Performance of Marine Vehicles at Sea

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Lecture No. # 13
Introduction to High Speed Crafts Part – II

We will start with resistance of high speed crafts, how it changes with, as the speed increases? We have seen that at about a speed of 0.357 you get third hump by a simple calculation, it may not be exactly 357, but linear about that, and we have seen that as the speed increases further as we go to 0.4 or so, the speed or the wave resistance forms a barrier, resistance becomes so much that it cannot overcome it in displacement mode and go further. What happens?

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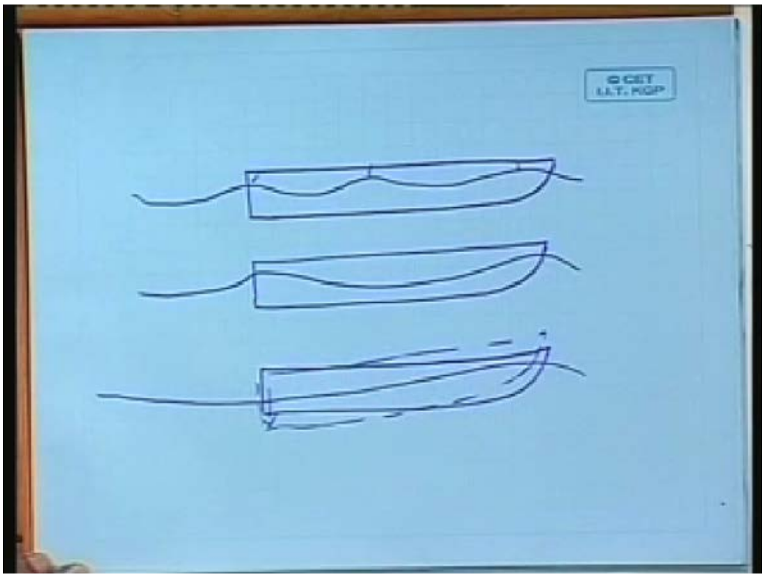

Let us look at the wave making of a ship. We have seen that at low speed there may be a number of waves, transverse waves- these are the transverse waves humps- as the speed increases the wave length increases and you may get a speed at which wave length is equal to ship length, this should normally work about this 0.357 Froude number or there about. And then, if you still increase the speed, then the wave will become bigger, wave length, transverse wavelength will become bigger than the ship length and it will become like this that means, there is only one bow wave, what is the effect, what is happening here? You see, there is high pressure here and low pressure here because of the trough, buoyancy is very little in the aft side; if you remember, the conventional stern of a ship, the buoyancy as this draft reduces at the stern, the buoyancy reduces drastically, but the weight is there, so the vessel would sink, the stern would like to squat.

So, what will happen to the vessel is, vessel will go like this- do you understand what I am saying?- the vessel will trim by stern, the stern will keep going down so that, so, the drag will increase tremendously because the vessel is not designed with a half trim- do you understand that?- the vessel will sink and trim heavily by aft. So, physically this is what will happen. You might have noticed that even in normal merchant ships of high speed type such as LPGs and passengers vessels if you have moved, if they go at high speed, a Froude number of about 0.35 or so, you will find there is a squat on the stern side, so the vessels starts sinking at the stern and it is unable to climb up anymore, so, as if the vessel is facing a barrier and it cannot come out of it.

So, what we do to reduce this effect as the speed increases, not beyond 0.4, but even towards 0.4? We tried to make the stern fuller at the lower level so that even if it squats there is still adequate buoyancy available at the stern, so, stern starts becoming fuller; if you remember in the normal merchant ship forms we like to close the stern smoothly, but here is the case when you want to make the stern fuller, so, slowly we go for providing a transom stern right till the bottom- unlike the ships when you provide a transom sterns only more or less near the weighted, near the free surface, closing it at the free surface- here underwater portion we like to make it fuller so that we get some buoyancy at least so that the squat can be controlled.

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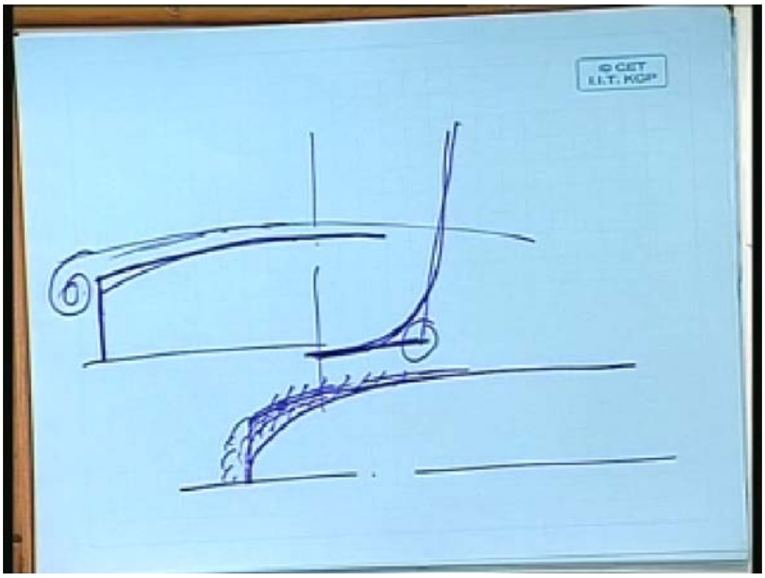

And as the speed increases in round bottom forms- round bottom means vessel's cross section of which is round, these are the round bottom boats- the stern starts becoming fuller and as the speed increases further and further because of the flatness of the bottom you start getting lift- do you get what I am saying?- so, as the speed goes beyond 0.4- more or less around 0.4 is the limit which you cannot cross in purely displacement mode- so, if you try to move a vessel at higher and higher speed with certain flat bottom coming up, certain flatness in the aft side of the vessel coming up because aft is trimming now then, the vessel start experiencing lift at the second half of the portion, not the first, not at the forward side, but on the aft side.

So, there is a lift force coming on the aft side which will give a slight trim to the forward that is, it will try to balance the trim by which the stern has started sitting- am I clear? So, the vessel will adjust its trim to have a very low trim by aft typically about 3, 4, 5 degrees so that the angle of attack, we have seen the angle of the vessel is moving this way the water is coming like((No Audio from 7:07 to 07:11)) lift- we have seen in last class only- so that small angle of trim is essential 3, 4, 6 degrees so that the water comes and it generates a vertical lift- so, that is how the vessel stars rising. Now, in a round bottom boat what else happens?

