Rapid Manufacturing

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Lecture - 44
Rapid Manufacturing case studies

So, welcome back to the last lecture in the course of Rapid Manufacturing. In this lecture I have just put some live case studies from the industry and you will see how rapid manufacturing is happening today.

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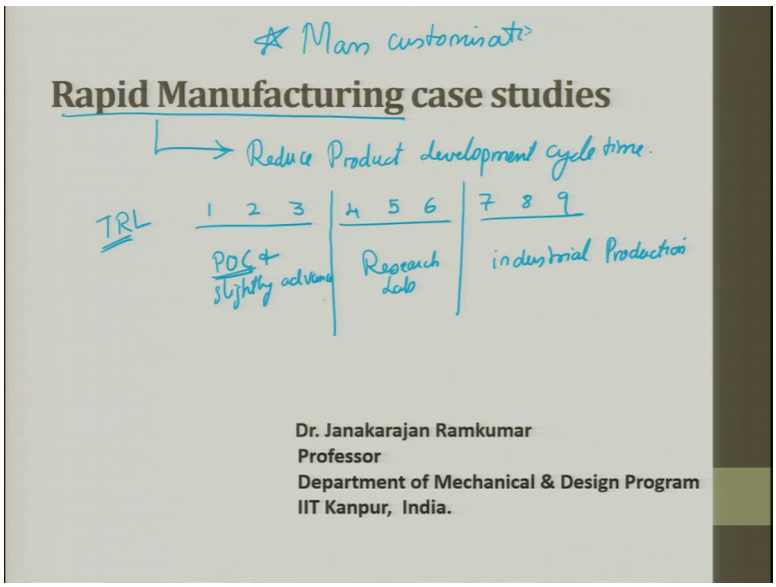

If you want to understand or if I have to put in a very small capsule or in a nutshell, rapid manufacturing basically is used to reduce the product development cycle time. When we talk about technology readiness level 1 2 3 4 5 6 and 7 8 9, so here it is most of the time it is called as for POC level and proof of concept and slightly advanced.

So, it can we can say it is like alpha level, here when it goes it goes to here what happens is the industrial production and 4 5 6 is converting this into pushing it towards the industry, here there is some ; research labs or something where POC is done. Now, they start working out how do we scale it up towards the production ok.

So, when we are looking at rapid manufacturing what we are trying to say is we are trying to shrink down this 1 2 3 and make it as early as possible and also when we go to the next level, so 4 5 6 level what is happening is we will also try to reduce the time here. And of course, when we talk about production we are now talking about directly making use of the product into the industry by using some machining process to lot of versatility ok.

So, in this way the Technology Readiness Level are TRL level 1 2 3 4 5 6 7 8 9 this time generally takes depending upon the component for a long time. This cycle time is reduced drastically why? Because the ultimate aim is mass customisation; is mass customisation ok. In order to do mass customisation of products we follow rapid manufacturing and interestingly today the market has changed its requirements. Today we do not talk about what have you produced, we talk about what have you delivered ok.

After all this online shopping, online food stalls coming into existence we more talk about what is the delivery you do rather than producing, you produce and if you do not deliver that is not rapid manufacturing. Today we talk about the concept of mass customisation and more focused towards delivery of the product to the customers. In order to achieve this we have to go rapid manufacturing.

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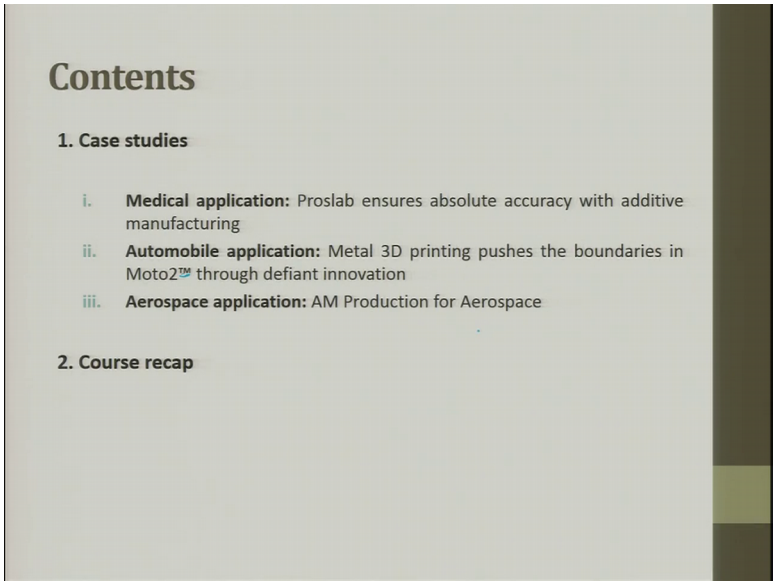

So, I have just taken free case studies one in the medical field which is exhaustively talk about today and second thing is in automobile application, third in aerospace and the last

I would like to recap what are all the broad perspect broad divisions of this course where we went through it.

When we talk about medical application we talk about Proslab ensures absolute accuracy with additive manufacturing we will see that case study. Then when we talk about automotive application metal 3D printing pushes the boundaries in the Moto2 TM trade mark through defiant innovation. Aerospace additive manufacturing production for aerospace materials for aerospace products.

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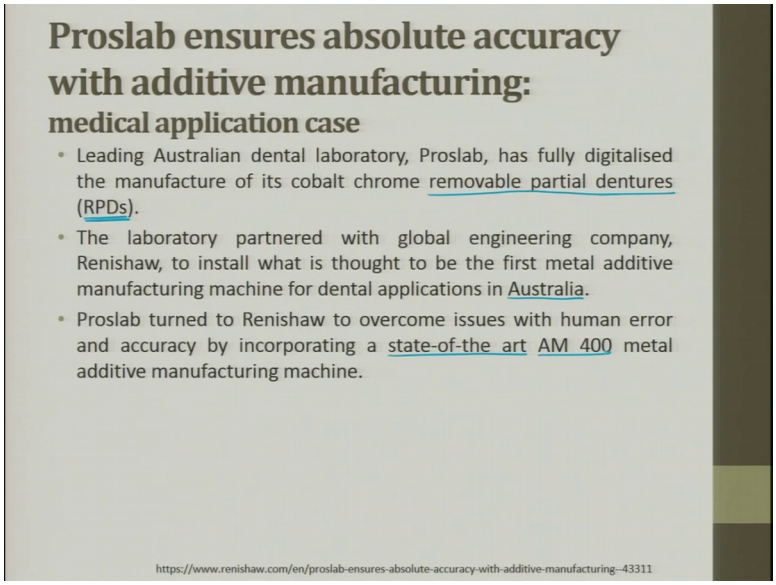

Proslab ensures absolute accuracy with additive manufacturing which is a medical application case study we are talking about. Leading Australian dental laboratories, Proslab has fully digitised the manufacturing of its cobalt chrome Removable Partial Dentures RPDs. The laboratory partnered with global engineering company, Renishaw who is very famous for making props to install what is thought to be the first metal additive manufacturing machine for dental applications in Australia ok.

This can be used for old people, this can be used for sportsman, this can be used for artist whatever it is, so they have started making partially removable partial dentures. The Proslab turned to Renishaw to overcome issues with human error and accuracy by incorporating a state of the art additive manufacturing machine 400 metal based machine further application.

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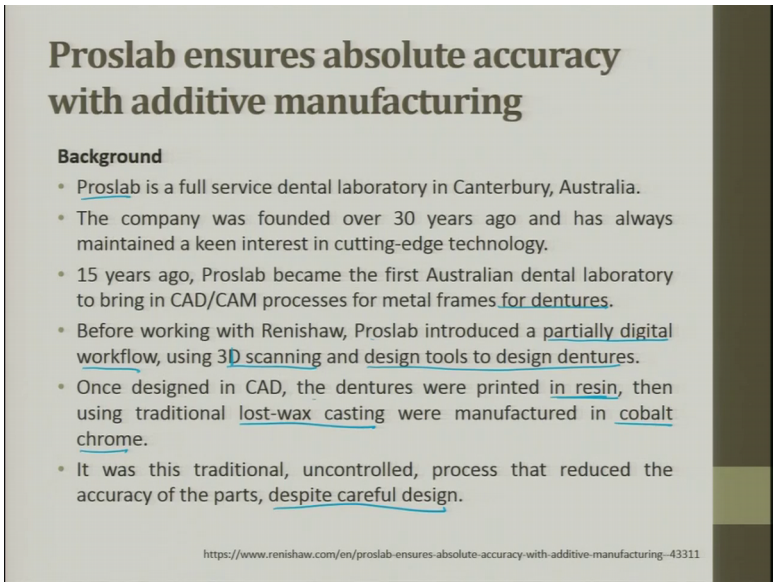

Let us see the background, Proslab is a full service dental laboratory in Canterbury, Australia. The company was found over 30 ago and has always maintained a keen interest in the cutting edge technology Proslab right. 15 years ago, Proslab became the first Australian dental laboratory to bring in CAD CAM processes for metal frames for dentures ok.

So, what are they doing? They are just trying to digitise the data which is available. So, who are where is a data available every customer comes and tells them. So, what do they tell they show that they show that job they just try to use the digitisation techniques like whatever we have gone through in this course reverse engineering techniques they scan get the point cloud data. And then they do some patchwork correction where in which what you studied in CAD, nerves all the baseline complex surfaces they try to take and then what they do is they store the data. Moment they store the data they try to develop a 3D object of it.

Once the 3D object is ready, now they look into what are all the manufacturing processes could be used such that they can quickly produce the output that is what they were been doing in the past. Now, with the existing CAD data solid model they are now pushing that solid model data into rapid prototyping machines or rapid manufacturing machines, where in which you use powder as the starting material or liquid as the starting material process the building block and get the part.

So, earlier they used it for CAD scanning and identifying the process and quickly developing the process plan and then getting the output. Now they have moved into additive manufacturing and they have moved into rapid manufacturing. Before working with Renishaw, Proslab introduced a partially digital workflow, using 3D scanning and digital tools to design denture this is what I was trying to say. Moment you have data with you a solid model data, then you can start thinking what are all the process to be done and what are all the sequences to be carried out, what are all the locating points and how quickly you can get the required output.

