Naval Architecture & Ocean Engineering

Computer Aided Ship Design

Part II. Curve and Surface Modeling

Ch. 1 Introduction

September, 2013

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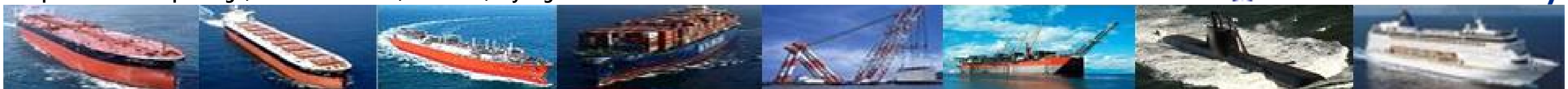
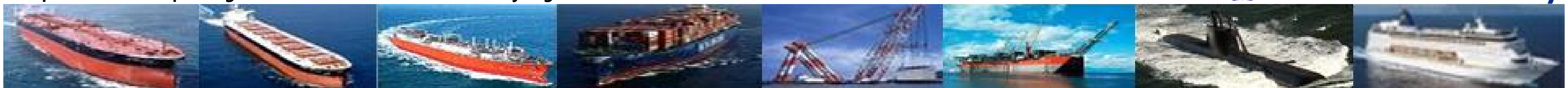


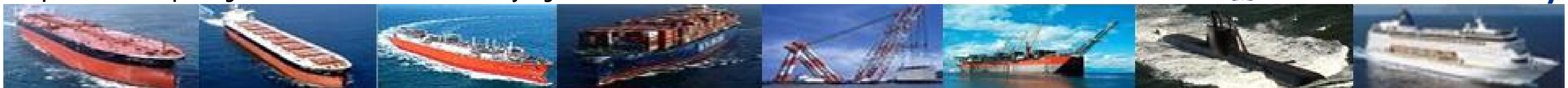
Ch. 1 Introduction



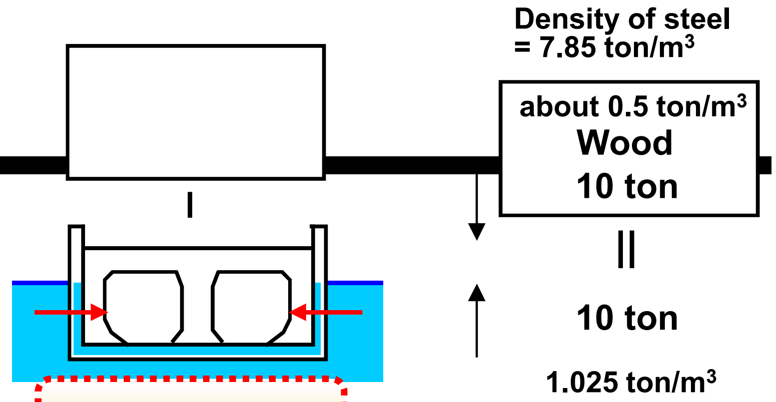
Naval Architecture & Ocean Engineering

1.1 Application of Curves and Surfaces to Ship Design

SYstem Design Laboratory



Basic Requirements of a Ship



■ The basic requirements of a ship

(1) Ship should float and be stable in sea water.

Ship stability

➡ Weight of the ship is equal to the buoyancy* in static equilibrium.

(2) Ship should transport cargoes.

Ship compartment design

➡ The inner space should be large enough for storing the cargoes.

(3) Ship should move fast to the destination and be possible to control itself.

Hull form design, Ship hydrodynamics, Propeller design, Ship maneuverability and control

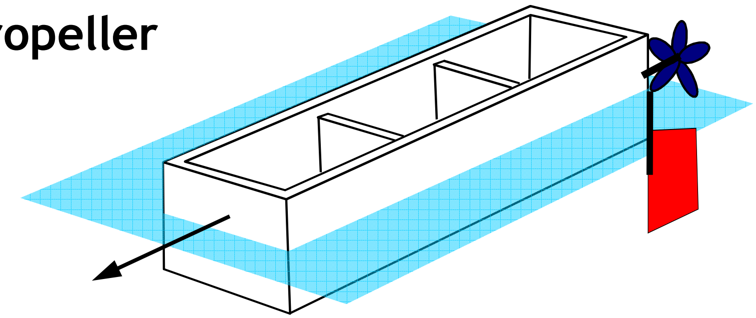
➡ Shape: It should be made to keep low resistance (ex. streamlined shape).

➡ Propulsion engine: Diesel engine, Helical propeller

➡ Steering equipment: Steering gear, Rudder

4) Ship should be strong enough in all her life.

➡ It is made of the welded structure of steel plate(about 10~30mm thickness) and stiffeners.



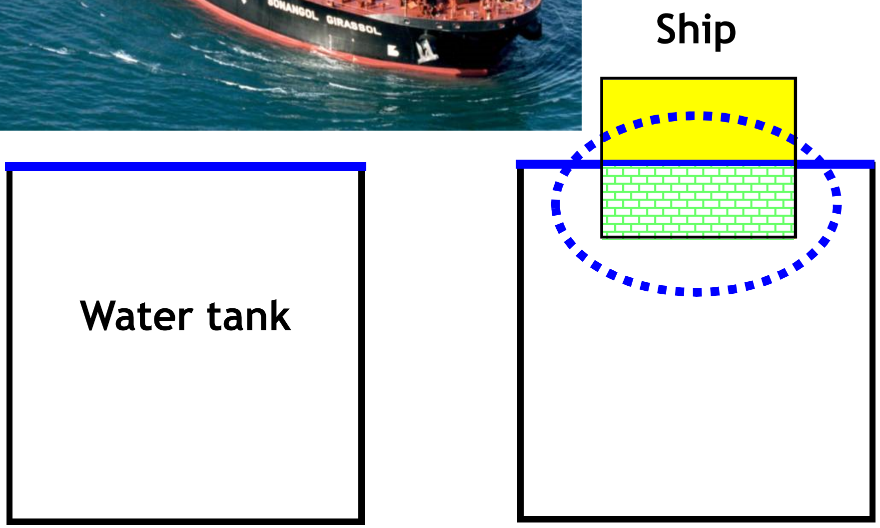
Ship structural mechanics, Structural design & analysis

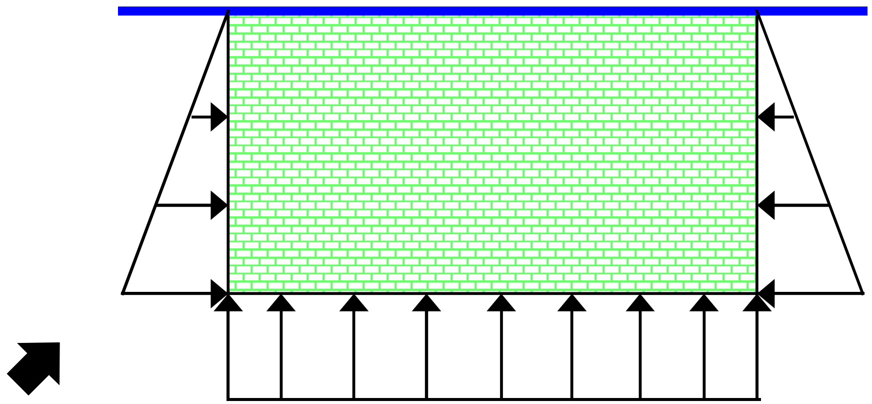
* Archimedes' Principle: The buoyancy of the floating body is equal to the weigh of displaced fluid of the immersed portion of the volume of the ship.

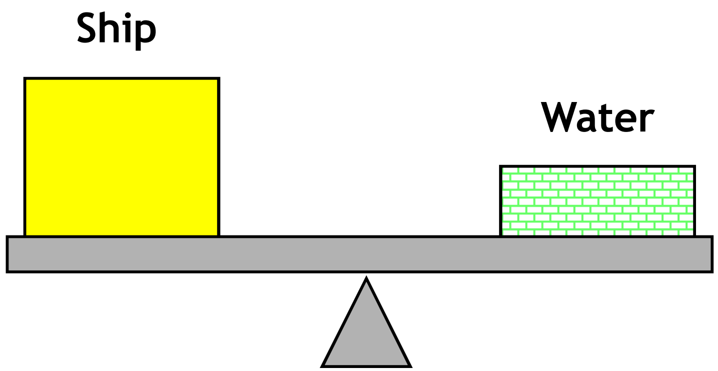
How does a ship float? (1/3)

☑ The force that enables a ship to float ➡ **“Buoyant Force”**

- It is **directed upward**.
- It has a magnitude equal to **the weight of the fluid** which is **displaced by the ship**.







How does a ship float? (2/3)

☑ Archimedes' Principle

- The magnitude of the buoyant force acting on a floating body in the fluid is equal to the weight of the fluid which is displaced by the floating body.
- The direction of the buoyant force is opposite to the gravitational force.

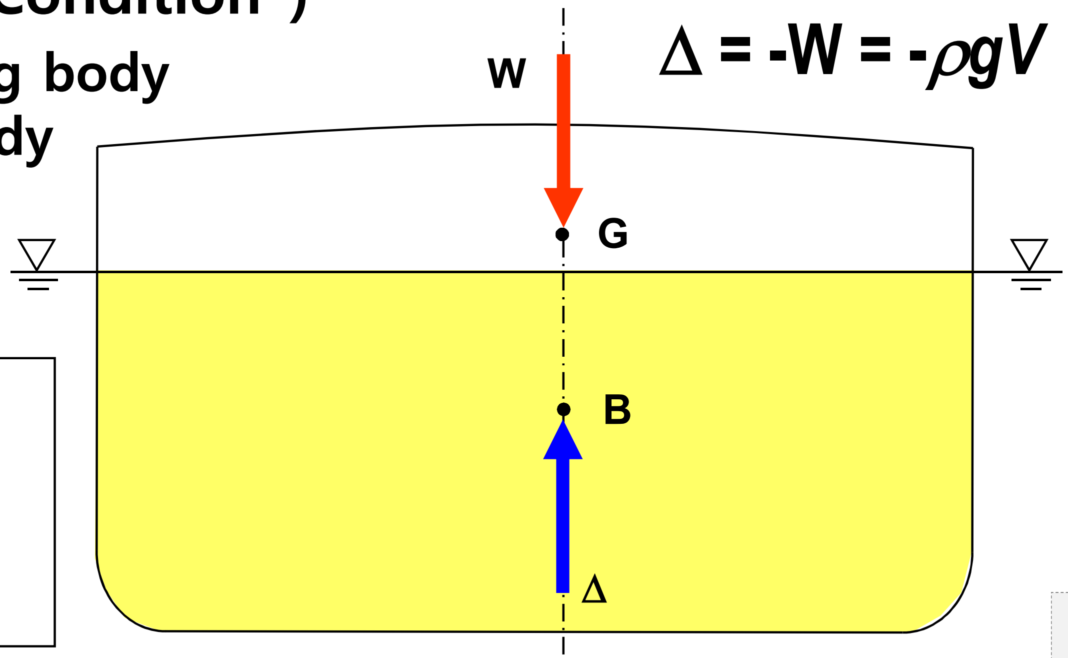
Buoyant force of a floating body
= the weight of the fluid which is displaced by the floating body ("Displacement")
➡ Archimedes' Principle

☑ Equilibrium State ("Floating Condition")

- Buoyant force of the floating body
  = Weight of the floating body

$\therefore$ Displacement = Weight

$$\Delta = -W = -\rho g V$$



G: Center of gravity
B: Center of buoyancy
W: Weight, Δ: Displacement
ρ: Density of fluid
V: Submerged volume of the floating body (Displacement volume, ∇)

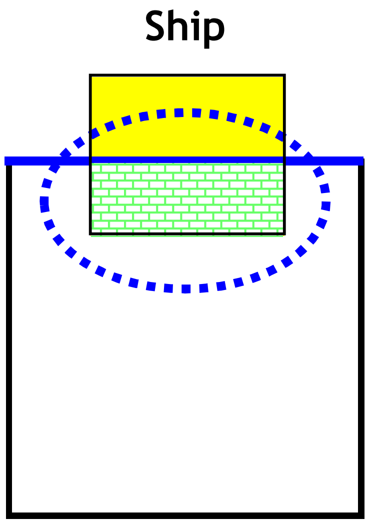
How does a ship float? (3/3)

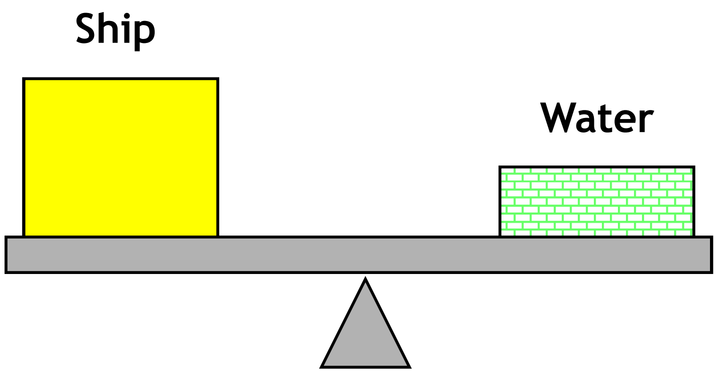
☑ Displacement(Δ) = Buoyant Force = Weight(W)

$$\Delta = L \cdot B \cdot T \cdot C_B \cdot \rho$$
$$= W = LWT + DWT$$

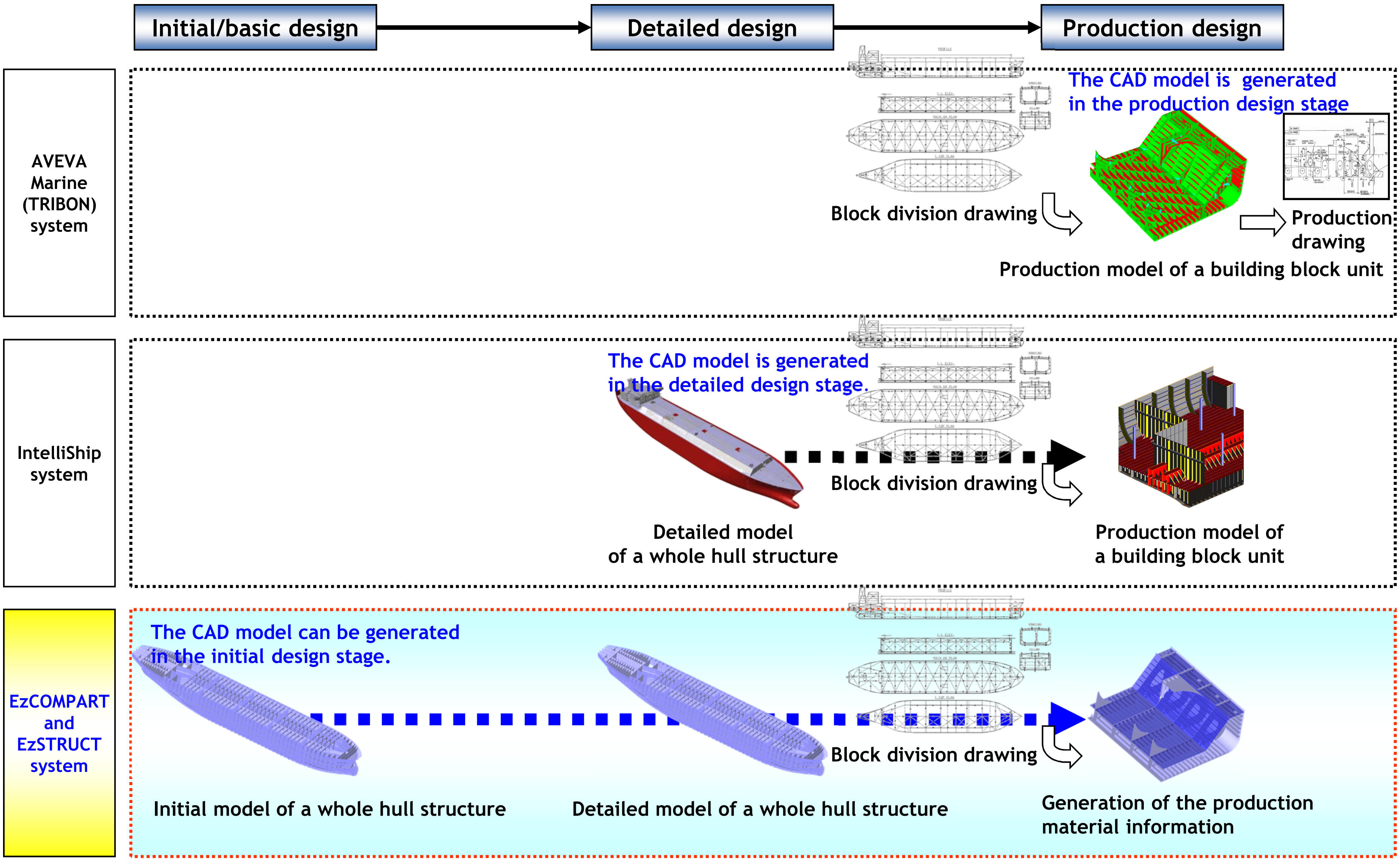
T: Draft
C_B: Block coefficient
ρ: Density of sea water
LWT: Lightweight
DWT: Deadweight

☑ Weight = Ship weight (Lightweight) + Cargo weight(Deadweight)



