ATMA 2025

STABILITY of NAVAL SHIPS

Val de Reuil, Friday 16 of May 2025

Application of electrically-driven anti-roll fins on a 65-meter fast attack craft

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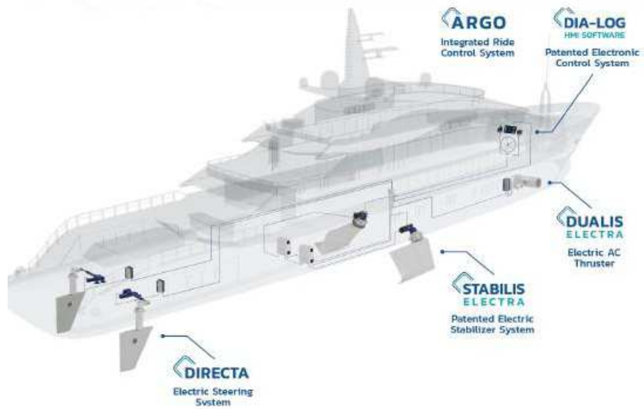
CMC Marine Srl



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Agenda

- Roll stabilization in the naval field
- Mathematical model
- Test case
- Conclusion

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Roll stabilization in the naval field

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Roll stabilization on navy ships

- Rolling motion caused by waves and wind must be minimal. It must be guaranteed:

1. **Platform stability**: to operate equipment and conducting tasks like helicopter and drone landings or deploying small craft.
2. **Effectiveness**: weapons, sensors, and communication equipment remain functional, despite the vessel motions and accelerations
3. **Crew comfort and safety**: onboard operations limited by seasickness and accelerations

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Roll stabilization on navy ships

- Passive and active stabilizing systems have been developed to mitigate roll motion.
- Bilge keels (passive fin stabilizers)

ON THE ROLLING OF SHIPS.

By W. FROUDE, Esq., Assoc. I.N.A.

[Read at the Second Session of the Institution of Naval Architects, March 1, 1861, the Rev. Canon MOSELEY, M.A., F.R.S., Vice-President I.N.A., in the Chair.*]

CONSIDERATIONS RESPECTING THE EFFECTIVE WAVE SLOPE IN THE ROLLING OF SHIPS AT SEA.*

By W. FROUDE, Esq., F.R.S., Associate and Vice-President.

[Read at the Fourteenth Session of the Institution of Naval Architects, 4th April, 1873; Admiral Sir ROBERT SPENCER ROBINSON, K.C.B., F.R.S., Vice-President, in the Chair.]

SS Great Eastern (1859) - Based on her trial voyage, Froude proposed the usage of bilge keels (Perez, 2005)

Federico Martinengo (F 596)

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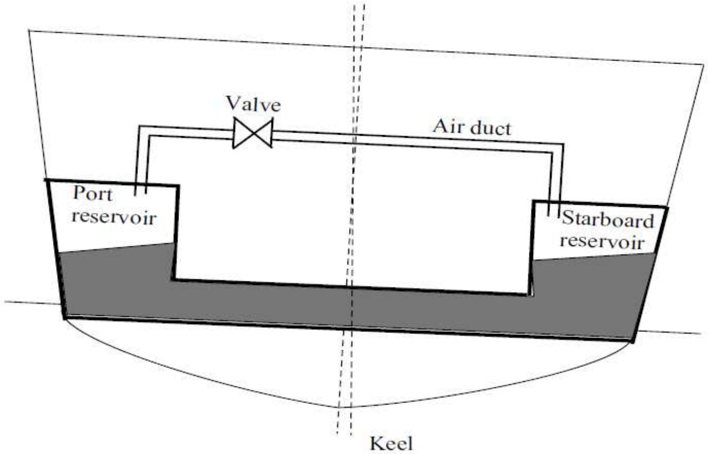
Roll stabilization on navy ships

- Anti-rolling tanks (passive or active): as the ship rolls, the water in the tank moves with the same period the ship moves, but with a shift of a quarter of period behind the rolling of the vessel. The weight of the mass of fluid produces a moment that opposes the roll motion.



