STANDARD MANOEUVRES SIMULATION OF A FISHING VESSEL

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Master Thesis

developed at "Dunărea de Jos" University, Galaţi
in the framework of the
"EMSHIP"
Erasmus Mundus Master Course
in "Integrated Advanced Ship Design"
Ref. 159652-1-2009-1-BE-ERA MUNDUS-EMMC

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Reviewer: Prof. Dr. Ing. Marco Ferrando

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MAIN GOALS OF THE THESIS

Investigation of accuracy and reliability of existing initial design programs *(TRIBON, MPP1)*

Validation of the university-developed simulation code for detailed design (*PHP code*)

Analysis of the CFD techniques application in manoeuvring prediction *(ShipFLOW)*

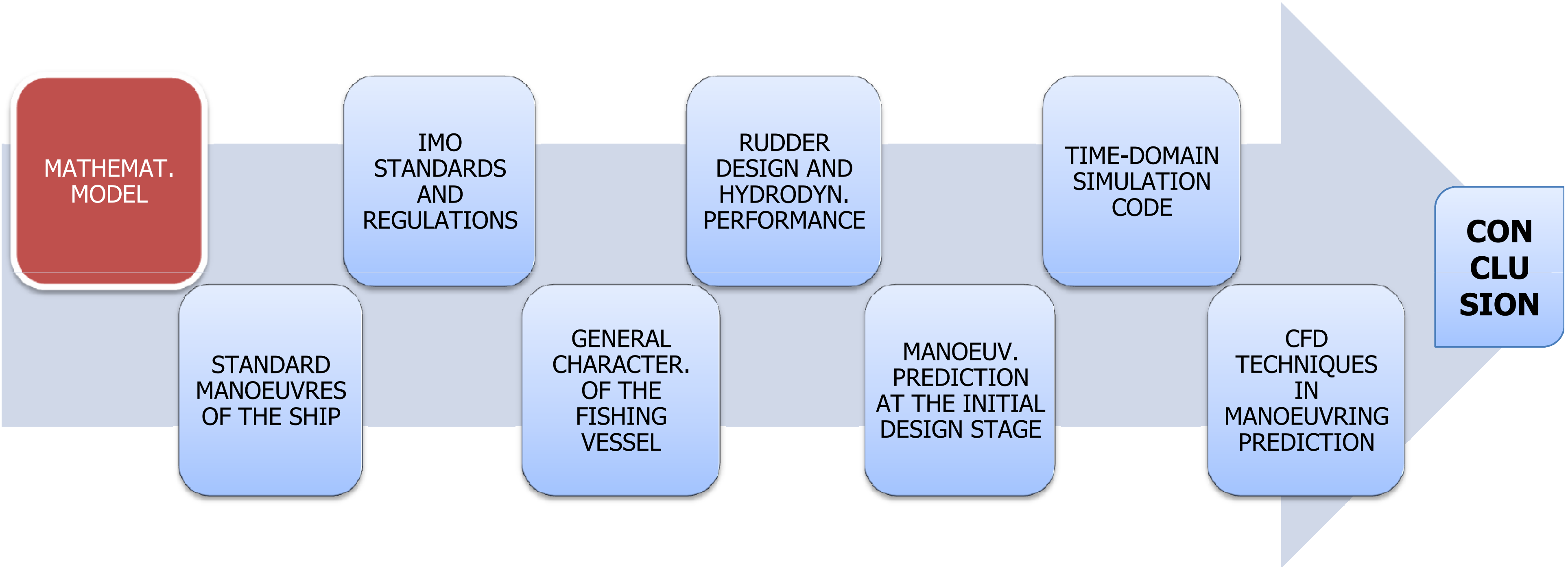
MILESTONES OF THE THESIS

1. Design of the rudder geometry

2. Estimation of the hydrodynamic forces and moments generated on the rudder
   - determination of the position and diameter of the rudder stock
   - preliminary checking of the rudder cavitation

3. Estimation of the manoeuvring performance
   - by means of the preliminary methods (based on regression formulas and linear hydrodynamic models)
   - using simulation code based on fully non-linear hydrodynamic model

4. CFD simulation of forces and moments on the hull and rudder itself at different drift and rudder deflection angles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GENERAL CHARACTER. OF THE FISHING VESSEL
RUDDER DESIGN AND HYDRODYN. PERFORMANCE
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MATHEMATICAL MODELS

General form of differential equations of motions system (horizontal plane):

$$X = m\left(\frac{\partial u}{\partial t} - rv - r^2 x_G\right)$$

$$Y = m\left(\frac{\partial v}{\partial t} + ru + \frac{dr}{dt} x_G\right)$$

$$N = \frac{\partial r}{\partial t} I_{zz} + m x_G \left(\frac{\partial v}{\partial t} + ru\right)$$

Linear equations of motion (1st order terms only):

$$X_e + X_u u + X_{\dot{u}} \dot{u} = m\dot{u}$$

$$Y_e + Y_v v + Y_r r + Y_{\dot{v}} \dot{v} + Y_{\dot{r}} \dot{r} = m\left(\dot{v} + rU + \dot{r} x_G\right)$$

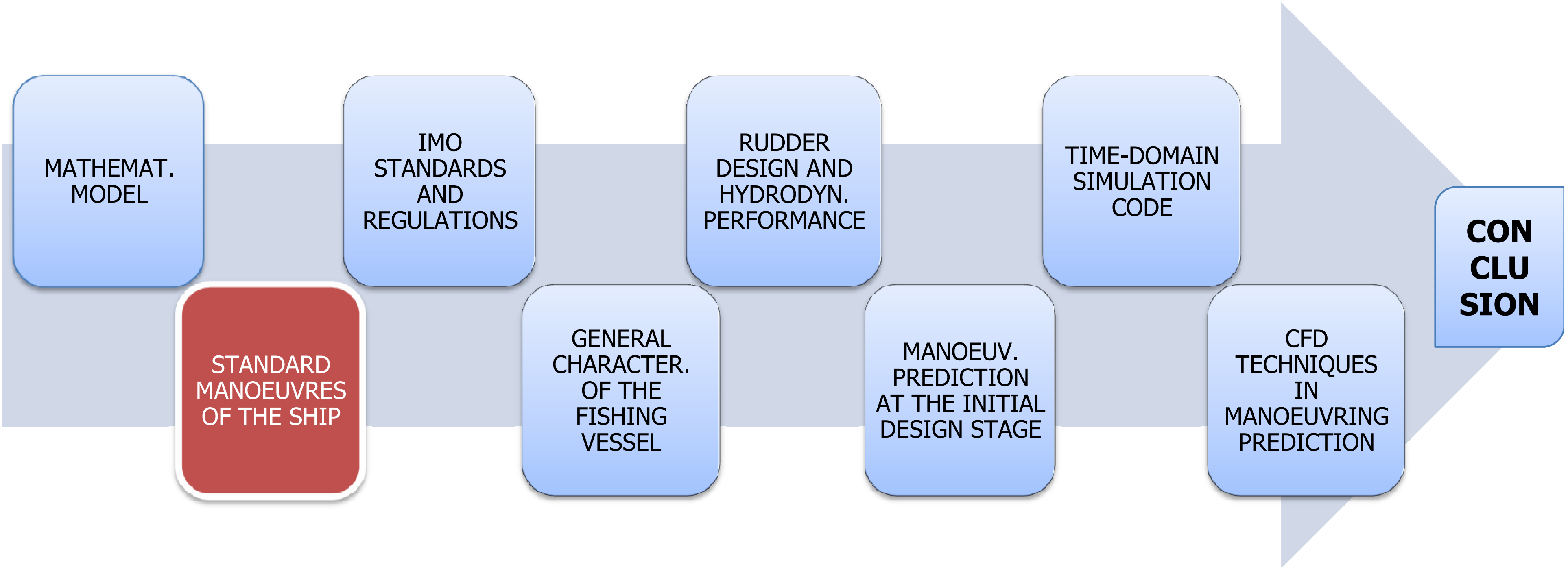
$$N_e + N_v v + N_r r + N_{\dot{v}} \dot{v} + N_{\dot{r}} \dot{r} = I_{zz} \dot{r} + m x_G \left(\dot{v} + rU\right)$$

Non-linear model for ship's manoeuvrability (*Abkowitz, 1964, Chislett and Strom-Tejsen, 1965*):

$$\left(m - X_{\dot{u}}\right)\dot{u} = X_u u + X_e + f_1\left(u, v, r, \delta\right)$$

$$\left(m - Y_{\dot{v}}\right)\dot{v} + \left(m x_G - Y_{\dot{r}}\right)\dot{r} = Y_v v + \left(Y_r - mU\right) r + Y_e + f_2\left(u, v, r, \delta\right)$$

$$\left(m x_G - N_{\dot{v}}\right)\dot{v} + \left(I_{zz} - N_{\dot{r}}\right)\dot{r} = N_v v + \left(N_r - m x_G U\right) r + N_e + f_3\left(u, v, r, \delta\right)$$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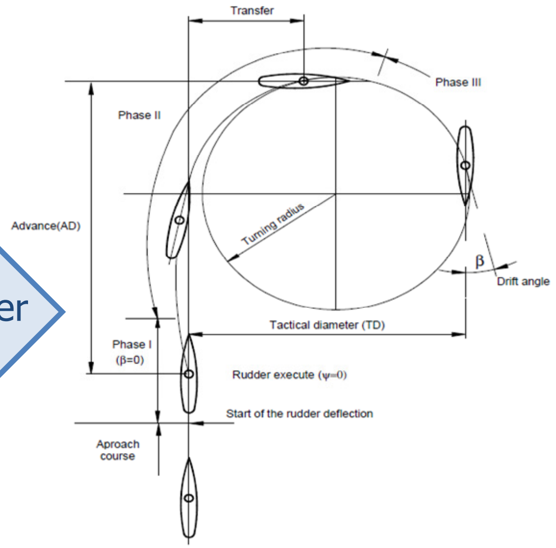
STANDARD MANOEUVRES OF THE SHIP

