Systems Engineering
Prof. Deepu Philip
Department of Industrial & Management Engineering
Indian Institute of Technology – Kanpur

Lecture - 19
Functional Analysis

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Good afternoon. Today we are going into the 19th lecture of systems engineering. And today we are getting into what we call as the second most important aspect called Functional Analysis.

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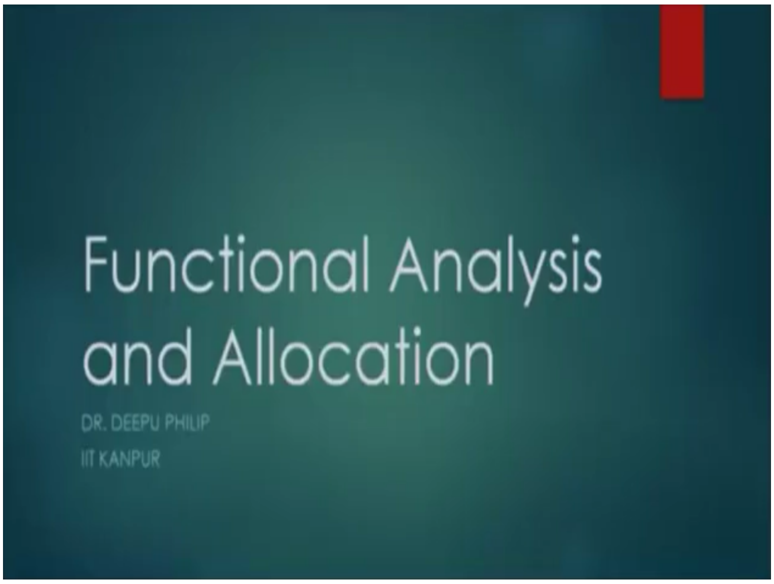

So the functional analysis and allocation is a very important step in systems engineering because once you do the requirement analysis from there we move into what we call as a functional analysis where we convert the requirements specified by the user into specific functions of the system and then allocate performance requirements accordingly. So we will see in detail what is functional analysis and how it is important before we do the third aspect which is called as the design synthesis.

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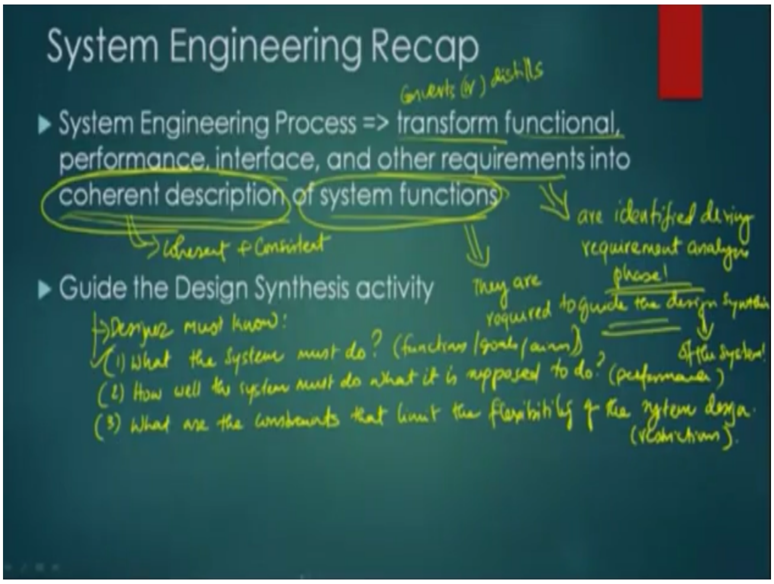

So in the system engineering recap we all know that the systems engineering process, we all know that it transforms or it converts, transforms, another word to use is called converts, or distills, so convert, distills, transforms any of these words are fine. The functional, performance, interface and other requirements, these are all the requirements that are obtained during the initial phase requirement analysis phase into coherent description of system functions.

So these requirements, all these requirements are identified during requirement analysis phase. So initially when we are doing the requirement analysis we actually get all these requirements out of that. Also, if you think about it, these requirement analyses what we talk about it is also significant because you want to convert it into a description of system functions. The question obviously is that why do you need system functions, think about it.

They are required to guide the design synthesis. Whose design synthesis? Of the system. So when you are going to design the system, when you are going to synthesize the design of the system, we require these system functions to actually description, coherent description of system function is necessary. Coherent description in a sense means that it is logical, it makes sense and it is coherent and consistent. So in a way the question obviously is that why is it necessary for the design synthesis because the reason is the designer, which designer?

The designer of the system, he must know. Number one, what is the most important thing he needs to know what the system must do. This is the functionality of the system. What the system must do. Second, how well the system must do what it is supposed to do. Then the third is, what are the constraints that limit the flexibility of the system design. So as a system design he should know what the system must do in a way the functions or goals or aims all these kind of things.