Let us look at the water plane of such a boat, somewhere near the water line. Water plane, we have closed like this, we have now increased the area here, so this water line will become something like this- am I understood? Now, there is a curvature starting from somewhere here and going all across till here, so, as the water starts flowing past, we have seen there will be starting of eddies here because of the large curvature, there will be large separation coming up starting from somewhere near the aft till the complete aft- am I understood? So, you have a large drag increase due to separation, you get lift, but lift is limited to the flatness of the bottom because the vessel is rounding up- you do not get the lift due to the complete breadth of the ship that is immersed because it is rounding up.

So, we get some lift, the vessel starts rising, but the drag severely increases as we increase speed because there is a separation over a long distance, long separation starting from somewhere in the aft region till the complete aft. So, what is the next step? If I still want to go further, I want to increase speed further, I must generate more lift and I must try to reduce torque; so, to do this the next step is if I can have a water plane which is like this, then what happens, or even like this flat, there is no curvature coming up here, so there is no separation here, the water will flow nicely here to the boundary layer, but suddenly they will get drop here, so there will be large separation coming up here- do you understand? So, what I would do, what I have done in this process is I have reduced this zone of separation to a very well defined separation point, all separation will take place at the transom only, there will be no separation before that or forward of that.

So, if I want to generate more lift I require to provide- you look at the bottom section, now- I require to provide more flat area and therefore, my vessel will come down like this- if I can avoid a curvature here, then I get more flat area which will give me more lifting surface therefore, more lift. And the transom I will make like a transom, the stern I will make like a transom and this also will come and cut like this; now, ultimately, you have a section shape which has a chine line and a sharp section shape with a line of discontinuity which is called a chine line- I will show you the diagram here.

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((But for the propeller called as there we have to come down.))

I will come to propeller in this way.

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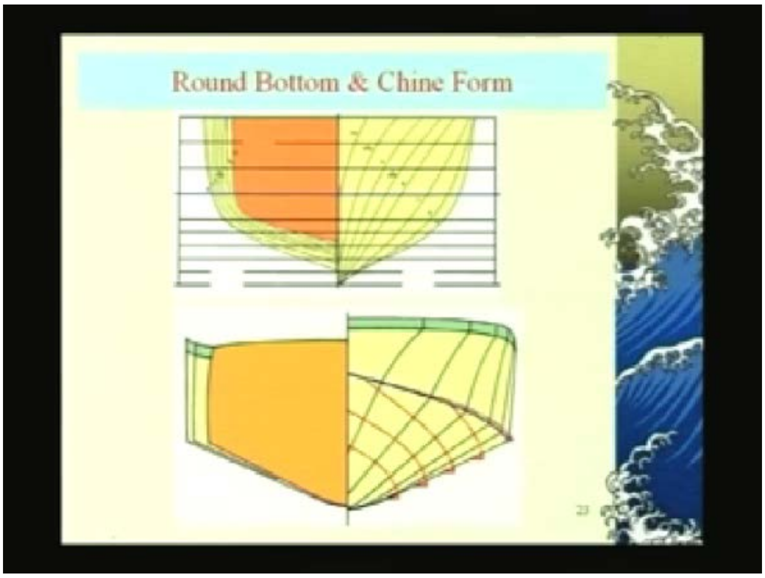

Now, you see, the round bottom boat is the one on top, you can see the sections, all the sections are rounded, the forward sections are more or less ‘V’ shaped sections, which are good from seakeeping characteristics point of view, and these sections will anyway come out, as the boat plans the forward portion will come out or slightly come out- they will not come out completely in round bottom boat because round bottom boats are semi planing, they will not plane fully.

So, the forward end will still be in water therefore, it has to be designed for better seakeeping characteristics, so, you can see they are very nicely ‘V’ formed, which is good from seakeeping, is like providing like a knife edge which is entering into the sea; and the aft portion you see, the flatness of the bottom is coming up, but still it is not ideal and that pink portion you can see is the transom in a round bottom boat, so it has crossed the speed barrier, lift has been generated, but it is not in fully planing region, it is what we normally called, round bottom boats are used in semi-planing or semi-displacement mode- is that clear, how it works?

Now, in a fully planing boat on the other hand, you see what we have done, the sections are all having this chine line- can you see the chine line in blue in the forward portion? You can, I hope.

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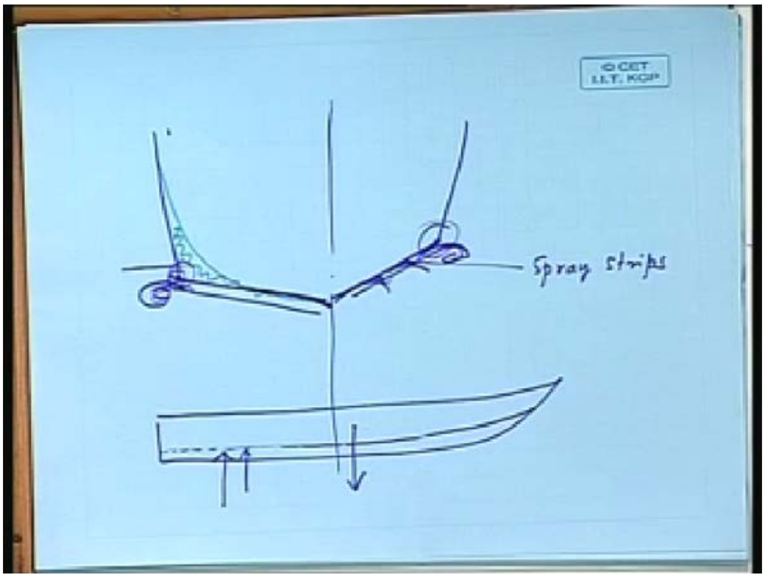

The forward section full will look like this and aft sections may look something like this, this is the chine line. So, if I draw the profile of a planing boat, I will have a chine line which will go like this in the profile view that is, this point and this point. So, why this chine is important? Apart from giving lift also, there is another important characteristics of this; see, the water, we have seen, does not move only in longitudinal direction it also moves transversely, so when the water comes up here it will not climb up if the speed is high it will break here, so, similarly, what I did at the transom I do on the sides, that there is clean separation here unlike a round bottom boat. On the other hand, if I had a round bottom boat here, if I had a round bottom boat here, I would have separation in all these regions, so I am trying forcibly to throw the water out at this place, in a planing boat I am trying to forcible throw the water out even if the water plane was here, I am trying to forcibly throw the, throw the water out- water should not climb up, that is one of the design considerations of a planing boat.

I can aid this process starting from the forward end if I can provides small strips here, if I provide small strips, the water will start being thrown out here, but some water will climb up, this will be thrown out here and ultimately all the water will be thrown out here; this can go right from the forward side from the immersion point till quite aft, these are called spray strips.

