

Lecture Note of Innovative Ship and Offshore Plant Design

# Innovative Ship and Offshore Plant Design

## Part I. Ship Design

### Ch. 8 Hull Form Design

Spring 2017

**Myung-II Roh**

Department of Naval Architecture and Ocean Engineering  
Seoul National University

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- ☑ Ch. 6 Resistance Prediction
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## Ch. 8 Hull Form Design

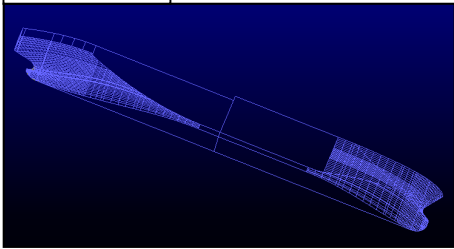
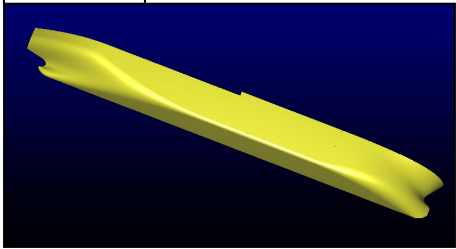
1. Hull Form and Hull Form Coefficients
2. Hull Form Variation
3. Hull Form Fairing
4. Performance Evaluation of Hull Form
5. Generation of Hull Form Surface
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## 1. Hull Form and Hull Form Coefficients

## What is a "Hull form"?

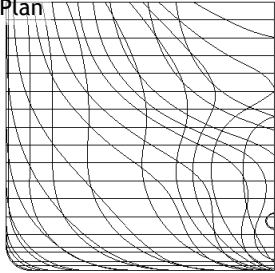
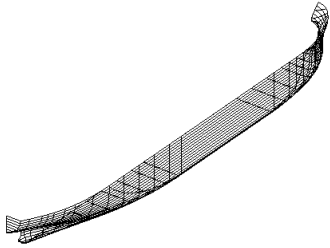


- ☑ **Hull form**
  - that is streamlined in order to satisfy requirements of a ship owner such as a deadweight, ship speed, and so on
  - Like a skin of human
- ☑ **Hull form design**
  - Design task that designs the hull form

Hull form of the VLCC(Very Large Crude oil Carrier)

<p style="font-size: small; border: 1px solid black; padding: 2px; margin-bottom: 5px;">Wireframe model</p> 	<p style="font-size: small; border: 1px solid black; padding: 2px; margin-bottom: 5px;">Surface model</p> 
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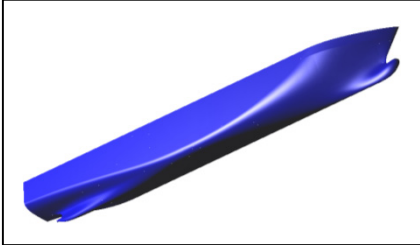
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## Lines

<p style="font-size: small; margin-bottom: 5px;">Body Plan</p> 	
<p style="font-size: small; margin-bottom: 5px;">Water Plan</p> 	<p style="font-size: small; margin-bottom: 5px;">Sheer Plan</p> 


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## Hull Form Design vs. Car Exterior Design



❑ Hull form design

- A hull form is related to **the resistance and propulsion performance** of a ship.
- Order production: new design for each order
- Large structure of about 100~400 m length
- **The performance like speed and deadweight is most important.**



❑ Car exterior design

- A exterior is related to **the air resistance and esthetic design** of a car.
- Mass production: one time design for each model
- **The performance and esthetic design are simultaneously important.**


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## Procedure of Car Exterior Design


Idea Sketch & Rendering

Tape Drawing

Clay Modeling




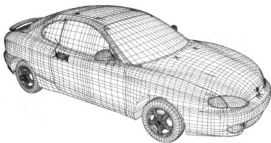





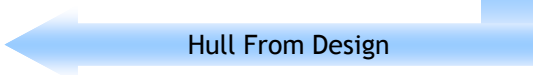
Digital Modeling (Reverse Engineering)

Measuring



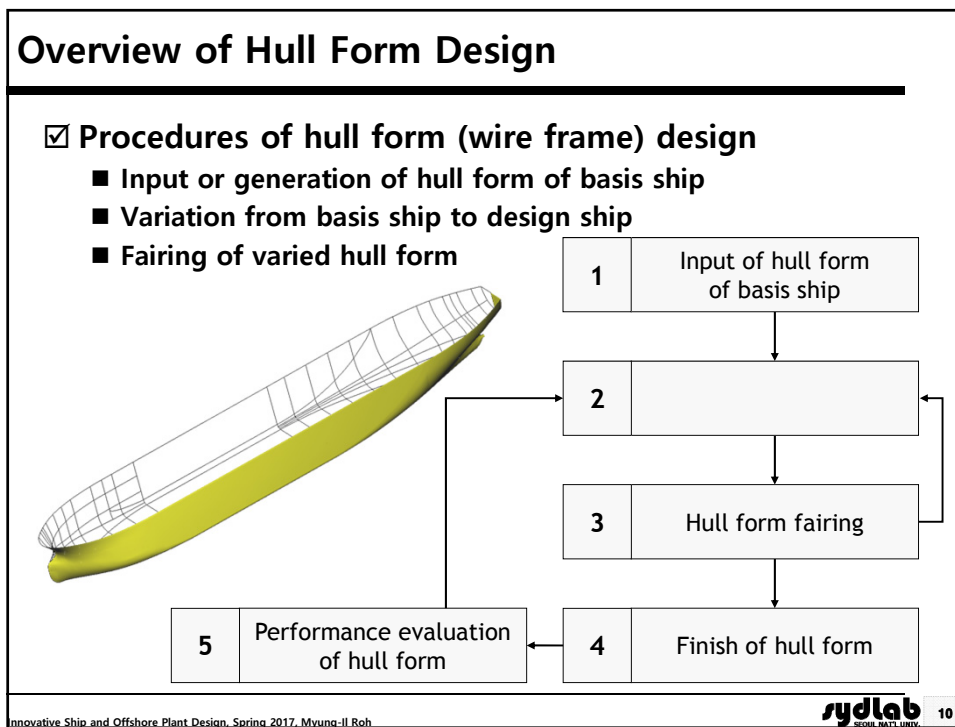
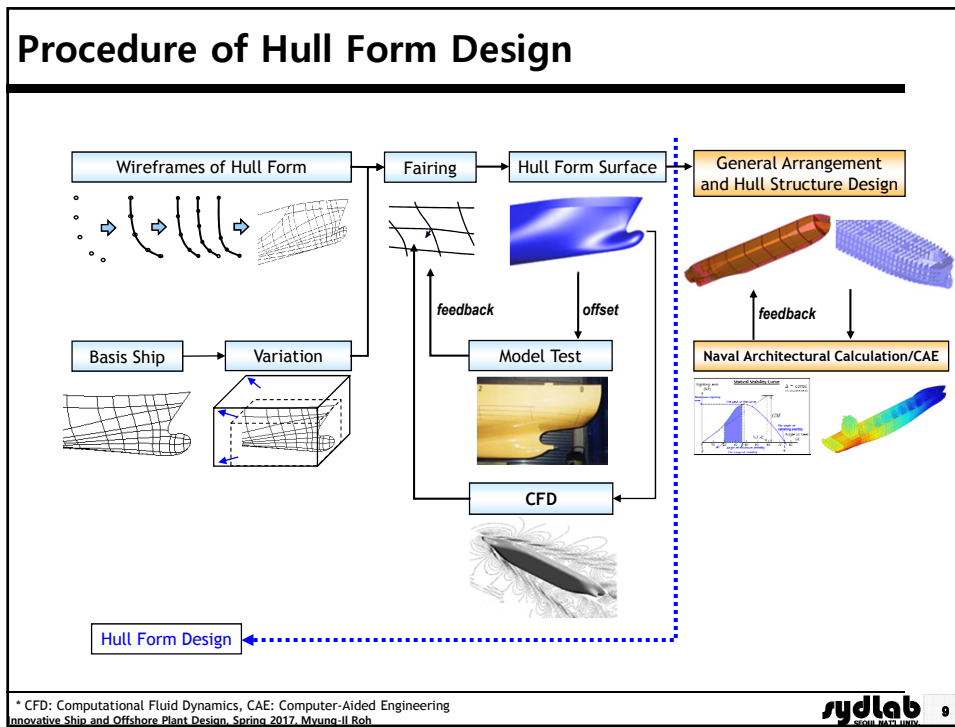


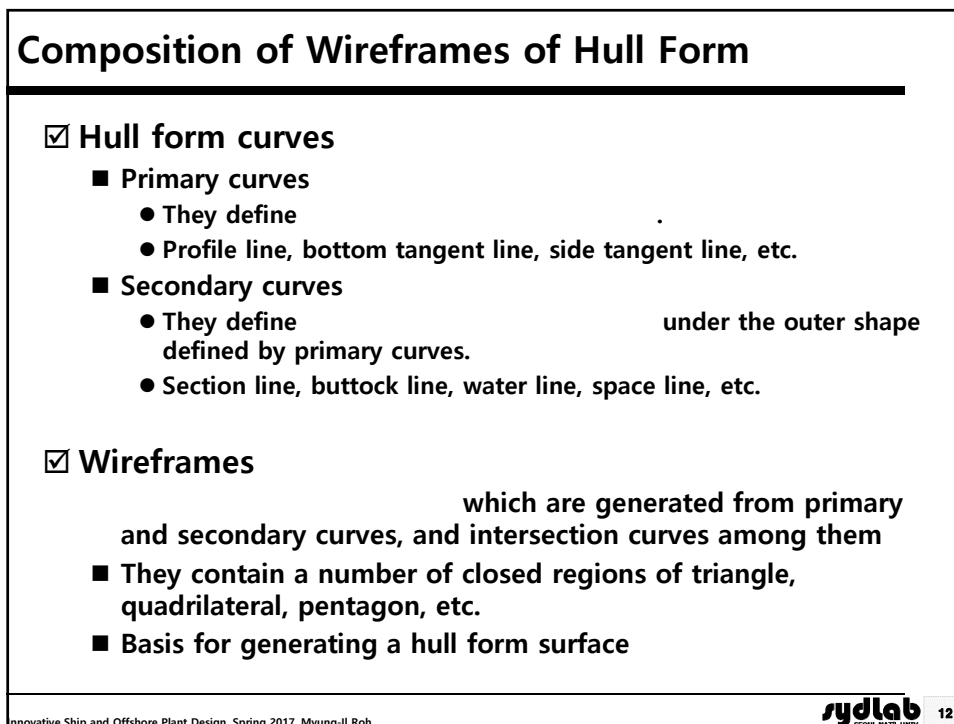
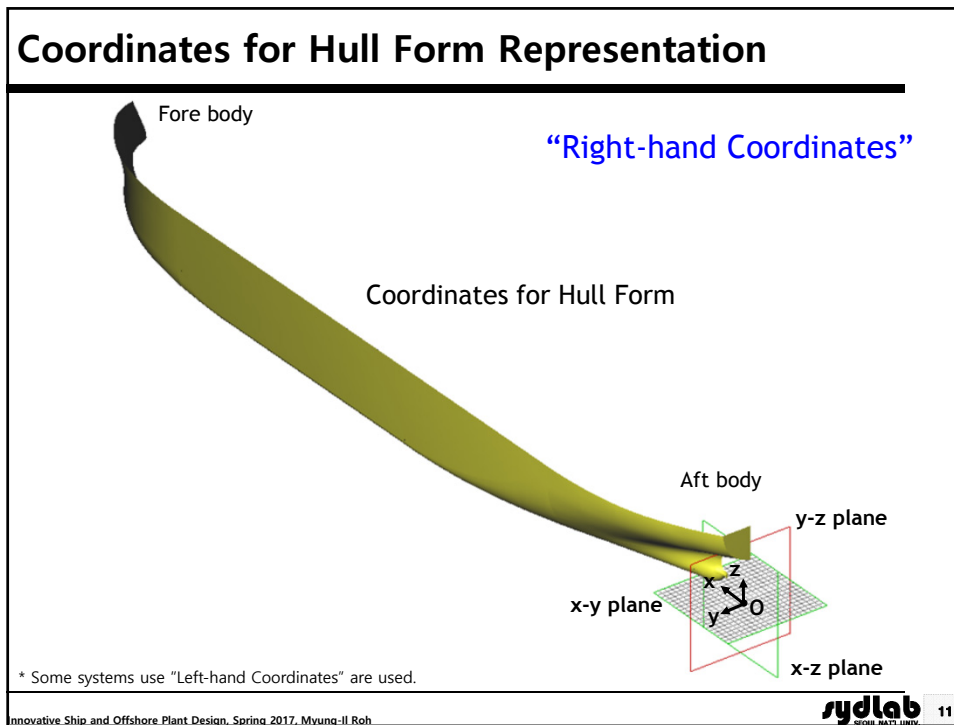




