Systems Engineering

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Lecture - 18
Need Analysis

Good afternoon. Today we are into the Need Analysis option we are studying the unmanned system case earlier. And we are today going to see how we did the Need Analysis, and what are some of the basic considerations that we did. From the previous videos you have actually seen how the basis user input or user analysis is been collected where you actually go watch the system-- existing system that is in operation.

And then look at the users and talk to the users; identify what the user wants; what is the issues with the current system; how the current system can be improved; what are the lacunas that are available in existing system and from there come up with a new option. So we were discussing the Unmanned Aerial Vehicle UAV's earlier and we have seen as case where we were talking about a short range short range Unmanned UAV that we were developed within as a part of the project.

And we said there are so many requirements from the user and how that it actually translated into certain specifications. So today what we will do is in a short lecture we will actually go through how some of those constraints or some of those aspects that were mentioned by the user got translated into what we call as a specification. So if you remember, we will take two today.

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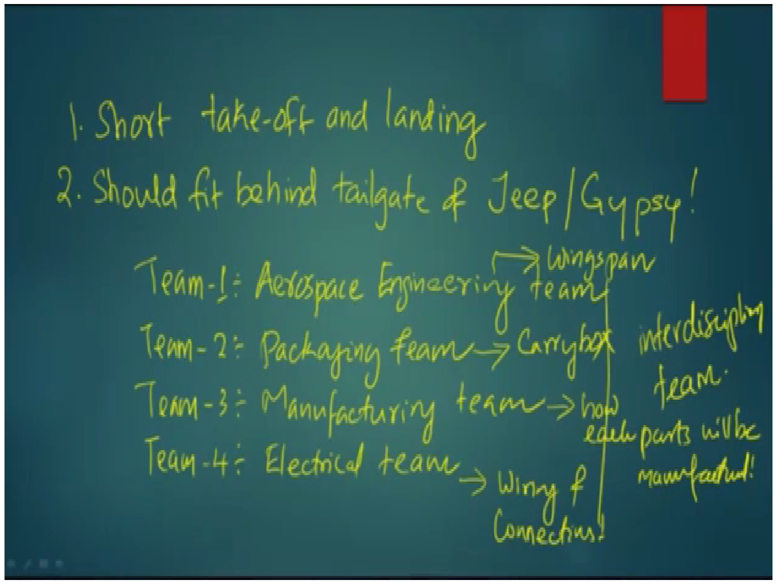

So the first one we would like to talk about is - the first one we are going to talk about is ‘Short take-off and landing’. And second one is ‘Should fit behind tailgate of Jeep/Gypsy’. So obviously these two things we will see these are two segments that are made by the user. And we will try to see how these statement gets translated to what we call as a type of specification. So one thing is that the teams involved in this the first team.

We will say Team one is the Aerospace Engineering -- engineering team, second one Team two involved this in the packaging team; Team three that is involved in this was the Manufacturing and we also included Team4 the Electrical. So this is what we call as the Interdisciplinary team.
So what we did was we first wanted to get the size of the UAV. We wanted to know how big UAV’s. So the right people to give that input. How big in the sense?

What is the span of the UAV? The right people to give you that input will be Aerospace engineering team, so there input will be on the wingspan. The Packaging team will be the one who would decide the Carry box. The manufacturing team will be deciding how each parts will be manufactured. Or the process they are going to use, what is the minimum size that they can manufacture. And the electrical team was wiring and connections. Because you will understand when we talk about the details of it.

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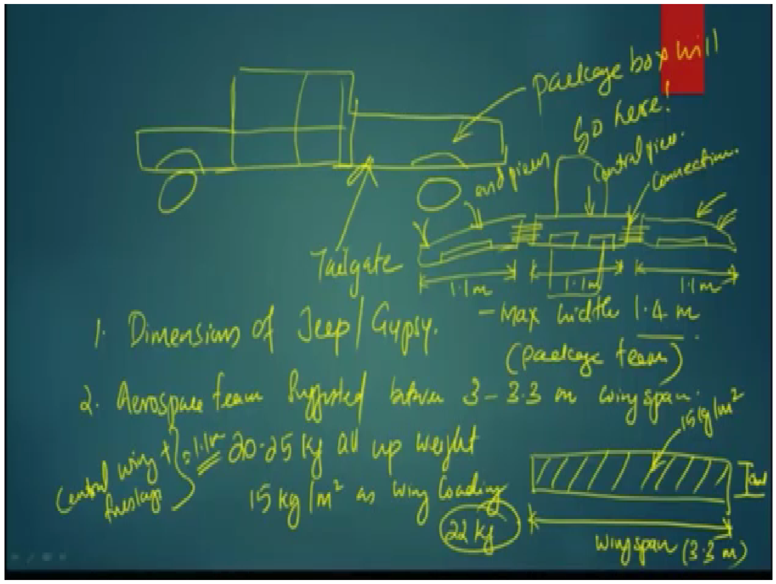

