Aalto University
School of Engineering

MEC-E2004 Ship Dynamics (L)

Course Introduction

The Big Picture

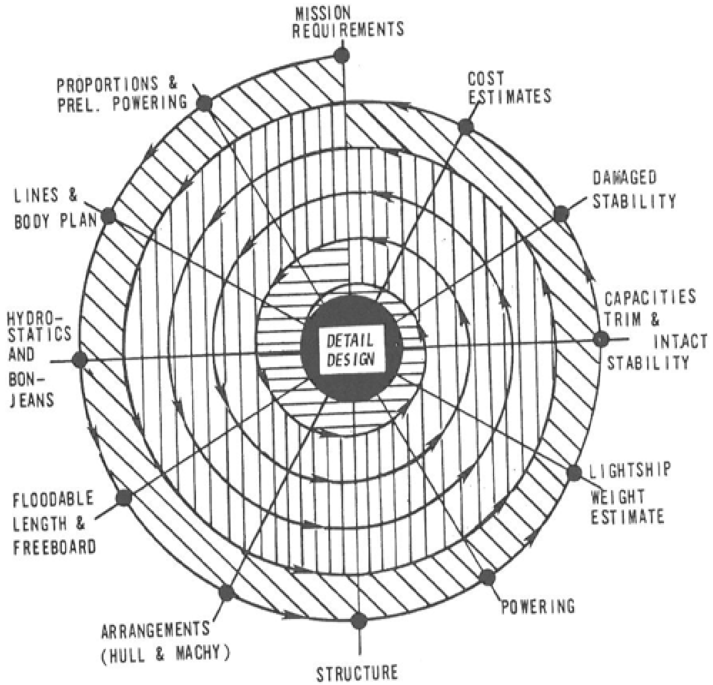
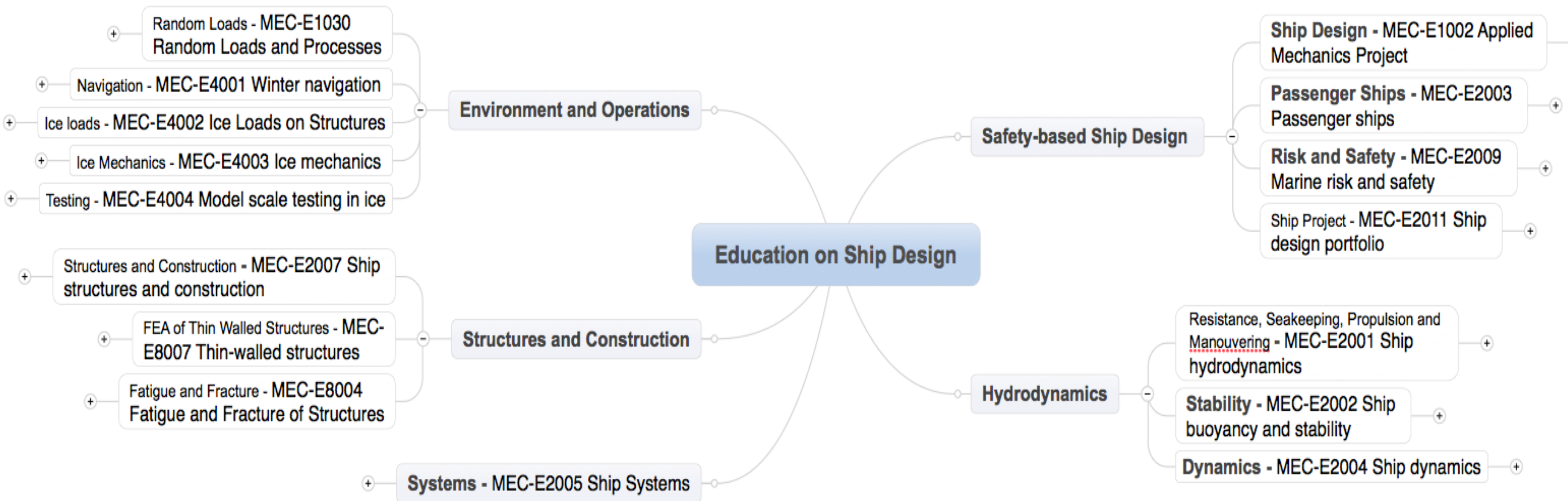


Fig. 1 Basic design spiral

- Ship dynamics is essential part of ship design. It relates with:
  - Ocean Waves
  - Seakeeping
  - Manoeuvring and directional control
  - Dynamic stability
  - Added resistance

- This course focuses on seakeeping, manoeuvring and some elements of resistance/propulsion with direct impact to design
  - NAPA is used for computations
  - The limits of various analyses are discussed thoroughly
  - Specialist topics such as numerical methods for wave modelling, ship motions, loads, directional control etc. are outlined as much as practically possible. However, further post-graduate studies (e.g. coding strip or panel methods etc.) may be necessary

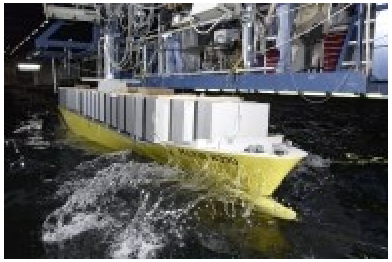
MSc courses on Maritiem Tech.