Why is the system being designed? That kind of a question. How well the system must do it is to an extent we can talk about its performance and then what are the constraints. These are the restrictions. These are important for anybody who is working on any aspect of system design, any person who is working in developing a new system this is very important.

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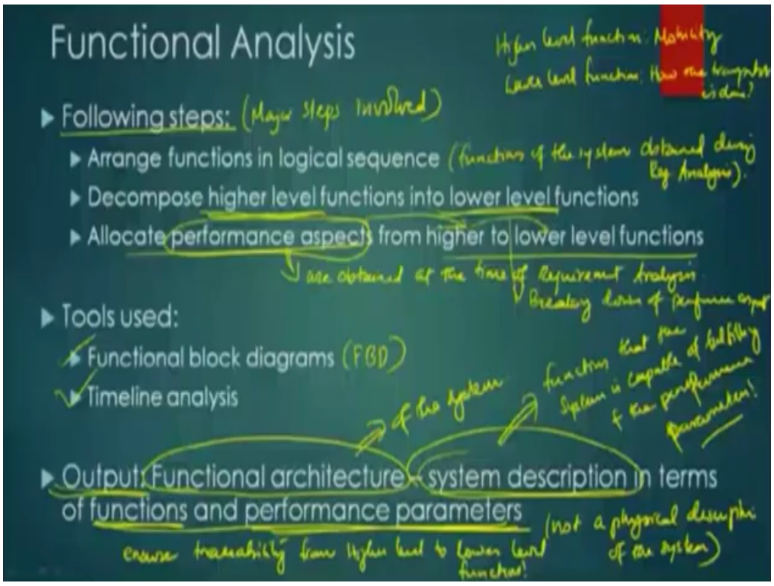

So one obvious question that we always ask is what is the function of analysis. So it is kind of like a step, we can talk about it is these are the major steps and the following steps are the major steps involved in this process where we arrange functions in a logical sequence. So this means the functions of the system obtained during requirement analysis.

All these things were obtained at the time of requirement analysis. So arrange functions in a logical sequence, then we decompose higher level functions into lower level functions. So higher level function means somebody would say, something like a rapid transportation or instead of rapid transportation we might create something called as mobility. So a higher level function could be mobility.

The lower level function would be how the transportation it done or how mobility is achieved, that is one thing. So what are the steps involved in achieving that. So that we will see an example and it will probably be more clear to you. But the aim is to decompose higher level functions into lower level functions and then we allocate performance aspect from higher level functions to lower level functions.

So the performance aspect again these are obtained at the time of requirement analysis. So the user might have given feedback in a different form which has resulted in creating this the high level functions and from there low level functions are derived. But the performance aspects, these performance aspects are typically attributed with the higher level functions. They have to be broken down into lower level functions, so this is where the breaking down of performance aspects happen.

The two major tools that are used as part of it is called as the functional block diagrams, people call it as FBD mostly and another tool is called timeline analysis. We will see this later down the road in the subsequent lectures what these tools are but just the names are mentioned here for the time being. So the main aspect here is the output of this whole stuff or functional analysis is the functional architecture of the system.

So this is the functional architecture of the system. So what do you mean by functional architecture. It is a description of the system. It is a system description in terms of functions and performance parameters. So what we talk about it is, this is not a physical description. This is the most important thing that we need to remember.

Not a physical description of the system but rather it is a functional description they are a description of the system or a system description in terms of functions and performance parameters what are the functions that the system will accomplish. Function that the system is capable of fulfilling plus the performance parameters or what are the limitations. You can also think about it as performance limitations as part of this, okay?

This is also done to ensure something called as ensure traceability. We mentioned earlier in the lecture. Ensure traceability from higher level to lower level functions. So this functional analysis ensures that the higher level traceability, the traceability of requirements specified by the user are narrowed down to the lower level functions.

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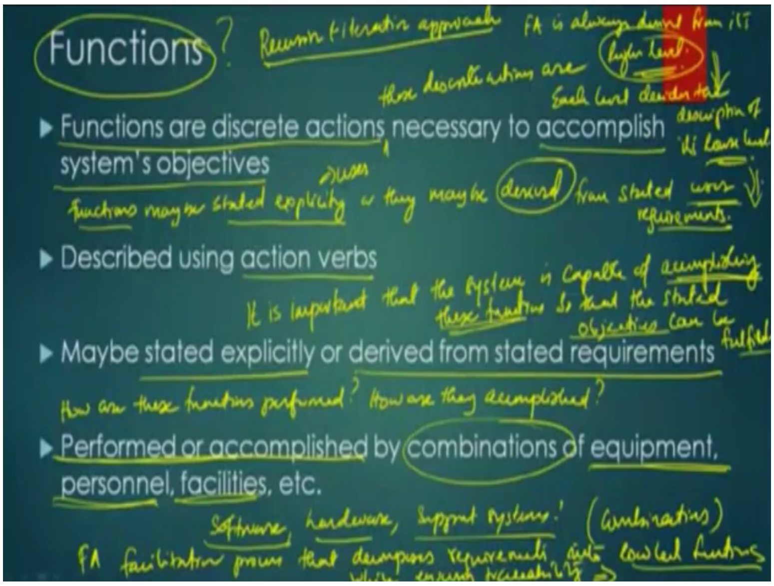