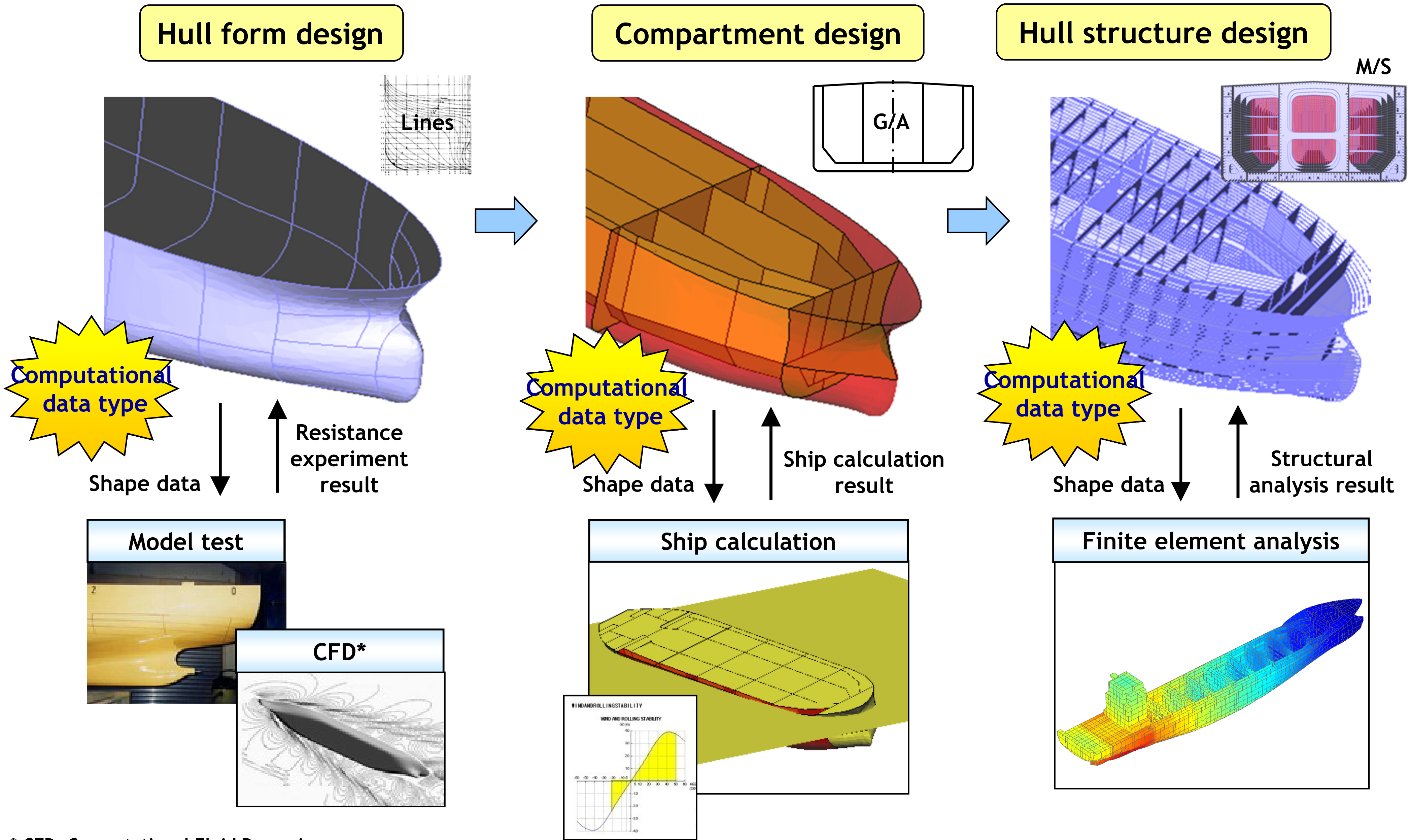


Design Stages and CAD Systems for a Ship



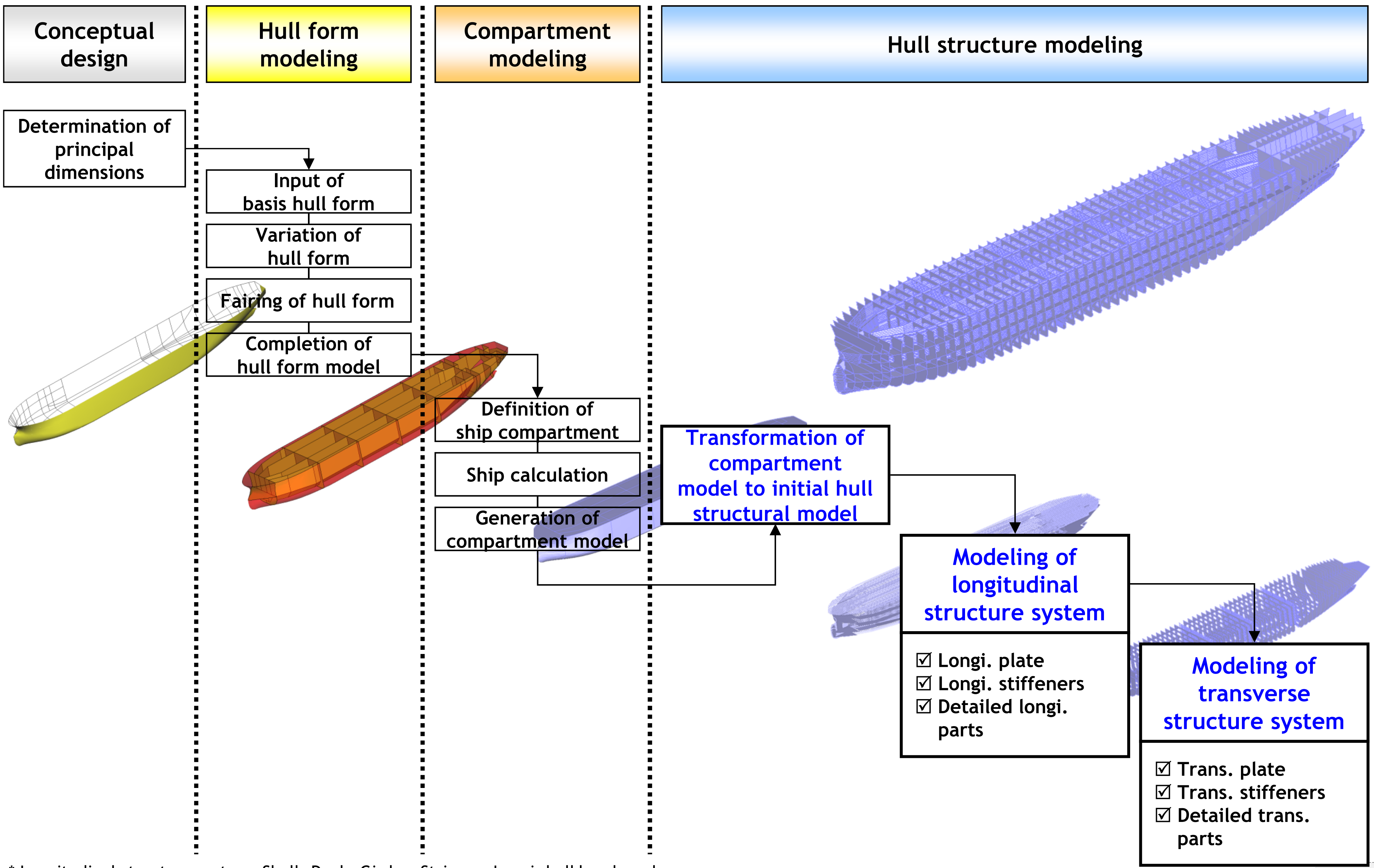
* TRIBON: CAD system (the exclusive use of shipbuilding), developed by Product of TRIBON Solution in Sweden
* IntelliShip: M-CAD systmem(the exclusive use of shipbuilding), co-developed by Intergraph, Samsung Heavy Industries, Odense shipyard in Denmark, and Hitachi Shipyard in Japan

Initial or Basic Design Stage of a Ship



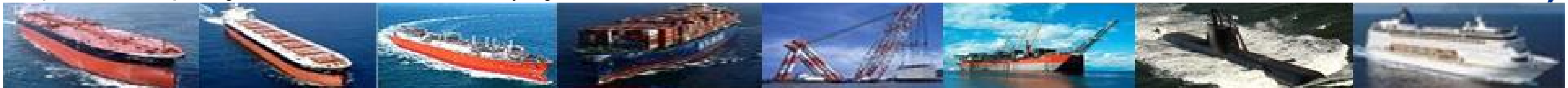
* CFD: Computational Fluid Dynamics

Modeling Stages of the Initial or Basic Design



* Longitudinal structure system: Shell, Deck, Girder, Stringer, Longi. bulkhead, and so on
* Transverse structure system: Trans. bulkhead, Web frame, and so on

1.2 Hull Form Design



What is a "Hull form"?

☑ **Hull form**

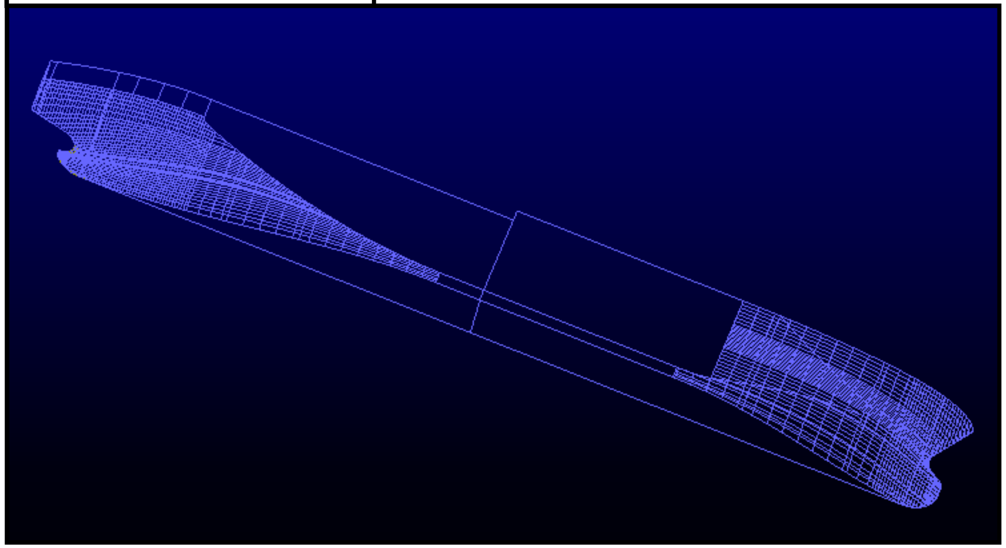
- **Outer shape of the hull** that is streamlined in order to satisfy requirements of a ship owner such as a deadweight, ship speed, and so on
- Like a skin of human

☑ Hull form design

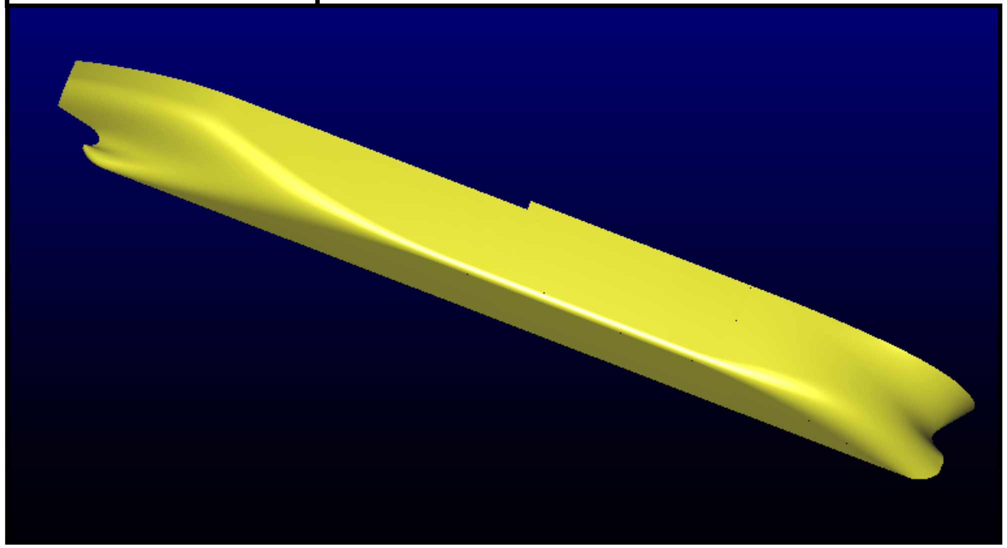
- Design task that designs the hull form

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

Wireframe model

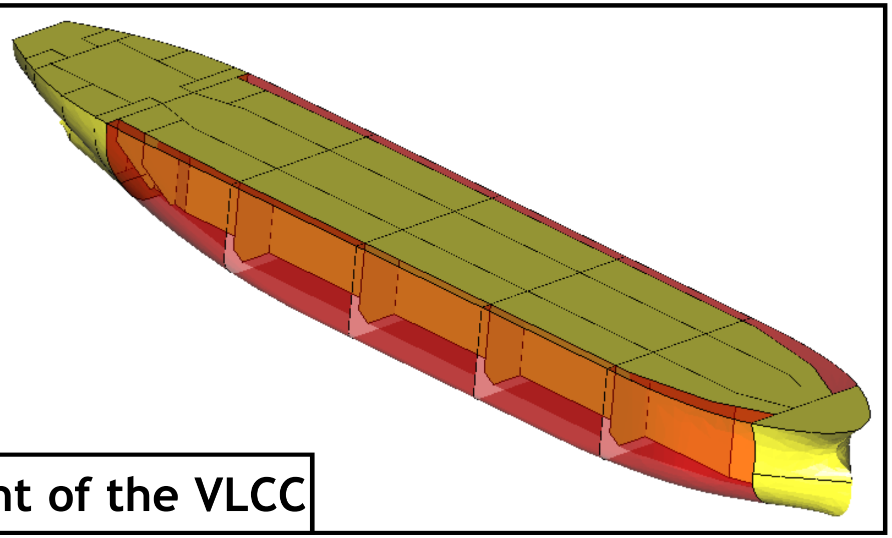


Surface model



What is a “Compartment”?

- ☑ Compartment
  - Space to load cargos in the ship
  - It is divided by a bulkhead which is a diaphragm or peritoneum of human.
- ☑ Compartment design (General arrangement design)
  - Compartment modeling + Ship calculation
- ☑ Compartment modeling
  - Design task that divides the interior parts of a hull form into a number of compartments
- ☑ Ship calculation (Naval architecture calculation)
  - Design task that evaluates whether the ship satisfies the required cargo capacity by a ship owner and, at the same time, the international regulations related to stability, such as MARPOL and SOLAS, or not

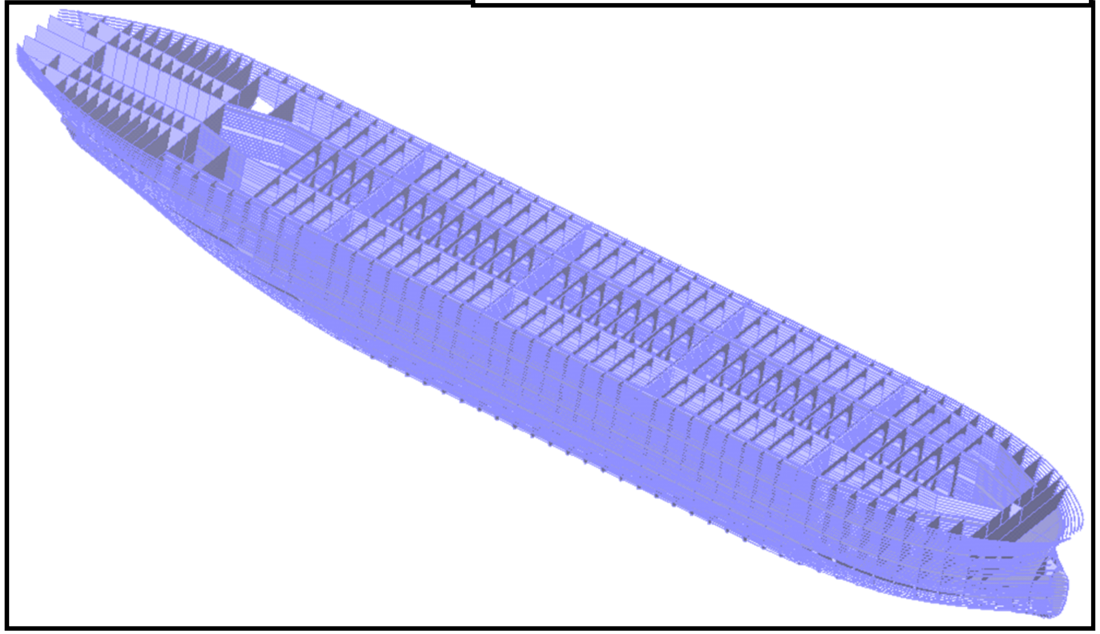


Compartment of the VLCC

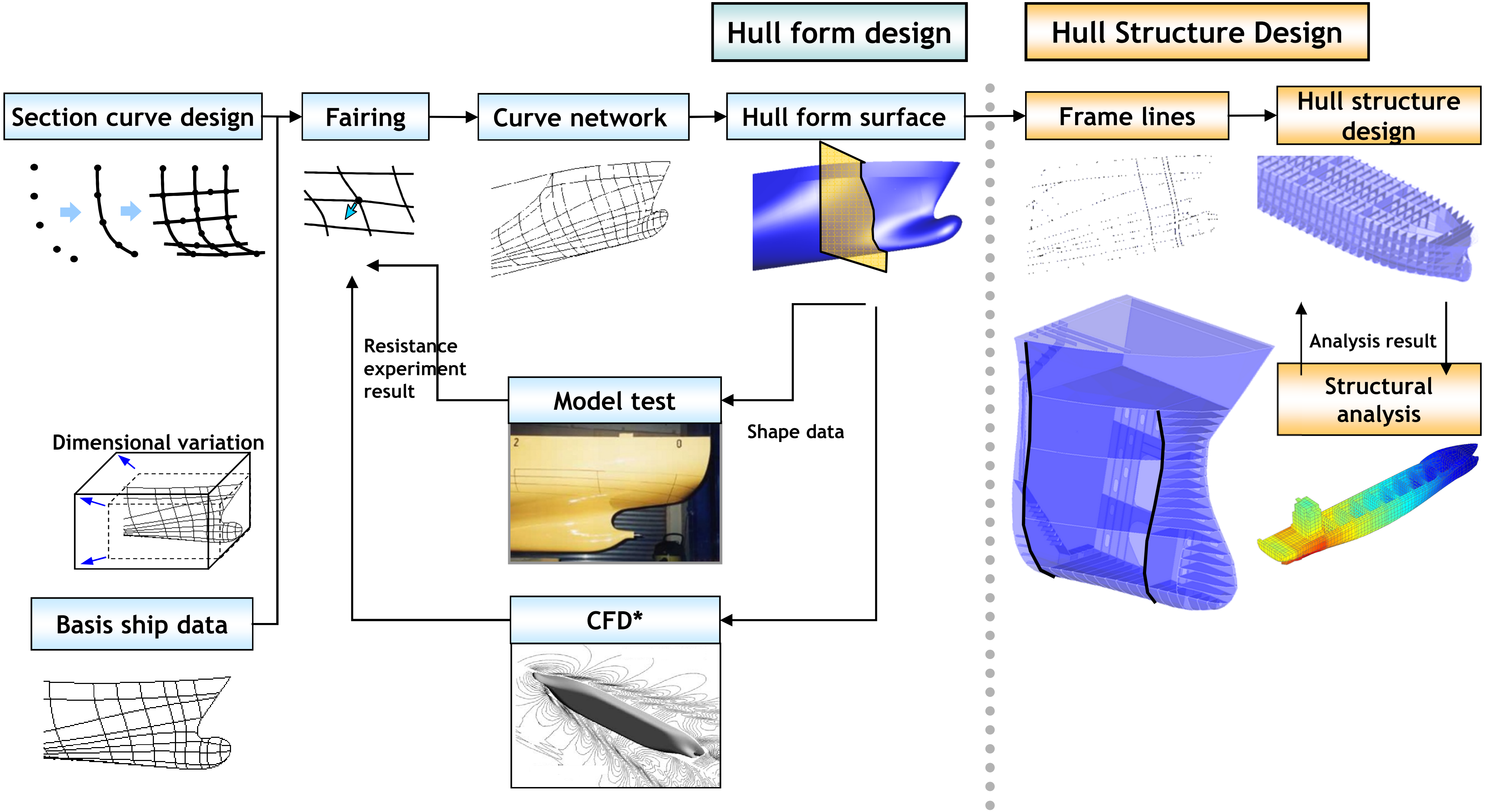
What is a "Hull structure"?

- ☑ **Hull structure**
  - Frame of a ship comprising of a number of hull structural parts such as plates, stiffeners, brackets, and so on
  - Like a skeleton of human
- ☑ **Hull structural design**
  - Design task that determines the specifications of the hull structural parts such as the size, material, and so on

Hull structure of the VLCC

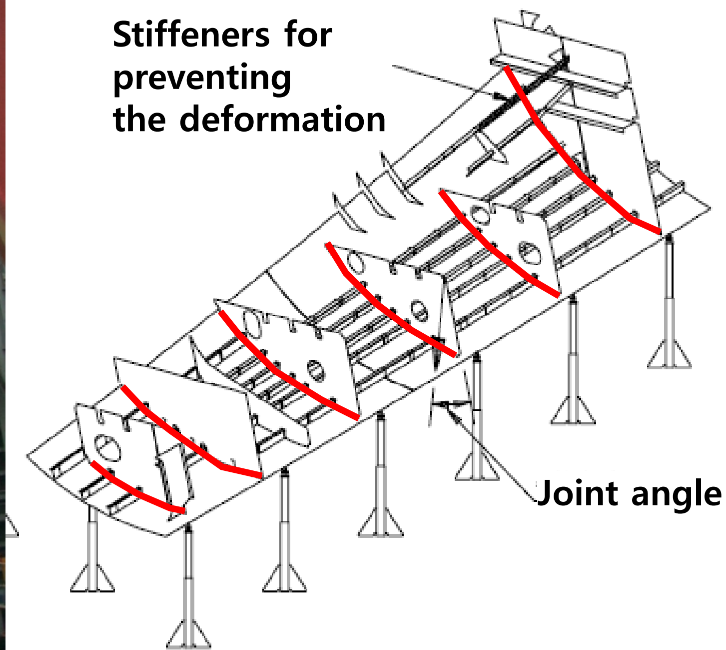


Ship Shape("Hull Form") Design



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.