So if you think about G for a Gypsy it is like-- if you draw about it, it has a bonnet, cabin and there is a portion behind it, this is wheels. This is what we call the Tailgate. So the idea is that it should-- this is where the driver, passengers everybody sits. The UAV should be able to fit here in that box so the package box will go here. Okay. Then the packaging team when then actually took dimensions so the step one is Dimensions of Jeep/Gypsy.

So they took the dimension and they said okay max width is 1.4 meters. So the wider the maximum width of the component that they can fit into the behind this 1.4 meters. And then this input came from the package team. Then the Aerospace team suggested between 3 to 3.3-meter wingspan, okay. So the 3.3-meter wingspan and some additional connectors and other things that is part of this.

The 3.3 meter wingspan if you try to find out how do they come up with that the idea was that the UAV has to lift something close to 20 to 25 kilograms all up weight and they calculated a wing area -- they took an assumption about 15 kilogram per meter square as wing loading and so in that regard if you want to- if you have- so per meter square you can actually take up to 15 so they ended up creating a nice wing which would actually be able to take the all up weight of 20-22 kg and they said okay fine.

The wing, this the wingspan; we are not talking about the (()) (07:25) this is the -- you can think about as the cord or the distance. So you multiple this—this total area should come up in such a way that if you assume 15kg per meter square this area this total area should be able to lift a total weight of about 22kg. Once this was finalized this wingspan set to 3.3-meter. Once wingspan set to 3.3 meters we knew that there is a packaging restriction of 1.5 meters.

So we took some clearance and other things out and we found out okay if we make this one 3.1 into 3 equal parts you get 1.1 meters which is within this 1.4 meters. Then we decided okay we will make the wing into three equal of part of 1.1 meter each. So then the wing shape came to be something like one part this is 1.1 meters and the second this is again another 1.1 meters and the third part another 1.1 meters. Okay.

So that all these-- and obviously if you are making into three parts then you require a connection. Because the wings always will have its own control surfaces on it, you are elevators, ailerons all those kind of things will be available on the wing. So they are all controlled by server mottos so the connections—the wiring has to run through. So it was decided that the central piece of the wing this was the-- these two are the end pieces and this is the central piece.

So, the central pieces of the wing were mounted on the fuselage. So the fuselage was mounted. So the central wing plus fuselage together 1.1 meters was within this. So that will actually go as one assembly and to the packaging box. Then these two side pieces of the wing will actually be put on to the sides. That was the way the packaging box is designed. So based on the packaging team—the packaging teams input the connectors and other things were taken care off.

Then the electrical people said okay if you are running all these wires and conduits then these are the connectors; these are the wires that you need; these are the other additional stuff you need to put it in which were also taken part of that.

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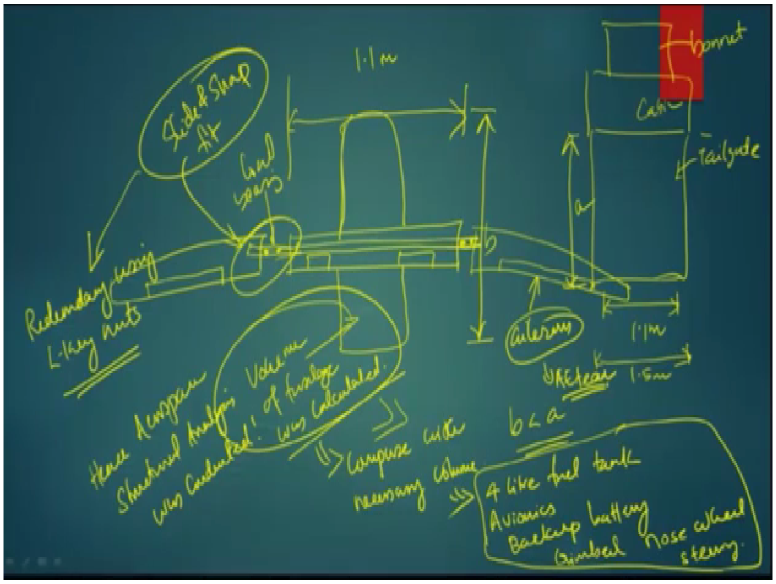