Hull Form Design

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## Primary Curves for Hull Form Representation

### - Profile Line (1/2)

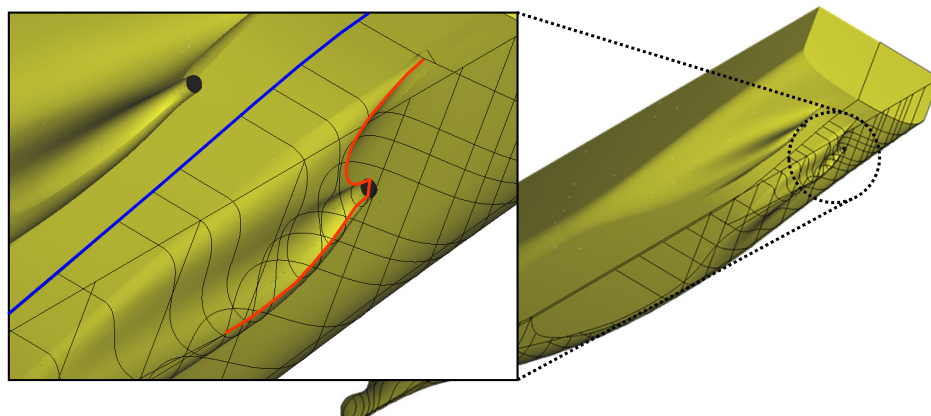
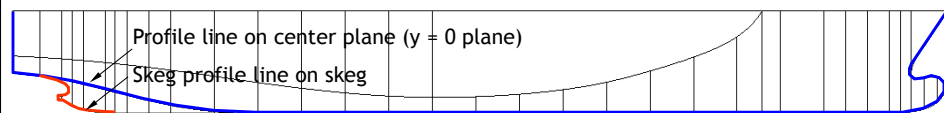
- ☑ Profile line is an intersection (or tangent) curve between hull form surface and center plane (center plane,  $y = 0$  plane) except for deck.
- ☑ Also called center line



Example of profile line of a 320K VLCC

## Primary Curves for Hull Form Representation

### - Profile Line (2/2)



Example of profile line of a twin-skeg container ship

## Primary Curves for Hull Form Representation - Bottom Tangent Line

- ☑ Bottom tangent line is an intersection (or tangent) curve between hull form surface and base plane ( $z = 0$  plane)



Example of bottom tangent line of a 320K VLCC

## Primary Curves for Hull Form Representation - Side Tangent Line

- ☑ Side tangent line is an intersection (or tangent) curve between hull form surface and  $y = B_{mid}/2$  plane.



Example of side tangent line of a 320K VLCC



## Primary Curves for Hull Form Representation - Deck Side Line

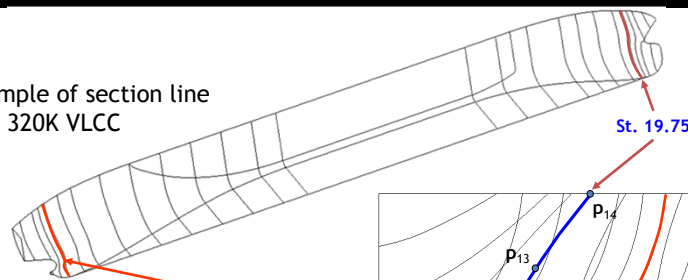
- ☑ Deck side line is a curve representing the side of upper deck
- ☑ Both ends of the curve contact with profile line.



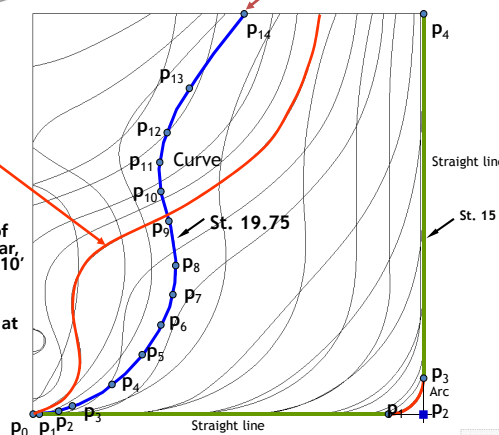
Example of deck side line of a 320K VLCC

## Secondary Curves for Hull Form Representation - Section Line

Example of section line of a 320K VLCC



- ☑ Section line is a curve located on a cross (longitudinal) section (y-z plane).
- ☑ Stations are ship hull cross sections at a spacing of  $L_{BP}/20$ , station '0' is located at the aft perpendicular, station '20' at the forward perpendicular. Station '10' therefore represents the midship section.
- ☑ In generally, because the section lines are located at the stations, they are called \_\_\_\_\_ lines.
- ☑ Section lines make up the \_\_\_\_\_ of lines.



## Secondary Curves for Hull Form Representation - Buttock Line

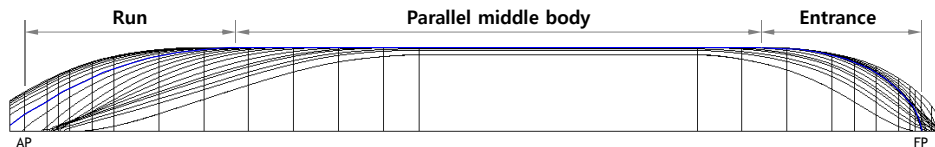
- ☑ Buttock line is a curve located on a profile (lateral) section (x-z plane).
- ☑ Buttock lines make up the \_\_\_\_\_ or \_\_\_\_\_ of lines.



Example of buttock line of a 320K VLCC

## Secondary Curves for Hull Form Representation - Water Line

- ☑ Water line is a curve located on a water plane (vertical) section (x-y plane).
- ☑ Water lines make up the \_\_\_\_\_ or \_\_\_\_\_ of lines.

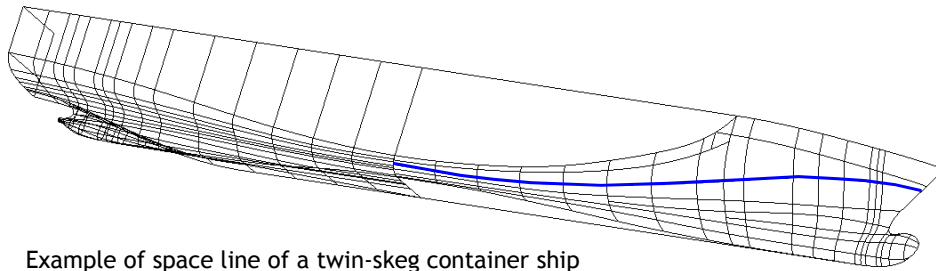


Example of water line of a 320K VLCC

— DLWL (Design Load Water Line)  
→ Design Draft

## Secondary Curves for Hull Form Representation - Space Line (1/2)

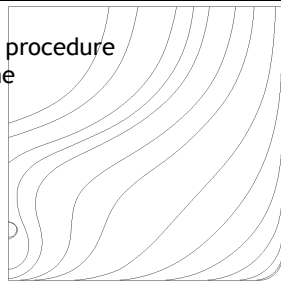
- ☑ Space line is a curve located on a 3D space, as compared with plane curve such as section line, buttock line, water line, etc.
- ☑ For the complicated hull form, space lines are additionally required with plane curves for defining the hull form.



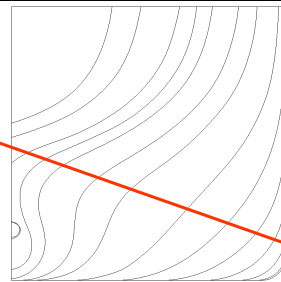
Example of space line of a twin-skeg container ship

## Secondary Curves for Hull Form Representation - Space Line (2/2)

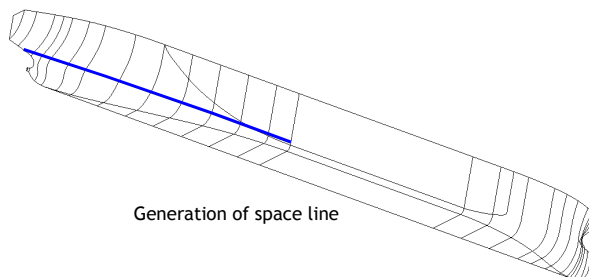
Generation procedure  
of space line



Projection on y-z plane



Generation of 2D auxiliary line



Generation of space line

## Generation of Wireframes of Hull From

### ① Input

- Primary curves, secondary curves

### ② Intersection

- Generation of intermediate curves such as water lines and buttock lines through intersection between primary and secondary curves

### ③ Wireframes generation

- Generation of wireframes using ① and ②

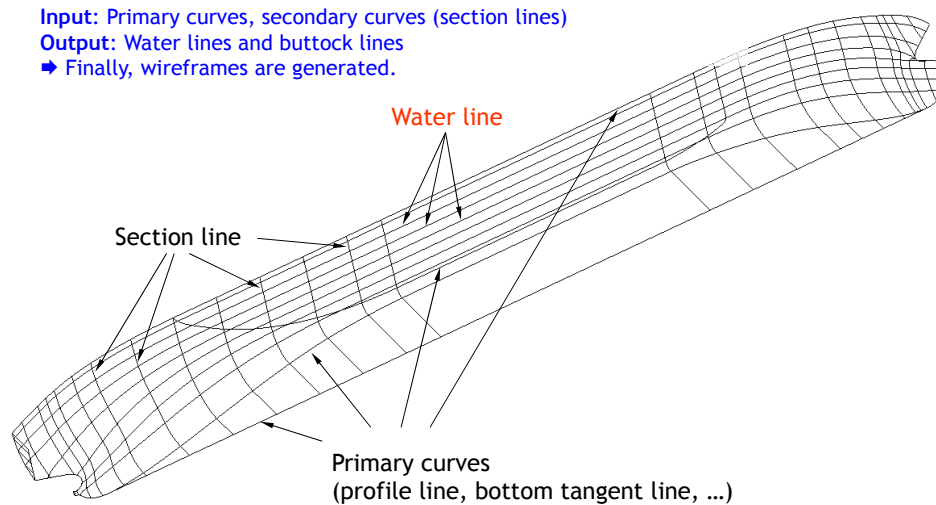
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## Wireframes Generation

Wireframes generation using primary & secondary curves

- Input: Primary curves, secondary curves (section lines)  
 Output: Water lines and buttock lines  
 ➔ Finally, wireframes are generated.



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### Generation of Water Lines (1/2)

St. 19.75 St. 19 St. 15

→ Generate a water line by intersection calculation between 'z = a' plane and all primary curves and section lines.

Z = a

Intersection points for generating the water line at 'z = a'

Z

Y

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### Generation of Water Lines (2/2)

Intersection points at z = 0.5

section line (station)

Fitting using a NURB curve with all intersection points at 'z = a'

→ Generation of a water line at z = a

↓ Repeat this for the z position what we want.

Generation of water lines

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### Generation of Buttock Lines (1/2)

St. 19.75 St. 19 St. 15

→ Generate a buttock line by intersection calculation between 'y = b' plane and all primary curves and section lines.

