Lighter-Than-Air Systems
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Lecture - 78
Statistical Data Used in Airship Design Methodology

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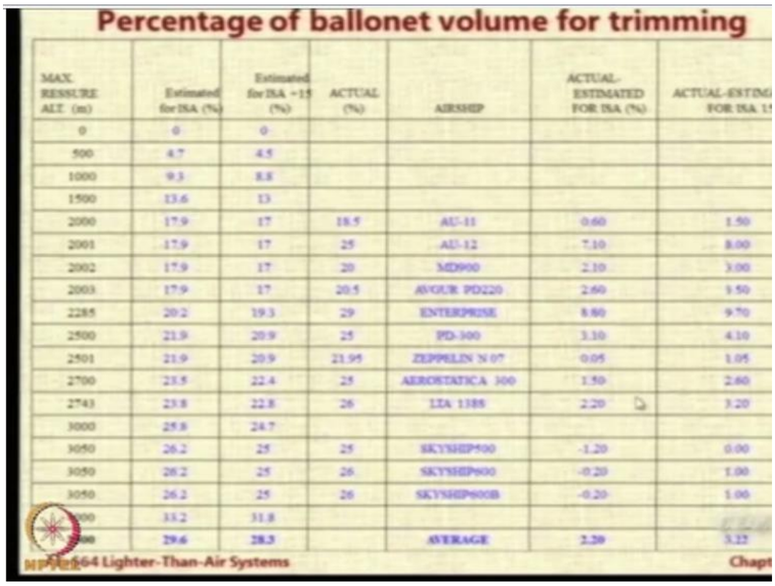

Percentage of ballonet volume for trimming

MAX. RESSURE ALT. (m)	Estimated for ISA (%)	Estimated for ISA +15 (%)	ACTUAL (%)	AIRSHIP	ACTUAL-ESTIMATED FOR ISA (%)	ACTUAL-ESTIM FOR ISA 15
0	0	0				
500	4.7	4.5				
1000	9.3	8.8				
1500	13.6	13				
2000	17.9	17	18.5	AU-11	0.60	1.50
2001	17.9	17	25	AU-12	7.10	8.00
2002	17.9	17	20	MD900	2.10	3.00
2003	17.9	17	20.5	AVGUR PD220	2.60	3.50
2285	20.2	19.3	29	ENTERPRISE	8.80	9.70
2500	21.9	20.9	25	PD-300	3.10	4.10
2501	21.9	20.9	21.95	ZEPPELIN N 07	0.05	1.05
2700	23.5	22.4	25	AEROSTATICA 300	1.50	2.60
2743	23.8	22.8	26	LTA 1388	2.20	3.20
3000	25.8	24.7				
3050	26.2	25	25	SKYSHIP500	-1.20	0.00
3050	26.2	25	26	SKYSHIP600	-0.20	1.00
3050	26.2	25	26	SKYSHIP600B	-0.20	1.00
[illegible]	33.2	31.8				
[illegible]	29.6	28.3		AVERAGE	2.20	3.22

So, the statistical data established to answer specific questions. One question is how much should be the ballonet volume to meet the trim requirement over and above the requirement for the pressure altitude correction. So, what we did is first we tried to arrive at a theoretical formulation using the formulae that we discussed. Then we collected data of various airships. You can see this AU-11, 12 MD these are all airships which have either been designed or they were somewhat underdesign.

And the data was available in reports, websites, papers, etc. And we said okay assume our theoretical calculations and look at the data actually available, now the same information here. So, I just wanted to look at this line which says that for a height of three and a half thousand meters, which is what we are expecting the airship to operate, the estimate ballonet percentage was 30% and received 29.6% and the average value of all these is around 2.2%. So, therefore we said let us take it as 2%.