Manoeuvring Prediction Methods:

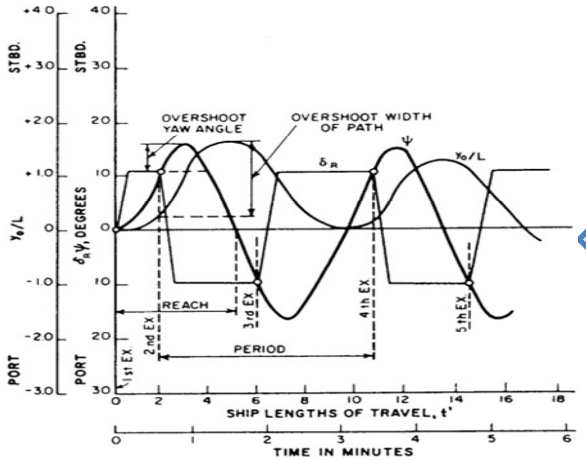
- Data-bases of manoeuvring qualities
- Experimental model tests
- Mathematical models and numerical simulations

Standard Manoeuvres:

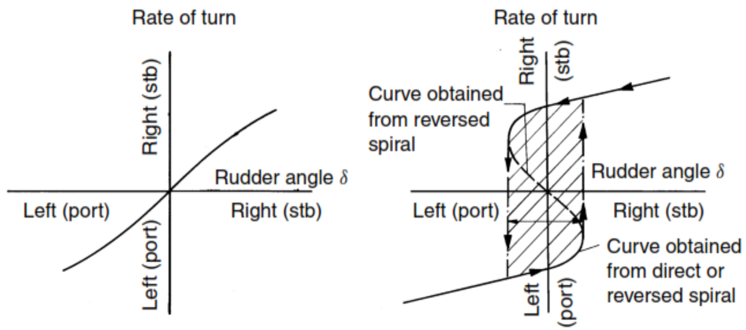
- Turning Circle Manoeuvre ⟹ turning ability and efficiency of the rudder

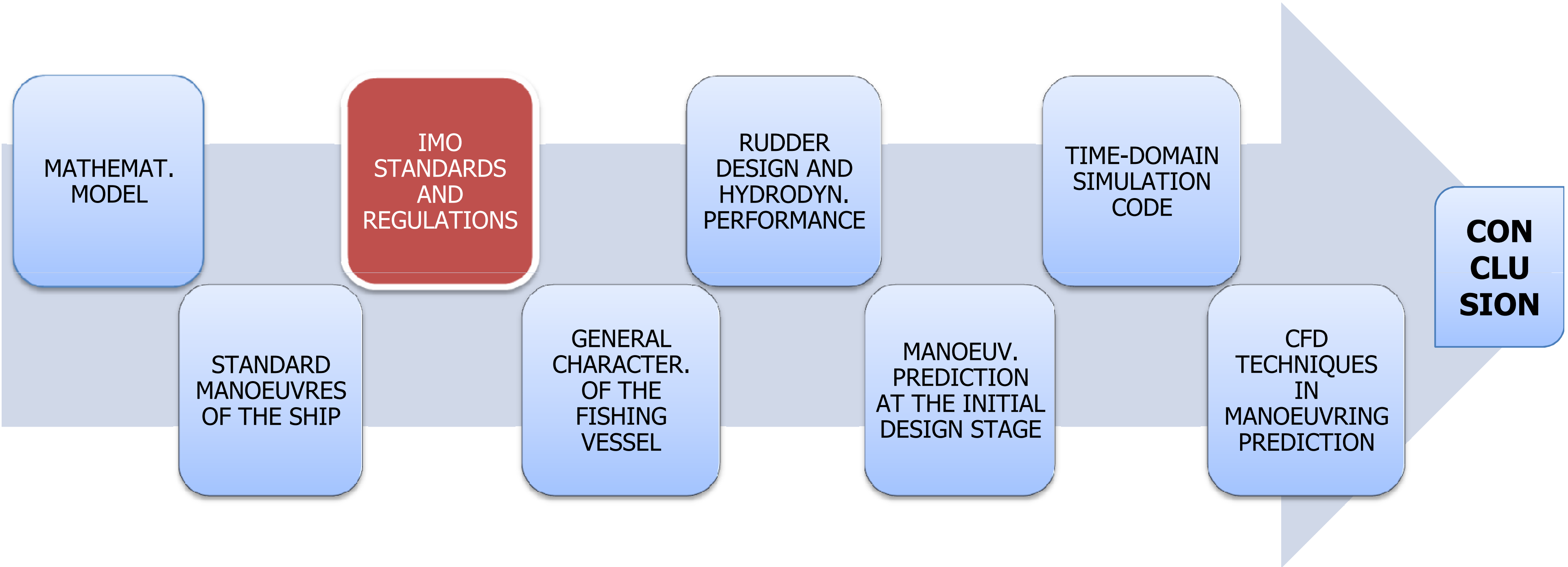


- Zig-Zag Manoeuvre ⟹ initial response to rudder action



- Spiral Manoeuvre ⟹ controls-fixed straight line stability

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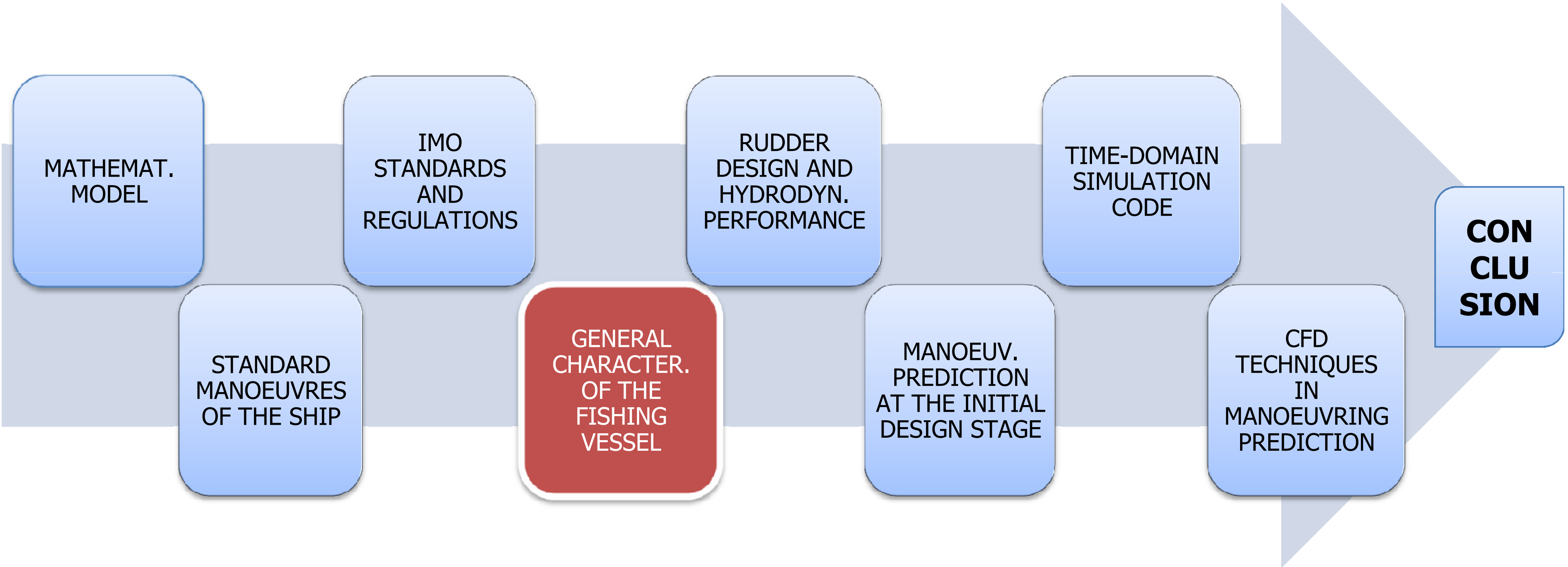
IMO CRITERIA FOR STANDARD MANOEUVRES

IMO

ABILITY	TEST	CRITERIA
Turning ability	Turning test with max. rudder deflection (35 deg.)	Advance $< 4.5\,L$ Tactical Diameter $< 5.0\,L$
Course-keeping and yaw-checking ability	10°/10° test	1st Overshoot $< 10°$ for $L/U < 10$ sec. $< (5+0.5\,L/U)°$ for $10 < L/U < 30$ sec. $< 20°$ for $L/U > 30$ sec.
		2nd Overshoot $< 25°$ for $L/U < 10$ sec. $< (17.5+0.75\,L/U)°$ for $10 < L/U < 30$ sec. $< 40°$ for $L/U > 30$ sec.
	20°/20° test	1st overshoot $< 25°$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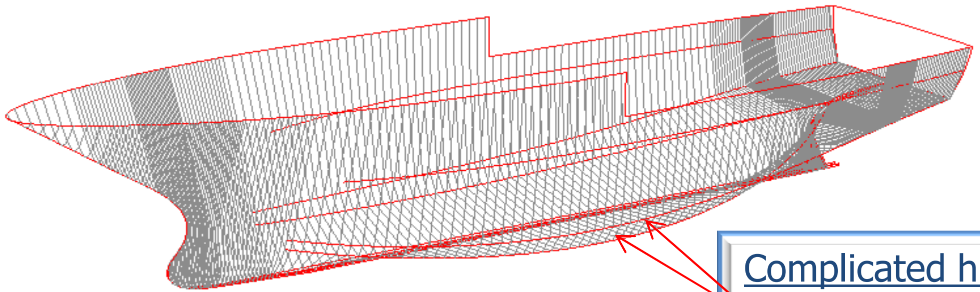
GENERAL CHARACTERISTICS OF THE FISHING VESSEL

