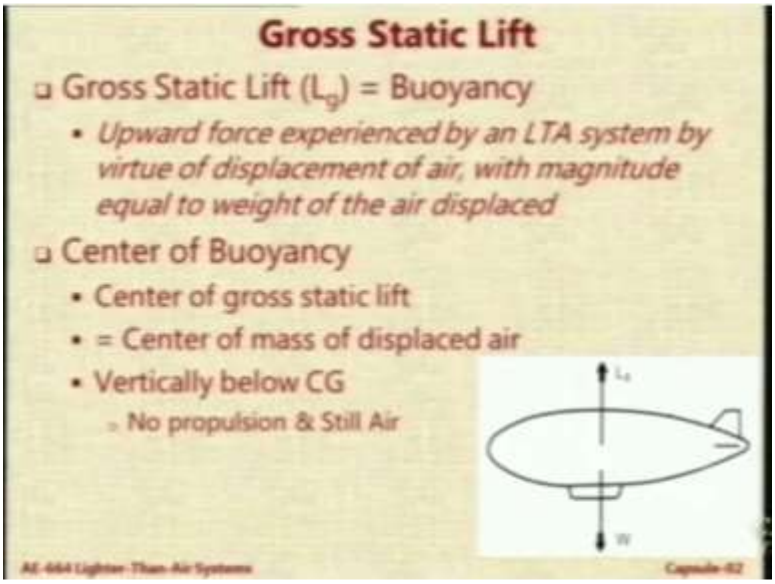
Lighter-Than-Air Systems
Prof. Rajkumar S. Pant
Department of Aerospace Engineering
Indian Institute of Technology - Bombay

Lecture – 22
Basic Concepts of Aerostatics

(Refer Slide Time: 00:30)



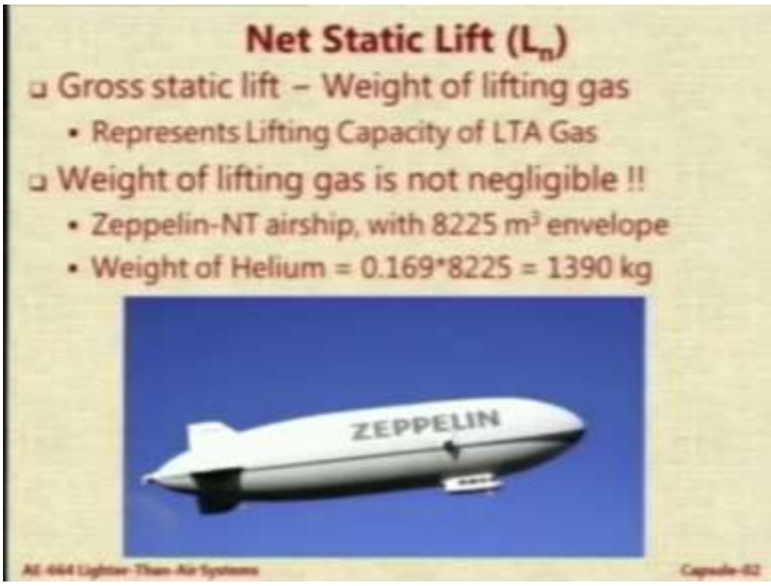
So now let us start with our concepts of aerostatics. Because we are going to use aerostatics as our primary lift generation tool, therefore it is important for us to know what are the important basic concepts now. The gross static lift or Lg as I will call it from now on is nothing but the buoyancy, which is what you saw. So, the upward force experienced by this dustbin bag which is an LTA system by virtue of displacement of air with magnitude equal to the air displaced that is the vertical buoyancy force.

And there is a center of buoyancy. Just like we have center of gravity, center of mass, we have a center of buoyancy that is the center of the gross static lift and this particular center will be the center of the mass of the displaced air. Now in this particular case, the hot air or LTA gas hot air it had covered the entire envelope. So, therefore the center of the hot air bag and the center of buoyancy will be the same.

But that may not be the case in many systems as we will see. So, remember, do not get confused between center of gravity which is the mass center and center of buoyancy, which is the buoyancy center. Generally, it is vertically below center of gravity So, if you have no propulsion, that means no engine force and if the air is still, then obviously the center of the volume, but there could be differences, is not it?

There could be a situation where you mount some equipment such that the centre of gravity moves forward. Let us say if I mount the camera on this airship, the centre of gravity will move slightly forward, center of buoyancy will remain same. So, in general we try to bring the center of gravity below center of buoyancy, but it need not be the case that is a very important point to note. So, that is gross static lift. But we are not concerned about gross static lift, what we are concerned is the net static lift.

