Design of Fixed Wing Unmanned Aerial Vehicles
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Lecture – 01
Introduction, Course Content and Classification of UAVs

Good morning friends. Welcome to this course on design of fixed wing UAV. I am Subrahmanyan Sadrela, instructor for this course and here we have 2 of our TS, Mr. Deep Pareek and Mr. Salaudeen Kazi. They will be helping us in solving the assignments and whatever doubts you have, you can mail them. They will be helping you. You are okay? Thank you. Thank you being a part of this course.

So right now we heard that registration has clicked about 2500. Now we can no more assume the students who have registered in this course have performed the previous visit. So we have to redesign the course content in such a way that even the fresher, a student who is out of this aerospace engineering should be able to understand whatever we are going to discuss in this lecture. So let us look at what are we going to discuss in this course. So we will start with some basic introduction, right.

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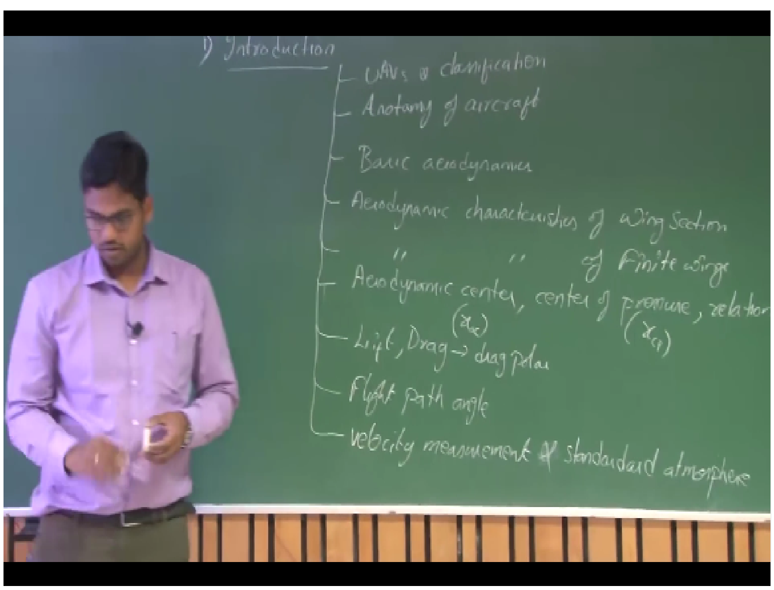

First few lectures will cover the introduction about UAVs and their classification. And then some brief anatomy of aircraft. Followed by these, we discuss about some basic aerodynamics. And then aerodynamic characteristics of wing sections and also aerodynamic characteristics of finite wings. And then we will also talk about what is aerodynamic center which is very important for us, one of the important variable and center of pressure and their relationship.

Relationship between aerodynamic center and center of pressure. So we will also discuss about what is lift, drag which is in fact the drag polar. And some concepts related to flight path angle, right. Followed by this, we will look at how to measure the velocity during flight, subsequently the standard atmosphere, right. These are some of the introductory concepts that we will cover.

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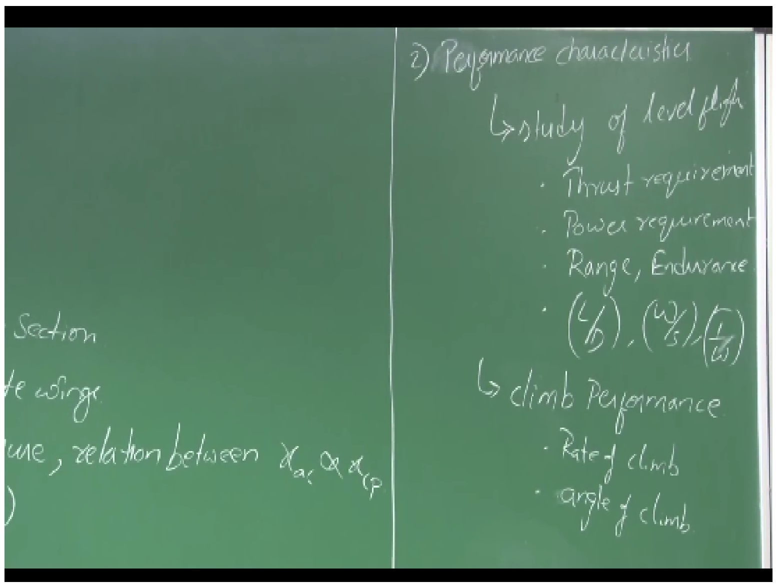

And then we will look at some of the basic prerequisites of this course that relates to performance characteristics. This includes study about, study or analysis about level flight, such as, we will talk about thrust requirement and power requirement and range, endurance, and then by L/D, wing loading and thrust loading, right. So we use this concepts to figure out what should be the weight of that fuel or the battery that you would like to carry to perform a particular mission.

How do we get to know? By understanding what is the thrust requirement of the system to perform or to execute that particular mission from which we can also identify. Since most likely we will be talking about propeller driven aircrafts or UAVs here, right. So we have to talk in terms of the power requirement, right. So whether which kind of propulsion system should I select, the answer for me, I mean, the answer that I get is by performing this performance analysis, right.

