Lighter-Than-Air Systems
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Lecture - 80
Envelope Shapes for LTA Systems

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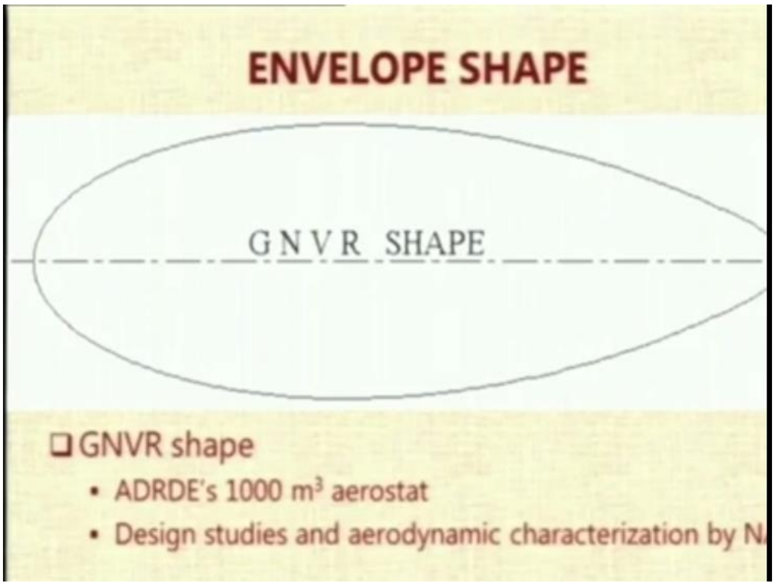

Now some idea about the envelope shapes. First question is why is the envelope shape important? **"Professor – student conversation starts."** What does it affect? Drag. One is the drag. So what would you like to have? A shape with low drag, right? Yeah. A better aerodynamically shaped envelope. What else does a shape affect? Maximum dimension along the length and width and height will be decided by the shape once the volume. Correct.

So a shape that you choose decides the storage space, the hangar, and the clear area required to operate. If you go for spherical you will have the least height and the least width for a given volume. You cannot play with the volume because volume decides the buoyant force, density difference in volume. So, the best shape from the point of view of size is spherical, but very poor drag characteristics for sphere.

Anything else is affected by the envelope shape? The location of CG. The location of CG, how does it get affected? So, the location from the nose would not be at the center of the length, it will be maybe slightly forward okay. Then central buoyancy. Central buoyancy will be at the center of volume. Yeah but then that depends, which would also be slightly ahead of the halfway mark because it will be more towards the front as you can see in this shape, agreed.

So, that case that affects the trimming, but you can locate your tail appropriately. Something more fundamental. Remember that, sorry, surface area. That is a big killer. Sphere is preferred because sphere has the least surface area for a given volume. And the most lengther you make it you may get better aerodynamics. But you need more area not only to store it, but it also weighs more because it has more surface area. Anything else? Volume is fixed.

Shape is changing between sphere and a long one. What else will change? Dynamic lift. Dynamic lift yes will change because that depends upon the C_L and C_L will be different for spherical and what else? But dynamic lift I really do not bother too much because at max it is 15% of the total and I need to be able to cater to operate without dynamic lift anyway. So that is a bonus, but yes it will matter. Anything else will matter?

How about stress in the envelope? What will that depend on? ΔP inside and outside. Yes, ΔP inside and outside. Let us say I fix that number. Why should I have more pressure for sphere and less for a oblate, you can have the same. So yes, pressure inside how much it will be more than outside will determine the stress. Other than that? So let us say that P is fixed. Is the radius of curvature along the distribution edge must be affected if we have very sharp corners.

I know but we do not have sharp corners. In an inflatable structure you cannot have sharp corners. But anything that is if the radius of curvature should be as larger as we cannot get it. Yes. But if the envelope is inflatable and if you start filling it, it will automatically acquire a smooth curvature. **“Professor – student conversation ends.”** You cannot say that it will be very difficult for you to make very sharp change in the curvature if it is inflatable. It would not allow you.

It will get more stressed at that area. So you have to put more material there to strengthen it which will of course increase the weight. How about hoop stress? It depends mainly on the pressure inside which is constant, then maximum diameter, thickness will be the same because it is the same material, so diameter. So, if you use maximum diameter if it is reduced, you can reduce the hoop stress. So, the shape optimization of the envelope.

One more thing is the weight of the fins of the control system. If it is slender as I said you can put a very small fin far away, a smaller fin far away will give you the same moment as compared to a larger fin on a less slender shape. So, there is flight dynamics or stability, there is structure, there is weight, there is aerodynamics that is why we have done an M.Tech project on shape optimization of envelopes keeping in mind all these multiple considerations.

So GNVR shape is one standard shape. This was suggested by a professor of IISc, Bangalore called as GNV Rao. That is why it is called as GNVR shape. And this shape has been suggested by Professor GNV Rao for aerostats used by ADRDE in Agra. All aerostats use this particular shape. And NAL has done a lot of windtunnel testing, CFD analysis about this shape, so the data is kind of available.

It is not a very good shape for airships. It is a very good shape for aerostats. So now my question to you is what do you think is the principal difference in the aerodynamic considerations between airships and aerostats? Or why would a shape like this be good for aerostats but bad for airships or not so good for airships? Remember aerostats are designed to remain stationary, airshps are designed to move. So this is a question for Moodle.

A question for Moodle, think about it. You will not probably get the answer on some website by searching, you will have to apply your mind slightly. Interestingly, there is a paper by professor GNV Rao on modified GNVR shape suitable for airships. It is a very small paper, 6-7 pages in which he argues that in the same GNVR shape, now what you do is if you do a simple Google search on modified GNVR shape, I am sure you will hit into one of our papers.

