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

Lecture - 55
Flight Above Pressure Height

Now, let us look at those very rare scenarios in which for some reason you are required to fly above the pressure height. So, in these cases you have reached a situation where the ballonet is flushed, there is no air inside, but still you want to go slightly higher. So, how do you go higher? What is the option you have? Engine thrust, yes so you can start swiveling your engine, you can give vectored thrust that is one option available.

Suppose your engine is not having vectoring capability, now what do you do? You still want to fly higher than needed higher than the pressure altitude?
"Professor – student conversation starts." Throw the stuff. Throw the stuff and make the airship lighter. That means throw away the ballast. So, it is possible to do that, but is there any danger with that? What is the danger? Whatever you throw out you will not recover it. You may not be able to recover it, correct.

You may throw water or you may throw even sand so that you do not hurt people below, right. So, you have thrown 500 kg or 300 kg of water or sand. So, now when you come down to land, you will be stuck at some altitude at which ballonet becomes fully inflated and now you cannot come down unless you accumulate some weight. So, yes you can do this, you can throw off some payload or you can make yourself statically light.

But the danger is then you have to ensure that you are statically heavy to the required value when you come down. So, that is not a safe thing. So, is there any other way? You have to take off with the contracted envelope and as you go up you keep on relaxing the envelope so that the volume increases and you may cut in an airway. In this case, you are talking about changing the envelope volume as you go up allowing more.

But essentially you are changing the shape of the envelope. So, you are saying that fly with an envelope which is folded or contracted and then allow it more and more expansion, but ultimately the envelope will reach some maximum expanded condition I want to go above that what do I do?

"Professor – student conversation ends" So, yes the only way that you have is to throw some lifting gas, no other way.

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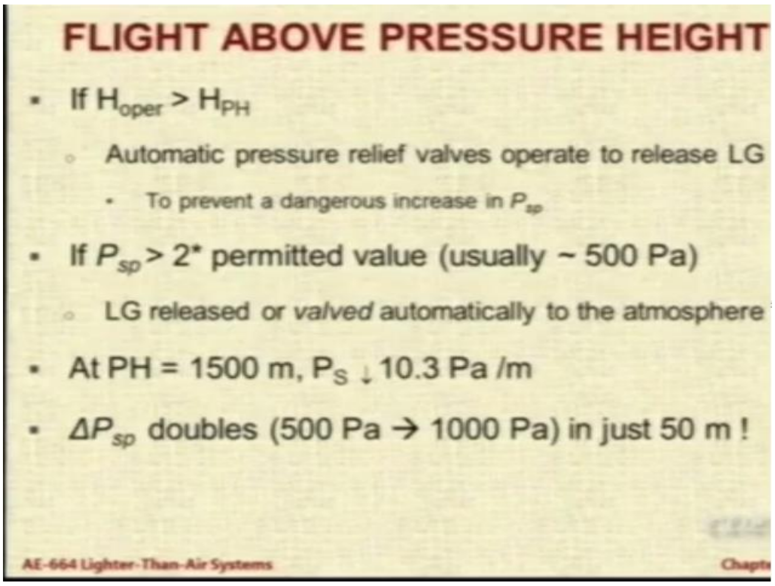

So, what happens in an airship is that there are automatic pressure relief valves. See, the gas wants to expand because the engine pressure is falling and the envelope cannot take it, it will tear. So, the best way is to allow the gas to expand by going out. So, there are pressure relief valves which are automatically primed at a particular delta P and if for some reason the ΔP becomes more than that lifting gas is released.

This is because if you do not do that, there will be a very high superpressure and that can tear the envelope. Now, typically we allow the superpressure or the ΔP values to be approximately 500 Pascals and these valves open when the ΔP becomes twice that, this is a normal practice just for your information. So, it is released or valved automatically. Now, if you are able to get that pressure height of 1500 meters per meter altitude you know that pressure also changes with every altitude.

So, per meter altitude, the change in pressure is 10.3 Pascal and you can only go up to 1000 Pascals. So, what it means is that in 50 meters itself the pressure will double from 500 to 1000 Pascals. So, within 50 meters of ΔH the valve will open. So, you might be able to fly perhaps only 50 meters higher than the pressure altitude before the gas is pumped out to reduce the envelope pressure, right.