So just to revisit on this one the central piece of the wing with its own control surfaces was mounted onto assumed that this is fuselage. This whole total assembly 1.1 meters. Then obviously the second part of this so this is the width of the-- if you look at from the top view of a jeep or a gypsy this is the-- if you call this as the bonnet; if this is the bonnet this is the cabin and let us say this is the tailgate the 1.1 meter will fit in the within the 1.5 meters.

This length was also measured. And this was matched. So assume that this A and this is B we ensure that B is less than A so that it actually fits with the-- the packaging actually fits within it. Once that was over we were able to calculate the-- this length was fixed then all we need to do is we need to know what the volume? So the volume of fuselage was calculated then compare with necessary volume. So what are the necessary volumes?

You should have at least a four litter fuel tank. Then Avionics, Backup battery, Gimbal then you would also require nose wheel steering so all these things-- we calculated what is the volume necessary for that by individually calculating this and when we calculated the volume of what we decided, the size of the fuselage then we were able to find out that this volume that is available was way much bigger than what we needed. So we decided okay this fuselage is a good design.

So once the general dimensions were made available then-- the next thing we have to be done is there is two pieces of wings like this that need to be connected, so they need to be connected in between, but also when this flies this is also load bearing equipment. So hence, aerospace structure analysis was conducted. So we studied whether this connector in between has the capability to hold the-- will take the load.

It was found out that it is better – rather than having this it is necessary to have a connector throughout the length which is bolted onto the entire central piece of the wing and then onto the connector these wings will slide, so it was a-- so this joint was designed as a slide and snap fit. So then the question obviously raised is will the snap fit will be sufficient enough for hold the wing part. Then it was decided that redundancy using L-key nuts.

The decision LN key was used was because it is easy to operate in any field you can quickly tighter and loosen the nuts. So once the wing parts are coming then nut were provided to tighten them. So that they do not separate during flight. So then the manufacturing team came and told that okay fine we can make it provide give you the specification and other details. Then it was also decided that these wings both wing pieces will have its control surfaces the elevators-actually not elevator it is ailerons.

So the size of the ailerons was again provided by the AET or the AE team the aerospace team said okay this is the size of the ailerons. So then the manufacturing team said the wing will be fabricated in two parts. So the fabrication of the wing was – so the wing was conducted this way.

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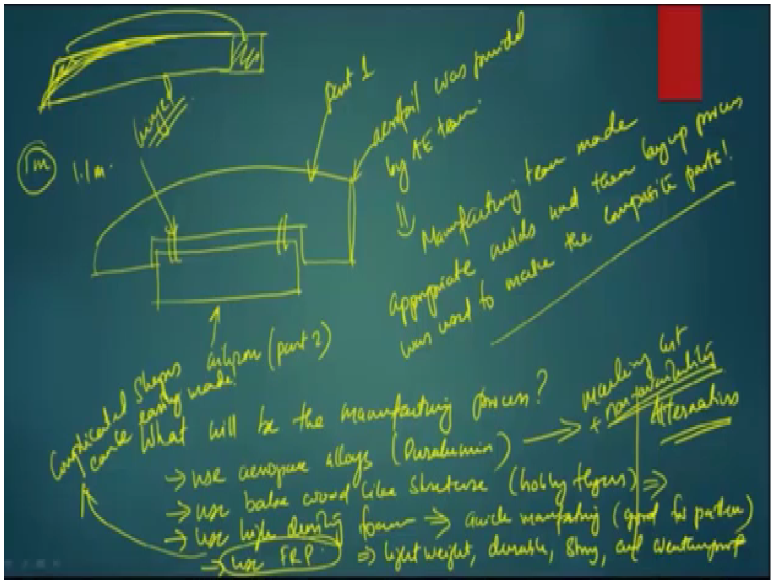

So the side piece if you take the left side piece it was fabricated something like this. It was created this and then. If you assume this is the wing piece this much of the wing was -- this much was built as first part of the wing and the aileron this was part two and this was part one. So the manufacturing process made this in two separate parts and then they were these were hinges they were hinged onto the general structure of the weight.