Once designed in CAD, what is a CAD? Point cloud data to solid, the denture were printed in resin this is after additive manufacturing coming into they were printed in resin. Then, using traditional lost wax casting where manufactured in cobalt chrome ok. Now, you see CAD; CAD they made through resin and they had a pattern, so this pattern they immersed in to wax and they manufactured yeah cobalt chrome output product.

It was this traditional, uncontrolled process that reduce to the accuracy of the part despite careful design why because of this lost wax casting, here we look for very high precisions by the way and its a three dimensional object. So, along the form if there is a deviation the error will be very high.

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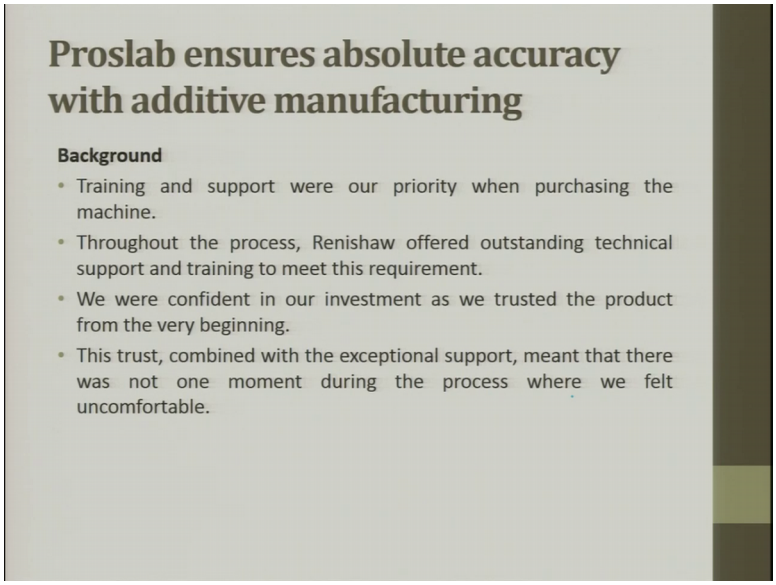

So, training and support were their priorities when purchasing the machines. Throughout the process, Renishaw offered outstanding technical support and training to meet this

requirement. We were confident that our investment as we trusted the product for the very beginning. So, they had a trust, so here what I am trying to say in front of you is not to advertise a company we are just trying to say please replace, if you are not comfortable Renishaw with the company which supplies a machine a machine supplier.

And this in the lab whatever it is a research lab or a dentist hospital ok. A dentist hospital joining hands with lot of trust with a machine and the machine developer give enough of support such that whatever was the dentist imagination could get converted into realisation. This trust, combined with the exceptional support meant that there was not one moment during the process where we felt uncomfortable, this a company supported.

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So, this is the typical lab environment where they work and please do understand it is very rare to find two human being having a same facial and dentistry patterns ok. So, this is the Proslab dental laboratory you can see digitisation is there people keep working on a process plan, people keep finishing the part all this things are there.

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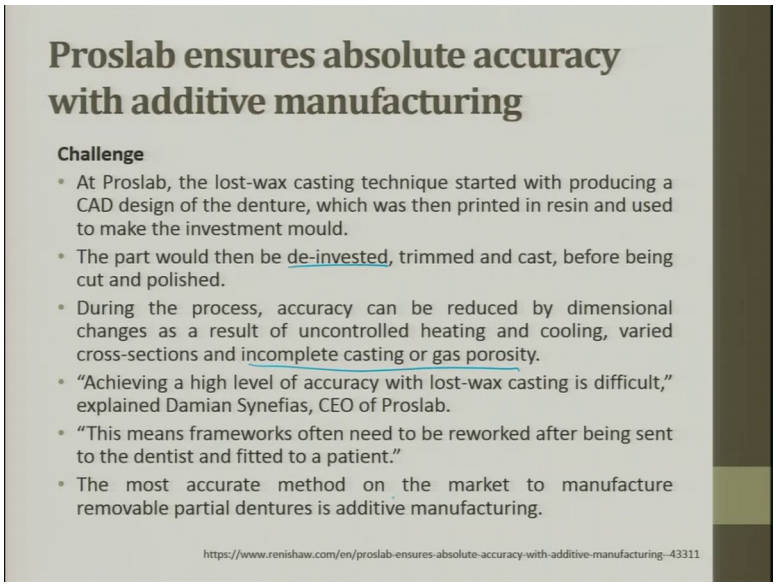

So, what are the challenges did this company face it is not a cat walk what I discussed in the class and what I discussed in this course as though it is they after this next step happens; after that next step happens its not so easy it evolves, when the process of evolution happens then challenges become easy to handle

A Proslab the lost wax casting technique started with producing a CAD design of the denture which was then printed in resin and used to make investment moulds ok. So, now, you see we made resin from the resin you made a lost wax casting technique was used and then what they made is they made moulds. Now, these moulds will be filled with the final material whatever it is to get the part.

The path would then be de invested, trimmed and casted before being cut and polished. So, cutting and polishing are finishing parts finishing operations. During the process accuracy can be reduced by dimensional change as a result of uncontrolled heating and cooling, in casting the biggest challenge is the thermal gradient control.

If we do not do the thermal gradient control properly the product whatever you the quality of the product whatever you get is no way good. As I told prior grain engineering is one area where people are working hard to get uniform strength and tailor made strength at the desired locations.

So, uncontrolled heating and cooling varied and varied cross section because our across your teeth denture, the cross section is not going to be uniform. See as far as engineering applications are concerned where you design a product and start doing we will always make sure that design for manufacturing concept is used, we make it in such a way such that it is easily doable.

But when we want to make spare parts for our body or bio mimicking some products or applications, then there is a huge challenge because it has freeform surface and keeping sensitivity in the mind there are places where the cross section keeps changing drastically. Freeform surfaces one challenge cross section change is the other big challenge. So, by reducing the dimensional changes as a resulting uncontrolled heating and cooling varied cross section and incomplete casting and gas porosity was a challenge for them to avoid.

Though data was done by CAD and then they used investment casting method which is very well known, they still had these two problems because when you pour removing the porosity is a challenge. Achieving a high level of accuracy with lost wax casting is difficult. So, this means framework often we need to be reworked after being sent to the dentist and fitted to the patient.

So, finally, when it is fitted on to the patient there was always a grinding operation required which always put the customer the patient into a mental stress. So, in front of the customer if you start grinding something he or she feels very uncomfortable and they are they have a depression that how well it is going to work.

So, doctor generally trying to avoid rework in front of the patients because if it is exactly fitting the patient will also go with confident that yes something good is happened it is only a mental block. The most accurate method on the market to manufacture removable partial dentures is additive manufacturing. So, 15 years back story now they identify additive manufacturing is the possible route to get out.

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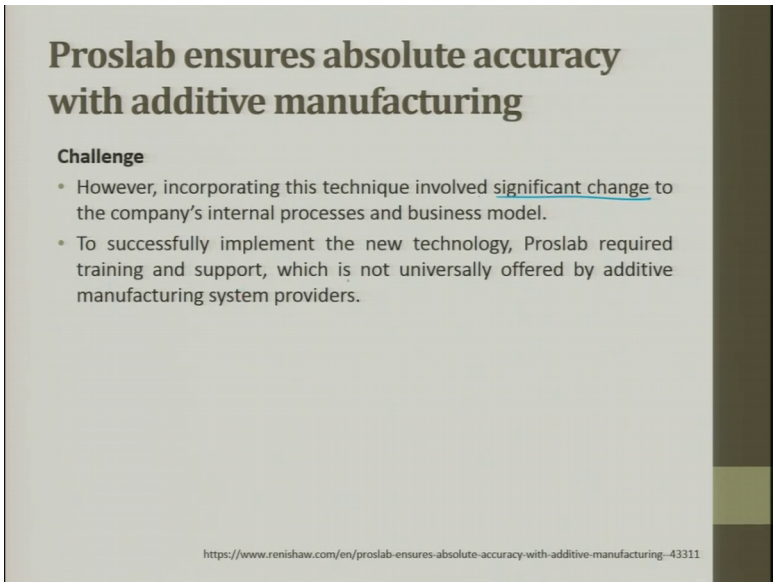

However, incorporating this technique involves significant change to the company's internal process and business model. If you want to move as a company towards rapid manufacturing there has to be two important things to happen in your company, one is your the mind set of every stakeholder in the company has to change, two there has to be initial high capital intensive investment to happen. To successfully implement the new technology, Proslab required training and support, which is not universally offered by additive manufacturing system providers.

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So, this is the denture built plate inside Renishaw this is a machine, so getting the scan data they were able to make multiple products each of varying denture size and shape, they were able to make to the highest accuracy. Here you can think of using laser as a source, you can think of using E beam as a source, moment you go for E beam you have a precise control, laser has its own advantage and disadvantages. So, you use any one of the sources inside the machine and start using metal powders powder means, it is not pure powder it is an alloyed powder mix it and then you can start getting it ok.

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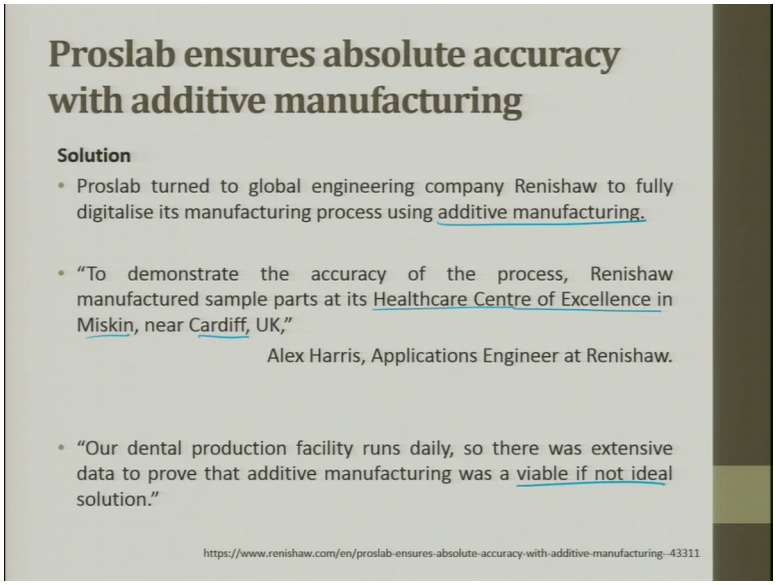

The solution was Proslab turned to a global engineering company Renishaw to fully digitise its manufacturing process by additive manufacturing. Now, it is very easy lost wax casting is removed further manufacturing processing time has shrunk down, you have all the data hit the data inside the machine get it what the get out of the get out with the product whatever you want ok.

