Performance of Marine Vehicles at Sea
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Lecture No. # 09
Ship Hull Form and Resistance

Good morning. And this hour we will talk about ship hull form and its relationship to resistance.

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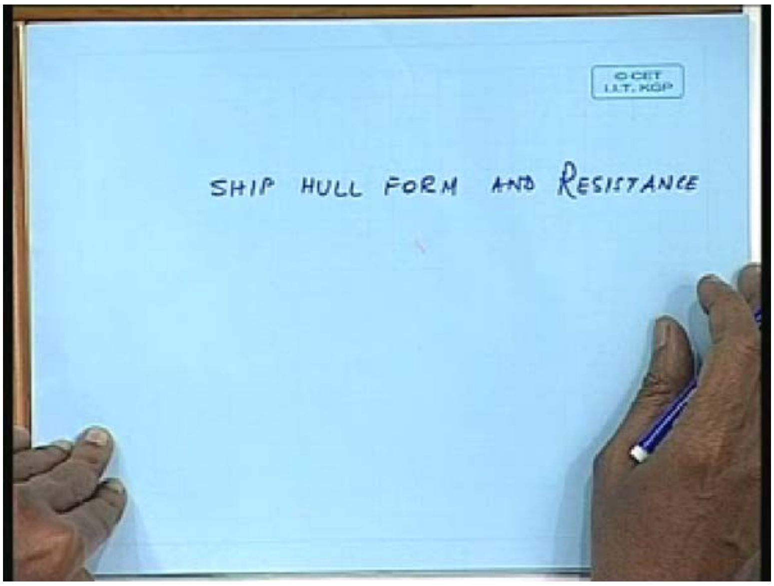

From the understanding of resistance it is possible for us to draw some guidelines as to how we can develop a hull form, or what are the parameters of hull form that can be controlled to give better resistance characteristics at a design stage, because once the design is over the hull form is fixed- if the resistance characteristics are not good, the ship will suffer for its entire life. So, we will see some main parameters of the hull form and how it affects resistance? This should be fairly general analysis of relationship of hull form to resistance.

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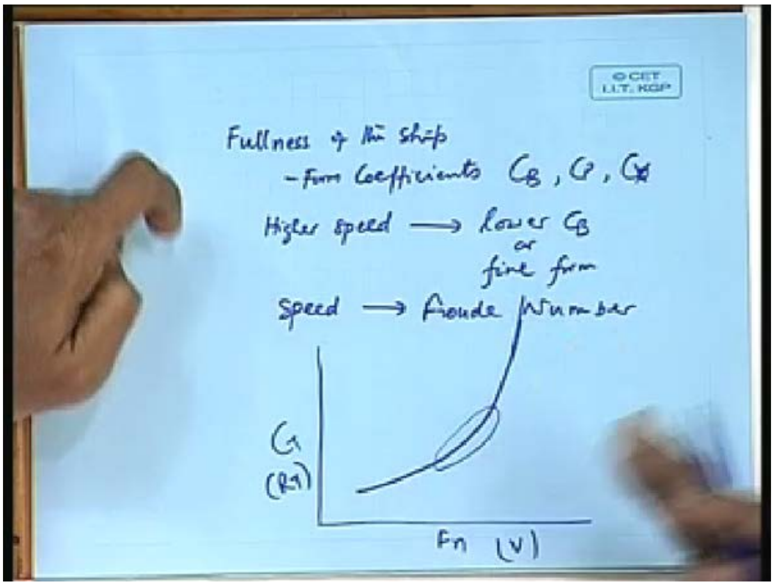

The parameter that affects most the resistance of the ship is the fullness of the ship. How full the ship is, is represented by the form coefficients; mainly, CB and CP and Cmidship- we will see all of these. CB, of course, the block coefficient, tells us how full the ship is and gives us some idea about how the ends are shaped so that, generally we can say that if the ends are shaped more smoothly or more narrowly, then I can get a higher speed- that means, speed, higher speed will lead to lower CB or fine form. That is the reason you will find bulk carriers and tankers are full form ships with high CB, and passenger ships, container ships etcetera, are finer form.

