Systems Engineering
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Lecture - 15
Unmanned Aerial Systems

Good morning. Welcome to the MOOCs course of systems engineering and as we continue in the learning more about systems engineering and systems engineering process. We decided to have a small case study today to see how the intricacies of the systems engineering process is put into place on a specific scenario. So, today we will do a one example case study and what we are going to talk today is the unmanned aerial systems typically what most of the people called as UAVs.

We talked about unmanned aerial systems here and this was a systems engineering case study. So we looked into an indigenous development of an unmanned aerial system in India and how systems engineering was used to realize the development of the unmanned aerial system. So, before getting into the applications of unmanned aerial systems and trying to find out what the unmanned aerial systems are about?

How the systems are being put into development? What are their uses and this kind of stuff? For the benefit of the audience, we will have a small discussion on what UAS are and why they are important and what are the typical missions that they do. One of the most important thing that a systems engineer need to have is the person should how a background knowledge about the project that is going to happen.

He or she need not be the expert in everything, but at least there should be sufficient that the word that we use is working knowledge. The person should have sufficient working knowledge in that project that he or she is going to lead as systems engineer. So, this initially we will talk about providing some working knowledge to the audience and then we talk about how we went about developing the unmanned aerial system.

So, we start with what is an unmanned aerial system. There are many, many, many definitions to this you know and many people have talked about this in many ways. There will be so many names for this and all those kind of stuff, but from the systems engineering standpoint it is again a system, so that's why we called is at UAS (Unmanned Aerial Systems). It includes the vehicle, it did include the communications and payload every aspect of it which we will see.

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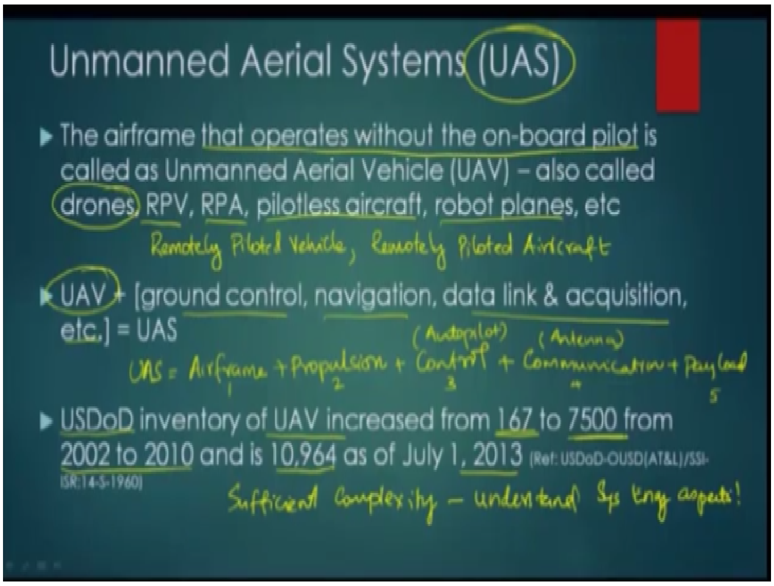

So, the UAV, the main part of it, the unmanned aerial vehicle, it is that airframe, it is the aircraft actually, that operates the airframe that operates without an on-board pilot is called the unmanned aerial vehicle. So, there is no human being on the flying platform to control it. So, it is a nonhuman. There is no specific individual or any human being is present there to control the aircraft.

It is being controlled from a remote location. So, that is one of the other reasons why it is also called as RPV, RPV stands for remotely piloted vehicle. Some people also called it as RPA that is remotely piloted aircraft. Some people also called it as pilotless aircraft, robot planes, there are many names for it and obviously yes the most common name which we called as drones.

We are not going to get into the details of where does this nomenclature of another stuff came in. It is very common that people have names and pet names and different type of nomenclature that they use. So, as for as the systems engineer is concerned our term is UAS (Unmanned Aerial System) which we focus on the systems. We do not focus about just whether is a drone or RPV or something like that.

So, the UAS, what we called about as a system, the total unmanned aerial system for a systems engineer includes the unmanned aerial vehicle, the UAV, the flying platform plus its ground control, navigation, detailing an acquisition, payload, all those aspects together gives you the UAS (Unmanned Aerial System). So, in a broader sense the systems engineer looked at UAS, unmanned aerial system having 5 parts.

So, the UAS, we can think about it as the UAS is the sum of UAS equal to the airframe which you called as a UAV plus the propulsion. We can talk about as the control, some people also called the control as the autopilot, what is a control system, plus communications, some people colloquially called this as antenna, but it not just antenna. There are so many other things as part of this plus payload.

So, these 5 systems, 1 airframe, 2 propulsion control, communication and payload together gives us the unmanned aerial system. So, a system engineer is supposed to look into when we talked about the development of an unmanned aerial system it is the development of all these 5 individual systems to meet the user needs as we said earlier. If you ask why are we talking about unmanned aerial systems as an example, a case study it is one of the most advancing field currently and lot of new and new systems are being developed in this area.