To demonstrate the accuracy of the process Renishaw manufactured sample parts as it at its Health Centre care of Excellence in Miskin near Cardiff UK. Our dental production facility runs daily today, so there was extensive data to prove that additive manufacturing was a viable if not an ideal solution. Please make a note it is it need not be the ideal solution, but it can be an alternative and a viable solution looking into the cast.

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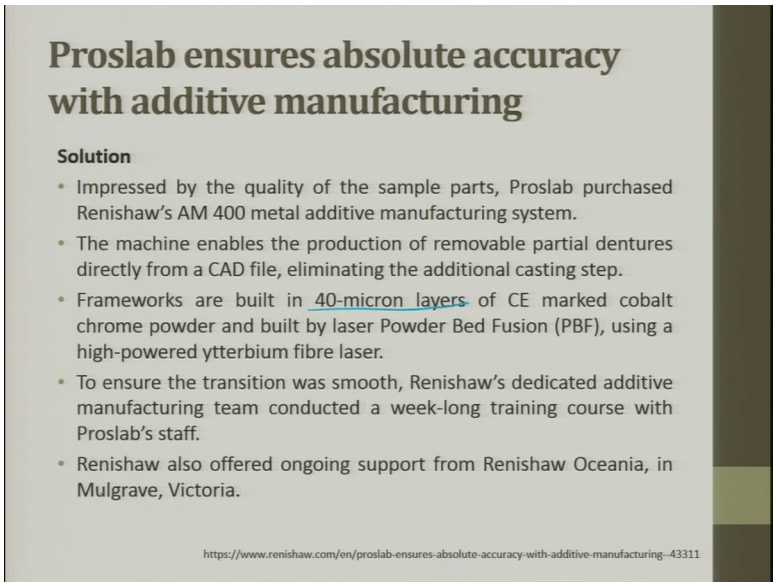

However, the raw material cost is still high when you talk about metal parts even today it is expensive, but; however, all the companies have come forward to accept third party powders. So, moment there is a third party powder available, then with the business competition available now the prices are getting slashdown. Impressed by the quality of the sample part, Proslab purchased Renishaw AM 4 metal additive manufacturing system. The machine enable the production of removable partial dentistry directly from CAD file, eliminating the additional casting step in between.

So, you made a resin then from a resin you made a last wax from the last wax you made a mould through a mould you got the output, now directly you get the output. The framework was built in 40 micron layer of CE marked cobalt chrome powder and built by the laser powder bed fusion which we have already seen, using a high power ytterbium fibre laser ok. To ensure the transition was smooth, Renishaw dedicated additive manufacturing team conducted a week long training course with the Proslab staff. Renishaw also offered ongoing support from Renishaw Oceania in the Mulgrave, Victoria.

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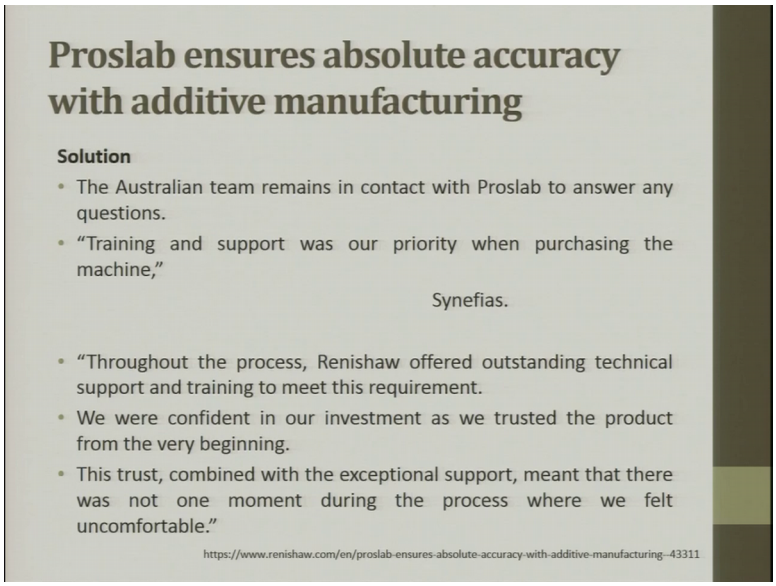

So, finally, they could get the required output. The Australian team remind in contact with Proslab to answer any question. The training and the support was our priority that is what I said any modification has to happen in an industry you need two important things one is skilling the manpower. So, it has to be a manpower wherein which they are ready to learn new things and they should be agile to accept the technology.

Today technology is changing very fast. Beyond your imagination what earlier we talked about a generation, my father was a generation right. Today I when I say generation is 10 years and when I talk to my undergrad students here they say generation is 4 years, my son who is in school talks about generation of 1 year the time scales have shrunk down.

So, you should be ready to accept technology and you should be agile to keep moving in developing it. Throughout the process Renishaw an offered outstanding technical support and training to meet the requirement. So, please I repeat once again Renishaw and you can replace it by any company; company offered whoever is the supplier see it is the new development can happen when all the team members who are working not within the factory, but outside the factory also should work on a common cause. Then your confident in our investment as we trusted the product for from a very beginning. This trust combined with the exceptional support meant that there was not one moment during the process where we felt uncomfortable.

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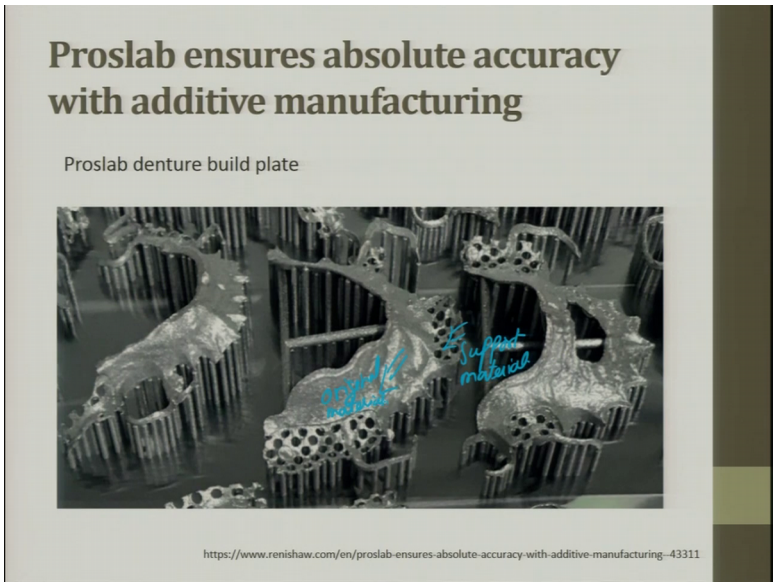

So, these are the dentures which were built, so it was very good, so these are the dentures, these are the supporting material, these are the original material; original material means final product ok.

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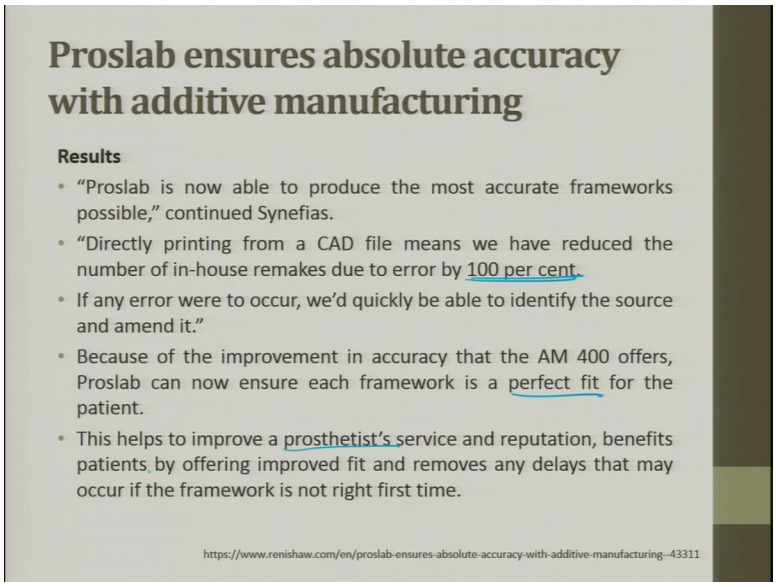

The result is now able to produce the most accurate framework possible. Direct printing from a CAD file means we have reduce the number of in house remakes due to error by 100 percent. So, you have a proper data most probably the first part what you produce is

the final part and we have stopped doing rework on it. If any error were to be occur we quickly be able to identify the source and amend in it.

So, nowadays you have very good simulation software, the simulation software's what they do is they try to make sure before they tried to show layer by layer how is it building, when the laser moves how is it building is there any porosity coming, is there any delamination happening between layers, whether the melt powder is perfect? So, you should have a uniform homogeneous heating.

Because of the improvement in accuracy that AM 400 offered Proslab can now ensure each framework is a perfect fit to the patient which is a big breakthrough. See are the online business whatever is happening today has become, so much it has changed the perspective of a customer. Earlier, if I say my son that I have booked a cycle for you, he will be ready waiting for the cycle even for a month.

Today the technology has gone so much, if I say I have booked for the cycle next he ask when is my delivery. So, because of so many things happening, so the technology development we are able to produce what a customer wants, the first part is the best parts, so the delivery time is reduced drastically.

And again here by using all this AM RM techniques Additive Manufacturing or Rapid Manufacturing techniques these examples what I present here in this case study is a single part a product. If you wanted to have multiple parts getting assembled and then you take a product even now it is a challenge. So, the way out of it in when we talk about rapid manufacturing is they are trying to make the; the products or the parts structure more complex and reduce the number of parts.