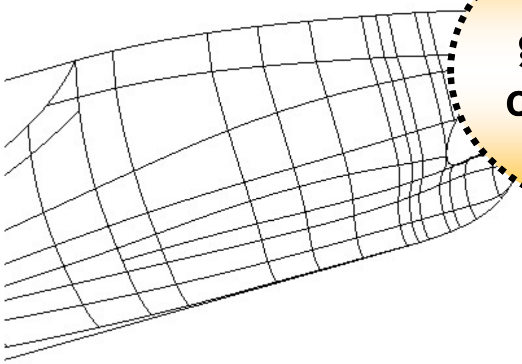
Quality Requirement of a Hull Form Surface

Initial hull form design

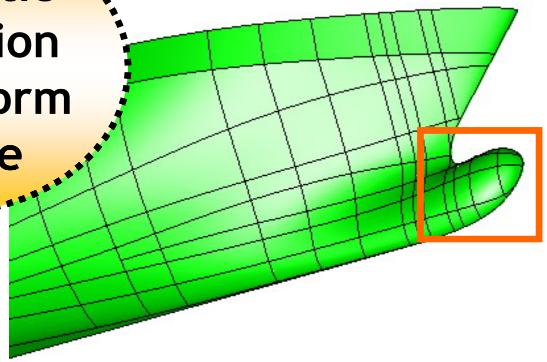
Detailed design / Production design

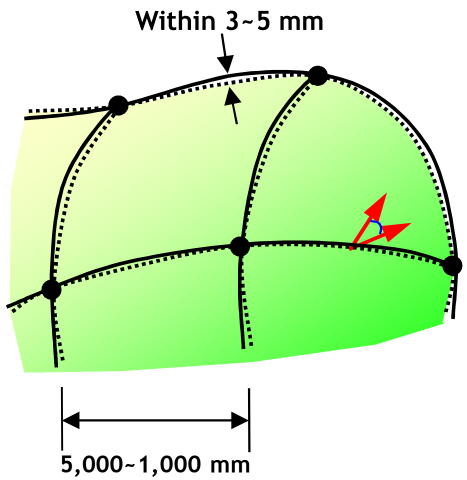
Find: Smooth hull form surfaces

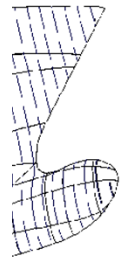
Given: Curve network



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^1**

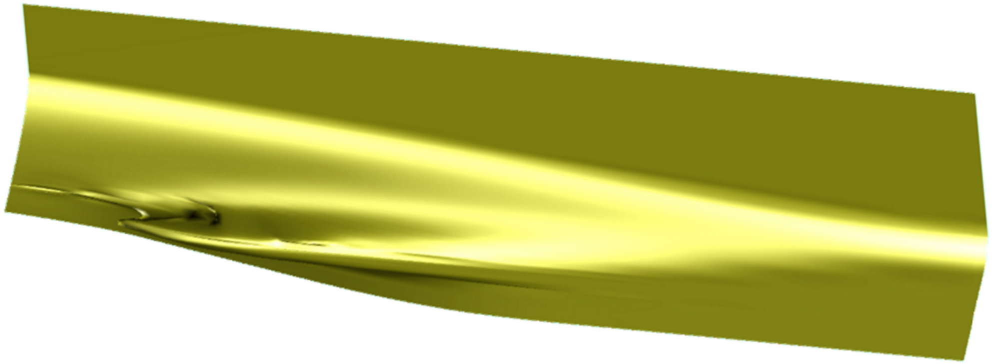
- Intersection between surfaces and plane
- Validation of the fairness

* Acceptable tolerance in shipbuilding industry is about 3~5 mm.

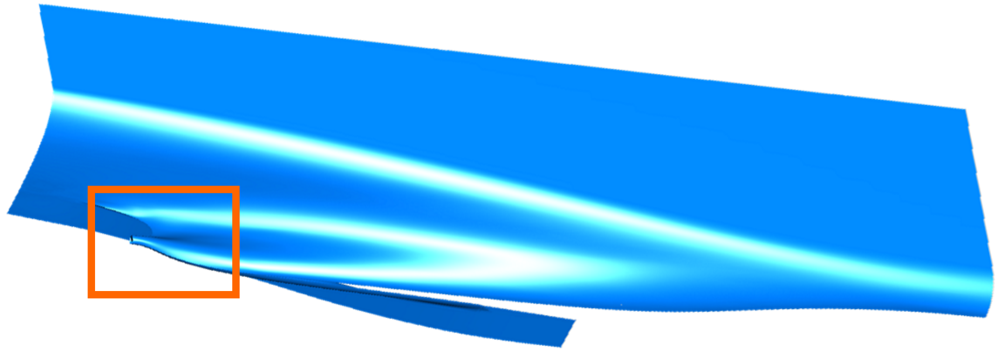
** G^1 means geometric continuity or tangential plane continuity. IntelliShip requires exact G^1 hull form surfaces.

Hull Surface Modeling by Single Patch Approach and Piecewise Patch Approach

- Single patch approach

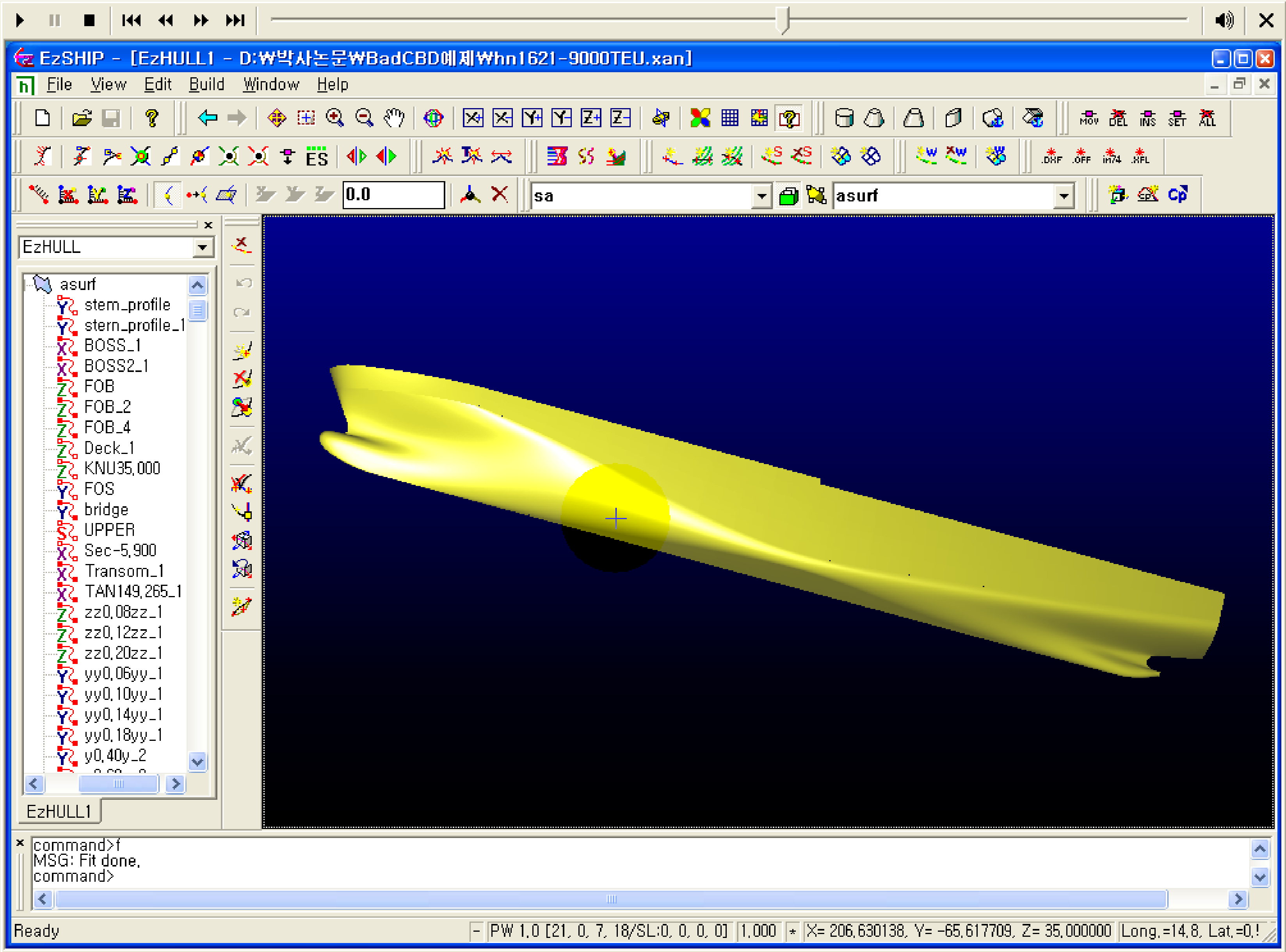


- Piecewise patch approach



Method	Single patch approach	Piecewise patch approach
Advantage	• Easy to represent the hull surface • Mathematically, the 2nd derivatives are continuous at all points on the surface(C^2)	• Suitable for representing the complicated free form surface • Able to represent the knuckle curve
Disadvantage	• A single patch approach cannot exactly represent a complex shape in the bow and stern parts and also knuckle curve.	• It should satisfy the complicated continuity equations for tangential plane to generate a fine hull form surface. • It needs a special method to handle the region which is not rectangle.

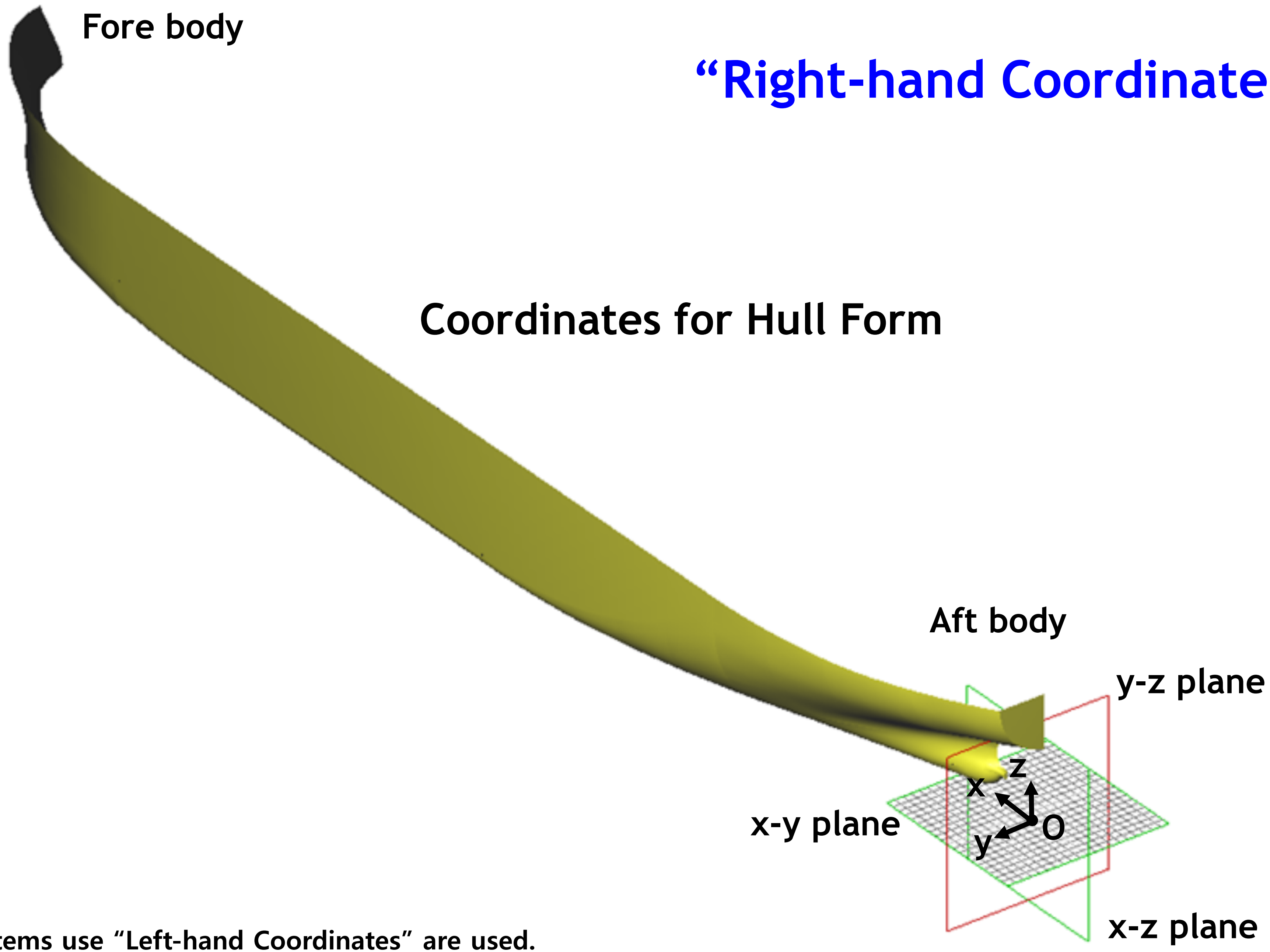
Example of Hull Form Surface



Coordinates for Hull Form Representation

"Right-hand Coordinates"

Coordinates for Hull Form



* Some systems use "Left-hand Coordinates" are used.

Composition of Wireframes of Hull Form

☑ Hull form curves

- Primary curves
  - They define the outer shape of a hull form.
  - Profile line, bottom tangent line, side tangent line, etc.
- Secondary curves
  - They define the inner shape of a hull form under the outer shape defined by primary curves.
  - Section line, buttock line, water line, space line, etc.

☑ Wireframes (Curve network)

- Group of hull form curves which are generated from primary and secondary curves, and intersection curves among them
- They contain a number of closed regions of triangle, quadrilateral, pentagon, etc.
- Basis for generating a hull form surface

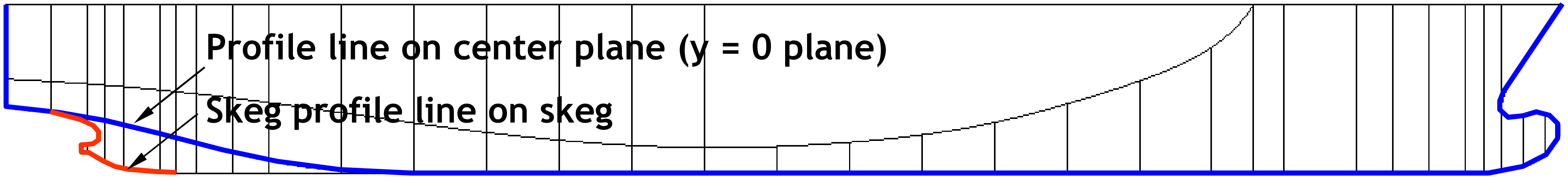
Primary Curves for Hull Form Representation - Profile Line (1/2)

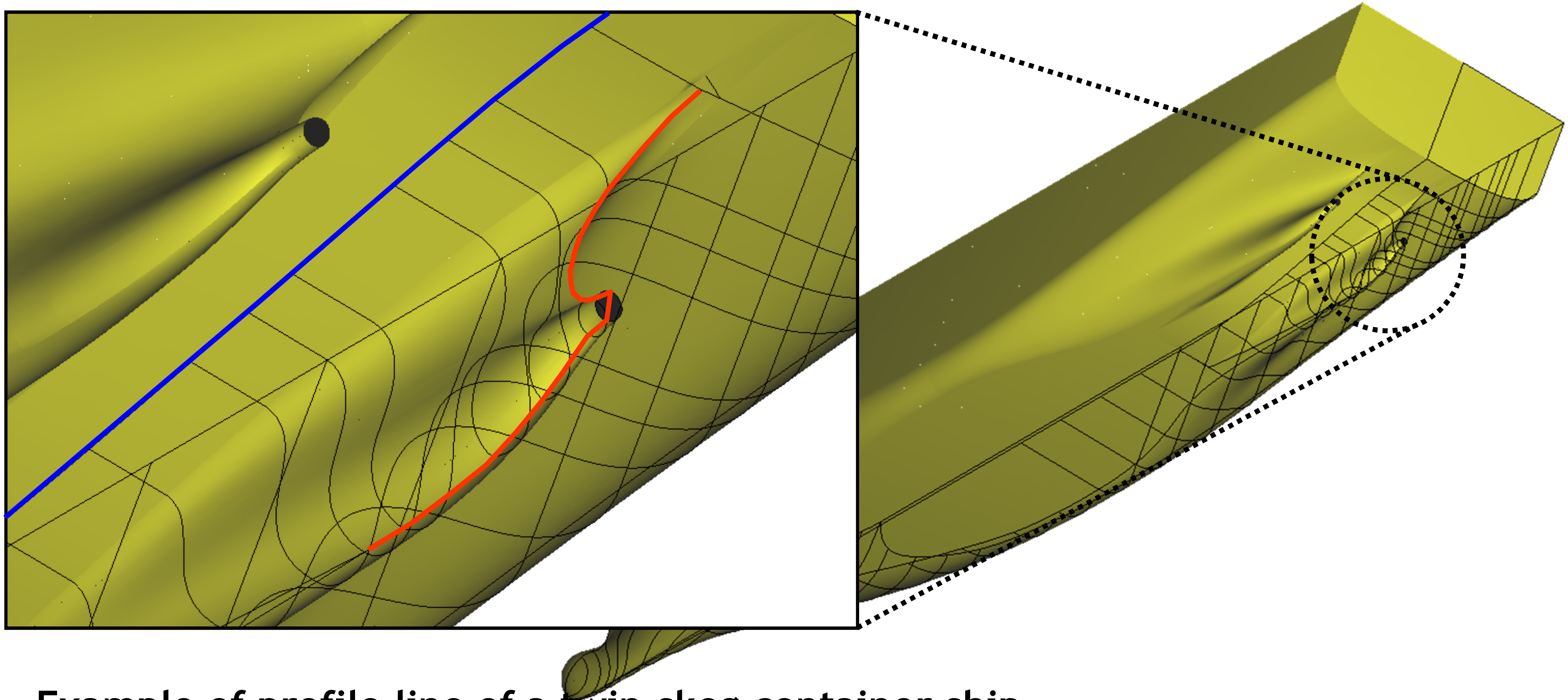
☑ Profile line is an intersection (or tangent) curve between hull form surface and center plane (center plane, y = 0 plane) except for deck.

☑ Also called center line

Example of profile line of a 320K VLCC

Primary Curves for Hull Form Representation - Profile Line (2/2)

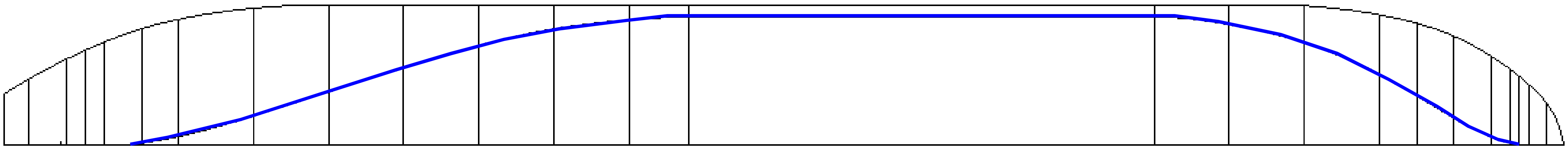




Example of profile line of a twin-skeg container ship

Primary Curves for Hull Form Representation - Bottom Tangent Line

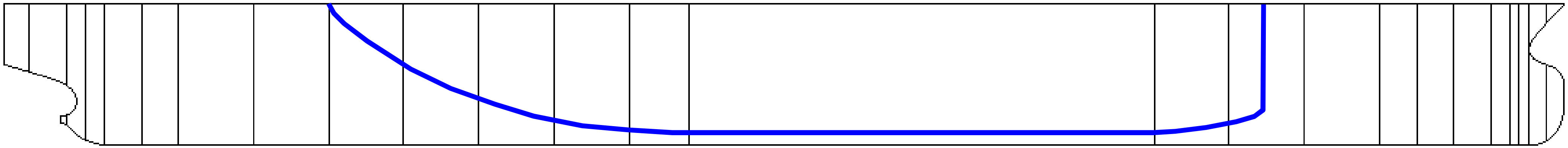
☑ **Bottom tangent line is an intersection (or tangent) curve between hull form surface and base plane (z = 0 plane)**



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 = $B_{mld}/2$ plane.