So, a simple example of this is US Department Defense, the inventory of drone or UAVs, or unmanned aerial systems, the increased from just 167 to 7500 in a time period of just 8 years and the 7500 increased to 10,000 in a span of just 3 years. So, if you think about or 4000 UAS, 3964 UAVs. So, what I am saying here is the number of unmanned aerial systems that are being developed, designed, and then used in the field are quite large.

And they are used for multiple purposes. So, this is one area, lot of systems engineering tricks, trade, tools are being applied. So, it makes this a relevant case for us to understand how systems engineering can be applied to a development of a complex system. Yes, people can say that unmanned aerial systems are not that complex as such probably, but we are not worried about taking a too complex of a system.

We are worried about taking a system with sufficient complexity. The aim here is understand a system with sufficient complexity. The complexity sufficient enough for us to understand systems engineering aspects. So, for that UAS I believe is a good option.

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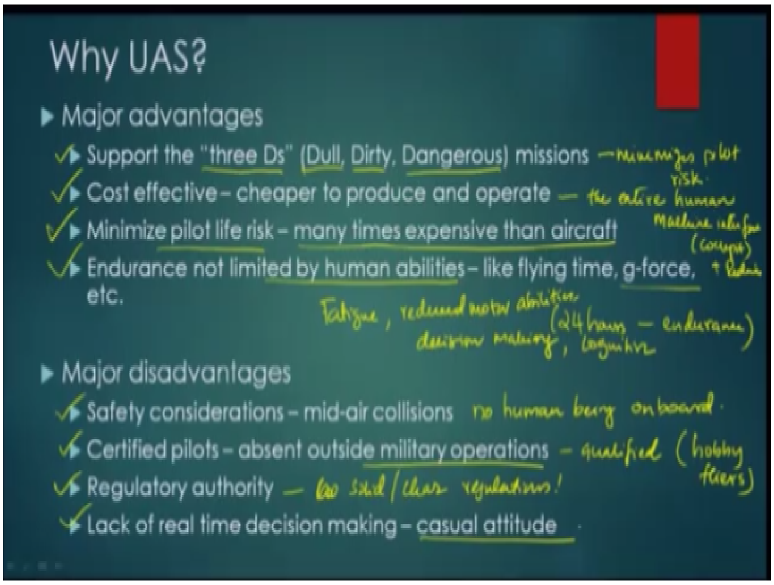

So, why unmanned aerial system, why people go behind unmanned aerial system. Why are we moving away, not moving away, why are we augmenting or we are increasing the fleet size of unmanned aerial systems when compared to the piloted aircrafts, because there are some major advantages for unmanned aerial systems. The first and foremost advantage is it supports the 3D missions or the dull, dirty, and dangerous missions.

So if you are talking about flying very low and taking pitches, then UAV is a better bet than a piloted aircraft because if a piloted aircraft is shot down, then the aircraft is lost and there is a high chance of loss of life to the pilot. It is always the loss of a pilot is way more expensive and it takes a long time to substitute that expertise when compared to losing an aircraft. So, having a manned aircraft to do this 3D's, the dull, dirty, and dangerous missions is quite expensive proposition.

So, this is in a way it minimizes pilot risk. So, in these such kind of missions which are dull, dirty, and dangerous missions, it is better to use a UAS or unmanned aerial system rather than using a piloted aircraft that is one thing. Second part is it is cost effective. It is much cheaper to produce and operate because the entire human machine interface what is called as cockpit plus all those redundancies and everything that are part of the unmanned aircraft is just not there.

And hence in that way we also do not need things like oxygen cylinders or personalize the cabin, all those aspects or a seat and then ejection mechanisms and other safety features, all those aspects we do not really need to spend money on. So, hence the development of an unmanned aerial system, the aircraft in itself is quite a cheaper proposition than development of a manned piloted aircraft. So, it is a much cost effective solution.

Then as we said earlier, it minimizes pilot life risk. So, because a pilot life is many, many times expensive than the aircraft itself. So, the pilot is a very expensive resource and you are saving an expensive resource by performing simple dull, dirty, and dangerous missions, so that is one other aspect how you reduce the pilot risk. Then, the endurance is not limited by human abilities.

Like for example if you make a UAV, you can make the UAV fly for 24 hours, if you want to do that missions like for example the global hawk and all, the endurance is more than 24 hours actually there are UAVs which are endurance greater than 24 hours. It is usually impossible for a human being to fly an aircraft for 24 hours without losing attention and all those kind of things because our attention span has limitations.

We have aspects like fatigue, the pilot fatigue comes into picture then reduced motor skills as time progresses the motor abilities reduces, then the decision making power reduces, then the cognitive power starts reducing. So, all those things comes into picture. So, as the mission along (()) (11:11) then the chances of pilot making a mistake also exponentially goes up. Similarly, the amount of g-force or the like if an aircraft rapidly changes its direction while it is flying at a very high speed.

