

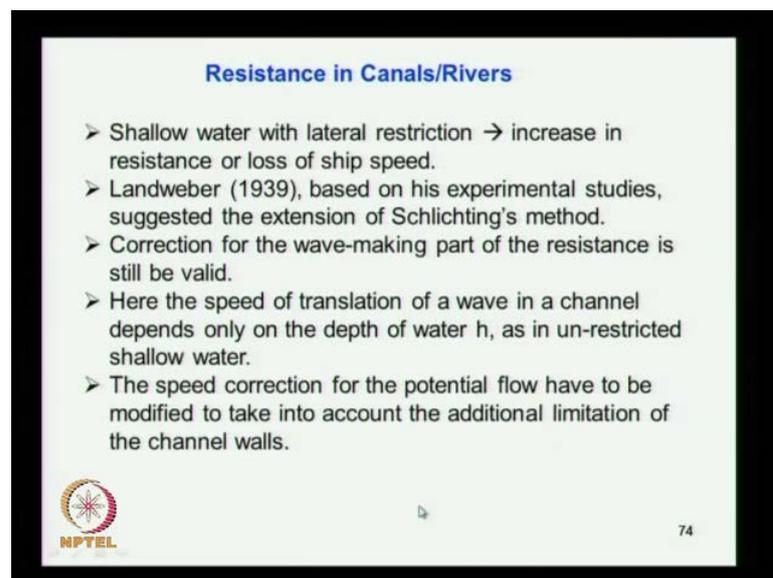
Ship Resistance and Propulsion
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Lecture - 12
Canal Effects on Resistance Holtrap-Mennen Method for Ship Resistance Prediction

We have been discussing about shallow water resistance in the previous class, and when we consider the shallow water, we have not considered any restriction the width wise direction. That means we have not considered the canal effect or river effect, we considered only the water effect on their resistance. Also we have seen that the resistance when the vessels move from deep to shallow water, the speed of the vessel reduces in two counts.

One is due to the flow around it, which is called the potential effect, because of the construction of the flow under the bottom the flow velocity increases, and where we have pressure decrease and ship sinks more resulting in more wetted surface. Increase in resistance of the ship is termed as a potential effect other aspect is the wave making increases in the shallow water. There will be increase resistance due to the increase in the wave size and subsequent increase in resistance due to the higher waves formed by the vessel when it moves in the shallow water region.

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Resistance in Canals/Rivers

- Shallow water with lateral restriction → increase in resistance or loss of ship speed.
- Landweber (1939), based on his experimental studies, suggested the extension of Schlichting's method.
- Correction for the wave-making part of the resistance is still be valid.
- Here the speed of translation of a wave in a channel depends only on the depth of water h , as in un-restricted shallow water.
- The speed correction for the potential flow have to be modified to take into account the additional limitation of the channel walls.

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Now, the things get more complicated when the ship moves into a canal or into a river where the boundaries and the banks of the river canal is getting closer to the ship. They will be additional effect coming to which and hence the flow velocity around the ship and subsequent effect on the resistance of the vessels. So, that is what is what we are going to look into in this lecture, so the shallow water with lateral restriction that what you consider here for the canal effect. So, you know ships mainly or vessels which are designed to operate in the inland water ways.

You know we have the three national inland water ways which are one Brahmaputra and other one Hubli and third one Kerala. So, this the auto vessels are operating in these region vessels exclusive designed exclusively for operation in inland water ways. So, the vessels which you design for the operation inland water ways should be able to operate at the required speed for which you need to consider the increase in resistance due to the restrictions imposed by the water depth.

That is the shallow water and also the effects coming from the boundaries of the canal or river so the aspects also should be considered. So, here Landweber suggested based on the experimental studies the extension of Schlichtings method what we have discussed in the shallow water. We said a Schlichtings method which has been used for the prediction of resistance in shallow water provided. You know the resistance of the vessel in deport a condition the resistance of the vessel in deport a condition is normally estimated because of standard procedure. The standard methods for the estimation of resistance vessel in deport a condition, so an information about the deport resistance of the vessel is readily available.

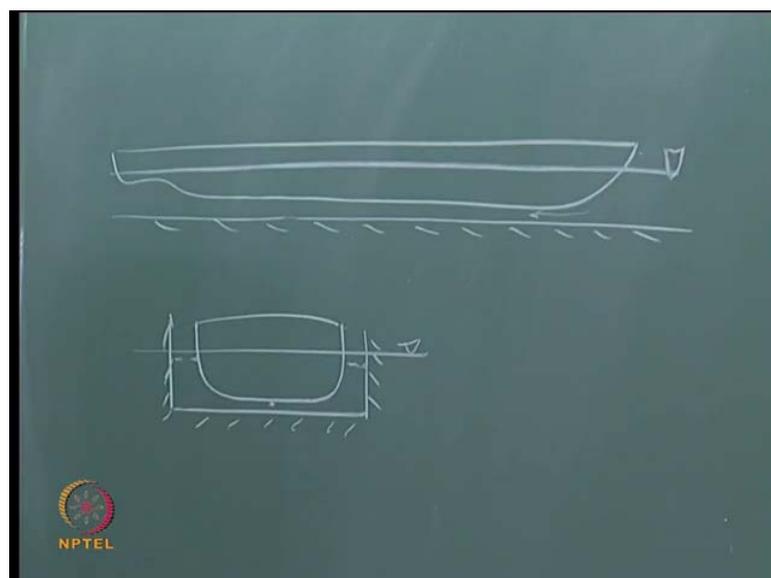
So, what do you do is you take that values and now you make corrections which will apply for the shallow water effect that is what is done interesting where he made many assumptions, many assumptions are controversial. Still, it gives a practical solution or engineering solution for the problem still continuity, we used to estimate the shallow water resistance. So, what Landweber does is, he just borrowed the same method Schlichtings method and applied for the vessels operating in canals and also for rivers. So, here he has given that correction for the wave making part of the resistance is still value that is what its assumption that is its Schlichting used assume that the waves generated by the ship in deep water.

The same type of waves, same pattern same size of the wave is created when the same vessel operate at a lower speed in shallow water. So, that means the same wave resistance applicable at the lower speed in shallow water which a vessel implies that the wave size increase at the same speed as it does in the deep water condition. So, that is what is done here, Landweber also assumes that or he has found from the experiment that the what way restrictions in the transits direction are not go into influence the wave part. So, the correction which has been applied for the shallow water still holds good for the vessel which operates in canal.

Also, no correction required for the wave making part whether its operation shallow water mean meant compare with shallow water and canal. So, the same can be extended here the speed of the translation of the wave in a channel depends only on the water depth. So, that is what it says it is unrestricted as in unrestricted shallow water, so the same water depth whether you use restricted water depth or un restricted shallow water it is going to be the same wave.

Hence, the methods suggested by Schlichtings can be adopted in this case also when the vessel operates in canal or rivers the speed correction for potential flow has to be modified. The ship operates through shallow water and also through canals the flow around the ship will be different.