Now, you see when I am talking of speed I am essentially taking about Froude number, not speed as such; that is, if I have a container ship which is said 250 meters long, one of the larger container ships, it can move at 24 knots. Now, what I do is I geometrically bring the ship down in size, instead of 250 meters, now, let me see I bring it down by half to 125 meters- every dimension reduces by half- if that was moving at 24 knots, will this ship move at 24 knots, would it mean that it will move at 24 knots? The answer is no, it will move at a speed which will be at the corresponding speed that means, it will move at 25 divided by root 2 because the scale is two, so that optimum speed will be 25 divided by 1.414, which will be something like- what?- 17, 18 knots, of that order.

So, you see, you cannot say if I have a small ship, I will move at high speed, you just, it just does not follow, the fullness remains constant, if that had a block of 0.65, this ship will also have a block of 0.65, only the size, length has come down, but its speed has also come down based on Froude number equality. So, we keep this in mind- speed is represented by Froude number. You may think for example, since it is a smaller ship I will put more power and it will go at a higher speed, now, we can afford more power, the bigger ship had large power, you could not go on increasing the power, but you have got now a smaller ship reduced by half, speed has fallen, so the power is less; say, in that big ship you had a 10,000 kilovolts of power and in this ship you have something like a 3000 kilovolts of power, now, you may say that it adds another 2000 kilovolts again, afford 5000 kilovolts, if I give 5000, I will get 24 knots, but will you, will you say this is Froude number, this is CT? Or we can also draw RT versus speed for that length, how will the curve be?

We have seen the resistance curve goes, wave making resistances at higher speed becomes more prominent and it is to the power of six, varies to the power of six. So, somewhere after this speed, somewhere around this speed is my optimum speed, anything more than this, the power consumption will go up tremendously without any further addition of speed, appreciable addition of speed. So, every ship will have an optimum speed and if you reduce in scale, that optimum speed will come down based on Froude ((similarity))- you cannot just go on adding power and say the speed will go on increasing, that does not happens.

So, how does, or let me say, the next important characteristics apart from fullness of the ship is how the displacement is distributed over the length of the ship, how do you represent this, how does the volume of displacement get distributed over the length of the ship, do you know how it is represented? You should know.

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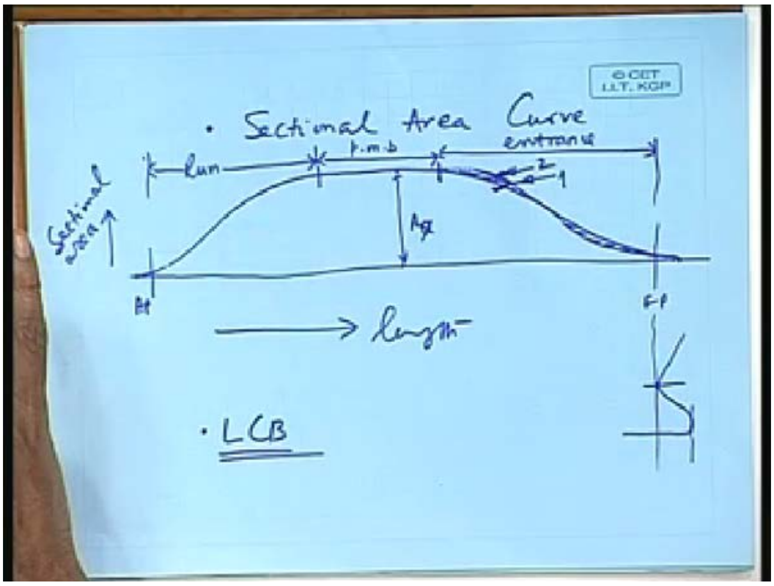

Sectional area curve, you know this, are you aware what is a sectional area curve, are you aware, yes or no? If you are not aware, I will have to draw it for you. This is the forward perpendicular of the ship, this is the aft perpendicular of the ship, and somewhere here is the mid ship let us say, here is the mid ship. So, I know if I draw this, this is length dimension and this is sectional area- you know what is sectional area, no, area of the section- if I draw this curve, then here will be the mid ship, mid ship section is so much, a mid ship, which we have talked in the previous hour, and it may be zero a little aft of AP if my transom or the stern is immersed in AP, then, AP is at the rudder stock there may be some portion still to the aft, so at somewhere here it will become zero.