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This is speed boat to see (( ))

Yes, the purpose is to throw the water out so that it does not continue the separation of flow or along the length of the ship; as we optimize the flowing out of the water, throwing out of the water by providing spray strips and providing this chine line here and here we get better and better performance, and then the planing boat can be really plane, the weight, can be supported by a large amount of lift and small amount of displacement- displacement is essential, you cannot avoid, you cannot have a boat which works on hundred percent lift, that is not possible in a planing boat because unless the boat is in contact with water you do not get the lift. Is that clear?

So, I have already told you why we are giving a 'V' shaped section in the aft primarily, to see that some buoyancy is there, some volume of displacement is there, as well as we have slightly better course stability; if you had a completely flat bottom, then your course stability would be a problem, you have to provides skaggs, if you have a 'V' bottom may be you can avoid a skagg.

Now, what is the parameter on which this planing phenomenon depends? You can understand that the trim in the planing mode is a very important parameter in generating lift- trim means the vessel bottoms orientation with regard to still water line. We have seen that a small angle gives large trim, would like to limit the trim angle to between 3 to 5 degrees, not more than that not less than that- less than that will reduce trim and reduce lift and more than that may cause further separation and stall, so, we do not want that the stern sitting down, we do not want, but we want a little trim- so, 3 to 5 degrees trim is an ideal condition for planing boats. And trim as you know will depend on the moments due to vertical forces.

What are the vertical forces? One is weight acting at the LCG of the boat, weight acts as the congenital center of gravity; then, lift which is generated at its centroid, which is somewhere between the mid ship, mid boat and the aft position depending on the geometry of the bottom; and buoyancy, buoyancy, if we know the water level in planing position we can calculate what will be the buoyancy generated and its centroid.

So, these three forces typically, the weight may act somewhere here, lift may act somewhere here and buoyancy also may act somewhere here; so, this is trying to lift and trim the vessel this way and this is trying to trim the vessel this way, so there will a balance between, the trim will be a balance between the moments of the three forces- lift, buoyancy and weight. Lift and buoyancy will depend on the geometry, design of the boat, but weight on the other hand will depend on weight distribution. If these are not controlled, then your vessel's planing characteristics will be totally bad therefore, these boats are very weight sensitive boats with regard to their distribution.

Even if you copy a design from somewhere else if you cannot control weight, the same boat will not give you planing, which has happened in many of the planing boat-manufacturers, when they do not understand this very important factor, they get a design from somewhere else, the hull form, they manufacture it, put all the weights, but they have not taken control of it and it just does not play, this happened.

Propulsion of these boats, how do you propel these boats?

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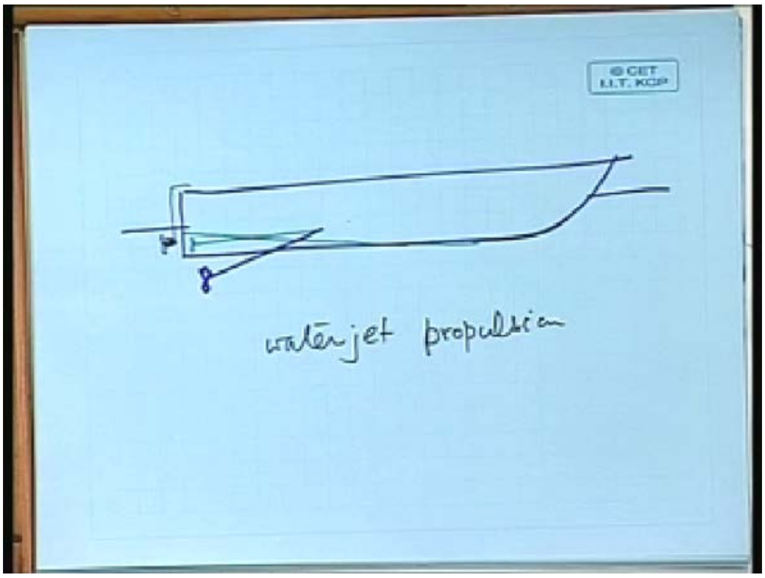

Invariably, if this is a boat, then I will have a engine which will be bring down the propeller here, this is one way of propelling the vessel; the other way is if this is my water line, the other way is if I can bring a stern up by somewhat designing it in such a manner that my stern can come up, then I can give a propeller here.

Alternative. So, fitment of propeller will depend on how much of water depth is available with you. Of course, you can always have a third alternative, a product propeller, here completely behind; but here one has to be careful that, you see this is the position where all the separated flow is taking place at the stern, so if a propeller is not separated from this kind of flow by a small distance, then it is likely to not only not generate thrust, but may cause a large vibration- we have to be careful about this.

So, these are the conventional propulsion methods, the new ones are what is called waterjet propulsion. That is, if I push water, take water from front and push it behind, the momentum will move the ship forward; but for a waterjet propulsion therefore, I have to design a pump, a pump which will cause a pressure difference on both sides so that the water can be pushed, pulled from one side, from behind the, from some somewhere here and thrown out here. So, waterjet propulsion invariably consists of designing of a pipeline and a pump inside it, and the throw process. Advantage with waterjet propulsion is that if you can orient that pump and pipe, if it can be mounted on a swivel kind of thing, then that pump itself can act as a steering device, you do not require a steering device any more.

So, waterjet propulsions are normally designed that way that they can serve the purpose of steering as well as propulsion, but most people still feel comfortable with propellers, the efficiency levels are more or less same- may be propellers will have slightly higher efficiency than waterject, but then there are good waterject designs with speed as good to propellers.

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Single jet are always (( ))

We normally use, you can have single jet or double jet. If you have a twin system, then you have two jets whereas single centralized system you have a single jet, but in these boats normally two engines are provided because the engines themselves can maneuver the ship. Yes, we can turn.

The other thing about planing boats is a seakeeping characterizations, I have mentioned this to you. We can definitely design the fore body with a very extreme ‘V’ shaped sections which will behave like an high fetch when the vessel moves and therefore, even if the waves are coming it can cut through the waves and take the boat, but it is not so simple because your lifting characteristics are dependent on the surface phenomena; so, if a wave comes and immerses more water at one point, your lift characteristics will change, plus since the vessel has very little immersion the vessel is slightly to oscillate more. So, planing boats generally have- whether single hull planing boats or catamaran planing boats- generally, have bad seakeeping characteristics with regard to heave and pitch.

If you have a twin catamaran type of planing hull it may be better from stability, but role is, role can be quite high. So, since the rotational motion magnitudes are high the farthest you are from the central line of axis of rotation the higher will be your linear acceleration due to rotational acceleration. If the angle is phi here and you are far away from the point of rotational axis there the displacement will be high at a higher rate therefore, the acceleration will be high. So, generally these boats are uncomfortable. So, before you get on a planing boat you must be prepared that you are going to get large motions particularly if the boat is going at before scale 3 and above.