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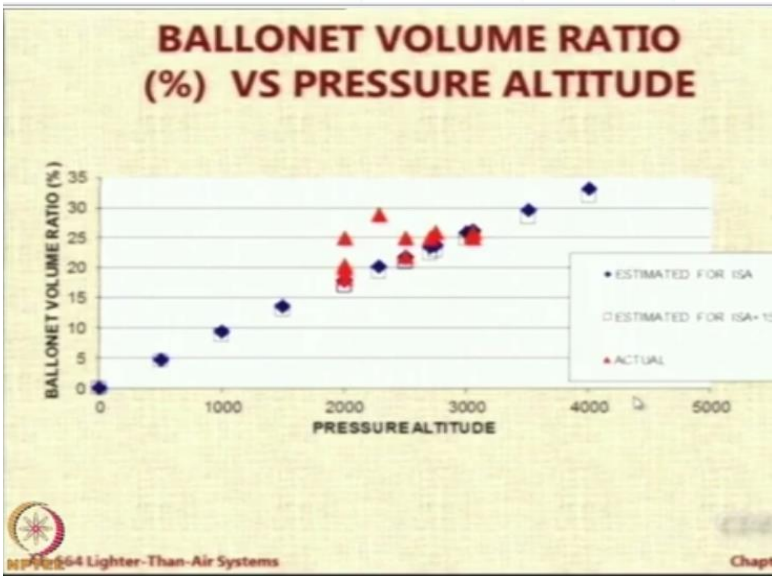

The same information that you see is projected now in a graphical form. The red triangles are the points corresponding to the actual ballonet volume ratio as published by them in the reports versus their pressure altitudes. And the blue dots and the open rectangles are the mathematical estimates using our formulae for the ballonet percentage needed with pressure altitude for either ISA conditions or ISA + 15 conditions.

So, we noticed one thing that the numerical value of the ballonet needed is not too high if it is ISA + 15, which means temperature does not play that much of a role. It is the altitude which plays that much of a role because of the pressure loss. And we see that the red dots some of them have higher than what we need, some of them are trying to follow on the trend line that we got. So it is a very encouraging result for a person doing this work for the first time, which is what we were.

We had no prior experience of working on airships. When we plotted our theoretical lines against the actual red dots, we were very happy to see that the trend that we have got is somewhat relevant. However, some airships you can see have far higher ballonet percentage than what we expected. So the reason for that is the technical requirements, the mission profile are not released by companies for public consumption.

So we are assuming that they go from sea level to a height of 2000 or 3500. But they may be going from some altitude to some other altitude we do not know. So that is why actual practical data will never fit perfectly along the line, but the trends are very encouraging. So this gave us some confidence that we will be able to capture roughly how much is the percentage ballonet needed for a particular operating requirement.

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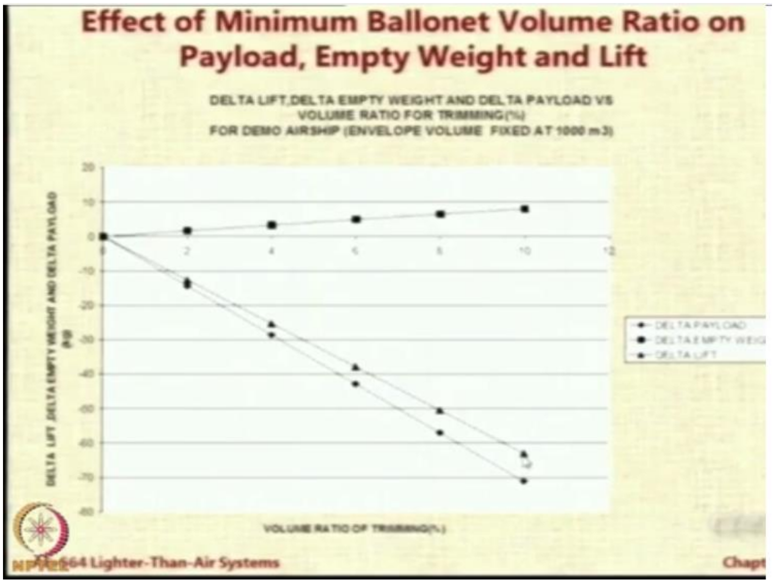

Then we wanted to also investigate what is the effect of the ballonet volume ratio on payload. Suppose I am making more than needed that means suppose I make a larger ballonet than needed, what is the big deal? If you make a ballonet larger than needed, first of all you have extra dead weight. So there was you who did the calculation do you remember the numerical value of difference in weight between an integral ballonet and what do you say spherical ballonet?