Length overall, L_{OA} [m]	32.7	Draft at fore perpendicular, T_F [m]	2.42
Length between perpendiculars, L [m]	25.0	Draft at aft perpendicular, T_A [m]	2.74
Moulded breadth, B [m]	8.0	Block coefficient, C_B	0.574
Volumetric displacement, ∇ [m³]	296.0	Stock propeller diameter, D [m]	1.8
Medium draft, T_M [m]	2.58	Ship speed, U [kn]	12.0



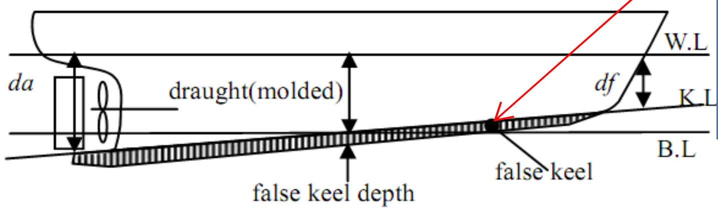
Complicated hullform:

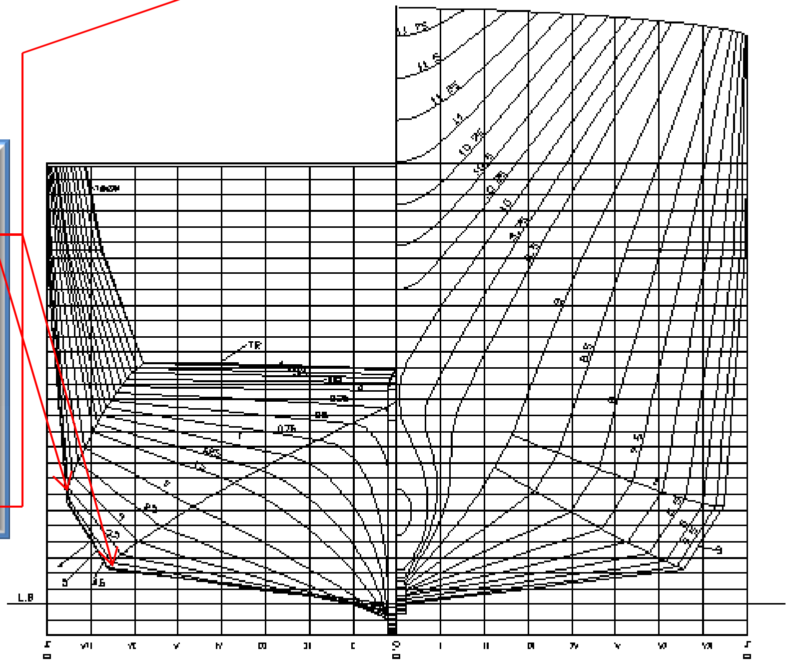
- double hard chine
- inclined (false) keel

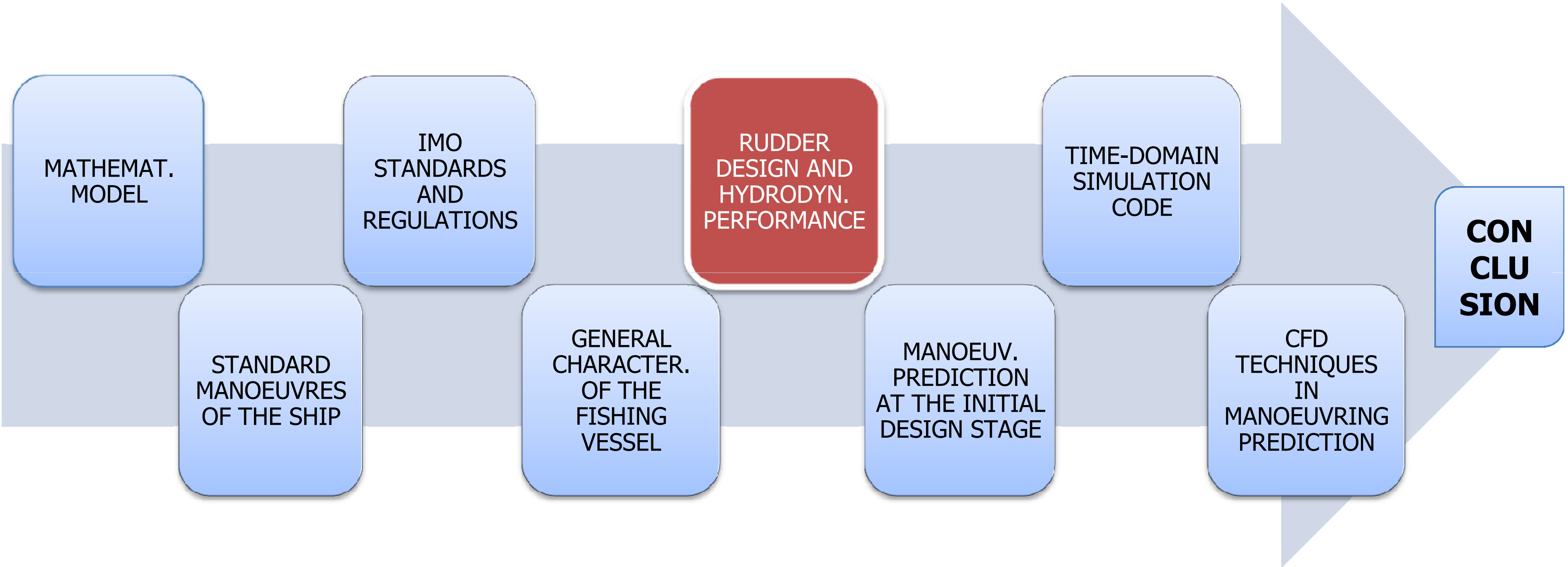
+

Operation:

- at fairly high Fn 0.4
- in trimmed condition



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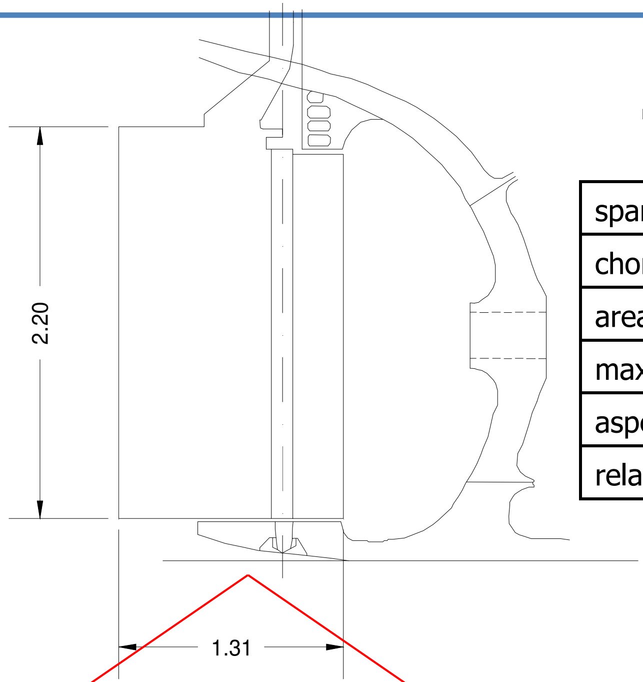
RUDDER DESIGN AND HYDRODYNAMIC PERFORMANCE

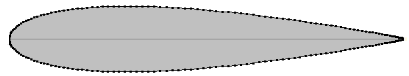
➢ *DNV recommend. for min. A_R :*

$$\frac{A}{L \times T} = 0.01\left[1 + 50C_B^2\left(\frac{B}{L}\right)^2\right] = 0.027$$

➢ *Typical values of aspect ratio:*

TYPE OF SHIP		Aspect ratio
Ships with single screw	Coaster ships	1...1.15
	Tugs	1.8
	Fishing vessels	1.5...3.33





span [m]	$\bar{b}$	2.20
chord [m]	$\bar{c}$	1.31
area [m²]	A_R	2.88
max. thickness [m]	t_{max}	0.24
aspect ratio [-]	λ	1.68
relative thickness [-]	$\bar{t}/\bar{c}$	0.18