Example of side tangent line of a 320K VLCC

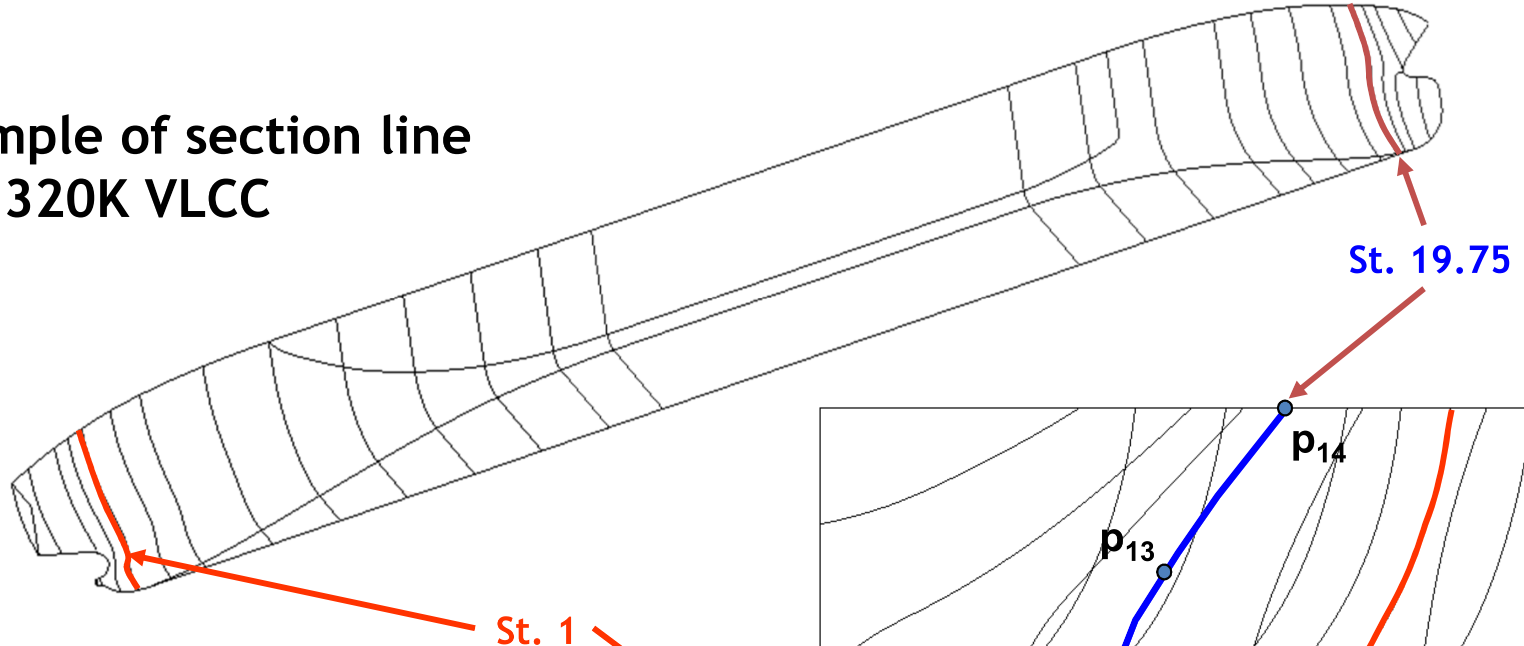
Primary Curves for Hull Form Representation
- Deck Side Line

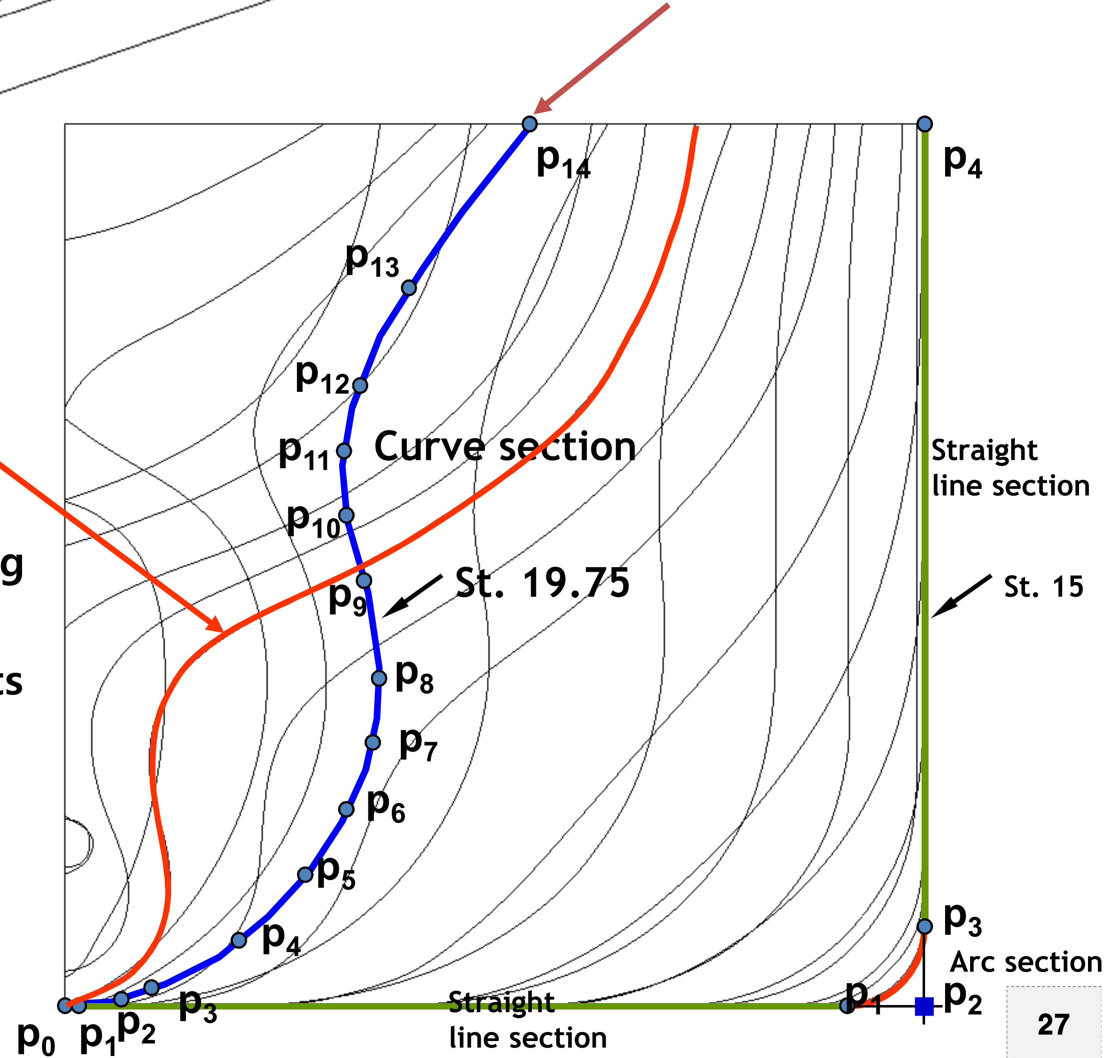
- ☑ Deck side line is a curve representing the side of upper deck
- ☑ Both ends of the curve contact with profile line.

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 section 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.

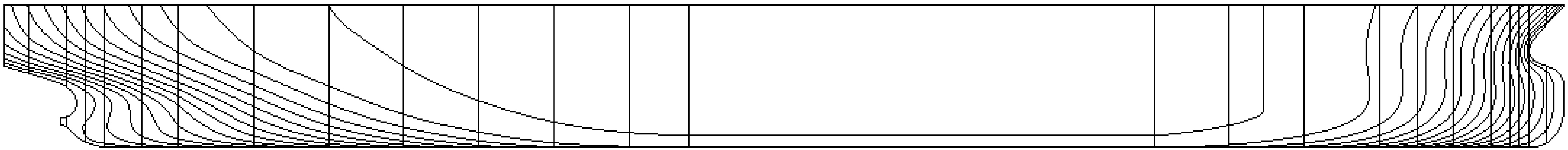
☑ In generally, because the section lines are located at the stations, they are called station line.

☑ Section lines make up the body plan 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 sheer plan or buttock plan of lines.

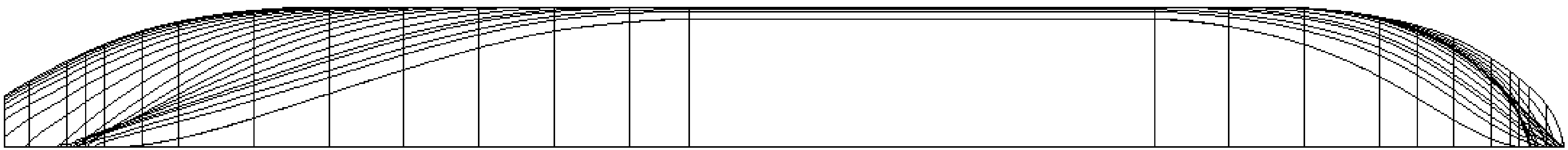


Example of buttock line of a 320K VLCC

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 **water plan** or **half-breadth plan** of lines.

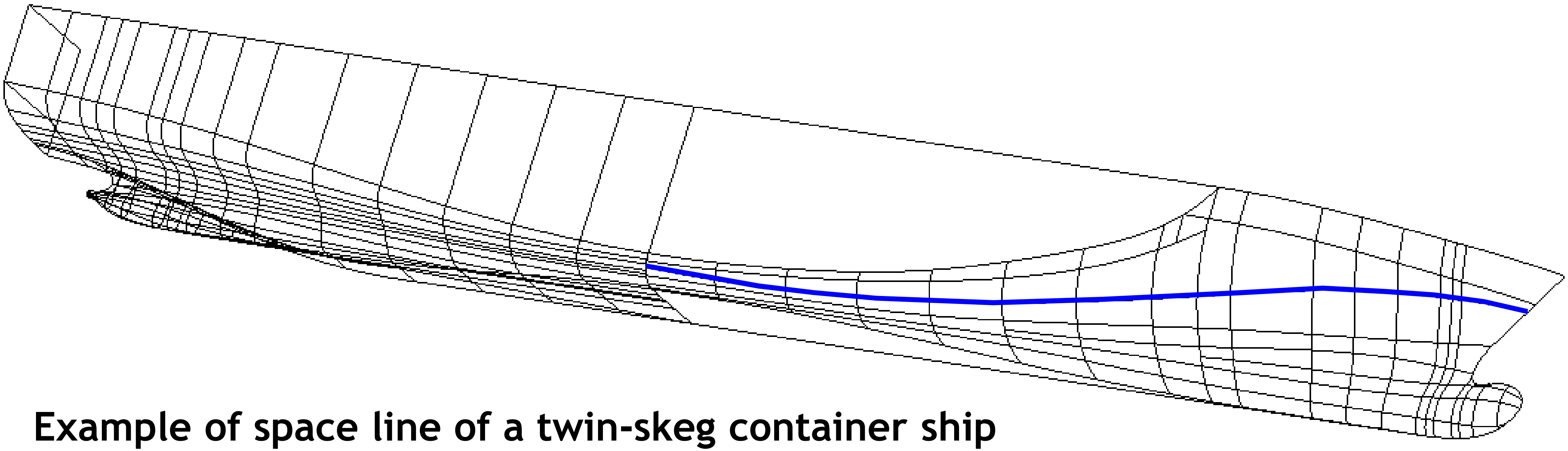


Example of water line of a 320K VLCC

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.

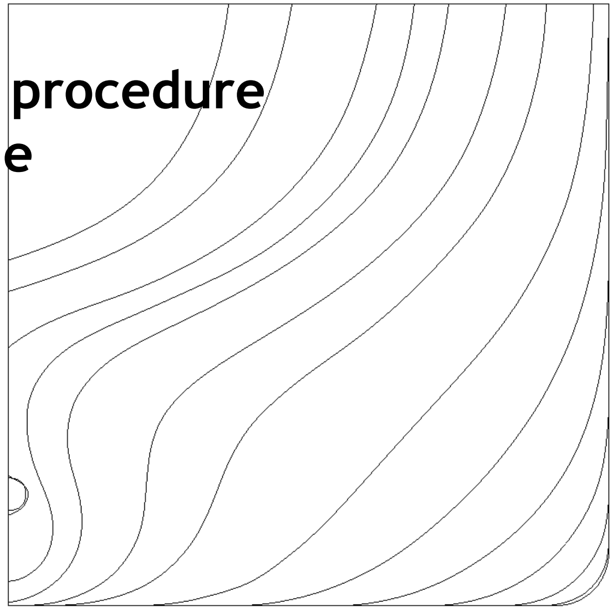
☑ For the complicated hull form, space lines are additionally required with plane curves for defining the hull form.



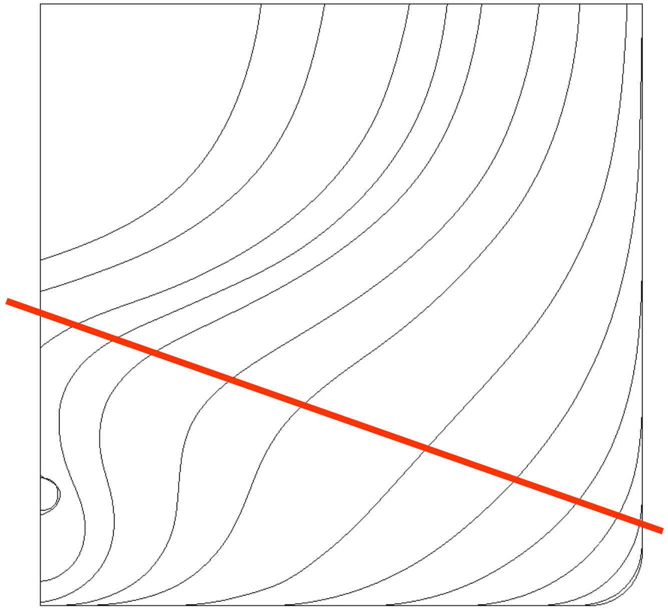
Example of space line of a twin-skeg container ship