And obviously yes the Air foil-- aerofoil was provided by AET; the manufacturing team made appropriate molds and then lay-up process was used to make the composite parts. Obviously, the question will here is that why did we choose composite parts? There are couple of reasons. So there is discussion on what will be the manufacturing process. Obviously, one option is you use aerospace alloys like duralumin and all.

Other option is use like balsa wood like structured which is many of the hobby flyover to do this. Or use high density form or use FRP Fiber reinforced plastic. This was ruled out this is what you call as alternatives. This was ruled out because of the machining cost plus non-availability, non-availability means this is not readily available in the open market. Balsa wood option ruled out because that actually do restrict a lot of manufacturing and as well moisture and other things if we fly it in water and other stuff.

This will actually create a problem further so this was ruled out. Third one was high density form obviously yes this is a cheap and quick equipment manufacturing option but not the sturdiest of the options it is good for it is good for pattern but not very good for the final product. So then that is where we finally came down to FRP because it will be a light weight, durable, strong and weather proof. Also it is easily complicated shapes can be easily made.

So because all these things then, finally it was decided that the trade off in this process was that okay we will use combo sets. So once this was decided then the next major thing was what will be model or how will be the pattern. Then making the pattern from there imprint of the part is being taken out so that process was started. So you can see that one iteration of the-- so during this process different iterations happen.

Initially the wingspan was decided that three meter then it was found okay it was-- the earlier design of the wing the first design of the wing was kind of like a straightedge something like this. Then somewhere down the road the aerospace team came back and said no not possible actually we need to do something like this to reduce the weight turbulence. So the wing area was reduced. So when the wing area-- this much area is reduced then you have to increase the length of the wing.

So when the wing length was increased so from one meter initially it increased to 1.1 meters so that this much area was compensated right here something like this. So different iterations were happening in the process and when multiple iterations were created, different version of the product actually I mean not different version this is where the initial first prototype then the prototype was again revised based on the input from the different interdisciplinary teams and then it kept on revising.

Okay so this is one aspect of it. Then the second aspect was once this wingspan and other things were decided the next option for is to decide power plant.

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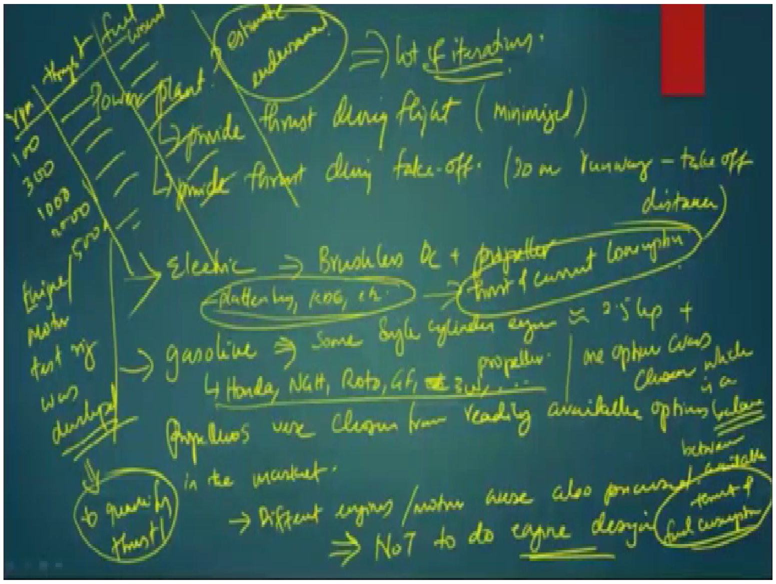

So the power plant asks two things to do. Provide thrust during flight. The second one is provide thrust during take-off. So if you want to do long endurance or maximize endurance this should be minimized. You cannot keep on run the entire aircraft at the take-off throttle okay. It is not possible. Because it will eat up and reduce your endurance. But here also there was restriction not here. Sorry, the take-off the thrust during take-off was said like 30-meter runway was the take-off distance.

So we would be able to provide some 30-meter flat from the aircraft will be able to take-off. So then the thing was the power plant became it can be either electric or gasoline. In electric, what are the options? So it could be a brushless DC plus propeller this is some single cylinder engine approximately 2.5 hp plus propeller. So it was decided that we should look into different type of propellers that are readily available.