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So, what do you consider here is you consider shallow water effect the ship is floating at the spot line and you see the bottom is very close to the bottom of the water bottom of the water waves where to close the bottom of the ship. So, when you consider shallow water, we have already seen that there is a construction of flow over just between the bottom and the water wave which leads to the increase of flow velocity. When the flow velocity increase the pressure drops and when the pressure drops the ship has to sink more to make up the loss by and see due to the reduce the pressure. When it sinks more, then they will be the wetted surface increases and due to the increase in wetted surface area.

Also, due to the increase in flow velocity there will be increase in resistance, but when you consider now the case with canal, you just consider just rectangular canal channel and base of water level. Now, you consider a ship the section view cross section ship is folding is like this, so this is the boundary of the canal. So, in addition to the construction here due to shallow water you have also there is a restriction of region for the flow of water when the ship is moving the water is escaping towards half side towards the raise side.

So, due to this restriction again the flow velocity increases and further drop in pressure and for the sink age of the vessel. Hence, more increase in resistance of the vessel so that is a reason physical reason given for to increase in resistance when the ship operates in canals or rivers, so that is what we have explained here.

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Resistance in Canals/Rivers (contd...)

Landweber used the term $\sqrt{\frac{A_x}{R_H}}$ in place of $\sqrt{\frac{A_x}{h}}$ in un-restricted shallow water case, where the hydraulic radius

$$R_H = \frac{\text{area of C.S. of channel}}{\text{wetted perimeter}}$$

$$R_H = \frac{bh - A_x}{(b + 2h + p)}$$

for a rectangular channel of width b and water depth h

For $b \gg h$, same as shallow water case, $R_H = h$

When a ship is in a rectangular channel, $R_H = \frac{bh - A_x}{(b + 2h + p)}$

Where p is the wetted girth of hull

Landweber curve $\frac{V_h}{V_t}$ versus $\frac{\sqrt{A_x}}{R_H} \rightarrow V_h$



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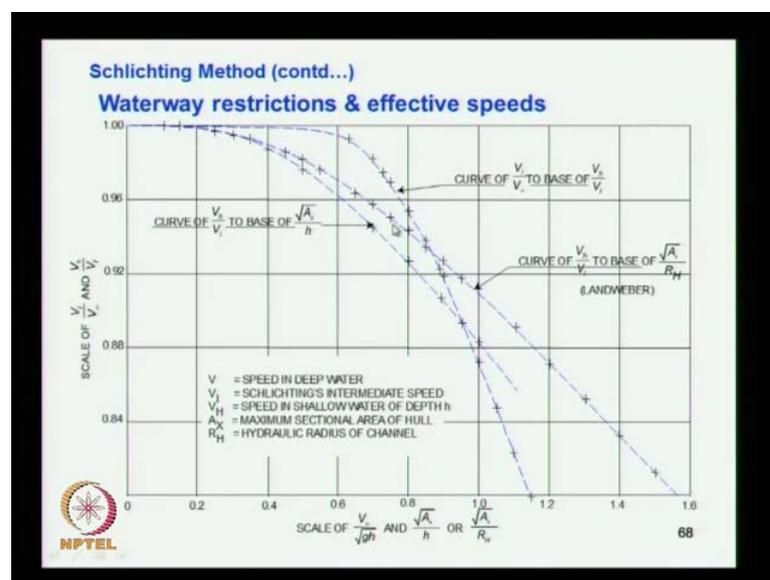
So, there will be an additional limitation on the channel walls, so due to the lateral restriction of the water wave. So, Landweber he has used another parameter that is the square root of A_x by R_h that is A_x is a section area of the maximum section of the ship under water below water and R_h is the hydraulic radius.

So, in their Schlichtings method he used A_x by R_h was the water depth, now Landweber when we when we considers the resistance of the ship in a canal the h component or h . The water depth is replace by another factor called the hydraulic radius, how do you estimate the hydraulic radius or how do you define the hydraulic radius that equal to area of the cross check of the channel divide by wetted perimeter. So, here if you consider the rectangular channel as we consider here with width is b and water depth is equal h , then you can see that the area of the section is on the water is $b h$ minus A_x that is the total water section area.

That is the section area of the channel and divided a perimeter b plus $2 h$ that gives a wetted perimeter of the channel plus p that is a wetted perimeter of the ship. So, that gives a total wetted perimeter, so this is an expression which he has suggested to estimate the hydraulic radius which will go as a parameter here. So, we have already seen we will come to that the whole that velocity difference is estimated, so the same expression what is if you look if b is very high b means breadth of the channel is very high.

It is as good as saving the shallow water because the boundaries are far away, so it is as good as shallow water. So, if you look to this b is very high, so the second term becomes insignificant because the b is very high here also b is very high. These two term becomes insignificant, so that means $b h$ by b its leads to h , so which implies that R_h is equal to h . So, the same formula holds good for the shallow water also not only for canal if b is large which implies that the boundaries of the channel are far away which is as good as saying it is a shallow water region. So, when a ship is rectangular channel we have already said that this is the expression for hydraulic radius

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If you look to the figure which we discuss in the previous class and see that here, again see that this is the pictures used Schlichtings and Landweber added one more curve to that this is the one Landweber. So, what do you did is you plotted $v h$ by $v i$ $v h$ by $v i$ in this axis against square root of A_x by R_h , so we do that is spot is plotted, so this you have this curve. Now, what do you do is you know what is this value A_x you know what is the ship section area under water you know what is the hydraulic radius which we have what we discuss.

Formally, you can find out R_h , so you know what this value square root of A_x by R_h is and then you find out with along this axis what the value is. Then take the inter section of that curve this curve, then you find out what is $v h$ by $v i$, So, $v h$ by $v i$ we have already

discuss in the previous Schlichtings method v_h is the actual speed of the vessel when it operates the shallow water and v_i is the intermediate speed which we have already seen.

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Shallow water effects (contd...)

Ship & wave speed relations

In order to generate a transverse wave with wave length L_w , the ship is required to have the speed of the wave V_w

In deep water, the ship speed $V_w^2 = \frac{gL_w}{2\pi}$

In finite water depth h , the same wave length L_w would be generated at some lower or intermediate ship speed V_i

$$V_i^2 = \left(\frac{gL_w}{2\pi}\right) \tanh\left(\frac{2\pi h}{L_w}\right)$$


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I think if you recall the expression which we discussed v_i is coming from this expression, so it is coming from the finite water depth wave theory. So, v_h is coming from this expression which is known and from this curve what do you get is the v_h by v_i I know v_i , we will find out what is the v_h that is the speed achievable by the vessel when it operates through the channel, so we have seen here.

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Resistance in Canals/Rivers (contd...)