And similarly, if I have a bulbous bow, let me assume there is a bulbous bow, there will be area forward of the fore perpendicular and it will become zero at the end of bulbous bow, because remember the ship- if this is the FP- the ship's water line and FP will coincide at loaded line and if there is a bulbous bow, it will go like this, so sectional area curve below the (( )) will end at the end of the bulb. So, this end comes here and if I draw this curve, it will look something like this, if I draw the sections and join them by means of a curve, this is how I will get it. Now, this gives me the distribution of sectional area over the length of the ship. What else does it give me? The area under this curve gives me the volume of displacement and the moment, if I take the moment of this curve about any point, then I will get where the lcb of the section is, of the ship is- at loaded line, this is the at loaded line. What does this curve show me? It tells me that a portion of the ship's length from here to here is constant, is giving constant sectional area therefore, the section is constant. So, this is what we call parallel middle body and this I call entrance and this I call run.

Let us look at this diagram. If I change the parallel middle body, how it will look? If I change the pmb, suppose, I want to increase the parallel middle body see, if I have a longer parallel middle body, it is easier for me to manufacture because I am manufacturing the same section for a longer length- is it not?- so, I may be tempted from production point of view to increase the parallel middle body. Let us say, I take it up to here in the forward part, obviously, if I take it down parallelly to this curve, I will have more volume in there than what is desired so I cannot do that, what I will have to do is, if I take it out from here, I have to bring it down somewhere here so that this volume is equal to this volume. Now, which of these curves is better? This one you mean, this one is better or this one? Let me write 1 and 2- this curve is 1 and this top curve is 2.

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((One curve, one is better based on the other when there is forward part where we are getting talking is less in forward part starting.))

So, you mean to say two is better and you are saying one is better. Now, we have a problem. We have both these forms coming out as better say, difficult to say which is better, but we can make some general statement. If my fore part is narrower, then it generally says that my fore part is narrower, if the sectional area curve is less at the fore end, then I can generally say my fore end is narrower; whether it is better or not I will know only when I do my fore sections, we will come to that, but what does this portion show? Shoulder. In the case of curve 2, in case of this curve, curve 2, the shoulder is more prominent and in case of curve 1 the shoulder is less prominent; Now, we have seen about wave resistance, wave making resistance, the curve 2 will give me a more prominent shoulder wave. So, looking at it from this point alone, I will prefer curve 2 to be worst than curve 1 that is, I will prefer curve 1 where I have a smoother shoulder, understood?

Therefore, generally, less parallel middle body for the same volume is better from resistance point of view of course, you cannot have this, you have to have compromises always- how much parallel middle body- if you have one advantage of parallel middle body is if you have some parallel middle body, you can reduce something and get a different length of ship depending on the requirement of an owner.

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((In previous case increases at two and decreases at one.))

To some extent this is true, volume as such will remain same, interior volume will remain same, but the cargo space becomes more organized with 2, no doubt, no doubt about it. But definitely the shoulder effects matter, this also the same thing.

For the same reason the LCB plays an important part in resistance. Longitudinal centre of buoyancy- it indicates how much volume is in the forward and how much volume in the aft, is it not? So, if in my design, if the forward portion is giving me a major effect of resistance, then I should adjust my LCB accordingly, maybe I require to move the LCB aft, so my aft becomes full and forward becomes finer may be. But that is not always the case, this is the case generally for fast ships, fast fine ships that I move my LCB aft so that my forward portion is finer, but in full form ships just the reverse occurs, I may have large amount of separation coming up in the aft, so I may like to refine my aft more than my forward where wave making is not a major component, I may like to shift my LCB forward. So, as the block coefficient goes up the LCB starts moving from aft to forward, this is general, I am only talking to you how the parameters get affected due to resistance, I am not saying these are guidelines strictly, you can have a different design with different LCBs, test it and find that it is better- am I clear?

Now, you see, this sectional area curve is so much related to how much area I give in the middle- is it not?