Perez T., Ship Motion Control (2005)

Dattilo-class – Italian Coast Guard OPVs

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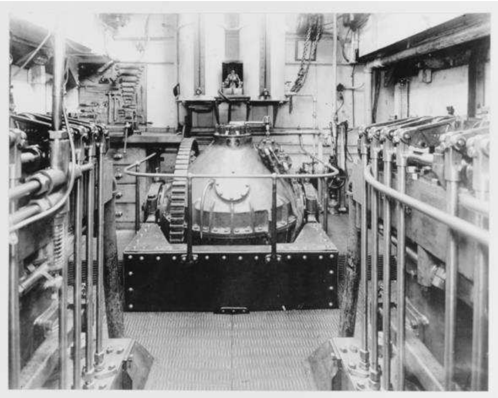
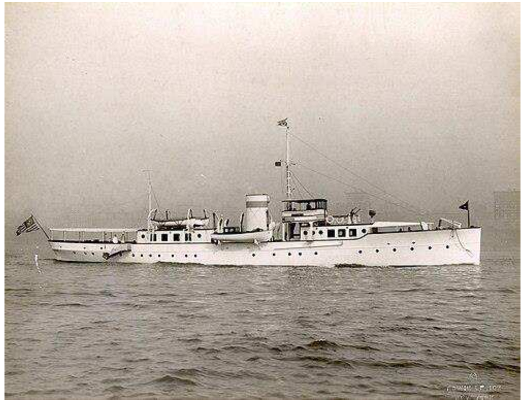
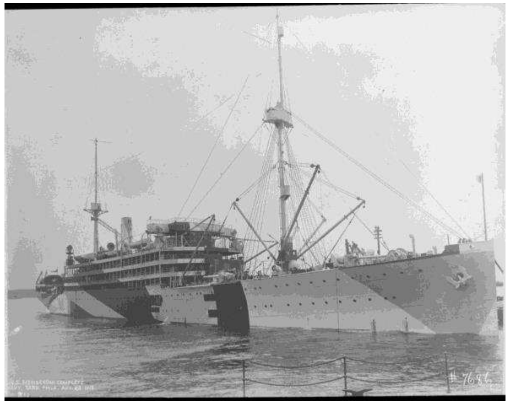
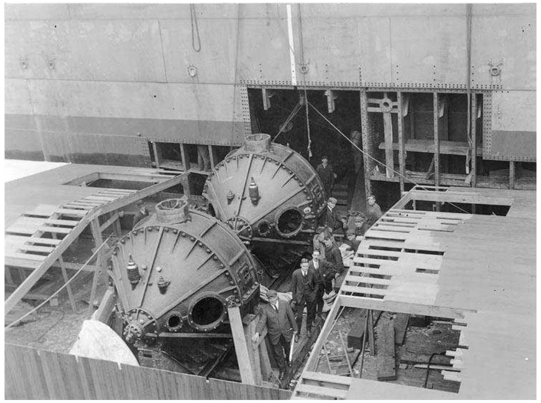
Roll stabilization on navy ships

- Gyro-stabilizers: gyros were tested aboard smaller ships during the late 1800s and found to be successful. However, it was not until 1917 that the United States troopship USS Henderson became the first large ship to use gyroscopic stabilizers.

Sperry Gyro-Stabilizer installed on USS Aramis (SP-418), 350 ton guardship (1917)
https://www.history.navy.mil/our-collections/photography/numerical-list-of-images/nhhc-series/nh-series/NH-57000/NH-57631.html

The transport ship USS Henderson (AP-1) was the first large naval ship to utilize a gyroscopic stabilizer system. (1916). Each gyroscope weighted 25t.
https://www.navygeneralboard.com/warship-stabilization-systems-warship-tech/

Within two decades the gyroscope was replaced by fin stabilized systems that were generally simpler and less costly compared to gyroscopes.

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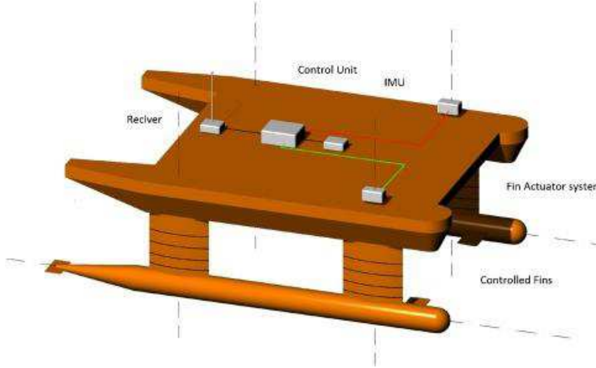
Roll stabilization on navy ships

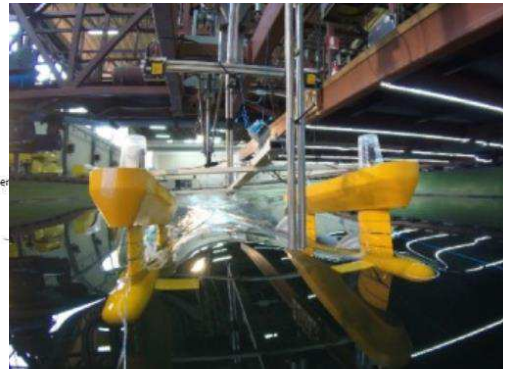
- Active fins: fin stabilization systems first began arriving during the 20s (Motora's patent). Though they were used with success on ocean liners during the 1930s, it took longer for warships to adopt the technology. It was not until the 1970s that fin stabilization systems started to be more widely adopted by warships.