Related Courses

- Fluid Mechanics
  - Input: potential flow theory
  - Input: CFD

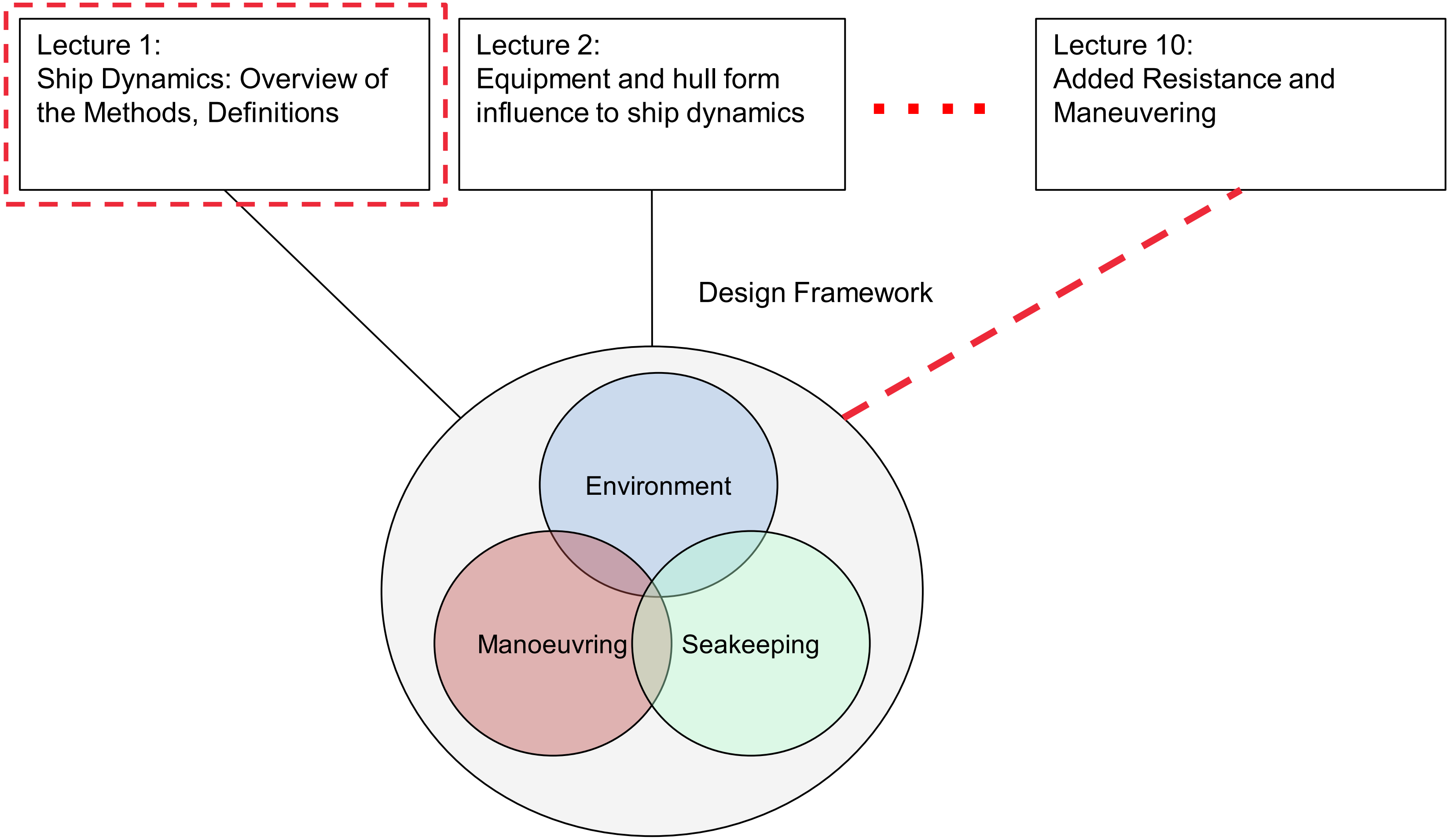
- Dynamics of rigid bodies
  - Input: equations of motion
  - Input: solution techniques for equation of motion in time and frequency domains



- Random Loads and Processes
  - Input: spectral treatment of random loading
  - Input: statistical prediction of short and long term loads and responses

- Ship Structures and Production
  - Input: loads for structural design
  - Output: weight and weight distributions
- PNA & Ship Design portfolio
  - Input : Design principles, ship knowledge and NAPA
  - Output : Concept ship design

Where is this lecture on the course ?



Contents

Aims

Understand the contents of ship dynamics and most often used assumptions.

- What we mean by the term ship dynamics ?
- Are there available engineering tools ?
- What are the basic assumptions in terms of modelling and how important non-linearities may be?

Some literature

- Bertram, V., ”Practical Ship Hydrodynamics”, Butterworth-Heinemann, Ch. 4, 5
- Lewis, E. V. “Principles of Naval Architecture - Motions in waves and controllability”, Vol. 3, Society of Naval Architects and Marine Engineers, Chapters 8 and 9
- **Matusiak, J., ” Dynamics of a Rigid Ship”, Aalto University** https://aaltodoc.aalto.fi/handle/123456789/24408
- Journee, J., and Pinkster, J., ”Introduction in Ship Hydromechanics”, Delft University of Technology, April 2002.
- K.J. Rawson and E.C. Tupper, Basic Ship Theory, 5th Edition, Various Chapters, ISBN: 978-0-7506-5398-5

Ship Dynamics – Key literature

Ten Lectures on Ship Dynamics
(1st Edition)

Assoc. Prof. Spyros Hirdaris CEng FRINA
Aalto University, FI
February, 2021

Department of Mechanical Engineering

Dynamics of a Rigid Ship

Jerzy Matusiak

https://aaltodoc.aalto.fi/handle/123456789/24408

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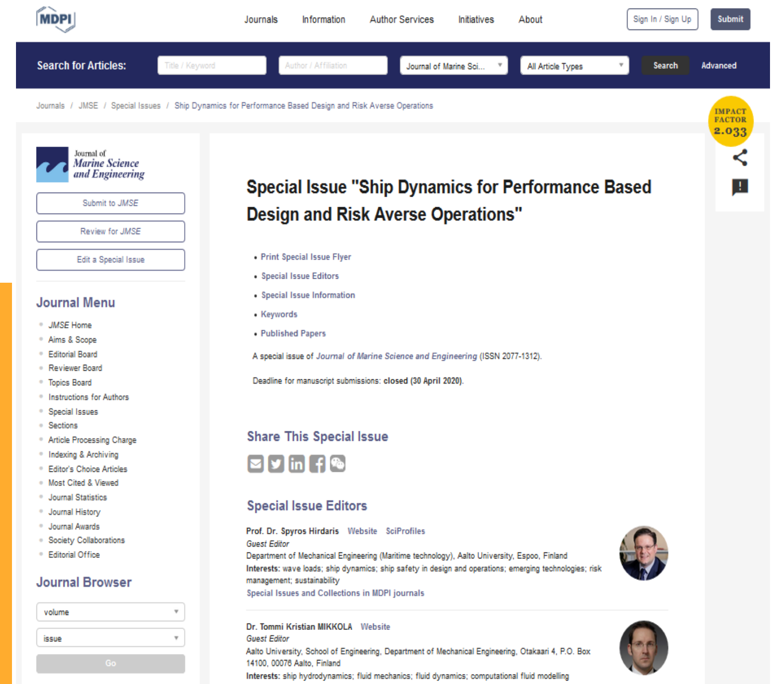

https://www.mdpi.com/journal/jmse/special_issues/ship_dynamics

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Some key questions

How can we define ship dynamics ?
What is Seaworthiness and seakeeping ? Do they relate ?
What do we mean by the term sea loads ?
What is added resistance and ship directional control ?
What affects ship maouvrability
How ship dynamics influence ship design for safety or concept design development ?

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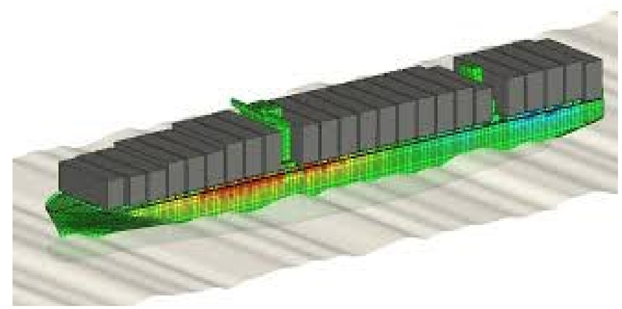
Ship Dynamics – A very broad subject

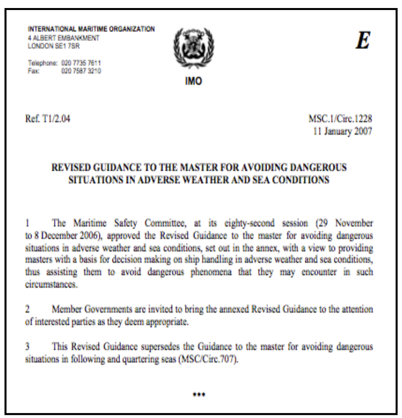
- The term implies that all operational conditions of a vessel where *inertia forces* play role are important.
- Thus, all situations that differ from the ideal still water condition, constant heading and constant forward speed should be considered.
- Traditionally different simplified models are used within the context of
  - ✓ *ocean wave dynamics*
  - ✓ *seakeeping*
  - ✓ *manoeuvring*
  - ✓ *structural vibrations*
  - ✓ *hydroelasticity*
  - ✓ *Stability (intact, damage, static/dynamic)*
  - ✓ *Added resistance in waves*