So L/D, W/S, here. And we will also look at climb performance. Here we talk about rate of climb and angle of climb. This is what limits your rate of climb or what limits your angle of climb. For the design that you are going to do, what are the parameter that limits your rate of climb and angle of climb. So if we have to know, then we have to perform this and we have to study this climb performance, right. We will look at both, study rate of climb as well as accelerated rate of climb, right. Yes.

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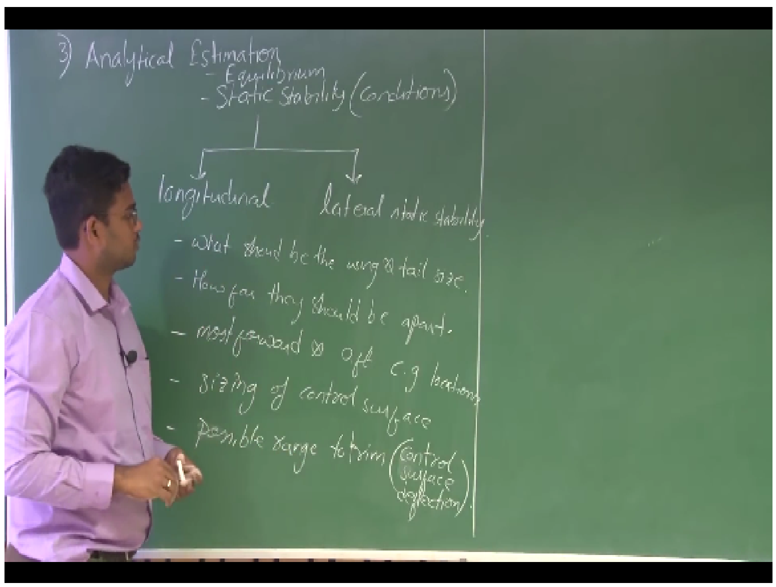

And the third chapter will be about more or like, we can say analytical estimation where you talk about various stability and control derivatives of the system, right. So analytical estimation. So the main emphasis is how to design a system which is stable by itself without any add on, like control system, right. How do you make the system stable by itself during its flight, right? So here we start, we talk about static stability.

So start with equilibrium, static stability, conditions to satisfy that and then, so there are 2 case studies. One is about longitudinal static stability and the second part is about lateral static stability. So in longitudinal static stability, you will talk about which, what should be the size of the wing for example or what should be the wing and tail size, right. So how far they should be apart for a stable flight, right.

Again when we say wing, tail, fuselage and all these things in propulsion system, each carries a weight, right. So there exists a cg for this entire system. Once you assemble it, you know, you will figure out a cg location, right. So where does this cg location should be? What are the limitations of this cg travel? So we will also look for most forward, you try constraints on cg location, right. Aft, cg locations, locations for a stable flight.

So this, all these conditions are meant for a stable flight, okay. And we will also look at like how big should be your elevator or the control surface, right. If you have, if you want to control your aircraft, how big should be your elevator? Does that sizing involve the distance between wing and tail or this cg place any role in that sizing of this elevator. So we will address these questions while performing this sizing of control surface. So sizing of control surface, like how the sizing can be performed and what is the role of the cg location as well as the distance between wing and tail.

When I say the distance between wing and tail, we broadly talk in terms of distance between the aerodynamic centers of these 2 components, right. So once we do this control surface sizing and at the same time the distances are fixed, then we need to understand what is the range of angle of attack, yes, range of angle of attacks for which the aircraft can be trimmed for. So we will look at that possible range to trim. So when we say possible range to trim, it talks about control surface deflection, okay.

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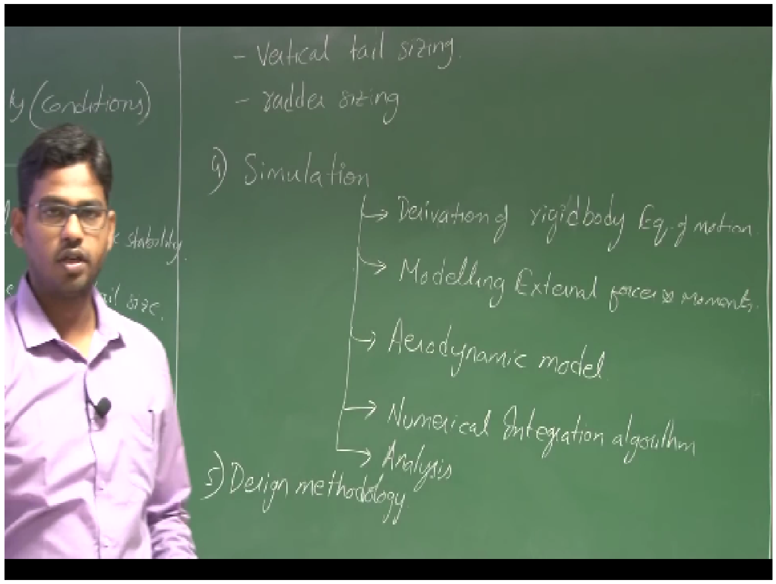

At the same time for lateral directional case, we will perform vertical tail sizing, right which are mainly governed by means of some lateral directional parameters, stability and control parameters, right. We have to design such a way that the vehicle should be able to come back to its equilibrium whenever there is a disturbance in lateral direction, okay. And then vertical tail sizing, radder sizing.