(Refer Slide Time: 02:57)



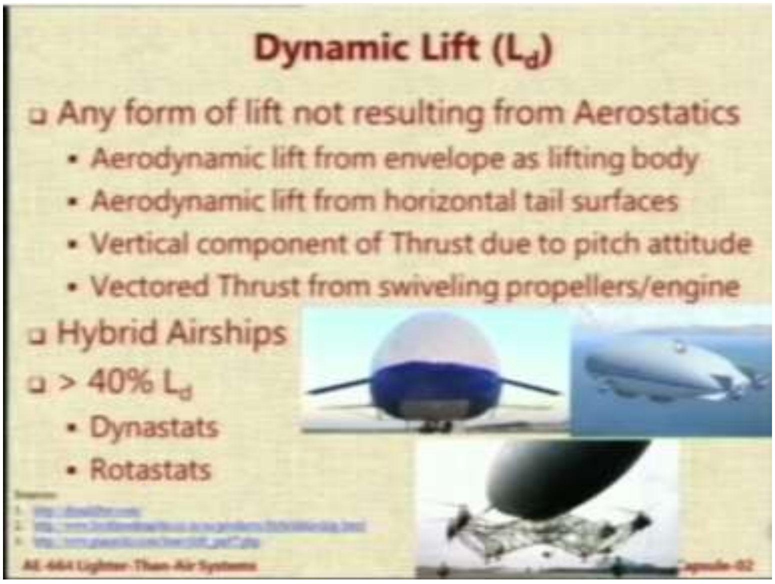
Now, the net static lift is going to be the gross static lift minus the self-weight of the lifting gas because the lifting gas will have its own mass, correct. So, this is important for us. Because this represents the lifting capacity of the gas. You may have a very large gross static lift, but if the gas where itself is very large of course it has to be less than air, but still let us say it is almost equal to air. For example, the hot air.

Hot air, the mass of hot air is not very different from the mass of cold air. It is slightly less because we know that with temperature density reduces, but not so much. Therefore, the lifting capacity of the less static lift of hot air is far below that of helium or hydrogen. So, this is the real. This is what we are really interested in. Now, the weight of the lifting gas, you might say anyway it is gas what is the problem? It is not a small thing.

For example, if you look like Zeppelin-NT which has got around 8000 meter cube of envelope, the weight of the lifting gas is more than a ton, 1390 kg. So it is not a negligible number okay. In calculation, suppose you say let us ignore the weight of the gas because it is an LTA gas, you will end up with an error of this huge magnitude. So be very careful. And also do not do double accounting for gas.

So some people what they do, they will say lifting capacities so much and then minus self-weight and then there will also be minus gas weight. This is a very common mistake people do. The gas weight is already accounted for in the net lifting capacity. So do not do a double deduction of the gas okay.

(Refer Slide Time: 04:29)



Now, although we are looking at aerostatics, we also have to understand what is dynamic lift as far as LTA systems are concerned. Now, any form of lift that is generated in an LTA system other than because of buoyancy. It could be because of the engines, by tilting the engines. It could be because of the aerodynamic force acting on the body because it is a bluff body. The bluff body when it flies at some angle of attack, it will definitely generate lift.

Drag also, I am not saying that elevator will be very high, but I am always sure that there will be some lift at particular angles of attack. And again acting on such a large body such a large area, it will not be negligible, it will be there. Now, do not forget tails. Tails are horizontal surfaces. They are like small wings. And on big airships, the size of the tail may be bigger than that of many aircraft wings.

They will generate lift and that is a vertical force, although it is used for balancing but the force is vertical. So, in the equilibrium it will give you a vertical component, so that is also very important. And the other thing is by either tilting the engines. Now, there also could be one situation you have an airship which is flying at an angle of attack of let us say 5 degrees. Now, the engine is also at an angle of attack of 5 degrees. It has a thrust vector.

There will be a vertical component. So, the vertical component of thrust vector, although it is direct force, we include that in the dynamic lift. This is only accounting principles. Where do we put it? We put it as dynamic lift. Strictly speaking even if the airship is stationary and the angle is 5 degrees for the propeller, there will be some vertical force. So, one can catch and say why we call it dynamic?

It should be called as thrust component in static lift. We are just using the nomenclature here. So, anything other than aerostatics is dynamic lift. We will look at this particular class of vehicles very soon called as hybrid airships. Now they are a cross between aircraft and airships. In these cases, the dynamic lift can be very large in magnitude, it can be of the order of 40. Now, there is no hard and fast definition of hybrid airship.