Ship Dynamics – A very broad subject

- RED Bishop, WG Price and BG Keith (1973). The uses of functional analysis in ship dynamics, *Proc. R. Soc. London A*(332):23-35.
- J. C. Brown, J. D. Clarke, R. S. Dow, G. L. Jones and C. S. Smith (1991). Measurement of wave-induced loads in ships at sea, *Phil. Trans. R. Soc. Lond. A*(334):293-206.
- K.J. Spyrou and J.M.T. Thompson (2000). The nonlinear dynamics of ship motions : a field overview and some recent developments *Phil. Trans. R. Soc. Lond. A*(358):1735-1760.
- Craig B. Smith (2007). Extreme Waves and Ship Design, 10th International Symposium on Practical Design of Ships and Other Floating Structures, Houston - Texas, United States of America
- S.E. Hirdaris & P. Temarel (2009). Hydroelasticity of ships: Recent advances and future trends. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, *223*(3):305–330.

Ship dynamics are regulated by e.g. IMO. Classification Societies also develop Rules and procedures to simulate ship dynamics. On this basis they develop notations on top of basic IACS requirements (Typical URS11A).



INTERNATIONAL MARITIME ORGANIZATION
4 ALBERT EMBANKMENT
LONDON SE1 7SR

Telephone: 020 7735 7611
Fax: 020 7587 3210

IMO

E

Ref. T1/2.04

MSC.1/Circ.1228
11 January 2007

REVISED GUIDANCE TO THE MASTER FOR AVOIDING DANGEROUS SITUATIONS IN ADVERSE WEATHER AND SEA CONDITIONS

1 The Maritime Safety Committee, at its eighty-second session (29 November to 8 December 2006), approved the Revised Guidance to the master for avoiding dangerous situations in adverse weather and sea conditions, set out in the annex, with a view to providing masters with a basis for decision making on ship handling in adverse weather and sea conditions, thus assisting them to avoid dangerous phenomena that they may encounter in such circumstances.

2 Member Governments are invited to bring the annexed Revised Guidance to the attention of interested parties as they deem appropriate.

3 This Revised Guidance supersedes the Guidance to the master for avoiding dangerous situations in following and quartering seas (MSC/Circ.707).

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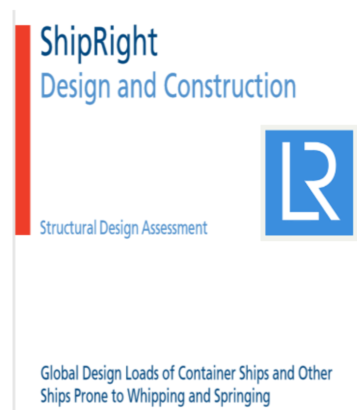


Seaworthiness

"The general term of seaworthiness must embrace all those aspects of ship design that affect her ability to remain at sea in all conditions and carry out her specified duty", **Basic Ship Theory (Rawson and Tupper), Chapter 12**

What we should check :

- Are the motions excessive or harm the crew (e.g. falling, man-overboard) and ship functions (e.g. deck operations, equipment), and passenger comfort (e.g. motion sickness, fear) ?
- How much the resistance of ships is increased by the motion in waves and how much motions are affected by speed reduction ?
- Can and should we optimise the route to minimise fuel/total costs or transport time ?
- If the wetness of deck becomes excessive do we need to increase the freeboard, repair structures etc. ?
- Do we experience slamming that causes high stresses ?
- What are the operational limits for the ship? For example what would be the speed that would assure avoidance of excessive motions, capsizing, propeller racing and excessive loads on the hull girder?

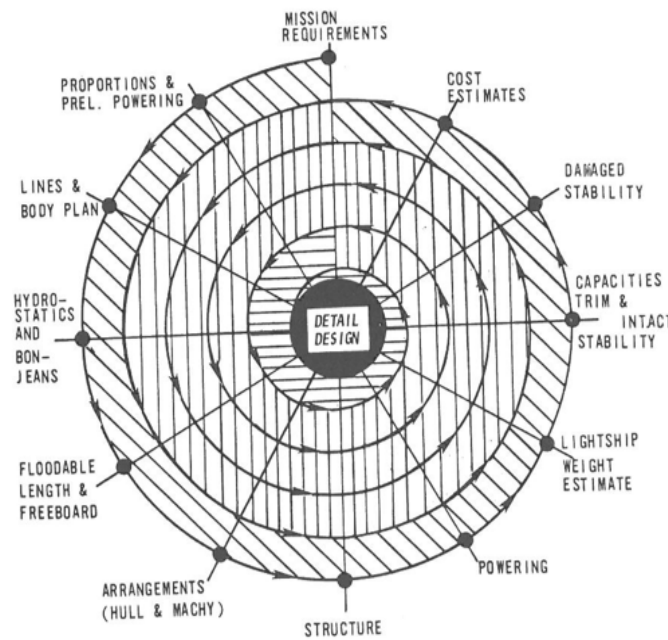
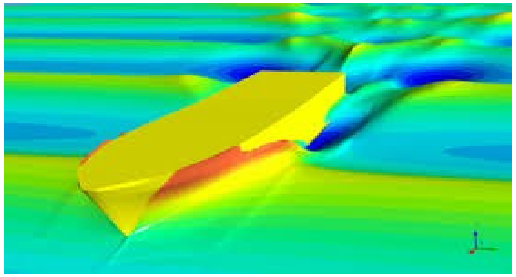


Fig. 1 Basic design spiral

Seakeeping

Good seakeeping is desirable feature, but we need to compromise with each ship's special design features and dynamics. Those may be related with the appendages, cargo, lifting equipment etc. Typical design process: design, tests, redesign, test etc.…
Simulations shorten the numbers of iterations in design.

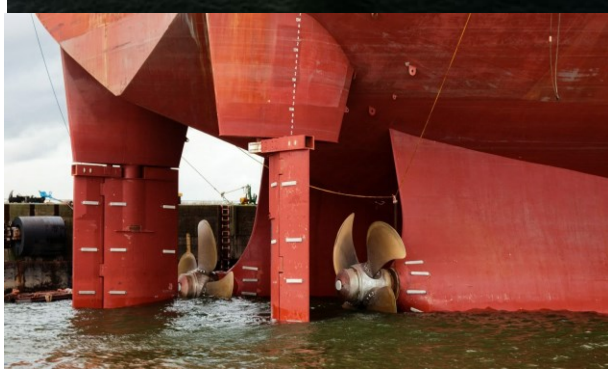


https://www.youtube.com/watch?v=atk4_KsxV6s

Ship manouvering and directional control

A ship is said to be directionally stable if a deviation from a set course increases only while an external force or moment is acting to cause the deviation. Neither stability nor instability obviates the need for devices to maintain a course or to change it on command.