Landweber used the term $\sqrt{\frac{A_x}{R_H}}$ in place of $\sqrt{\frac{A_x}{h}}$ in unrestricted shallow water case, where the hydraulic radius

$$R_H = \frac{\text{area of C.S}^n \text{ of channel}}{\text{wetted perimeter}}$$

$$R_H = \frac{bh - A_x}{(b + 2h + p)}$$

for a rectangular channel of width b and water depth h

For $b \gg h$, same as shallow water case, $R_H = h$

When a ship is in a rectangular channel, $R_H = \frac{bh - A_x}{(b + 2h + p)}$

Where p is the wetted girth of hull

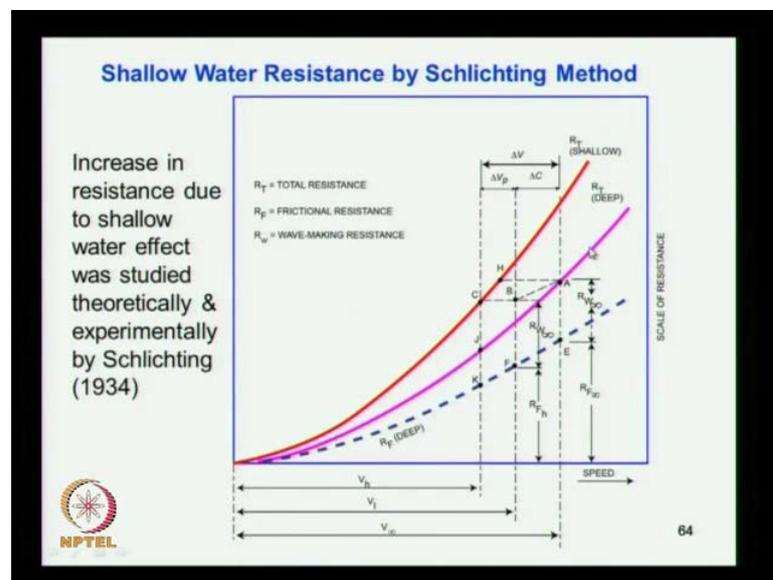
Landweber curve $\frac{V_h}{V_i}$ versus $\sqrt{\frac{A_x}{R_H}} \rightarrow V_h$



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So, what do you get we get this quantity the curve we have seen there is a Landweber curve v_h by v_i against square root of $A \times R_h$. I think there is a mistake here there should be square root only in the top that numerate, so this quantity from the graph you get this value and from which by knowing v_i which is known from the wave theory expression what I have shown to you now. So, you get v_h that is a speed of the ship in the canal, so here what implies that if you recall what we discussed in the shallow water effect assume that for the same resistance what is the speed. We have found that there are speed reduction in two counts, one is by we will show that.

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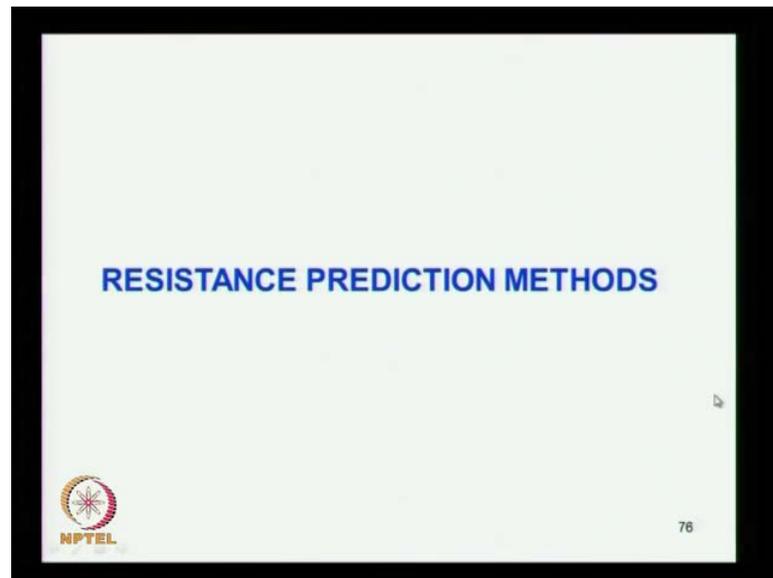


Here, what we have seen that which we use for the Schlichtings method, so here what do you have is you have there is a depart the resistance which you estimate through any of the methods. It may be Guldhammer Harvald method or maybe there are different methods which will be saying later. So, this is easily available, so from for this curve and for this resistance you are taking a point a here for this resistance what would be the speed of the vessel when it operates in a shallow water that is this curve referring. So, here it refers to the first a reduction due to the wave making the speed reduces due to wave making so the fractional resistance curve is this.

Wave making is taken as same at a lower speed, so that is how you put the same wave making resistance here and here. From that point, you put another for the potential effect that is due the drop Δv_p is due to the drop in the speed due to the potential effect.

Finally, you get a point c and that point c is a point on the total resistance of the vessel in shallow water that is the procedure adopted by Schlichtings. So, here also you follow the same procedure only thing that v_i is now come b_h is come from the Landweber curve, so that is the difference where you use the hydraulic radius in place of the water depth.

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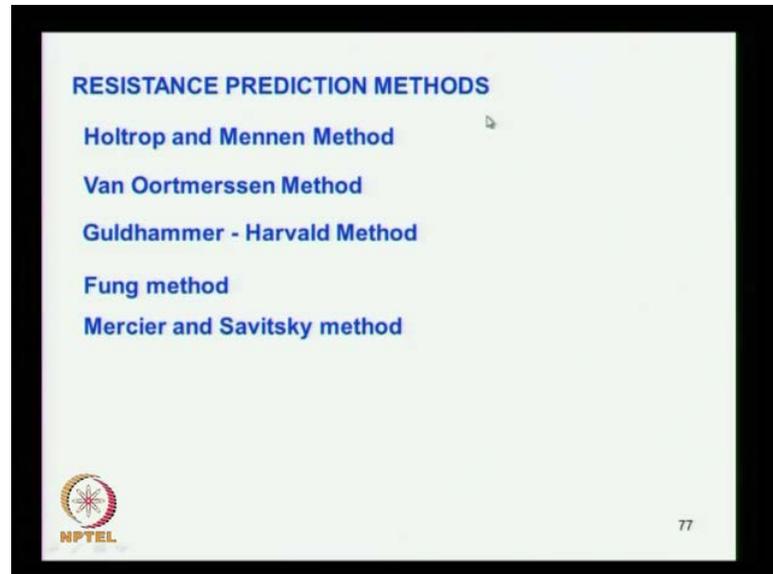
So, that completes the water depth effect and the boundary effect a wall effect on the total resistance of the ship. Now, we see there are different methods of prediction of the resistance of a ship for different that we will see what the limitations applications of a different methods and most of this methods based on the experimental studies are. Systematic model tests have been carried out and the resistance let has been obtained and that has been presented in a very systematic way for the use of designers.

When you design a ship you know that you need to know the recommend what is that resistance offered by the vessel and then by knowing the propulsion c efficiency and all that you will be able to predict the power required for the ancient. So, which again go as input into the design of the ship and so the initial stages of the design and even after even different stages were designs.

These methods are useful to estimate resistance some powering of the ship and finally, wants a design has been converged. Then you go for a model tests and using the model tests you recheck the resistance recheck the power. They are propulsion aspects including the performing self propulsion does and all that and also the purple efficiency,

then you find out what is the transmission losses de rating and all that and finally, arrive at the ancient power required for the ship.

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So, we see the different methods with various methods which we discuss as here are one is Holtrop and Mennen method other one is Van Oortmerssen method then Guldhammer Harvald method Fungs method Mercier and Savitsky method. So, these are the different method which will be discussing here which is used for the prediction of resistance of vessels marine class there are small vessels some others exclusively for small vessels. Some methods more general, some methods are exclusive of bigger shapes and all that, so you just that when a progress with the lecture.