Then the pilot experiences g-force and they usually wear a G-suit to actually compensate for that and how to limit the amount of g-force an aircraft can pull because there is a limit to each human body can tolerate on that. When you do not have a pilot, you are actually in a much better situation to deal with or ask the UAV to take a tough maneuver where it is pulling very much more g-force than what a human body can tolerate.

Because there is no living being inside it, there are no human being is piloting that aircraft. So, many of the human capabilities since a human is out of the aircraft, the limiting aspects of the human is also removed and hence the machine is not just limited by the capabilities of the operator. There are some disadvantages also, not just completely great figure. There are mainly safety considerations, midair collisions as such there is no human being on-board.

So, there is nobody there make decisions according to what the (()) (12:37) alarm is saying that (()) (12:41) is also says there somebody else coming to collide you.

So we know the pilot (()) (12:44) if you hear the (()) (12:47) alarm it says go down or nose down, the pilot just nose down the aircraft, the other pilot noses up and the collision is avoided typically, but there is no pilot to do that. So a computer you have, you are pretty much dependent upon a computer to do that. And also other thing is that lack of certified pilots outside military operations, there are not many qualified pilots to operate drones.

So, most of the people who fly it in the civilian world they are hobby flyers what we called it. So the hobby flying there most of the people are self taught and most of the people also are not gone though the rigorous training that military pilot would have gone through or military UAV pilot would have gone through. So, hence the approach can also be become quite (()) (13:42) people who are flying it because you are not sitting in the aircraft.

So there is a tendency that with lack of proper training, you have a much higher risk of creating mishaps. About the regularity authorities, everybody is still confused. So, it is like we are talking about no solid or clear regulations, we also know how regularity authority in India is dealing with the UAV question. Basically at this point we are not planning to deal with that unless somebody else comes up there.

So, all the regularity authorities are also in a soup with how to deal with this and again the lack of real time decision making or the casual attitude. As I said earlier, you are not flying the aircraft, you are not sitting in that aircraft, you have flying from the safety of the ground. So the pilots who are not very well trained and who are not very well emphasized upon the risks that are involved in it they can take a casual attitude.

And it could result in a much bigger damage. So, that also one of the disadvantage.

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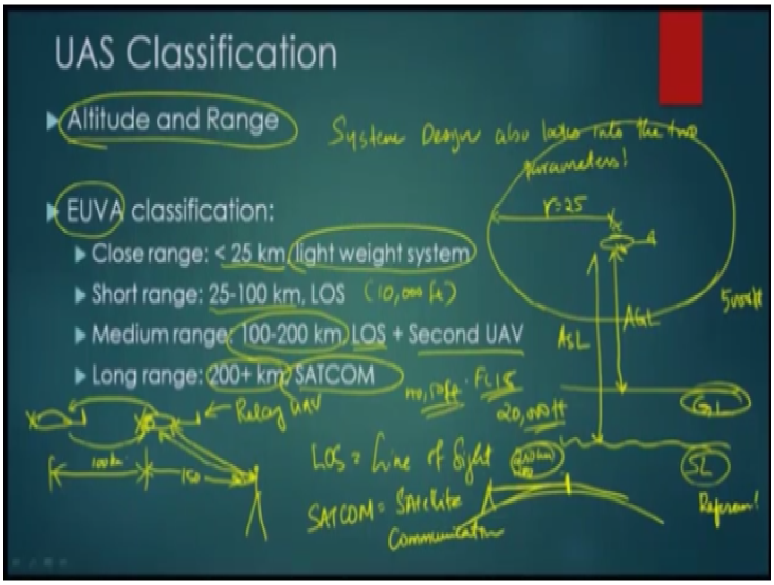

Typically unmanned aerial systems are classified in many ways. Most of the time the altitude and the range are the two parameters that are used to classify this. So, to a large extent when you designing this as a system engineer these are the two parameters. So the system design also looks into these two parameters.

They are important for us, so the altitude and the range. Altitude is basically if you draw a diagram, if this is called the ground level, the height at which the UAV is flying. This is what we called as the altitude. There many ways this can be called as a AGL above ground level, or if we talked about a sea, this can be talked about above sea level, ASL, AGL. There are many ways you can specify the altitude.

So, either the ground level is a reference point or the sea level is the reference point. So, these are the reference points. So, the altitudes are usually specified based on the ground level or sea level. And then the range is if you take off from this location then how far it can operate and this radius within which the UAV can operate. This we can talk about as the range or we talk about the radius of the circle if you draw a big circle, how much it can do.

So, based on which the UAV has ranged, sometimes translates to what we called as an endurance also, but we will talk about that later. So, the range is basically the radius of the circle that it can fly at to the maximum without loss of communication. So, many agencies who classify UAVs, but the EUVA classification, European Union classification is pretty much like this. The UAVs that have a 25 kilometer or less range.

So if this R=25 kilometer and then it is called as a light weight system. Typically, these types of UAVs fly about 5000 feet from the ground, so that is the idea. So, this classification is called as a light weight UAV systems. If the range is between 25 to 100 kilometers and LOS stands for LOS is equal of line of sight, so the communication is through line of sight and they typically fly up to an altitude of 10,000 feet mostly.