How many kgs do they affect? Some of you answered the question, In fact one student uploaded within 15 minutes or 20 minutes of the lecture. That means he went home to the hostel and did the calculations, scanned it and put it up, very nice, that is very good. So what is the numerical value?

“Professor – student conversation starts.” 20 kg lighter, 21 kg lighter. So I think somebody said 50 kg lighter. So, yeah the numbers can be checked, but even if it is 20 kg lighter is 20 kg for nothing. **“Professor – student conversation ends.”**

So, just for a little bit of manufacturing ease will you go for 20 kg heavier airship? Imagine that means you can have 20 kg more payload authentication more fuel compared to what you can have with integral ballonet. So, similarly empty weight will be more because you have a bigger ballonet for no reason.

Now if the ballonet occupies more volume than needed it will also give you a problem with the lift. So, here is the output of our analysis. So, the line on the top with dark rectangular boxes indicates the change in the empty weight in kilograms. So if I have 10% extra ballonet. Now why do you want to have more ballonet other than the pressure height requirement? Why should you even think about it? Not even 1% why should you have more than?

You know that ballonet is need basically for the ability to provide you the delta H pressure altitude from ground altitude operating altitude, right. Larger the difference more will be the ballonet volume needed. But suppose that number is 20% should you have more than 20%? For what? Recall our discussion from last time. For trim conditions. So, you should need something more for trim conditions.

Because you can also use if you have 2 ballonet front and back you can also use them differentially to provide trim and that trim can reduce drag during flight a lot. Now, how much should we give? Correct, no, I just told you that we have used 2%, but here is the logic and justification. I can use it 10%, 8%, 6%, 2%. I saw that as long as I go up to 2%, so I have this see this particular figure tells you how much is the change in the empty weight.

So, up to 2% ballonet the empty weight change is only about 2 kg approximately. But if I have 10% ballonet it becomes almost like 8 to 9 kg. This is for the demo airship, the small airship that we designed with the envelope of 1000 meter cube. But look at these two lines which indicate the change in the payload, which is the rhombus and change in the lift which is the delta or the triangle.

So, we see that if you accept up to 15% or 15 kg difference in, not percentage 15 kg, percentage nahi**,** 15 kg difference in payload and 15 kg in the lift, then 2% is the limit. Beyond that there is a drastic reduction. So, I can give more ballonet, I can give 10% more ballonet. let us have more margin for trim, but the penalty I pay is 8 kg in the empty weight and around 70 kg in the lift and around what 65, 52, 64 kg; 64 kg in lift and around 70 kg in payload.

So, my payload capacity was only 77 kg and I would compromise 70 kg of that in giving extra ballonet, so you have to be very careful. Percentage ballonet should not be too much additional. So that is why we said okay we will keep 2%. We also confirmed that most airships have around 2%. So it is a double reason based on what others have done and the confirmation that more than that is going to be very harmful.

So design decisions are normally driven by analysis results. It cannot be and should not be arbitrary, right. Now, there is another small contribution that many people have used and that is, so you have this question always I decide the envelope shape, now should I do a detailed stability analysis for every shape I investigate to find out the area of the fins that is actually too much of an overkill for conceptual design.

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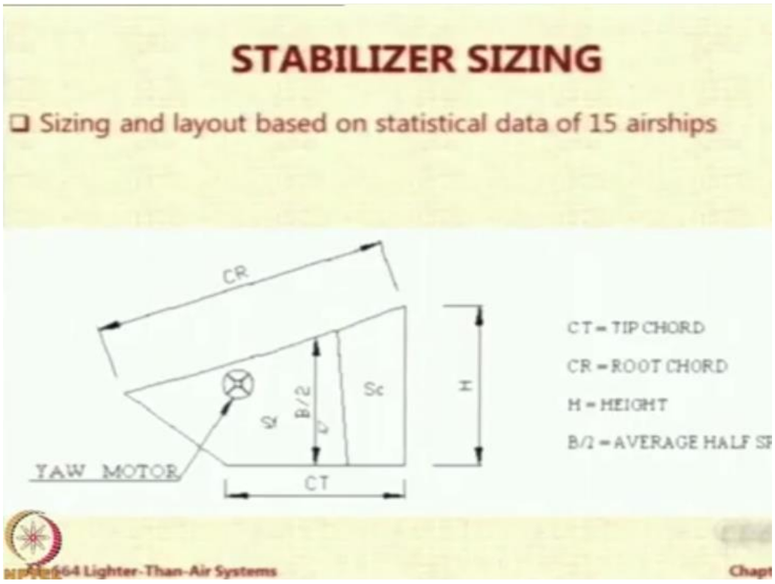

So, what we did is we just looked at the statistical data. So the logic is that if 30-40 airships which are flying have fins located at some place or some proportion from the nose or some area, we also should not go too much away from that. We should not give too less or to more than that. So, what we did is simple analysis of statistical data. So, we parameterize the geometry of a fin in these standard symbols.