So, that what you make is perfect and the delivery is on time. This helps to improve the; the protestant service prosthetic's or I would say dentist service and the reputation benefits patience by offering improved fit and removes any delay that may occur if the framework is not right not right first time.

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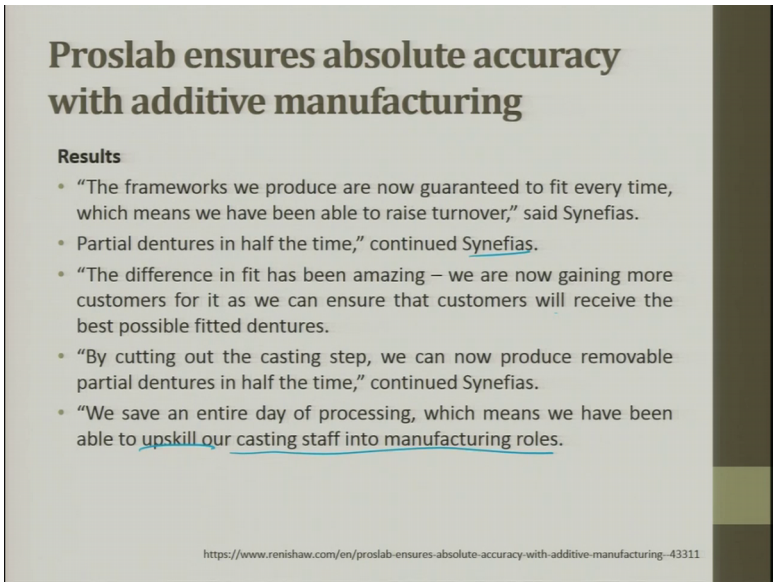

Result there is a major advantage the framework reproduced are now guaranteed to fit every time which means we have been able to raise turnover. Partial denture is half the time continued by is continued. The difference in fitting has been amazing, we are now gaining more customers for it as we can ensure that the customers will receive the best possible fit dentures.

By cutting down the casting step we can now produce removable partial dentures in half of the time. We save an entire day of processing which means that we have been able to upscale our casting staff in to manufacturing role. So, our process is reduced, the production time is increased in the production time I am sorry it has to be a delivery time has reduced a lot and you are able to produce and deliver sound products.

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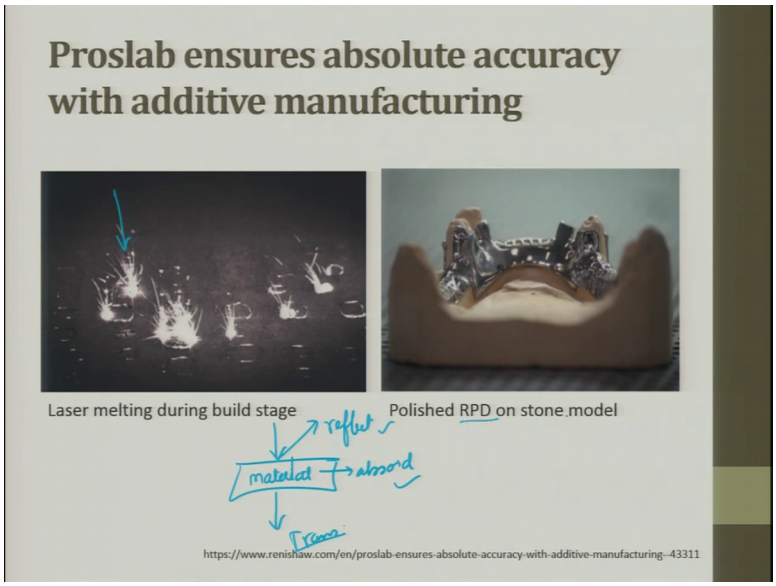

So, this is during the process of melting, so you can see laser is heating when the laser interacts with material, the powder material through when light hits at a material or I would material and a light is sitting you can have reflection, transmission and absorption right absorption.

So, when the light reflex it is this spark you see that outside when it observes it heats and melts and very rarely it transmits. So, here we use these two phenomena's in a large extent and we get the required output. So, polished RPD on a stone mould.

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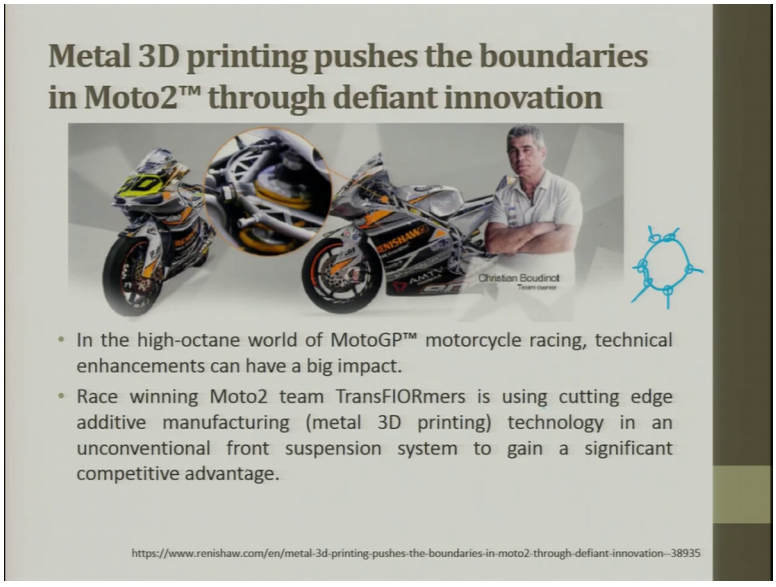

The next one is metal 3D printing pushes the boundaries in Moto2 TM through defiant innovation. In the higher octane in the world of MotoGP TM motor cycle racing, technicians enhancement have been a big impact. So; that means, to say earlier there were more number of parts and when there are more number of parts the assembly was always a challenge when you up.

When you run at very high speeds in this racing bikes very high speeds, these even a small stone gives a big jerk and these get unassembled. So, now what has happened is they have stop may using large number of parts and they have made the part geometry complex integrated all the assembly into a single part itself and see how best they can do.

For example, if there is a ring and if there are rods which are attached to it for fastening, now this rod along with the ring is built up right there. So, number of process are reduced and the parts are getting integrated into one part the part geometry has become complex. So, this will try and you can also selectively strengthen the part wherever you identify there is a failure zone here alone you can have more material compared to rest of the pipe that is you decide.

The race meaning Moto2 team TransFIORmers is using cutting edge additive manufacturing technique in an unconventional front suspension system to gain a significant competitive advantage ok.

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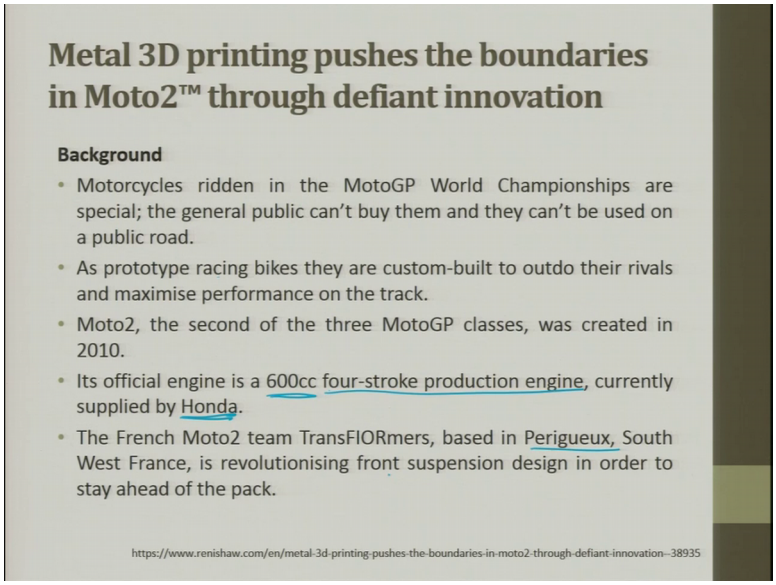

So, they are started by the weight is reduced this suspension quality has enhanced. So, the rider is given more comfort. So, the motorcycle riding with the MotoGP world championship are special, the general public cannot buy them and they cannot be used on a public road. As prototype race biking they are custom build to out do their rivals and maximize performance on the tracks. Moto2, the second of the third MotoGP class was created in 2010.

Its official engine is 600cc typically what in Indian conditions earlier we used to talk 100 cc as the high power, now we have also amount to 100, 125, 150, 200 it has come ok. So, but what engines are used in this particular racing bike is 600cc with four stroke production engine, currently supplied by Honda ok.

The French Moto2 team TransFIORmers, based in southwest France is revolutionizing front suspension design in order to stay ahead of the pack; that means, to say of their competitors.

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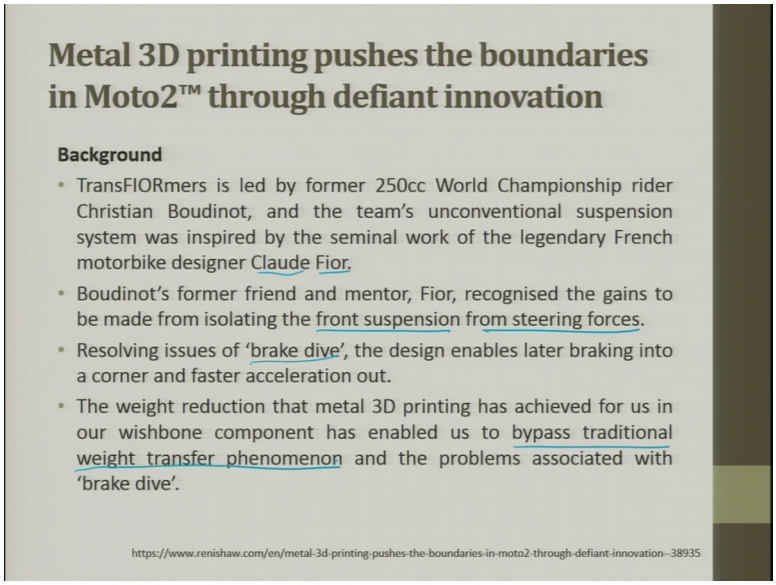

TransFIORmeris led by former 250cc world championship rider Christiana and the team unconventional suspension system was inspired by a seminal work of a legendary French motor bike designer Claude Fior. Christiana former friend and mentor Fior, recognise the gain to be made from isolating the front suspension from steering process. Suspension will be independent steering forces is the front frame is independent, so this gives them a more flexibility or applies less force for steering, be more sensitive towards steering ok.