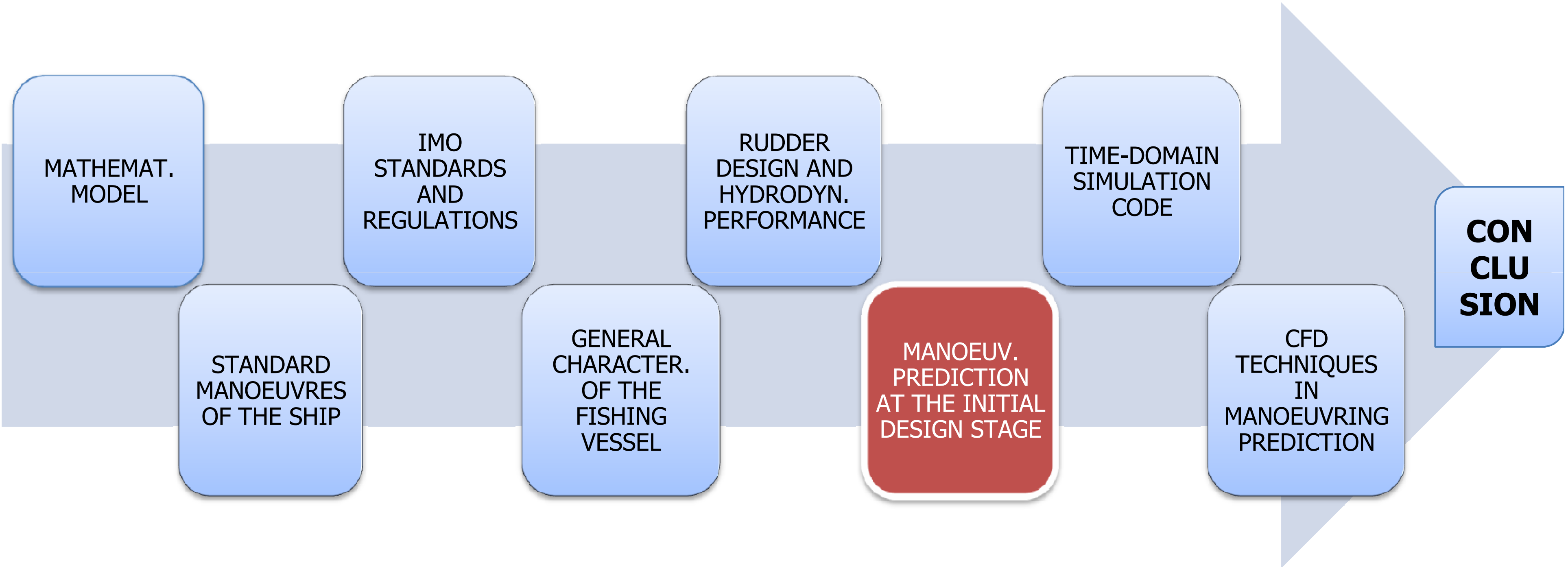
BRIX METHOD

Flow angle, α [deg]	*Static pressure [kPa]*	*Dynamic pressure [kPa]*	*Total pressure [kPa]*
13	112.320	-54.014	58.306
22	112.320	-74.642	37.678
26	112.320	-86.624	25.696

VOITKOUNSKY METHOD

Hydrodynamic characteristics	*Value*
Optimal distance from the the rudder stock to the leading edge [m]	0.240
Optimal distance from the the rudder stock to trailing edge [m]	-1.070
Total hydrodynamic torque [kNm]	38.697

all +ve = no cavitation risk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VERIFICATION OF RESISTANCE ESTIMATION METHODS

Holtrop & Mennen method (accuracy claimed to be satisfactory for 95% of the cases)

for trawlers, coasters, tugs:

$Fn \leq 0.38 \quad 0.55 \leq C_P \leq 0.65 \quad 3.9 \leq L/B \leq 6.3 \quad 2.1 \leq B/T \leq 3.0$

Van Oortmerssen method

small ships such as trawlers or tugs:

$Fn \leq 0.50 \quad 0.50 \leq C_P \leq 0.73 \quad 3.0 \leq L/B \leq 6.2 \quad 1.9 \leq B/T \leq 4.0$

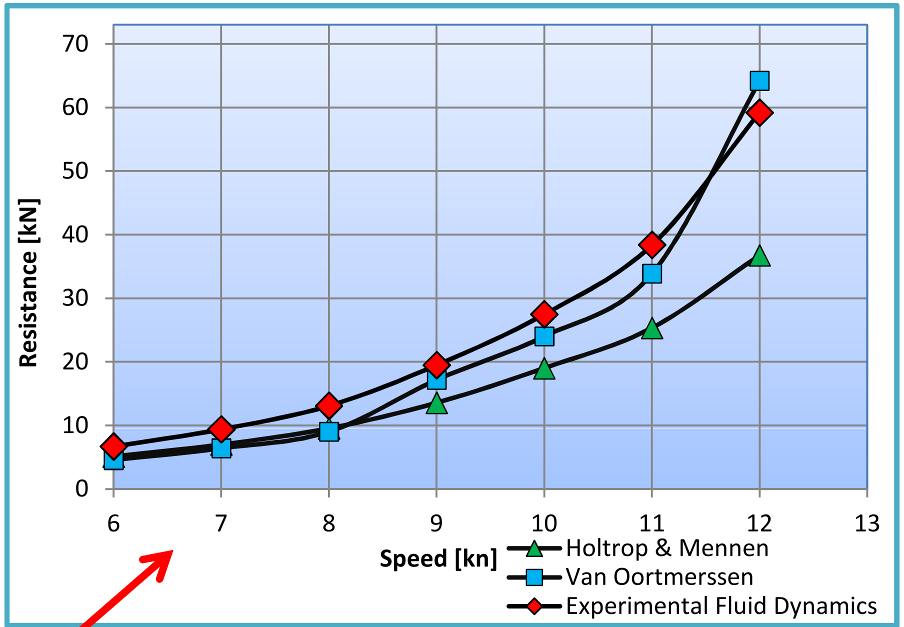
$8.0 \leq L_{WL} \leq 80.0$

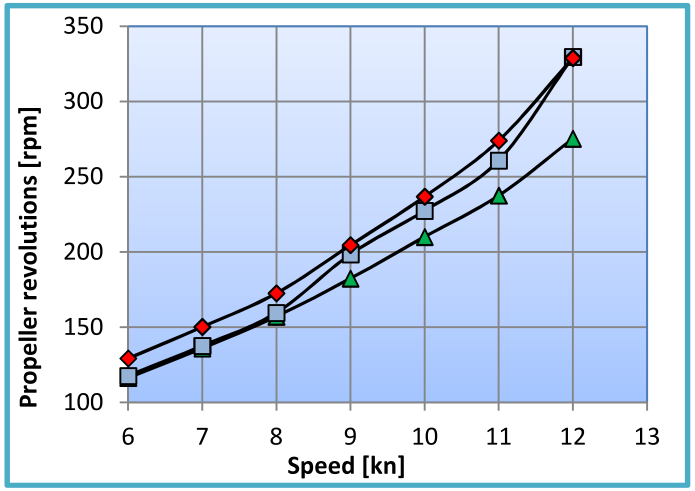
Fishing vessel's parameters

$Fn = 0.39 \quad C_P = 0.652 \quad L/B = 3.1 \quad B/T = 3.1 \quad L_{WL} = 26.7\ m$

Resistance comparison

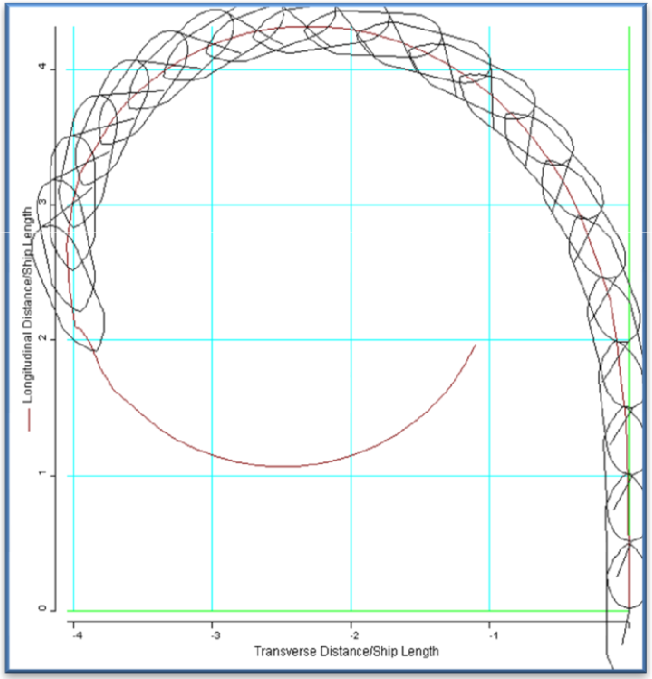
Propeller revolutions comparison

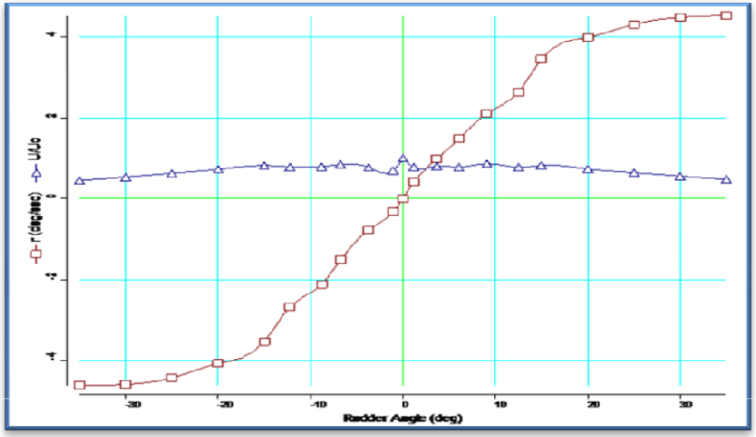




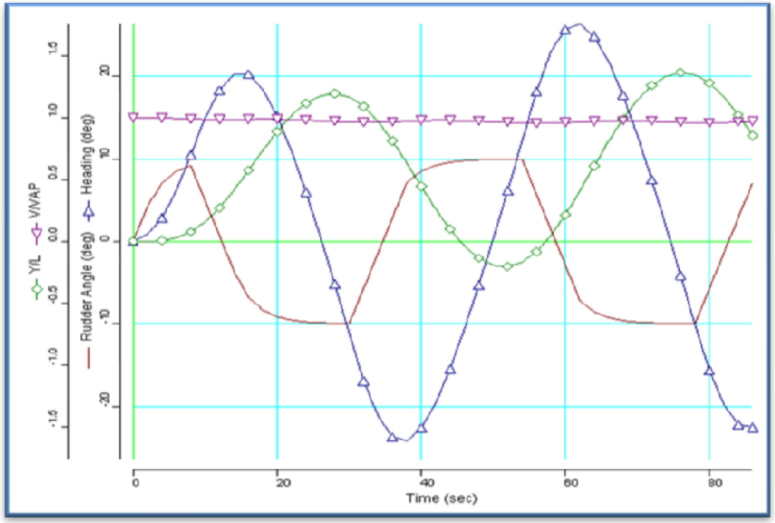
MANOEUVRABILITY PERFORMANCE PREDICTION IN THE INITIAL DESIGN STAGE

Characteristics	Numerical result	IMO max. value
Advance [non-dim.]	4.24	4.50
Tactical diameter [non-dim.]	4.01	5.00





