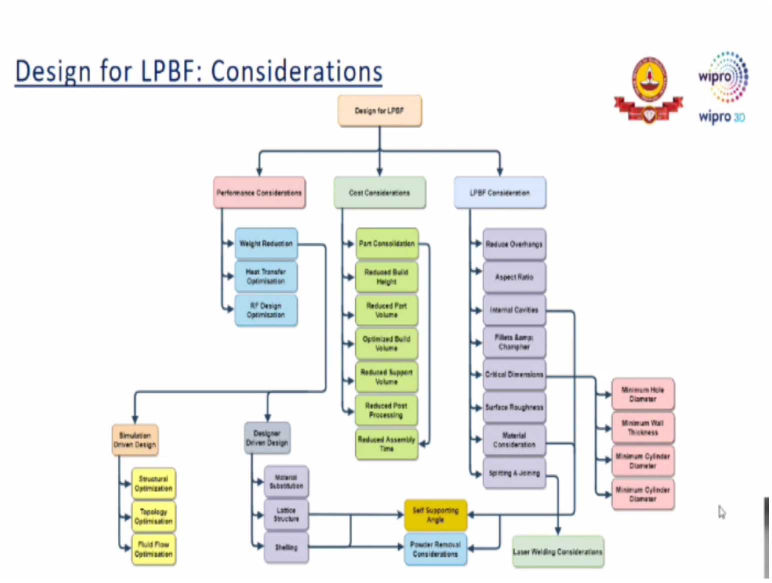

So, when we are dealing with design for additive manufacturing and specifically designed for LPBF in this case, there are certain types of considerations. What I will do? Whatever considerations we spoke about in the case studies that I have shown you whether it be the feed cluster or whether it be the altimeter component, there are these 3 considerations.

The performance considerations, the cost considerations, and the LPBF considerations which needs to be given to the designing stage, at the designing stage itself if you want to have an economic manufacturing process plus an economic life cycle of the component, and when I say economic it has to take into considerations the performance and the cost as well and the manufacturing process.

So, what are the considerations that we are taking for cost? It is the weight reduction; how much weight reduction is required or how weight reduction is adding value to the process. Heat transfer optimization. Your design objective can be a heat transfer optimization objective where you want to optimize the heat transfer through certain geometry or through certain features then it can be an RF design optimization as you see.

One thing I would like to mention that the weight reduction, if you are going for weight reduction it can either be a simulation driven design or it can be a designer driven design. In the next slide, I will show you a small example of the simulation driven design where we will do topology optimization of a structural component for an electric vehicle Contessa Pride. Designer driven design is something that we have already covered.

So till now the feed cluster case study that I had shown you where the designer has to identify the design space, non-design space and the designer has to develop the features and later on the FEA is done based on the end application conditions, but in simulation driven design things are going on simultaneously. The design is being developed based on the FEA guidelines.

Then in cost consideration basically you see that there are methods of part consolidation, then we need to optimize the total build height, then we need to optimize the material used, we have done that in case of the feed cluster. So, all these things I need to perform all the design objectives or the design methodologies I need to go through which will help me in reducing the cost.

The ultimate goal here is for LPBF to reduce your build height and to reduce the volume of the support structures and the part that we saw in the feed cluster. Then when we come to LPBF; my basic considerations which come under LPBF are those which will help me in improving the performance of my manufacturing process, which will allow me to produce a component which is adhering to the required quality standards.

For example, if I am making an internal channel of 2 mm diameter, then I need to be sure that I will be able to remove powder from the diameters because LPBF will always have some heat affected zone wherever the part is melting. So, the channel should not be such that it will sinter some powder particles and it may end up in blocking the channels. So, if I am making a channel or if I am making a hollow structure or a lattice structure, I need to figure out a way to pull powder out. This is an example of LPBF consideration.

Now suppose you are making a big part into 3-4 components and welding it together, then the welding has to be integrated in the design, at the design stage itself, in the CAD data itself because there will be some extra material that will be required for machining the surfaces which we are going to weld together. So, these particular LPBF considerations will help you in manufacturing an economic component which will be commercially feasible from the point of view of the end application.

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I would like to end this session by showing one more case study which is in the form of a small video where we have tried to optimize the topology of a critical component from the suspension module of an electrical wing. When we are doing topology optimization, we basically start with the conventional design CAD model.

We do a baseline analysis of a conventional design CAD model and in order to do the baseline analysis it is very much required from us that we put in the actual boundary conditions. When I say boundary condition what I mean is the location of the forces acting whether it be a remote force or at the force acting on the part directly, the magnitude of the forces.

The direction of the forces and the constraints, the various types of constraints that you are having so you need to input all these things. You need to input the material properties, then you will get how the component is performing in the actual working conditions. By analyzing the stress and by analyzing the deflections, factor of safety what we do? We try to identify the pain point, what is my pain point that I am trying to solve.

Once I am clear about that what we will do, we will de-feature the component. By de-featuring means we will remove the features which were given in the designing of the component for the purpose of light weighting keeping in mind the earlier manufacturing method. So, in this case all these features that we have defeatured they were given only for milling, keeping milling as the primary method of manufacturing.

But in this case we want to remove all the constraints of milling and we want to create a design space which will generate a new topology keeping additive manufacturing laser powder bed fusion as the primary method of manufacturing. So, in this case what we are doing we are designating the overhang. The face that I marked that is the base plate and I am also telling the direction.

Now, I am also telling what is the objective so in this case the objective was to of maximize the stiffness. We are giving them a target of weight reduction while maximizing the stiffness because stiffness is an important criterion. The other way we can do it we can designate a target stiffness and we can minimize the mass. So, either way we can work out in simulation driven design. The software gives me a geometry.

What I need to do? I need to model it using few parametric design tools which are fed in the software and the free forming tool which are already there in the software. So, you see how the designing process in itself is very much different when it comes to additive manufacturing. So, you do not need to just make your manufacturing method economic.

Basically, what I am trying to say is that the manufacturing method is allowing you certain freedom to manufacture different design complexities, but you have to pay attention in the designing phase itself in order to make it really beneficial for that particular component whether in terms of manufacturing process or whether it be in terms of end application. So now this you can see.

This one is a conventional upright and this is a 3D printed upright to build topology optimization and that was all from my end. I hope these case studies give you the right guidelines like which is the right direction if you want to start designing for LPBF. This was Krishna Kashyap Singh from Wipro 3D. Thank you all.