But it is generally considered that an airship that has dynamic lift component more than around 40%, it starts getting classified as a hybrid airship. And if it is 60-70% it is definitely a hybrid. So, you can see there are two types. Of course, we will study this in more detail down the line. But there are two principal types of hybrid airships. One is called as dynastats. So hints is searching dyna and stat, dyna is dynamic moving, stat is stationary.

So, dynastats are hybrid airships, which generate lift either because of the presence of a wing like structure. So, this airship, the one in the center you can see there are these wings, one here and one here. These wings are attached to the semi-rigid airship structure. This is a company called as Ohio airships and they are trying to build this particular airship for transporting large amount of cargo.

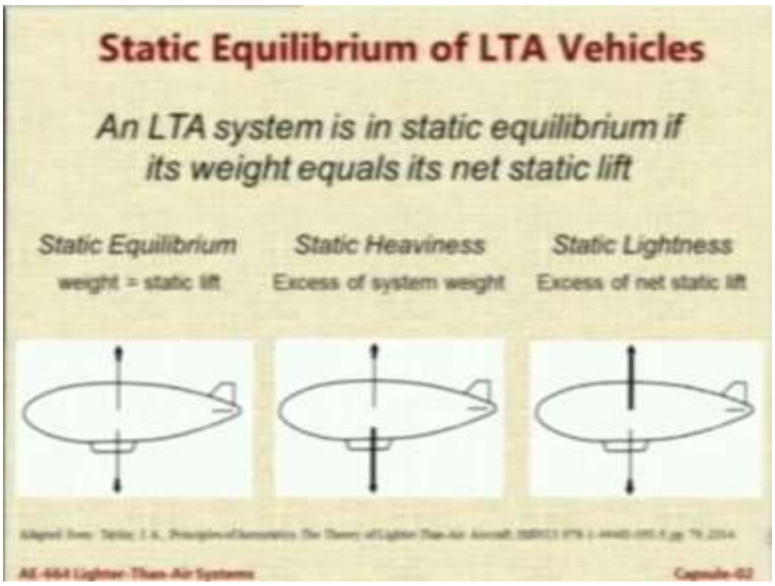
And they say that for that application, a hybrid airship such as this is much better than a classical airship. So please visit their webpage, have a look, I will show you the link very soon, and see what they are doing. But practically what they were able to do so far is only make a small airship which can carry the pilot. So they have made a small demonstrator. The second one on the extreme right is the airship from Lockheed Martin called as P-791.

This is the only hybrid airship which has actually been built and they have been fabricated against an order by the US military okay. Unfortunately, the order has been cancelled okay that is because of financial reasons because of the economics. It is not because of anything wrong with this particular airship, but it is there, there is a prototype which is flying, actual flying prototype. So these are dynastats.

Now in case of the P-791, the shape of the envelope is a double or a triple bubble. And this shape generates more dynamic lift as it starts moving. Then we have rotastats, which are I would say airships plus helicopters in which you augment the lifting capacity of the airship by attaching rotors to it. So there are many concepts, single rotor, double rotor. The one which actually flew and was tested is that airship.

Unfortunately, there was an accident of this airship during the flight testing, so it caught fire. And interestingly the same place New Jersey where Zeppelin-NT caught fire, sorry not Zeppelin-NT but the Hindenburg caught fire. But still, the concept was proven that it is a concept which can be used for heavy lift. So more than this we would not discuss now because as I said we have a separate section on hybrid LTA systems. At that time, we will discuss these in more detail, right.

(Refer Slide Time: 10:43)



Let us look at now the static equilibrium of LTA vehicles. Now, a system is in equilibrium when forces and moments are balanced and a static equilibrium for an LTA system occurs when the forces are in balance. So, when its weight equals the net static lift that means the entire lifting capacity is consumed in overcoming the weight and nothing is remaining. So, if they are equal, we say it is neutrally buoyant or it is in static equilibrium.

If on the other hand, the weight is more and the net static lift is less, then the vehicle has a tendency of going down. So this vehicle will be considered to be statically heavy. It is heavy. Statically heavy means the weight is more than the net static lift. And then we can have an aircraft or an LTA system which is statically light in which case the net static lift is more than the weight. And that is why if you release it, it will start moving up till it reaches a situation of static equilibrium.

Now my question is why will an LTA system which is statically light, I can understand why it starts going up? Because there is an imbalance in force and if that force overcomes the drag or the resistance it will go up. But why does it reach a situation of static equilibrium? Is it always the case that it will reach static equilibrium as it goes up? Or there can be something else happening before it reaches static equilibrium?

So what do you say? Will statically light LTA system while released and starts moving up, will it always reach a state of static equilibrium?

“Professor – student conversation starts.”