There is a dual-degree student called Ravinder Joshi. He did his dual-degree project on an interesting topic on knowledge based engineering design and for that as a sample he used this. So he has described the modified GNVR shape in his paper. Basically, what GNV Rao said is put a constant diameter portion if possible in the center of this shape, extend l/d value to 4.5 it will become a good shape for airships.

But what we did is we said that for demo airship we will stick to the shape just because we had aerodynamic data for it, just because we had its coordinates and just because it is a well tested shape. It may not be superefficient for airships, but what the hell let us go with it.

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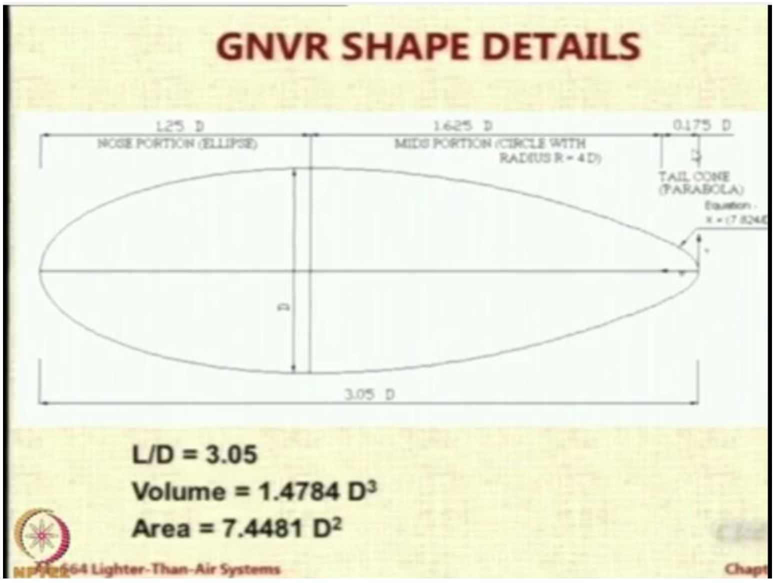

Now, what is so special about this shape? So, first I want you to just look at this particular picture and try to get a hand. See this is the genius of a person who has experience picked up by years of aerodynamic analysis and experiment. Try to understand the contribution of professor GNV Rao in giving this particular shape. First thing that comes out is that this shape consists of three standard geometrical constructs from the max diameter forward it is an ellipse, with the semi minor axis is equal to 1.25 times diameter.

So, if you know that it is an ellipse and if you know that the semi major axis is 1.25 times diameter you can easily generate the coordinates analytically from nose to the max diameter portion. On the rear somewhere here the last 17.5% times of the diameter it is a parabola. Now, why a parabola? Because he was told by the scientists who make aerostat envelopes that a parabolic shape is a good shape to attach the fins.

This is just an input from a user saying that you can give me any shape on the back, you can make it straight line but it would not remain straight line it is an inflatable structure. You can give me high curvature, but that will be bad as it may had been pointed out. So, they said that if the tail cone is parabolic it kind of remains rigid and we are able to mount fins easily. So, he gave the last version as parabolic and he gave an equation for that.

In between these two he fitted a circle or an arc of a circle. So, 1.25 times dia from nose is an ellipsoid shape. Mid portion is circle with radius r equal to four times diameter and the rear part is the tail cone parabola which is 0.175 times diameter length and these numbers 1.625, etc. they have come by intersection. So, geometrical construct where will it intersect if it is four times diameter radius.

Interestingly behind the maximum diameter, the slope of this particular shape is something like 1 is to 7 roughly you can make out or you can cross check it. So, it is what? 1.8 times diameter. So, through windtunnel testing and through experience of aerodynamics of bodies professor Rao knew that if you give almost 1 is to 7 times.

You know if you reduce the diameter 1 meter in 7 meters, you get a nice shape after Max diameter from academics point of view from the flow behavior point of view or separation point of view. Interestingly, the complete coordinates of this shape can be obtained analytically in terms of diameter. If I say GNVR shape of diameter equal to 1 meter, I do not have to say anything else.

All of you individually can get the exact coordinates of the shape from nose to tail that is the beauty. Not only that you can analytically calculate the volume and area in terms of diameter. So, how easy it becomes, just multiply the diameter cube by 1.4784 you get the exact volume of the shape. You multiply diameter square with 7.4481 you get the exact and this number will not come from top of the head or from any numerical integration, this will come from analytical information. So, they are exact.

So, this is for you on the Moodle page to upload. Take the shape, do an integration analytical and confirm that you can actually get. So, what will be the equation of the ellipse? It will be you know

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

with a and b related with diameter. Similarly parabola, already equation is given. Similarly, the arc of a circle, r = 4. It will be very interesting for you to do it and just do an integration.

I did it myself and I confirmed. And when I see sufficient interest, I am going to upload the solution also for your information, but not right away, I do not want to spoon feed you. Do it yourself, struggle a little bit and you upload your calculations or your results. Eventually, I will give you the correct calculation. So now the length upon diameter ratio of this shape is 3.05. It is a very popular shape and we have also used this shape for aerostats as well as smaller airships.

In fact the first airship that we made the one which I showed you called as a microairship it had this particular shape. Admittedly it is not good for airships, but it is a convenient shape to work with. When you work for the first time, you always work with known and established geometrical information. The first UAV that you make is somebody else's design. You do not start sizing and doing the calculations, every time you do something. You do it once, get it right, get the hang of it, then you can say I can improve it now that is how we also did.