Non-retractable

Retractable (higher AR)

Hydraulic fin stabilizers
https://www.fincantieri.com/globalassets/prodotti-servizi/sistemi-e-componenti/sistemi-e-componenti-navali/brochure_fin_stabilizers_system.pdf





Experimental study on hydrodynamic performance of SWATH vessels in calm water and in head waves, Begovic E., Bertorello C., Bove A., De Luca F., Applied Ocean Research, Volume 85, April 2019, Pages 88-106, https://doi.org/10.1016/j.apor.2018.10.012

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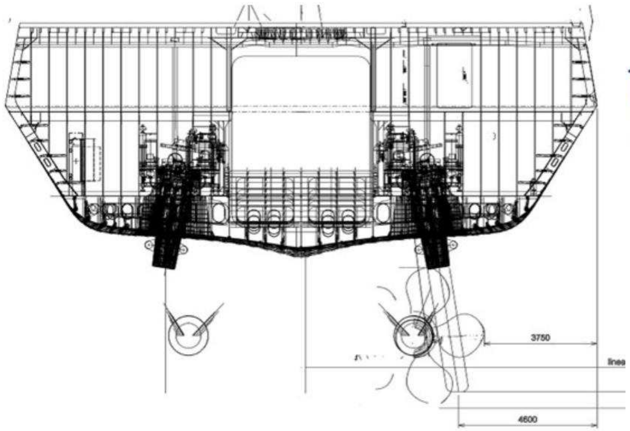
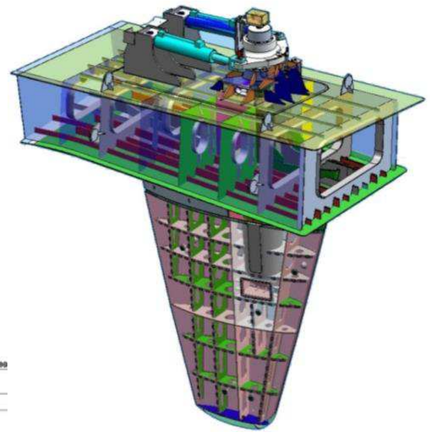
Roll stabilization on navy ships

- Rudder-roll stabilization

Carlo Bergamini (F 590)





L_{pp} = 132.5m
B = 19.7m
Δ = 6700t
Rudder axis inclined by 9°

FREMM multipurpose frigate
https://www.marina.difesa.it/noi-siamo-la-marina/pilastro-logistico/log_amm/marinalles/Pagine/FREMM.aspx

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Roll stabilization

- Magnus effect stabilizers (stabilization at anchor and underway)
- They generate lift proportional to the speed and direction of its rotating cylinders.

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Mathematical model

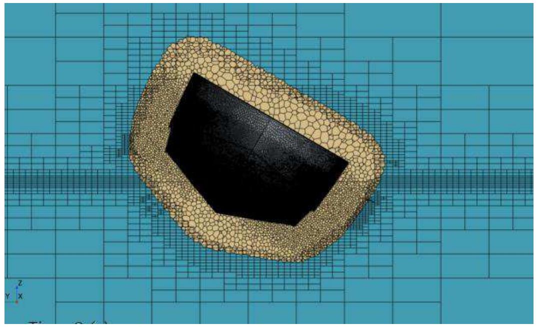
Mathematical model

$$\ddot{\phi} + 2\alpha\dot{\phi} + \beta|\dot{\phi}|\dot{\phi} + \omega_0^2\phi = m_{waves}(\omega_e t) + m_{fins}(t)$$

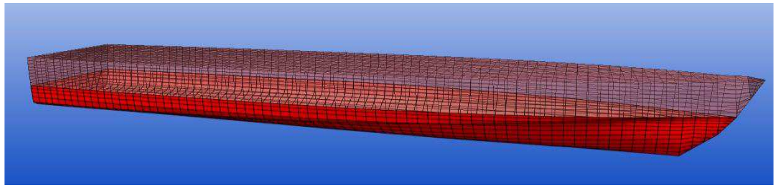
MATLAB SIMULINK

- 1-DOF non-linear roll motion equation
- Model validated:

1. Numerically (CFD and potential theory)
2. Experimentally (based on data from literature experiments held at the University of Naples Federico II towing tank)