Condition	Stable



Characteristics	Numerical result	IMO max. value
1st overshoot angle [deg]	10.31	10.00
2nd overshoot angle [deg]	14.21	25.00

TRIBON: LIMITS OF APPLICABILITY AND COMPARISON WITH MPP1

Limits of applicability of **TRIBON**:

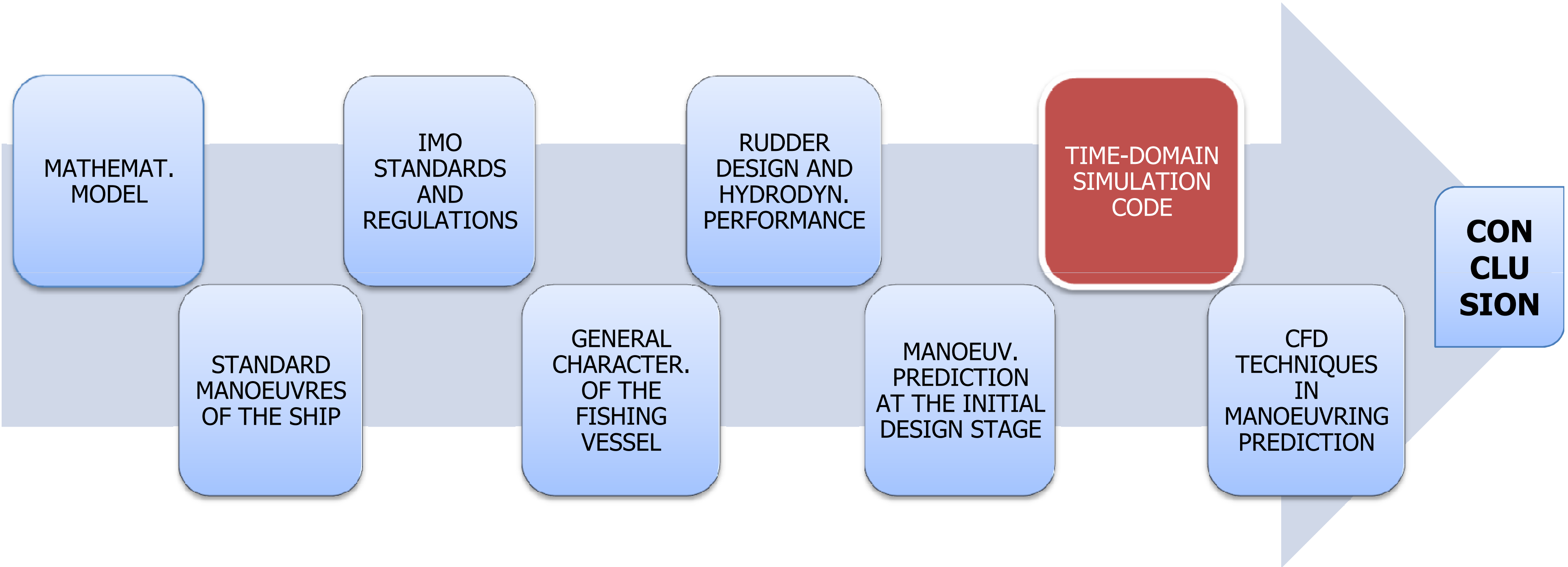
- resistance estimation with BSRA method in Manoeuvring Module (Methodical Series Experiments on Single-Screw Ocean-Going Merchant-Ship Forms with $0.55 < C_B < 0.85$)
- conventional rudders only in Manoeuvring Module (conventional, Becker or Schilling rudder types in other modules)
- based on mathematical models derived from regression analysis of manoeuvr. characteristics of merchant and naval vsls

SHIP	Min. value:	Max. value:	Fishing vsl	OK?
Block coefficient (C_B)	0.480	0.850	0.553	YES
Beam/Draft (B/T)	2.15	6.247	3.1	YES
Length/Beam (L/B)	4.0	8.0	3.1	NO
Length/Draft (L/T)	13.66	40.11	9.69	NO
LCG from midships/Length	-0.050	0.057	-0.023	YES
Draft	0.67*Prop. diam.	-	2.58	YES

MPP1 (University of Michigan):

- computation based on LWL instead of LPP
- Clarke et al method for course stability, turnability and controllability
- Lyster and Knights regression results for the estimation of turning circle characteristics

Parameter	% Difference
Advance	28.3 %
Transfer	13.0 %
Steady Turning Diam.	22.1 %
Tactical Diameter	16.5%
Steady Speed in Turn/App. Speed	33.3 %
Directional Stability (C > 0)	YES / NO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TIME-DOMAIN SIMULATION CODE FOR STANDARD SHIP MANOEUVRES (1)

PHP numerical code:

- Naval Architecture Faculty of the "Dunarea de Jos" University of Galati, Romania

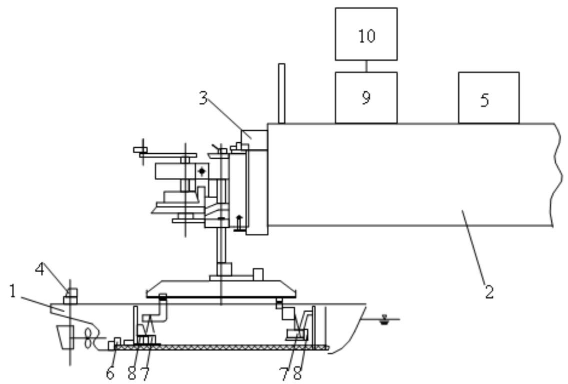
  +

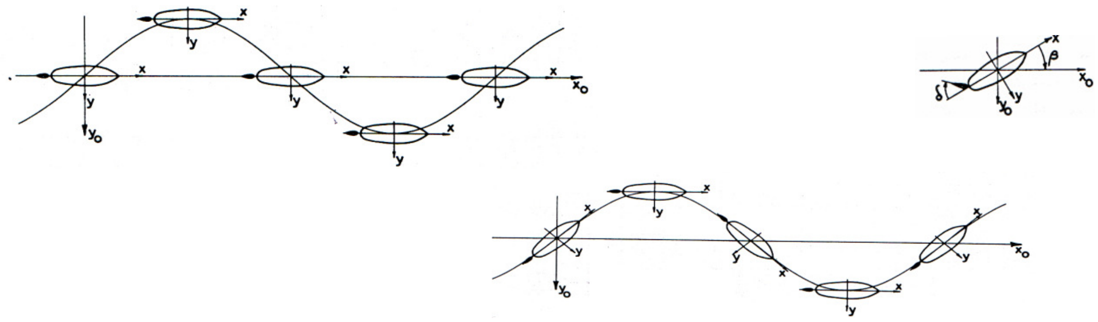
  Department of Naval Architecture, Ocean and Environmental Engineering of the University of Trieste, Italy

- Validated by the experimental tests

- Only few full nonlinear simulation models of merchant vessels e.g. VLCC tanker, ro-ro passenger, containership, ferry, etc. known in literature

PMM EXPERIMENTS → HYDRODYN. DERIVATIVES → INPUT IN THE SIMULATION CODE



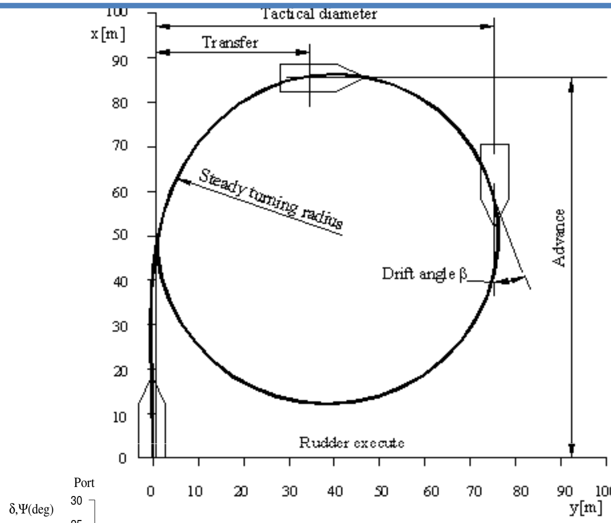


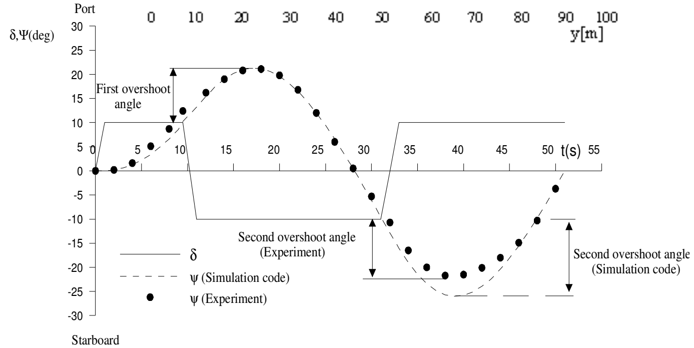
TIME-DOMAIN SIMULATION CODE FOR STANDARD SHIP MANOEUVRES (2)