Intersection points for generating the buttock line at 'y = b'

Z

Y

y = b

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### Generation of Buttock Lines (2/2)

Intersection points at y = 28

section line (station)

Fitting using a NURB curve with all intersection points at 'y = b'

→ Generation of a buttock line at y = b

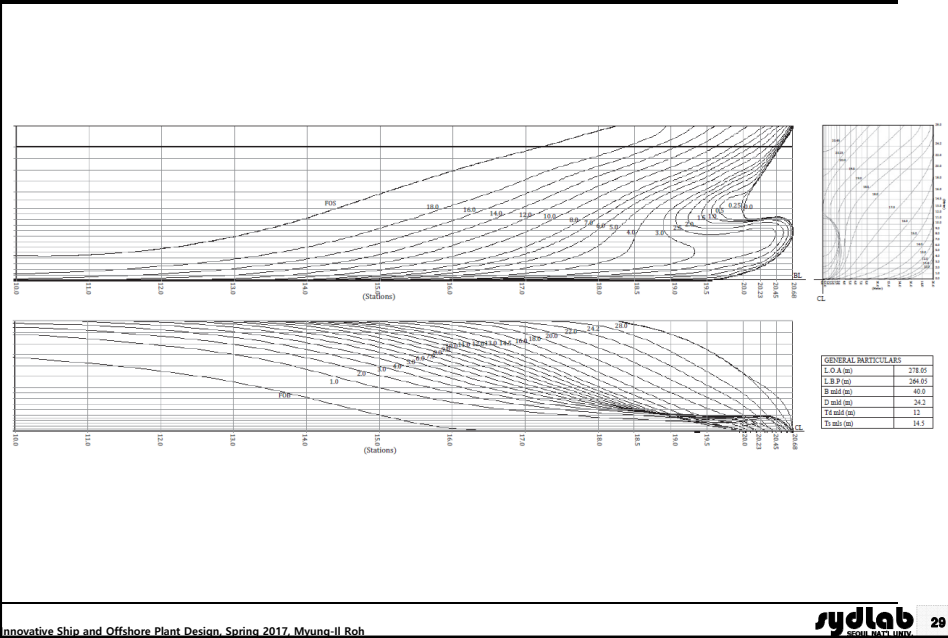
↓ Repeat this for the y position what we want.

Generation of buttock lines

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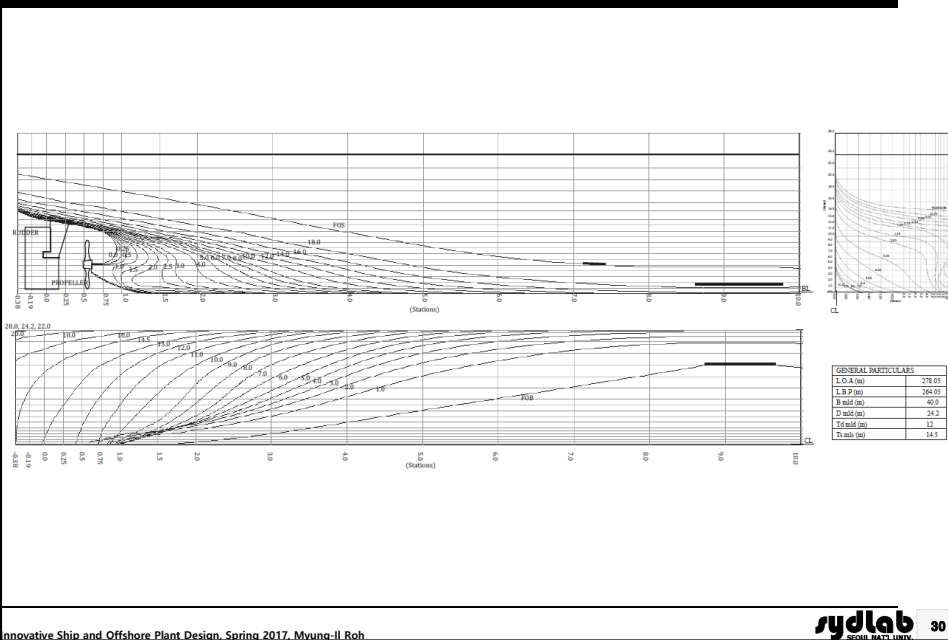
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### Example of Lines of a 6,300TEU Container Ship - Fore Body

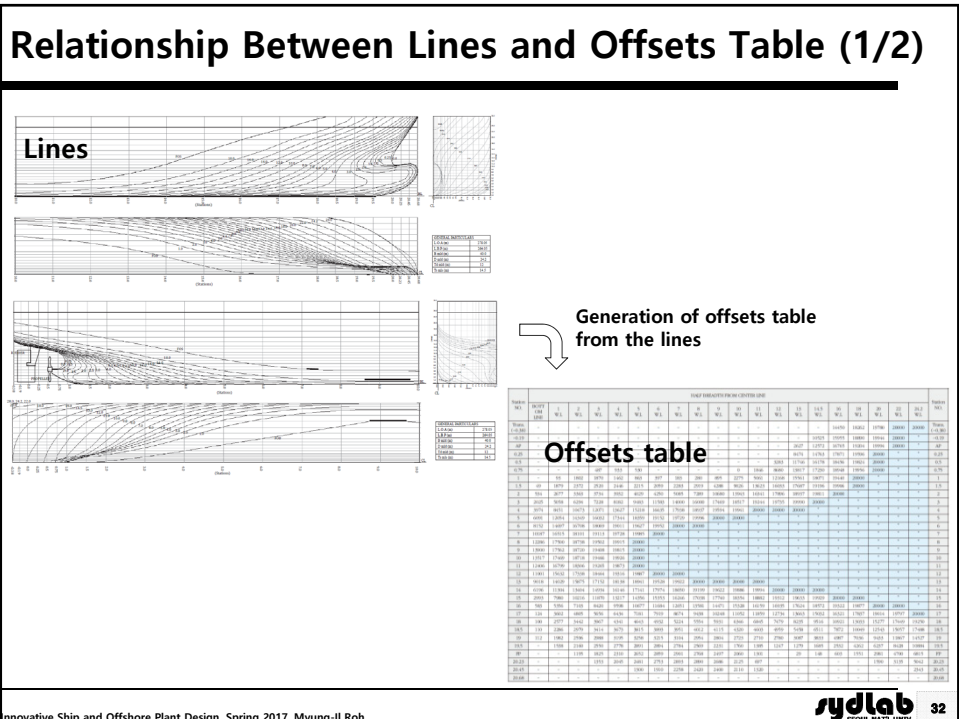
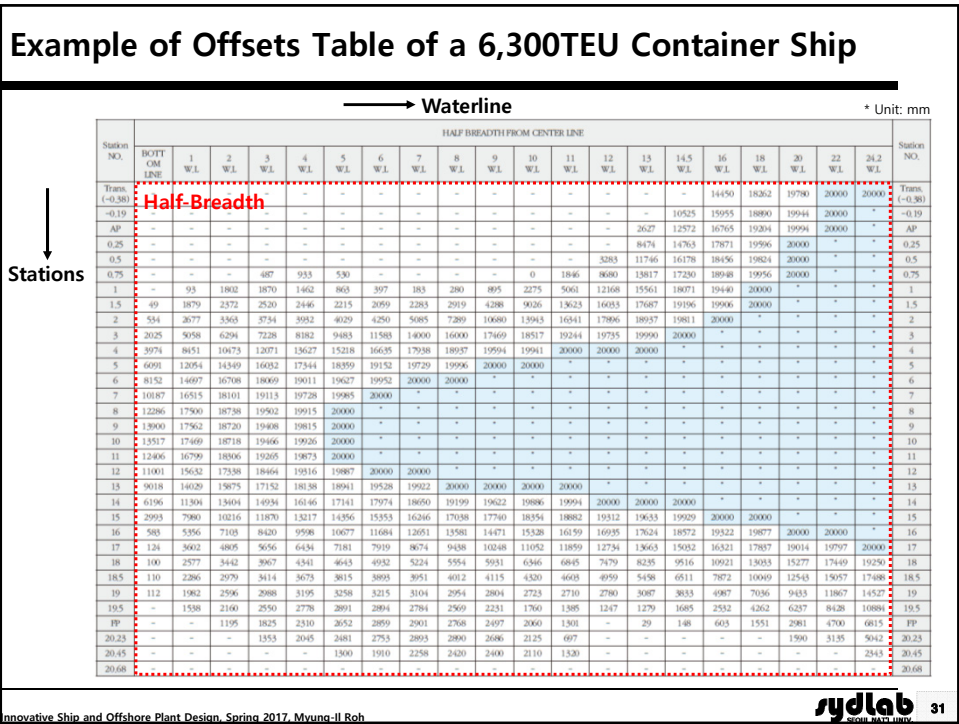


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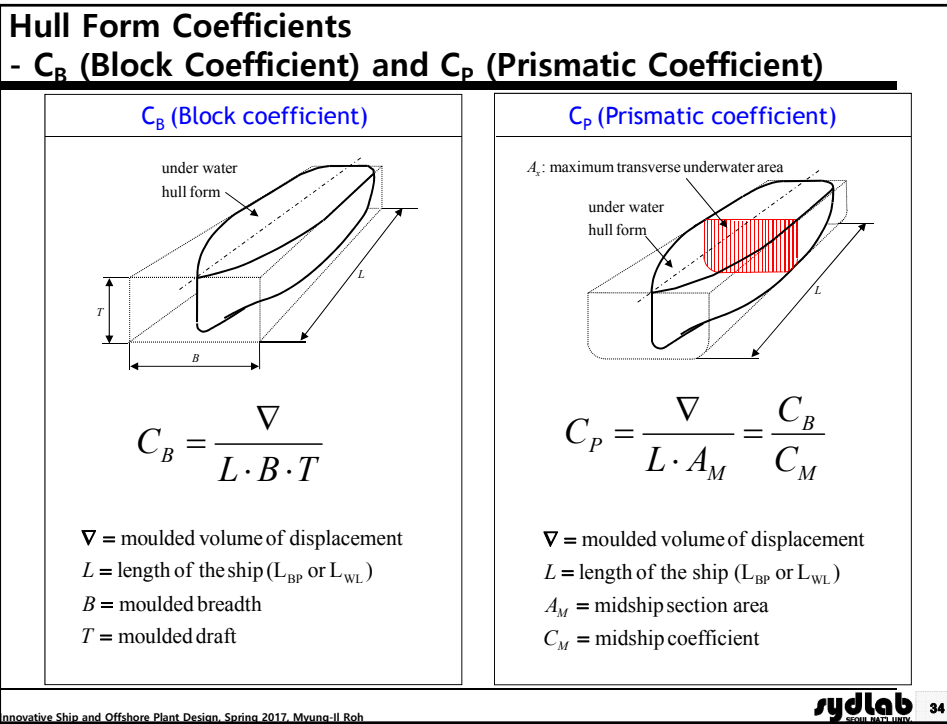
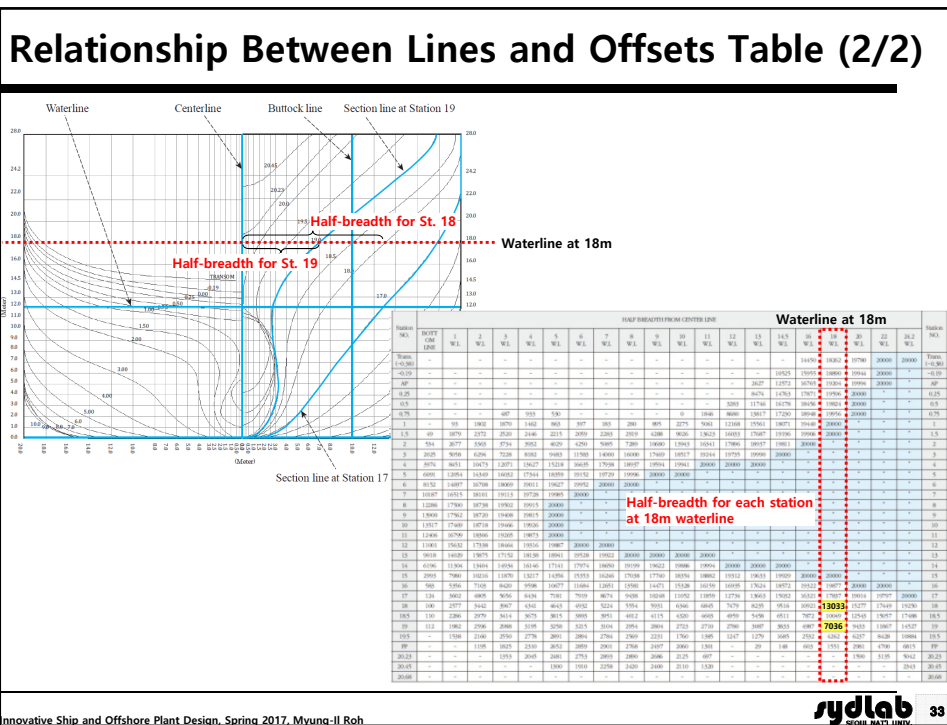
### Example of Lines of a 6,300TEU Container Ship - After Body



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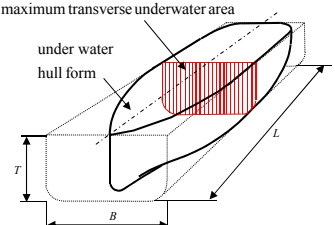
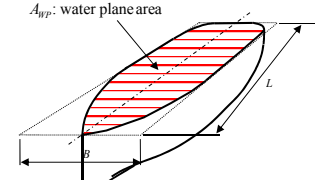