Resolving issues of brake dive and design enabled later breaking into the corner faster acceleration out, where put as the objective functions and this was done. The weight reduction that metal3D printing have achieved for us in our wishbone component has enabled us to bypass traditional weight transfer phenomena and problems associating with brake dive.

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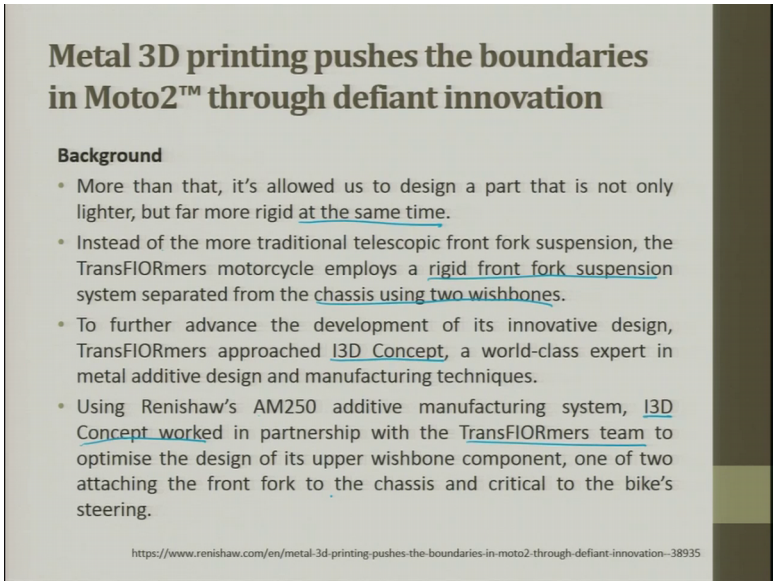

More than that, it allowed us to design a part that is not only lighter, but far more rigid at the same time. So, weight of the vehicle goes down, efficiency goes high number of components attached to the steering has been reduced. So, if you want to do this trial testing you have to do many things and in the conventional way it takes a hell lot of time. By using this rapid manufacturing techniques they could iteratively change and get the best fellow out of it.

Instead of the more traditional telescopic front fork suspension, the TransFIORmers motorcycle employed a rigid front fork suspension system separated from the chassis using to wishbones. To further advance the development of the innovative design, TransFIORmers approach I3D concept, a world class expert in metal additive design and manufacturing technique. So, they made good techniques, they did some analysis software simulation analysis and they felt that yes this is going to be the trend setter, then immediately what they did was let us make few prototypes and see. So, they approached an additive manufacturing company.

Using Renishaw AM250 additive manufacturing system, I3D concept worked in partnership with the TransFIORmers team to optimise the design of its upper wishbone component, one of two attached attaching the front fork to the chassis and critical to the bike steering.

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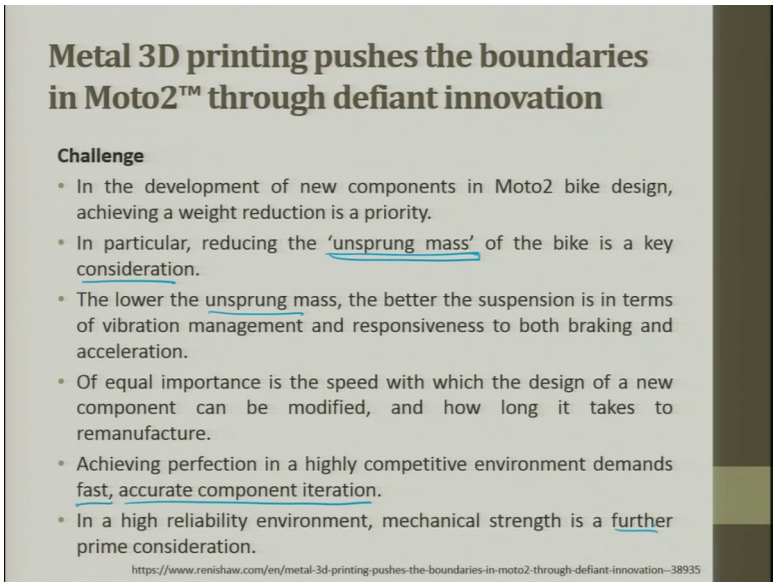

The challenges when faced by them is, it is not as challenging as the front the first case what we studied biomedical is a very challenging case, but here you conceptualize you imagine an engineering design to a large extent it is not so much of freeform and the cross section area does not vary so drastically like in the dentures case.

In the development of new components in Moto2 bike design, achieving a weight reduction is a priority because here that is what is a priority. So, in particular reducing the unsprung mass of the bike is a key consideration jumping of the mass. The lower the unsprung mass, the better is the suspension in the terms of vibration management and a responsiveness to both braking and acceleration unsprung mass vibration.

Of equal importance it is the speed with which the design of a new component can be modified and how long it takes to remanufacture. Achieving perfection in highly competitive environment demands fast accurate component iteration. In a high reliability environment, mechanical strength is a; is a further prime consideration.

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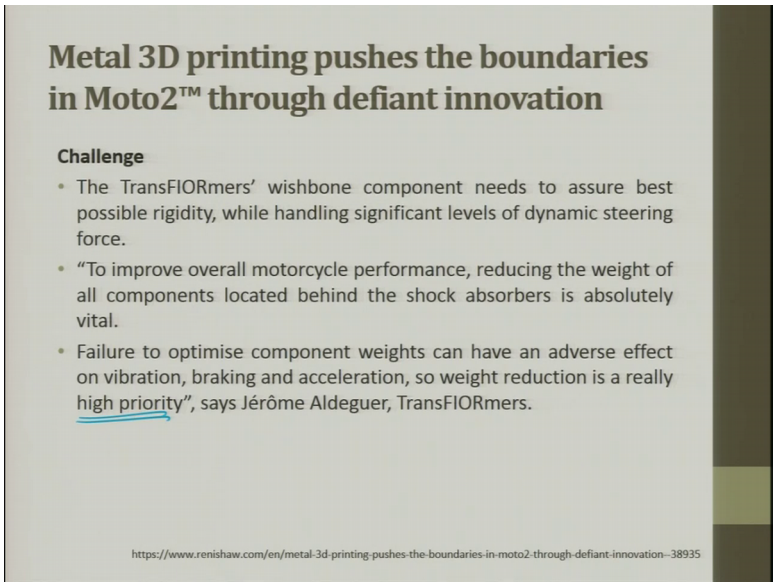

The TransFIORmers wishbone component needs to be assured best possible rigidity, while handling significant levels of dynamic steering forces. To improve overall motorcycle performance, reducing the weight of all components located behind the shock absorb is absolutely vital. Failure to optimise components weight can have an adverse effect on vibration, braking acceleration, so weight reduction is really a high priority ok.

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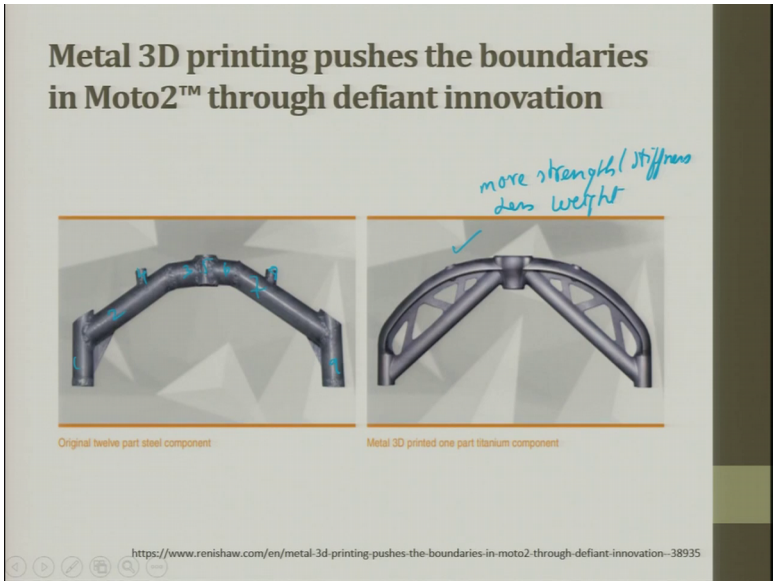

So, all these things were done, so this was the original 12 part steel frame you see that 1 2 3 four I told you know 1 2 3 4 5 6 7 8 9 and then you have other sides also parts. Now, you see this is it has 12 parts cutting, welding and you see it is very complex making a fixture for welding it is a challenge.

Now, you see the entire thing is done by a 3D part has one part you see it has come and now this has more strength less weight or I would put stiffness and this gives a better control over the objectives whatever we want.

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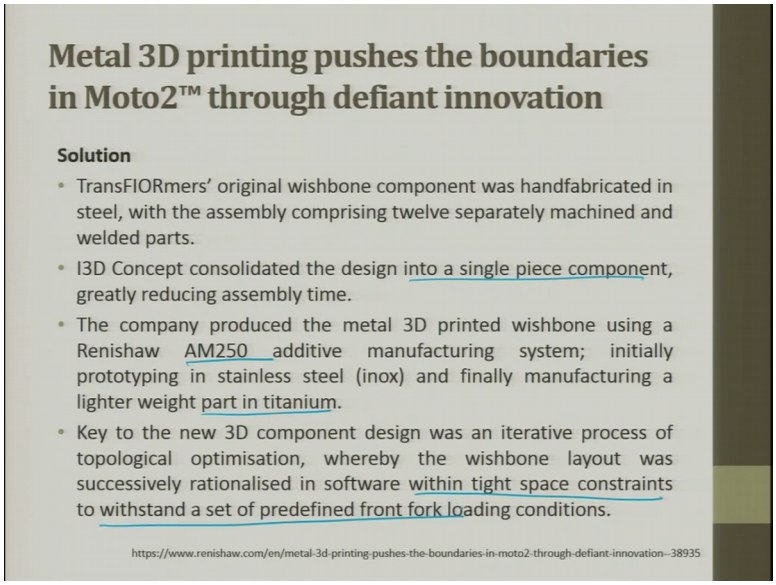

So, originally wish wishbone component was hand fabricated in steel with the assembly comprising of twelve separate machine done by that parts. So, now, it is made of a single part ok. It is made through AM250, machine initially prototype is in stainless steel and finally, manufacture a lightweight part with a titanium because titanium is much lighter the density of titanium is lighter.