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

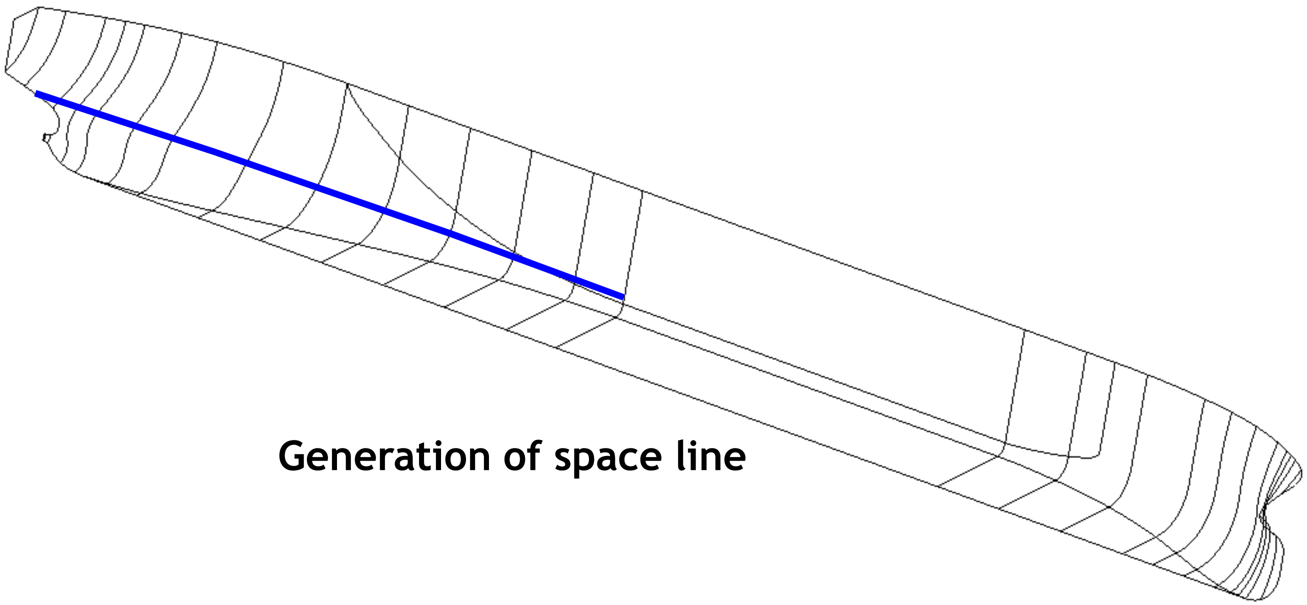
Generation procedure of space line



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

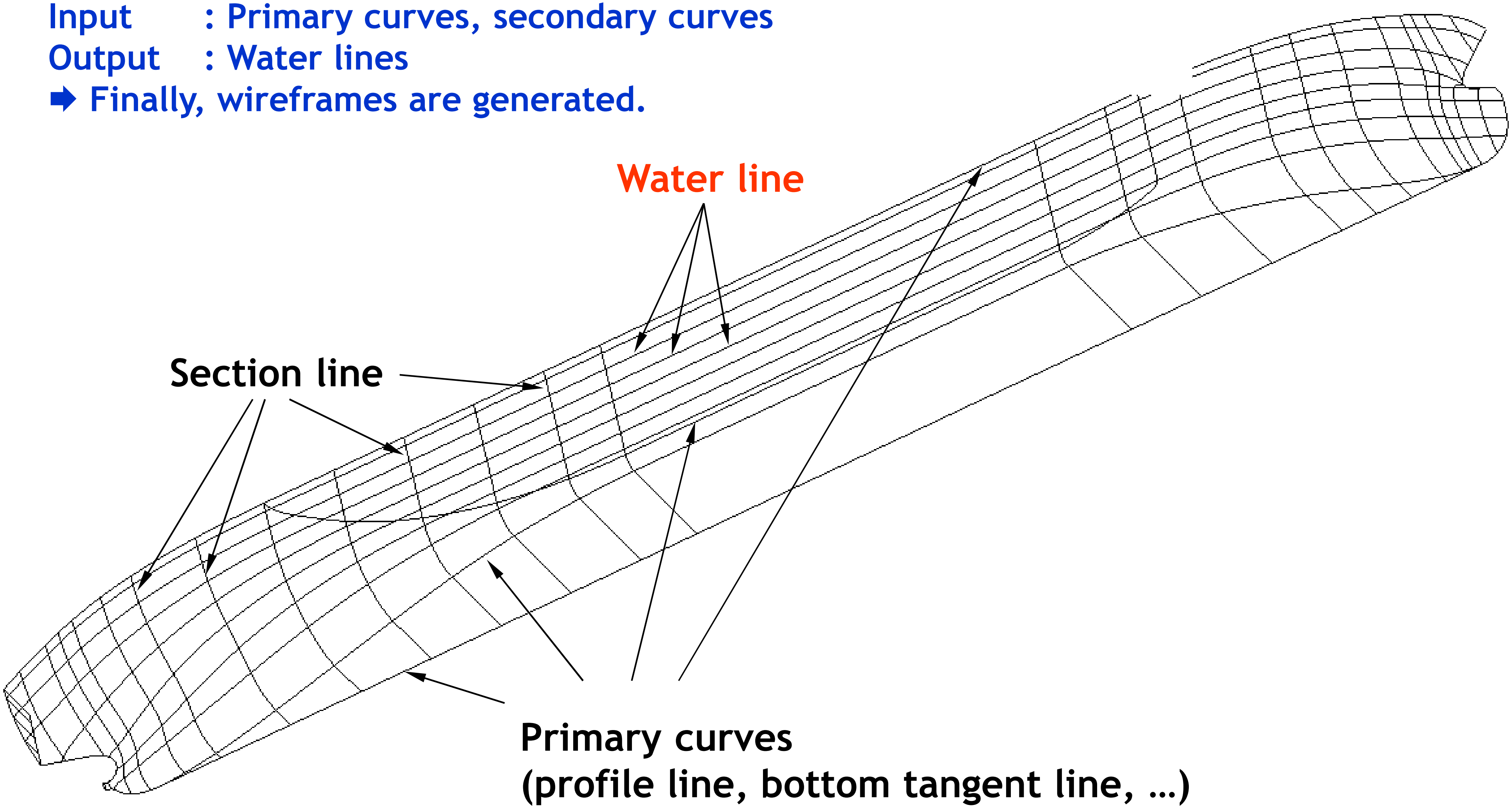
③ Wireframes generation

- Generation of wireframes using ① and ②

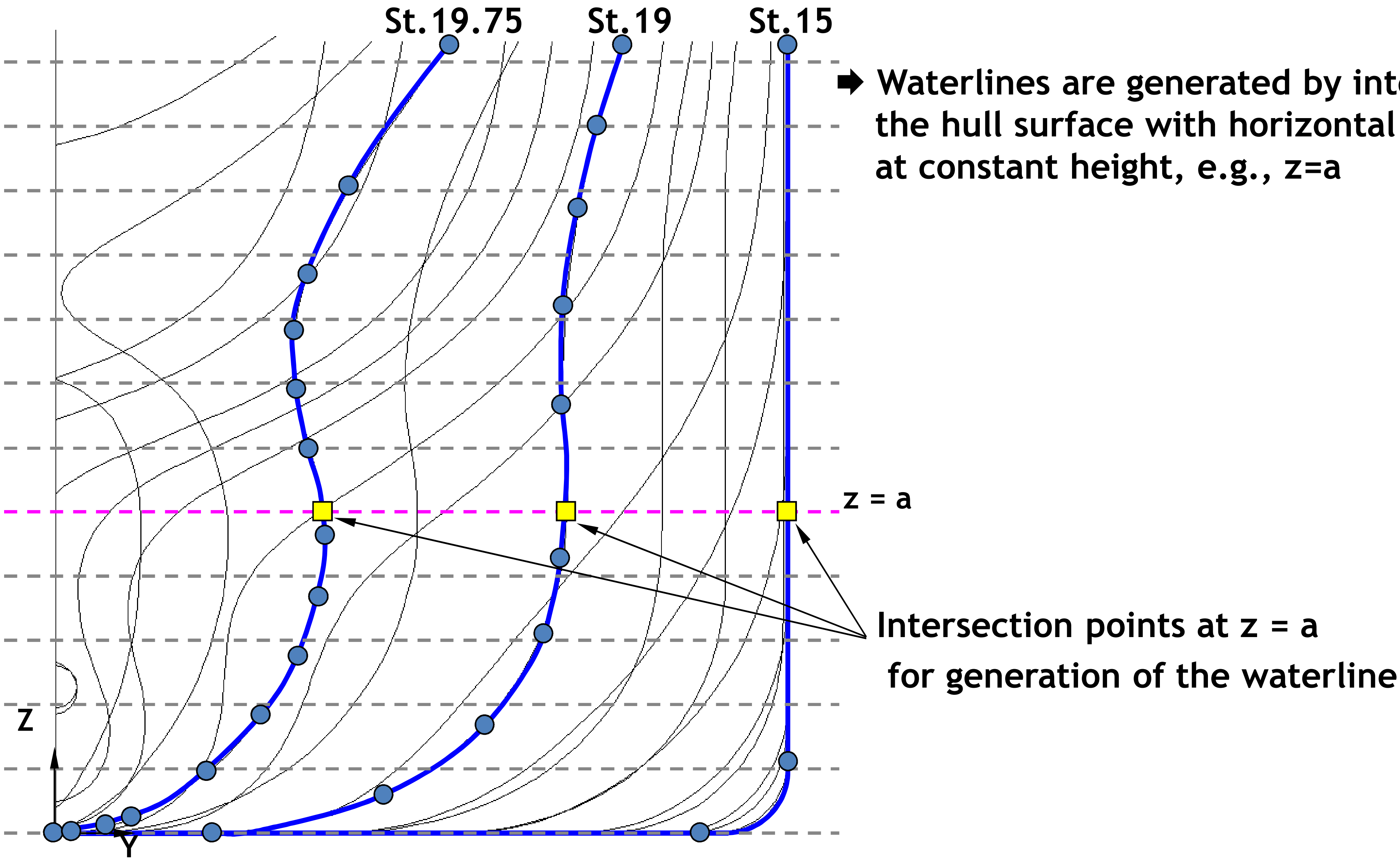
Wireframes Generation

Wireframes generation using primary & secondary curves and water lines

Input : Primary curves, secondary curves
Output : Water lines
➡ Finally, wireframes are generated.

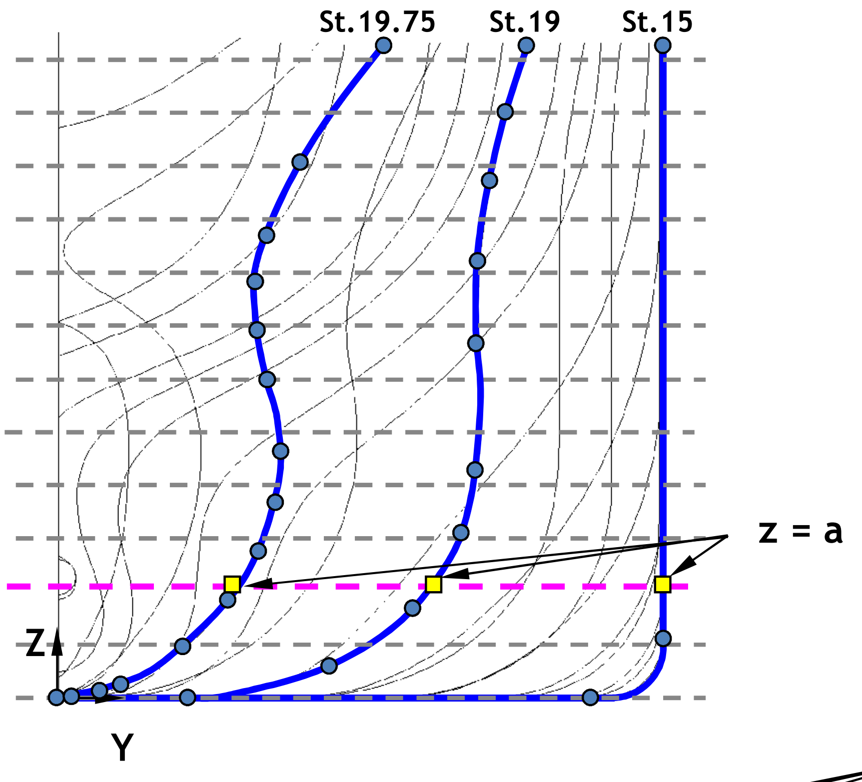


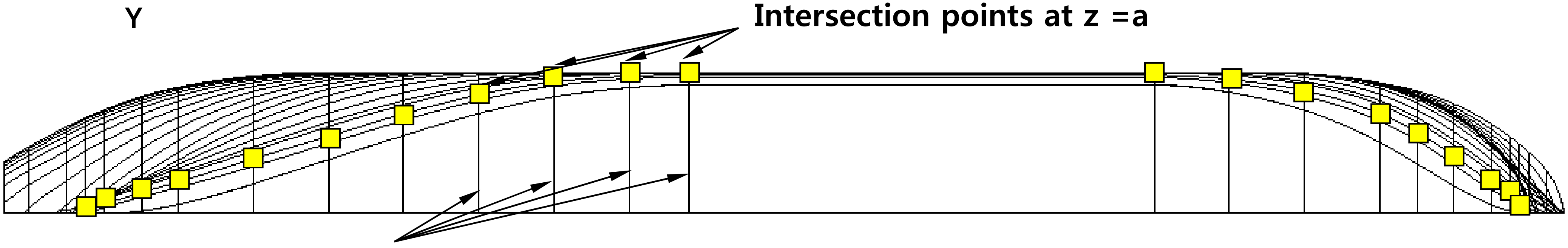
Generation of Waterlines (1/3)



➡ Waterlines are generated by intersecting the hull surface with horizontal plane at constant height, e.g., z=a

Generation of Waterlines (2/3)





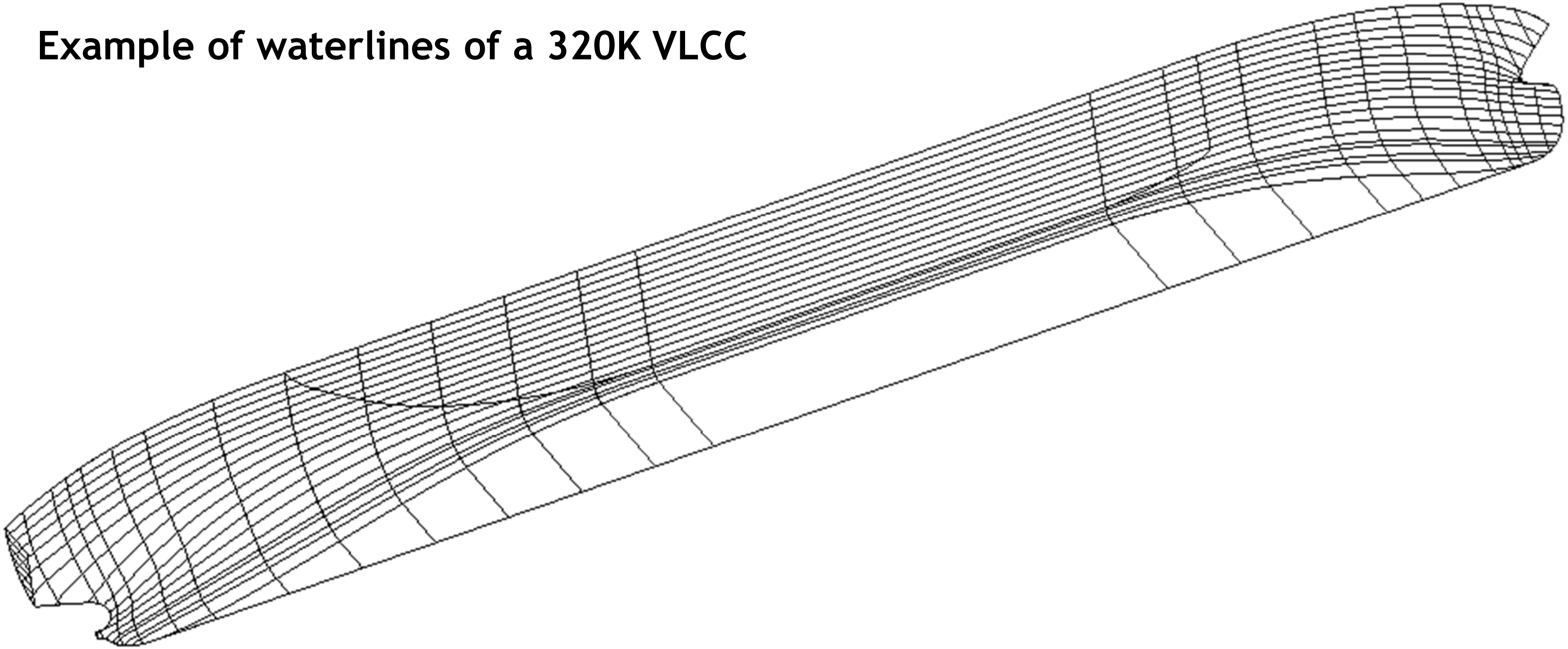
Interpolate all Intersection points at z = a by using a NURB curve
➡ Generation of a waterline at z = a

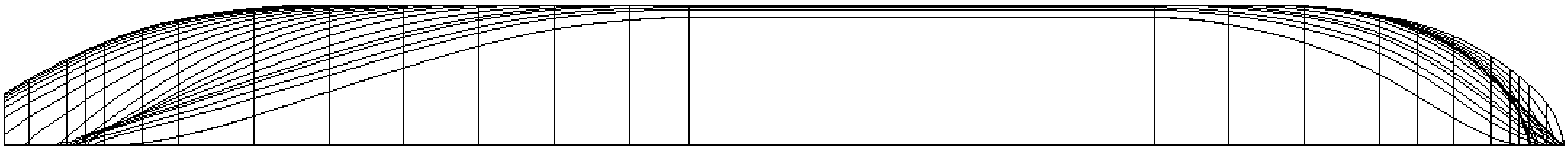
➡ **Generate Waterlines**

Repeat the above steps at different height

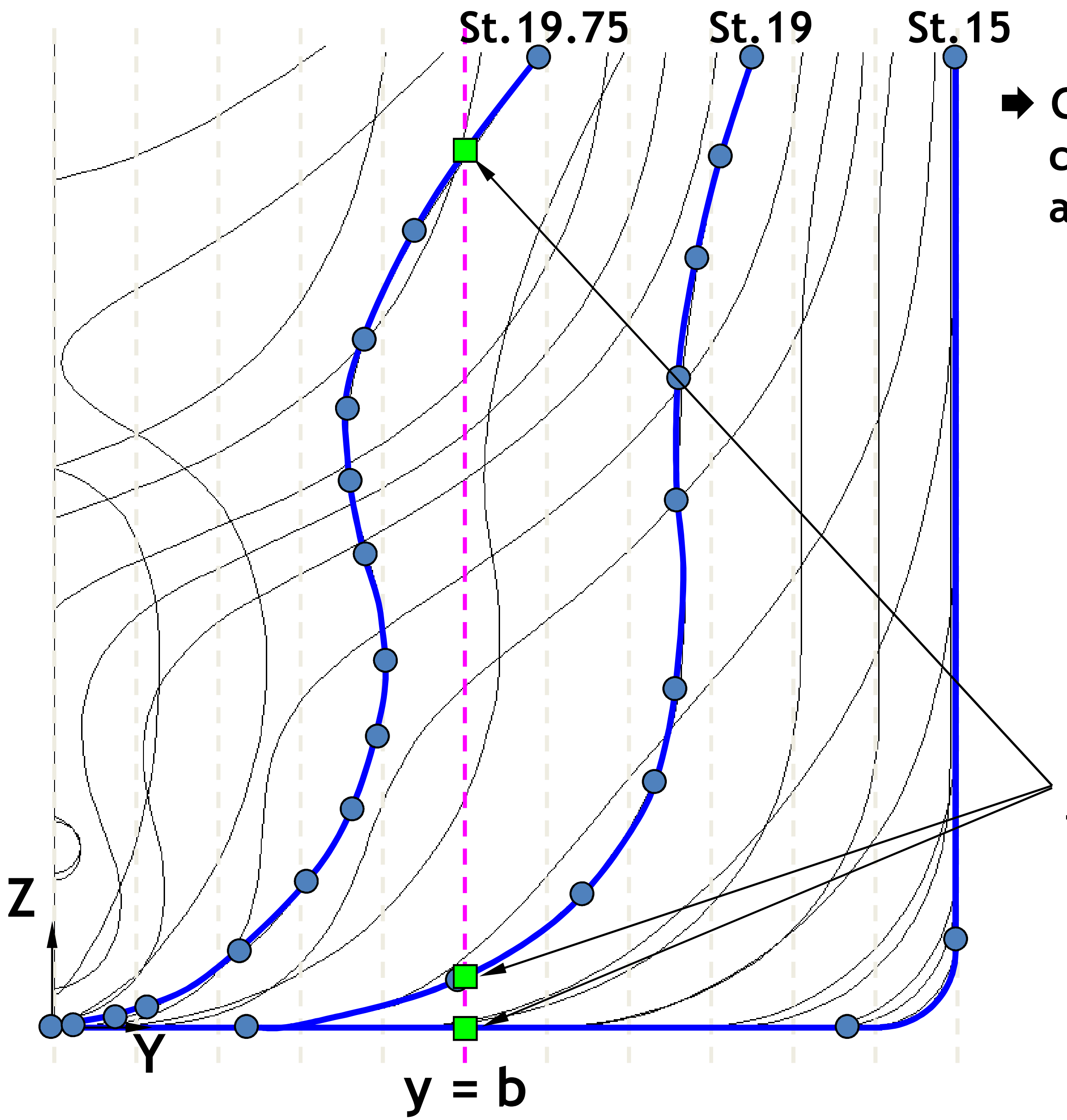
Generation of Waterlines (3/3)

Example of waterlines of a 320K VLCC





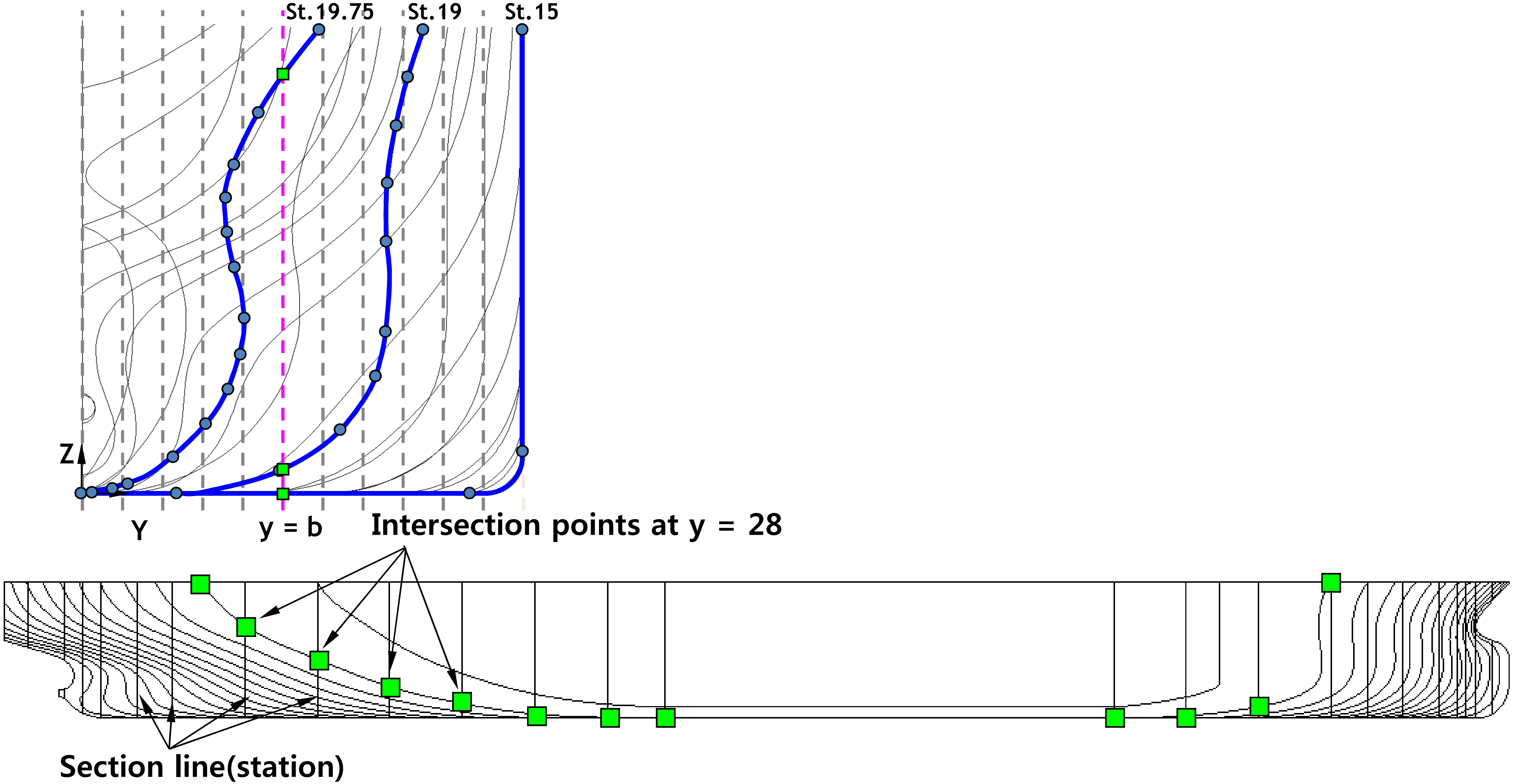
Generation of Buttock Lines (1/3)