### Hull Form Coefficients

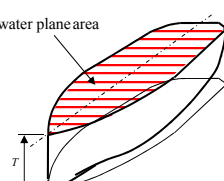
-  $C_M$  (Midship Section Coefficient) and  $C_{WP}$  (Water Plane Area Coefficient)

$C_M$ (Midship Section Coefficient)	$C_{WP}$ (Water Plane Area Coefficient)
 <p style="text-align: center;"><math>C_M = \frac{A_M}{B \cdot T}</math></p> <p style="text-align: center;"><math>A_M</math> = midship section area  <math>B</math> = moulded breadth  <math>T</math> = moulded draft</p>	 <p style="text-align: center;"><math>C_{WP} = \frac{A_{WP}}{L \cdot B}</math></p> <p style="text-align: center;"><math>A_{WP}</math> = water plane area  <math>L</math> = length of the ship (LWL or LBP)  <math>B</math> = moulded breadth</p>

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### Hull Form Coefficients

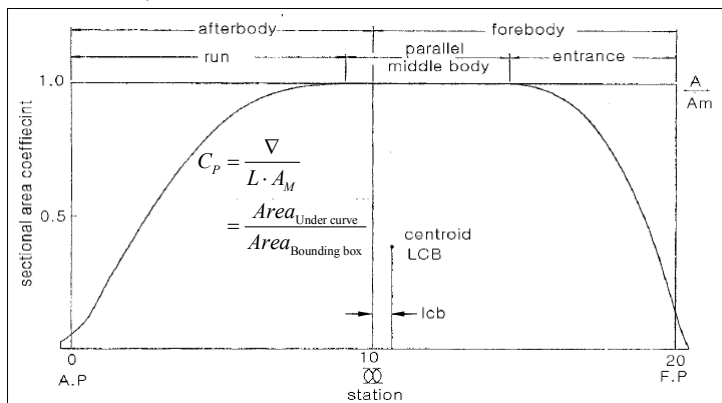
-  $C_{VP}$  (Vertical Prismatic Coefficient)

$C_{VP}$ (Vertical Prismatic Coefficient)
 <p style="text-align: center;"><math>C_{VP} = \frac{\nabla}{T \cdot A_{WP}}</math></p> <p style="text-align: center;"><math>\nabla</math> = moulded volume of displacement  <math>A_{WP}</math> = water plane area  <math>T</math> = moulded draft</p>

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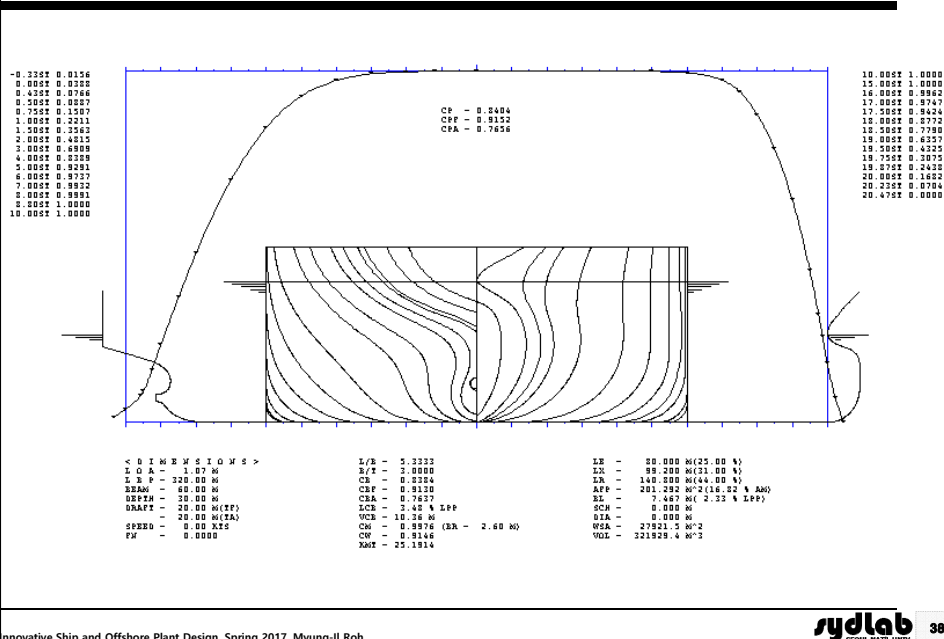
## C<sub>p</sub> Curve (Sectional Area Curve)

- C<sub>p</sub> curve (or sectional area curve) is a diagram of transverse section areas up to the designed water line, plotted on a base on length.
- This diagram may be made dimensionless by plotting each ordinate as the ratio of the area A of any section to the area of the maximum section.
- This diagram represents the



Sectional area curve or C<sub>p</sub>-curve and LCB (Longitudinal Center of Buoyancy)

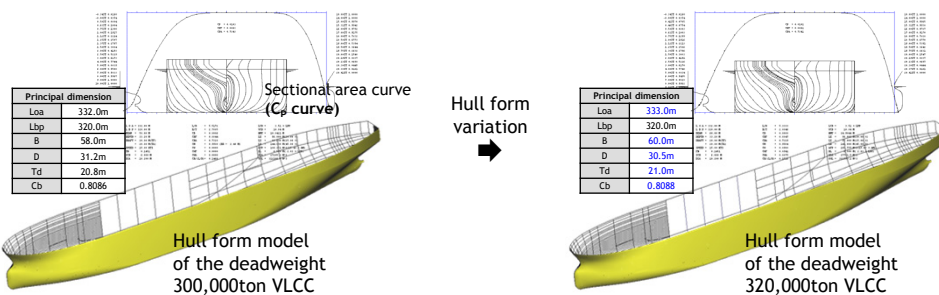
## Example of C<sub>p</sub> Curve of a 320K VLCC



## 2. Hull Form Variation

### Hull Form Variation (1/2)

- Design task for obtaining a hull form of a design ship from the variation of that of a basis ship

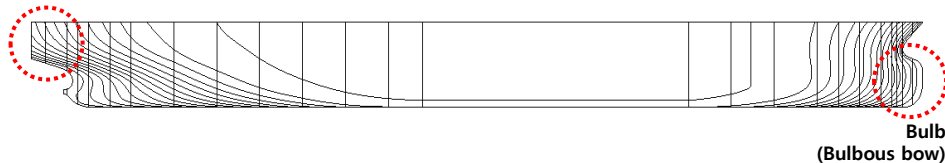


## Hull Form Variation (2/2)

### ☑ Categorization of Hull Form Methods

- Change of principal dimensions ( $L_{BP}$ ,  $B$ ,  $D$ ,  $T$ )
- Change of hull form parameters (e.g, transom height, shaft center height, bossing end radius, maximum deck height, bilge radius, etc.)
  
- Change of  $C_B$  (actually, displacement) and LCB
- Miscellaneous dimensions (e.g., transom length, bulb length, etc.)

Transom

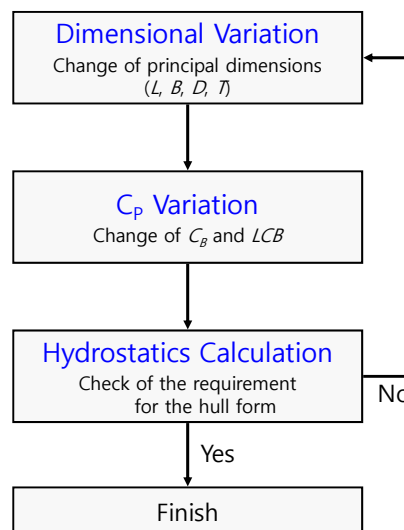


Bulb  
(Bulbous bow)

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## Procedure of the Hull Form Variation (Overview)



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### 3. Hull Form Fairing

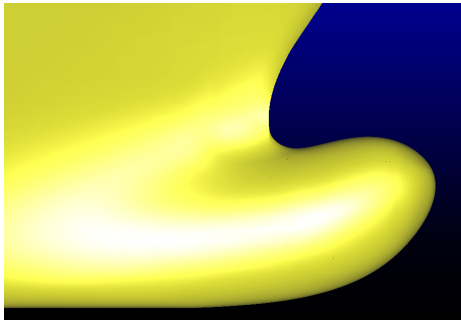
#### Hull Form Fairing

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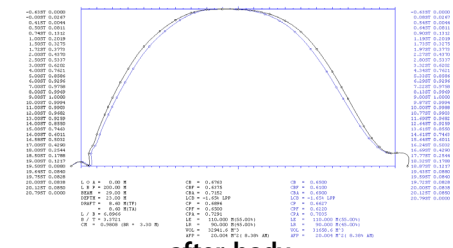
- Design task for obtaining a hull form of high quality after hull form variation
- A kind of touch-up process for the hull form
- Quality check by using  $C_p$  curve

## Example of Hull Form of High Quality

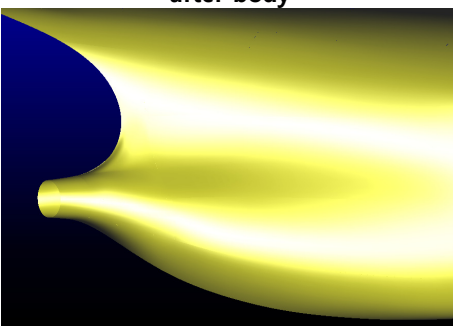
### Example of a single skeg container ship




**Fore body**



**after body**

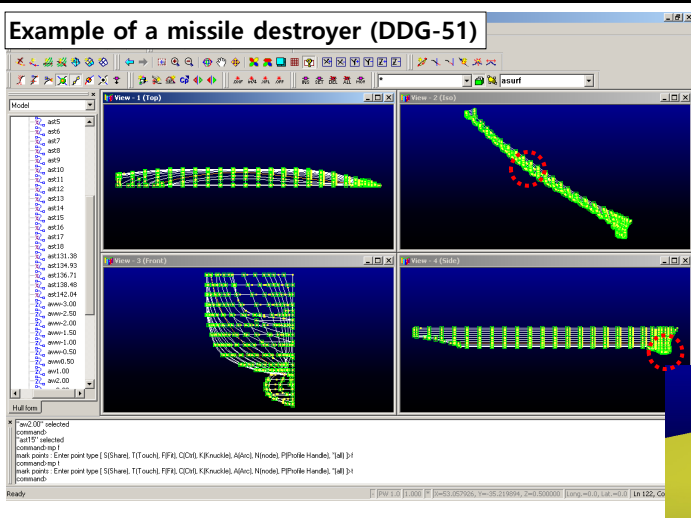


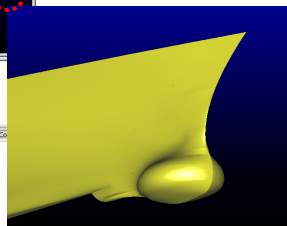

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## Example of Hull Form of Low Quality (1/2)

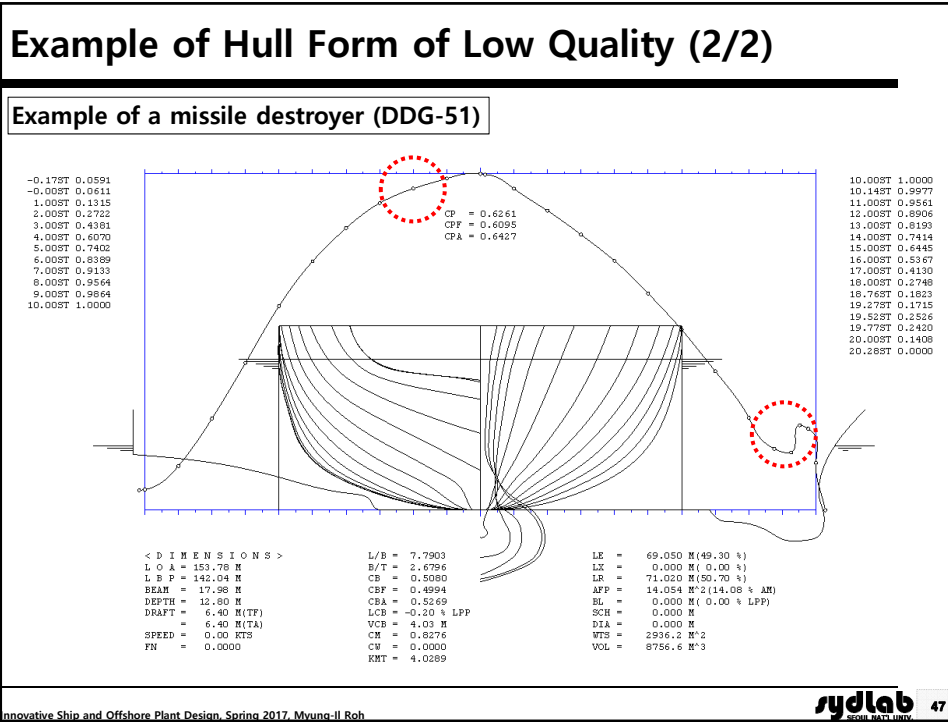
### Example of a missile destroyer (DDG-51)