Key to a new 3D component design was an iterative process of topological optimisation, whereby the wishbone layout was successfully rationalised in software within tight space constraints to understand a set of predefined front fork loading conditions.

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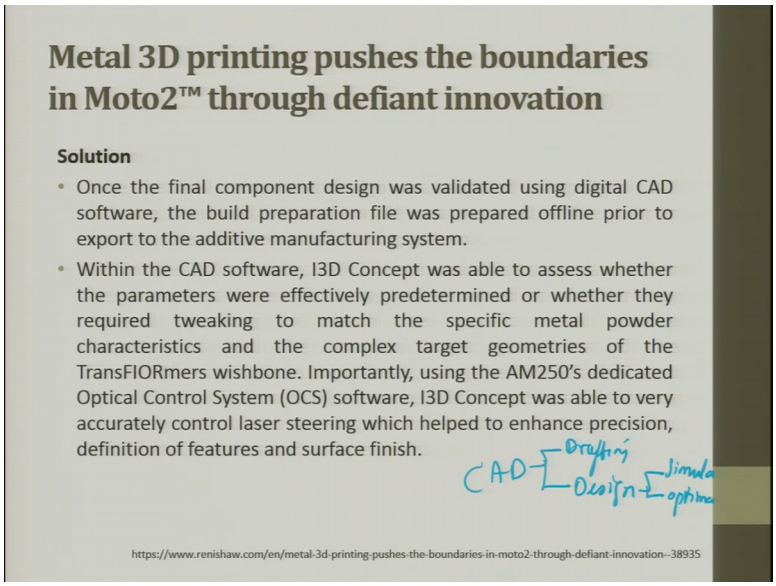

Once the final component was decide and validated using a digital CAD software, when I say CAD software it does not mean drawing a load CAD means it is including of drawing simulation and they also try to do optimisation ok. Today CAD means it is not drafting, it is design wherein which we have simulation, we have optimisation also done in terms of shape, material whatever it is right.

So, once the final component design was validated using a digital CAD software, the built preparation file was separated offline prior to export to the additive manufacturing system. Within the CAD software, I3D concept was able to assess whether the parameters where efficiently predetermined or whether they required tweaking to match the specific metal powder characteristics and complex target geometry of the TransFIORmers wishbone.

Importantly, using AM250 dedicated optical control system software, I3D concept was able to very accurately control laser steering with a help to enhance precision and also control the surface finish.

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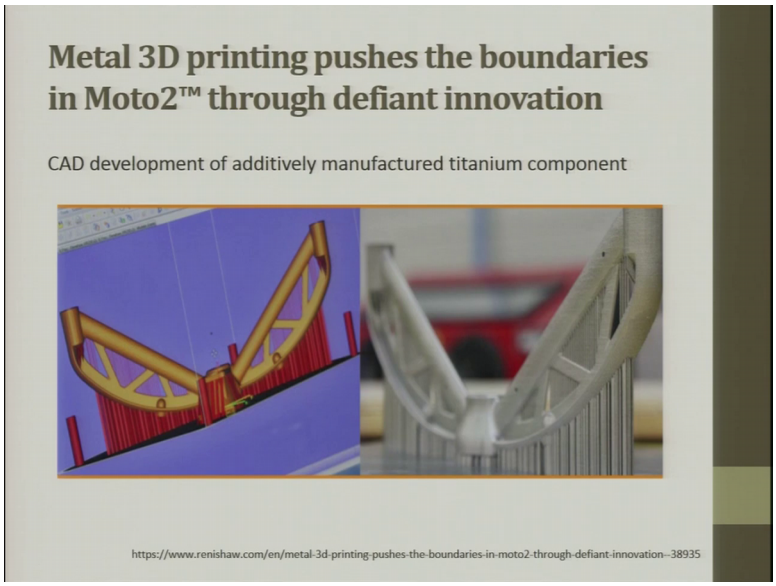

So, this is a CAD develop of additive manufacturing of using titanium and here is a part this is the CAD, look at it how; how have you reduced this is rapid manufacturing we have reduced the cycle time in terms of manufacturing also.

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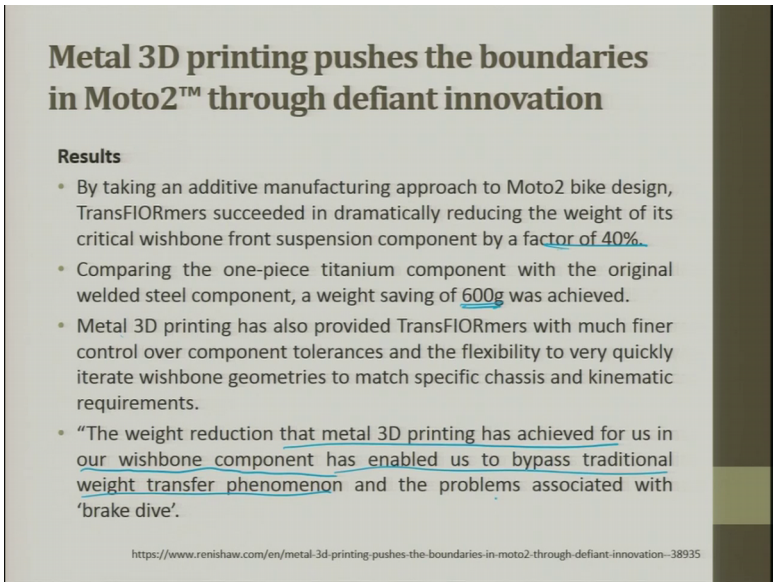

Result by taking an additive manufacturing approach Moto2 bike design, TransFIORmers suspend succeeded in drastically reducing the weight of its critical wishbone front suspension component by a factor of 40 percent. Comparing the one piece titanium component with the original welded steel component, a weight saving of

600 grams was achieved, it is a huge reduction, so you get more speed you can win the by racing bike ok.

A metal 3D printing has been also proved TransFIORmers with which much finer control over component tolerances and the flexibility to a very quick iteration wishbone geometries to match the specific chassis and kinematic requirement. The weight reduction that 3D printing has achieved for us in our wishbone component has enabled us to bypass traditional weight transfer phenomenon and problem associated with brake dive.

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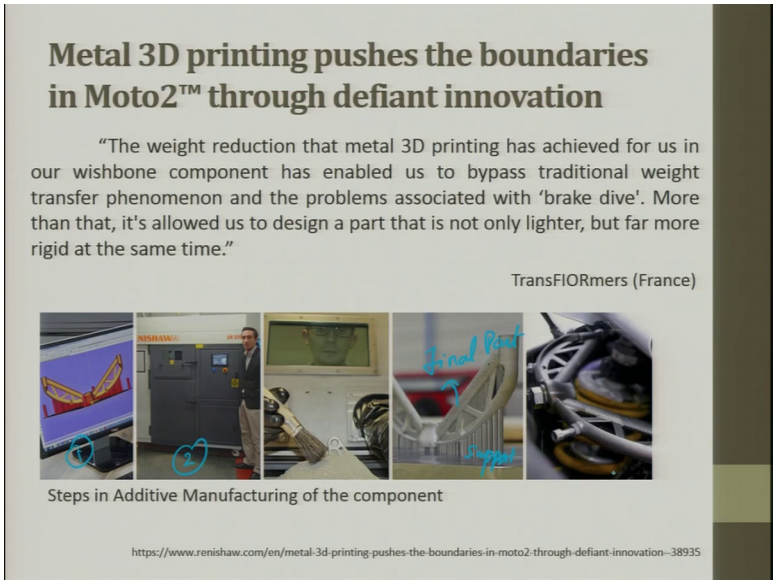

So, this is what it is a CAD model has been developed it has been manufactured. So, then what you can do is when the part is get produced you have the other powder free powder particles this is how the free powder particles are removed, these are the supporting structures this is the final part ok. And this is when it is fixed, when it is put on application this is how it looks like.

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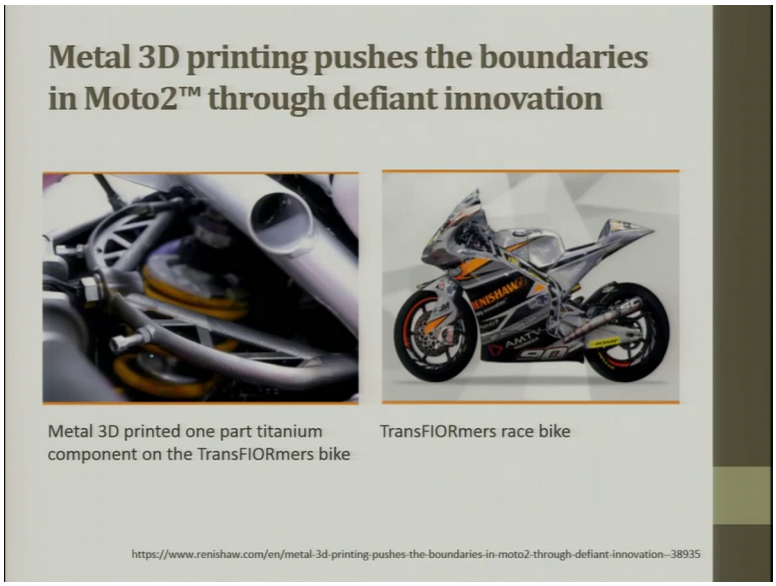

So, part of one piece titanium which is done this is the bike which they used it for winning.