So the propellers where chosen from readily available options in the market. So once these propellers were available then different engines/motors also procured. The aim was that not to do engine design. The aim of this project was not to do develop a UAV engine it was actually build a UAV. So the focus was not build on building am engine it was more on like choosing from what are the available engines in the market.

So obviously for gasoline there was options like Honda, NGH, Roto, GF then etcetera., 3W many options where tried in this case, so these were the alternatives. Electric they were – we have tried Plettenberg, KDE etcetera different type of brushless motors were also tried. These motors were tried with different propeller-- so engine/motor test rig was developed. To do what? To quantify thrust.

So adding different motor propeller combination or engine propeller combination we need to quantify how much thrust would it give. So you are looking at a table something like this like RPM and thrust. So 100 RPM, 300 RPM or 1000 RPM, 2000 RPM, 5000 RPM something like this. Your different RPMs here and the thrust that were available was also measured. And based on which-- also once you measured thrust the next thing you measure is the fuel consumption so in gasoline you can measure how much fuel was consuming.

Electric propellers we are measuring how much of current it was drawing based on which from here for different RPM thrust combinations you actually estimate endurance. So once the endurance was estimated we could actually say okay fine for the desire endurance these are the different combinations or propeller in engine and RPM that we should ideally be planning for. This was a tricky exercise because this required a lot of iterations.

Sometimes easy to get a thrust it is not a hard thing to do but you might be consuming lot of fuel. So somehow the engines were found out to be extremely fuel consuming not fuel efficient so then alternative options have to be explored. So from there one option was chosen which is a balance-- this is the most important word ‘Balance’ balance between available thrust and fuel consumption.

So the gasoline engine that was decided for the UAV came out of this balance trying to establish a balance between the fuel consumption and the thrust available. And once it was established then we were quite sure about the fact that we could actually get the desired endurance from a gasoline engine. Similarly, for the motor-- electric motor the thrust and current consumption was quantified and based on which appropriate motor was chosen that would have actually provide the appropriate thrust.

And as well appropriate and as well as minimize the or maximum the life of the batter I apologizes. So the aim was you have to maximize the life of the battery and here was also to carry the minimum fuel but gain the maximum endurance.

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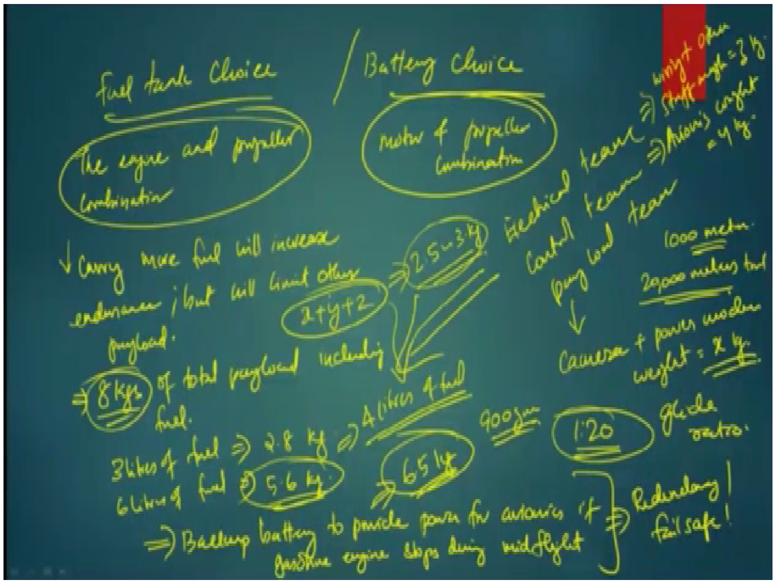

So once this established-- this was done then we can talk about fuel tank choice, choice or battery choice. So we know the engine and propeller combination so this was done from the previous studies. Here also we know the motor and propeller combination. The trick is you can carry as much as propellers you want-- it is nobody going to create an issue on it.

But then the trick is when you carry the fuel in this case in the here carry more fuel will increase endurance but will limit other payload. So on an average we can think about it in this way the payload capability was somewhere close to 8 Kgs of total payload including fuel. So if you carry three liters of fuel that will transfer you something close to 2.8 kilograms, okay. If you carry 6 liters of fuel you can get double the endurance but it will also become like 5.6 kg.