It is surprising, what I say may, you may find it surprising, but it is true. Whenever people go on planing boats they do not fall more sea sick than boats which do not have this motion; see, sea sickness is basically a function of acceleration at the point where you are standing, linear acceleration where you are standing, though I have said planing boats experience more acceleration, it would normally follow that more people should be sea sick, but normally this does not happen to lot of planing boats moving all over the world, why does it not happen? Because basically people are mentally prepared that you are going at high speed and you are likely to experience some motions, consciously or unconsciously people are prepared to withstand some amount of motion; but that does not mean that you increase the speed of the boats, because beyond a certain acceleration anyway nobody can experience, withstand it.

So, if you want to move a planing boat at higher speed definitely comfort will be a casualty. So, if you have to move the boat it must be for reasons other than a comfortable ride that is, for military purposes or customs or something like that it will more (( )).

I have also covered planing catamarans in this process.

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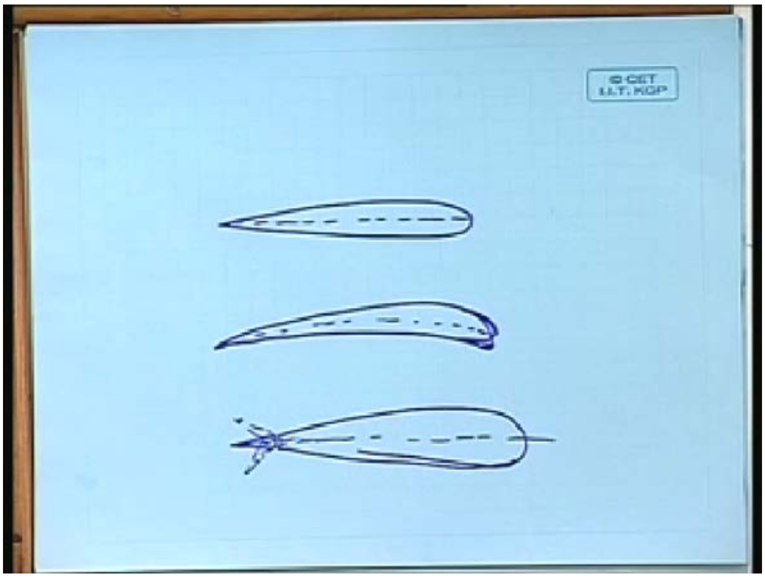

Now, let us go and see what happens in hydrofoils. In a hydrofoil we have seen that the foil is the one that gives the lift, we have seen that foils can be either be symmetrical or cambered- yesterday we have seen this- like this related camber. We have seen that a cambered foil gives better lift at small angles of inclination that is why cambered foils are used. You can generate camber, a variable camber, by not having a single foil, but foil in two pieces. For example, you can have- sorry- I have foil in two pieces like this, which is symmetrical, and this last piece can be rotated into two sides to a certain angles. Now, if you look at this, this changes now the shape depending on the length, I have given only a very small length, but you can go up to this length, then you can actually change the camber of the airfoil. If you change the camber of the airfoil, then the lift characteristics change, it can become more, or you can also reduce it by changing the foil direction. Why is this used?

I mentioned to you like in planing boat, in hydrofoil boats you generate a large amount of lift and perhaps no buoyancy, so generally hydrofoils are fitted with a forward foil and a aft foil; suppose the boat is like this, you have forward foil here and a set of aft foil here- we have seen in the diagrams, forward foil and aft foil- so, you have lift coming up at two places and weight is acting somewhere in the center. Now, when in, your design should be such that in stable equilibrium position the weight and lift should balance each other that the lift the trim is suitable for the foil to operate and give you that lift- you are getting my point?- any foil whether is a planing boat bottom or a hydrofoil, the lift that will be generate will largely depend on the angle of attack therefore, you are must be very careful that you get the correct angle of attack.

So, this lifts of forward foil and aft foil and the weight will determine what sort of trim you will get, that trim may be acceptable and good at the design stage will determine and the vessel moves. But now there are waves, when there are waves the wave forces will change the behavior of the foils and the vessel will start oscillating- do you understand that?- and when it starts oscillating, what do you do? One of the reasons you wanted foil bond vessels is that you should go smoothly in the waves, but now that is not possible, so it will oscillate, so to control the oscillation you could have this flap foil, foils with flaps, which can control the camber of the foil and therefore, control the lift that is being generated. So, the vessel can through a very complex control mechanism, having sensors everywhere and measuring the oscillation forward and aft, this control of the foils can be made so that your vessel is stable.

The other way, this is one way, the other way is increase the surface, weighted surface, sorry, not surface, water plane surface so that we can control, just by having the control, having the water plane this thing, the motion is reduced and therefore, you need not have controls in the foil. So, you have these two types of foils.

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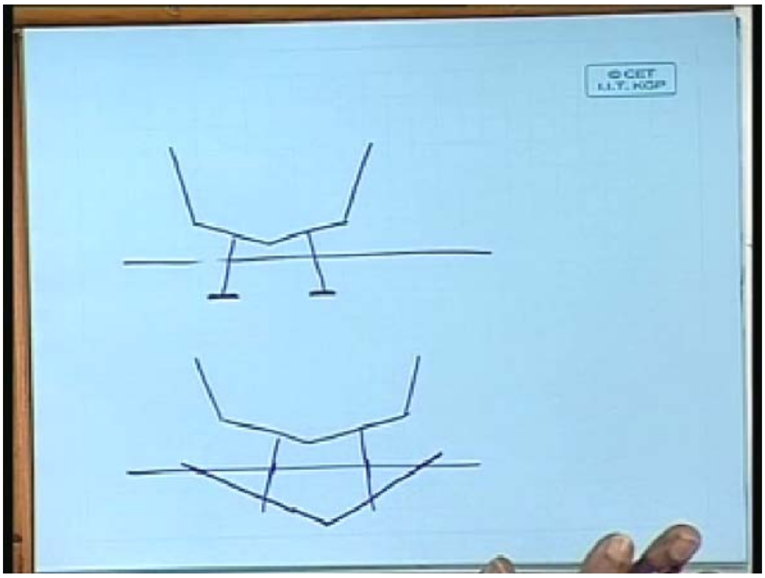

I have mentioned this earlier also, these are the completely immersed foils, we can have like this or have one foil from one end to another end, and this is your water plane. In this case, this foils will have, will be based on this thing, controls, these are the typical American hydrofoils, American navy's hydrofoils, which have controls in the flaps themselves, but the flaps have to have automatic control, you cannot have manual control and expect that your vessel will remain steady.