➡ 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'

Generation of Buttock Lines (2/3)



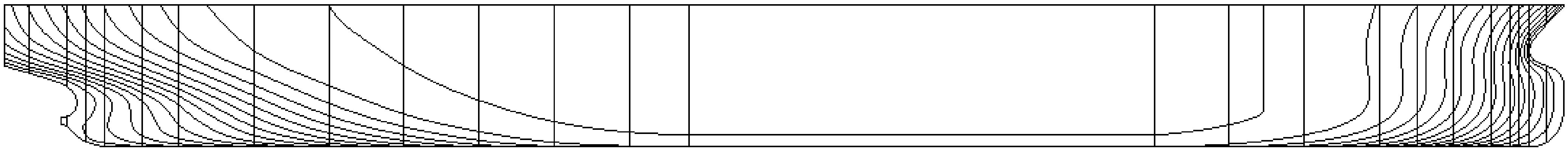
Interpolate all Intersection points at y = b by using a NURB curve
➡ Generation of a buttock line at y = b

➡ **Generate Buttock Lines**

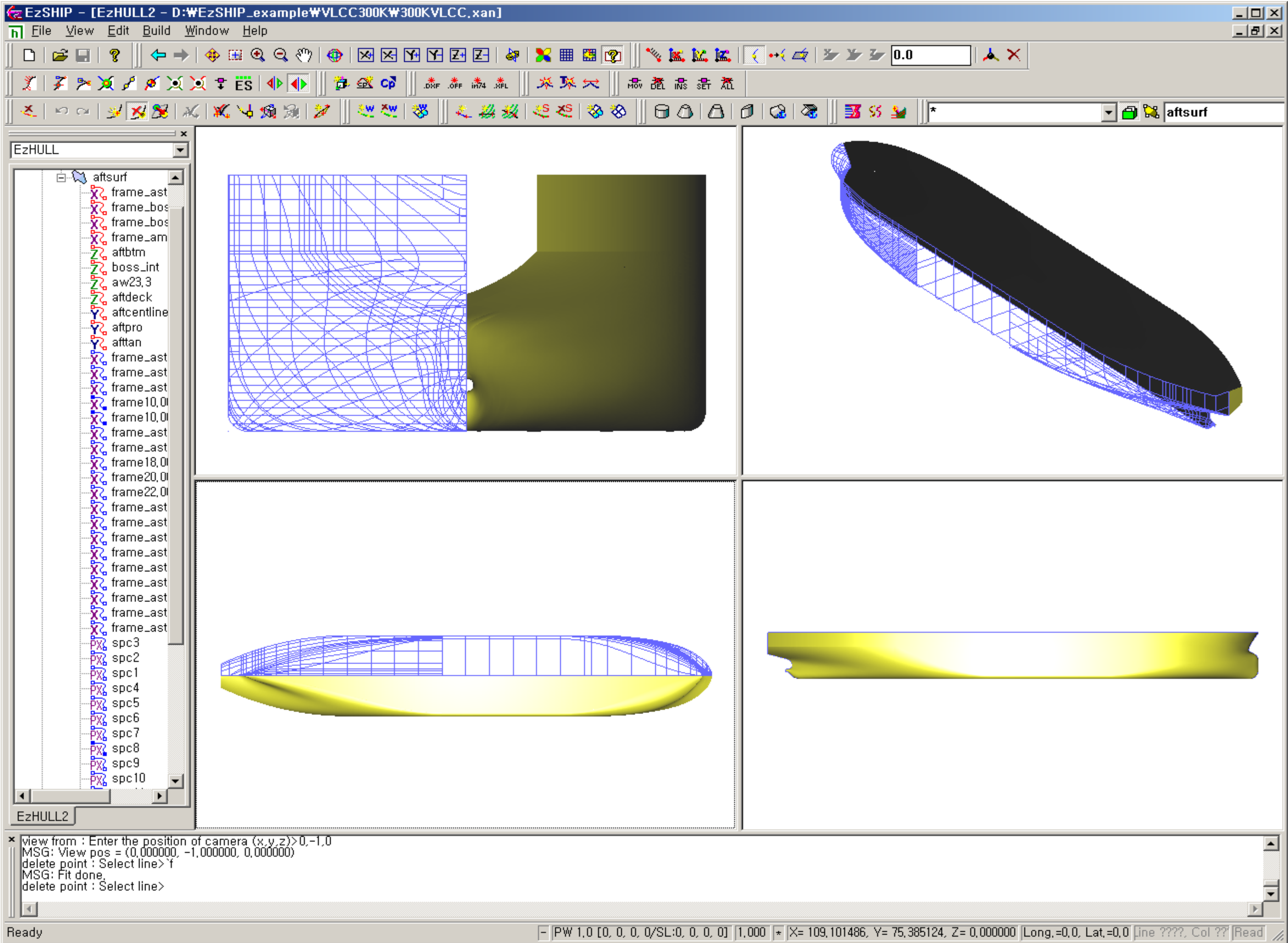
Repeat the above steps at different breadth

Generation of Buttock Lines (3/3)

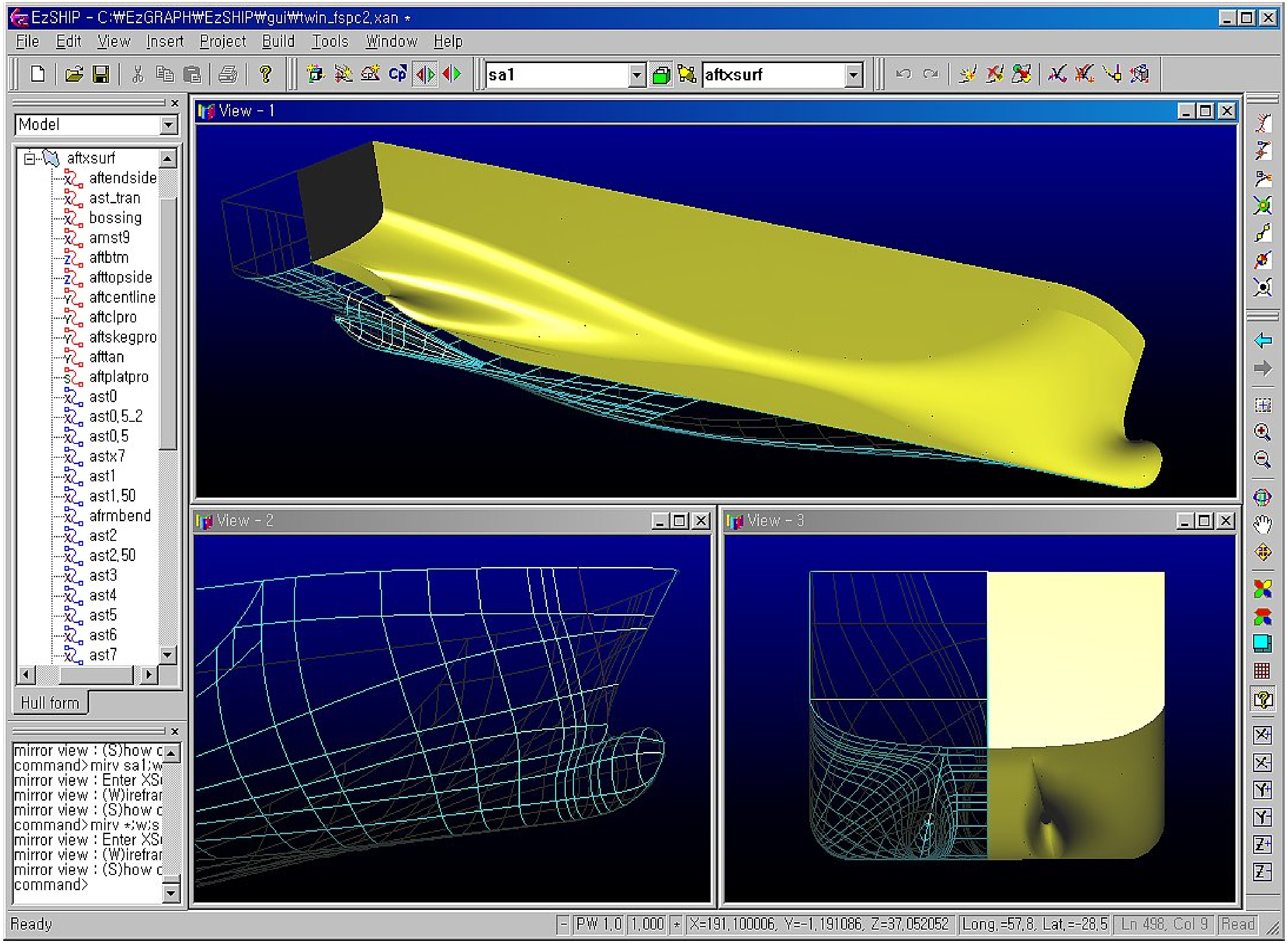
Example of buttock lines of a 320K VLCC



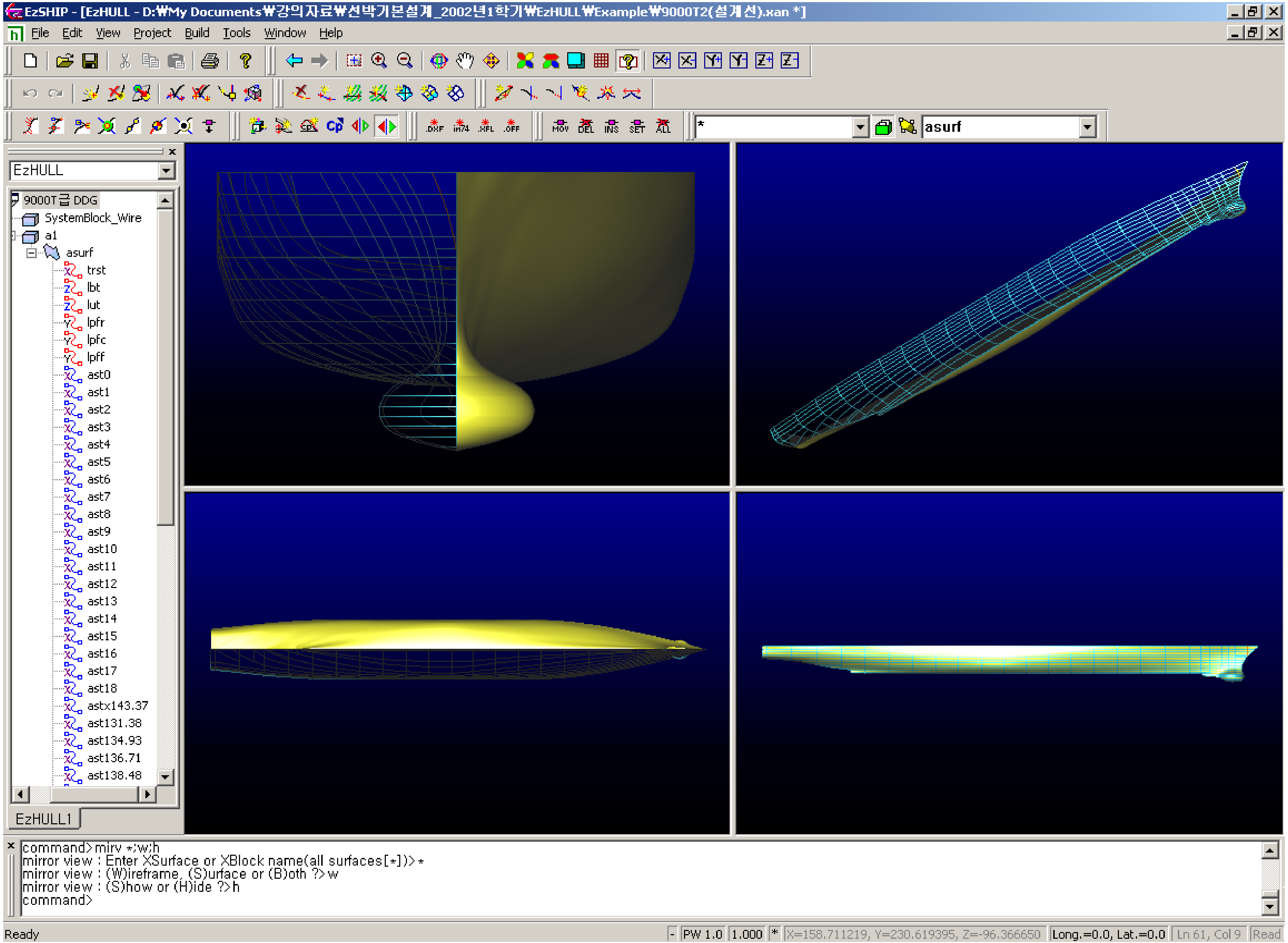
Hull Form Modeling of a 320,000 ton VLCC



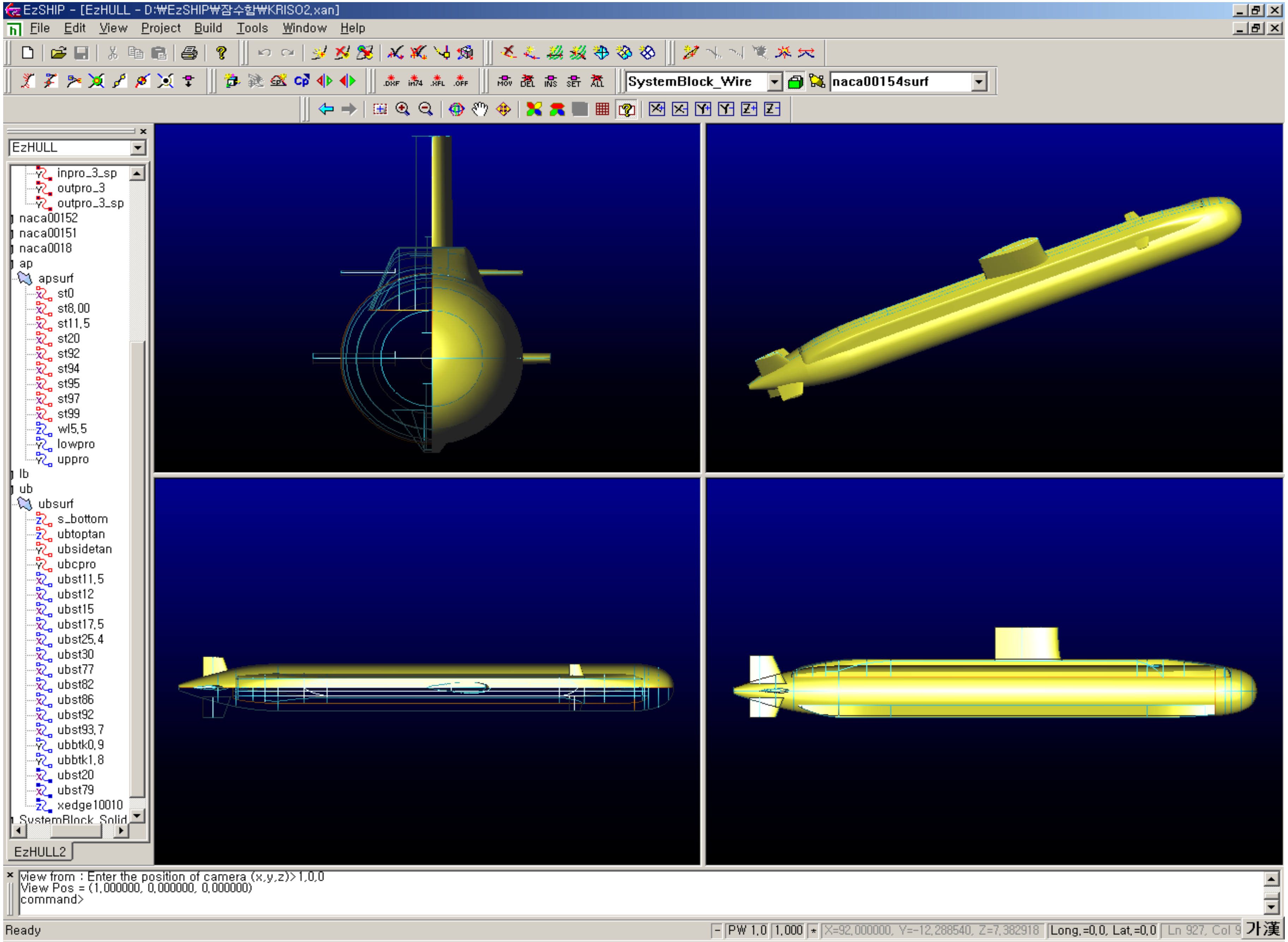
Hull Form Modeling of a Container Ship



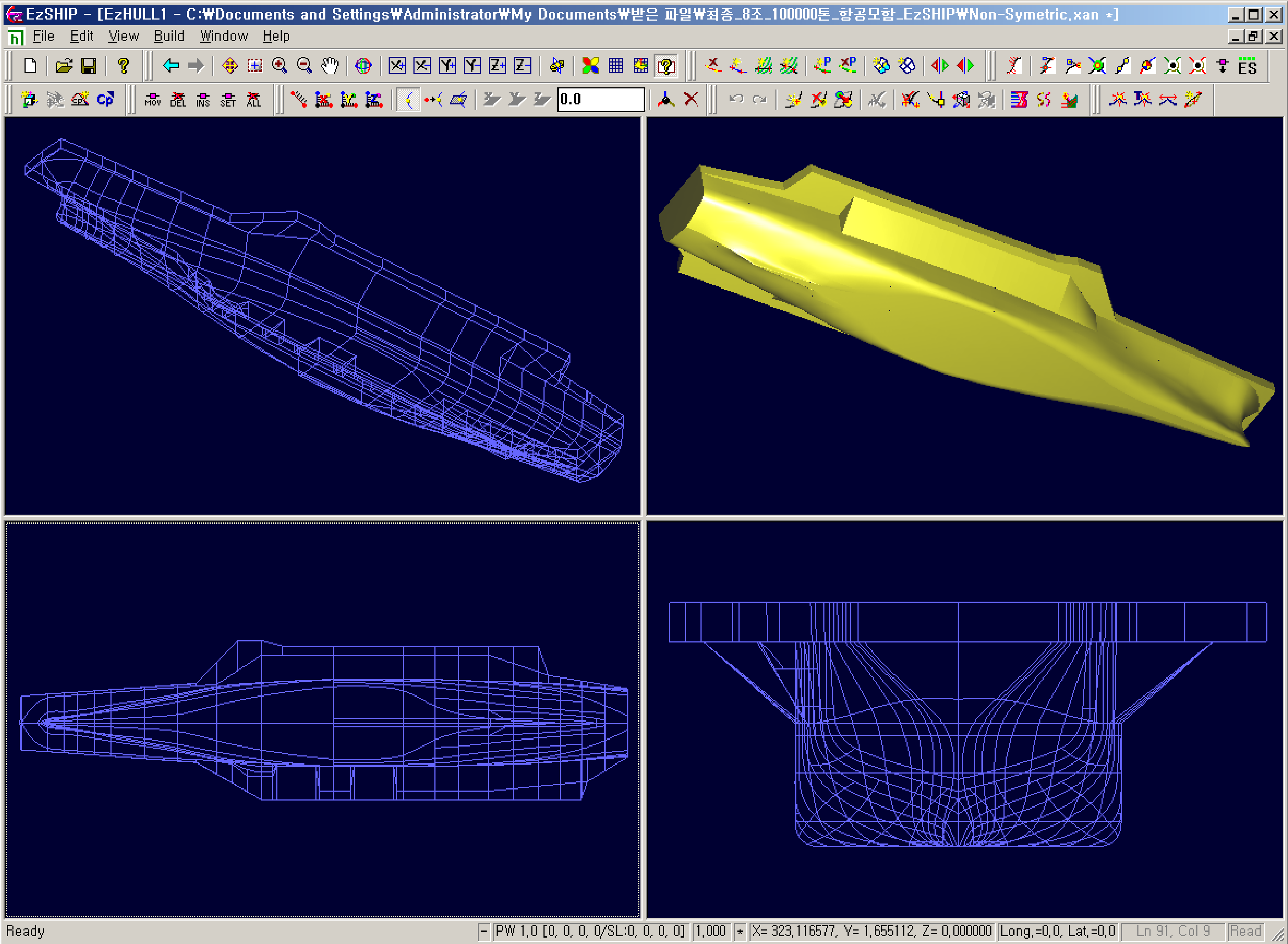
Hull Form Modeling of a Guided Missile Destroyer