Radder is a control surface that is located on this vertical tail which is used for directional control, right, yes. And then we will proceed to talk about simulation. Why do we need simulation? So whatever you have designed, you have to translate since you may not be, before fabrication, right. See ultimately design, what is the output of this design? **"Professor - student conversation starts"** Working model. Yes. What should be the output?

It will be like some physical. Yes. **"Professor - student conversation ends."** You should have some physical dimensions. Ultimately you should have the plan for geometry as well as the cross-sectional properties, right and their respective locations with each, right. Let us say if you have where you have designed the wing with the span with chord, right with a particular span and chord and you have a tail and you have located both of them.

So the output should be a geometry, right. Now whether this geometry will, in reality will fly or not. Or do we need to, I mean is there a step that is involved before flying the actual design, right or the prototype. We can still do that by means of simulation, right. So what do we do in simulation is like convert this physical model to mathematical domain, right. You translate to the mathematical domain and then give various inputs and see how the system behaves, right.

If it has sufficient stability or whatever the disturbance that you give, does it vanish with time or increases with time, right. All these things you can analyze before actually going for fabrication. Since we will not be fabricating any design, any model that we are going to design in this course, let us concentrate on simulation. It is worth spending sometime performing the simulation. So what we do here is derive, derivation of a rigid body equations of motion, right.

So rigid body equations of motion are common but how can you simulation give a design by using that rigid body equations of motion, right. So the answer is modelling external forces and moments. Whatever the shape or whatever the design that you have performed, I mean, you made, will reflect in terms of external forces and moments called aerodynamic forces, right, forces and moments.

I call it as aerodynamic model here, right. This aerodynamic model will go as an input, right to this equations of motion and you use a numerical simulation, some numerical algorithm, numerical integration algorithm to solve the derived rigid body equations of motion which in general or in differential form, right, first order differential equations. So numerical integration and then analysis, right.

And finally, now you actually start to design, design methodology. We will take 1 or 2 case studies and we will do the entire process. Like without understanding the performance and stability aspects of this, we will not be able to design a configuration. If possible, we will also try to include some optimization here, right. So but this limits the scope of this particular course.

And yes, our TS will take you to the UAV as per the UAV laboratory here where there are few UAV models like and if possible, we will also include the flight test of those models during this course, right. Yes. So you might have heard a general term called drone and what does, how does it differ from an UAV, right. We should know that. We more or less use drone and UAV for as a common word, right. Now we need to know what is the difference between them.

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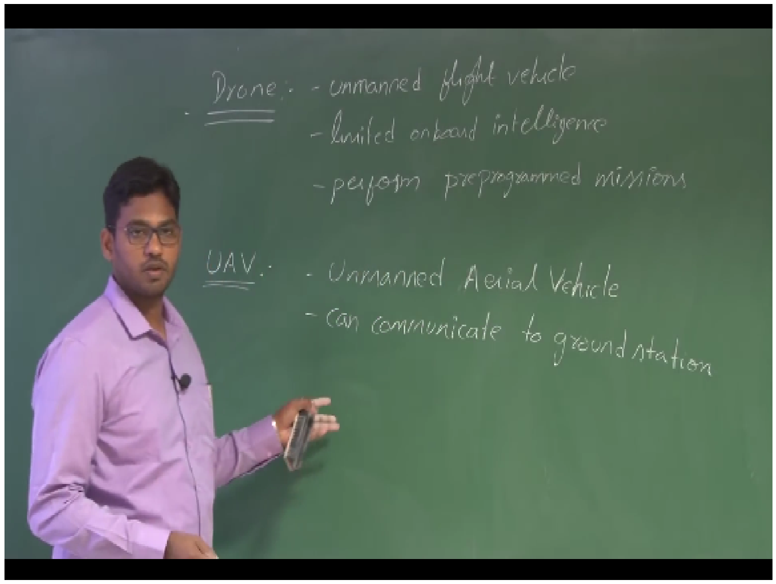

Drone is also an unmanned system, right and which is meant to perform a mission, more a pre-programmed mission, right. So that means it will not be able to send whatever data that it has acquired during that particularly mission to the ground station unless it come back to its home, right. So it is like limited intelligence, limited onboard intelligence, right. It is also an unmanned flight vehicle with limited onboard intelligence and mostly designed to perform pre-programmed missions, right.

Whereas as most of you know the word UAV stands for unmanned aerial vehicle. So unmanned aerial vehicle, of course there is no onboard pilot, yes, right. So it is more controlled from the ground station or in an autonomous mode, right but it can communicate to ground station. So when there exists a communication link, you will be able to change the mission whenever it is required, right. During the flight, it is like dynamic mission planning. You can actually change the mission whenever it is required.