Then those UAVs are called as short range UAVs 25 up to the height of 10,000 feet, we can think about as 10,000 feet altitude. Then we talked about a medium range UAVs which are between 10 to 200 kilometers, they typically again operate on line of sight LOS communication and you could actually fly another UAV to enhance the range. So, what happens is you have your ground antenna here.

You have one UAV flying here, this one UAV that is flying, it is communicating with the ground and then here is another UAV that is flying and these UAV is communicating with this particular UAV. So this type of a communication back and forth. So this could probably if we could fly to 150 kilometers, if this the range and then this could probably fly to another 100 kilometers by enhancing the range.

So this kind of thing is called as a range enhancement or with a second UAV or this UAV is typically called as a relay UAV which relays in between. So, that type of range enhancement is also possible. Such UAVs are typically called as a medium range UAV. They typically fly it on altitude about flight level 18 and those kind of stuff, 18,000 feet, 20,000 feet, up to 20,000 feet above the ground or something like that what they fly mostly.

Then comes the long range UAV whose range is 200 plus kilometers because after 200 kilometer, the line of sight communication becomes a problem because of the earth curvature. If you do not know you possibly should read it because the earth is kind of like this and you have an antenna and the communications after some point of time, the curvature will result in the signal not being able to transmitted.

So, typically people say that this is 200 or 250 kilometers is the max we can talk about getting here in a line of sight. Otherwise, you would require another relay UAV, if not, you will require what we called as a SATCOM. SATCOM stands for satellite communication. It is satellite communication. So, the big UAVs the one that are used in people what we called as a drones or the Predator, Reaper, you know, all those kind of big UAVs that are used in combat.

They actually fall in the long range UAVs. They pretty much fly 40-50,000 feet above the ground and then they are able to do very long missions for like 24 hours nonstop flying and providing data, video feedback and all those kind of stuff. So, these are typically the classifications and depending upon what the customer wants you might end up building an UAV in one of these classes.

So, if this classification you should also know because you should probably decide what are the UAV are going to build based on the customer needs or what type of a UAV would satisfy the customer need that one should be able to understand.

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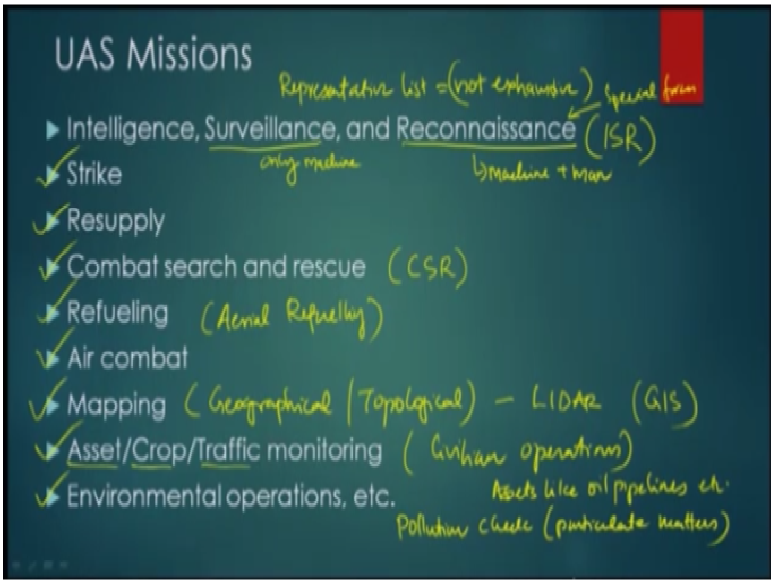

So, what are the typical missions of the UAVs or UAS, unmanned aerial system missions. There are lot of them, this is just a representative list not an exhaustive list please remember that. There are so many more missions that UAVs are used for currently. We are not listing everything. We are just talking about the main important missions. So, the first and foremost missions that they are used for is called as ISR missions.

It is intelligence, surveillance, and reconnaissance missions. So intelligence gathering and your surveillance means you are keeping track of something, reconnaissance means you are actually assisting. So, there is a difference between a surveillance and a reconnaissance operations. Surveillance means you are basically only dependent upon the machine where as recon it involves machine and a man.

There is a human being also there. So, this is usually done at the time of special operations, special forces does this quite a lot more. This surveillance is done for any battle or any war time operations. So, the ISR operations the UAVs are heavily used then they are also used in strike, we read left, right and center of newspaper saying that drones strike has killed this many peoples , so it is used to launch lethal weapon against the enemy.

Resupply they are also used for resupplying troops at very tough situations like presently we used helicopters to supply the people or the troops in Siachen, but if you think about it, it is a very risky operation because of the extremely inhospitable weather and flying condition. So you have a UAV and all resupply missions currently at the high altitude war locations put the life of the pilot the person who is flying the aircraft at risk.

So, UAVs are a much better option to do that type of mission and we talk about CSR which is combat search and rescue. So if people get lost in a big location or a jungle or a battle field or a desert or something like that. If you looking for people and you want to keep on flying without tiredness and keep looking for whether you can find the missing troops then UAVs are much better option.