So, there is a root chord, tip chord, half span, area of the control surface that is S_c deflectable area, S_f is the area of the fin which is the fixed portion, the total area will be S_c plus S_f. This is the height which is equivalent to the, I mean this is not exactly equal to the half span because half span is a function of the geometry and this is the tip chord. So, there will be a taper ratio for the fin. There will be aspect ratio for the fin.

There will be area ratio. Now if you were doing this analysis, I want to get from you how will you obtain a correlation or what will you use as a correlation parameter for the area of a fin?

So, you have data of n number of airships and you want to develop a correlation so that you can size the fin of your airship. How would you proceed? What geometrical parameters of the airship will you take for scaling up or scaling down? Is the problem clear to everybody?

You have geometrical data of n flying airships. By that I mean you have the envelope diameter, envelope length, envelope surface area, you have the fin area, number of fins are all 4 for everybody. Let us assume all of them are plus fins. So, you know their fin areas and all that. You have now a new shape or some shape, you want to estimate what will be the fin area that I will need for my airship. What will you do?

Let us see if you can think like a designer. So, normally what people answer is I am going to calculate the center of buoyancy, center of gravity, calculate the moment arm acting, calculate if the moment that is generated by the control surface is matching with what is needed. But that means you will do a basic stability analysis. You could do that. But there will be so many imponderables there. Is there a simpler way of doing it and still not being too much away from reality?

So, let us think and let us see if you can suggest a solution.
"Professor – student conversation starts." Sir there is a change in surface area ratio of fin and envelope. Okay. So, what you will do is you will find the ratio of area of one fin upon envelope surface area for all these airships, right. All fins, yeah all. So, each airship fin area upon its envelope area is the ratio. Then what do you do? Sir I took the estimate of area is known. Provided this number is somewhat same for all.

So interestingly we did the same thing and we tried to find a correlation, right. So that means you are saying that the area of the envelope decides the area of the fin. Somewhat. Somewhat, yeah you are right. **"Professor – student conversation ends."**

We did the same thing. In reality it would only be the side area of the envelope. Because you take two airships of the same volume, one spherical and one longish one. The longish one will require smaller fins because they are farther located.

So the moment arm will be smaller. A sphere would actually need a long stick and then a big area so that you can get some momentum. But that we thought was now our airship for all axisymmetric bodies with large l/d. So we said anyway the side area will be a function of the envelope area only. So we did the same thing as you said, just divide and obtain the ratio.

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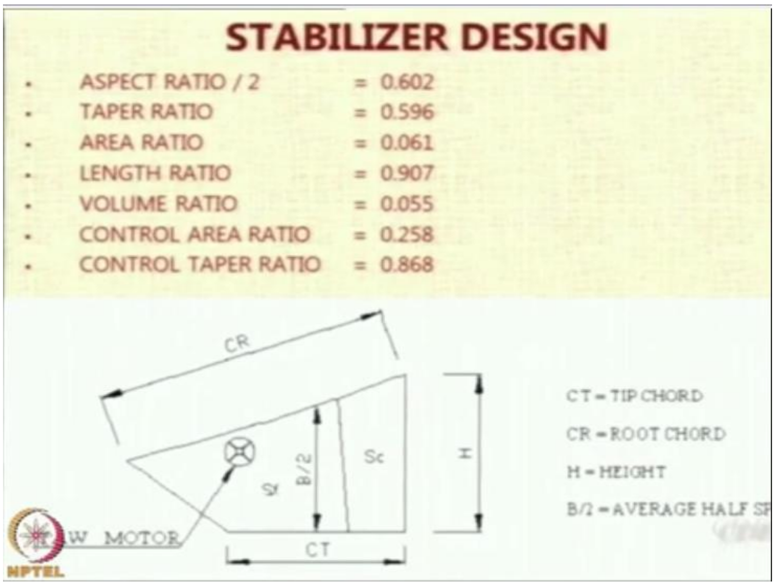