The other alternative is the so called surface piercing foils where you have this, this is the water plane and you have the foils right like this, so, you have this surface piercing area a coming up here, the struts are there, so, you have more area on the water surface, so the disturbances due to waves etcetera can be minimized; also it gives adequate transverse stability- transverse stability is very important for a hydrofoil, when you are going at high speed you have hardly any time to control in the event of something happening, a wind blowing or something like that, so you must have adequate transverse stability so that the vessels can go. So, in either way you can see that the seakeeping characteristics of such a vessel is much better than that of a catamaran, sorry, that of a planing hull.

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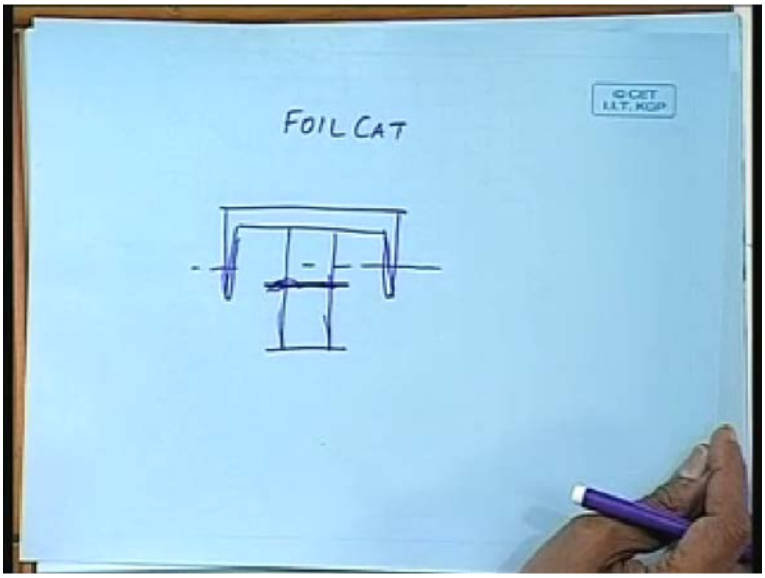

You can have catamaran hydrofoils, in fact, what is called foil cat, foil cat, foil catamarans is then, you have foils here... So, you can have many combinations, or you can have foils coming down also, you can have foils here where you have small immersion of the hull giving you the effect of surface piercing also, you can bring down the foil so that the entire thing can come up, we can have narrow hulls here, which will be advantageous for low speed condition. See, you see you have to understand that whatever high speed you are talking of, the vessel has to go through the low speed region to reach that high speed- is it not?

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(( )).

Same while stopping.

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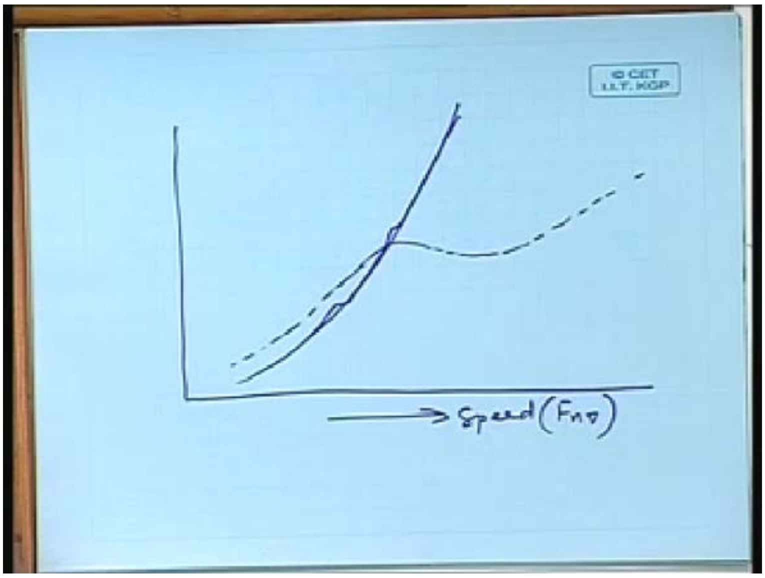

So, if you look at the resistance characteristics of a normal monohull, it would look like small oscillations here, may be some waves here, goes like this, functional speed; if you take one of this high speed craft you cannot expect them to be- speed or we can call it displacement froude number-you cannot expect them to be as efficient as a complete displacement hull in displacement mode when the lift has not been generated, so generally their resistance will be higher in low speed range. But soon around 0.35 to 0.4 this will have a fall and it will rise only at a lesser speed because, mainly because the wave resistance is vanished, there is no wave making resistance any more at high speed.

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((They come out of water))

Whether it has come out of water, or even in a planing boat there is no wave making resistance anymore because the wave has been left behind, it is far away. So, let us see some of the diagrams that I have.

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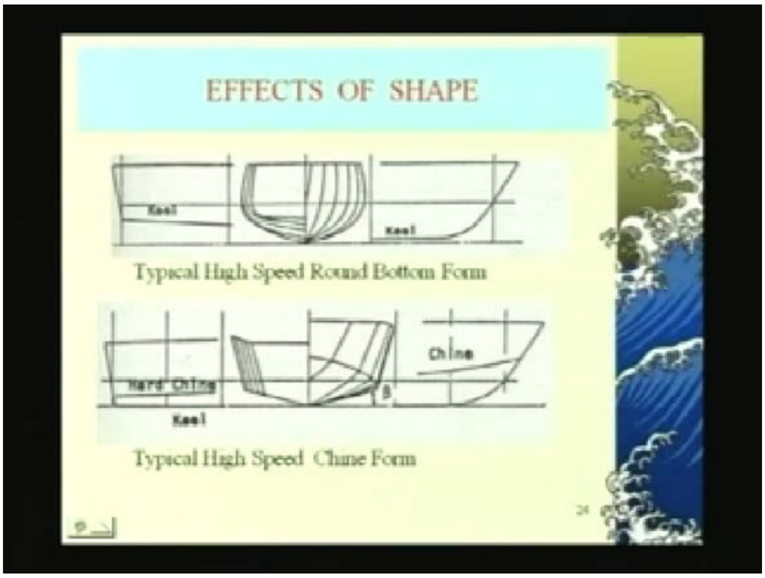

This is the hull shape, I have already described to you.