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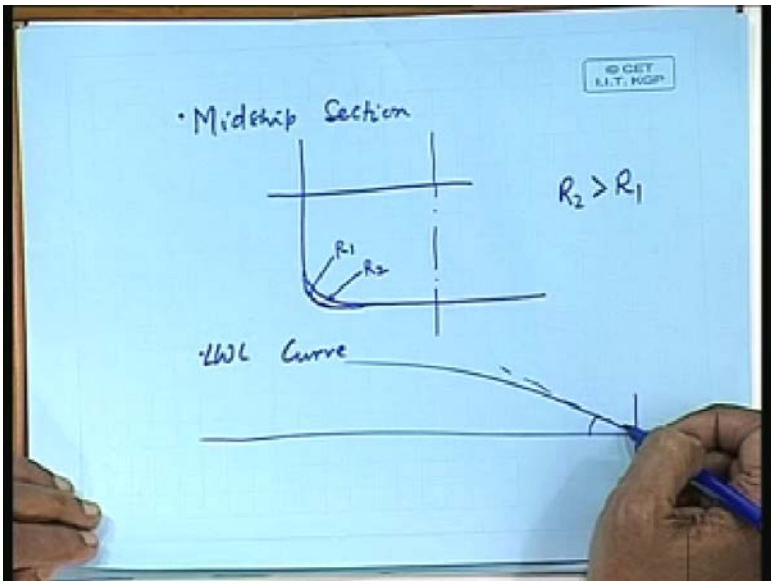

Now, suppose, I have got two sections let us say, mid ship section or mid ship section coefficient, it is the same thing. I have got one mid ship section, which is like this, this is a centre line, and I have got another mid ship section, which is like this; that is, this bilge radius is R1 and this bilge radius is R2, R2 bigger than R1- bilge radius- what does this indicate? R2 will have a lesser section than R1, is it not? Suppose, this was made with R2, how will the curve look for R1, or let us, let us say this is, this sectional area curve corresponds to R1, the lower sectional area, lower radius therefore, higher sectional area. Now, I think that no if I have a larger bilge radius, flow around the bilge will be smoother so, I will give a larger bilge radius, my sectional area will drop, but I want the same volume. So, if I drop my sectional area to here let us say, how will my curve change? My forward and aft will become fuller, I will have a large parallel middle body, but my forward and aft will become fuller- do you understand that?- it will become like this. This area that I will lose will have to be made up here and here, which is better?

You see, now my parallel middle body has increased, good from production point of view, I have reduced, I have made the bilge radius large thinking that the bilge flow will be smoother, but in the process I have made my shoulders very prominent, and if I have large shoulders I know I will get into trouble. So, you see, what I wrote in the first page, I talked about CB first and you see how CP and CM are playing roles; CP, what is prismatic coefficient? In these two cases, you can see that CP for this case, the dotted line case, is higher because Cmidship is lower, so, this dotted line that is, lower CM or Cmidship, lower midship area coefficient coming out of larger bilge radius will give me lower CP, sorry, higher CP, and this is having lower CP. So, whatever may be the CB, for the same CB you will have a range of CP based on your bilge radius; and you can see that lower CP is better than higher CP from shoulder point of view of course, you can then say that I will go to the extreme and make the Cmidship as one, then my CP is same as CB, I got a, is that desirable? I cannot go lower than that, is that desirable to have a CP like that? That is not desirable because you are introducing large separated flow, because the bilge will be now totally discontinuous you will introduce large separated flow. So, there is a compromise between the CP you can give and in the range of CP that you can give, you have to make a compromise in the range of CP that you will give. And normally from merchant ships, your bilge radius is limited to between about 1.5 to 3 meters- you do not go beyond that.

Then, next important item in this is the water plane area, water plane curve, load water plane, LWL curve. We have seen the sectional area curve, we have already discussed the role of half angle of entrance in the class when we discussed wave making resistance- do you remember, half angle of entrance, we talked about that, that determines how smoothly the hull is going into water and what will be the wave crest. So, LWL, if it is smooth at fp, if this angle is small, half angle of entrance is small, then it is always advantages and therefore, this follows for our curve 2, you see the curve 2 that we showed before, though it has a prominent shoulder this sectional area curve here has narrowed, which leads to a finer angle of entrance.

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((Sir we can got that 19 point 28 we can go below that also))

Yeah, you can go, that 19.28 is for a pressure point. So, loaded line curve is also an important parameter.