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Holtrop and Mennen Method

Suitable for resistance prediction of the following vessel types.
Limited for vessels with $Fn < 0.5$.

Valid range of parameters

Ship Types	Max. Froude Number	C_p		L/B		B/T	
		Min	Max	Min	Max	Min	Max
Tankers, Bulk carriers	0.24	0.73	0.85	5.1	7.1	2.4	3.2
Trawlers, coasters, tugs	0.38	0.55	0.65	3.9	6.3	2.1	3.0
Container ships	0.45	0.55	0.67	6.0	9.5	3.0	4.0
Destroyers							
Cargo liners	0.30	0.58	0.75	5.3	8.0	2.4	4.0
RO-RO ships, Car ferries	0.35	0.55	0.67	5.3	8.0	3.2	4.0

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So, here first we look into the Holtrop and Mennen method so here generally says that this is limited for the vessels with Froude number less than 0.5, so do not have play to planning cross and high speed vessels. So, limit the use this method only for vessels with Froude number less than 0.5 and also he put other parameters of the vessels which have been considered for the experimental studies by this group. Based on this, the resistance data has been prepared and presented in more systematic way may be finally using a regression expression. We see that later words have expression used, so here they are of with this side these types of vessels we can apply that is tankers and bull carriers.

You can do it, he has put the limit Froude number 0.24 that is the Froude number of maximum Froude number 0.24. Usually, these vessels come in that range then the prismatic coefficient various from 0.73 to 0.85. That is the range of the ship, so if your ship which the ship which you design follow of all in within this range, then only you apply it if you apply for the vessels which fall outer than the range.

Then, naturally this standard chance of inaccuracy in that prediction then length and breadth ratio of the ship 5.1 to 7.1 that is the range suggested and b by t breadth to draft ratio is 2.4 to 3.4. So, this is the range of applicability of this method and for other type of ship trawlers coasters and tugs small curves. Generally, we can see it is the Froude number maximizes allows 0.38 and these are the limits for C_p that is 0.55 to 0.65 l b by

3.9 to 6.3 b by t 2.1 to 3. So, these are the application limits for these types of vessels, similarly we have the containers ship and destroy relatively faster ship.

You can say the max of Froude number is 0.45 and this are the ranges of C p l by b b by t, so then cargo liners relatively low velocity 0.3 is the Froude number maximum limits. This methods application and this are the range of application of the parameters like C p from 0.56 to 0.75. So, its big bite range and l b by b y 0.3 to 8 again its range is wide took then b by t 2.4 to 4, so these are range of application of this method for type of vessel. Then RO RO ships and car ferries this is a Froude number maximum then you can see the variations here C p l b by b and b by t. So, when you use when you design any of this vessels and you see that its falling with in this limits then you can use Holtrop and Mennen method more reliably.

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Holtrop and Mennen Method (contd...)

The total resistance of a ship is subdivided into:

$$R_{Total} = R_F \cdot (1 + k_1) + R_{APP} + R_W + R_B + R_{TR} + R_A$$

- R_F frictional resistance (ITTC-1957 friction formula)
- $1 + k_1$ form factor
- R_{APP} resistance of appendages
- R_W wave-making and wave-breaking resistance
- R_B additional pressure resistance of bulbous bow near the water surface
- R_{TR} additional pressure resistance of immersed transom stern
- R_A model-ship correlation resistance

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So, here R_d presents is a total resistance is equal to this expression given for that where is common is R of referring to fractional resistance which come from ITTC. You already know that c_f is equal to 0.075 divided by $\log R_n$ minus to the whole square that is the expression for c_f value. Then this is a form factor which has been suggested by ITTC 1978 method, so we have to use the form factor. We have already discussed about what is form factor, it is due to the increase in flow velocity due to the three dimensional curvature of the ship. The ITTC formula has been derived based on the tests carried out on flat plates whether three dimensional flow variations has been ignored.

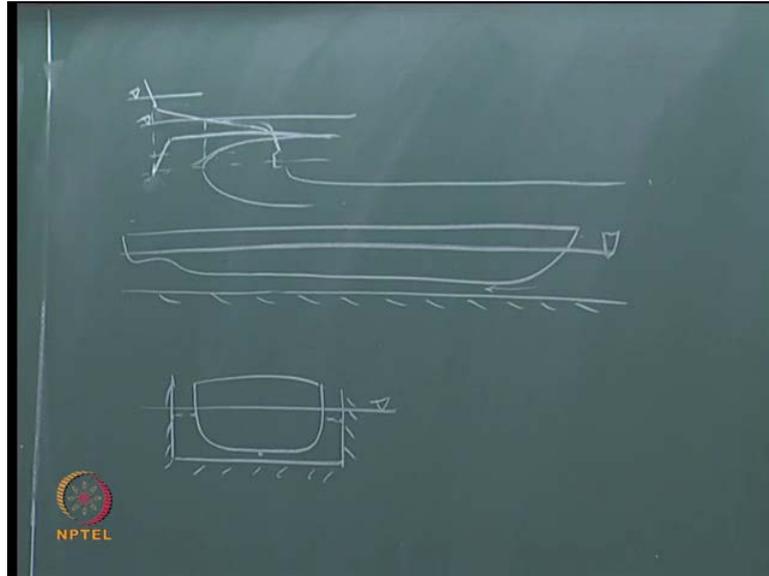
So, when you cancel the ship which is totally different from the flat plate then the flow around the ship the velocity of the flow increase due to the curvature nature. This flow velocity results in increased frictional resistance because we know that frictional resist is proportional to v power 1.825. So, naturally when the velocity increases the friction resistance was also increase, so that variation is not considered in the ITTC flat plate formula so this accounts for that form effect.

We have already discussed about the how the estimation of the form factor mainly use by Prohaskas method, we have just been followed adopted by ITTC and recommended for yours. Then you have the R , this quantity is appendages of resistance, so often you do the resistance tests without the appendages without the rudder without Bleigh Keel without the sharp brackets. So, there are many appendages which are of included in the resistance estimation performed by model tests. So, if it is not included then you have to give a allowance for the appendages resistance additional resistance offered by the appendages so that is what is doing here by this term. Then you have the wave making resistance R_w which is the primary component in resizer resistance.

So, you have the wave making resistance here and all set includes the wave breaking resistance. So, wave breaking resistance you already know that is due to the rest increase into resistance due to the breaking of the bow wave. When the bow wave exists a limit or the straightness of the bow wave go beyond a limit and it breaks and resulting in increasing resistance due to the breaking of the wave.

Then, R_b is an additional pressure resistance of bulbous bow near the water surface though if there is an increase in resistance effect when the bulbous bow which comes closer to surface it creates more disturbance and effect. Due to that, then the transom with the transom is not if it is immersed, then obviously there will be a sudden flow separation and the transom and the transom immersed there will be a flow separation I think you know that.