Having a manned aircraft after some times the pilot will be feeling fatigue and he or she might miss things whereas a UAVs with a high resolution camera pointed down, you can keep on changing the person who is watching the video at the ground when the person is approaching a fatigue level and you again keep on continue to search for the missing troops without the endurance of the pilot being worried about because the UAVs flying as long as it has fuel.

Then another thing is also for refueling, refueling missions are currently quite risky because this refueling we talk about as aerial refueling. So such an operations, UAVs are much better choice because currently you are putting too different aircrafts at risk while doing a aerial refueling. So there are researches being going on to develop UAVs that can be flying fuel dispenses in the sky.

So they just keep on flying with a fuel there and other aircrafts will go there and take the fuel from that flying platform and then continue to fly or enhance the range. Then air combat is another one where you are talking about fighting the enemy in the air in itself which is usually air to air combat or some people called as a dog fight and those kind of things. We are not talking about dog fight or those kind of movies.

We are talking about dealing with the enemy or combating the enemy in the air. So that is also a part of the UAS missions, then mapping this involves what we called as geographical or topological operations. So, most of the time people use things like LIDAR to scan the terrain and then create the topographical map to figure out to create 3D profile of the area to estimate quantities you would have to find contours and those kind of stuff.

So, the GIS related operations, so the some people also called as GIS (Geographical Information System) that operations are definitely got a boost by the advent of unmanned aerial systems. Similarly, it can be also used for asset monitoring, crop monitoring, traffic monitoring etcetera. Out of monitoring operations, these are mostly civilian operations. So you can see the monitor the highway traffic jams from a remote locations.

And then control traffic lives accordingly. You can also used to monitor crops across a wide large area of farming land to see whether there is any attack by pests or the crops are getting matured, went to do the harvesting all those kind of things can be studied as part of this. Then we can also talk about asset monitoring, the asset monitoring like for example assets like oil pipelines etcetera which requires regular monitoring can be monitored here easily.

Because again instead of sending a human beings in a vehicle which continued to try wherever the oil pipeline is. We can actually have a UAV fly across the pipeline and use high resolution cameras to actually monitor the stuff. Similarly, environmental operations stuff like pollution monitoring or pollution check which is like particulate matters and all those kind of things and then measuring the level of different type of pollutants in the air.

All those aspects can be taken care of by the unmanned aerial systems. So, I hope by this you have a fairly clear idea about what is an unmanned aerial system and what are some of the particular missions associated with this. So, now we get into the aspect of how we developed the unmanned aerial system or how we went about applying systems engineering principles to develop the UAS unmanned aerial systems which was a small unmanned aerial system.

We are not talking about a larger development, they are still under development, we are talking about a small systems here, but it is a good example.

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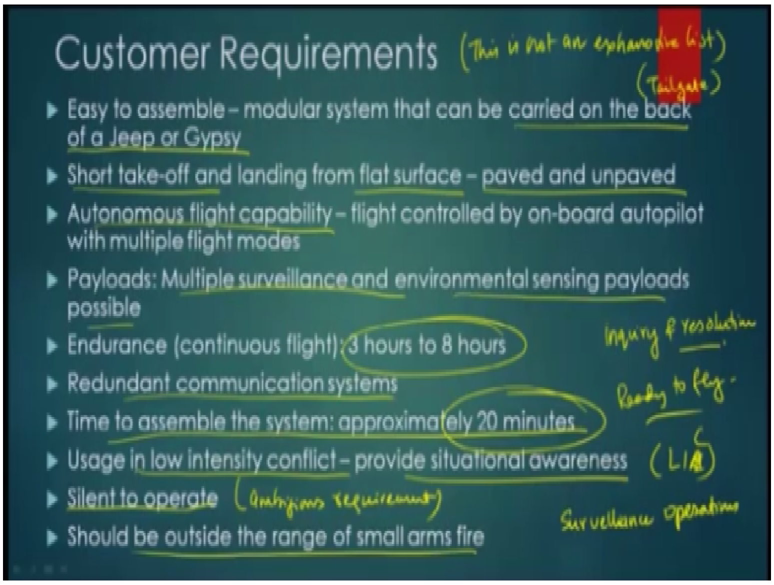

So, first here we will start with what we called as the customer requirements. The customer requirements in this case again this is not an exhaustive list. I just put some of the customer requirements which I thought it was important to begin with and then we will keep on adding more customer requirements as we will continue to discuss this case throughout the rest of the course at different stages.

But initially when we discussed with the customer it was because we do not have explicit permission from the customer, so we are not diverging the details, but when we talked about the customers initially about what type of UAV they were looking for, the question was that these UAVs were typically supposed to be used for surveillance operations. So the idea was that surveillance operations was the main applications.

And also they wanted to operate within a reasonable range, we will talk about what it is as we go through the customer requirements. So, the first customer requirements that was presented to us and by the way remember the customer will never prioritize the requirements. The customer will keep on saying the requirements as and when the customer feels or customer remember something.