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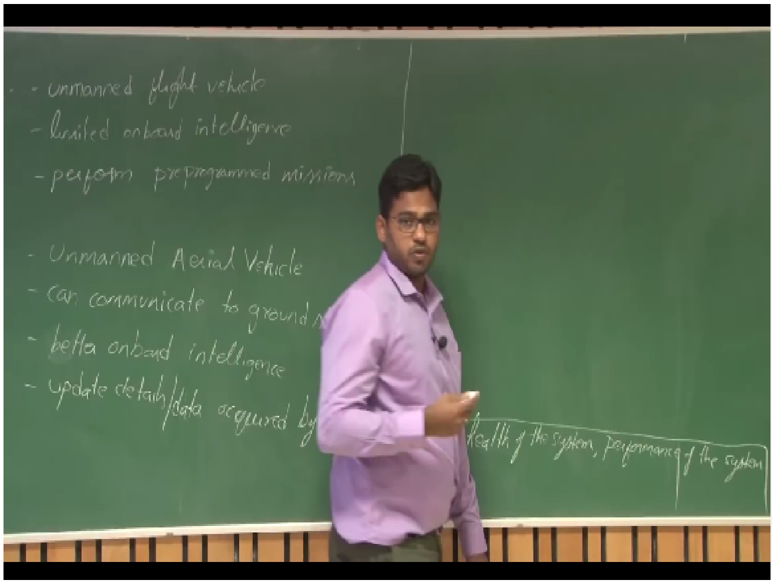

Better onboard intelligence. And then it can also, when I say it can communicate to the ground station, it can update onboards the payload data as well as health of the system, right and the performance of the system. So it can update details for the data acquired by onboard payload as well as data related to sensors health or say health of the system and also the performance of the system, right. So in this course, we will talk about this UAVs, right.

So how can we classify these UAVs? There are many UAVs, right. Starting from 10 cm UAV to a 10 m UAV, right in terms of span. How to classify these UAVs?

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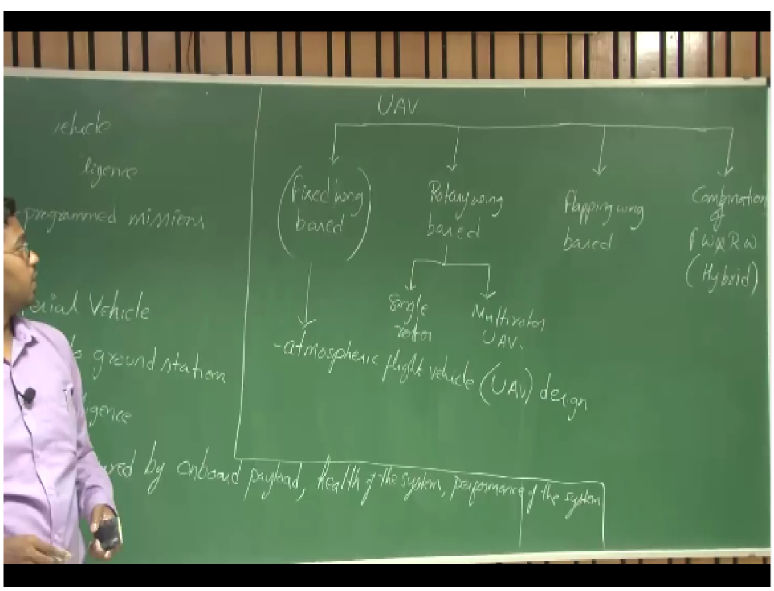

First of all let us look at the mode of operation and how they are nomenclatured, right. So UAVs can be broadly classified into a fixed wing based UAVs and rotary wing based, and a flapping wing based as well as combination of them, right, combination of either of this fixed wing, rotary wing, mostly a combination of fixed wind and rotary. Can say hybrid UAV, right. Okay. Flapping wing are mostly also termed as ornithopters, right.

So where the aerodynamics is, I mean, the design is carried by means of the aerodynamics associated with the insect's flights and all, right and birds, so on. So in case of rotary wings again there are a single rotor and multirotor UAVs. So there are single rotor as well as multirotor based test birds, right, that you can develop under this rotary wing UAVs. So what we will be talking about is fixed wing UAVs.

So the content that we have presented here is more or less related to this, fixed wing UAVs. To further narrow it down as we know fixed wing works well in the atmosphere, right. So we will be more closely talking about in atmospheric flight weight or atmospheric flight vehicle which in our case is an UAV design. So we will be talking about fixed wing atmospheric UAV design. So here, this classification is made by means of principal of operation.

Now let us look at the classification based upon the size and weight. At the same time, the mode of operation.

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Let us look at the classification of these UAVs based upon their size and weight as well as their mode of operation, right.

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Classification of Unmanned Aerial Vehicles

No.	Class	Mass	Size	Normal Operating Altitude	Range	Endurance
1	Micro	< 0.2 lb	< 10 cm	< 50 ft	0.1-0.5 km	< 1 hr
2	Mini	0.2-1 lb	10-30 cm	< 100 ft	0.5-1 km	< 1 hr
3	Very small	2-5 lb	30-50 cm	< 1000 ft	1-5 km	1-3 hr
4	Small	5-20 lb	0.5-2 m	1,000-5,000 ft	10-100 km	0.5-2 hr
5	Medium	100-1,000 lb	5-10 m	10,000-15,000 ft	500-2,000 km	3-10 hr
6	Large	10,000-30,000 lb	20-50 m	20,000-40,000 ft	1,000-5,000 km	10-20 hr
7	Tactical/ combat	1,000-20,000 lb	10-30 m	10,000-30,000 ft	500-2,000 km	5-12 hr
8	MALE	1,000-10,000 lb	15-40 m	15,000-30,000 ft	20,000-40,000 km	20-40 hr
9	HALE	> 5,000 lb	20-50 m	50,000-70,000 ft	20,000-40,000 km	30-50 hr

*slide credit – Unmanned Aircraft Design, sadraey Introduction and Classification of fixed wing UAV 17

So the micro UAVs, there are 4 different classifications, 5 different classifications, right in terms of dimension as well as weight of these UAVs. There are micro, mini, very small, small, medium and large, right. Very small and mini, they are more or less, we cannot exactly differentiate them. But here the micro UAVs whose weight class falls below like, I mean, the size is less than 10 cm.