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If you concerned ship with a transom, so if you consider transom, so oppose a water line is here the transom is not immersed. So, if you consider water plain at this land, then you will get a very smooth shape, if you consider at this position. So, it is more suppose the transom immerses suppose the water design water line is here, so you will have the same thing here it will be somewhat or may be like this. So, the ship will have an abrupt change when the flow is there, there is an abrupt change of the flow at that when the transom immerses.

Due to that, there will be a increase in resistance because in the flow separates there will be a formation of dish and a dish leads to increase in resistance. So, when the transom is immersed there will be a increase in resistance which is accounted by this term $R_t R$ so that is what is prescribed here. Then you know that is a model ship correlation allowance which we also we discussed the correlation allowance is given when you do the resistance estimation for prototype ships because the model which is normally made of wax or fibre glasses.

Other materials having very good very high finish for suffers, but when it comes to a ship the ship is not going to such a good finish it will have the all the wall joints or it may have the plates deformations between the frames. These things are not properly predicted by the represented if the geometric model of the ship when it done the model tests. So, there will be the increase in to resistance due to the in coefficient of the surface

and also due to the increase in roughness of the skin of the ship, so that increase in resistance accounted by this allowance. So, this called the model ship correlation, so these are the different terms which appear in the total resistance represented by Holtrop and Mannen.

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Holtrop and Mennen Method (contd...)

The form factor is given by

$$(1 + k_1) = c_{13} \left\{ 0.93 + c_{12} \left(\frac{B}{L_R} \right)^{0.92497} \cdot (0.95 - C_p)^{-0.521448} \cdot (1 - C_p + 0.0225 \cdot lcb)^{0.6908} \right\}^{1.2}$$

C_p is the prismatic coefficient based on L
 lcb is in percentage of L about midship (+ve forward)

$$\frac{L_R}{L} = 1 - C_p + \frac{0.06 \cdot C_p \cdot lcb}{4 \cdot C_p - 1}$$

$$c_{12} = \begin{cases} \left(\frac{T}{L} \right)^{0.2228446} & \text{for } \frac{T}{L} > 0.05 \\ 48.20 \left(\frac{T}{L} - 0.02 \right)^{2.078} + 0.479948 & \text{for } 0.02 < \frac{T}{L} < 0.05 \\ 0.479948 & \text{for } \frac{T}{L} < 0.02 \end{cases}$$

 T is the average moulded draft

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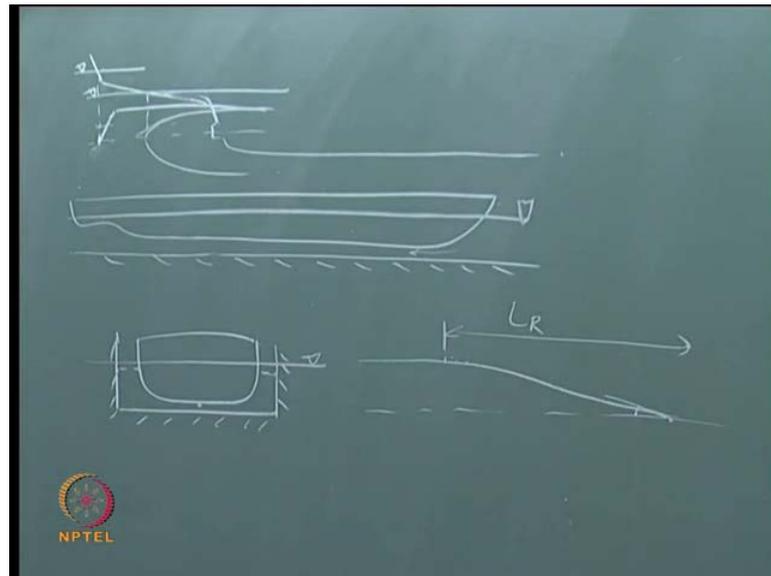
Now, we see how these components are estimated, so R f we know the first component we know it is coming from ITTC formula. This is coming from that is because c f you get from ITTC formula into half row s v square you get R f value. So, you do not need that explanation for that, then we have this form factor one plus k one next term is given by this expression by Holtrop Mannen.

So, we have to put c 1 3 into 0.93 plus c 12 into b by l R into whole raise to point this of quantity, then you have 0.95 minus C p, C p is the prismatic coefficient raise to this one. Then 1 minus C p plus this into l c b raise to so much l c b is a natural centre of point c and l c b is here is given as percentage of the length about midship. I mean forward of midship is taken a positive, so there is this gone percentage usually you get about two to three percent forward of the midship or some ships we get so much. So, there it will be negative, so l c b is place an importance role in resistance because when you say l c b is positive that means the centre of forward a midship.

It implies that the hull of the ship is more in the forward side when you say l c b forward means it is the concentration of volume is towards of forward. So, when the hull become

more in the forward the flow separation though the flow will be or the resistance component will be higher. So, usually that is you know correction given for the l_{cb} position so if faster ship you will find that l_{cb} is after midship you will say slow ship. Then you may find l_{cb} forward of it, so here $SS C_p$ say then l_R is a length of a run means you must have studied will a consider the ship.

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Suppose, against the water plain it is coming like this half of it and you know that you call this angle this angle is entry angle, half entry, half angle, half entry and this length we continues till the when it is a parallel region. This length you call it angle length say l_R , so that is the length here, once you know the water plain of the load water length then you know the form of it you can measure what is l_R from that. So, that is $l_R b$ is a breadth, so all this parameter is known is b is known, so you know what is C_p you know what is l_{cb} all from the design accept c_{13} or c_{12} . These two parameter c_{12} know which is define below, so here l_R what you get is if you do not you can use this formula also for l_R l_R by l is equal to $1 - C_p$ into 0.06 into $C_p l_{cb}$ by $C_p - 1$.

We know all this values from the design, so you get what is l_R by l is known from which you will get l_R . So, you get substitute here you get l_R , then you need c_{12} this quantity here, so c_{12} is given here that is for t by l greater than 0.05 use this expression for t by l between 0.02 and 0.05 use this value this expression over here. For t by l less

than 0.02, use these values, so depending on what is the draft to run the ratio of the ship, so which was appropriate relation here and find out what is c_{12} substitute it here.

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Holtrop and Mennen Method (contd...)

$$c_{13} = 1 + 0.003 \cdot C_{stern}$$

C_{stern} coefficient indicates the after body form

$C_{stern} = -10$ for V-shaped sections

$C_{stern} = 0$ for normal sections shape

$C_{stern} = 10$ for U-shaped sections

The wetted surface area of the hull can be approximated by

$$S = L(2T + B)\sqrt{C_M} \left(0.453 + 0.4425C_B - 0.2862C_M - \frac{0.003467B}{T} + 0.3696C_{WP} \right) + 2.38A_{BT}/C_B$$