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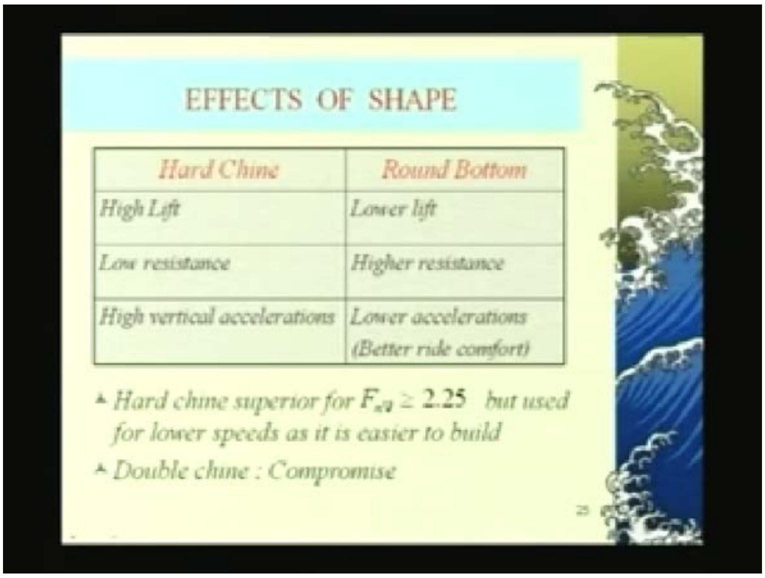

If I compare the hard chine forms with round bottom forms, we can see hard chine forms will give high lift and round bottoms boats will not give you so high a lift; hard chine boats will reduce resistance and round bottom boat will have higher resistance; hard chine boats will have high vertical acceleration and round bottom boats will have lower acceleration hence, better ride comfort; hard chine will be superior for a Froude number, displacement Froude number 2.25, but normally use hard chine much earlier than this; double chine can be a compromise, what is a double chine? Comprise between a single chine and double chine.

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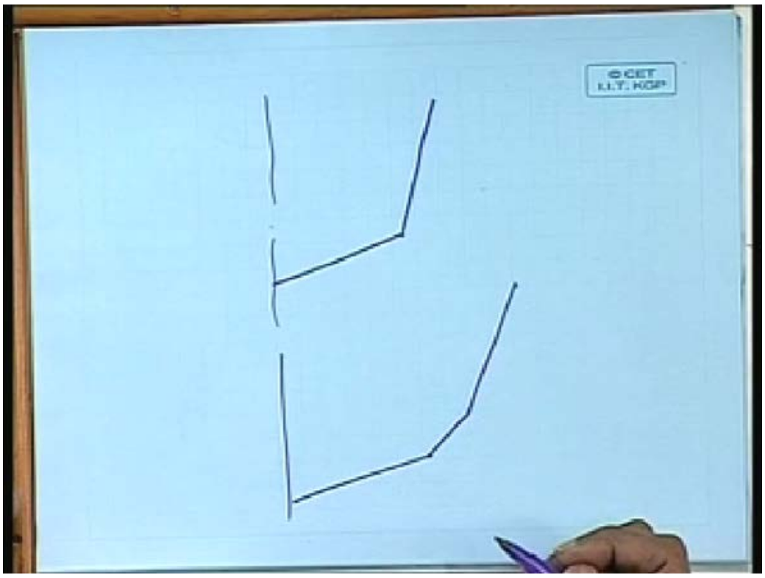

This is a single chine boat, this is called a chine line; a double chine boat is two chines, which we can say is a compromise between single chine and a round bottom form. Sometimes this is used for other purposes than purely hydrodynamic.

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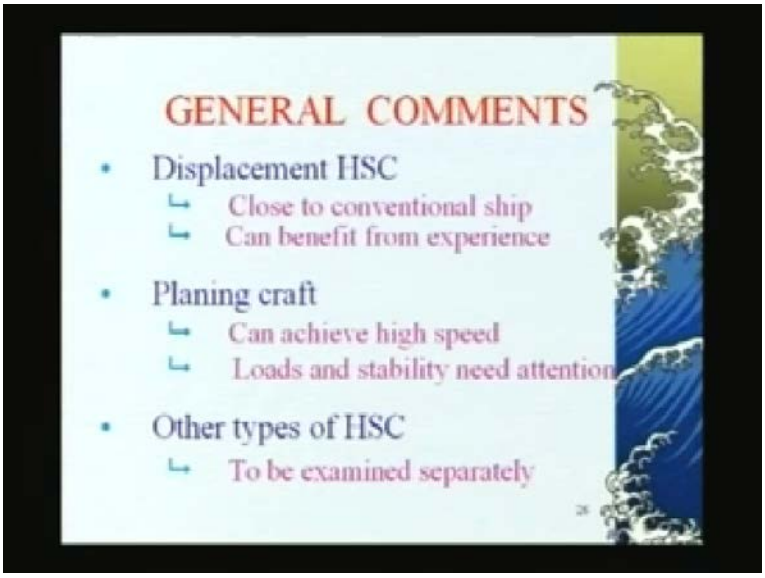

Displacement high speed crafts are generally close to conventional craft going to round bottom boats, and designing this one can benefit from experience- understand that high speed boats which are not displacement type our experience is limited.

Planing craft can achieve high speed, loads and stability need attention. Loads means, what loads are we talking about, in a planing boat what loads are coming into picture, after all it is a, we have already said the weight sensitivity, weights are known, there is no buoyancy, so what is the load we are talking about? When the planing boat goes there is a point of contact between water and hull bottom at a particular point somewhere near the midship and this point is always oscillating- do you understand?- that means, if we reduce speed a little bit, it comes down, if the speed goes up, it goes up, so, this portion particularly, the portion which is near the contact of water in its optimum condition, is prone to slamming because a flat bottom, we have said a flat bottom, so there is large pressure coming up there- there is plenty of literature on this subject- large of pressure development is there and the vessel experiences slamming at that place. Therefore, that portion has to be designed very strongly, so that is why the loads have to need attention.

Other types of high speed craft, they have to be examined; see, planing boats lot of literature is there, you cannot use the same technique for other high speed craft because the hydrodynamic behavior is completely different from that of planing.

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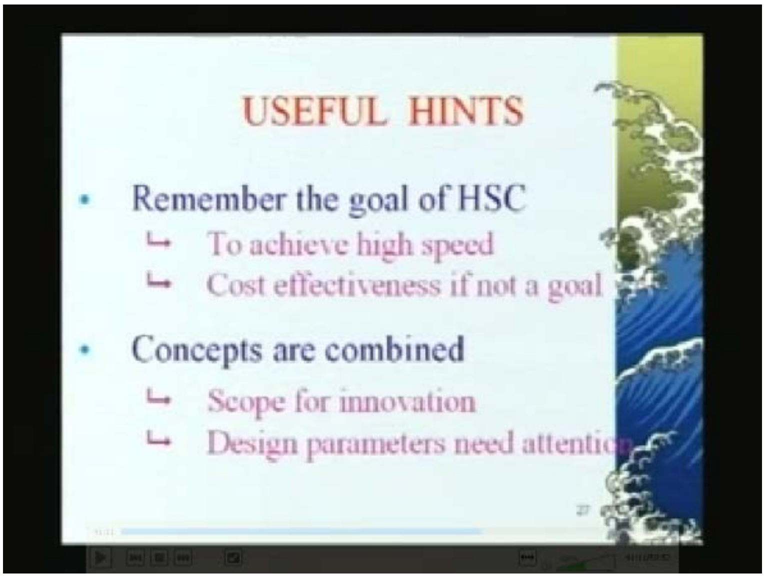

So, while designing a high speed craft you have to remember why you are doing it, as I said you cannot in general say that all high speed crafts will be comfortable, planing boats will have their limitation. To achieve high speed you have to remember the goal of course, cost effectiveness if not a goal, if it is not a goal, then put it has a goal because ultimately whenever you are building a high speed craft in military otherwise everywhere you will say what is the cost, not only the building cost, but what is the fuel consumption; we are talking 5000-6000 kilowatts of power in a small boat somebody has to justify why so much of oil has to be burnt and perhaps you say gas trouble (( )).