Similarly, we did the same thing for other parameters also. Find the tether ratio of all these airships. You find it will be 5 and 6; 5.29, 5.73, 5.63 like that. Take the average of that. Typically it came 0.596**.** So what we have done is looking at the statistical information for many airships, we got these ratios. And you will be surprised that these ratios are now being used by many people all around the world to size fins. Many people have quoted our paper and said the main thing we have taken is the sizing of the fin because it is a big headache to do a stability analysis.

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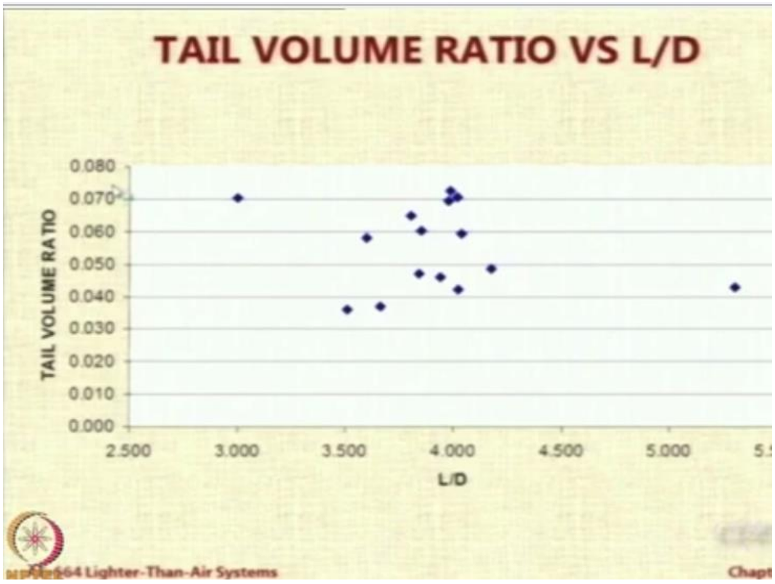

Then we thought this tail volume ratio, do you know what is tail volume ratio? How do we do the sizing of the aircraft vertical tail, horizontal tail. We defined something called as the tail volume ratio And that tail volume ratio apparently is in a very small band for aircraft. So, what is tail volume ratio? It is the ratio between two multiplicative terms for the aircraft.

In the numerator you have the distance between the aerodynamic center of the wing and aerodynamic center of the tail is called as a tail arm into the area of the tail divided by the mean aerodynamic chord C. So, like that you can create certain ratios from geometrical data, For airship we found that there is a huge spread between the tail volumes. So, we could not take a tail volume ratio as a fixed number because if you can see from three to l/d equal to five and a half.

It spreads from 0.03 to 0.07 more than double. So, there is no great correlation, so we could not, we will take some number and go with it.

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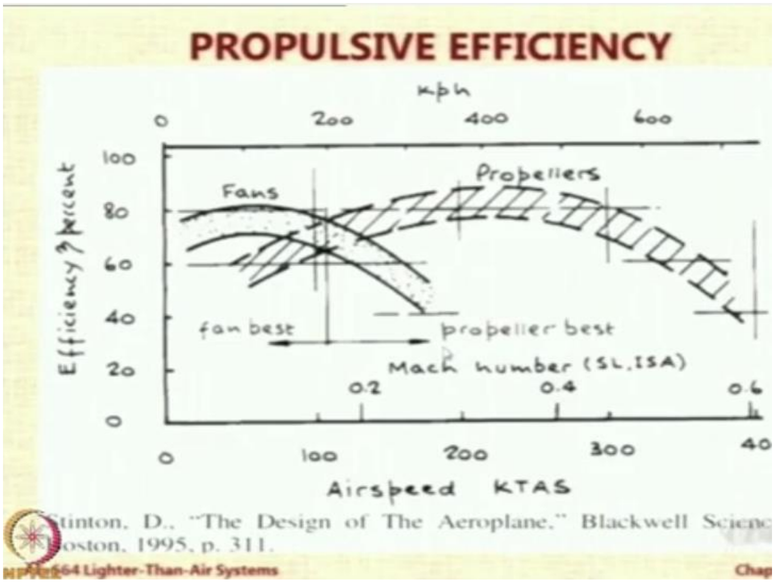