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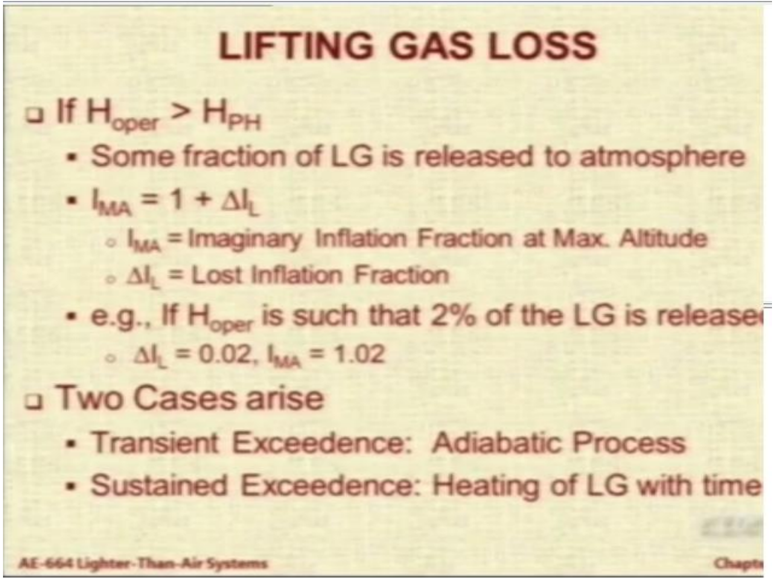

Now, what will happen is that the lifting gas will be lost because valves are opening and the gas is going out. So, let us see what happens because of that. So, let us look at a scenario where the operating altitude is more than the pressure altitude. What is happening there is some fraction of the lifting gas is valved or released to the atmosphere. Now, let us try to find out what is that fraction.

So, what we do is we define something like an imaginary inflation fraction at maximum altitude so something like the inflation fraction is equal to 1 at the pressure altitude, it is lower than 1 at lower altitudes and we go to a higher altitude you have let us say 1.02 or 1.03 it is an imaginary number because it cannot be more than 1. So, this imaginary fraction is equal to the original fraction which is 1 at pressure altitude plus delta inflation fraction which is equal to the ratio of the lost gas.

See you can put it like this, this is something like if the pressure altitude was actually higher so much more fraction would have been needed at the sea level. So, I_{MA} is now the inflation fraction at the maximum altitude which is higher than the pressure altitude and there is this lost inflation fraction. If you can calculate the value of ΔI_L that will give you how much lifting gas has to be thrown out or how much lifting gas is lost.

Yeah, for example you can see here this example this number will help you. Suppose the operating altitude or called as the maximum altitude suppose the maximum altitude is such that 2% of the inflation lifting gas is lost then the imaginary inflation fraction at the maximum altitude is equal to 1.02, one gives you pressure altitude 2% is lost hence that is equivalent to that height which would have got 2% more inflation fraction requirement at sea level.

So, in 90% inflation fraction gives you a pressure altitude of 1500 meters, then 1560 meters would be at maybe 92%. So, that 2% is the imaginary additional inflation fraction. Now, there are two cases which arise. Listen very carefully, this is a very interesting scenario now. You might exceed the pressure altitude only for a momentary reason or momentarily as a transient or you might do it with a sustained manner that means for a very long time you fly.

So, what happens is if it is a transient phenomenon, which happens over a small period of time. So, the process of changes in the pressure and the temperature inside the envelope is an adiabatic process. There is no time for heat exchange to take place. So, we assume that the temperature does not really change a lot, it is an adiabatic process, but if you allow it to fly for a long time then you are giving time for the air to become in equilibrium with the ambient conditions because you are giving time to it.

So, depending on whether it is a transient exceedance of pressure altitude or a sustained exceedence of pressure altitude, you are going to get two different expressions because one process will be adiabatic, one process will not be a adiabatic.

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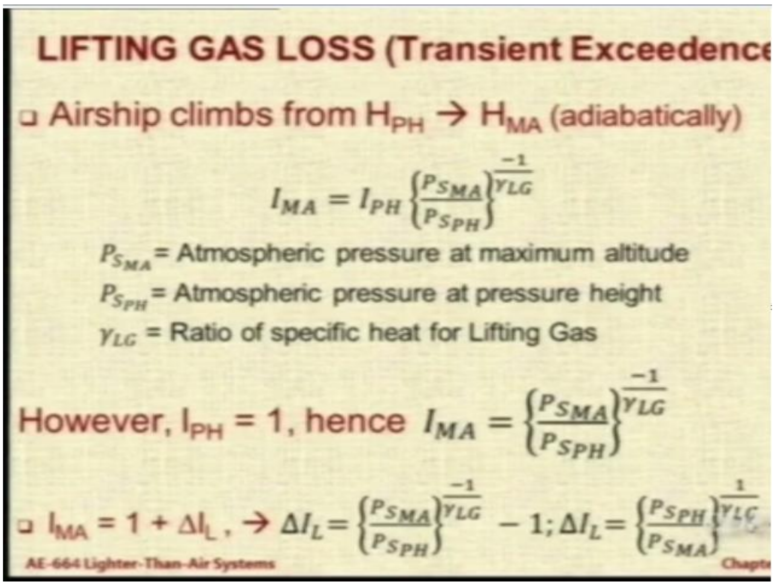