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## 4. Performance Evaluation of Hull Form



## Performance Evaluation of a Hull Form

- Hull form coefficients
- Hydrostatic tables and hydrostatic curves
  
- Traditional and standard series methods
- Regression based methods (Statistical methods)
- Direct model test
- Computational Fluid Dynamics (CFD)
  
- Dependent on coupled effect between hull form and rudder

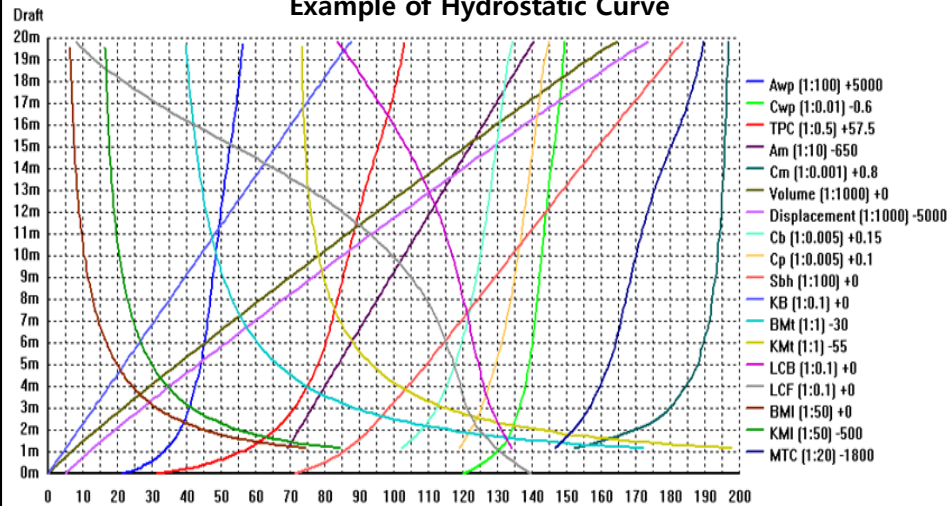
## Stability Performance - Hydrostatic Values

- ☑  $Draft_{Mid}$ ,  $Draft_{Scant}$ : Draft from base line, moulded / scantling (m)
- ☑  $Volume_{Mid}(\nabla)$ ,  $Volume_{Ext}$ : Displacement volume, moulded / extreme ( $m^3$ )
- ☑  $Displacement_{Mid}(\Delta)$ ,  $Displacement_{Ext}$ : Displacement, moulded / extreme (ton)
- ☑ LCB: Longitudinal center of buoyancy from midship (Sign: - Aft / + Forward)
- ☑ LCF: Longitudinal center of floatation from midship (Sign: - Aft / + Forward)
- ☑ VCB: Vertical center of buoyancy above base line (m)
- ☑ TCB: Transverse center of buoyancy from center line (m)
- ☑  $KM_T$ : Transverse metacenter height above base line (m)
- ☑  $KM_L$ : Longitudinal metacenter height above base line (m)
- ☑ MTC: Moment to change trim one centimeter (ton-m)
- ☑ TPC: Increase in  $Displacement_{Mid}$  (ton) per one centimeter immersion
- ☑ WSA: Wetted surface area ( $m^2$ )
- ☑  $C_B$ : Block coefficient
- ☑  $C_{WP}$ : Water plane area coefficient
- ☑  $C_M$ : Midship section area coefficient
- ☑  $C_P$ : Prismatic coefficient
- ☑ Trim: Trim(= after draft – forward draft) (m)

## Stability Performance - Hydrostatic Curve

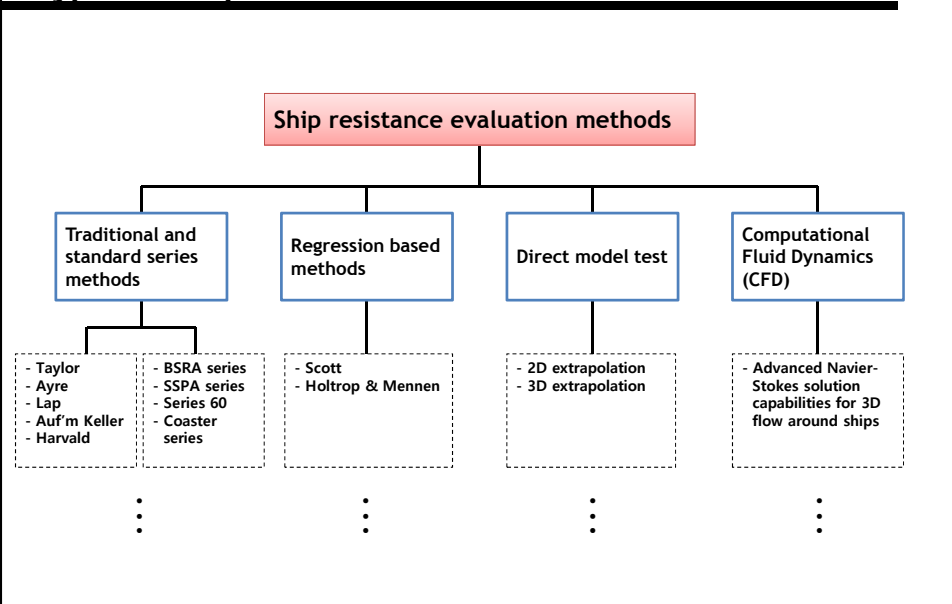
Hydrostatic curve: Curve for representing hydrostatic values

Example of Hydrostatic Curve

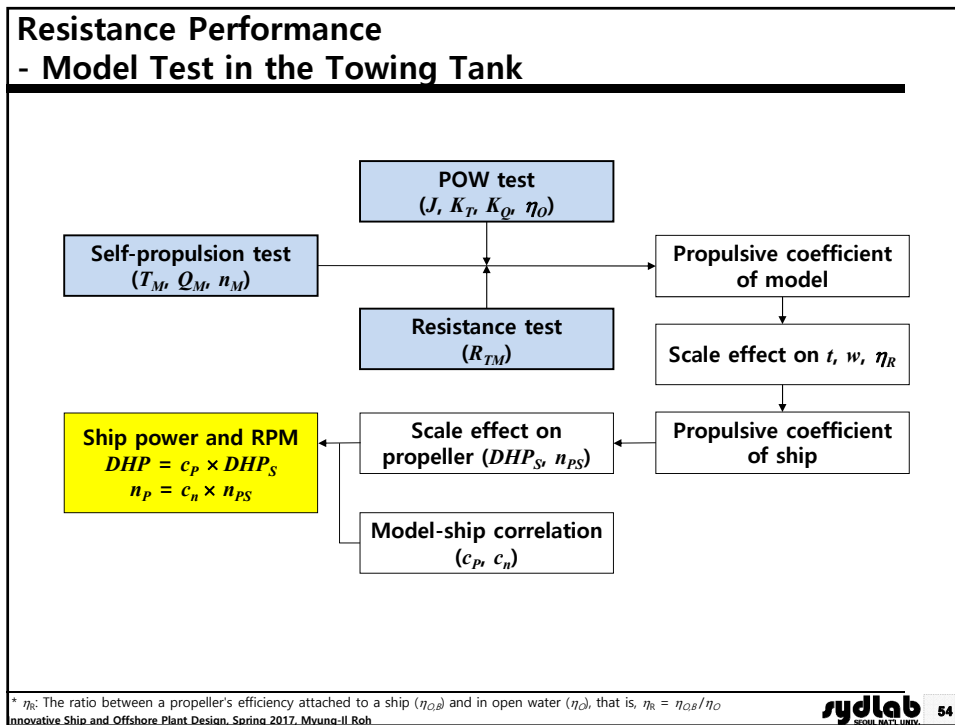
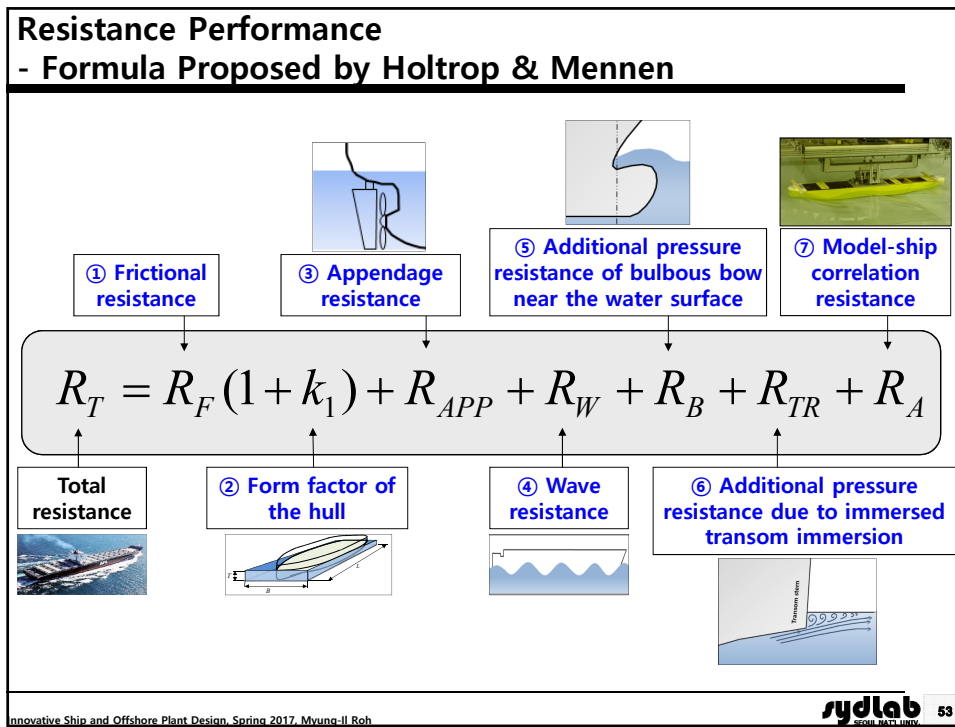


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## Resistance Performance - Types of Ship Resistance Evaluation Methods



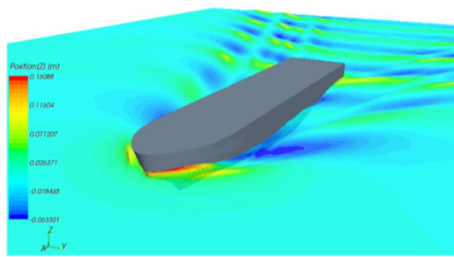
\* John Carlton, Marine Propellers and Propulsion, 3<sup>rd</sup> Edition, Elsevier, 2012  
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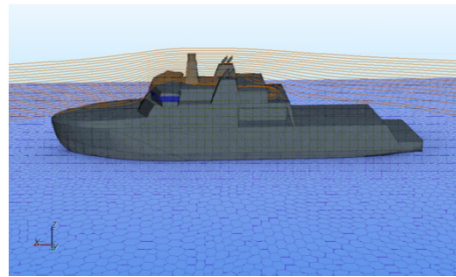
\*  $\eta_k$ : The ratio between a propeller's efficiency attached to a ship ( $\eta_{Os}$ ) and in open water ( $\eta_O$ ), that is,  $\eta_k = \eta_{Os}/\eta_O$

## Resistance Performance - Computational Fluid Dynamics (CFD)

- ☑ A branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows
- ☑ Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions.