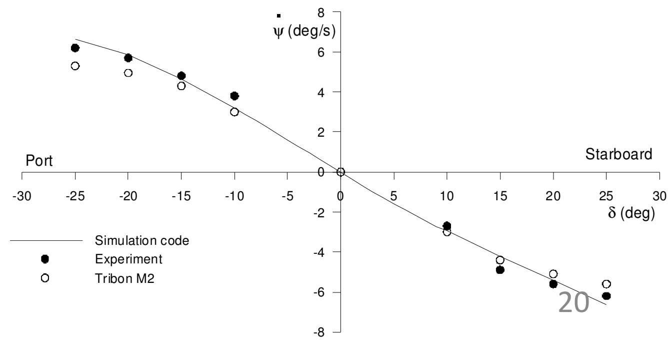
CHARACTERISTICS	SIMUL. CODE	TRIBON	MPP1	IMO
Advance/L [m]	3.44	4.24	3.04	4.5
Transfer/L [m]	1.39	1.84	1.60	-
Tactical diameter/L [m]	3.04	4.01	3.35	5.0
Steady diameter/L [m]	3.02	3.03	2.36	-
Steady drift angle [deg]	8.10	14.14	-	-
Speed/Approach speed	0.59	0.60	0.40	-
Stability criterion, *C*	0.000176	+ ve	- ve	-

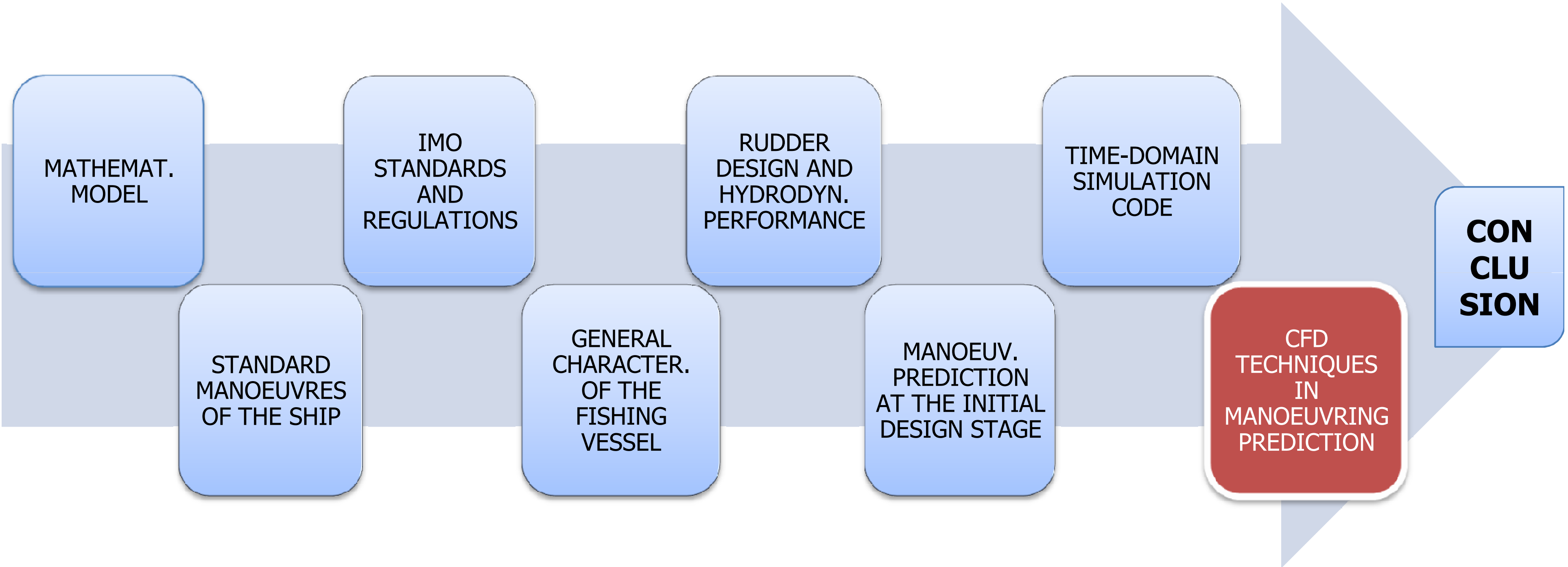
CHARACTERISTICS	SIMUL. CODE	EXPER.	TRIBON	IMO
1st overshoot angle [deg]	11.3	11.3	10.3	10.0
2nd overshoot angle [deg]	16.0	11.9	14.2	25.0
Initial turning time [sec]	9.8	-	8.0	-
Time to 1st max. heading [sec]	17.0	-	14.0	-
Reach time [sec]	28.0	-	26.0	-

CHARACTERISTIC	SIMUL. CODE	EXPER.	TRIBON	MPP1
Vessel condition	stable	stable	stable	unstable





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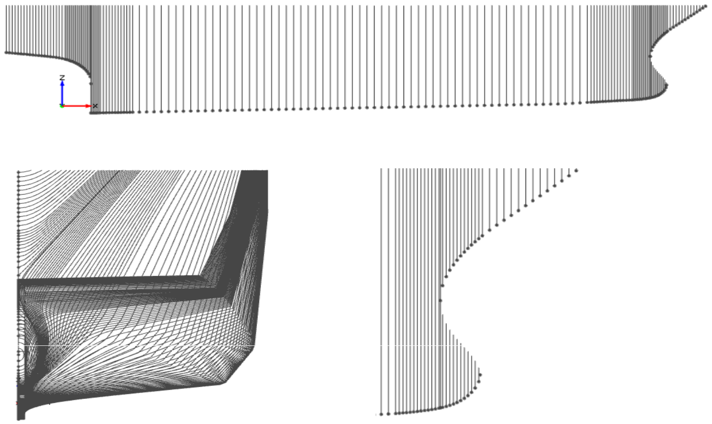
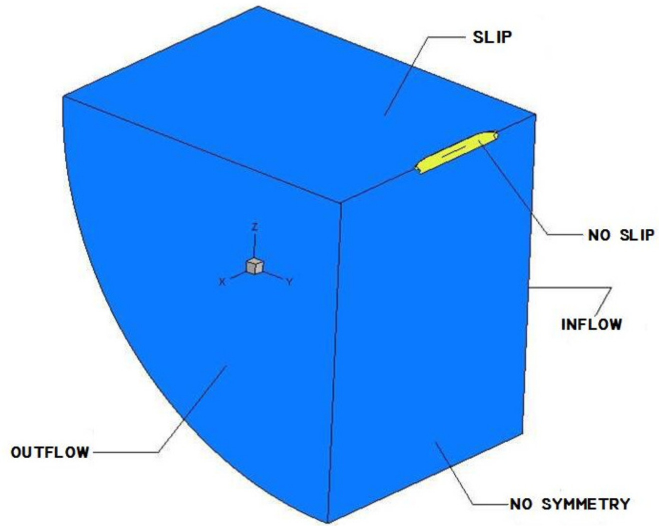
CFD TECHNIQUES IN MANOEUVRING PREDICTION

1. Offset file

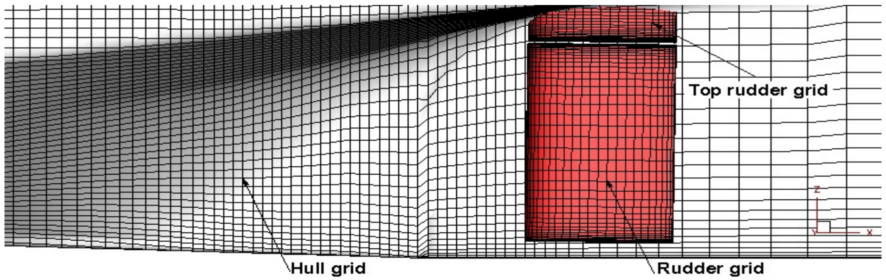


3. Boundary conditions

	No slip	*Slip*	*Inflow*	*Outflow*
u	$u_i = 0$	$u_i n_i = 0$ $\frac{\partial u_i}{\partial \xi_B} = 0$	$u_i = const.$	$\frac{\partial u_i}{\partial \xi_B} = 0$
p	$\frac{\partial p}{\partial \xi_B} = 0$	$\frac{\partial p}{\partial \xi_B} = 0$	$\frac{\partial p}{\partial \xi_B} = 0$	$p = 0$