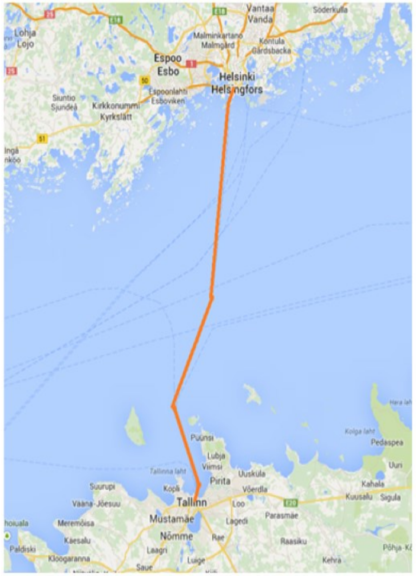


Assignment 1

- **Grades 1-3**
  - ✓ Select paper related to ship dynamics and read it
  - ✓ Define the operational profile for your ship, operations including seasonal effects and ship dynamics requirements
  - ✓ Define the shape, size, location and space reservation of the maneuvering devices of your ship and sketch them on top of your hull (Napa-input)
  - ✓ Describe the main features of your ship's hull form that affect the ship dynamics

- **Grades 4-5**
  - ✓ Read 1-2 scientific journal articles related to ship dynamics
  - ✓ Reflect these in relation to knowledge from books and lecture slides

- **Report and discuss the work**

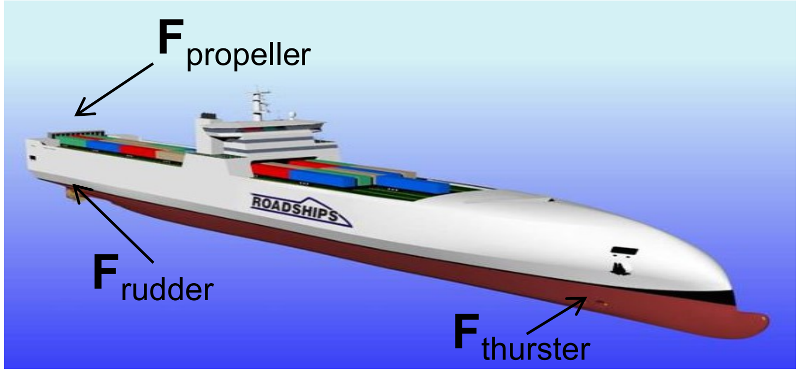


Baltic Sea
- 9 months in open water
- 3 months in ice

X trips per day/week
Y speed
Z cars and ZZ busses
…

Ice loads affect in-plane motions
Parametric rolling possible due to aft shape
Slamming due to bow shape
…

Any other relevant info for Ship dynamics, such as
- Moving cargo
- …



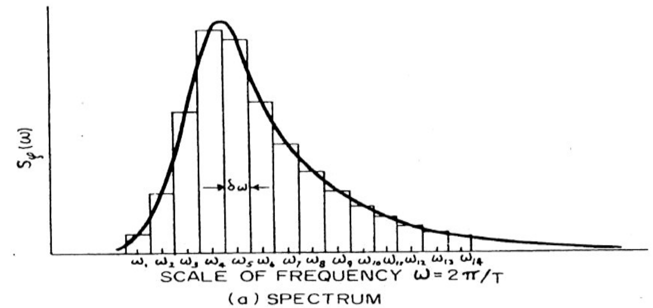
Seakeeping basics

- Prediction of motions/loads in irregular seas
  - ✓ Scatter diagram for wave conditions
  - ✓ Wave spectra for energy contents
  - ✓ Response amplitude operator for responses

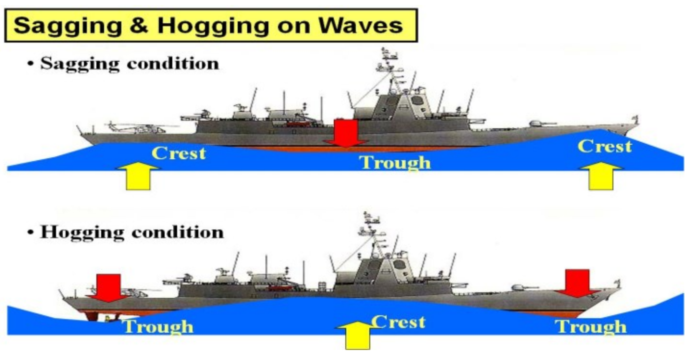
Table 5—Observed Percentage Frequency of Occurrence of Wave Heights and Periods (Hogben and Lumb data)
Northern North Atlantic

Wave height, m	Wave Period T_1, sec: 2.5	6.5	8.5	10.5	12.5	14.5	16.5	18.5	20.5	Over 21	Total
0-1	13.7204	3.4934	0.8559	0.3301	0.1127	0.0438	0.0249	0.0172	0.0723	0.3584	19.0291
1-2	11.4889	15.5036	6.4817	1.8618	0.5807	0.1883	0.0671	0.0254	0.0203	0.0763	36.2941
2-3	1.5944	7.8562	8.0854	3.7270	1.1790	0.3713	0.1002	0.0321	0.0091	0.0082	22.9629
3-4	0.3244	2.2487	4.0393	2.9762	1.3536	0.4477	0.1307	0.0428	0.0050	0.0040	11.5724
4-5	0.1027	0.7838	1.6998	1.5882	0.9084	0.3574	0.1443	0.0433	0.0072	0.0049	5.6400
5-6	0.0263	0.1456	0.3749	0.4038	0.2493	0.1200	0.0382	0.0067	0.0027	0.0027	1.3702
6-7	0.0277	0.1477	0.3614	0.4472	0.2804	0.1301	0.0504	0.0113	0.0011	0.0032	1.4605
7-8	0.0084	0.0714	0.1882	0.2199	0.1634	0.0785	0.0353	0.0069	0.0018	0.0034	0.7772
8-9	0.0037	0.0325	0.0856	0.1252	0.1119	0.0558	0.0303	0.0045	0.0027	0.0033	0.4555
9-10	0.0034	0.0204	0.0674	0.1173	0.0983	0.0550	0.0303	0.0173	0.0079	0.0047	0.4220
10-11		0.0005	0.0012	0.0023	0.0031	0.0012		0.0005			0.0088
11+		0.0005	0.0007	0.0019	0.0035	0.0002			0.0005		0.0073
Totals	27.3003	30.3043	22.2415	11.8009	5.0143	1.8493	0.6517	0.2080	0.1306	0.4691	100.000

- Frequency domain linear models allow for
  - ✓ Representation of natural seaway as superposition of regular (harmonic) waves and Fourier decomposition
  - ✓ Determination of ship responses
  - ✓ In most cases this model gives a sufficiently accurate prediction of loads and ship motions



- Linear models cannot predict the loss of ship stability in waves, parametric resonance of roll and asymmetry of sagging and hogging wave loads



- Ship steering and maneuvering motion are also often disregarded

Seakeeping – a practical example

How important are deck openings?