Resistance test using CFD to optimize hull form

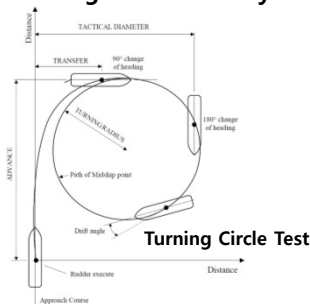


Aerodynamic analysis of turbulence levels over the helicopter flight deck

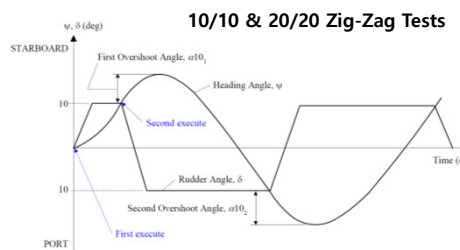
\* Reference: STX Canada, US Marine  
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## Maneuvering Performance - Maneuverability

- ☑ Key measures of maneuvering capability
  - Turning ability
  - Course changing and Yaw checking ability
  - Stopping ability
  - Straight line stability and course keeping ability



Turning Circle Test



- ☑ A hydrodynamic derivatives of ship are required to predict numerically its maneuvering capability.

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## Maneuvering Performance - Methods for Estimating Maneuvering Capability

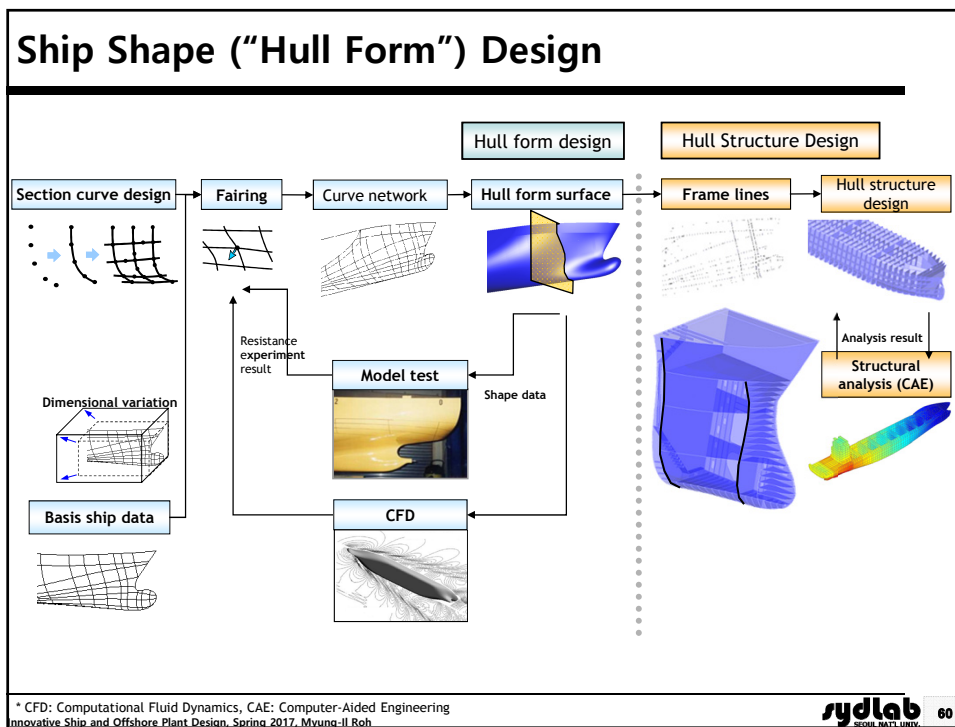
- Regression Analysis Results from Similar Ships (Semi-empirical Methods)
- Theoretical Prediction Methods
- Model Tests (Experiments with Scale Models)
  - Straight line test
  - Rotating arm test
  - Planar Motion Mechanism (PMM) test
  - Free running (radio controlled) model test
- Full Scale Tests
  - Tests of adherence to classification society standard

## Maneuvering Performance - Standards and Criteria of Maneuverability

Measure of Maneuverability	Criteria and Standard	Maneuver	IMO Standard	ABS Guide Requirement
<i>Required for Optional Class Notation</i>				
Turning Ability	Tactical Diameter	Turning Circle	$TD < 5L$	Rated $Rtd \geq 1$
	Advance		$Ad < 4.5L$	Not rated $Ad < 4.5L$
Course Changing and Yaw Checking Ability	First Overshoot Angle	10/10 Zig-zag test	$\alpha 10_1 \leq f_{101}(L/V)$	Rated $Rt\alpha_{10} \geq 1$
	Second Overshoot Angle		$\alpha 10_2 < f_{102}(L/V)$	Not rated $\alpha 10_2 < f_{102}(L/V)$
	First Overshoot Angle	20/20 Zig-zag test	$\alpha 20_1 \leq 25$	Rated $Rt\alpha_{20} \geq 1$
Initial Turning Ability	Distance traveled before 10-degrees course change	10/10 Zig-zag test	$\ell_{10} \leq 2.5L$	Rated $Rti \geq 1$
Stopping Ability	Track Reach	Crash stop	$TR < 15L^{(1)}$	Not rated $TR < 15L^{(1)}$
	Head Reach		None	Rated $Rts \geq 1$
<i>Recommended, Not Required for Optional Class Notation</i>				
Straight-line Stability and Course Keeping Ability	Residual turning rate	Pull-out test	$r \neq 0$	Not rated $r \neq 0$
	Width of instability <sup>(2)</sup> loop	Simplified spiral	$\alpha_{cr} \leq f_{\alpha}(L/V)$	Not rated $\alpha_{cr} \leq f_{\alpha}(L/V)$


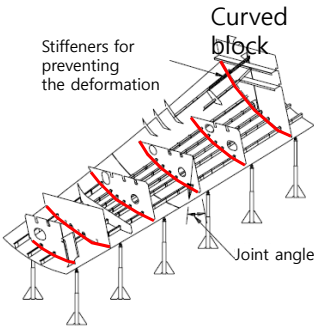
Note) 1: For large, low powered vessels,  $TR < 20L$ . 2: Applicable only for path-unstable vessels.

## 5. Generation of Hull Form Surface



## Needs of the Hull Surface Modeling

- ☑ The important production information such as joint length (welding length), painting area, weight, and CG of the building blocks should be estimated at the initial design stage.
- ☑ For this, we need the hull surface modeling not hull curve modeling.
- ☑ Furthermore, the **estimation of the cost and duration of the construction**, the **jig information** for the fixed curved block can be estimated.

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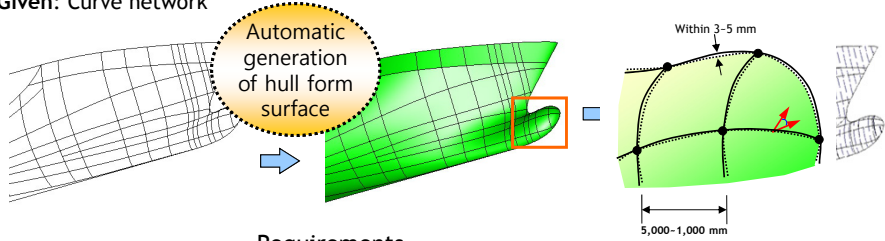
## Quality Requirement of a Hull Form Surface

Initial hull form design

Detailed design / Production design

Find: Smooth hull form surfaces

Given: Curve network



Automatic generation of hull form surface

- Irregular topology
- In the form of non-uniform B-spline curves

**Requirements**

- In the form of Bicubic B-spline surface patches
- Max. distance error between given curve network and generated surface < tolerance\*
- Smoothness: exact or close to G<sup>1</sup>\*\*

- Intersection between surfaces and plane
- Validation of the fairness

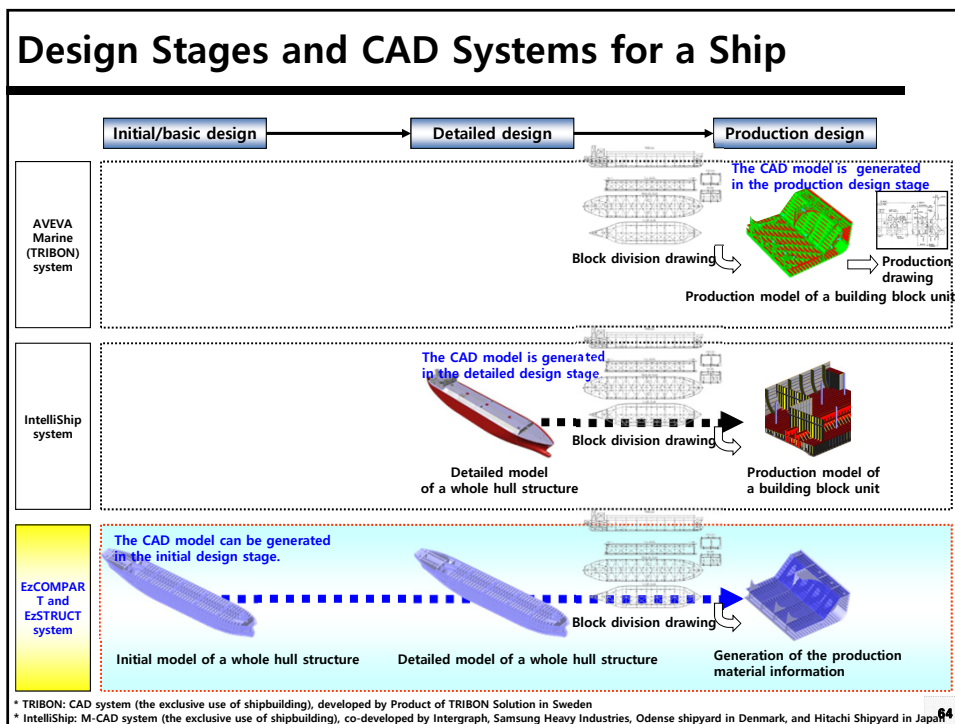
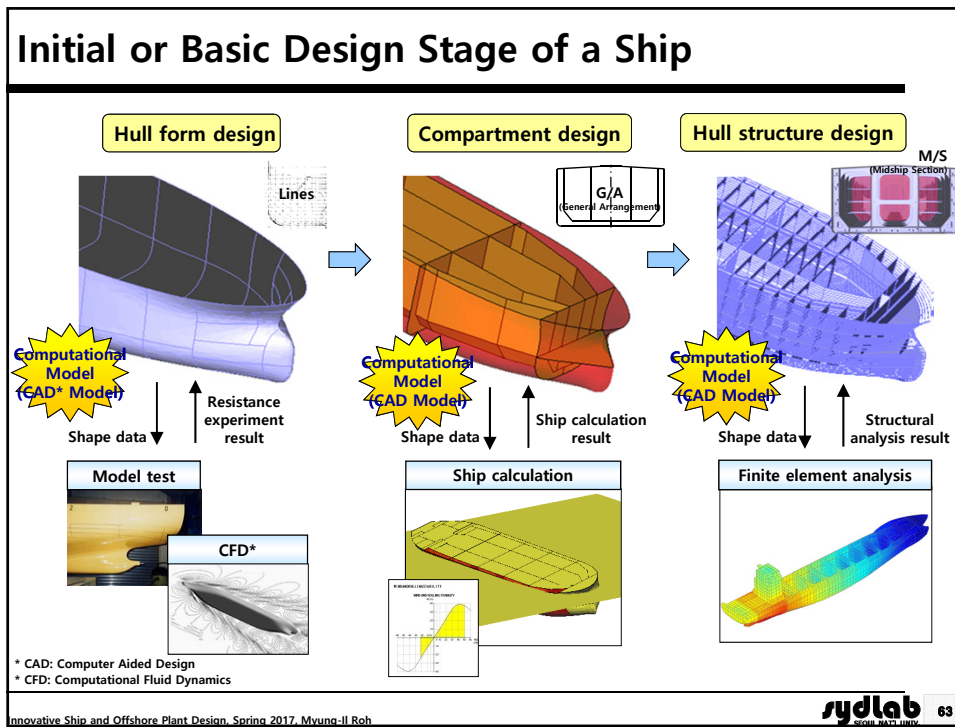
Within 3-5 mm

5,000-1,000 mm

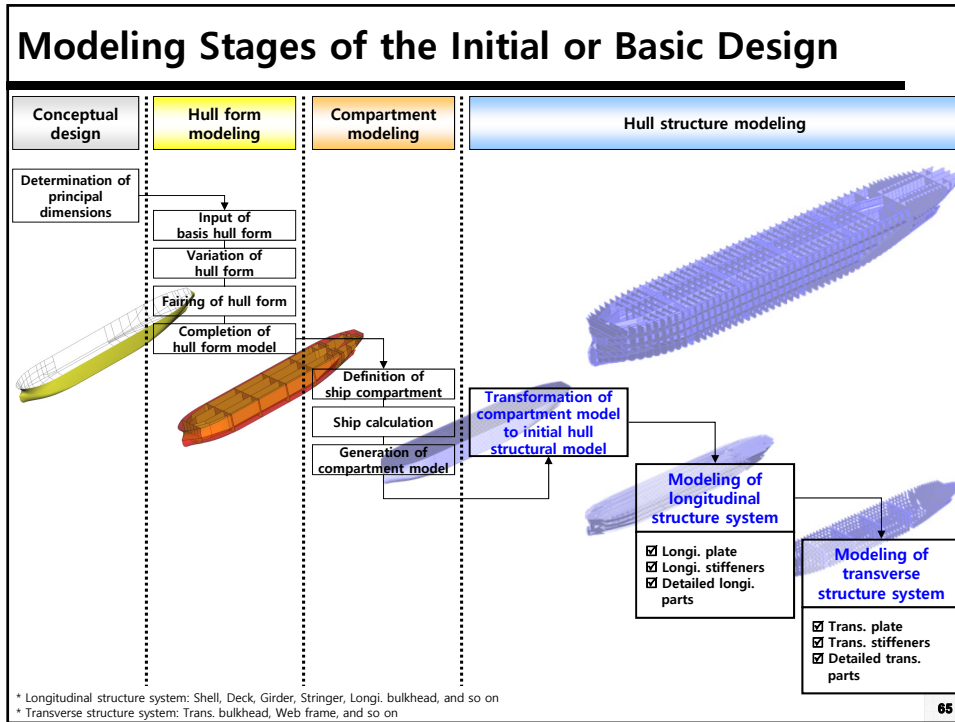
\* Acceptable tolerance in shipbuilding industry is about 3-5 mm.  
\*\* G<sup>1</sup> means geometric continuity or tangential plane continuity. IntelliShip requires exact G<sup>1</sup> hull form surfaces.