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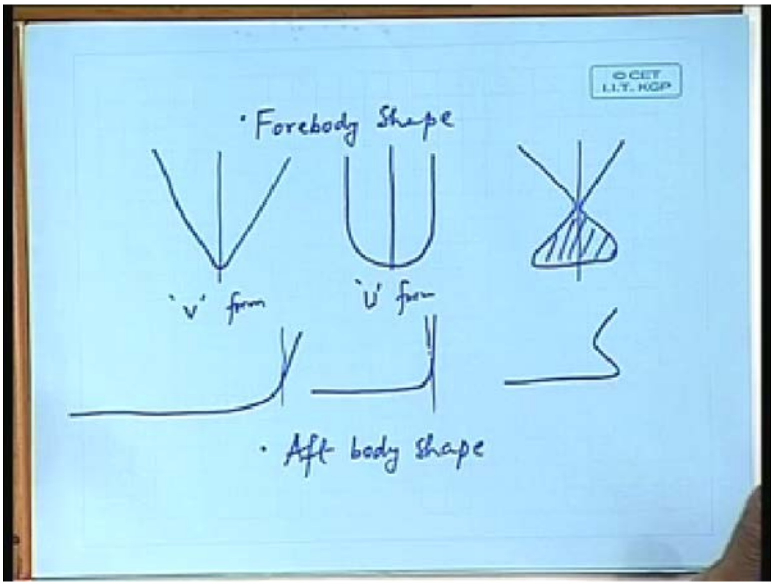

Now, then, next comes the fore body of the ship, fore body shape. We have three fore body shapes, which are ((extreme)), and we have to choose one of them or in between them. One is called typically a fore body section shape which is like this- this is called 'v' form like a V, normal ships that have a shape like this will have a section like this, the section comes down like this. The other one is what you call a 'u' form section, more like a U, this case, because it will be difficult for one to close the sections this will look more like this, the end, profile view will look something like this- sections are more u. And lastly, you will have the bulbous bow and if you draw a section here at the f p itself, you will have this bulb.

As we have discussed in both these forms as compared to v form the volume comes down; if the volume comes down, imagine the sectional area curve, we are providing volume, but below the water line, so the water line becomes smoother unlike here, in v form water line is sharp, is more blunt, angle of entrance, half angle of entrance is higher in this case, lower here and lowest here. So, as far as the water line is concerned this comes much better with the bulbous bow then, u form then, v form.

So, typically, the wave making resistance for a well designed bulb, I mention that again, for a well designed bulb, will be the lowest because of the bulb, as well as because of the load water line shape; a little worst, then this will perhaps be u form, but this will definitely be better than this because the water line shape here is better than what we would get here. So, this is better than this from calm water resistance point of view.

Then, you may ask me, why is this used at all? Resistance is not only, not the only characteristics for which ships are designed. We can imagine a vessel slamming, the fore body going up and down, the impact pressure will be much larger here, largest here and least here, so this is a distinct structural advantage in a fore body like this with regard to structural design as well as structural safety. So, you have to look at the fore body shape and finally, the aft body shape, the type of stern you have. But aft body shape is not considered to have large impact on resistance alone, why I say this is that if you design a reasonably good aft body as a convention al aft body, you will not have any penalty on resistance, if you do a bad aft body of course, it will have penalty everywhere, but the aft body is primarily designed with flow consideration such that flow onto the propeller is good and it does not generate vibratory forces- that is how aft body is generated

So, these are some of the considerations we take while designing the hull form so that we get favorable resistance, calm water resistance. Then, after the hull form is designed we go and do the model test, from model test we extrapolate for full scale and then during trial condition you compare whether you have got good prediction or not. But this is not enough for us to draw up a hull form. So, what else we have, how do you know the resistance at the very early stage, or for a ship for which resistance data is not available, the tank test data is not available, what methodology do we follow to estimate the resistance if such data is not available, tank test data is not available? Over the years, over the last, I would say nearly 70, 80 years, a number of ships, a series of ships have been designed and tested.