© Marine Technology, Vol. 46, No. 1, January 2009, pp. 27–33

Experimental Study on the Behavior of a Swimming Pool Onboard a Large Passenger Ship

Pekka Ruponen,[1] Jerzy Matusiak,[1] Janne Luukkonen,[2] and **Mikko Ilus[3]**

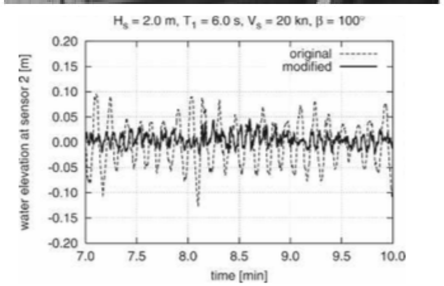


Fig. 19 Example of the wave elevations at sensor 2 for the original and modified pools in the normal sea state

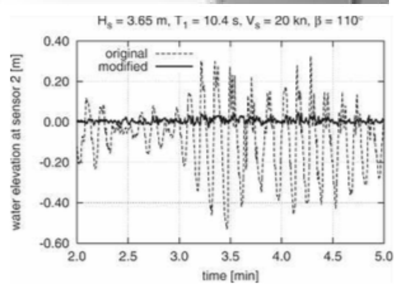
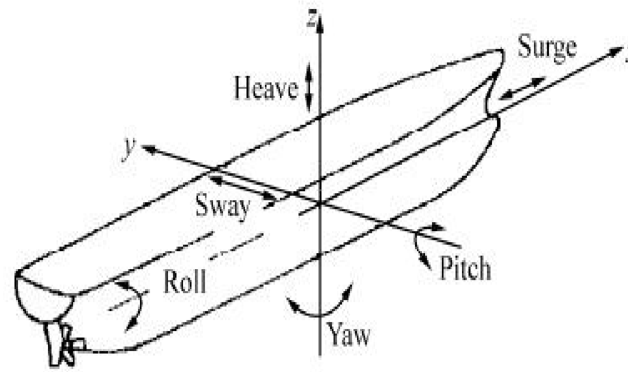


Fig. 20 Example of the wave elevations at sensor 2 for the original and modified pools in the harsh sea state



https://www.youtube.com/watch?v=8JT9mgWfrA8

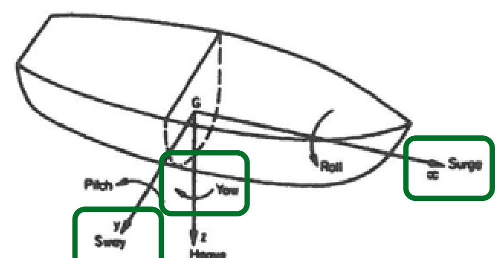
Manouvering basics

- In manoeuvring the design aspects are
  - Course-keeping and changing
  - Track keeping
  - Speed-changing

- The terms directional stability and control are also used

- Manoeuvring concerns shipyard / owner
  - IMO sets minimum requirements for all ships (IMO A751)
  - Ship-owners may be much more strict (e.g. port of Miami)
  - *Practical Questions: Does the ship keep straight course? Is tug assistance needed to berth and under which wind speeds? Could the vessel initiate/sustain/stop turning? Could the vessel stop and accelerate safely?*

- Manoeuvring requirements affect the equipment to be selected (e.g. rudders and pods, waterjets, fixed fins, jet thrusters, propellers, ducts and steering nozzles etc.)



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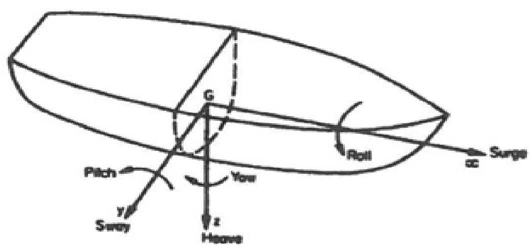
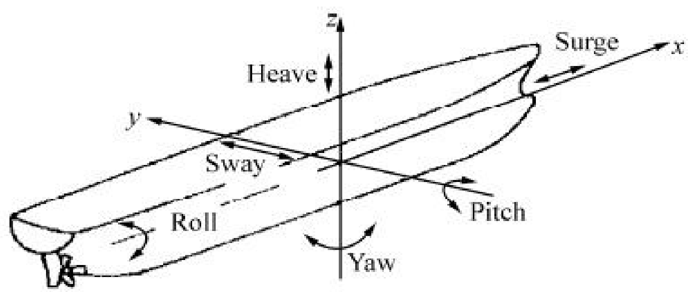
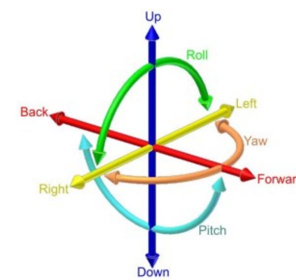
J. E. Matusiak, *Dynamics of a Rigid Ship*. Aalto University publication series on Science and Technology, e-ISBN: 978-952-60-7262-3; e-ISSN: 1799-490X, 2017.

Manouevring vs Seakeeping models

- Time dependent investigations are a norm in manoeuvring but an option in seakeeping
- Manoeuvring is often studied in shallow waters but seakeeping in open seas
- Seakeeping is studied by an inertial coordinate system while manoeuvring by a ship fixed system
- Viscosity is not always neglected in manoeuvring but can be neglected or simply superimposed in seakeeping. This is mostly because of mathematical difficulties and computational cost



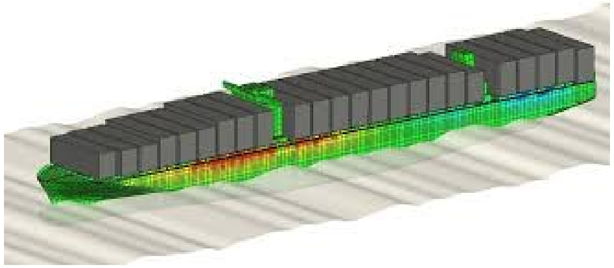


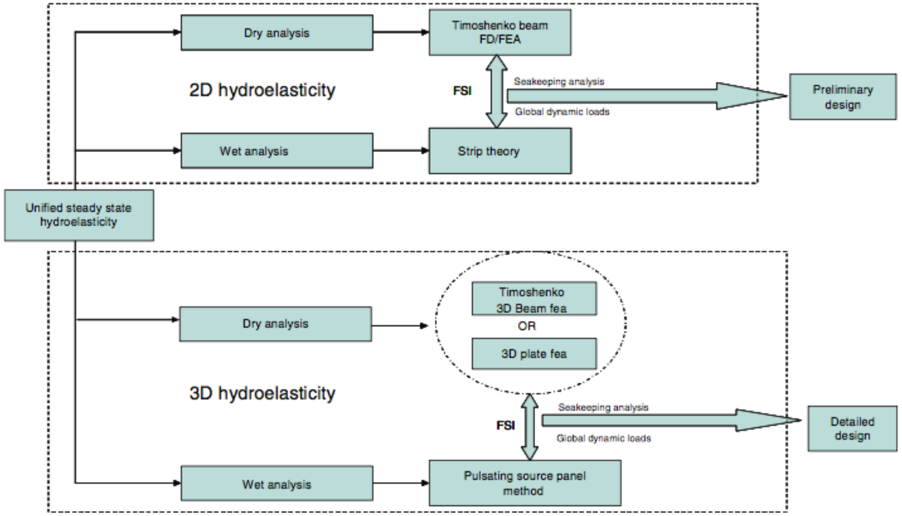


Ghalib Taimuri, Jerzy Matusiak, Tommi Mikkola, Pentti Kujala, Spyros Hirdaris, (2020). A 6-DoF maneuvering model for the rapid estimation of hydrodynamic actions in deep and shallow waters, Ocean Engineering,Volume 218,108103, https://doi.org/10.1016/j.oceaneng.2020.108103