So let us see first a transient exceedance which is an adiabatic process. So, the airship climbs from the pressure altitude to something like a maximum altitude in an adiabatic fashion. So it can be shown, now I am not deriving this expression, but it can be shown that the inflation fraction in this case will be equal to the inflation fraction at the pressure altitude which is 1

$$I_{MA} = \left\{\frac{P_{SMA}}{P_{SPH}}\right\}^{\frac{-1}{\gamma_{lg}}}$$

So, this particular expression comes from a standard adiabatic pressure relationships which you must have learned thermodynamics. From there you can easily assume that the inflation fraction will be related like this and since $I_{PH} = 1$ Therefore, I_{MA} for the inflation fraction for the operating altitude or maximum altitude higher than the pressure altitude.

So, this is one expression which we have to keep in mind. That means the inflation fraction for a temporary exceedance will be the ratio of pressures to the power $\frac{-1}{\gamma_{lg}}$. Now, I_{MA} is basically equal to $1 + \Delta I_L$. So, the ΔI_L can be back calculated as

$$\Delta I_L = \left\{\frac{P_{SMA}}{P_{SPH}}\right\}^{\frac{-1}{\gamma_{lg}}} - 1$$

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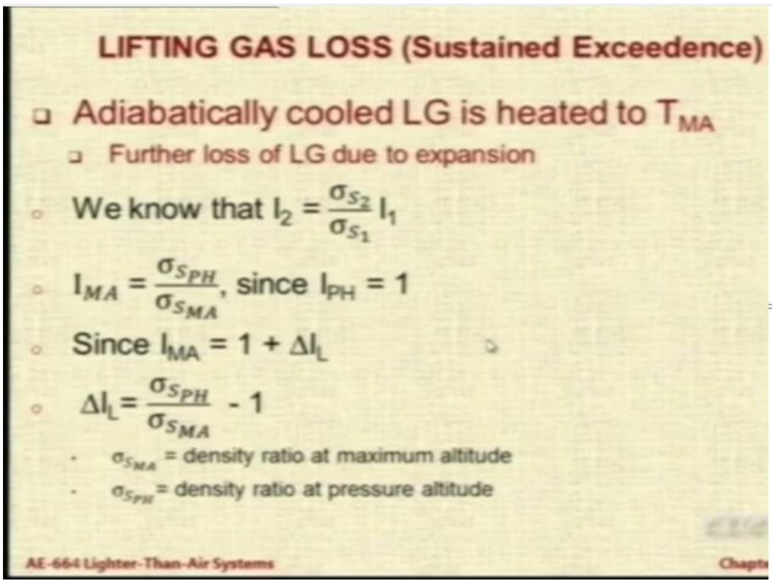

Now, suppose we allow it to fly for a very long time above the pressure altitude, then we will allow heat transfer to take place. We will allow the gas to adiabatically cool. Initially it will be heated, but then it will be cooled and it will be heated to the temperature at that particular altitude. So, now, what will happen, the gas is going to be slowly expand. If it expands there will be further loss of lifting gas.

So, if you allow it to sustain you will find that the lifting gas loss will be larger. We will see that in an example that we will solve soon. So for this we do not worry about the transient phenomena, we look at the final expression. This here we looked at the formula which says that the inflation fraction at any condition 2 is equal to the density ratios upon the initial value. So therefore,

$$I_{MA} = \frac{\sigma_{SPH}}{\sigma_{SMA}}$$

And since $I_{PH} = 1$, so this I_1 will be equal to 1, this will become PH, this will become MA. So once again, I_{MA} the inflation fraction required for the pressure at exceedance is