Whereas very small will come under anything between 30-50 cm. And the small UAVs will have a span of 0.5-2 m and medium sized UAVs will be of 5-10 m and the large size UAVs are 20-50 m, as high as 50 m, right. So these are some of these UAVs which can be classified based upon this, I mean, there are few examples for it. (()) (29:15).

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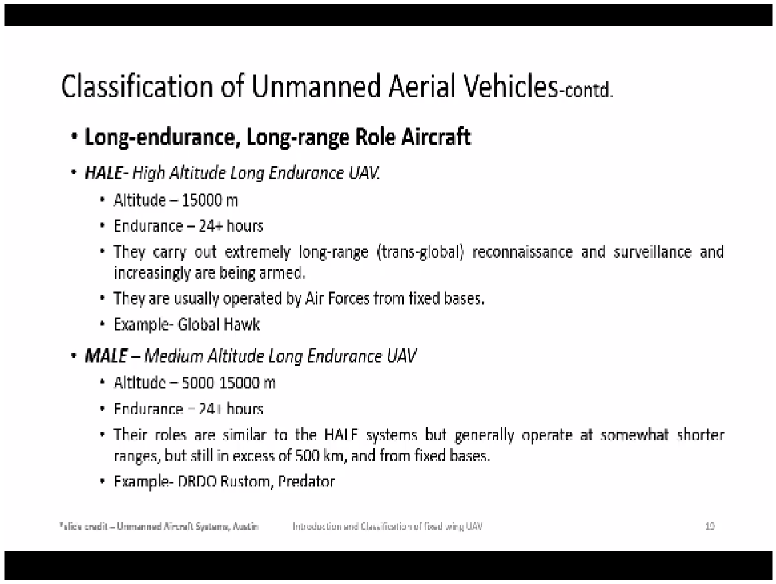

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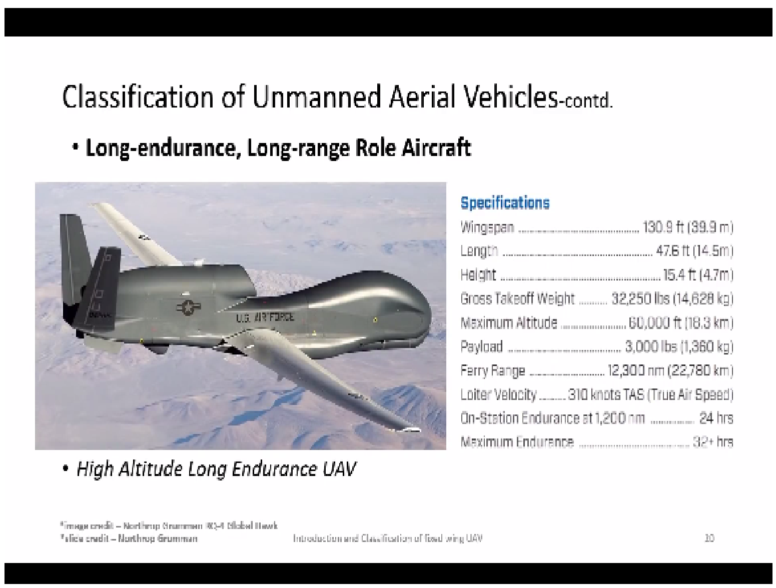

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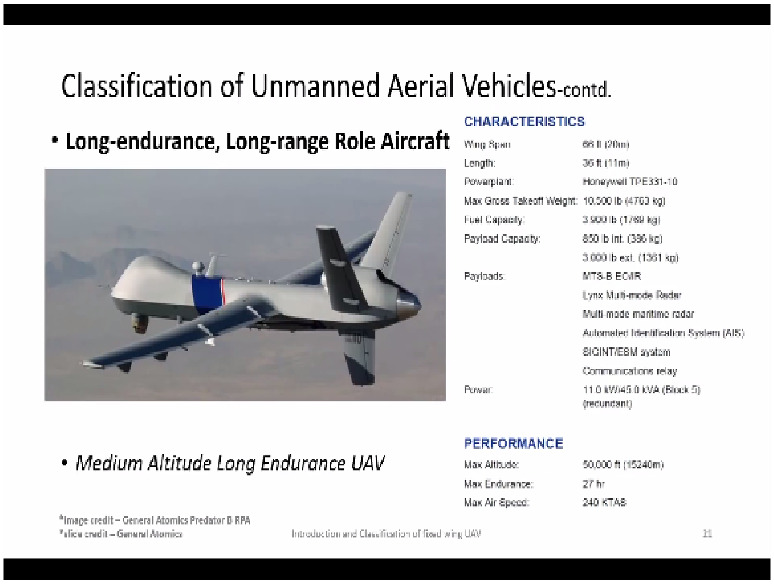