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## 6. Appendage Design

## Appendage Design - Example of a Propeller

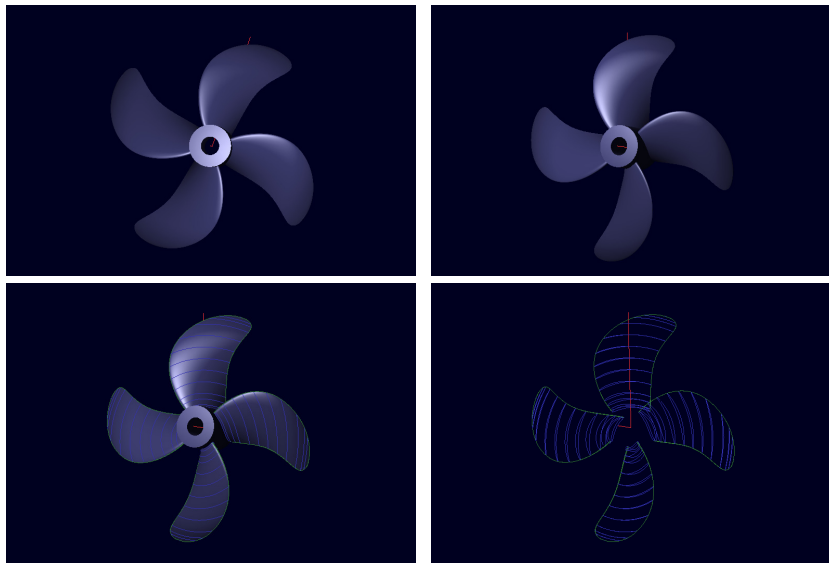


- ☑ Ship: 4,900 TEU Container Ship
- ☑ Owner: NYK, Japan
- ☑ Shipyard: HHI (2007.7.20)
- ☑ Diameter: 8.3 m
- ☑ Weight: 83.3 ton
- ☑ No of Blades: 5

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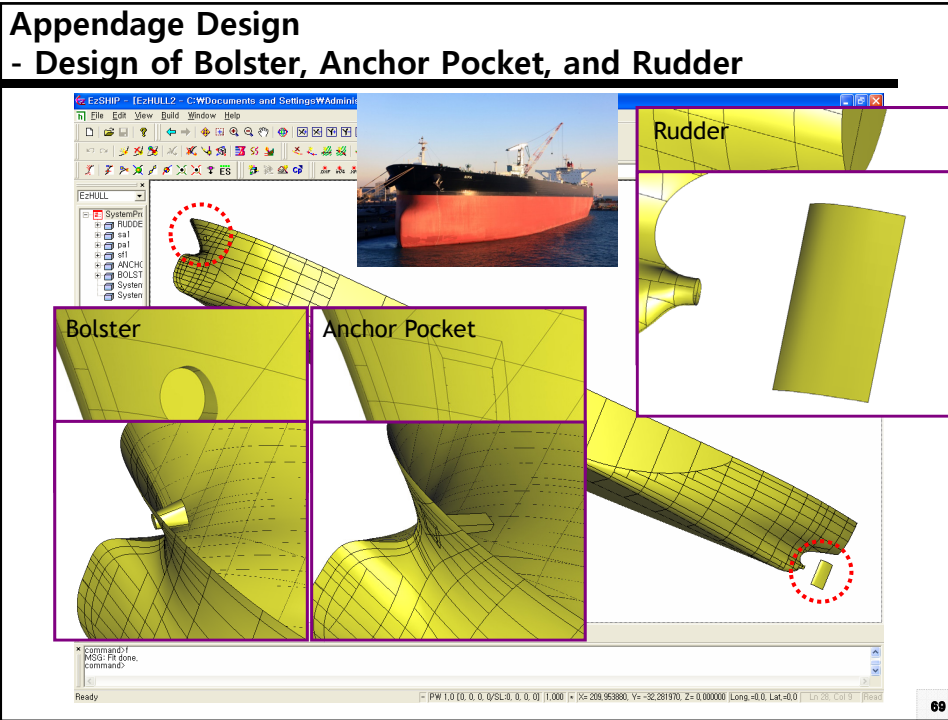
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## Appendage Design - Propeller



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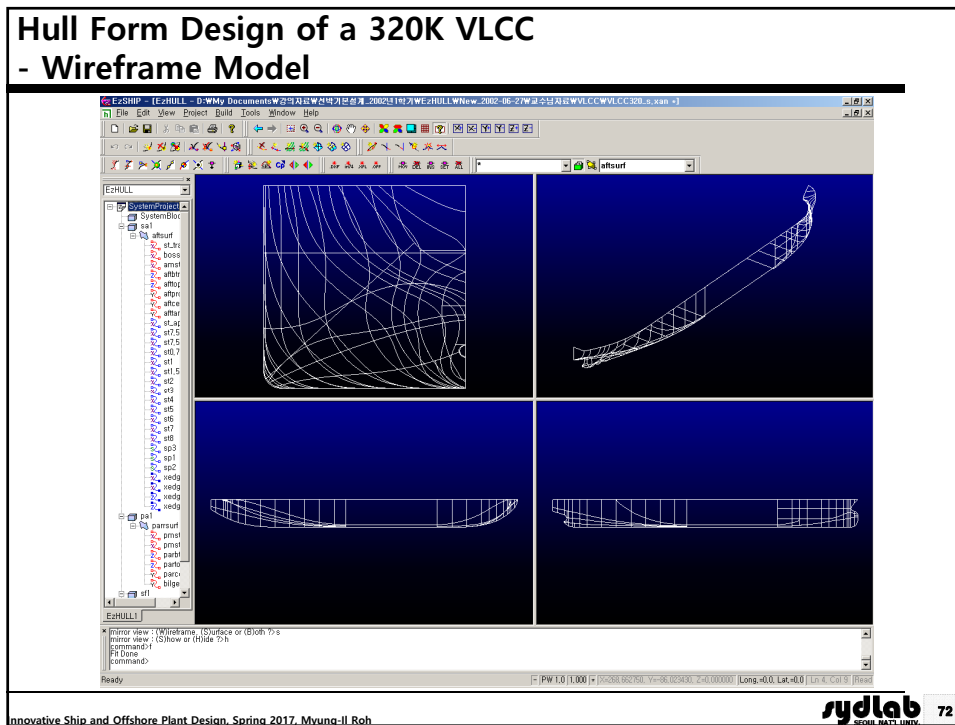


## 7. Examples of Hull Form Design

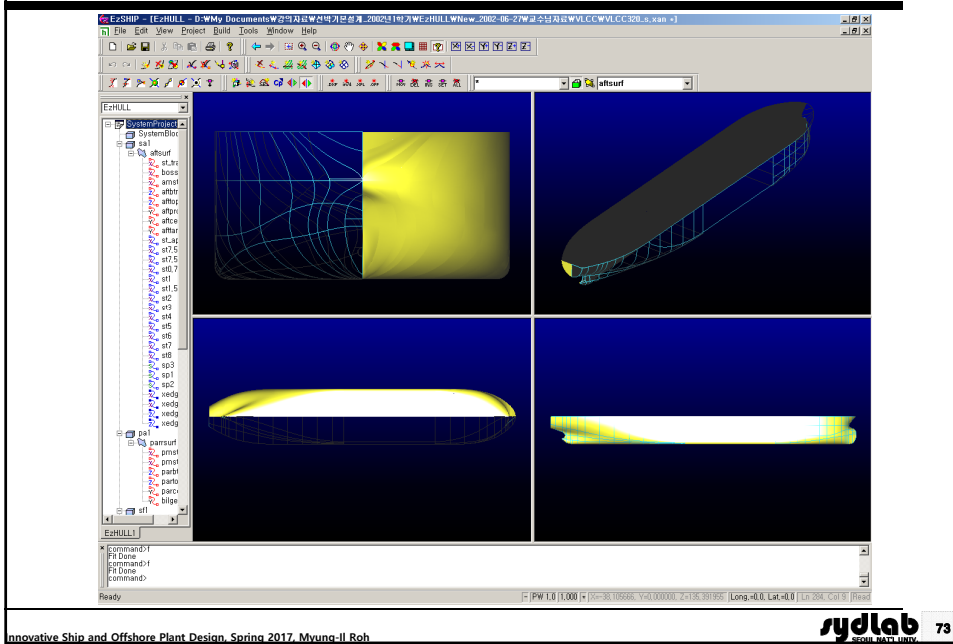
## Hull Form Design of a 320K VLCC

Principal Particulars			
Item		Value	Remark
Principal Dimensions	LOA	332.0 m	
	LBP	320.0 m	
	B	60.0 m	
	D	30.5 m	
	Td / Ts	21.0 / 22.5 m	
Cargo Capacity		320,000 MT	at Ts
Speed		16 knots	at Td
Main Engine	Type	SULZER 7RTA84T-D	
	MCR	39,060 PS x 76.0 rpm	
	NCR	35,150 PS x 73.4 rpm	
Propeller Diameter		10.2 m	

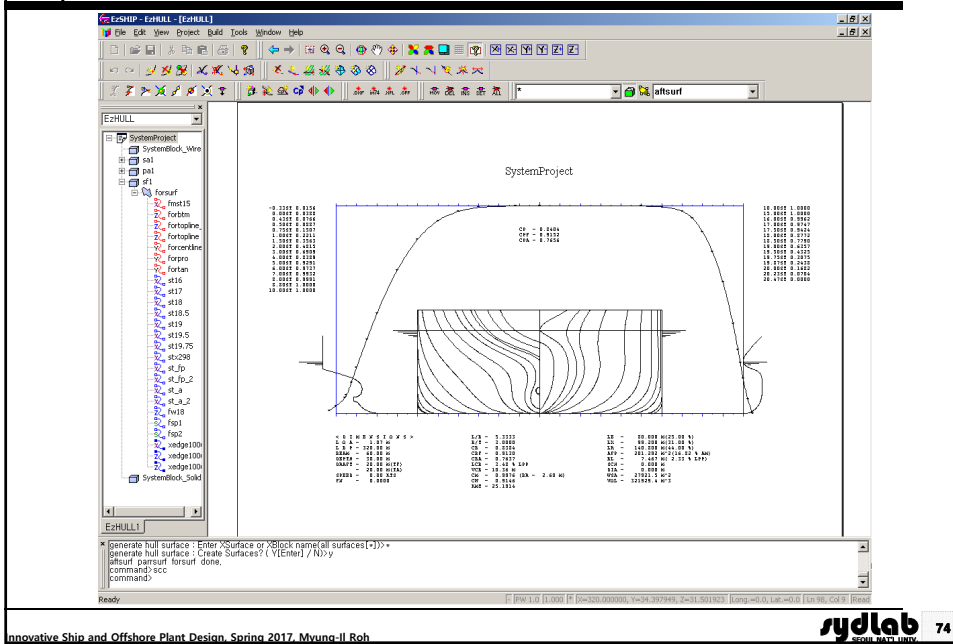
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## Hull Form Design of a 320K VLCC - Surface Model