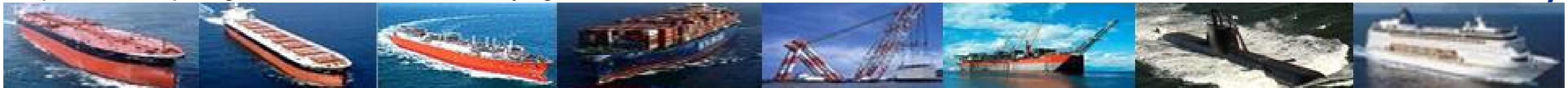
Hull Form Modeling of a Submarine



Hull Form Modeling of a 100,000 ton Nimitz Class Aircraft Carrier



1.3 Learning Objectives

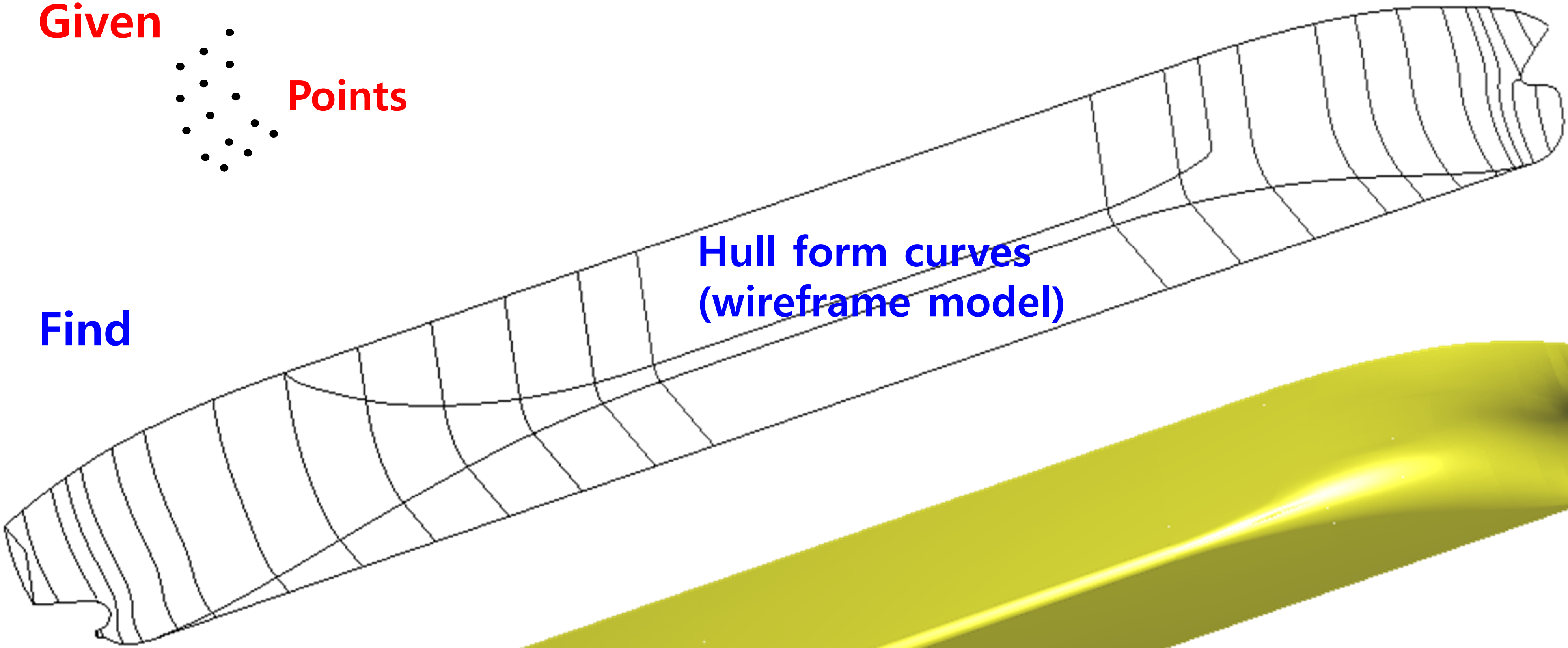


Program Implementation of Generating a Hull Form Surface by Using Single B-Spline Surface Patch (Term Project)

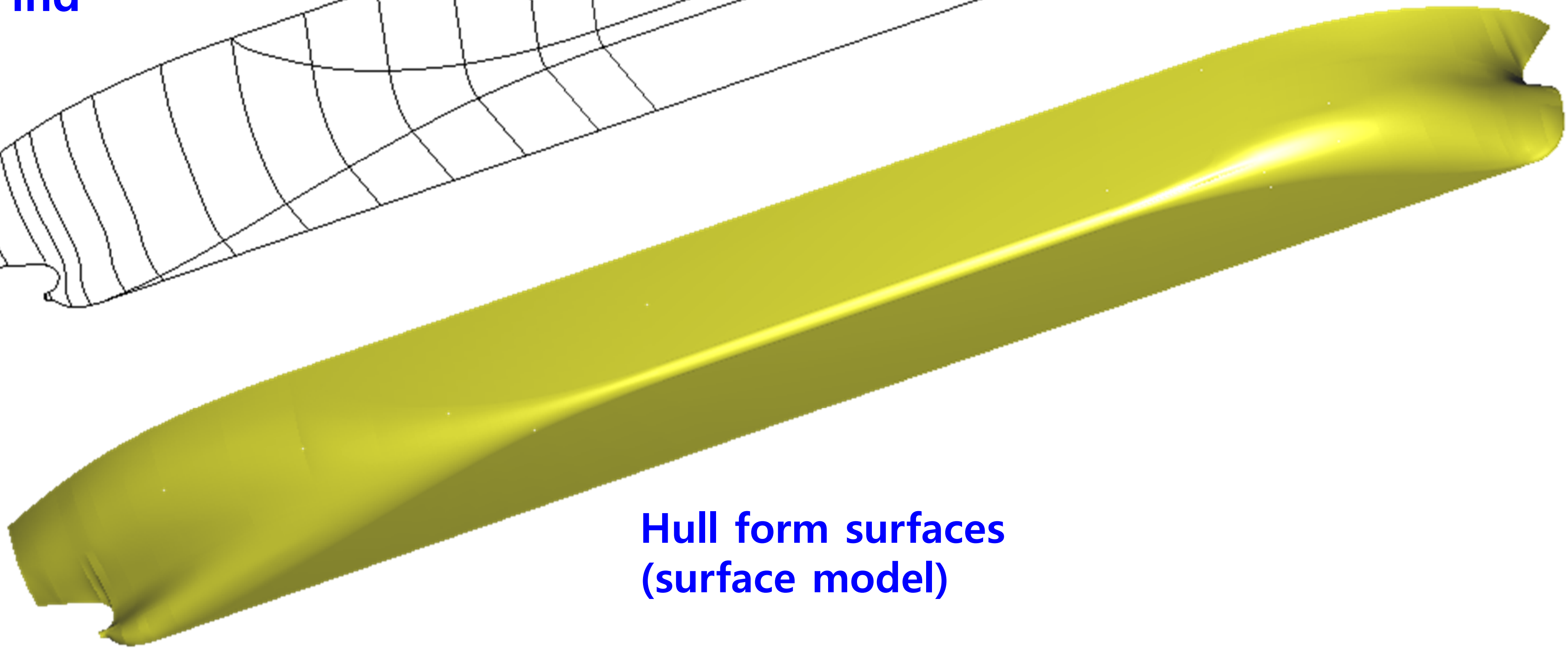
Given

Points

Find



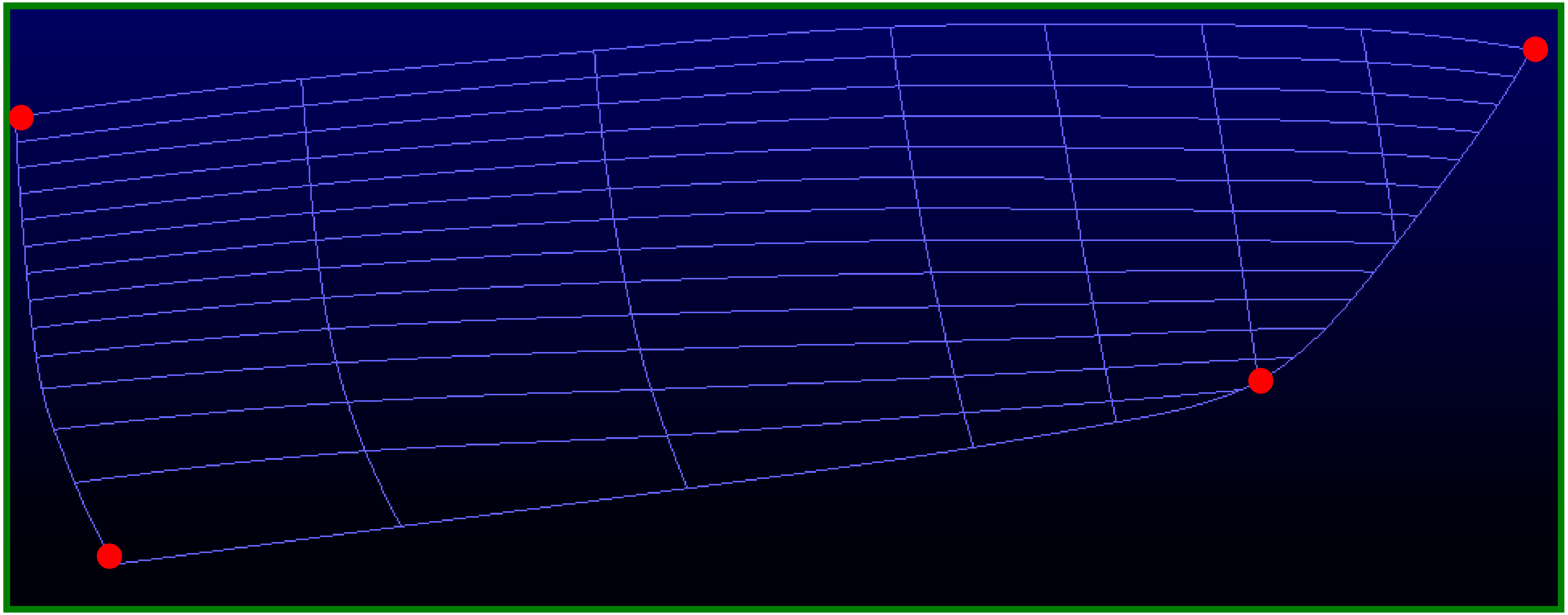
Hull form curves (wireframe model)



Hull form surfaces (surface model)

Modeling of a Yacht Surface (1/3)

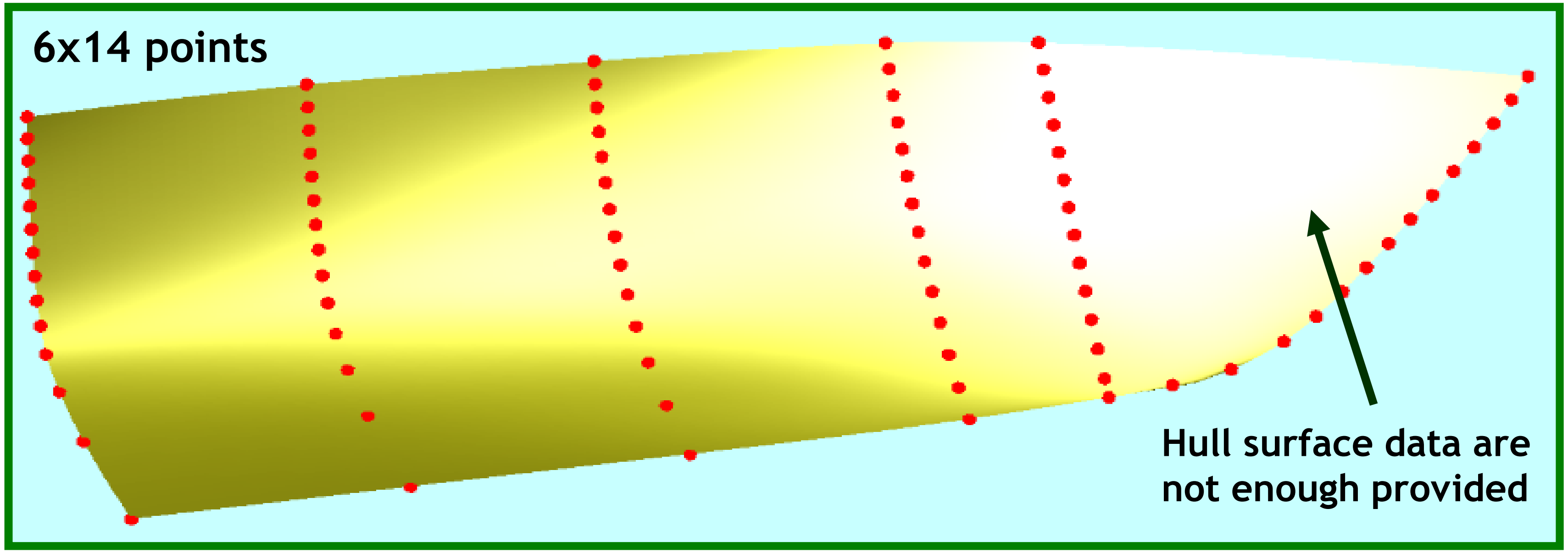
Determine the vertexes of tetragonal patch



• Example of a yacht surface generated by the Student during the lecture of "Planning Procedure of Naval Architecture and Ocean Engineering", Second Semester, 2005, Department of Naval Architecture and Ocean Engineering, Seoul National University

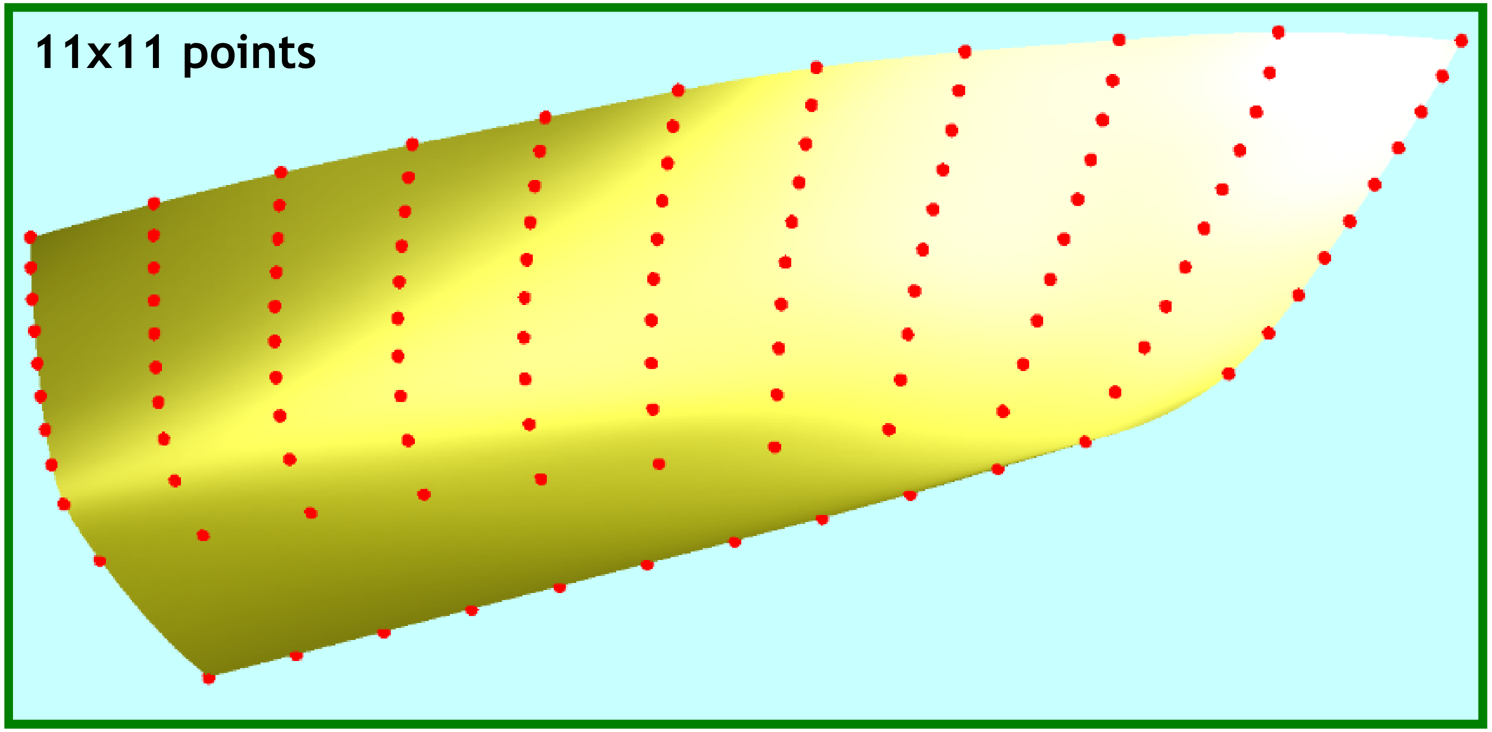
Modeling of a Yacht Surface (2/3)

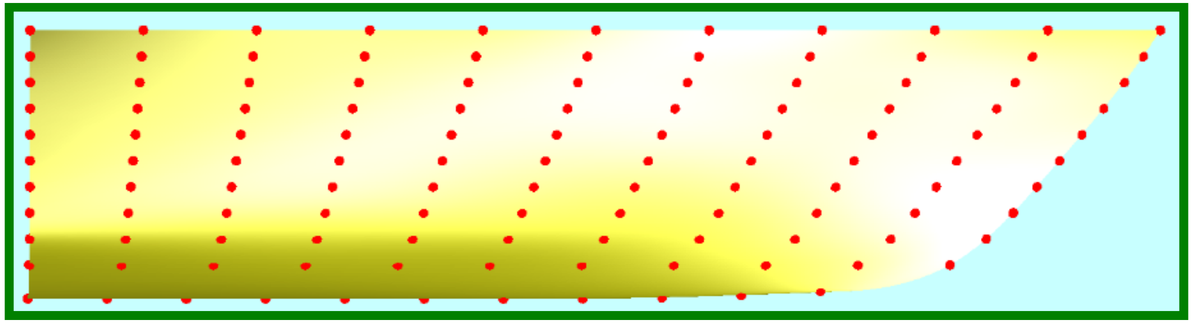
☑ **Modeling result of a yacht surface passing through the given data points that are located irregularly in the longitudinal direction**



Modeling of a Yacht Surface (3/3)