Wave Loads – basics

- Static, still water and wave loads
- Quasi static, dynamic and hydroelastic methods
- Hydroelasticity refers to the situation where the hull deformations and flow-field interact strongly, i.e. the problems cannot be decoupled
- Required in cases where the hull is slender, flexible and has large deck openings (e.g. large containerships)
- Simulations involve coupling of seakeeping hydrodynamics



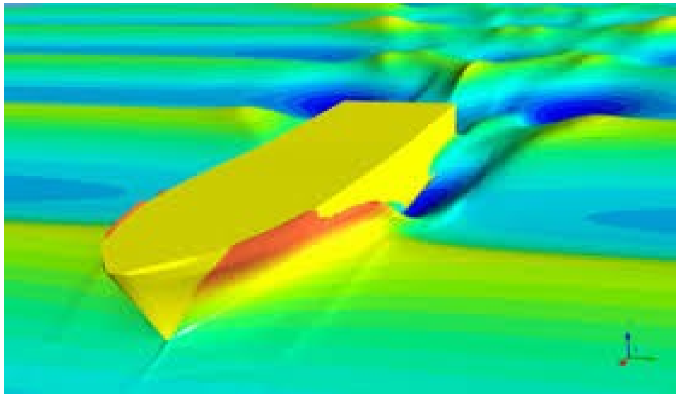


RED Bishop, WG Price and BG Keith. The uses of functional analysis in ship dynamics, Vol. 332, Issue 1558, Proc. R. Soc. London (A), https://doi.org/10.1098/rspa.1973.0011

Engineering tools

- Experimental approaches in model- or full-scale are used for
  - Validation
  - Special investigations on safety
  - Manoeuvring tests to define the coefficients in EoM

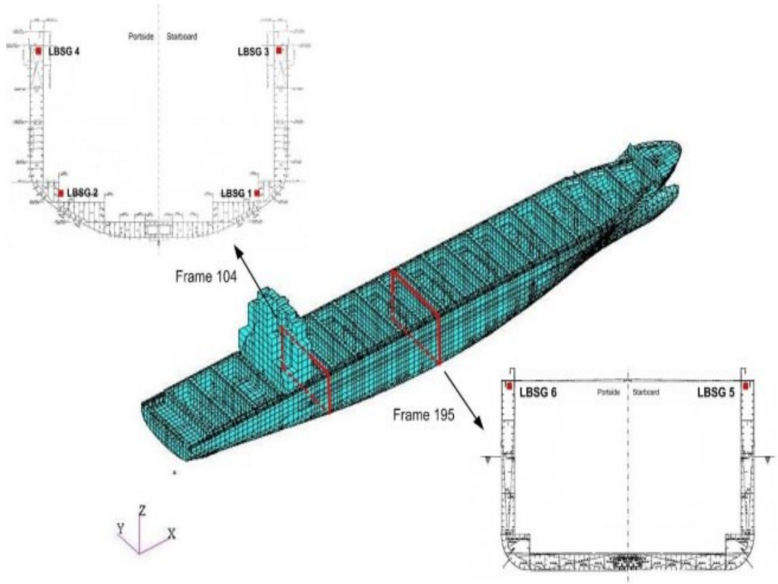
- Numerical methods
  - Strip theories, panel methods, CFD methods
  - Manoeuvring simulations using experimental coefficients (CFD can be used to reduce scaling errors)
  - Computations in Frequency domain, e.g. ship responses for harmonic waves in different wave directions and lengths
  - Computations in time domain, i.e. motions and forces in given point of space and time
  - Computations in statistical domain: statistically significant seakeeping values in irregular (natural) seaways

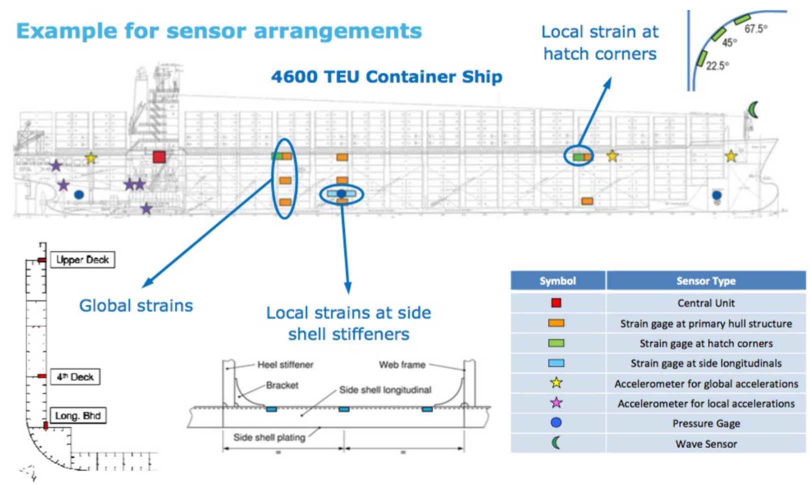


Full Scale Measurements

Ships can be assembled with gyros, strain gauges etc. to measure the responses

- Accelerometers for motions
- Strain gauges to extract wave bending moments
- Uncertainties relate with accurate seaway measurements and measurement equipment failures





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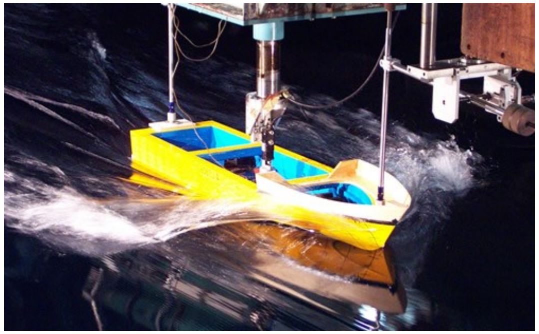
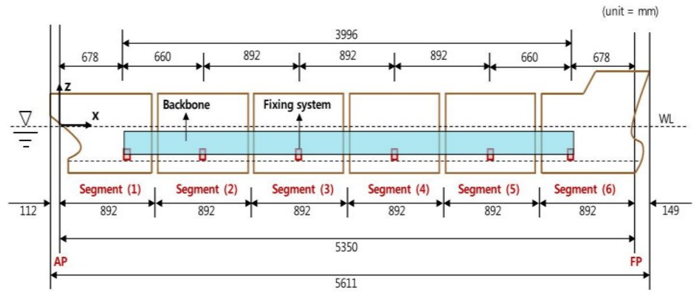
S. E. Hirdaris, N. J. White, N. Angoshtari, M. C. Johnson, Y. Lee & N. Bakkers (2010) Wave loads and flexible fluid-structure interactions: current developments and future directions, Ships and Offshore Structures, 5:4, 307-325, DOI: 10.1080/17445301003626263