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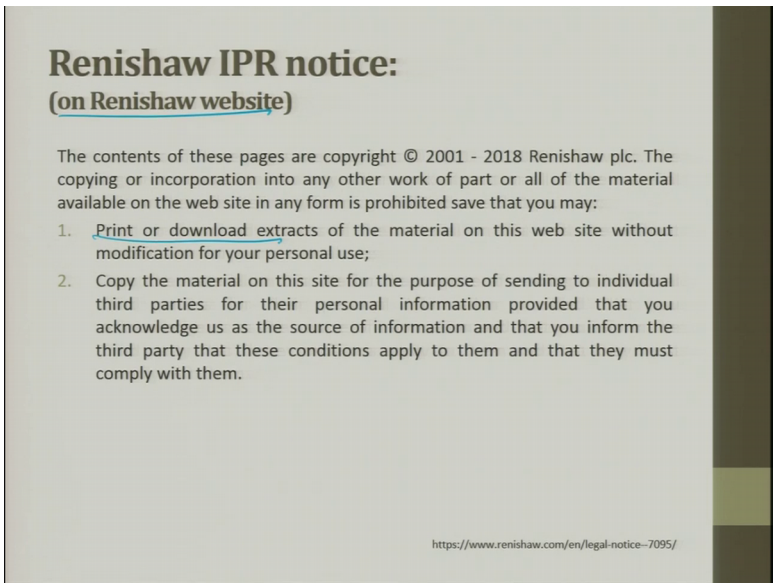

So, I have used this and on Renishaw website it is there, they have put many more applications and what I would suggest all the students is to go through this website learn more case studies which is available there I have picked all the case studies from them and this is what the copyright which is given and they approve it and agree it that we can use the case study for educational purposes.

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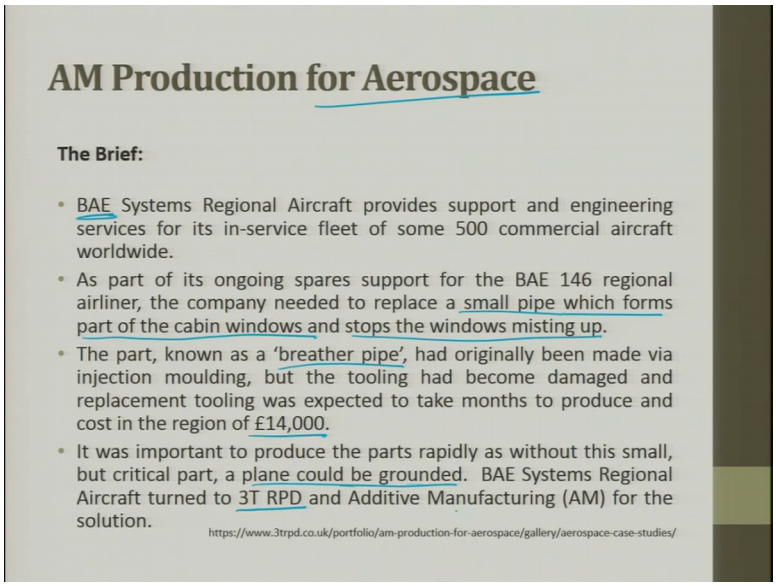

So, for aerospace BAE system regional aircraft provider support and engineering services for its in service fleet of some 500 commercial aircraft worldwide, they have BAE is a system. As part of the original spare support for the BAE 146 regional airline, the company needed to replace a small pipe which forms part of a cabin window and stop the wind windows miss fitting up.

So, the part known as breather pipe, had originally been made via injection moulding, but the tooling has become damaged and replacement tooling was expected to take months to produce and the cost was so much. So, this is a pipe which has to be produced, this is required for the OE Original Component which gets into the part fabrication and also to the spares market and all of a sudden one fine day the injection moulding die got damaged.

So, it is important to produce the part rapidly as without this small, but a critical part the plane could not be grounded. So, BAE system regional aircraft turned to a 3T RPD and additive manufacturing for a solution. So, this is a CAD model of BAE system breather pipe showing smooth angle of turn.

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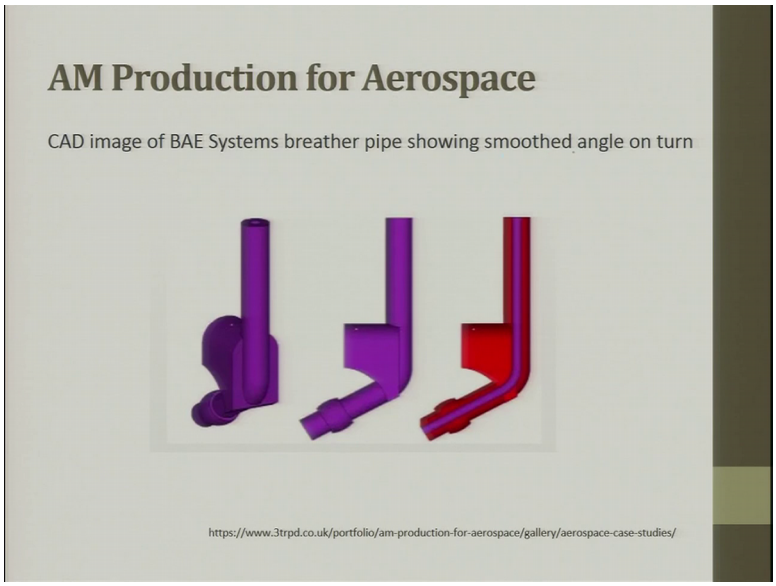

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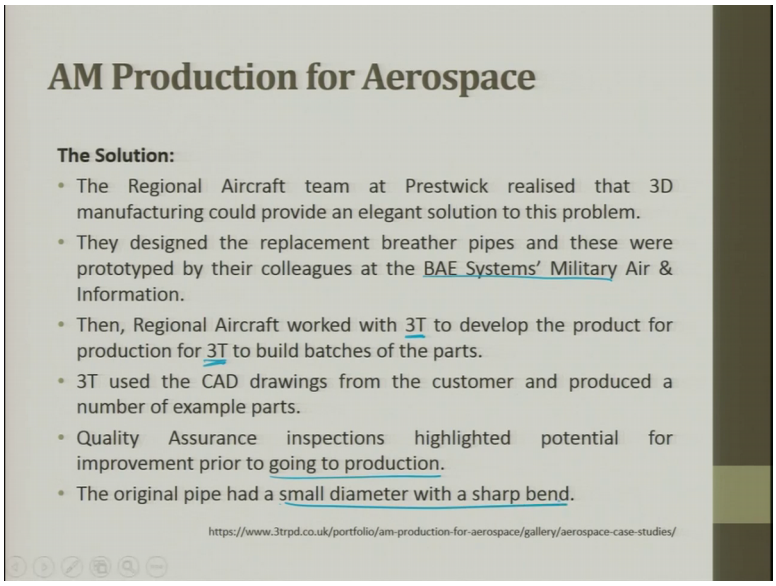

Aircraft team Prestwick realise that 3D manufacturing can provide an elegant solution to this problem. They design the replacement breather pipe and these were prototype by their colleagues at BAE system military air and information. Then, regional aircraft worker with 3T to develop the product for the production of 3T to build batches of parts.

That 3T used the CAD drawing from the customer and produced a number of example parts. The quality assured inspection highlighted potential for improvement prior to the

ongoing production. The original pipe had a smaller diameter with the sharp bend. So, that could be reduced because the conventional manufacturing was putting a restriction.

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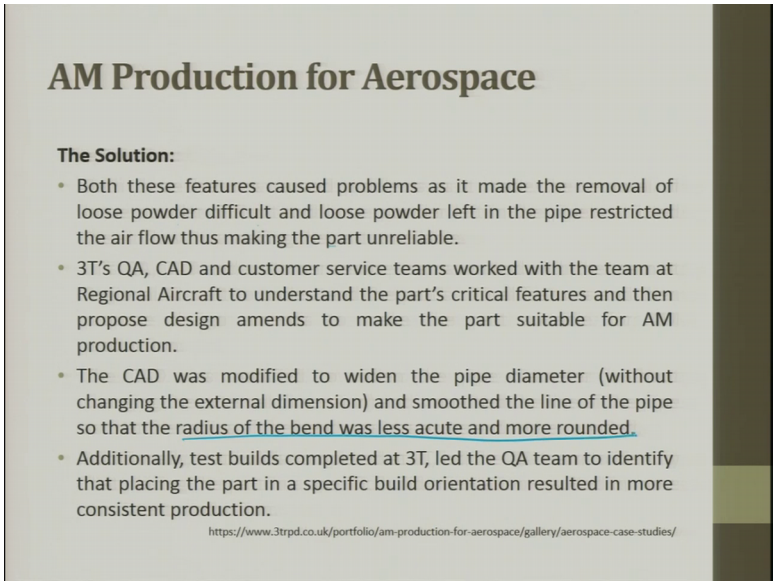

Both these features caused problem as it made the removal of the loose powder difficult and loose powder left in the pipe restricted the airflow thus making the part unreliable. So, the CAD was modified to widen the pipe diameter and the smooth and smoothen the line of the pipe, so the radius of the bend was less acute and more rounded. So, they could get the part done to their requirement.

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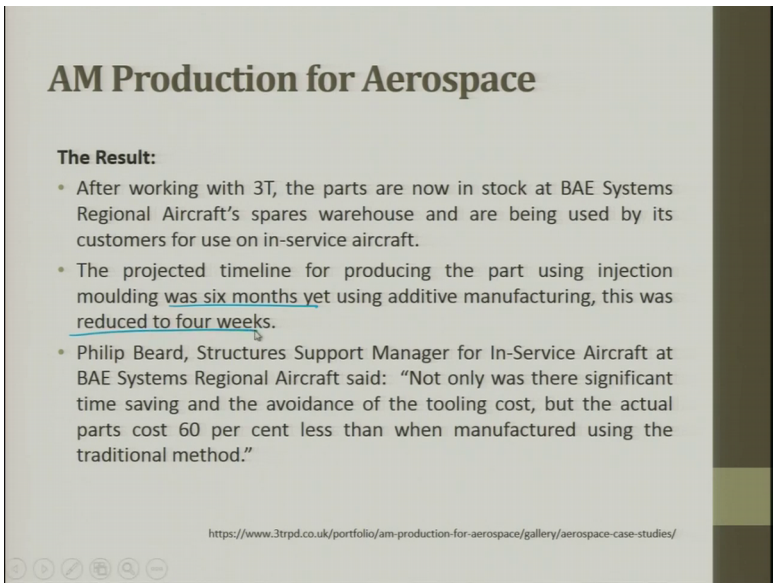

After working with 3T, the part are now in stock at BAE system regional aircraft spares warehouse and are being used by its customer for use on the in service aircrafts. The projected timeline for producing the part using injection moulding was six months yet using additive manufacturing, this has reduced to four weeks. So, this is what is rapid manufacturing and they were also able to improve the quality of the product.