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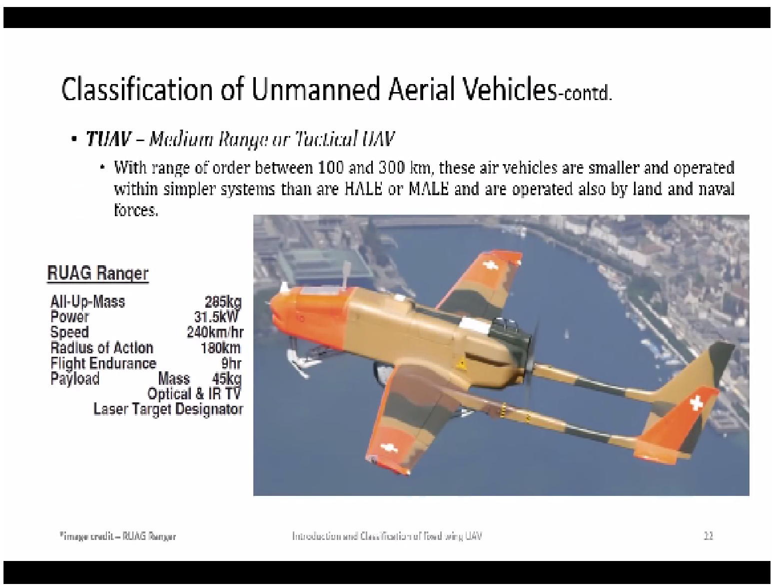

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Classification of Unmanned Aerial Vehicles-contd.

- ***TUAV – Medium Range or Tactical UAV***

Performance
- Endurance 12-14 hours
- Maximum altitude 16,000 feet (ft.) or 4,877 meters (m)
- Range 200 km
- Maximum dash speed 108 knots (kts) or 200 kilometers per hour (kph)
- Cruise speed 80 kts (148 kph)
- Loiter speed 65 kts (120 kph)

Technical Data
- Length 15.7 ft. (4.79 m)
- Wingspan 22.4 ft. (6.83 m)
- Maximum payload 91 lbs. (41 kg)
- Maximum gross weight 585 lbs. (265 kg)

*Image credit – AAI Shadow 600
*slide credit – AAI

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Classification of Unmanned Aerial Vehicles-contd.

- ***Close-Range UAV***
- These are used by mobile army battle groups, for other military/naval operations and for diverse civilian purposes.
- They usually operate at ranges of up to about 100 km and have probably the most prolific of uses in both fields, including roles as diverse as reconnaissance, target designation, airfield security, ship-to-shore surveillance, power-line inspection, crop-spraying and traffic monitoring, etc.

*slide credit – Unmanned Aircraft Systems, Austin

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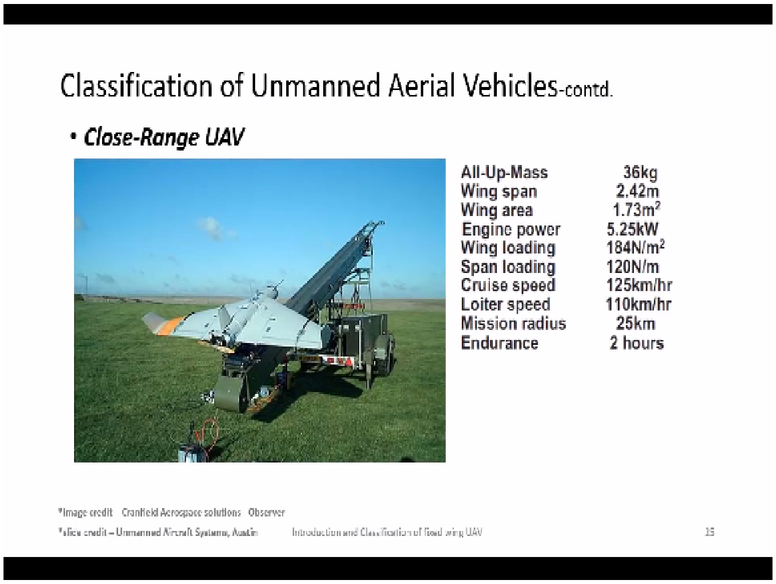

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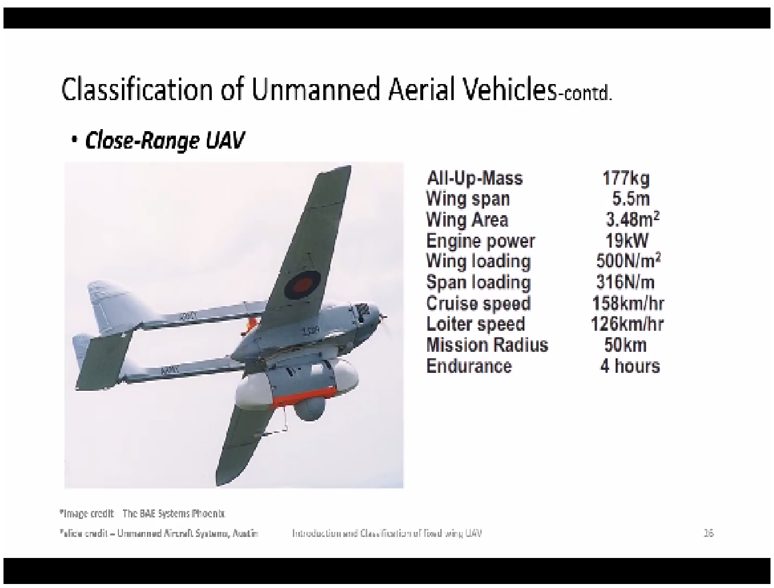