A_{BT} is the transverse sectional area of the bulb

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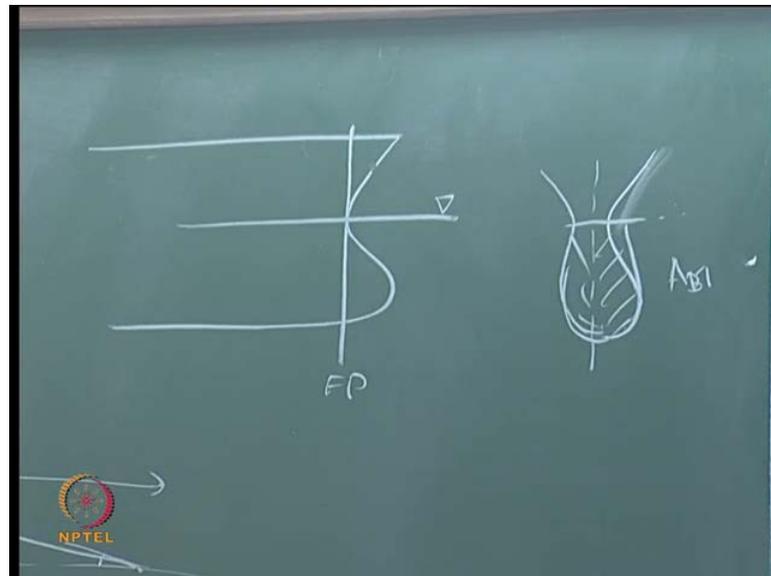
Now, we are left out with c_{13} , let us see that what is there c_{13} is equal to 1 plus 0.003 into C_{stern} what is C_{stern} what is C_{stern} a coefficient indicates the after body form after body form you have. You can see that the form of the ship is basically defined as normal form, it is the conventionally used for the test then there is a V form and there is a U form. So, these are the three forms generally classified, so depending on the what type of form of the section you used for the ship in the after region you choose the value from.

This if it is a V section, you choose minus 10, then C_{stern} is equal to normal no correction no this is not required and so here this is one C_{stern} . So, what you get is you get find out what is a c_{13} here and then you substitute back to the previous expression. So, everything is known you can find out what is 1 plus k_1 and then you put the 1 plus k_1 here.

So, R_f is not coming from ITTC 1 plus k_1 no way estimated, now you look to the wetted surface area. How it is defined the wetted surface area of the hull can be approximated by S , S equal to L , length of the ship 2 times draft plus breadth of the ship in the square root of mid ship be the coefficient into this expression into coefficient. Then you have the mid ship area of coefficient here then b by t here, then water plain area coefficient. Then finally the bulbous of fact A_{BT} there is a transverse sectional area

of the bulb divided by c_b the transverse section area of the bulb, means when you consider this ship as bulbous bow which is considered.

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Now, we are left out with c_{b1} a ship that bulbous bow and this is the forward perpendicular and you know this is the usually the position of the water line load water line. So, if we take a section here you will see that the section may be its coming in the forward section it may be slightly it is going to be like this. Then you take the area this is the half of it this into two because we have considering the full area the whole area that is A_{BT} area of a bulb it is a transom, so that is A_{BT} .

So, you take a section at the of the bulb at the forward perpendicular take the underwater area of that section that is given as A_{BT} is a transfer section area of the bulb so which go as a input here. So, all the parameter are known here, so you can find out what is the wetted surface area of the ship it is an approximate form which will be used.

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Holtrop and Mennen Method (contd...)

The appendage resistance can be determined from

$$R_{APP} = 0.5\rho V^2 S_{APP}(1 + k_2)_{eq} C_F$$

ρ is the water density,
 V is the ship speed,
 S_{APP} is the wetted area of the appendages,
 $(1+k_2)$ is the appendage resistance factor (see next slide)

$$C_F = \frac{0.075}{(\log Rn - 2)^2}$$


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In the design appendage, resistance is equal to 0.5 ρV^2 into surface area of the appendage you have the Bleigh keel, you have the rudder and other appendages. You have to know appendage into 1 plus k_2 equivalents into C_F , so you find out C_F again from ITTC formula. Then you have this 1 plus k_2 expression which is given in the next sheet, so ρ is the density V is the ship speed. So, once you the appendages, you will you can find out what is a surface area and all that, so 1 plus k_2 is appendages resistance factors. So, here one thing we have to note is that C_F is also I have mentioned it is coming from ITTC formula. So, one thing we have to note is the appendage resistance you know is directly only related to C_F and no other components.

Resistance are not considering appendage resistance, we are not having C_W here, no other or other components coming here the reason for that is the suppose you can say Bleigh keel which is at the bottom of the ship. It is not going to create in a wave, so you just a making an assumption that it contributes solute of friction essence is acceptable and may be the popular bracket and popular bossing and all that. So, this also sufficiently and submerged in water. So, its effects at the face of a, so create a wave is not there and rudder also moral a same so this appendages generally the contribution is only on the frictional side not on the wave making side.

That is why this expression is confirming only to the C_F parameter, not other parameters. So, once you know 1 plus k_2 , this surface area is coming from the

appendage once you design the rudder. Once you design the Bliegh keel, you know what a surface of this you can use that value C F is coming from here. You know the Reynolds number and all that, so you can that C F and only thing left is the unknown is 1 plus k 2, so we see it is given in a next slide here.

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Holtrop and Mennen Method (contd...)
Approximate $(1+k_2)$ values

Rudder behind Skeg	1.5-2.0
Rudder behind stern	1.3-1.5
Twin screw balance rudders	2.8
Shaft brackets	3.0
Skeg	1.5-2.0
Strut bossings	3.0
Hull bossings	2.0
Shafts	2.0-4.0
Stabilizer fins	2.8
Bilge keels	2.7
	1.4

The equivalent $(1+k_2)$ for a combination of appendages is determined from

$$(1+k_2)_{eq} = \frac{\sum(1+k_2)S_{APP}}{\sum S_{APP}}$$

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So, you can see the values here 1 plus k 2 rudder behind skeg, you have a skeg and rudder behind it. So, use this 1 plus k 2 values 1.522 rudder behind stern no skeg, then mean behind stern means behind the popular stern. Then you have this one this is a parameter twin screw balance rudder if you are using balance rudder twin screw. So, popularly to select the factor from here shaft brackets turn by this quantity the skeg alone. You give this one strut bossing, this one hull bossing, you have then shaft stabilizer fins if you are using it is a putting out to this subliming fin use this factor if say dome.

So, not domes are used for naval vessels, you know that if you have a dome previously it used to be a mid ship region. Now, a day's, they only preferred at the bulbous bow, the naval vessel they combined it with the bulb the bow part. So, the dome plus a bulbous will be sink loaded, so it is now they say generally preferred because that dome its basically for under water scanning in all that using sound waves. So, you if you put at the forward and it will be less disturbed, you know the seven should be less so the signals which you get are clearer.

So, the clarity of the signals is better when you put it the dome at the far end and also the dome will save the purpose of a bulbous bow. So, that is why, so if you are using that find out this, then Bleigh keel is this, so depending on what type of appendage you are using and you choose this 1 plus k 1 k 2 value from here. Then finally you find out the 1 plus k 2 equivalent is represented by this expression that is 1 plus k 2 of one component plus its wetted surface area.

Then, 1 plus k 2 of the next component and it is a wetted surface, and then divided by total wetter surface area. That gives the 1 plus k 2 which will go as in the go into this here and then you find out what is the R appendage and it goes into this portion that is an x what we get here, now the next component is wave making resistance R w.