$$I_{MA} = 1 + \Delta I_L$$

So therefore

$$\Delta I_L = \frac{\sigma_{SPH}}{\sigma_{SMA}} - 1$$

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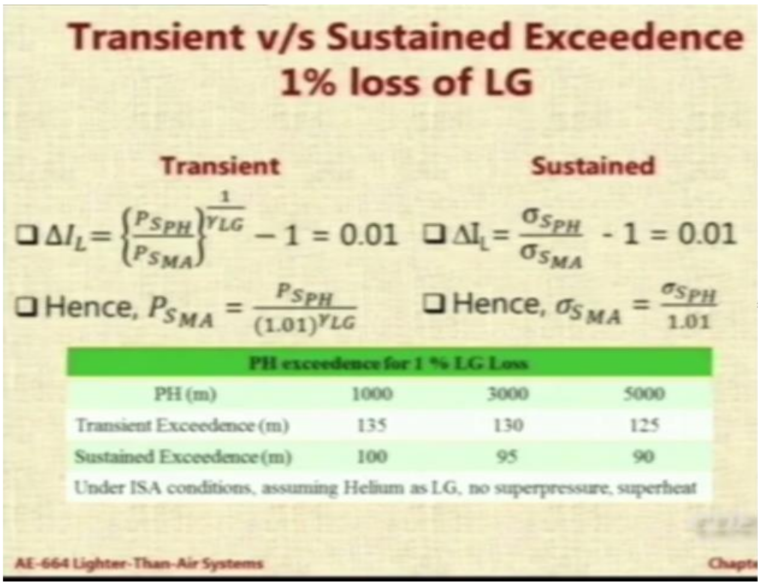

Now, let us assume a situation where you are only exceeding by 1%. That means 1% of lifting gas is lost whether we do it in a transient manner or in a sustained manner. So, in the transient manner as we have just now seen the ΔI_L and that value is equal to 0.01 because we have said there is a 1% change.

So, therefore P_{SMA} or the pressure ambient pressure at the altitude will be equal to the ambient pressure and the pressure altitude upon 1.01 times γ_{lg}. So with this now let us do the following. Let us calculate the values for the transient as well as sustained exceedance for 1% lifting gas assume it to be helium assumed to have no superpressure and no superheat.

So, I want you to calculate these numbers. So, there are two expressions available. What will be the value of γ of helium, 1.67, so try it out. So, first thing is you should know what is the value of σ at the various pressure altitudes. Now see there is something. To do this question you will need to know the value of sigma that means you need the atmospheric tables or you have to calculate the values.

So, I leave it for you to confirm when you go back home, just observe that in a transient exceedance the pressure height is 135 meters exceeding, in sustain it is only 100 meters for a pressure height of 1000 meters. When you are going to higher pressure altitude, the exceedance for 1% gas is less, so a sustained exceedence because of the cooling of the gas.

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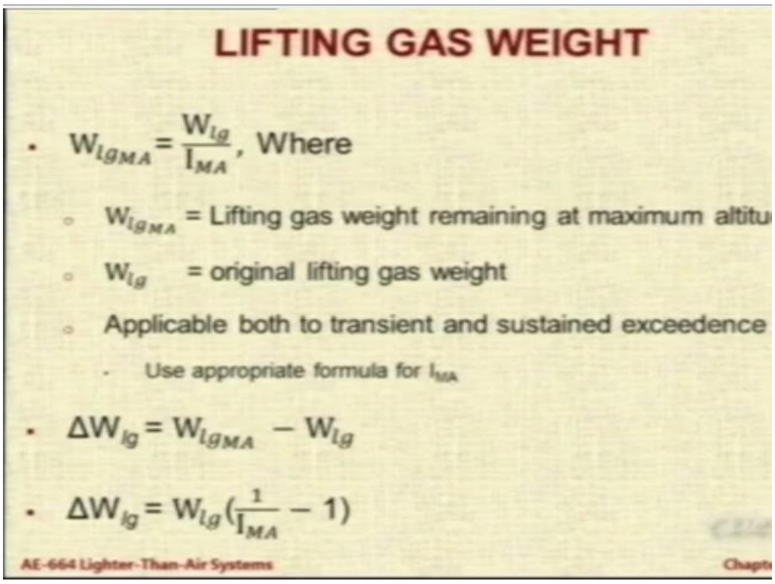

So now let us go ahead. What we also want to calculate is the weight of the lifting gas. So, how do you estimate the weight of the lifting gas? What you know is the percentage loss of the lifting gas, but I am interested in knowing the weight. So, the weight of the lifting gas will be equal to the weight of the lifting gas under the ground conditions divided by the inflation fraction at MA. Because under the ground condition, the weight of the lifting gases W_{lg}.

When you filled it on the ground you fill the gas and you fill the ballonet. So, there was some weight of the lifting gas right and the original inflation fraction was I, I_G at the ground level. So, when you go to the maximum altitude, the inflation fraction has changed to I_{MA}, basically I_{MA} is the percentage, inflation fraction basically is an indication of how much gas is lost.