So this is kind of the order in which they kind of initially mentioned it actually picked with up from my notes at that time. So, the first one that was told was it should be easy to assemble instead of the endurance, instead of the altitude and all those kind of things, the customer's first statement was it should be easy to assemble. It should be modular system that can be carried on the back of a Jeep or a Gypsy.

So back means the tail gate of the Jeep or a Gypsy. So, that was the first thing. It should fit in the back of a Jeep or a Gypsy. Okay good one requirement. Then it should be having a capability to do short take off and landing from flat surfaces, whether its paved or unpaved, it does not matter. It should take off from a flat surface paved or unpaved. So, we asked like paved means what.

Then we will talk about how we ask these questions later not now because it will confuse you, but whether it is paved or unpaved the customer wanted to take off from a flat surface and within a short length. So its kind of customer is saying that I do not have too long of a field, so you do not have luxury to keep on flying to reach the speed to take off, so take off quickly as possible from the flat surface whether it is paved or unpaved, do not ask for a runway kind of a thing.

Then the third one that was mentioned was autonomous flight capability upon dropping further they said the flight should be controlled by an on-board autopilot with multiple flight boards. So once a aircraft takes off and reaches an altitude he used to thrown up a button and the autopilot takes over and the mission is preprogrammed and then the autopilot just keeps on doing that mission as it is being programmed.

And with that no human interference is necessary or what they wanted to say is that while the takeoff and landing can be managed by a human being. The flying for that entire duration of the operation should be done by the system itself, nobody is going to fly an aircraft for that entire duration from standing from ground. So that was made pretty clear. Then the payloads were mentioned as multiple surveillance and environmental sensing payloads should be used.

We initially were in the listening mode, so we did not really drop too much into this and we dag it later as I said its an iterative process, so we got more details out of it different iterations and endurance well it was given as a range to us a pretty much like 3 hours to 8 hours of endurance. So it did fly for a 3 hours or it should from 3 hours to 8 hours. So the minimum time was 3 hours of fly time and maximum fly time that was given to us was 8 hours.

So, have an endurance between 3-8 hours. It should have redundant communication, redundant means if any one communication channel is lost there should be another communication channel available to still recover the UAV, so one other thing was that their customer also looked for some level of redundancy that was clear from that, but the redundancy was specified in the communication, not in something else.

So the customer wanted redundant communication, so what it is. Customer is the one who gives you the requirements of the needs and you design the system accordingly and the time to assembled even though they said the easy to assembled system, then the customer came up and said okay it should be assembled within 20 minutes. So, that means they would expect the UAV to be in a knocked down stage to transport from place A to place B.

And when you reach a particular location then you should be able to assemble it quickly and then fly it. So, approximately they expected to get ready to fly, so assembly means ready to fly in 20 minutes. Then it was supposed to be also used in what we called as a low intensity conflict. Low intensity conflicts are LIC are typically this is abbreviated in military language as LIC low intensity conflict or LIA is low intensity action, either way is fine.

So, low intensity conflict what happens is the firing is mostly or the conflict is mostly using small arms and other stuff. So, here the most important role of the UAV is to provide situational awareness to the commanders to figure out what is going on and then two tactics based on what the overall view the birds eye view of the situation is all about. So, the situational awareness the commanders was one of the major issue or more crystallized role.

It should be silent to operate, so it is kind of a double (()) (33:30) so you cannot never make a flying aircraft completely silent. It is kind of extremely difficult to do, but when they said silent means when we discuss them further than we were able to get into a further measurable quantity, but see that this is a ambiguous requirement because you cannot really measure what is silent. So that silence was not quantified in this regard.

Again, the redundant communication system that is also an ambiguous requirement, so there is lot of ambiguity initially when the customer puts the requirements to you and its your job as a system engineer to remove this ambiguity later down the road and then they also said should be outside the range of small arms fire, so it is partially ambiguous, small arms you assume that they are basically assault rifle systems and like that.

So the person takes an assault rifle and start shooting it at the sky, the bullet should not reach the UAV that is probably what the customer meant or also at some point of time long range sniper rifle as 50 caliber rifles are also small arms, but that the range of a 50 caliber rifle projectiles and a normal assault rifle projectiles are quite different. Thus actually travel a couple of kilometers, the 50 caliber rifles.

So is that also consider as a small arms, so that ambiguity was still there, but any way so the customer is looking for a UAV that is not a huge one that is quite clear from this because they want it to transport it using a Jeep or a Gypsy. I mean Jeep we are talking about it engine scenario about the Mahindra Jeep that is being used in various paramilitary forces and they want it mostly for surveillance.

So that means you are not interested in looking into arming the UAV or you are not talking about dropping something or you are talking about having a lethal payload anyway. So with this idea the first round when the customer ask specified all of this kind of things, the first thing is the system engineer would do is ask many questions, remember some of the things that we talked about it is, it is a process of enquiry and resolution.