Well, obviously one of the most important aspects about functions, obviously people say what are functions, I don't understand what the definition of function is. So this is a very big question, what are functions or how do we talk about functions. In a simpler sense functions are discrete actions and these discrete actions are necessary to accomplish the objectives of the system. So the main aim is to accomplish the objectives of the system and the discrete actions that are necessary to accomplish the objectives of the system is called as functions.

It is typically described using action verbs. So an example is functions or another thing about function is, functions maybe stated explicitly or they may be derived from stated user requirements. So some of the functions might be stated explicitly. Who states it explicitly, obviously the user or sometimes the user might given some requirements from which we derive those functions.

So the thing is that as it is written here, the stated explicitly or derived from stated requirements of the user. So obviously yes, the important part is, it is important, very important that the system is capable of accomplishing these functions so that the stated objectives can be fulfilled. So in a way completing this, accomplishing these functions they are important to complete the fulfilling the objectives of the system.

That is the critical aspect of this functions. So once you are able to describe the system in terms of its function and if the system is capable of fulfilling all these functions that you stated then the system will be able to, in that process system will be able to fulfill its stated objectives. And how are these functions performing?

The question is how are these functions performed or how are they accomplished? The answer to this question is, it is performed or accomplished by a combination of equipment, personal, facilities all those kind of things. It can also, other things that are involved are software, there can be hardware, then there are other specific aspects like support systems etc. There are many things that actually would come into picture.

But to perform this functions you require equipment, some sort of equipment, personal facility, software, hardware, support systems etc. So using or combinations of these. one or few or all of these combinations are possible. So by combining different aspects of the system these functions are performed or accomplished. So the functional analysis to a large extent what it does is, it facilitates, it is a facilitation process.

Let us say the functional analysis is a facilitation process, that decomposes requirements into functions, into let us call it as low level functions while ensuring traceability. So here you have decomposed the requirements, the customer requirements into low level functions while ensuring traceability which means the performance requirements or the performance aspects that are attributed to the higher level functions are appropriately brought down to the lower level of the systems.

So one other aspect is always remember, we talked about something called as recursive and iterative approach. So the functional analysis, FA is always derived from its higher level. So at any level you are looking at this, the details and aspects of this are coming from some level higher than this. So another thing is that you should also understand the fact that, it is each level, you think about this, each level decides the description of its lower level.

So when you are doing a functional analysis in a particular level, it has its origin from the higher level but it is also going to determine its lower level because you are going to use where level you are to go further level down until you reach the appropriate level which you are satisfied with the components of the system.

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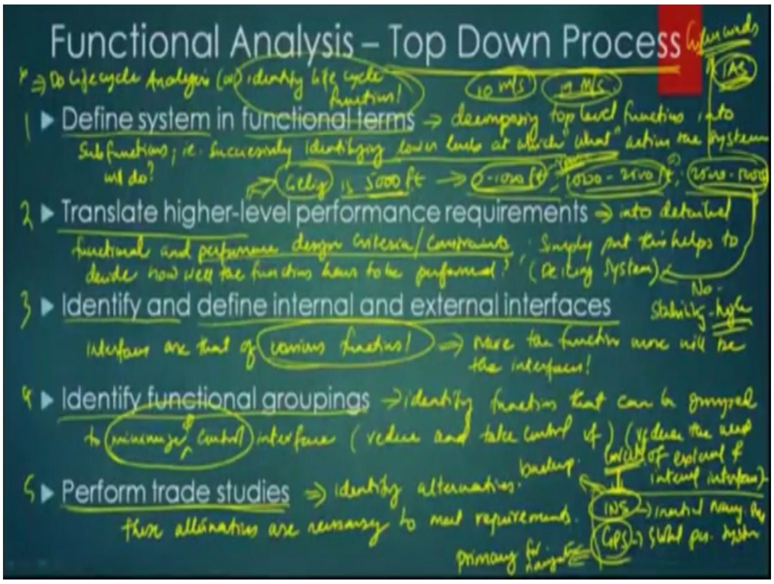

So this type of a system approach is called as a top down process. Top down process means we actually move from the top to the bottom. So some of the major aspect, major things or major goals for doing functional analysis is the definition of system in functional terms. So that means, so what we are doing is, it is basically in a way decomposing, top level functions into what we call as sub functions.