Then you only have very limited quantity left out to carry the-- carry your payload. Also it was decided at the same time that in all gasoline engines we will carry a small battery Backup battery to provide power for avionics if gasoline engine stops during mid flight. So this is what we call as a failsafe-- redundancy /failsafe. When the failsafe decided that we need to actually carry a battery with us that eliminate-- that reduce the payload capacity of a gasoline system to 6.5kg because 1.5kg was taken by the battery.

1.5kg was needed because that much of battery is necessary to manipulate the control surfaces and if the aircraft is 70 kilometers far away you should be able to bring it back there is a Glide ratio was calculated into this regard. Okay. The Glide ratio of UAV was 1 into 20. So for every one meter it falls vertically it will travel 20 kilometers horizontally, so it is very glide ratio available to the aircraft. This was the glide ratio. Okay.

So if you think about it this way if you are flying at an altitude of 1000 meters then if the altitude is 1000 meters you can drop 1000 meters it can actually 20,000 meters, travel it is about 20,000 kilometers. Okay. So you can easily think about it in such a way that the UAV was flying at 5000 meters then you know how much it can actually travel. So then we -- from there we calculated okay to that much distance how electricity, how much of electricity is needed.

Or how much of energy is needed to maintain the autopilot or the avionics continue to tick on and provide elementary another thing. So based on which the specific battery was chosen and that batteries weight came to be something 1.5kgs let us assume it is further but at this point for easier calculation we taking 1.5kg. So we had a payload of 6.5kg available. So immediately we know that this 6 liters of fuel is ruled out because you rarely have 900 grams left for your payload.

So we either-- so to do this case we have to weight optimization further and increase the payload capability. But for the initial design we were like okay this was not feasible. So for the initial design what happened was the fuel was designed to be 4 kgs of fuel sorry 4 liters of fuel. Four liters of fuel for the initial flying then the rest of it was reserved for the payload. Now-- here once this calculation was going on a team that was interfacing us was the electrical team then control team and the payload team.

So the payload team said camera plus power module weight equal to X kilogram they set some weight. The control said avionics weight equal to Y kilograms and the electrical team said wiring plus other stuff weight equal to Z kilogram. So the thing that we have to do was the X + Y + Z should be within the available. So this was given us as a number so we basically got an idea that this will somewhere come somewhere close to about 2.5 to 3 kg.

Once we have a ballpark figure of this we could always reserve a 3 kg separate and then work on other things. Pretty soon it was evident to us that the initial design we are going to be really, really, really pushed for weight or we have to find some way to do weight reduction.

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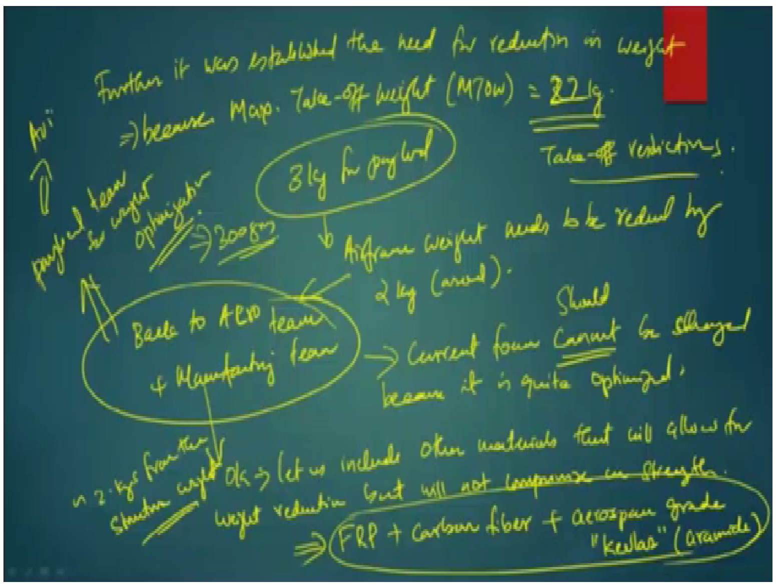

So then the further it was established the need for reduction in weigh because why was it is necessary because maximum take-off weight or MTOW was fixed somewhere at 22 kilograms it could not do better than this because of the take-off restrictions, okay. This was the take-off restrictions. So once this was there we said okay fine no matter what happens we have to reserve somewhere close to 3 kg for payload. Okay.