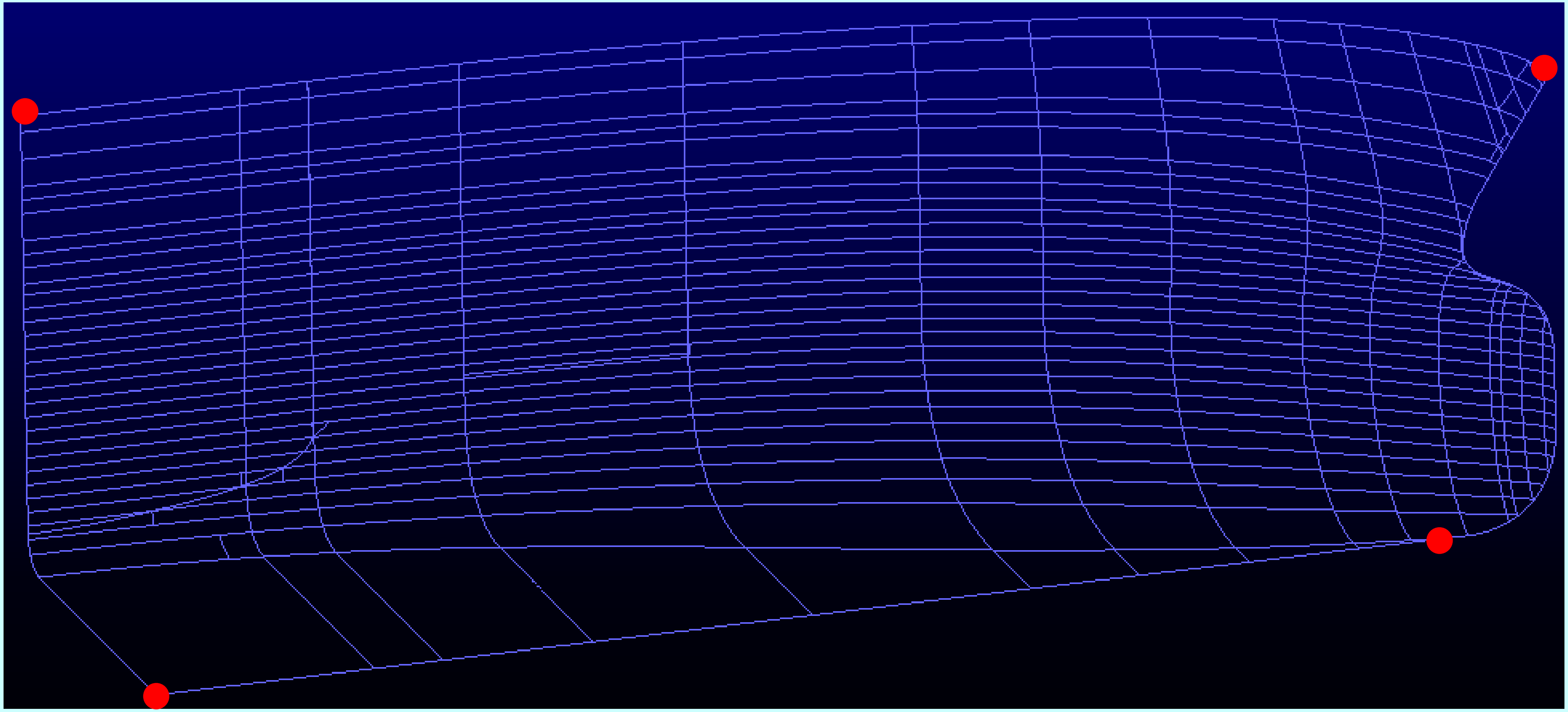
☑ **Modeling result of a yacht surface passing through the given data points that are located nearly at same distance in the longitudinal direction**



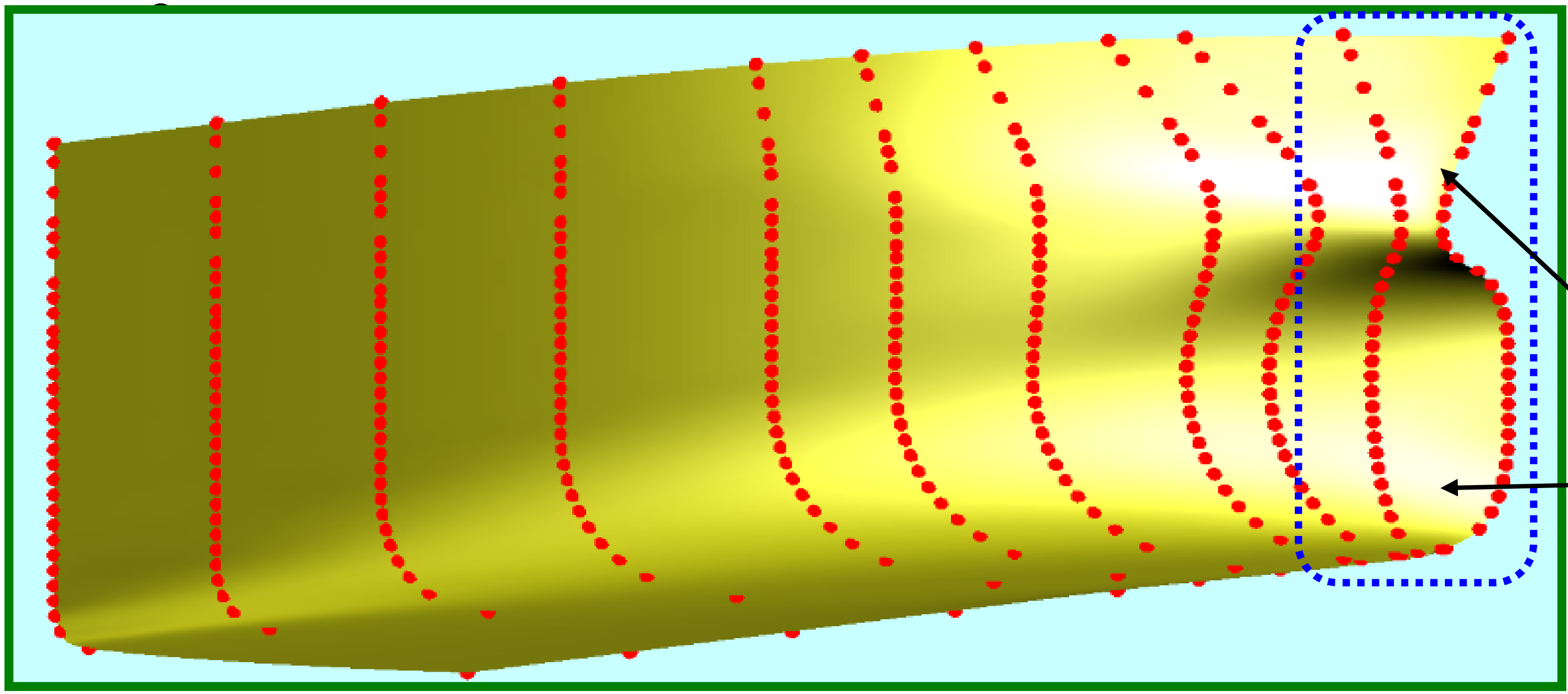


Modeling of the Hull Form Surface with a Bulbous Bow by Using Only One B-Spline Surface Patch (1/2)

Fore Body

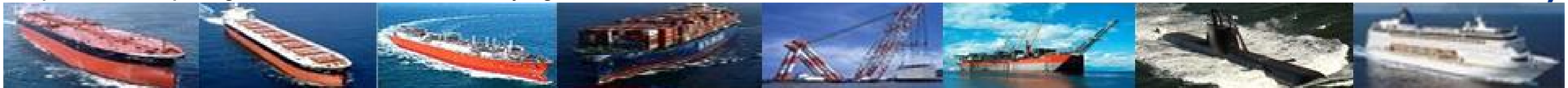


Modeling of the Hull Form Surface with a Bulbous Bow by Using Only One B-Spline Surface Patch (2/2)

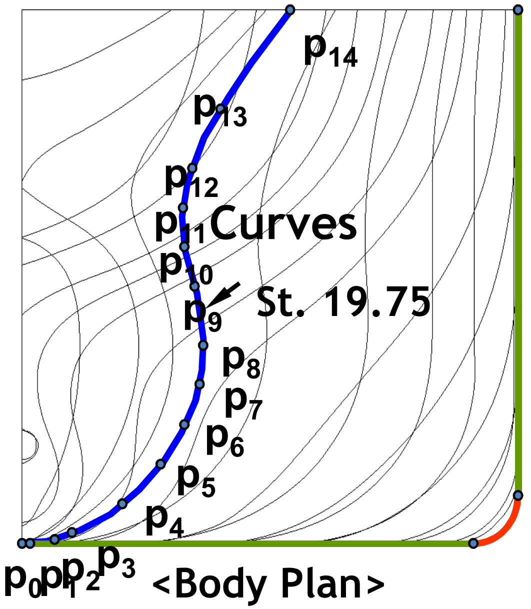


Distortion reduced by providing dense hull surface data

1.4 Summary



[Summary]
Representation of B-Spline Curve Passing Through Given Points



<Body Plan>

Given:

- Point p_i on the curve
- Knot u_j of the point on the curve
- Tangent vectors t_0, t_1 of both ends

Find:

- Cubic B-spline curve $\mathbf{r}(u)$ that is passing through the point p_i on the curve and satisfying continuity condition C^2
- That is, to find is control points d_i of B-spline curve

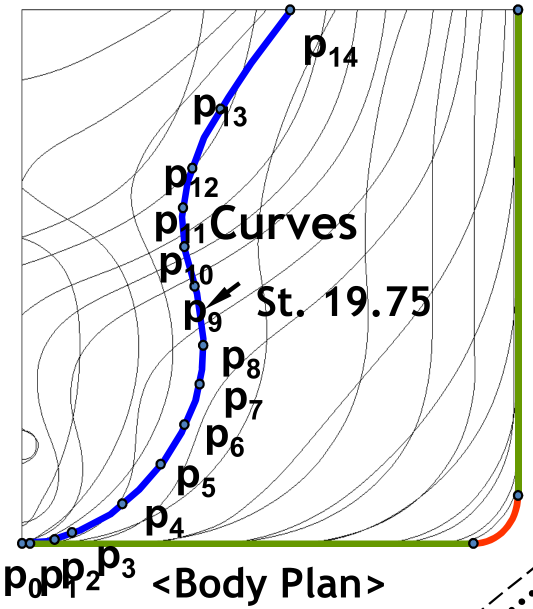
$$\mathbf{r}(u) = \begin{bmatrix} x(u) \\ y(u) \\ z(u) \end{bmatrix} = \sum_{i=0}^{D-1} \mathbf{d}_i N_i^n(u)$$

Linear Combination!

$\mathbf{d}_i$: Coefficient; $N_i^n(u)$: Basis function

To represent the curve $\mathbf{r}(u)$, we have to find the coefficients, i.e., the control points $\mathbf{d}_i$

Determination of B-Spline Control Points(d_i)



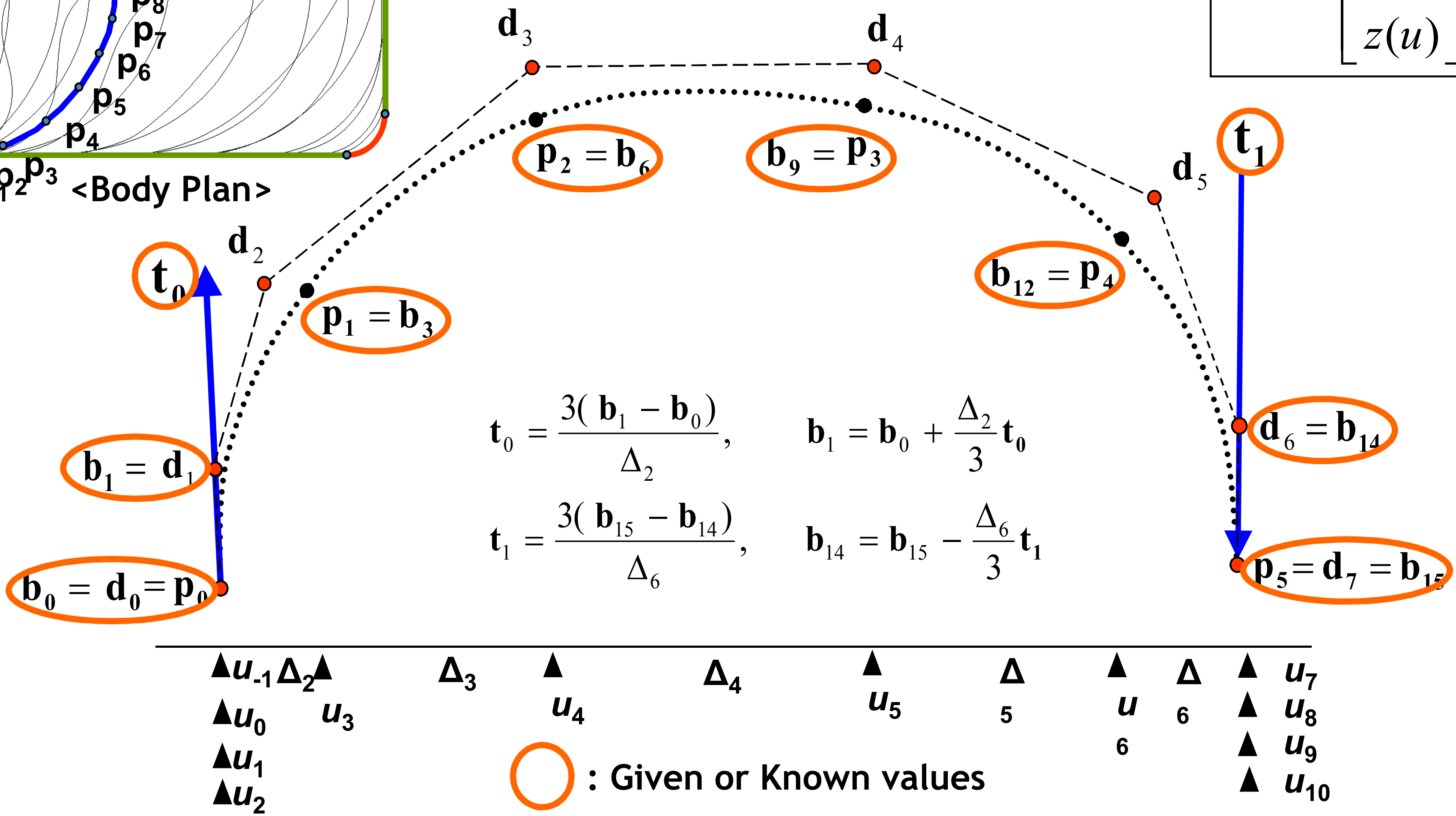
Given:

- Point p_i on the curve
- Knot u_j of the point on the curve
- Tangent vectors t_0, t_1 of both ends

Find:

- Cubic B-spline curve r(*u*) that is passing through the point p_i on the curve and satisfying continuity condition C^2
- That is, to find is control points d_i of B-spline curve

$$\mathbf{r}(u) = \begin{bmatrix} x(u) \\ y(u) \\ z(u) \end{bmatrix} = \sum_{i=0}^{D-1} \mathbf{d}_i N_i^n(u)$$



$$\mathbf{t}_0 = \frac{3(\mathbf{b}_1 - \mathbf{b}_0)}{\Delta_2}, \qquad \mathbf{b}_1 = \mathbf{b}_0 + \frac{\Delta_2}{3}\mathbf{t}_0$$

$$\mathbf{t}_1 = \frac{3(\mathbf{b}_{15} - \mathbf{b}_{14})}{\Delta_6}, \qquad \mathbf{b}_{14} = \mathbf{b}_{15} - \frac{\Delta_6}{3}\mathbf{t}_1$$

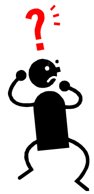
◯ : Given or Known values

Determination of the B-Spline Control Points(d_i) by Using Tri-diagonal Matrix Solution

$$
\begin{bmatrix} \mathbf{p}_0 \\ \mathbf{t}_0 \\ \mathbf{p}_1 \\ \mathbf{p}_2 \\ \mathbf{p}_3 \\ \mathbf{p}_4 \\ \mathbf{t}_1 \\ \mathbf{p}_5 \end{bmatrix}
=
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\frac{-3}{\Delta_2} & \frac{3}{\Delta_2} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \alpha_1 & \beta_1 & \gamma_1 & 0 & 0 & 0 & 0 \\
0 & 0 & \alpha_2 & \beta_2 & \gamma_2 & 0 & 0 & 0 \\
0 & 0 & 0 & \alpha_3 & \beta_3 & \gamma_3 & 0 & 0 \\
0 & 0 & 0 & 0 & \alpha_4 & \beta_4 & \gamma_4 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{-3}{\Delta_6} & \frac{3}{\Delta_6} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}
\begin{bmatrix} \mathbf{d}_0 \\ \mathbf{d}_1 \\ \mathbf{d}_2 \\ \mathbf{d}_3 \\ \mathbf{d}_4 \\ \mathbf{d}_5 \\ \mathbf{d}_6 \\ \mathbf{d}_7 \end{bmatrix}
$$

$= \mathbf{D}$ Known $\quad = \mathbf{A}$ Known $\quad = \mathbf{X}$ Unknown

$$\mathbf{r}(u) = \begin{bmatrix} x(u) \\ y(u) \\ z(u) \end{bmatrix} = \sum_{i=0}^{D-1} \mathbf{d}_i N_i^n(u)$$



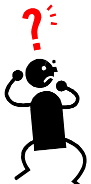
What is $N_i^n(u)$?

$$\mathbf{D} = \mathbf{A}\mathbf{X}$$

$$\mathbf{X} = \mathbf{A}^{-1}\mathbf{D}$$

Since a matrix A is a tri-diagonal matrix, a matrix A^{-1} is easy to obtain.

Given	B-spline control points $\mathbf{d}_i$ Parameter u B-spline basis function $N_i^n(u)$
Find	B-spline curve $\mathbf{r}(u)$

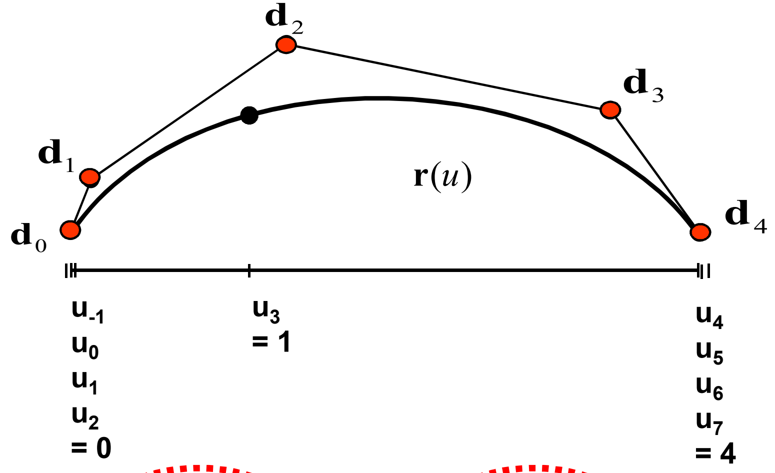


What is $N_i^n(u)$?

☑ B-spline curve

$$\mathbf{r}(u) = \begin{bmatrix} x(u) \\ y(u) \\ z(u) \end{bmatrix} = \sum_{i=0}^{D-1} \underbrace{\mathbf{d}_i}_{\text{Coefficient}} \underbrace{N_i^n(u)}_{\text{Basis function}}$$

Linear Combination!



$$= \mathbf{d}_0 N_0^3(u) + \mathbf{d}_1 N_1^3(u) + \mathbf{d}_2 N_2^3(u) + \mathbf{d}_3 N_3^3(u) + \mathbf{d}_4 N_4^3(u)$$

Example of Cubic B-spline curve

- **Cox-de Boor Recurrence Formula (B-spline function)**

$$N_i^n(u) = \frac{u - u_{i-1}}{u_{i+n-1} - u_{i-1}} N_i^{n-1}(u) + \frac{u_{i+n} - u}{u_{i+n} - u_i} N_{i+1}^{n-1}(u)$$

$$N_i^0(u) = \begin{cases} 1 & \text{if } \; u_{i-1} \le u < u_i \\ 0 & \text{else} \end{cases}$$