We are decomposing top level functions into sub functions that is successively identifying lower levels at which what actions the system will do. So the main question here is at lower levels, so it is successively decomposing top level functions into sub functions where what we are trying to do is we are identifying at lower levels what actions, this is in inverted commas because we specifically are trying to find what actions the system will do.

That is one point. Second is translate the higher level performance requirements. So these translation happens, it translates to what? It gets translated into detailed functional and performance design criteria. Or in a simple way to say it is constraints. So if in the UAV, for example if we say here as that the ceiling is 5000 feet, this could be a high level function, high level performance requirement, that it should fly at an altitude of maximum ceiling in the top altitude is 5000 ft.

That means that to an extent this we can further break it down into what we can say the UAV could fly from a 0 to 1000 ft is one band and then you can say 1000-2500 feet is another band and 2500 feet to 5000 feet is another band and in each cases what the system will do. You might end up because these are the specific altitude at which air density changes or in another word say, in our experience we found out that for such a small UAV this transition of separate heights, there were specific changes in the performance requirement.

So then you can say that within this altitude what is the rpm, ideal rpm for maintaining the cruise speed. We can decide what is the maintaining the cruise speed and then we can decide what is the rpm for maintaining this particular cruise speed. And so then when you reach at this point you can say usually 2500 to 5000 feet you find usually higher winds.

So then your indicated air speed, you are looking at an indicated air speed in this UAV we have found that okay approximately 19 meter per second was the indicated air speed and if you find out that fine at that altitude you have a wind of 10 meter per second then you can ensure that your propeller or the engine does not need to rotate at a high rpm to maintain this indicated air speed.

So these kind of things, that need to be brought down from just a ceiling is 5000 feet to various level of sub functions that we talked about and the performance or design criteria that governs the development of the project that is requirement. So this is in a way in simply put this helps to decide how well the functions have to be performed. So one example here is that somebody would ask in your UAV do you have de icing system and big UAVs there are de icing system.

But since we are only flying at the 5000 feet the answer to that it is no. We do not need to perform the de icing function. So how well the UAV need to perform the de icing function. It should need not perform it at all. How well the UAV need to be stabilized at this altitude because this altitude there are lot of type of winds. So the platform needs to be, the stability of the platform, on the other hand stability should be extremely high.

So that is the other aspect of it. So this kind of a trade off analysis that you can do as part of the system at different places that is also a part of this analysis. Then identify and define internal and external interfaces. So, what interfaces, the interfaces are that of various functions. Identify and define internal and external interfaces of various functions, this is important because the more functions you have usually more the functions, more will be the interfaces and more the interfaces are more the additional issues that will come into picture.

So obviously you have to identify all external interfaces as an important aspect of it because you have different functions, but also at the same time you do this one. Identify functional groupings or identify functions that can be grouped, why do you need to group, to minimize control interfaces. So the aim here is to do the grouping is to reduce and take control of the interfaces.

So lesser the interfaces, or if we can group the functions together and those functions can be taken care of by a singular component then you can always say that okay this is a good idea because what happens is, it reduces the need of interfaces. The aim is to reduce the need of external and internal interfaces. Fine, so then there is another thing also that is part of it is called as performing trade studies. Performing trade studies in a simple way put it is identify alternatives.

Why do we talk about identifying alternatives? The reason for identifying alternatives is, these alternatives are necessary to meet requirements. So one example in the UAV was that, what we ended up doing was the position of the UAV we have both INS which is the inertial navigation system and also the GPS which is the global positioning system. The reason was because the GPS is not available all the time. This was the primary for navigation.

So the heading another thing were primarily taken from the GPS but also INS ran as the backup. The minute the system, the GPS connection goes away the INS navigation kicks in and it will actually control the UAV under the GPS connection is back on. And the advantage of this is that when the GPS connection is back on it has a reasonably good idea where it is and then the GPS single can be used to triangulate further and this can be corrected at that point.

So this helped in ensuring that whether one signal is there or not, the UAV always know where it is so that you can always even in the worst case scenario you could ask it to come to its home place. And there are other aspects also which is not listed here, one other important aspect that we would like to say here is do lifecycle analysis or identify lifecycle functions.

So one important aspect is maintainability of the UAV. I will use that as an example. So there are many components who have like servomotor was an example that is used to manipulate the control surfaces. So these feedback servomotors have definite life and the obviously the maintenance of them was a headache.

So we have to do during the functional analysis part of it we had to decide, as we broke down, okay, this is the size of the elevator, this will be the servo that will be capable of producing this much of torque, then these are the options available, then let us pick this particular servo and when you are picking that servo then you are looking at different aspects.