So once these things are calculated out then we said okay fine Airframe weight needs to be reduced by 2kg around. So then, back to AE Team AERO team plus Manufacturing team. So they said well current form cannot be changed or they said instead of cannot should not be changed because it is quite optimized. Then obviously when the AERO team give that input then we looked at them manufacturing team.

Then they said okay let us include other materials and that will allow for weight reduction but will not compromise on strength. So the material was the manufacturing process got revised to include FRP-- Fiber Reinstalled plastic plus Carbon Fiber because when you add carbon fiber with FRP it will actually give you much more strength plus Aerospace grade reducing the term because everybody knows it Kevlar or Aramid or this is the right name is Aramid.

So this process instead of just FRP would allow us to reduce a number of layers that are necessary to provide the strength in the process reduce the weight and then through this manufacturing process we were able to save somewhere equal to 2kgs approximately 2kgs from the structure weight. So this 2 kg save us from the structure weight directly helped us to carry allowed us to carry little bit more fuel.

Then we went back-- so this is the time where we came back to aero and the manufacturing team and we went back to the-- from here we went back to the payload team for weight optimization. So then they worked on the Gimbal and the camera and another things and they were able to save of another 300 grams. Then we went to avionics and the control team so then the next thing was the avionics team. They saved of another 300 hundred grams.

So we did multiple iterations multiple loops because our Airframe weight was constraint and in this process we were able to get another 700 saved of from different places which actually gave us quite a lot of luxury. Once this exercise was completed to a reasonable extent then we decided okay fine it is time for build the prototype now. So in this process by splitting it into different parts we are also able to identify what are the components.

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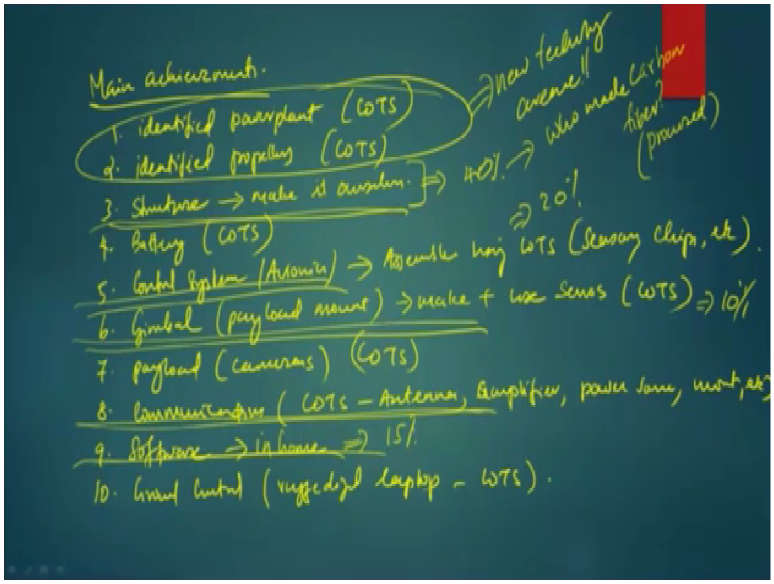

So if you think about it the things in this process main achievements were like identified power plant it was decided by the COTS- Commercial off-the-shelf; identified propellers that is also COTS; third is structure make it ourselves; four battery- COTS then it was the control system that is avionics, it was assembled using COTS. These are census, chips etcetera.

Then we also had the Gimbal; the payload mount you can about it this way okay. Make plus use servers these are COTS - Commercial off-the-shelf service then seven would payload which were cameras COTS - Commercial off-the-shelf we are not in the process of making cameras. Then was the-- it was the communications okay again COTS Antenna, we had amplifier, power source, mount etcetera. These were all procured directly Commercial off-the-shelf.

Then, obviously the software-- software in home. So this was built by ourselves and then it was ground control; this was ruggedized laptop again COTS so when you think about it-- it was actually assembly of lot of the COTS is Commercial off-the-shelf system available of the shelf system but intelligently put together. So you can think about this entire structure which is the most important component.

So this you can think about as 80 % of the whole thing is completely done. And as well as you can think about it this control system assembly you can think about okay I will probably put the structure at a little bit more of a lower rate let us say let put it as 40% instead. This would be like a 20% and then software would be another 15% right. And Gimbal this would another 10% okay. So you think about it 40 + 20 – 60+15 – 70+80 about 85 % of it you can assume that it was a different phase.