So, we started doing enquiry and resolutions and from there a bunch of specifications were arrived at specifications are achieved and I am going to show you the specifications and then after that I will explain to you how we reached those specifications in the process. So the specifications that were developed after discussion with the customer, multiple rounds of iterations happened.

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So the first thing was that, the payload surveillance payload, so it was decided as a camera based payload, so it was asked whether you would need what type of camera, either we are flying in the night or we are flying in the day. So we want one type of camera at this time because when the time changes from day or a night you will change the payload. It is not an issue for them.

So, they did not want to fly with two payloads, they just wanted to fly with one payload. So we said okay fine, a single camera payload, it can be a day camera or a night camera you can switch the camera according to your wish, but that is how it was taught through in our case. Then the communication they talked about is as a redundant communication, they said they need a redundant communication, upon enquiry it was clarified that they would require the redundancy in telemetry.

Telemetry means the communication from the ground to the aircraft, it should be redundant. They do not mind if the video or a video feed gets cut off, the real time video feeds get cut off they do not mind for few minutes, but they want the telemetry not to cut off. So then two separate channels two frequencies were chosen and in both frequencies telemetry happened. So one was telemetry and other was also telemetry, other had a telemetry plus video.

So, even if one shuts off then the other channel is available always so that the aircraft remained in communication with the ground control throughout the duration of the mission.
So, that was sorted out. I did not specified this clearly here, but yes that it is how it was sorted out. 21-kilogram maximum takeoff weight was the next one. So the weight of the UAV with a

maximum takeoff weight was classified to 21 kilograms.

So they said they wanted a small UAV and all those kind of thing should fit the back of Jeep or a Gypsy. It was crystallized which was derived and finally contoured at 21 kg as the ideal weight that is required. They said it should take off from a short surface and finally it was 30-meter distance runtime for takeoff from a paved or an unpaved surface, paved include runways or it can also include what we called as a public road and unpaved include even a flat field which is compacted with a level ground.

Then the endurance finally was kept at 8 hours even an upper limit endurance is 8 hours, you can always fly less than that by controlling the amount of fuel that you are carrying or by controlling the number of batteries you are carrying because the one way to deal with silence or the reduced noise was to actually do dual propulsion either gasoline or electric, so that was provided.

So hence 8 hours was the maximum endurance that was given and that was decided low cost, so per UAV cost was kind of fixed. In the long run if you manufacture in large quantities, how much the UAV should come to that amount was agreed to. Then the operational ceiling, the maximum height, so this is a ceiling AGL above ground level you should be able to fly at a maximum height of 5000 feet above ground level, so that is something that was decided.

About ground level again was decided because the major areas where the UAV will be put into place, the operating environments were specified and then 5000 feet above the operating environment was not really a hard thing to achieve. So it was decided that at 5000 feet at the specified environments. Some of the informations are not completely diverged out because of other reasons, but sufficient information is there to take care of we understand.

Then the 20 minutes to finish the assembly, so assembly time was specified at 20 minutes and that was measurable again a quantifiable requirement. The speed of the UAV, the maximum speed was spread at 100 kilometer per hour, so that is the operating speed, the maximum operating speed. And also the radius, the operation radius was set at 150 kilometer operation radius.

It is line of sight operation, the LOS, so 150 kilometers the UAV should be able to fly as far as from the base where takes off. Also we talked about having two propulsion the gasoline as well as the electric propulsion because flying silent was an important thing. So in a gasoline you want to fly at a much higher altitude to ensure that the noise is not heard by the people down stairs or people in the ground where is in electric we can fly to much lower altitude.

So flying lower means you can actually get much clearer pictures, so that was the other reason. So depending upon the usage they could actually the same platform it can be used with a propulsion of electric or a gasoline. All it needs is two things exactly the same except the propulsion changes. So that mechanism was built in. Then the UAV is physical dimension as we said earlier.

One of the output of it is some aspects will be the operational plan out of the requirement analysis, other is the functional one and then is the physical one. So here is an example of a physical 3.3 meters was designed as the wingspan and 2.2 meters were taken as a length of the UAV. So the wingspan is from if you look from the top, this is the fuselage you have two wings like this.

So wingspan means tip of the wing to the other tip of the wing. This was taken as 3.3 meters and let us see if there is a tail also here, then this length to this length was taken as 2.2 meter that is the total length of the UAV. And then obviously as said earlier should be autopilot. So it was decided that the takeoff and the landing will be manual and the other one is autopilot. The flying is autonomous.

So that is how it was decided. So you can see that some of these are physical, some of these are operational, and some of these are functional aspects. So, at the end of the day, all these things your functional plan or your functional specifications, your physical specifications and your operation specifications all the three need to be in sync. So these were the synchronized specifications that were derived out of these process and we will talk about how these were done later down the road.