You are trying to find out what is the life of the servo, how frequently the arm of the servo needs to be replaced. How much of the maximum load, what is this factor of safety available for the arm and all those kind of things of the servo that was also looked into picture, taken into consideration when that appropriate choices were made. So please remember that, even though these 5 that we mentioned here, one, two, three, four and five, along with the six which is the lifecycle analysis as well are the major reasons why you do functional analysis.

There are other also small reasons that are quite possible, some people will say we do functional analysis to find out what all things need to be build and what all things need to be commercially brought from off the shelve kind of thing. These are all part of this because at some point of time when you have identified the functional groups and do trade studies you will actually do identify the components to a good extent.

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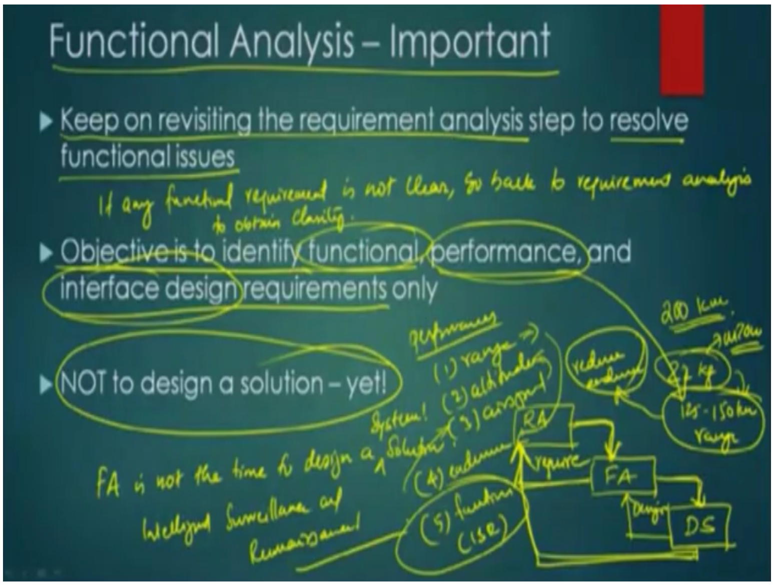

So the important thing that you need to remember, this is quite important because why do you do this is something that is very essential for us to remember, because if you think about it we had this loop where we had a requirement analysis from there we did functional analysis then we would revisit the requirement analysis.

Then we had designs in the sys as the next box from where the functional analysis becomes the design synthesis and it will go back to functional analysis, so where we would get the design loop and here is the requirement loop. So the most important thing that you need to define is, think about this. This is the most important aspect of functional analysis. It is not to design a solution. It is not time to design your system.

FA is not the time to design a solution or design a system solution. This is not the time to design it. You are still doing the requirements especially you are translating the user requirements into functional requirements. So the major aspect that we are trying to say here is, you will keep on revisiting the requirement analysis, this loop, you will keep on doing this loop and will keep on revisiting the requirement analysis step to resolve functional issues.

Like for example, something is not clear to you if any functional requirement is not clear, go back to requirement analysis to obtain clarity. Some cases you might even want to do the requirement analysis little bit again to obtain clarity in this regard. So the main objective, the main objective of FA is to identify functional performance and interface design requirements only. This is the objective, identify the functional, performance and interface design requirements, is not the design a solution here.

That is the important part that everybody need to remember in their mind. Yes, obviously somebody would ask why would we need to do this because during the design synthesis we again go back to the requirement analysis. So yes sometimes because sometimes when you design then you will find out that okay certain functions cannot be achieved at this whole thing.

So like for example we were asked in the UAV system we have said can you make the UAV fly to a range of 200 KM and we were like it is doable but within the approved weight of 22 kg. The max we could do was somewhere close to 125-150 KM range not more than that. So the maximum takeoff weight, MTOW to an extent ended up restricting this range of the UAV in our case.

Because it has to carry certain communication system and amplifier and the power requirements were, so because if you increase the range then the power requirements of the amplifiers will increase which will reduce endurance. So you will have to do some compromise at some point of time and that aspects what all functions it should do and how well, so this is where the performance comes into picture.

So different type of performance, your performance in the UAV, one of the performances will be, number one will be on range, two will be on altitude, third will be on air speed, the fourth will be on the endurance, fifth will be on functions, so we said okay this will only do ISR, intelligence surveillance and reconnaissance missions only. So these kind of things. So if you want to increase the range then you might have to compromise on endurance.

Because of the payload restrictions on this and then that will in turn change the air speed requirements. Once that changes then it will probably influence air speed, the altitude requirements and those kind of stuff and then it might really result in adversely impacting the stated objective or functions of the UAV to do intelligent surveillance and reconnaissance. So understand this is this process in which we run through different aspect of the system and then we try to decide what to do what not to do and how to do that.