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Holtrop and Mennen Method (contd...)

$$R_w = c_1 \cdot c_2 \cdot c_5 \cdot \nabla \cdot \rho \cdot g \cdot \exp\{m_1 \cdot F_n^d + m_2 \cdot \cos(\lambda \cdot F_n^{-2})\}$$

$$c_1 = 2223105 \cdot c_7^{3.78613} \cdot \left(\frac{T}{B}\right)^{1.07961} \cdot (90 - i_E)^{-1.37565}$$

$$c_7 = \begin{cases} 0.229577 \left(\frac{B}{L}\right)^{0.33333} & \text{for } \frac{B}{L} < 0.11 \\ \frac{B}{L} & \text{for } 0.11 < \frac{B}{L} < 0.25 \\ 0.5 - 0.0625 \frac{L}{B} & \text{for } \frac{B}{L} > 0.25 \end{cases}$$

c_2 is a parameter which accounts for the reduction of the wave resistance due to action of the bulbous bow,

c_5 expresses the influence of transom stern on wave resistance,

$$c_2 = \exp(-1.89\sqrt{c_3})$$

A_T represents the immersed part of the transverse area of the transom at zero speed

$$c_5 = 1 - 0.8 \frac{A_T}{BTC_M}$$


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So, this R w is expression c 1 into c 2 into c 5 into volume displacement rho g in the exponential of this parameter. Now, you find out what is c 1 on to all this parameter c 1 is done by this expression, so much into c 7 raised 2 of this value T by B draft by breadth power this and 90 minus i is the half angle entry raise with this, so this are the parameter, we see how this parameters x. So, c 1 is coming from here, now you have to know what is c 7, c 7 is given by this expression it is based on B by l less than b by l ratio.

If it is less than 0.11, you use this expression if it is between 0.11 in 0.25, you use this expression or if it is between greater than 0.25, use this expression. So, depending on the vessel dimensions L and B you find out where it lies and take the appropriate expression

and then find out what is c_7 c_2 is given by exponential of that is e power minus 1.89 the square root of c_3 and that is what is given here. We will see what is c_3 , now and k_R and c_5 is given by this expression, so here you can see that c_2 is a parameter which accounts for that reduction. The wave resistance due to the action of bulbous bow, so you can see that c_2 is coming from c_3 and will be in the next slide, we will see the c_3 , c_3 is coming here.

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Holtrop and Mennen Method (contd...)

The half angle of entrance i_E is the angle of the waterline at the bow in degrees with reference to the center plane is

$$i_E = 1 + 89 \cdot \exp \left[- \left(\frac{L}{B} \right)^{0.80856} (1 - C_{TP})^{0.30484} (1 - C_P - 0.0225 \lambda c_b)^{0.6507} \left(\frac{L_2}{B} \right)^{0.34374} \left(100 \frac{V}{L^3} \right)^{0.16802} \right]$$

The coefficient that determines the effect of the bulbous bow on the wave resistance is defined as

$$c_3 = \frac{0.56 A_{BT}^{1.5}}{B T (0.31 \sqrt{A_{BT}^2} + T_F - h_B)}$$

h_B is the position of center of transverse area A_{BT} above the keel line
 T_F is the forward draught of the ship

$$\lambda = \begin{cases} 1.446 C_P - 0.03 \frac{L}{B} & \text{for } \frac{L}{B} < 12 \\ 1.446 C_P - 0.36 & \text{for } \frac{L}{B} > 12 \end{cases} \quad \text{Appearing in Eq. for } R_w$$


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Here, c_3 depends on the bulbous parameter; c_3 is depending on A_{BT} that is area of the bulbous bow. I have already explain that, then though out of parameter related to the bulbous bow, so c_3 determined c_2 and hence c_2 is the parameter which accounts for the bulbous bow effect. So, c_5 what do we see here, the expresses the influence of transom you can say that represents a transom immersed area is a transom of the ship. So, take the transom of the ship and take the underwater area of the transom and there is a 80 , so then b_t into c_m .

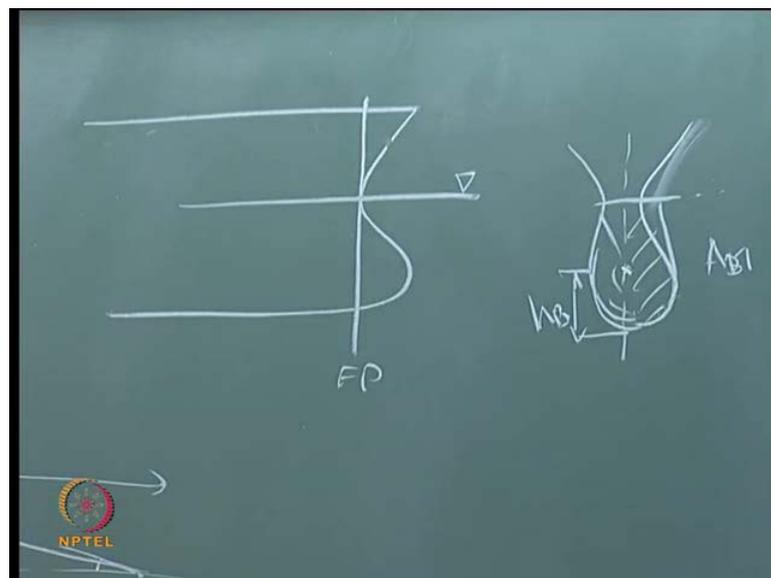
So, this gives c_5 , so that is what a t represents, the immersed the part of the transverse area of the transom at 0 speed. So, that means 0 speed means when the speed is high, the water surface changes elevation changes. So, do not take that in calm water, you take the static condition where the underwater area of the transom is.

So, the half next is half angle of entrance, now we have seen this we have seen c_1 , we have seen c_2 and coming from what is say from c_3 . It is coming c_5 is coming from

here and row and g , we know, now we see other parameters here half angle of entrance given by this expression. You know already what effects may half draught during into half angle of entrance and small of the half angle of entrains find out the ship form will be and fast. The ships usually have small values for half angle of entrains and bulk carries and tankers which are more fold.

They will have a larger angle of entrains for the load water line, so e that is a half angle of entrains is given by this expression even this all known l by $B C w p$ water plain area coefficient $C p L R$ already explained. Also, given in the expression, this known volume displacement L cubes, so everything is known so what you do is you can straight find out what is $i e$ value. Then $c 3$ as a c which use them $c 2$ had is area of the bulb and your having this the ratio of $1.5 A B T t f$ is a drafted forward and $h b$ is the position of centre of transverse area above the keel that is the $h b$, $h b$ is, you find out the centre of the position.

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You find this A , area centre may be somewhere here the word is this, it is $h B$, so that is the value, so which should get from the form descent. So, that is $h B$, so once you get all this parameter reason find out $c 3$ and then you substitute it here, you get $c 2$. So, all these parameters are obtained now and the one parameter left out you can see $m 1$ and $m 2$ and λ to be obtained. Let us see how it is a λ is given by this λ is

equal to given by this expression if L by B is less than 12 or given by this expression if L by B is greater than 12.