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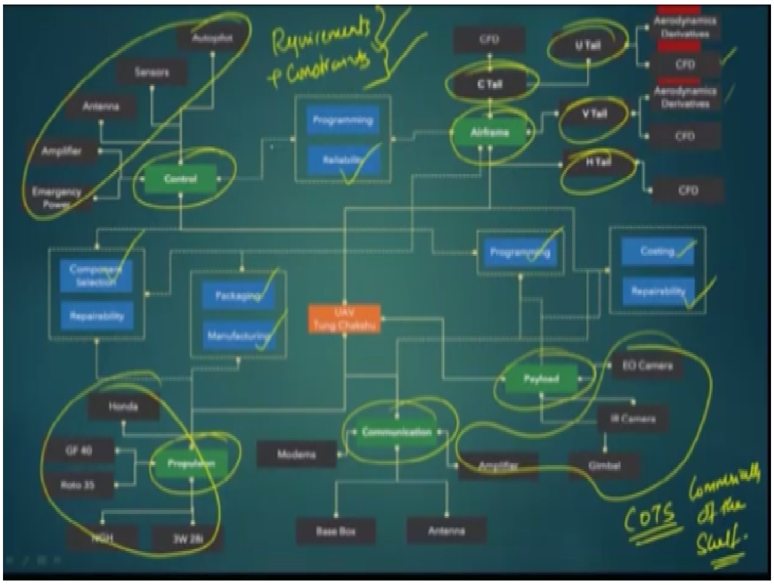

But if you look at the complication of the system, you can actually think about it as the UAV has like again as I said earlier we broke it down into an airframe then we broke it down into the control systems, we talked it in the propulsion, communication and payload. So this is the five major subsystems and there were so many of other things need to be taught through, so like for example there are different configurations where we looked into.

There were different studies were done, fluid dynamics, (()) (43:44) derivatives were done, computational fluid dynamics studies were done, then in between there are costing and reparability then programming, reliability, packaging, manufacturing, component selections, you can see all those kind of stuff choosing of different stuff which are COTS which are commercially of the shelf COTS stands for commercially of the shelf products.

So for cost reductions, so many things were done different type of engines were compared and picked up and the different type of sensors, antennas, amplifiers. So you can see that multiple type of products were taken into and different alternatives were taught through. So the user had one mission and as I said earlier one of the aspects of this all things is to provide viable alternative system engineering job is to provide what viable alternatives.

So in this case in itself it is a simple process you can see that we had a UAV with a C-tail, a U-tail, a V-tail and H-tail. So there were 4 different platforms, four different design alternatives were created or developed as part of this exercise. So that at the end of the day, once you are during the development you will be able to identify and choose the most the best suited platform which will actually fulfilled the customer requirements and specifications to the best possible extent.

So, remember we have requirements, the customer requirements and we have what we called as constraints. These are the 2 things that need to be satisfied. So then all these different options were compared again as these and finally appropriate combination of the system was derived or appropriate alternative was chosen which actually satisfies the requirements and the constraints the best possible extent.

So, with this you will actually do is we will start getting into how these customer requirements were crystallized and how these were translated into tangible specific needs as part of the systems engineering process and we will kind of see how systems engineering was applied in this whole exercise to realize this UAV. So, just as a quick recap of this, what we studied here was we had a basic introduction of what UAV is I think I would recommend everybody to read little bit more on what UAVs are and what are they used.

So, there are so much of literature available in the internet as well as other books are available on this. I will recommend everyone to go through this and get much more background knowledge about UAVs, because some of the stuff that we are going to talk about in this requires some of those background knowledge, so I suggest that you guys read and prepare for it because as we will be continuing this case in the next class.

So we will be discussing more about this. So, please have your background knowledge ready and also please remember all of these customer requirements that were given as a starting point and it is not complete and as time progresses I will add more customer requirements and how their additional information was elicited from the customer at this enquiry and resolution process how did this happen as part of the requirement analysis.

We will actually run through different step of it, so that you have a clear idea how to conduct this requirement analysis processes clearly and that is one part and then finally we talked about these specifications of the unmanned aerial system, how those initial customer requirements were translated to what we called as it should be verifiable and it is also an achievable and ambiguous, you know, all those kind of things.

So, how did we come across specifications those are verifiable that are achievable that are quantifiable, that are also like achievable within the reasonable cost, alternative solutions, technically feasible all those aspects how did we do all those things, how did all those reality checks were done in this process in the requirement analysis to come across crystallized to this level of this specifications which was finally agreed upon by the customer.

And also we will briefly discuss how we developed interdisciplinary teams for this process, we will also discuss that. And then finally as we said earlier how did we come up with the different alternatives. We will briefly look into this, we will not spend too much time on this because quite a lot of things cannot be diverged that much, but whatever possible we will clarify things to an extent where we have a broad idea of things.

But as I said earlier system engineering job is to explore for viable alternatives for the customer and then choose the appropriate one. So how did we develop different viable alternatives is also part of the discussion. So with that we will start now crystallizing much more details in the next classes to come, but I would request everyone to again I cannot emphasize this strong enough, please gain sufficient background knowledge about UAVs.

Because from the next thing or unmanned aerial systems because the next class onwards we are going to start discussing on this and where I am going to assume that you have gained a sufficient background knowledge. So, that is left to you. So, thank you for your patient listening.