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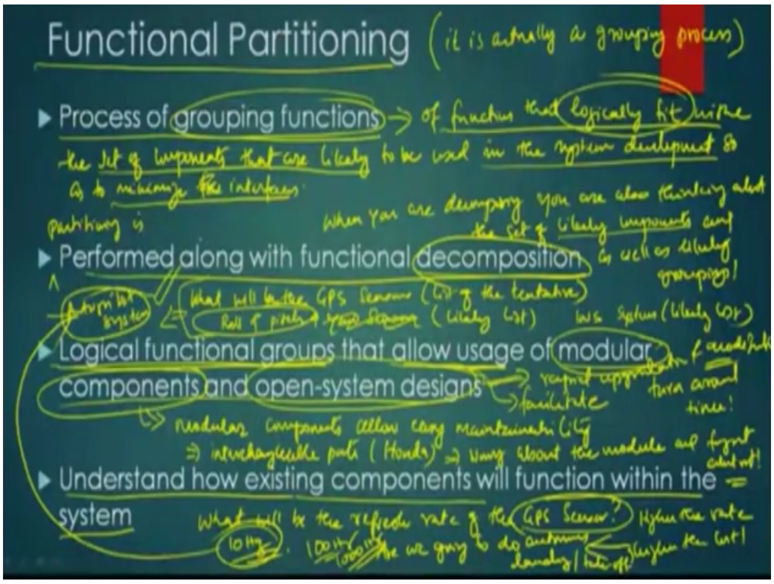

Alright, then we talked about something called as functional partitioning because we mentioned that we need to actually group the functions. So this functional partitioning even though it says partitioning it is actually a grouping process. What are you doing is, is a process of grouping functions. It is a process of grouping functions, a grouping of functions that logically fit with the set of components that are likely to be used in the system development, okay?

So has to minimize interfaces. The aim is that we group the functions that logically fit with the set of components that are likely to be used in the system development. So you have an idea of, some idea of the components that are likely to be used in the developmental system and the aim is so that you can minimize the interfaces. So typically this partitioning is performed along with functional decomposition.

So when you are decomposing you are also thinking about the set of likely components and as well as likely groupings. So you think about the likely components and as well as the likely groupings. So we have a general idea of what the components that we are supposed to use. So for an example I will give you, when we are designing the UAV we wanted, we had an idea of what will be the GPS sensors or at least the list of the tentative.

The tentative list of the GPS sensors were there. Then we also had roll and pitch and yaw sensors, likely list. That was also with us. INS systems, likely list. So these kind of things are available to us so then we decided okay, fine at the end of the day we found out that we don’t really need the yaw sensors because it is not necessary, we can actually group that along with the GPS and INS systems.

So okay fine, this we can do, we ended up using that and then later we found out okay we actually do need yaw sensors and then the yaw sensor was put back. But many of the aspects of identifying the heading also using the feedback from the sensors and fusing them together we found out that all these things could be interfaced directly with the autopilot system. So rather than keeping these sensors separate.

They were all integrated as part of the autopilot system or the control system so that the interface that are required will be like just the interface of the autopilot and everything else has got embedded into their autopilot because it is a small UAV. We didn’t require all those kind of things to be separated out. So this is also what we call as grouping of the functions because the UAV need to have two type of navigation, global positioning system and as well as INS.

But they were grouped together into one single component which we call as an autopilot or in another way the flight control computer. We have integrated all of those into the single box so that was our aim was to minimize the interface on that. Also, other thing is the logical functional groups, when you decide this, when we talked about this, when we were talking about it, it was a logical grouping, a logical fit, a logical grouping.

The logical functional groups is important because why is it to be logical, the logical functions it will allow or facilitate the usage of modular components and open system design. This is important because you do not want to design every aspect of the system instead modular components allows easy maintainability. I would like to draw attention to something called as interchangeable parts, concept.

Courtesy to Honda Motor Corporate who started this stuff so that what happens is if you make a modular approach, if anything goes wrong, all you need to do is worry about the module and forget about the rest. So if you find out that this is the error of the module all you need to do is change the module that is it, system is back to normal. So the modularity or usage of modular component that allows you to actually achieve high level of maintainability and turnaround time for the system.

Other one is also about open system designs in its way that the system that is allowed to be modified rapidly or this is also allows for rapid upgradation and modification. So we started with a GPS system and a GPS sensor and we found out that a new better GPS system actually came into the market and it actually follows the old interface as what it is but it has a much higher refresh rate, we didn't get much higher accuracy out of it.