2. Grid generation



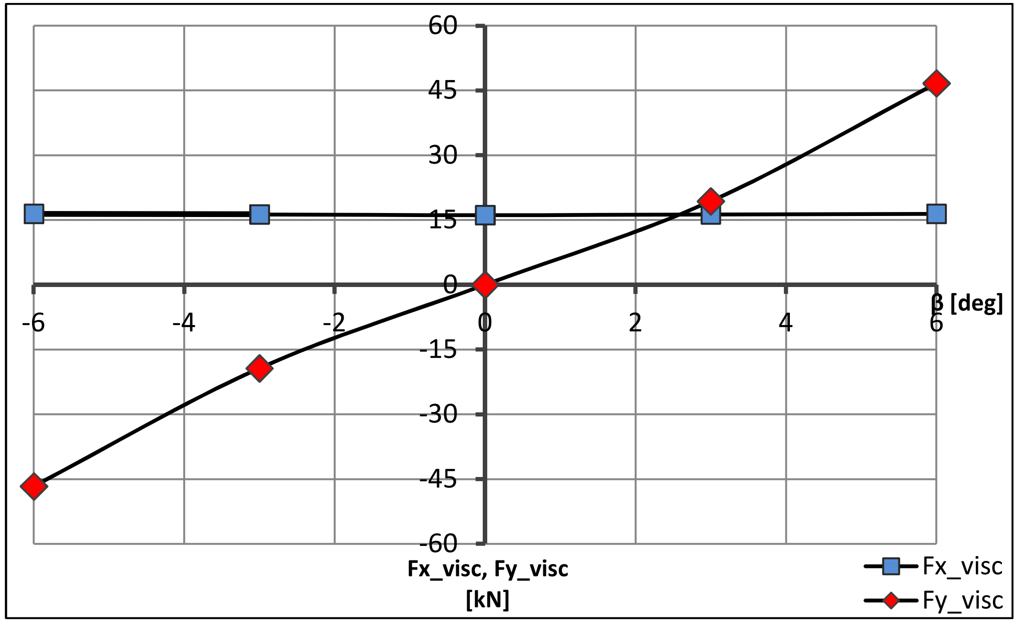
bare hull: 2.02 mil cells

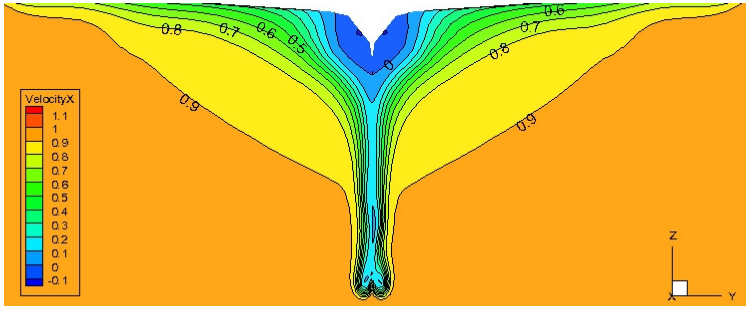
appended hull: 2.4 mil cells

SIMULATIONS AT DIFFERENT DRIFT ANGLES

Three drift angles (β = 0°, 3°, 6°) to determine the hydrodynamic forces acting on the bare hull

Existence of the free surface neglected (reduction of computational time)





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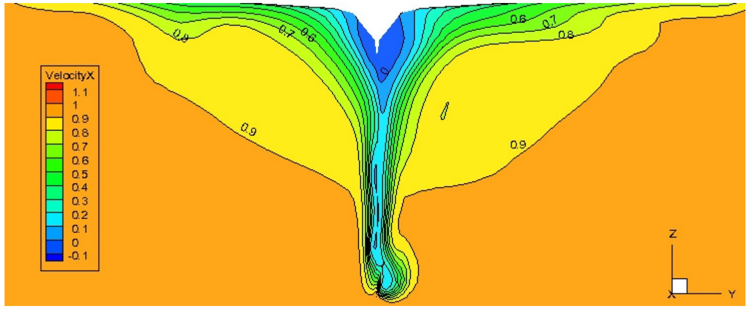

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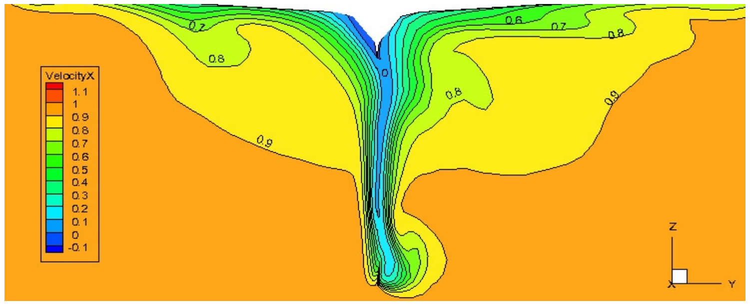


(3)

(1) Velocity field around the hull at 0° drfit angle

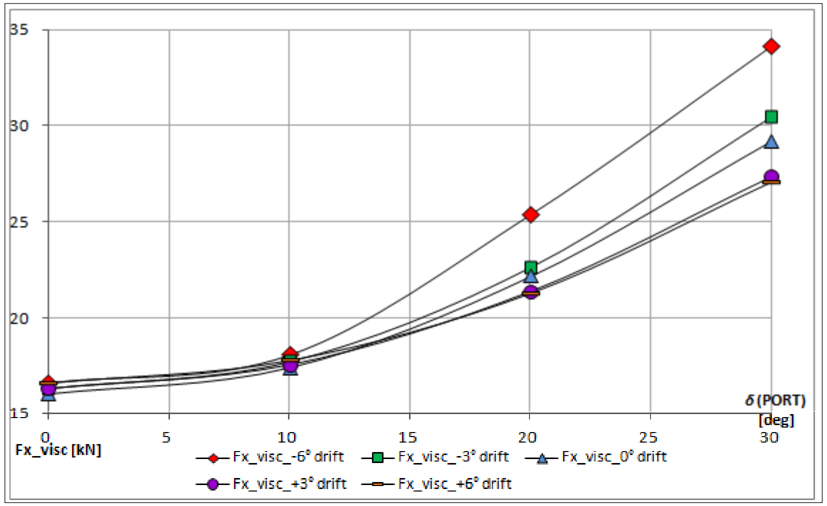
(2) Velocity field around the hull at 3° drfit angle

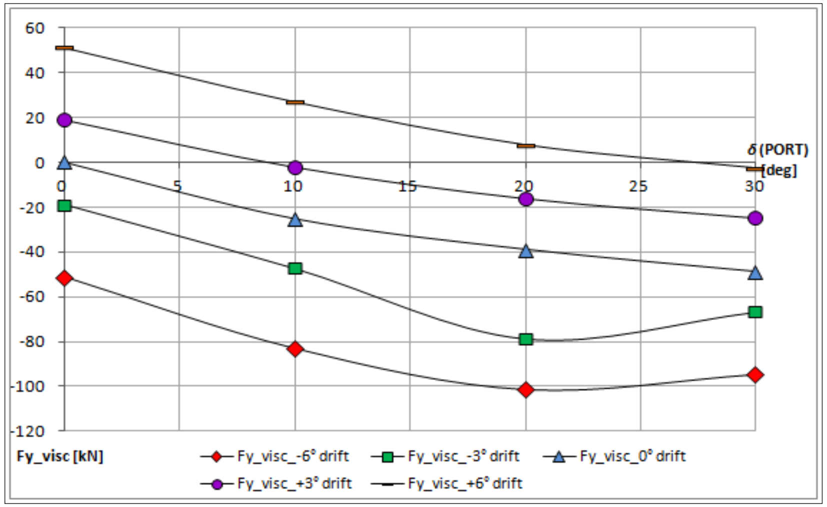
(3) Velocity field around the hull at 6° drfit angle

SIMULATIONS AT DIFFERENT DRIFT AND RUDDER ANGLES

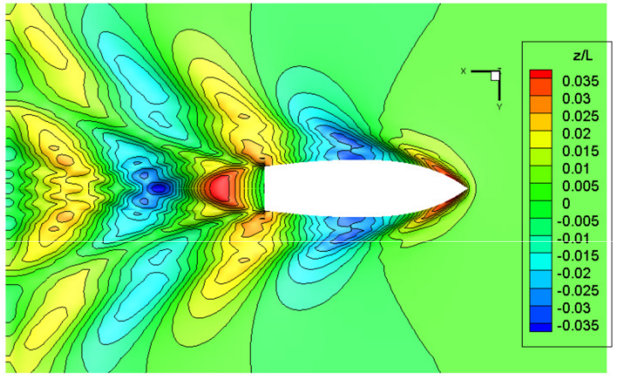
simulation cases:

RUDDER ANGLE (δ)	DRIFT ANGLE (β)
0 deg.	0 deg.
	3 deg.
	6 deg.
10 deg.	0 deg.
	-3 deg.
	3 deg.
	-6 deg.
	6 deg.
20 deg.	0 deg.
	-3 deg.
	3 deg.
	-6 deg.
	6 deg.
30 deg.	0 deg.
	-3 deg.
	3 deg.
	-6 deg.
	6 deg.