So, with this you can calculate the weight of the lifting gas that has been lost to reach a particular maximum altitude above the pressure altitude. Interestingly, this formula does not depend on whether you do it in a transient fashion or in a sustained fashion as long as you use the correct value of I_{MA}. The value of I_{MA} will not be the same in both the cases because the formula are different.

So, as long as you use the correct value of I_{MA} depending on whether it is a transient loss or a sustained loss, you can use the same formula to calculate the weight of the lifting gas. Therefore, the weight that is lost is equal to the weight at the end minus weight in the beginning or in other words

$$\Delta W_{lg} = W_{lg}\left(\frac{1}{I_{MA}} - 1\right)$$

So, we calculate the value of I_{MA} using the formula described earlier appropriate to the operating condition transient or sustained and from there knowing where lifting gas at sea level you can get the change value.

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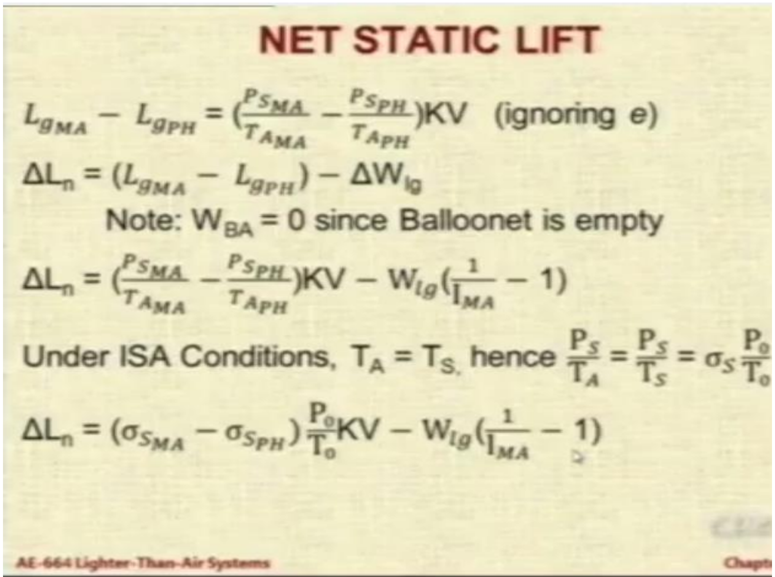

Now, once again I am copying and pasting an old formula about the net static lift. So, the net static lift is equal to the gross lift at the new altitude minus the gross lift at the pressure altitude. So we are now calculating the change in the net static lift when you move from pressure altitude to a slightly higher altitude. So, this will come simply by the ratio of pressure and temperature into K into V, we are ignoring the effect of any humidity.

This is the old formula. So, therefore that ΔL_N change in the net lift will be the change in the gross lift minus the weight of the lifting gas because what has happened is the airship is lighter. It is is lighter because some gas has been thrown out that is W_{lg}. How much gas has gone out, you know from the inflation fraction from the I_{MA} calculations and the rate of the original lifting gas and L_{gMA} and L_{gPH} are available using standard expressions for gross lift.

So, in normal circumstances, we also consider the weight of the ballonet air, but the ballonet is empty in this case. Therefore, the W_{BA} has been ignored. So, therefore one can say that

$$\Delta L_N = \left(\frac{P_{S_{MA}}}{T_{A_{MA}}} - \frac{P_{S_{PH}}}{T_{A_{PH}}}\right) KV - W_{lg}\left(\frac{1}{I_{MA}} - 1\right)$$

So, now everything is known to you in this expression from a pressure altitude to maximum altitude higher than pressure altitude. The value of P_S T_A is known to you from the atmospheric tables. The value of K if you recall is a constant depending on the lifting gas, V is the volume, W_{lg} is the lifting gas weight on the ground value that also known to you from the inflation fraction into the type of gas.

So, with this you can calculate, now use the correct value of I_{MA} whether it is a sustained or transient increase. If you are operating under ISA conditions, then things become simpler because then the value of T_A will be equal to T_S. So, when you put that in the expression it becomes much simpler.

The ratio is changed to the density ratios and then you get P_0 T_0 as a constant value and K into V minus this expression. So, now I think this formula is what you should note down because we will require this in calculation in the near future. So, the change in net lift is equal to under ISA conditions the change in the density ratios. So, $(\sigma_{SMA} - \sigma_{SPH})$ and density ratio at the maximum altitude minus density ratio at the pressure altitude into P_0 by T_0 which are constants.

$$\Delta L_N = (\sigma_{SMA} - \sigma_{SPH}) \frac{P_0}{T_0} KV - W_{lg}\left(\frac{1}{I_{MA}} - 1\right)$$