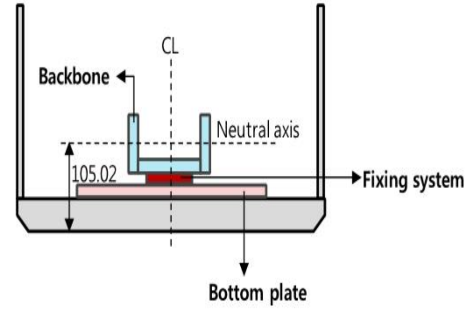
Model experiments

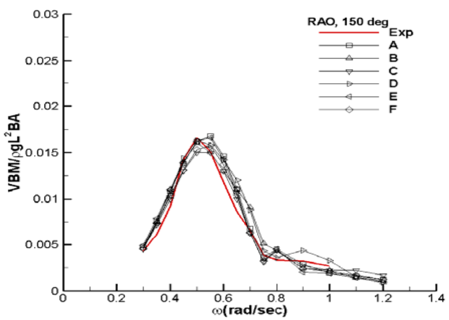
- Self-propelled models are used to avoid any extra reactions
- Remote control, autopilot, sometimes wires are used to restrain some DOF
- *Models may be sectional if wave loads are measured, moment gauge between sections*
- Expensive approach as water needs to settle between tests and models costs
- Many parameters can be changed: Froude similarity is key
- *Scaling issues :* slamming with viscous effects, water on deck, effects are not as important in seakeeping as in resistance, propulsion or manoeuvring

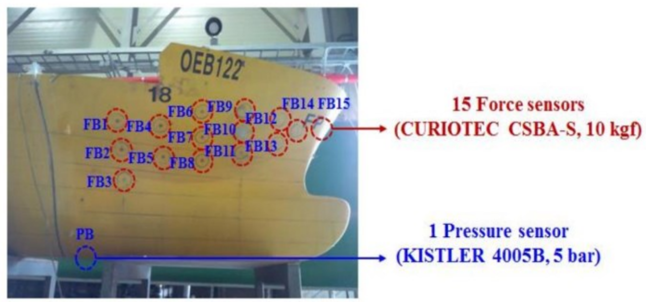


Model experiments









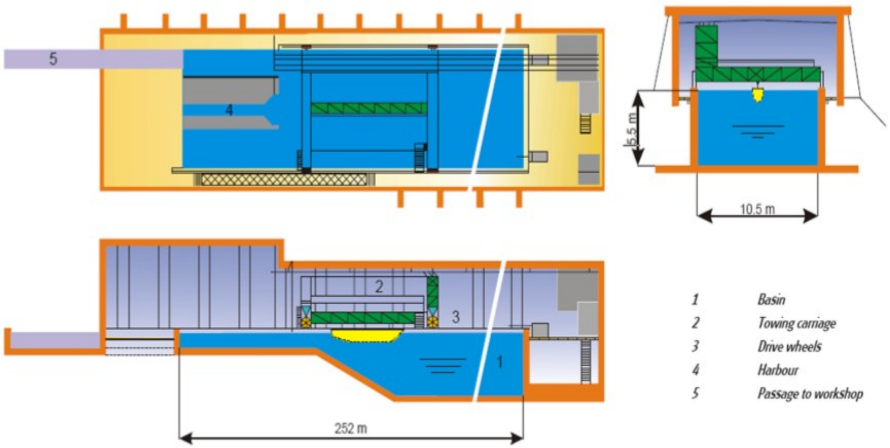
https://www.youtube.com/watch?v=GddCNp_m7JA

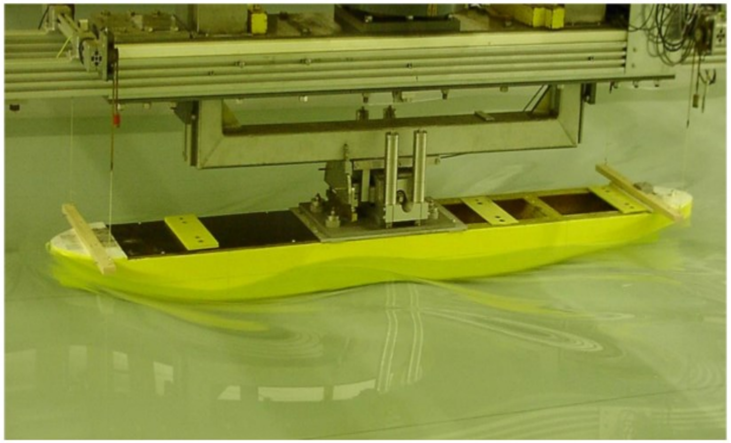
Ocean basins

https://www.youtube.com/watch?v=MLc-NRKYqis&feature=related

https://www.youtube.com/watch?v=Odkc4ic6jds

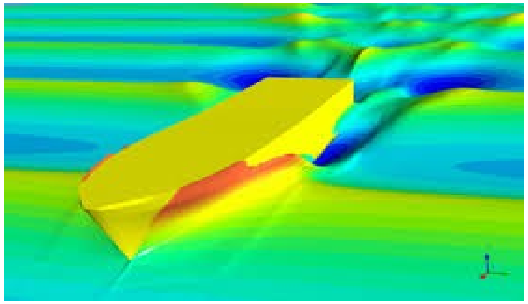
https://www.youtube.com/watch?v=RQfzXdTuceY&feature=related



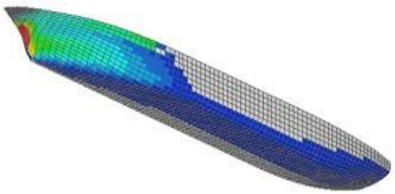


Simulation methods

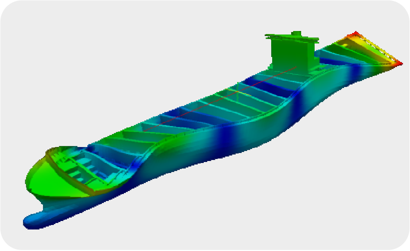
- Most common approach is to measure loads and responses in time. This involves:
  - ✓ Integration of velocities and motions
  - ✓ Fourier transformation to evaluate spectra in frequency domain (e.g. FFT)



- To achieve the above we need to identify the motions and significance of non-linearity. Often we consider two types of analyses
  - ✓ Screening in frequency domain: what are the worst conditions for our ship?
  - ✓ Simulations in time domain: when wave-amplitude dependency is violated, what is the impact?



- Different methods contain different assumptions on stochastics of the problem and fluid idealisations. Examples are :
  - ✓ Navier-Stokes, i.e. full CFD
  - ✓ Reynolds-Averaged Navier-Stokes where little turbulence fluctuations are omitted in boundary layers
  - ✓ Euler equations where viscosity is neglected and coarser meshes are used for faster simulations
  - ✓ Potential flow solvers where the flow is usually irrotational and we cannot model breaking waves or splashes



Hirdaris, S.E et al. (2016) The influence of nonlinearities on the symmetric hydrodynamic response of a 10,000 TEU Container ship. Ocean Engineering, 111:166-178.