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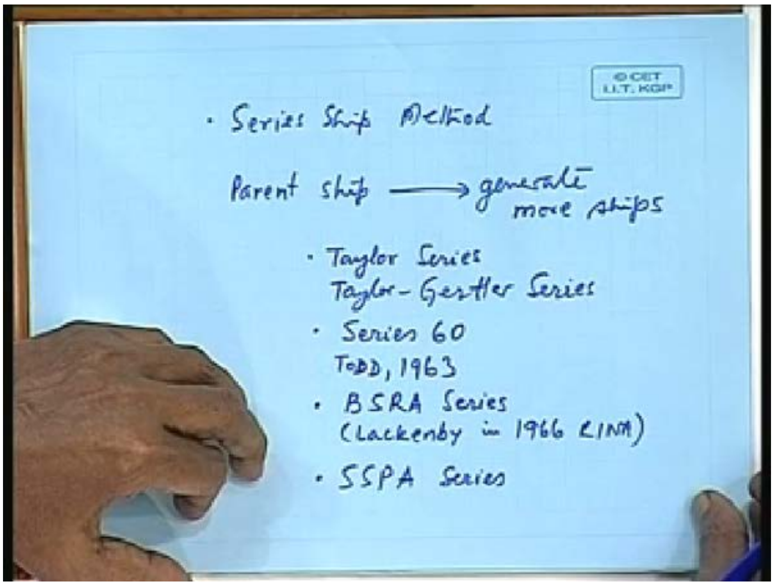

So, one of the methods of estimating resistance is so called series ship method, let me explain what it is. If I have ships of the of the same family that means, I define a ship, ship shape in a particular manner, like I can say my fore body will have v form, aft body will have cruises stern, etcetera. By some means I define a shape and try to generate more forms using that family, that ship, as the basis. That means, I can broaden the ship only- not increasing the length- use the scale and broaden the shape, or I increase the block by distributing the area equally over the entire length or in a particular manner over the entire lengths, so sections get full, if I am making a higher CB ship, then section gets full in a gradual manner, then I can call that ship to be of the same family as the original ship; that means, I have a parent ship or a number of parent ships and I generate from this parent ship more ships- do you understand what I am saying, can you understand?

If I have certain ship parameters as constant like fore body shape, I decide I will have sixteen forms with the same fore body, I can have, I can say that of these four will be constant l by b ratio, but each set of four will vary in l by ratio, l by b ratio slightly. That is first four, let it be seven, second four will be eight, third four will be nine and the fourth will be ten, let us say. Similarly, I can say b by t ratio to vary slightly, but the form remain same, I just geometrically change the shape. Similarly, I can say my LCB will be 1 percent aft or at mid ship or 1 percent forward, I do this by not changing the shape, but just by swinging the sectional area curve and putting the sections where the new sections is ((urgent)), should be there as we change the LCB position. Can I do that? It is possible to generate a large number of ships using the same form characteristics, but changing the main dimensions- am I understood now?

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((Could you please describe the xerox copies of different sizes))

No. Let us say, I just increase the breadth, then each section is pulled out, it is not a Xerox copy.

((Xerox copy with different sizes))

No, only one dimension I am changing, it is not scale, it is not scale change, is just one dimension I am changing, I can change l by b, b by t, I can change block coefficient, I can change LCB by changing (( ))... general nature of form remains same- this is called the series, developing a series of ships. So, if I generate a number of ships like this and test them in a tank, what I get is a matrix of ships for which all resistance data is available and if I can present it properly, then for any intermediate dimension I will be able to tell what will be the resistance- this was the thought way back in 1950's, 40's and 50's.

So, we had a number of series starting with the Taylor series and later modified to what is called Taylor-Gertler series, these are basically v form ships for high speed operation used mostly in naval vessels, to date. Till now, the naval vessels are built very near the Taylor-Gertler series where the speed requirement is high, and you can get a really good prediction of resistance and also get a hull form. But this is not very useful for merchant ships for the reasons already we have discussed, resistance is high, naval vessel use it because they operate normally in two or three speed conditions, a sprint speed, then a normal this thing, but merchant ship do not work like that.