Then instead of changing all other things all we need to do is basically change the GPS module, that is it. And the rest of the things actually would work accordingly. So these kind of a system design is also quite possible by allowing for functional partitioning. Even though where you are actually, when you are decomposing the function you are also grouping them according to the logical fit of each of the functions.

And also, this also provides, this grouping provides how the existing components will function within the system. So one of the question that we had was, we have to achieve at this is, what will be the refresh rate of the GPS sensor. So there are many types refresh rates are available, different types of sensors that we use, so based on that the rule is higher the rate, higher the cost. Then we have to decide what is the accuracy that we require.

The question came back to are we going to do autonomous landing slash take off. So the user has clearly mentioned that it should take off and land from a 30-meter runway but they wanted manual take off and landing. So there will be a trained pilot who will take off the aircraft from the runway or a flat surface and we will ensure that the aircraft comes and lands at that particular location.

And the autopilot will be engaged only after it reaches a particular altitude. Okay, then we were like okay fine fair enough, we do not require that extremely high precision, we require only sufficient precision in such a way that the aircraft can go to a specified location with reasonable level of accuracy. So then according to which a GPS sensor was chosen with sufficient refresh rate which actually provided the accuracy.

From there the autopilot system as designed in such a way that fine, you are getting the data at some particular, if the refresh rate is 10 hertz then we know how many times in a second that data comes in based on which the autopilot, okay you are going to get the data at this frequent intervals, so then from which you can calculate where the UAV is at that point.

Obviously people will ask why did not use a 100 hertz system or a 1000 hertz system. The answer is this was sufficient enough for us to achieve this function. This was the logical fit because there is no point in over kill. It has to perform a function and it has performance requirements and the aim was to actually achieve the desired performance requirements.

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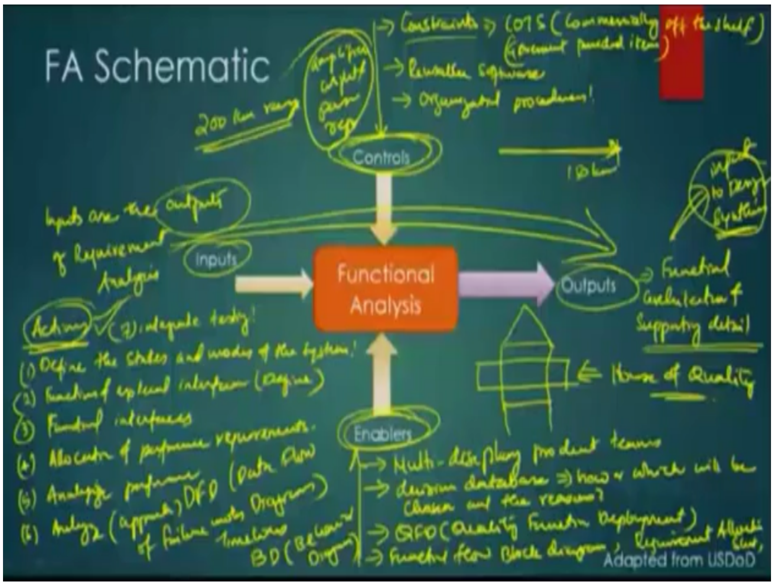

So I also want to talk about this function FA Schematic and in the next class we will actually talk about an example of how did we do the functional analysis and other aspects of it. But in today’s class the same way as the requirement analysis the functional analysis also has four aspects to it. There is the input aspects, there is control, there is enablers and outputs. So if you talk about the outputs, the outputs are pretty simple.

The functional architecture and supporting details, simple. The functional architecture and the supporting detail of the system is the output of the functional analysis. What are the inputs? Inputs are the outputs of requirement analysis. So whatever are the outputs of the requirement analysis that becomes the input to the system, right? Then what are the controls.

Controls we can think about the controls are, number one will be the constraints. So this is like, what we talk about it is COTS, that is commercially off the shelf items or it is a GFE or the government provided item. That means you cannot really but it as a specific item that is provided by the government. Then we also talk about system stuff like reusable software and we also will have something called as organizational procedures.

So we will talk about an example of these kind of aspects when we take the UAV case and look into it, how did we do the functional analysis and we will run through each aspect of it. And the enablers, this is another interesting list of items. Enablers are these are some of the aspects is the, as I said earlier is the multidisciplinary product teams.

I have discussed the importance of the multidisciplinary product teams that we had in the UAV and how each teams where integrated into the development of the system that we talked about the influence of the aerospace team, the manufacturing team, the communication team, the payload team, also we talked about the packaging team, how they actually get into this picture.

We talked about the control team, so all these multidisciplinary product teams are one of the enablers in achieving successful functional analysis. Then the second one is the, also what we call as decision database. Here is how or which will be chosen and the reasons behind it. So one example was that people said, why did you not make the UAK as autonomous takeoff and landing.