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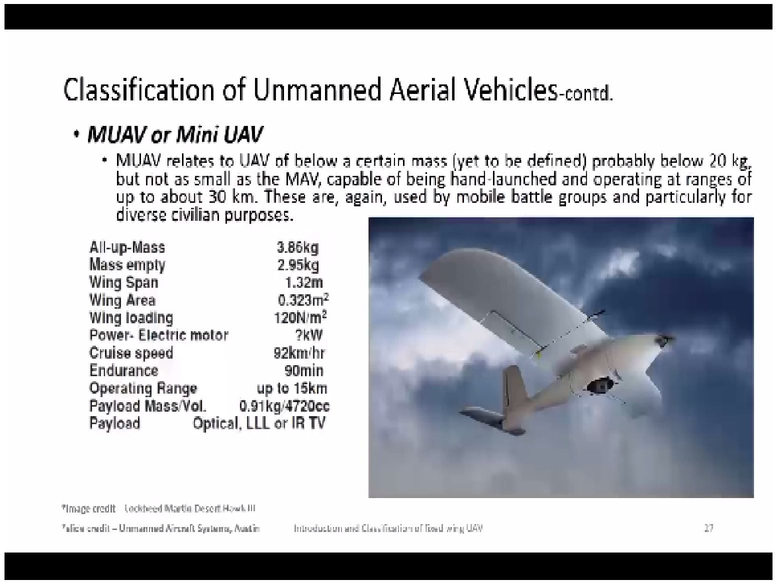

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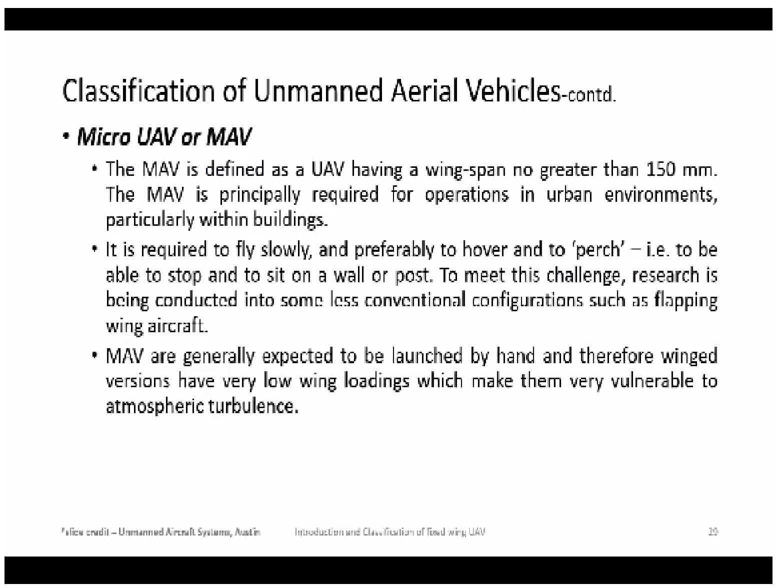

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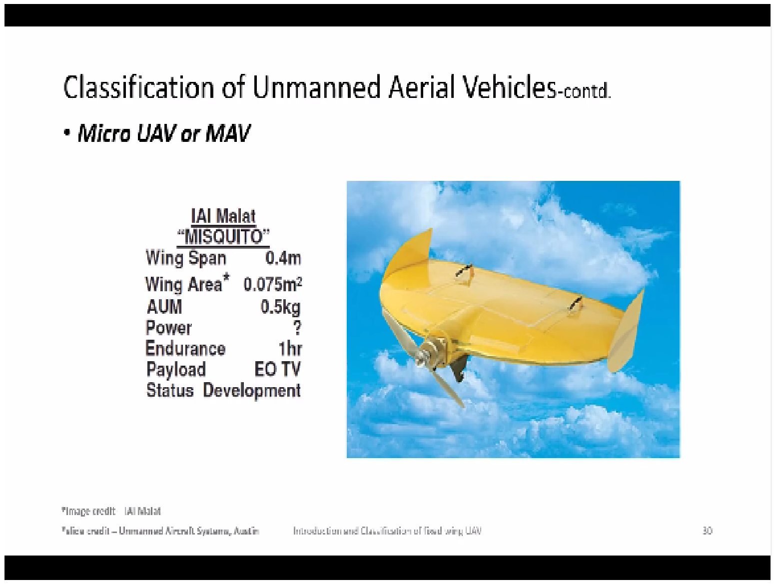