Yes. Always, okay. Why do you say that? Because the air density reduces with altitude so at some point it will attain the upper okay. So, you are saying that as this system starts ascending the altitude increases, hence the air temperature and hence air density will reduce.

So, a state will come when the density of the air is so less that the difference between the density of the air and the gas inside will vanish. It will be equal to the self-weight. It will be equal to the self-weight, right? Okay, but before that something else can happen, before that the envelope can tear because of the pressure difference. So it is not always the case. If that is the case, any balloon which I have left in a party will always be there up okay.

But I do not see my balloons up in the air, none of them have survived because they have blown or they have gone before they were able to attain static equilibrium, correct. So, you are assuming that the structural strength of the fabric will always overcome the pressure difference, but it would not happen. In many cases, there will be a tear before static equilibrium, but in some cases it can happen. It can happen in some cases, right?

Do you agree? Yes sir. Okay. So it is not that always there will be static equilibrium before that other things can happen. Now my question to you is would you like an airship to be in static equilibrium or statically heavy or statically light? You have to choose one of these three and you have to raise your hand and then we will see what most people think. You are an airship designer. Would you prefer the airship to be in category 1, 2, or 3?

And you must giving some reasoning also, not because what came to my mind, I like odd numbers, I like even numbers. I do not think that kind of an answer. Let me see. Yes. Option 2. You would like the airship to be statically heavy. Okay. What is the logic? okay. So, you are saying that you would like the airship to be statically heavy always so that you can run that additionally by some means that if there is a problem then how do you bring it down?

Okay this is one good reasoning. Any other difference of opinion? I will go for category 3. Statically light okay. Because I have two important parameters in mind, the first is economy and the second is safety. In terms of safety, I understand the second one seems safer okay. But what we could do is one have a propulsion system and second have a ballonet, both of them can help us bring it down.

And in terms of economy since it produces lift without any other mechanism, it will definitely fly for a longer time and consume lesser fuel as such yeah in terms of safety we have two different mechanisms. So if one fails, other can take care. Okay. You have mentioned a term called ballonet which I have not covered yet, I will cover it today. So, after that what we will do, we will revisit this answer after we discuss about this concept of ballonet okay.

Anybody from here okay. I feel that strategy like would not be fuel economic because at a constant altitude we will need constant downward as opposed to static equilibrium case so that will concern there. Okay so your point is that if you want to maintain the altitude. But why do you want to maintain the altitude? Because then only in any kind of flight we reach a specific altitude and then we carry out. But why? What is the necessity? Sir you go surveillance, so I need a constant altitude for surveillance. Okay. So you are saying that operationally an airship is used for surveillance, yes.

One of the big uses of airships is surveillance and you would prefer to have the same altitude if you are doing surveillance. Even for tourism. Even for tourism, for tourism there is no harm if there is a slight increase in altitude. But you forgot that if you fly an airship in the controlled airspace, there will be air traffic controllers also who will be monitoring its flight and this is a much slower animal compared to other aircraft.

So, it will be in the space for much longer time. It is more important from safety of the ATC, I mean from the point of view air traffic control that the ATC has a mental picture of where the airship is, if the ship continuously increases the altitude or decreases the altitude okay. The decrease will be a problem because they normally fly at low altitude. So, if they fly lower there is nothing else competing with them for the airspace.

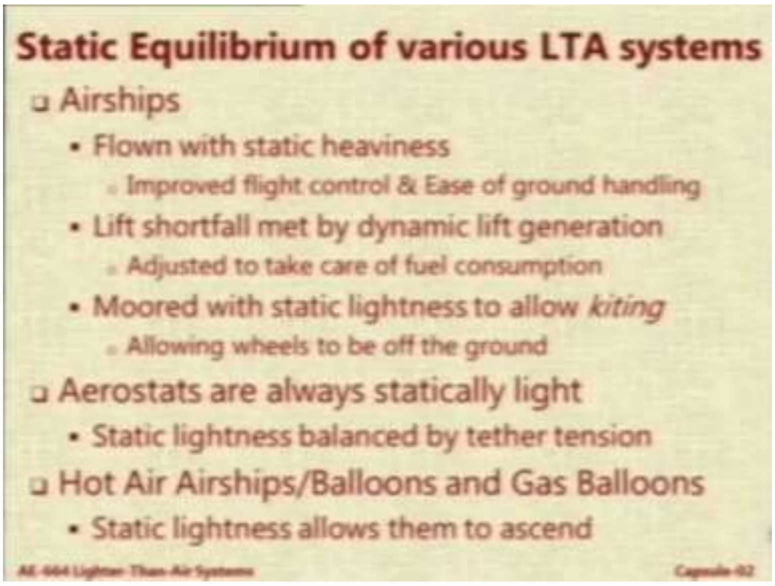
But near a major airport for example if you have an airship flying and there a helicopter is operating, so yes keeping same altitude is desirable from many operational considerations. Yes. Sir for the third category is not possible that after it has taken off and it has attained a certain altitude it attains the static equilibrium position, then you do not need any other mechanism. Correct, so that is what we will see now.