Concepts are combined, hybrid craft. Scope for innovation is very high, in this design and parameters need attention. Before going to conclusion I think I will go back to some more slides.

This we have seen, just go over slides. Now, where have I gone? This also we have seen, this we have seen. From here onwards talk to you...

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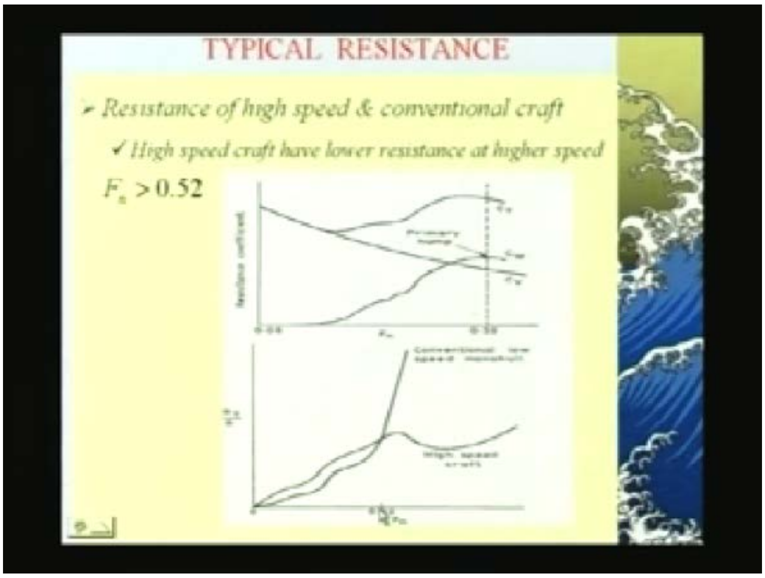

This is the resistance curve. You can see the top one is for a displacement hull and the bottom one is conventional hull versus high speed craft, the one that I have already drawn to you on the paper. So, you get a distinct advantage of going over to high speed if you have going for a Froude number above 0.52; so, normally above 0.4 or so we say high speed, but above 0.52 you start getting the advantage.

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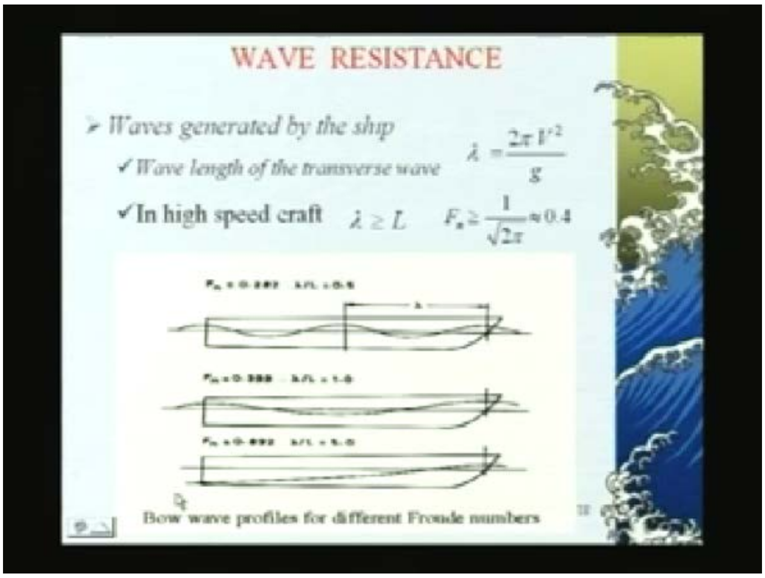

The wavelength, we have discussed this, I have given it to you in class that the wavelength of a transverse wavelength 2 pi v square by g and based on that you can see that when wavelength, at about 0.399 the wavelength equal to ship length, we said that as 0.4. And wavelength equal to half of the, wavelength is five times of ship length when Froude number is 0.892; you see what is happening to the stern, it is coming up, but it will sit in a, to come back there the stern will sink, so the vessel will have a high trim.

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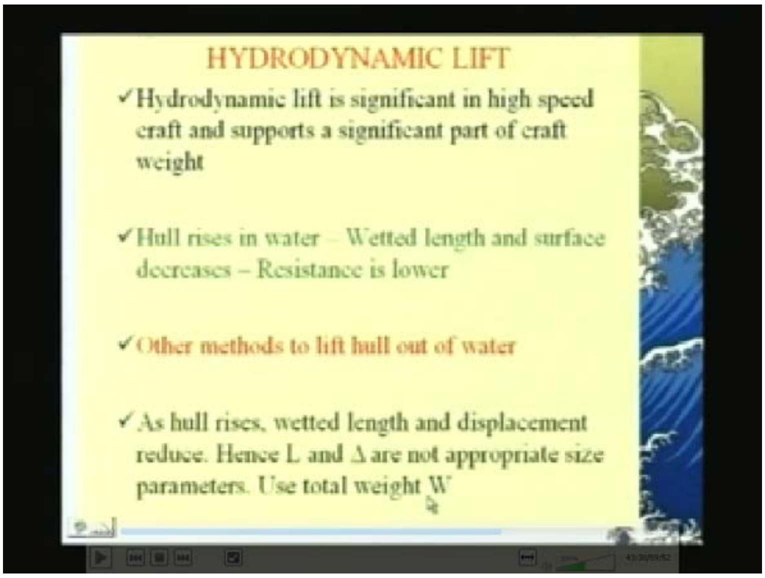

((What happened? Just do not understand this.))