Simplified hydro-analysis assumptions

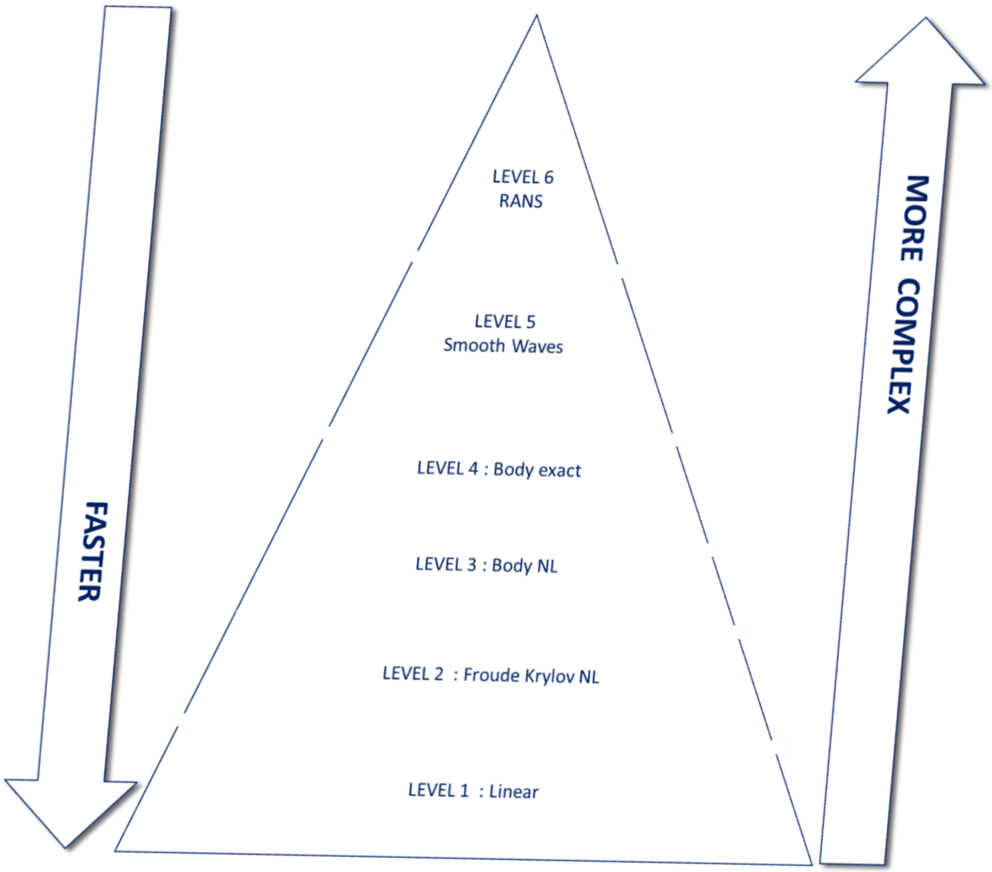
- Random seas lead to random responses
- Response due to one wave is not affected by simultaneous occurrence of another wave. This assumption is valid only for small wave amplitudes (e.g. airy waves with high harmonic contents and small amplitude)
- In many occasions hull deformation is excluded for motion computations
- The flow is potential & inviscid and irrotational. Compressibility effects are usually excluded
- Wave dynamics are modelled by 3 translations & 3 rotations. Roll & pitch are dynamic equivalents to heel and trim. Translations in x- and y-axis and rotation around z will not result in residual force or moment if ship displacement remains constant. For other movements forces and moments may be necessary.

The above assumptions do not hold in large waves, higher speeds, slender hulls,

AND

extreme scenarios (e.g. freak waves, groundings, collisions)

Why nonlinear hydrodynamics ?



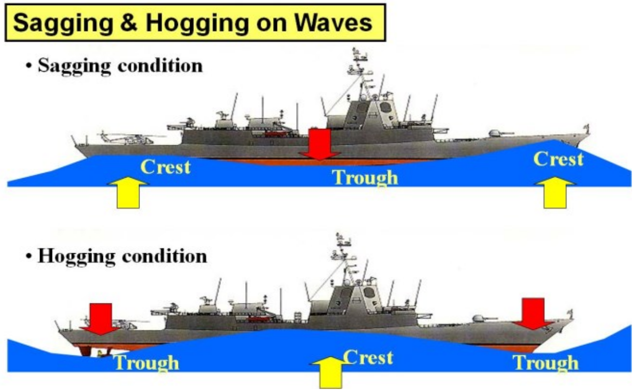
- ❑ Most applications use potential flow
- ❑ Ad-hoc codes use partly NL methods
- ❑ Fully NL & RANS solvers not mature
- ❑ Modelling & use in design not verified

Hirdaris, S.E et al. (2016) The influence of nonlinearities on the symmetric hydrodynamic response of a 10,000 TEU Container ship. Ocean Engineering, 111:166-178.(https://doi.org/10.1016/j.oceaneng.2015.10.049)

Applications of NL Hydro-models

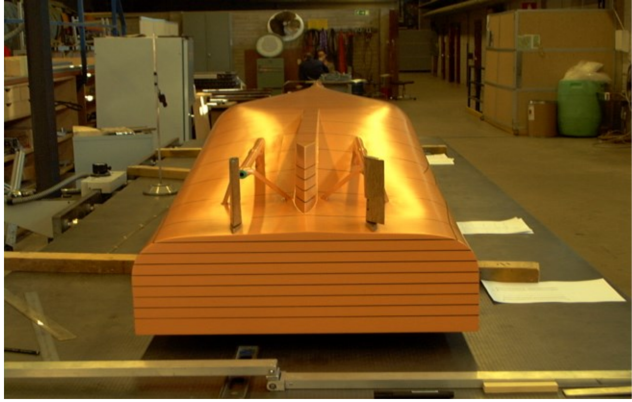
- The fact that motions are not linearly proportional to wave amplitude and period may lead to amplification of NL effects in large waves. This is why we need to understand :
  - ✓ Statistics of large waves
  - ✓ Non-linear wave theory
  - ✓ Non-linear model for advanced ship-handling simulations
  - ✓ Time domain simulations for motions/loads/stability
  - ✓ Ship hydroelasticity under intact and damage conditions

- Other example problems are :
  - ✓ Capsizing
  - ✓ Sagging and hogging moment ratios
  - ✓ Parametric roll, Broaching
  - ✓ Slamming (bow, bottom, stern)
  - ✓ Maneuvering in confined waters
  - ✓ High speed craft motions and loads



Some examples (Review at Home)

- Parametric roll tests are primarily concerned with dynamic stability
  - ✓ Loss of stability on a crest of a following wave
  - ✓ Parametric roll resonance
  - ✓ Regular and irregular waves
    1. Head and following waves
    2. Varied amplitude



https://www.youtube.com/watch?v=ewqaRMGv2mE

- Simulations indicate that there is a certain threshold value of wave amplitude below which paramatric roll resonance does not develop
- Ship dynamics in shallow waters : https://www.youtube.com/watch?v=49p8CHntVgA
- Bulk Carrier and Tanker Collision : https://www.youtube.com/watch?v=FjRUeKlpWAU
- Bank Effects Ships in Restricted Waters

  https://www.facebook.com/europeasiashippingmanagement/videos/ship-handling-in-restricted-waters/1920415011510141/

ABS

GUIDE FOR THE

ASSESSMENT OF PARAMETRIC ROLL RESONANCE IN THE DESIGN OF CONTAINER CARRIERS

APRIL 2019

Summary

- Ship dynamics, performance and safety go hand to hand

- Model experiments, simulations and full-scale measurements are essential part of the design and validation process

- Ship dynamics relates with
  - Seakeeping
  - Maneuvering
  - Wave loads
  - Added resistance, dynamic stability

- The models can be linear or non-linear, rigid or flexible
  - Linear in frequency domain to map the worst-case scenarios
  - Non-linear in time domain to simulate the behavior
  - Flexible to simulate hydroelasticity effects

- *For next time : Refresh your skills and knowledge on ship resistance and propulsion*

Aalto University
Thank you !

MEC-E2004 Ship Dynamics (L)