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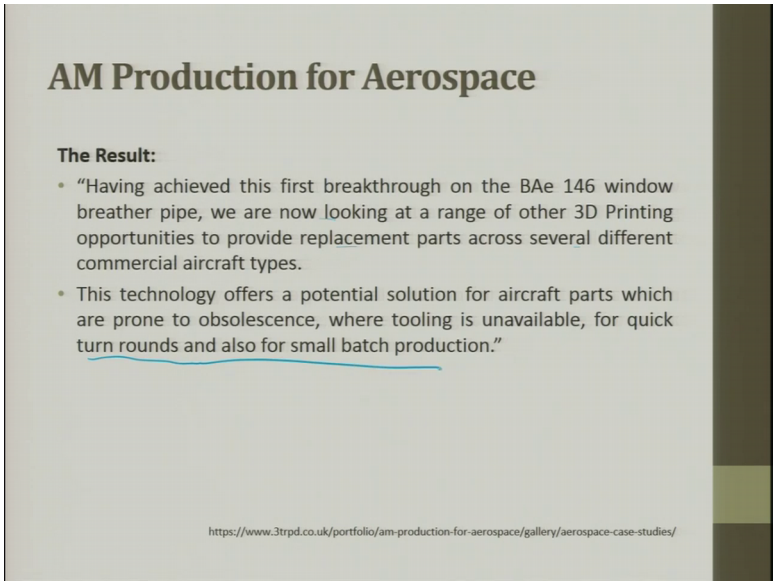

Having achieved the first breakthrough on the BAe 146 window breather pipes, we are now looking at a range of other 3D printing opportunity to provide replacement parts across several different commercial air craft types. The technology offered a potential solution for aircraft parts which are prone to obsolescence, where tooling is unavailable for quick turnaround and also for small batch production. So, BAE finished breather pipe this is what it is and it is made out of metal.

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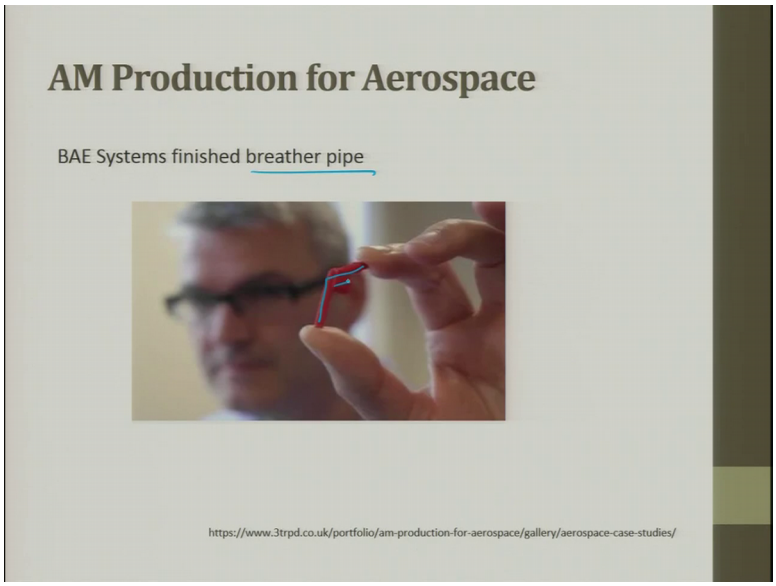

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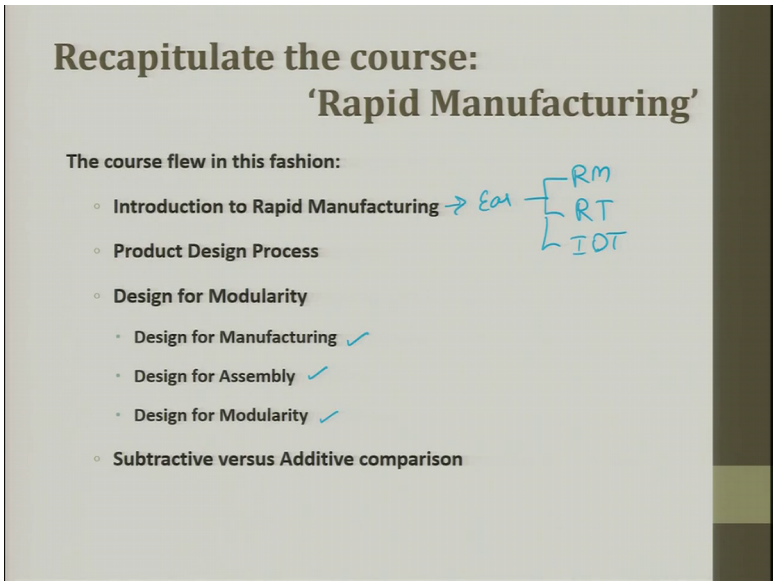

So, to recapitulate what we covered in this course, the course flew in this fashion introduction to rapid manufacturing was done and I give you an example of a ear. So, I taught you how to do rapid manufacturing, rapid tooling, I talked to you about indirect tooling also.

Then we talked about product design processes, design for modularity in that design for manufacturing assembly and design for modularity were discussed. Then we would also saw the advantage of subtractive process versus additive process comparison.

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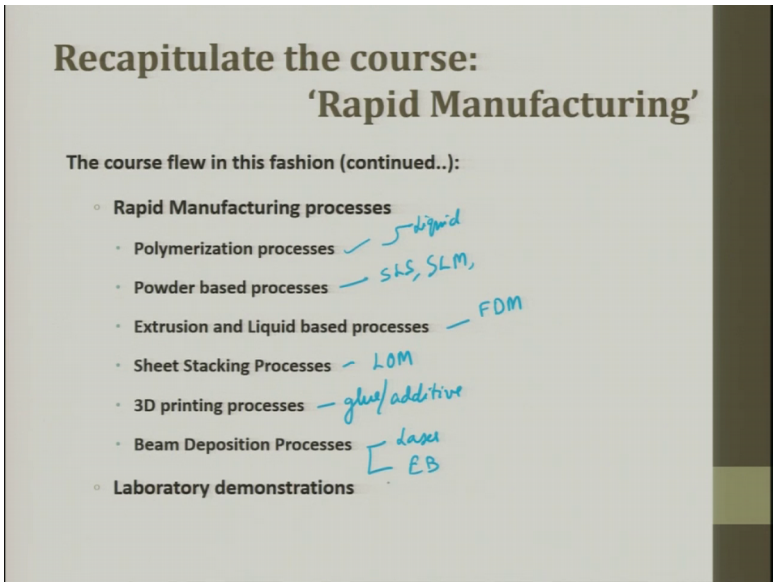

Then we entered into rapid manufacturing process first we saw powder polymerization process, where we saw liquid as a starting material we saw that. Then we saw powder based process wherein which most predominant one is SLS, SLM ok, we saw that on top of other processes, extrusion we saw FDM process and other liquid based processes we saw, then sheet stacked process basically a LOM process we saw here.

Then 3D printing processes wherein which we saw how glue could be used, glue or additives could be used for joining powder parts to produce the output. And finally, we saw how to use laser as a heat source or E beam as a heat source to get the output. In between we also had in this course lab demonstration, for reverse engineering, for 3D printing.

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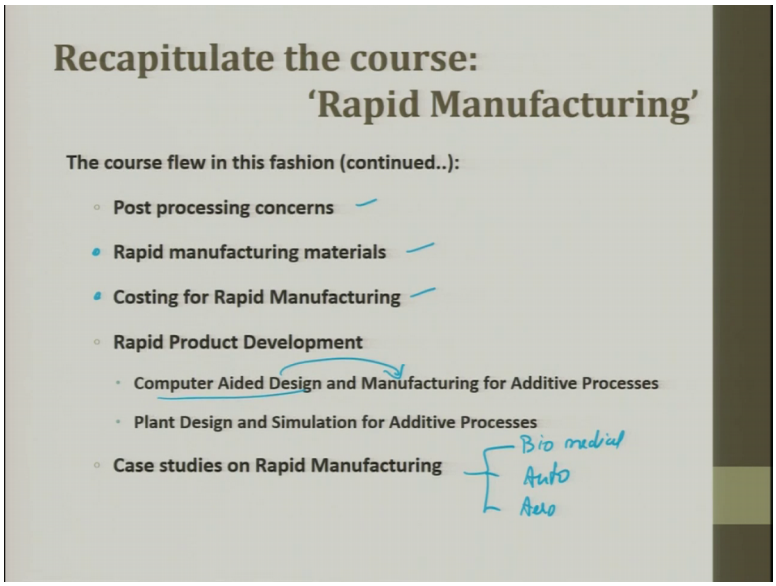

Then we also talked about post processing concern, we saw about rapid manufacturing materials which are there, costing for rapid material rapid manufacturing was also dealt in this course, so this two is very important. Costing is something which people always ask one is capital cost other one is recurring cost, so we discussed about that.

So, rapid product development computer aided design we saw wherein which we talked about 2D, 3D, solid surface, boundary representation all those things manufacturing of additive processes. Why is this important in additive manufacturing we saw that then plant design and simulation of additive processes we saw.

And finally, today we saw some case studies one in biomedical and biomedical auto and we also saw aero. So, these are the three case studies we saw, when we see this case studies I am sure you will appreciate, the rapid manufacturing is going to be the future.

Thank you very much.