So, these vessels are not good for merchant ships. And so in 1950's and 60's a series was generated in the David Taylor model basin of USA called series 60; a number of vessels were models were manufactured and tested, and you get huge amount of data on series 60 not only on resistance, these vessels have been tested for sea keeping, for resistance in waves and maneuvering. So, large tests have been conducted on series 60 vessels and a store house of data is available in open literature; the resistance data was published by Todd in 1963 in (( )). Now, series 60's basic feature is the forward sections are u shaped sections, so they have reasonably good resistance characteristics and they have good to start a hull form for at the initial stages of designing a vessel.

Then, we have two more series, I will just mention to you BSRA series, which is BSRA standing for British Ship Research Association. This series was developed in the 60's and published by Lackenby in 1966 in RINA- Royal Institute of Naval Architects. This series has the typical nature of again coming back to v shaped sections, they are more v shaped than series 60 and they have been designed over a wide range of block coefficients; you can get BSRA series forms right up to 0.80, 0.82 block coefficient.

Then, we have another series called SSPA series developed by the ((Swedish)) tank- and there are other series, I will not mention them. But these are the four most important series, the ship data available in open literature. There are of course, series data available for trollers, smaller vessels and also for other type of vessels such as ((planning)) craft, etcetera.

If your design is more near a series ship, then you can use the corresponding series ship and estimate the resistance and from their (( )), but many times you do not get a ship which is very near the series therefore, it is difficult to estimate resistance. So, the next method is statistical data. That is if you got, one thing you must have understood by now, that all these series that I have mentioned, they are all non bulbous forms and today we have ships with bulbous forms therefore, present day ships perhaps will be better than most of the series ships and therefore, this data cannot be used with any reliability for modern ships, they tend to overestimate the resistance if you use it for a modern day ship.

So, the best way to do is to find out what the statistics say. If you have a large number of ship data, then can we make a statistical analysis and say my ship, since large number of ships of all types fall in a particular pattern, the resistance falls in a particular pattern, may be my ship will fall in that; so, I can estimate my ship resistance and say it will have plus minus 5 percent actual resistance. Now, this has been done rigorously by Holtrop.

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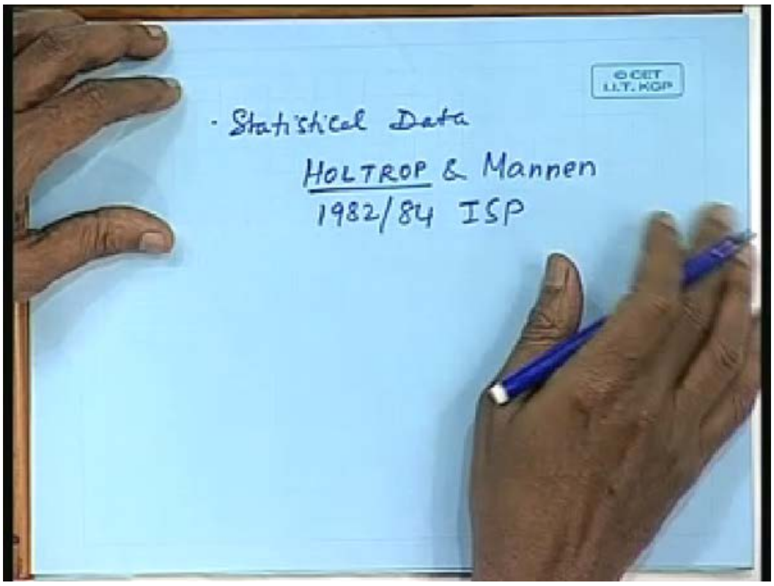

NSMB- Netherlands Ship Model Basin. Holtrop, and there was another chap called Mannen, they have published their statistical data analysis in the 1984, 82-84 ISP, International Ship Building Progress. What they give you is, they have analyzed slow form ships, fast form ships, bulbous bows, non bulbous bows, cruises sterns, transom sterns, stern immersion, various draft conditions with appendages and without appendages, large amount of data has been collected together and whole set of regression analysis has been done, and knowing your ship parameters of all these quantities, they give a method by which you can estimate the resistance. That is so far the most reliable method of estimating resistance for ships as of today; we do not have, I have mentioned this before, we do not have a fully theoretical method for predicting resistance as yet, so statistical analysis is the best way to get the resistance of a ship if we do not have the tank tested.

If there are no questions, then we will stop here. Thank you.