It was built in ourselves using a different-- like if you ask the question obviously in this case who made carbon fiber? Who made carbon fiber? The answer is procured because we do not have the technology to make it at this point. But using the carbon fiber we were able to make our structure. So many a time systems engineering is not about building each and every component. It is about building what is necessary to be build.

And using the material that are available quickly and build in such a way that the critical components are built and done with you. So the most critical components the structure, the control system, the software and as well as the Gimbal the control of the payload was pretty much built in-house and obviously other part you would be thinking about next would be to take care of the-- and then the communication aspect also.

When there the antennas and other things were bought from outside the communication, the encryption another thing is done as part of the project itself. This would be one area where obviously yes if you want to gain superiority you need to put more research and another things into it. So that would be something this is a new technology avenue. This is something where we can we need to demonstrate the capability of the technology that will be a spinoff systems engineering or system development process. Okay.

We need to now have gain expertise on the small single cylinder engineer that can be used in UAVs. Fine. That is a new technological ground. But that should not limit the development of the UAV that is was the most important part of that.

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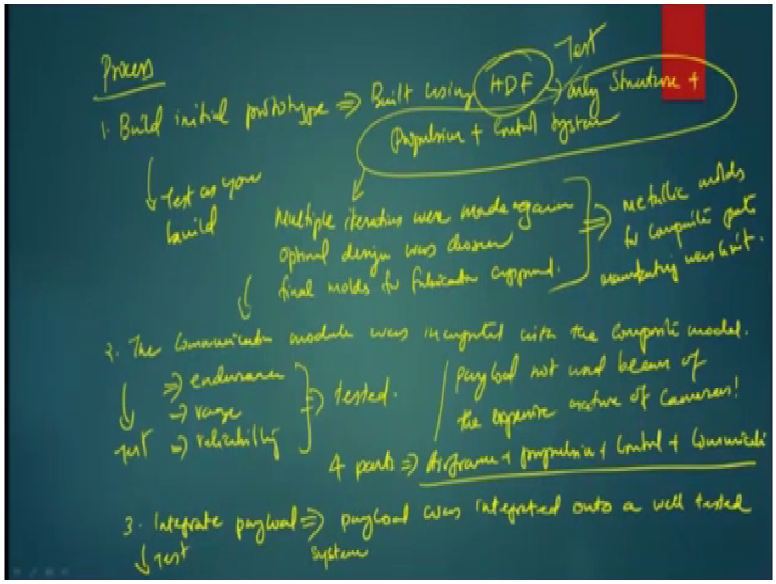

Now once all these aspects were decided then the next thing to be done is the process. So build initial prototype. This was build using HDF- High density form. Okay. Only structure plus propulsion plus control system. This was done really because of that these three things okay one it is finalized when you have sufficient confident in this then you can add the payload and as well as communication as part of it.

So, multiple iterations conducted. Iterations were made again. Optimal design was chosen. Final molds for fabrication approved. This much as done from where the metallic molds for composite parts manufacturing was built. So we built the molds after this process was over. Then from there the payload before the payload the communication module was incorporated with the composite model. Then endurance range reliability these were tested.

The reason payload is taken out of this picture was due to the payload not used because of the expensive nature of cameras. The cameras were all expensive and we decided that it was not good thing for us to really spend really break the camera while doing this test because a project funds were also limited. So we did not have money to break few infrared cameras and few (51:15) cameras. So the payload was not part of this.

So by the time this all process was over four parts air frame, plus propulsion plus control plus Comms or Communications these were completely tested out. And we had quite a good confidence in the system that we know okay fine it is time for us to third step Integrate Payload. So, payload was integrated onto a well tested system. So if any failure happens then the failure is only due to the payload.

So, what happens is that the testing this is actually what we can say is that test as you build, test, test. So it is not that you build everything and then test. You keep on testing at each phase each iteration okay when you build high density form model, test. From there you approve everything after that, test. From there you add Comms module then test.

So, every integration every new addition, every new revision, every new addition of the new system into the new components into the system testing is lifeline of developing a new system because without testing it is impossible to actually establish the viability of a complicated system like unmanned -- UAV system. So with the all these kind of things I think you would probably have a idea of a roadmap of how we went up about in developing UAV system small UAV system.

And in the next class, what we will do is we will actually look into what are some of the forms another thing some of the standards and other establishment, other established system engineering techniques that we use in this process. So, I will try to expose you guys to certain techniques as part of this course and see how this actually works in the development of a new system. Thank you.