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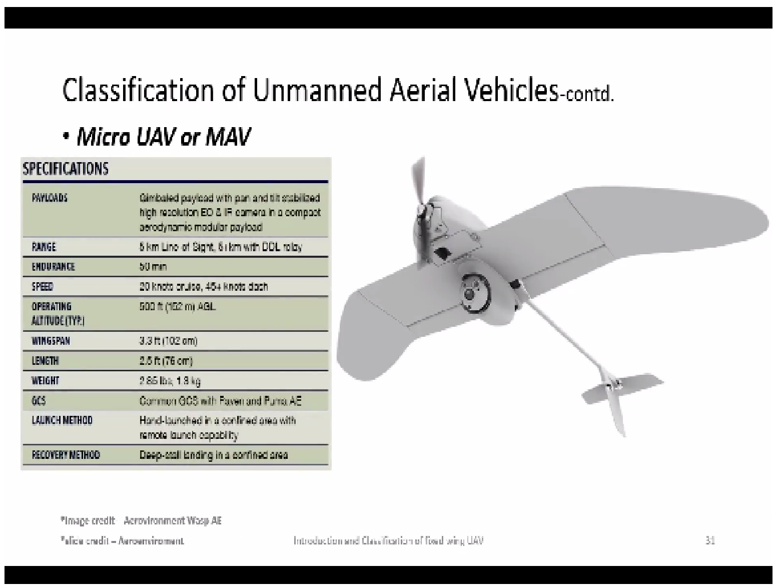

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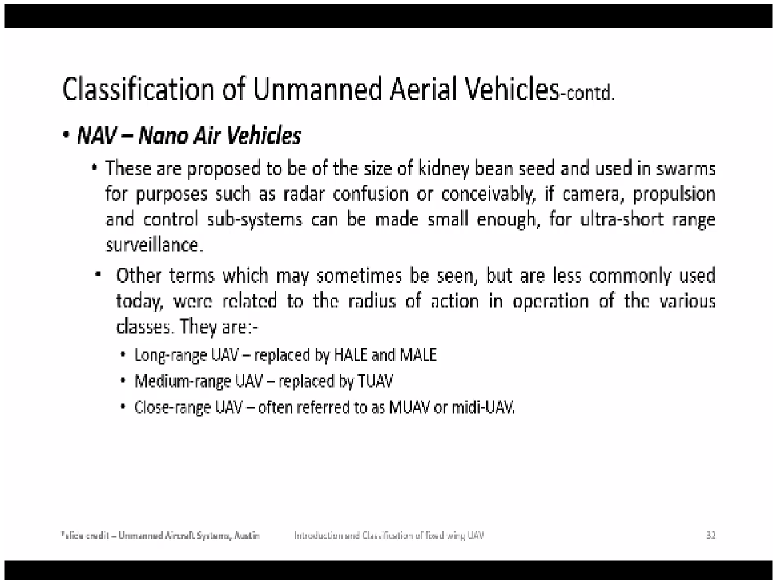

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(()) (32:08) And also there is a classification based upon its mode of operation.

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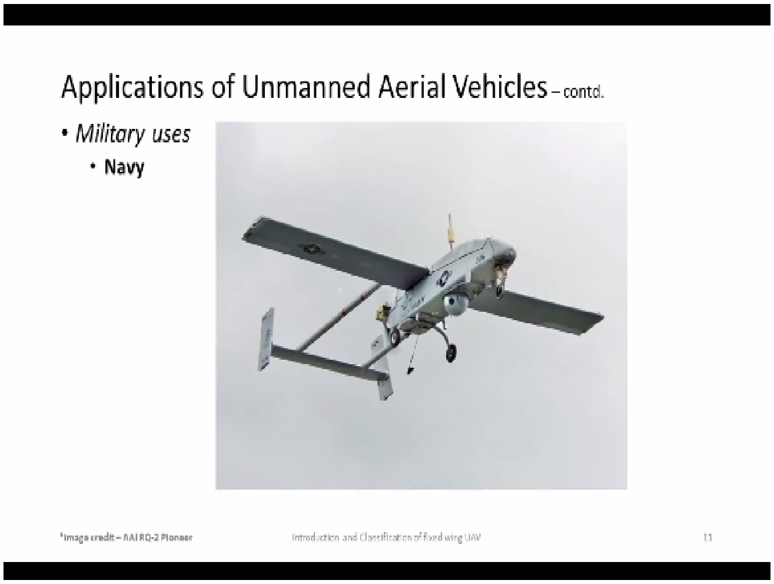

So there is a tactical and combat UAV which will be used more in a dynamic sense. Those are more active, they are used to drop the payloads and whatever the payload may be, right. It can be a warhead or anything. So these tactical and combat UAVs are more active in the sense and there is a MALE UAV which is abbreviated for medium altitude long endurance UAV.

And the HALE, high altitude long endurance UAV. These 2 UAVs are meant to perform surveillance and reconnaissance missions, right. So the high altitude long endurance UAV can have a range up to 40,000 km, right and a medium altitude long endurance UAV can have a range up to; yes, similar range but at a lower altitude. (Video Starts 33:03 - Video Ends 36:26)

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Dear friends, we are right now near the runway of this flight laboratory of IIT Kanpur. So flight laboratory is in front of me. We can see this as a fixed wing UAV. The 1.5 m class. Overall takeoff weight is 1.6 kgs and it was designed to have an endurance of 2 hours right now. So let me introduce our chief test pilot, right. He is a test pilot for most of our configurations, Mr. Naveen and you know Mr. Deep again.

He is here. So let us quickly have a flight test of this and this has been designed by us, right and see how this design behaves right now. So it is a bit windy as you can see the model is almost waving here. So let us see how this performs in the wind. So you can zoom that wind, right. A bit gusty. (()) (35:01) So we can witness a power of flight. So the model is gliding and is able to sustain its weight because of this gust.