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Holtrop and Mennen Method (contd...)

$$m_1 = 0.0140407 \frac{L}{F} - 1.75254 \frac{\nabla^{1/3}}{L} - 4.79323 \frac{B}{L} - c_{16} \quad \text{Appearing in Eq. for } R_w$$

$$c_{16} = \begin{cases} 8.07981C_p - 13.8673C_p^2 + 6.984388C_p^3 & \text{for } C_p < 0.8 \\ 1.73014 - 0.7067C_p & \text{for } C_p > 0.80 \end{cases}$$

$$m_2 = c_{15} \cdot C_p^2 \cdot \exp(-0.1F_n^{-2}) \quad \text{Appearing in Eq. for } R_w$$

$$c_{15} = \begin{cases} -1.69385 & \text{for } \frac{L^3}{\nabla} < 512 \\ 0.0 & \text{for } \frac{L^3}{\nabla} > 1727 \\ -1.69385 + \frac{\left(\frac{L}{\nabla^{1/3}} - 8.0\right)}{2.36} & \text{for } 512 < \frac{L^3}{\nabla} < 1727 \end{cases}$$


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So, this will also go to that expression m 1 and m 2 which written is also given here, m 1 depending again on length root draft ratio displacement raise to third by L and B by L. Then c 16, here c 16 we are getting from this expression which is depending on C p value C p less than 0.8. You have to use this expression if C p is more than 0.8, use this expression, so from which we get c 1 6 substitute c 1 6. Here, other parameters are known you get m 1, now coming to m 2 c 15 into C p square into this quantity over here. So, here you have to find out c 15, c 15 again depends on L q by volume displacement.

So, depending on that if it is less than 5, 12 use this greater than this, use this and if it is between this, use this expression. So, depending on once you find this quantity you should choose the appropriate relation here, find out c 1 5 substitute c 1 5, here you get m 2. So, all the quantities are now known here you get R w, so R w will go to this expression here.

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Holtrop and Mennen Method (contd...)

The total resistance of a ship is subdivided into:

$$R_{Total} = R_F \cdot (1 + k_1) + R_{APP} + R_W + R_B + R_{TR} + R_A$$

R_F frictional resistance (ITTC-1957 friction formula)
 $1 + k_1$ form factor
 R_{APP} resistance of appendages
 R_W wave-making and wave-breaking resistance
 R_B additional pressure resistance of bulbous bow near the water surface
 R_{TR} additional pressure resistance of immersed transom stern
 R_A model-ship correlation resistance



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So, you get this term here then the additional resistance due to presence of the bulbous bow near the surface is determined that is R_B .

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Holtrop and Mennen Method (contd...)

The additional resistance due to presence of the bulbous bow near the surface is determined from

$$R_B = 0.11 \exp(-3P_B^{-2}) F_{ni}^3 A_{BT}^{1.5} \rho g \mu (1 + F_{ni}^2)$$

Where P_B is a measure the emergence of the bow and F_{ni} is the Froude number based on immersion

$$P_B = 0.56 \sqrt{A_{BT}} / (T_F - 1.5h_B) \quad F_{ni} = V \sqrt{g(T_F - h_B - 0.25\sqrt{A_{BT}}) + 0.15V^2}$$

The additional pressure resistance due to immersed transom is determined from $R_{TR} = 0.5\rho V^2 A_T c_6$

The coefficient c_6 is related to the Froude number based on the transom immersion

$$c_6 = 0.2(1 - 0.2F_{nT}) \text{ for } F_{nT} < 5; \quad c_6 = 0 \text{ for } F_{nT} \geq 5$$

$$F_{nT} = V / \sqrt{2gA_T / (B + BC_{WP})}$$

The model-ship correlation resistance is determined from $R_A = \frac{1}{\tau} \rho V^2 S C_A$



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We have already seen that this is the additional resistance when bulbous bow comes to the surface. If it is not coming to the surface, you discard that if it is coming to surface, then you use this expression here. This is the expression P_B raise to minus two $f_{ni} A_{BT}$ you know that and you see that these are the is R_B value, so here P_B is measure is a measure of the emergence of the bow which is given by this. I can say that P_B is given

by this expression, now we know what h_B , A_{BT} is and all that you know you find out what is P_B then the F_{ni} is the Froude number based on the immersion. So, it depending on the immersion the water length changes so the Froude number also changes.

So, you take it accordingly here, so that is what is the v into curve g into t f minus h p minus all this parameter are known, so you find out what is F_{ni} . From this, once you get P_B and F_{ni} you go here you get R_b that is a next term appearing in the expression for the total resistance of put forward by Holtrop and Mannen. So, there is a, then you find out what additional resistance due to the immersion of transom, so R_{tR} that is equal to $0.5 \rho V^2 a_t$ into c_6 .

So, here what do you do is you find out all every you know everything except c_6 , c_6 is taken from this formula that is the c_6 is equal by F_{TFT} , F_{NT} is equal to less than 5, F_{NT} I think it should be a Froude number. It is given here F_{NT} is given by V by square root of $2g$ a_t into B plus B into C_w , so everything is now this are transom submerged area and B breadth is a water plain area coefficient.

So, we can find out what is F_{NT} , so F_{NT} you substitute here, then you get c_6 , then you substitute c_6 here, you get R_{tR} that is a transom in resistance due to a transom immersion. Then the model ship correlation allowance is R_A is equal to half $\rho V^2 S$ into C_A C_A is the correlation allowance coefficient. Usually, it is given as 0.0004, so that is a correlation allowance 0.000430 and 4 that is normal.

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Holtrop and Mennen Method (contd...)

Limitations on Hull parameters

Parameter	Limitations
C_p	$0.55 < C_p < 0.85$
L/B	$3.9 < L/B < 15$
B/T	$2.1 < B/T < 4$
F_n	$F_n < 0.5$
T_r/L_{wl}	> 0.04

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So, if you know that C_A value, you can use it and all if you have another expression that also can be used for that. So, with that we have we can estimate what is R_B what is R_T R and finally, we go to the expression here a total resistance. We have already seen all this terms you just subtitle it there, so you get the total resistance, so that is how the Holtrop and Mannen method has been revolt and presented.

Finally, you put the limitation of the hull parameters C_p between this 1.55, 2.85 L by B is taken 3.9 to 15 B by T for 2.1 to 4 Froude number less than 0.5. The drafted forward divided by load length of load water length should be greater than 0.04, so if you look all this aspects, then we will satisfy this parameters. You can use the Holtrop and Mannen method and the Holtrop and mannen method you know it is based on experiments carried out on the different types of models in a systematic way and you flow the vessel fall in this the results are reliable.

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Van Oortmerssen Method
For estimating the resistance of small ships such as trawlers and tugs

Limitations of Van Oortmerssen method

Parameter	Limitations
L_{wl}	8 to 80 m
Volume	5 to 3000 m^3
L/B	3 to 6.2
B/T	1.9 to 4
C_p	0.50 to 0.73
C_m	0.7 to 0.97
LCB	-7% L to 2.8% L
$\frac{1}{2} i_E$	10° to 46°
$V/(L)^{0.5}$	0 to 1.79
Fn	0 to 0.50

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So, that is what we have, so that completes the first method as the Holtrop and Mannen method for the estimation of resistance.

Thank you, we will continue in the next class.