The answer to that and we have a decision database that actually tells what was the reason why autonomous takeoff and landing was not made as part of the UAV that we designed because it was one of the customer requirements and as well there were other reasons because the intended usages of the UAV and the price range at which it was supposed to be built, autonomous landing and takeoff would have been a extremely high proposition.

Then also we talk about something called as QFD, quality function deployment. Many of you might have seen this. This is also called as the House of Quality. I will try to cover this up in one of the class later, but it will look something like this, you have a performance and requirements and there are aspects of it, then your competitors. So you might have seen, this is also called as House of Quality sometimes.

But this is actually a very good design tool that is used in the whole process. So we will talk about QFD sometime later down the road. And we also talk about it as functional flow block diagrams. Then what we also call it as requirement allocation sheet etc. So these are all and then we also have something called as DFD, which is called as Data Flow Diagrams. Then we also have as timelines, I mentioned earlier, then we have also called as BD which is called as, not block diagrams but behavior diagrams.

So there are many enablers that are used to perform functional analysis in the system or conduct functional analysis. So also as part of this, you should also remember or you should also understand that what are the major actions that happens as part of this functional analysis. One of the major action that happens is you define the states and modes of the system. That is the first point. Define this state and modes of the system.

Second one will be the functions and external interfaces of the system, you define them. What are the functions and the external interfaces of the system? The third one will be the interfaces, functional interfaces. This might be the internal interfaces. Then comes the next one would also be allocation of performance requirements. From high level functions to low level functions. Then it will also be analysis or analyze performance.

And then we will also have analyzed or approach for analysis of failure modes. And then you also have methods to detect fault, integrate all those kind of things. You also have mechanism to do what you call as integrate testing. I have shown you how the integrated testing is yesterday in the example, previous example of the UAV how we at each level, at each component of the system when it was developed, how testing was inbuilt into the system and how various aspects were conducted. So there are many actions that are part of the system.

So the aim is to take the inputs which are the outputs of the requirement analysis and you conduct functional analysis in which you perform multiple actions that are listed here to provide the output which is the functional architectural supporting details which then will become the input to design synthesis.

So what we will do today is, and we said also there are many enablers that are part of the system and there are also many controls that are also there which are other constraints, sometimes you might say that okay, like when somebody asked for in our case of a 200 KM range of the UAV, we said well, the current constraint is the amplifier weight and power requirements. They were constraints for us.

So that constraints basically then we controlled the, pretty much what we call as okay, the UAV the max range it can go is up to 150 KM or if you have to do more than that then you have to increase the weight of the UAV or the capability, we have to put in a much bigger engine and you would have to go pretty much into a new UAV. So these kind of things will be all part of this. We will discuss this in detail in the next coming classes.

But understand the most important aspect of it. The aim is not to design, I cannot emphasize this more, you are not talking about a design of a system at this point. You are basically translating the requirements into a functional requirement. We have not started to design the system yet. But you have at some point of time identify the possible components. That is it. You have not made the design of the system. That happens in the next step which is called as the design synthesis.

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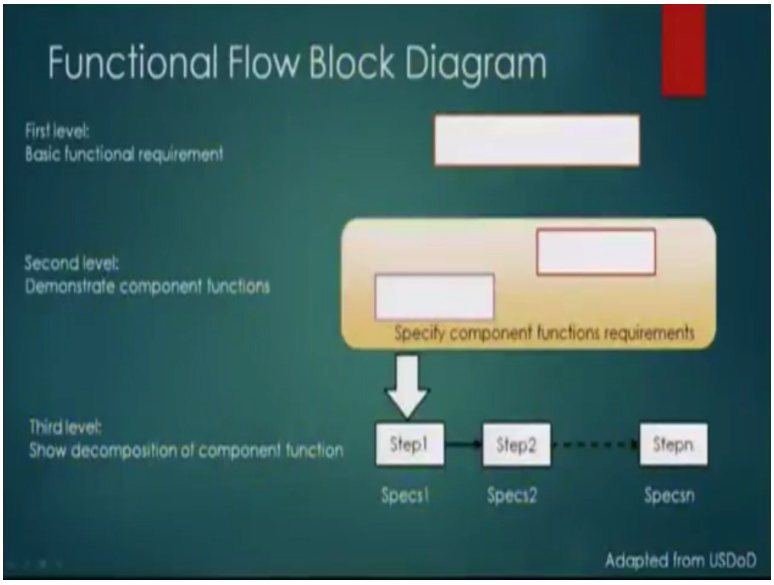

So in the following lecture what we will do is, we will take an example of a functional block diagram which is a tool. We will go through this and we will actually take an example of how the UAV was used which we will reserve it for the next lecture. Thank you for your patient listening. Good luck.