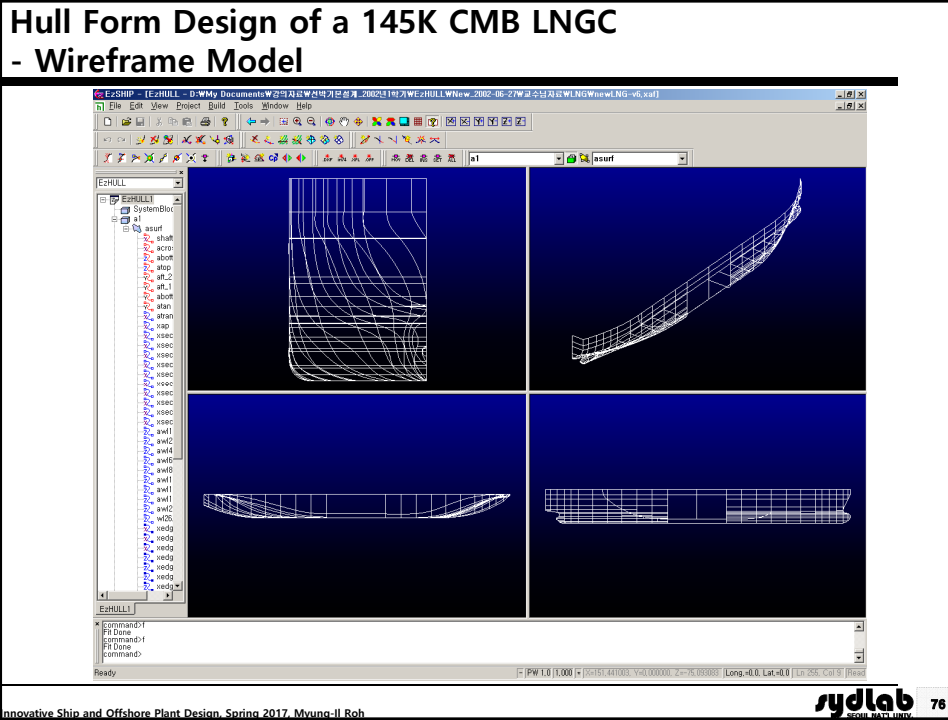
## Hull Form Design of a 320K VLCC - C<sub>p</sub> Curve



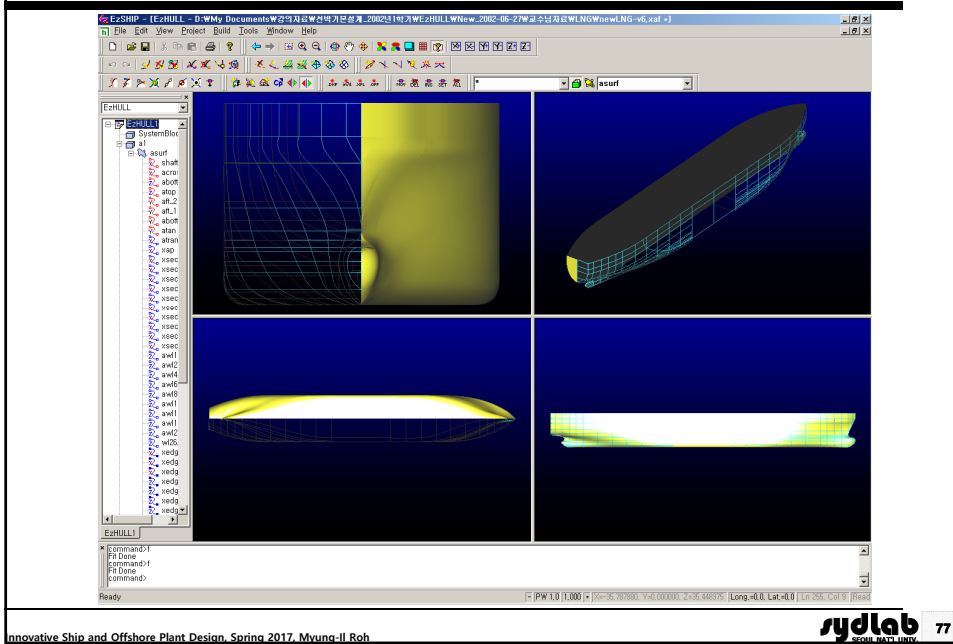
## Hull Form Design of a 145K CBM LNGC

Principal Particulars			
	Item	Value	Remark
Principal Dimensions	LOA	282.6 m	
	LBP	271.6 m	
	B	43.4 m	
	D	26.5 m	
	Td / Ts	11.3 / 12.0 m	
Cargo Capacity		145,216 CBM	at Td
Speed		20.2 knots	at Td
Main Engine	Type	Mitsubishi MS 40-2	
	MCR	38,709 PS x 83.0 rpm	
	NCR	34,838 PS x 80.0 rpm	
Propeller Diameter		8.28 m	

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## Hull Form Design of a 145K CMB LNGC - Surface Model



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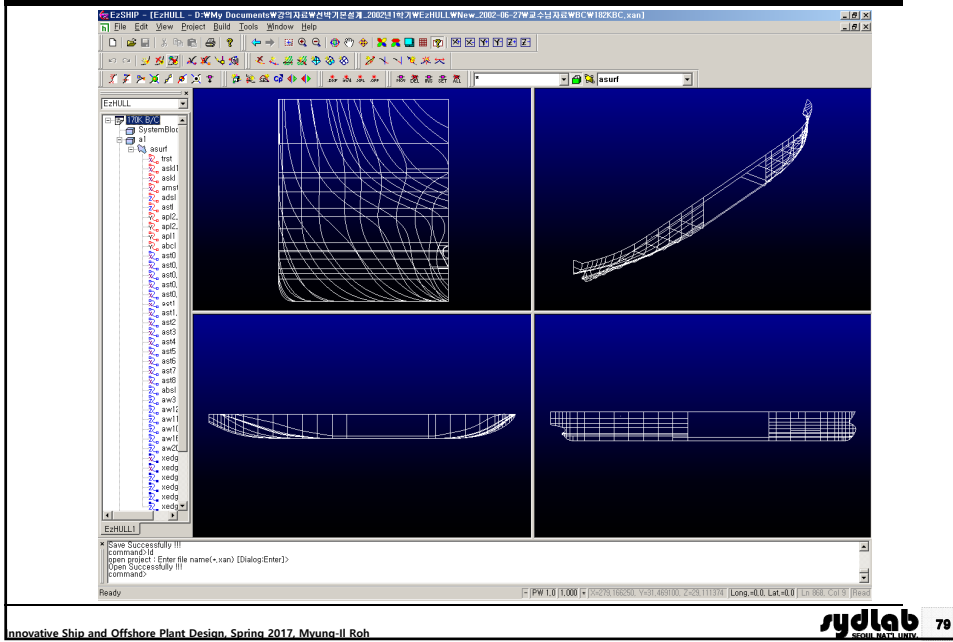
## Hull Form Design of a 182K Bulk Carrier

Principal Particulars			
Item		Value	Remark
Principal Dimensions	LOA	292.85 m	
	LBP	282.7 m	
	B	46.7 m	
	D	25.8 m	
	Td / Ts	17.9 / 17.9 m	
Cargo Capacity		182,000 MT	at Td
Speed		14.5 knots	at Td
Main Engine	Type	B&W 7S60MC-C	
	MCR	17,940 BHP x 93.0 rpm	
	NCR	15,249 BHP x 84.5 rpm	
Propeller Diameter		7.91 m	

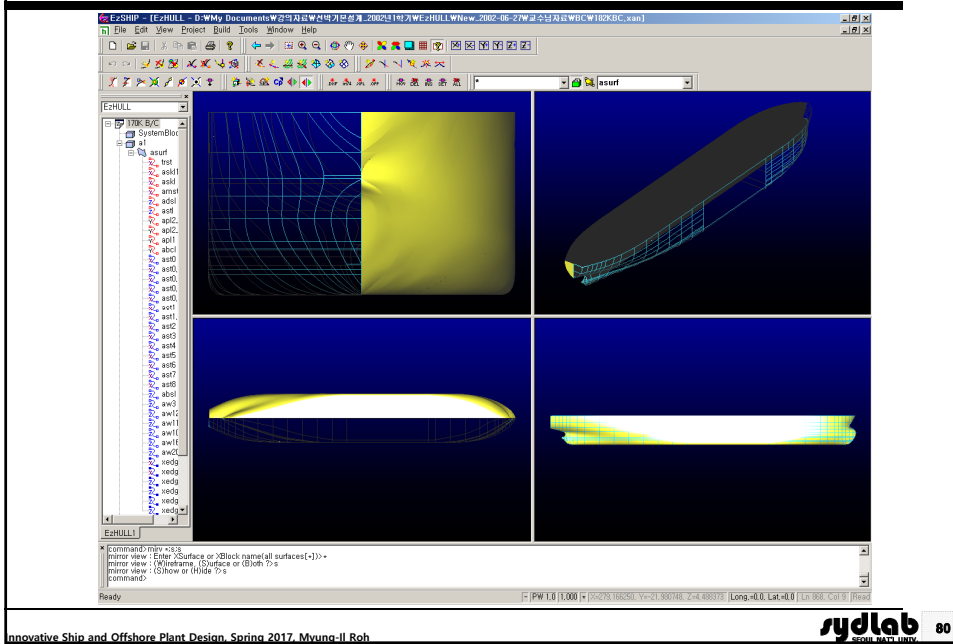
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## Hull Form Design of a 182K Bulk Carrier - Wireframe Model



## Hull Form Design of a 182K Bulk Carrier - Surface Model



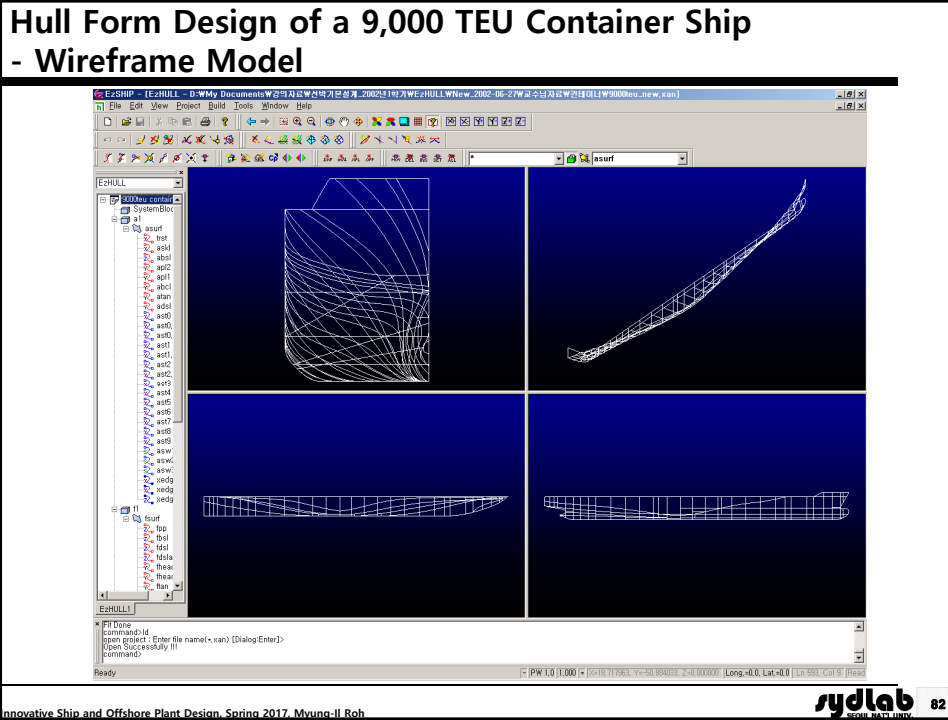


## Hull Form Design of a 9,000 TEU Container Ship

Principal Particulars			
Item		Value	Remark
Principal Dimensions	LOA	356.18 m	
	LBP	341.18 m	
	B	45.3 m	
	D	27.0 m	
	Td / Ts	14.0 / 14.0 m	
Cargo Capacity		9,012 TEU	at Td
Speed		25.0 knots	at Td
Main Engine	Type	HSD B&W 12K98MC-C	
	MCR	91,491 PS x 94.0 rpm	
	NCR	77,767 PS x 89.0 rpm	
Propeller Diameter		9.70 m	

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## Hull Form Design of a 9,000 TEU Container Ship - Surface Model