((Let us see what require this))

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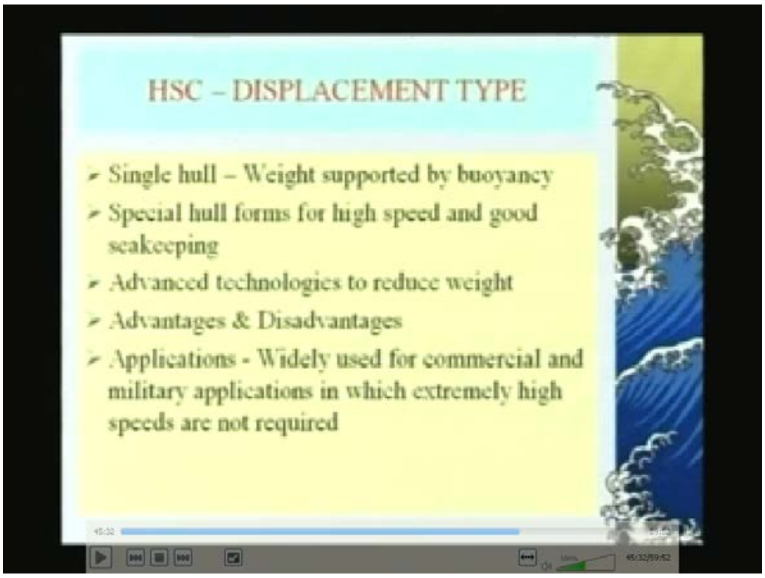

This all we have gone through I am just going through again. In high speed craft single hull is, single hull vessel's weight is supported by buoyancy; special hull forms for high speed and good seakeeping; advanced technologies to reduce weight- what is the advanced technology we used for reducing weight?

(Audio not clear from 44:02 to 44:22 min)

((material used)).

Main thing is materials. Should be going for aluminum or fiber reinforced plastics, no, titanium is not used in surface vessels and that much of strength requirement is not there. You see one thing you have to understand, strength may be very high, but you cannot reduce the thickness in that proportion suppose, titanium is four times stronger than steel I cannot use instead of 5 millimeter plate I cannot may use a one millimeter plate; there is a workability limitations is there apart from corrosion and other things, and other problems that come up with titanium, stress corrosion cracking and all those things will come. So, you cannot reduce thickness to a very small level, so, you do not get the benefit of high strength whereas, you should go for lighter material, that is why we prefer aluminum and fiber reinforced plastic.

Applications widely used for commercial and military, which we have said already.

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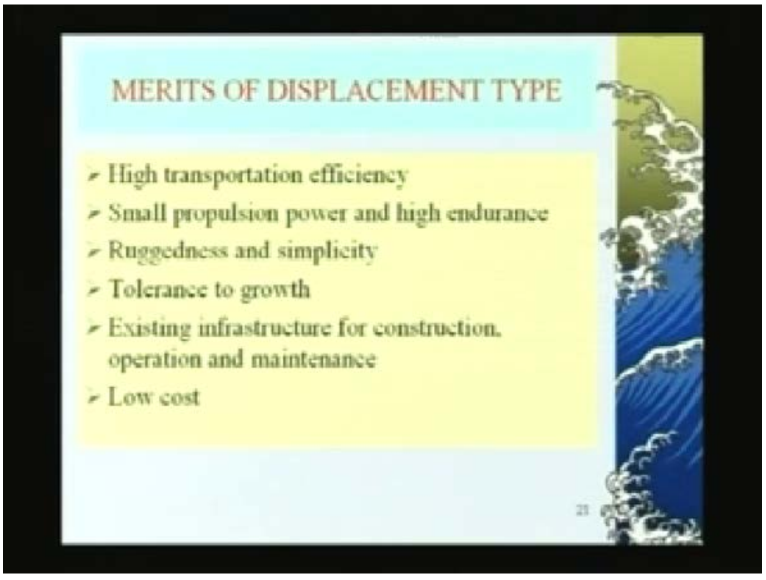

Merits of displacement type craft. Why we are use displacement crafts? High transport efficiency- that is understood because of the optimal fuel consumption basically; small propulsion power and high endurance- we can have large amount of fuel to for a large route length; ruggedness and simplicity- because of experience I suppose mainly; tolerance to growth; existing infrastructure for construction, operation and maintenance can be used; and low cost.

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Then, planing crafts. Flat stern to limit sinkage and trim- we have discussed this; fine entrance for low resistance and good seakeeping- V shaped sections, we have mentioned; at high speeds hydrodynamic pressures begin to lift hull which skims on water surface- hull planes; spray is generated, there is a large amount of spray in this because of the separation at the sides and at the end; round bottom or chine form; spray strips double chine forms. All these I have discussed, I think we have gone through all the slides.

And general comments we have seen, we can now go to the concluding slides, this also we have seen. What do we conclude from these two hours?

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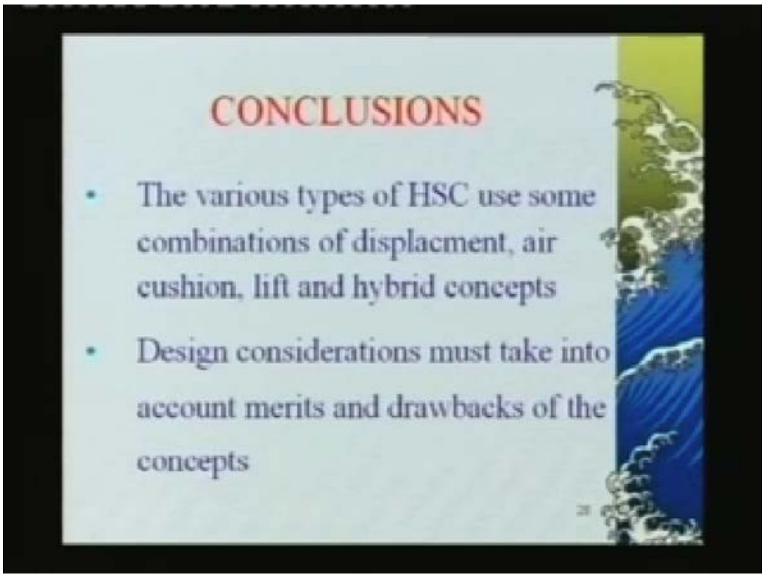

There are various types of high speed craft use some combinations of displacement, air cushion lift and also hybrid cushions, hybrid concepts, combining a two or three hydrodynamic phenomena or lift phenomenon, but basically all high speed craft use vertical lift and reduce the hydrostatic lift.

Design considerations must take into account merits and drawbacks of the concepts- this is very important, you cannot blindly use that I want 50 knots, so let me use any one of these. You have other considerations which are necessary for you to consider which one will be the more suitable.

Those are the two main conclusions we get from this chapter that how you generate the lift to lift the vessel out of water and the other one is for designing you have to consider the other types of behavior apart from drag, drag alone is not considered sufficient, you have to look at propulsion, how you fit a propeller, the power plant, the materials used, the loads coming on the vessel and its ride comfort. These are the things which you must consider for designing a, deciding on a high speed craft and later on perhaps designing and manufacturing, any questions? Then, thank you gentlemen.