What should be the propulsive efficiency assumed for an typical airship mounted engines. So, for that I got some data about general aviation aircraft from the book by Stinton. So, he has given this particular chart which relates the propulsive efficiency eta with the airspeed and he gives it in kilometers per hour in the top and in knots in the bottom and also Mach number. So, what he says is that the total propulsive efficiency of fans never goes beyond approximately 80-81%.

Propellers can have up to 85% also, but there is a band in which they lie and propellers or unducted propellers are useful if your Mach numbers are approximately beyond 0.2 or speeds are beyond 200 kilometers per hour which we will never achieve in an airship. We will actually hit the maximum at 90 to 100 kilometers per hour, perhaps 120 kilometers per hour that would be the top speed you will go. So, we learned that it is good to have a ducted fan, fans are better.

The efficiencies may be slightly lower compared to the peak efficiency of the propeller, but they are much better. So, he himself says that fan is the best for speeds below this and propeller is the best for speeds beyond this. So, with this information we said okay we will use ducted fans if possible, but as I said ducted fans are going to be heavier as well as they will cost more, but they are safer. So, operationally they are better, safer and they are also having better efficiency.

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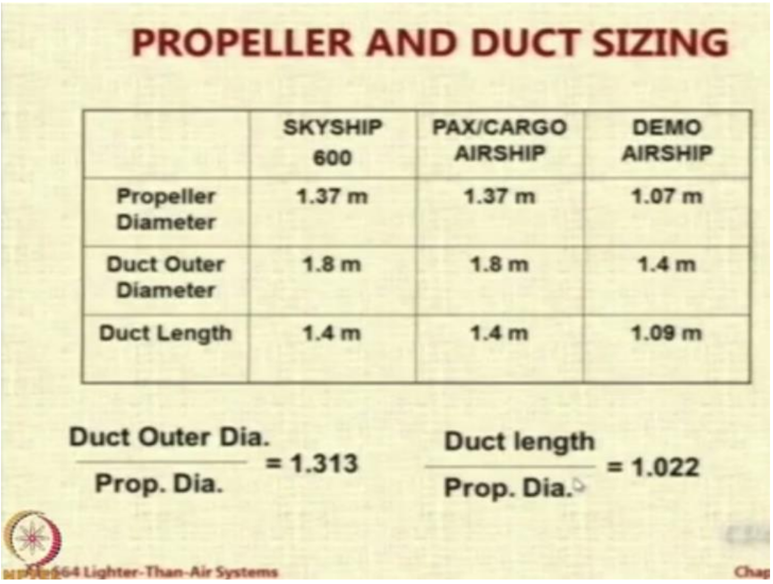

So then looking at the data of some existing airships like Skyship 600 was in front of us as a baseline airship. We got the propeller ratios by, so these are some correlations for you to be able to size the airship with the requirement. Now there are many more things, but I have left them out because they are too detailed and of course the papers have been already uploaded. On our Moodle page, this morning I uploaded two papers.

One is the conference paper which was written in 2003. And the next one is because the paper got heavily referenced and many people want it to be publicly available, I got several requests from people all over the world asking me to mail the paper. So then we actually wrote a technical note in Journal of Aircraft in 2008 after correcting the data and making a few changes.

So both the papers have been uploaded onto the Moodle page and it is important for you to note that they are not there just for fun, they are part of the course notes. So I expect you to understand everything that is mentioned in those papers. I expect you to be able to use the formulae, not mug up, but as a reference material paper is available, you should be able to use them procedure and format to do the calculations. So read them very carefully.

I thought it is very futile for me to copy and paste the formula from here and show it to you. You should do some self-reading. This is a Master's course, so you should do some reading on your own. And we have the Moodle page for clarifying any question that you may have. So it is very important and very desirable that you should read those two papers carefully. I want you to learn how to read technical papers and extract useful information. If you find any mistakes or errors, you should bring it to my notice.