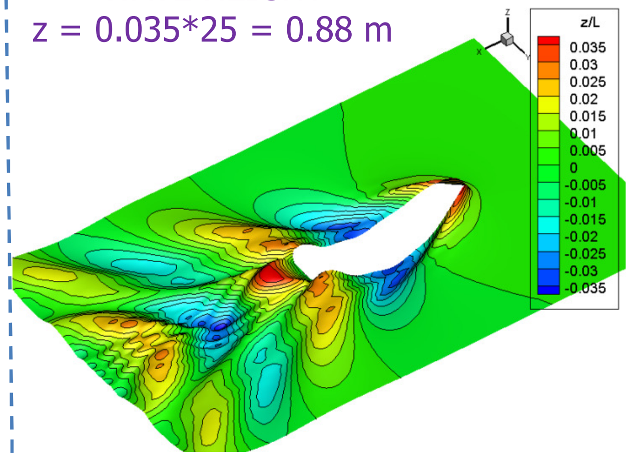


free surface elevation at 0°/0° condition



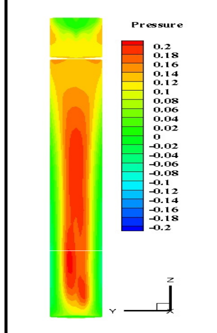
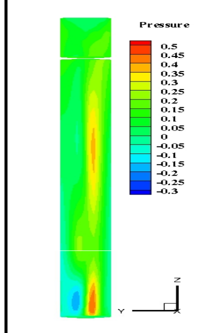
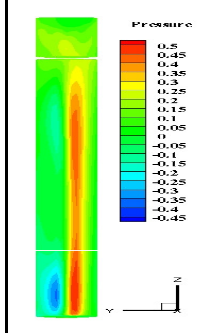
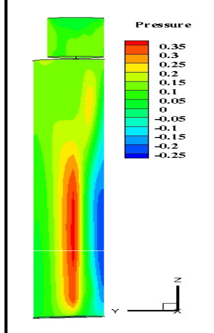
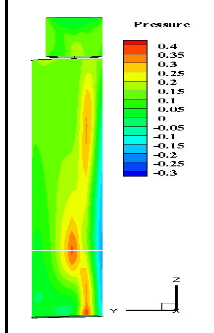
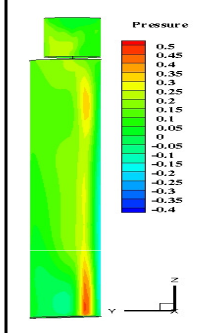
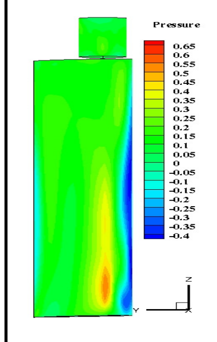
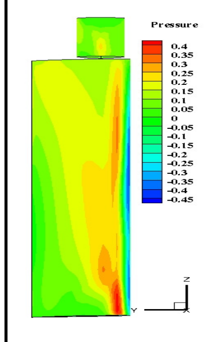
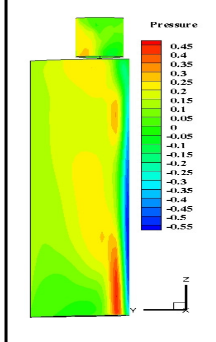
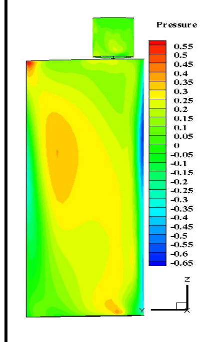
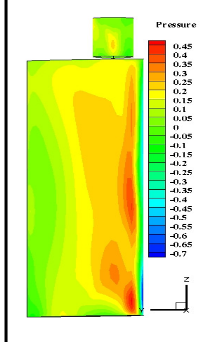
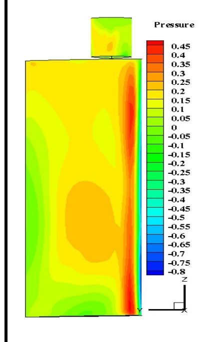
WAVE HEIGHT

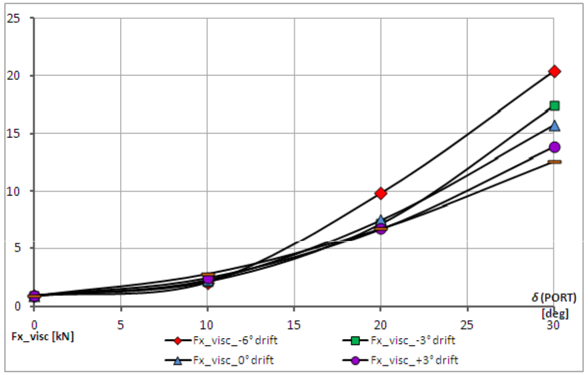
z = 0.035*25 = 0.88 m

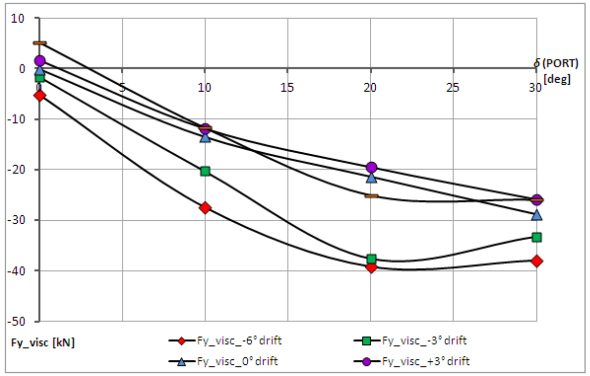


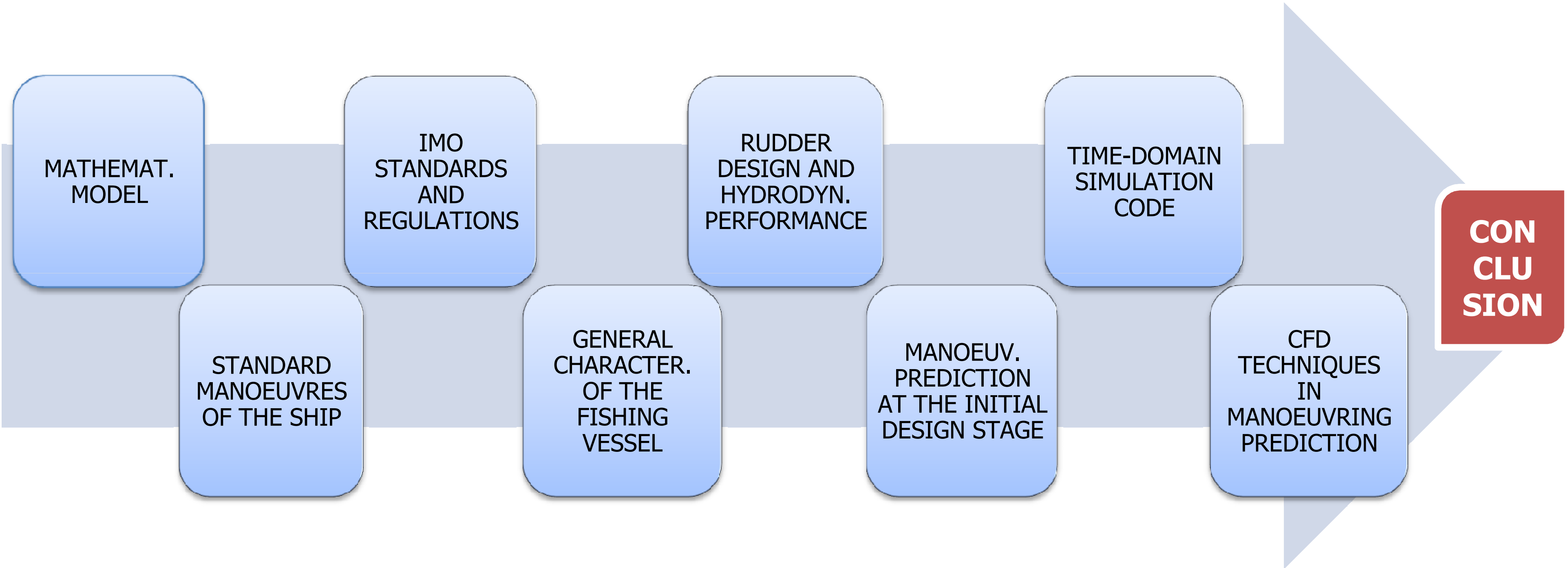
VARIATION OF HYDRODYNAMIC PRESSURE ACTING ON THE RUDDER

A small "top" rudder in the upper part ⟹ simplification of the grid generation of the stern part

					
0° deflection, 0°drift	0° deflection, 3°drift	0° deflection, 6°drift	10° deflection, 0°drift	10° deflection, 3°drift	10° deflection, 6°drift
					
20° deflection, 0°drift	20° deflection, 3°drift	20° deflection, 6°drift	30° deflection, 0°drift	30° deflection, 3°drift	30° deflection, 6°drift






MATHEMAT. MODEL
STANDARD MANOEUVRES OF THE SHIP
IMO STANDARDS AND REGULATIONS
GENERAL CHARACTER. OF THE FISHING VESSEL
RUDDER DESIGN AND HYDRODYN. PERFORMANCE
MANOEUV. PREDICTION AT THE INITIAL DESIGN STAGE
TIME-DOMAIN SIMULATION CODE
CFD TECHNIQUES IN MANOEUVRING PREDICTION
CON CLU SION

CONCLUSIONS

1. INITIAL DESIGN PROGRAMS

Q: Input data of main dimensions only, enough?

A: No. Significant differences , especially for unsual hullforms.

REMARK: more research needed

2. SIMULATION CODES BASED ON HYDRODYNAMIC DERIVATIVES

- Satisfactory agreement between numerical and experimental results
- Miscellaneous influence of derivatives on standard manoeuvres parameters
- Model tests needed to obtain the input data for the code

3. CFD TECHIQUES IN MANOEUVRING PREDICTION

- ✓ Determination of pressure and velocity spectra around the hull and rudder
- ✓ Base of further computation of hydrodynamic derivatives

THANK YOU

Sail successfully into the future!!!