“Professor – student conversation ends.”

What would be desirable is a complete control on lightness or heaviness. If the pilot can have a system by which you can make it statically light when needed, make it statically heavy when needed and make it neutrally buoyant when needed, then it will be the most ideal situation. So, I would design the airship to be statically heavy because in case all systems fail, only gravity is my friend to bring it down to earth.

But I need not make it always statically heavy because I can make it heavy by putting extra weight. So the airship will not be statically heavy, it can be flown statically heavy okay. So, let us see what kind of systems you have.

(Refer Slide Time: 18:59)



So, airships are normally flown with static heaviness okay. The reason is the flight control system is improved if you have a statically heavy system plus the ground handling is also improved. Because if a system is statically light, it will keep bubbling up. As soon as the wind comes a small lift gets generated because of the dynamic forces because it is statically light or even neutral it will start going up.

So then there will be more load on the mooring mast okay, which we will study in more detail in the future. And the thing is that you can always generate lift by flying a little bit faster. So if you are able to overcome, if you make the aircraft or airship slightly heavier than what the lift is available from static forces alone and if you start flying, you get more dynamic lift.

So, you can overcome the static heaviness by generating dynamic lift by flying at an angle or even by tilting the propellers if you can, if you have swivlable engines are available or some other thrust vectoring mechanism. So, this is the preferred option to fly in airship. Now, the lift shortfall can be met and you can adjust it to take care of fuel because as you consume fuel during flight you become lighter.

So, now something has to be done, we will see what has to be done and what people are done. Now, when you actually moored the airship, so there is a big difference between ground handling and mooring. Ground handling basically means she is coming into land or about to take off at that time there are people on the ground which are holding it with ropes or a system is holding it with the ropes. During that time, I want it to be statically heavy.

But if I want to leave it, then I do not want it to be very heavy because then it is going to rub on the ground, the landing gear will head on the ground some systems will be loaded. So what I can do? I can do kiting that is on the mast you make it statically slightly light for now she is going to go up in the air. So there will be no rubbing of wheels on the ground. So the airship is actually above the ground, maybe only one meter above the ground, but above the ground.

And even if there is a wind disturbance, it will go slightly above the ground, 1 meter will become 3 meters, 2 meters, but there will be no rubbing on the ground. This is called as kiting or like flying a kite. So, when you are mooring it you make it statically light to allow kiting, when you do ground handling, you want it statically heavy okay and aerostats on the other hand you cannot have them statically heavy or even neutral.

Because if they are statically neutral that means they will go to a height and maintain that height. But there is no force acting on it in the vertical direction. So, what will happen to the rope below? It will become loose okay. Now, a small wind disturbance it will start oscillating up and down. Then your surveillance cameras will start getting disturbed pictures. So for my aerostat I want it to be statically light that means the lift should be always more than what is needed to overcome the weight.

Now the rope will be under tension and that tension can be handled by the rope by careful design. The Aerostat will remain fairly stationary. So from operational point of view, you have to be very careful about what equilibrium position you like to provide to the airships okay. Any questions on this? So let us go ahead. Now, if you look at hot air airships and gas balloons, now you want them to ascend right like just like the balloon that we saw.

It was statically light that is why it went up. So for hot airships and balloons or gas balloons, remember a hot air airship is basically a hot air balloon. That means it has got continuous heating, but you have a propulsive system and a gas balloon is basically a closed balloon. So the static lightness is what is needed because we have to make them ascend. We want them to go up. But now if you want to bring them down, so what do you do if you want to bring a hot air balloon down? You made it statically light, so it went up.

Now the fun is over, you want to go back home. Stop heating, correct. Stop heating, very soon it will become cool. Just like our balloon came down when you stop heating or actually it came down after it got cold air as it went up. But during the process, I mean during this time when you stop heating and the slowly it cools it will drift away that is you have to accept it. So a hot air balloon cannot be expected to come back to the same place where you launched it.

Only by fluke what can happen, it can go up and go on this side and then you stop and then the wind brings it back and bring it down that just fluke. So hot air balloon enthusiasts, they are used to travel long distances away from the launch site. But for an airship, you need to have a facility that you should be able to come back to the place where you took off from.