Hydrostar® potential theory 3D panel software by Bureau Veritas



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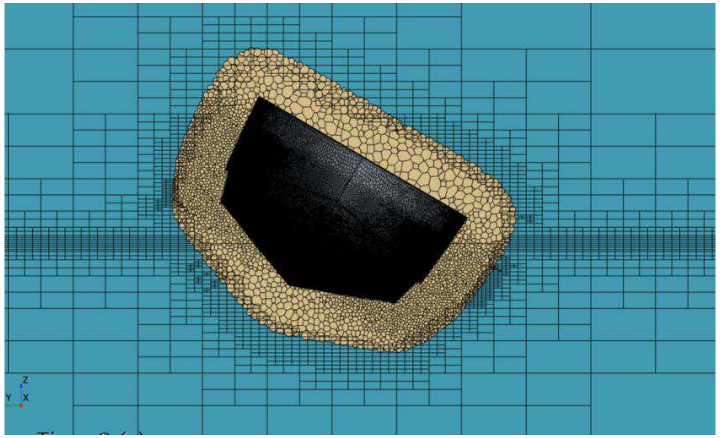
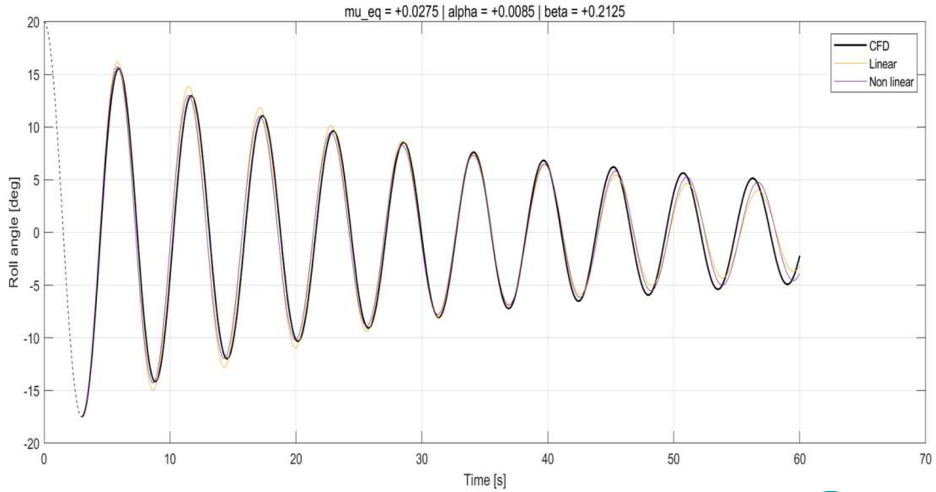
Damping coefficients

$$\ddot{\phi} + 2\alpha\dot{\phi} + \beta|\dot{\phi}|\dot{\phi} + \omega_0^2\phi = m_{waves}(\omega_e t) + m_{fins}(t)$$

- Dedicated CFD roll decay tests if the hull form is available, or
- Database of damping coefficients derived from CFD roll decay tests, or
- Semi-empirical methods (Simplified Ikeda's Methods and modifications)





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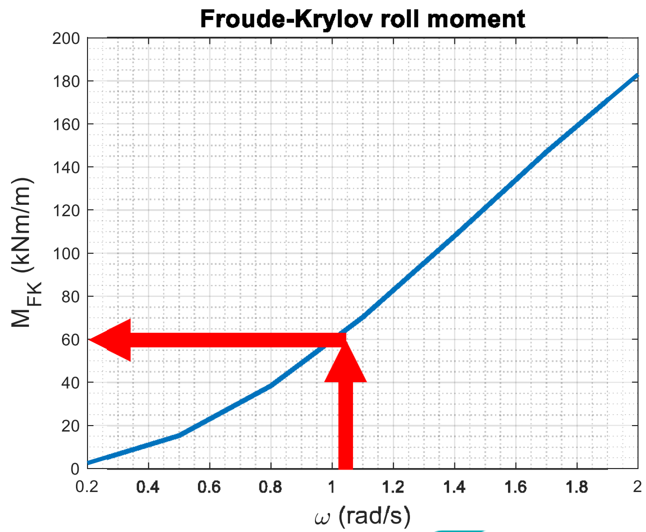
Wave excitation moment

$$\ddot{\phi} + 2\alpha\dot{\phi} + \beta|\dot{\phi}|\dot{\phi} + \omega_0^2\phi = m_{waves}(\omega_e t) + m_{fins}(t)$$

- Wave roll moment is modelled by Froude-Krylov component only.
- Possibility to simulate any wave heading.
- Two types of simulations:
  1. *Sinusoidal waves:*
     Interpolation at the selected wave frequency
  2. *Irregular waves:*
     Two possible wave spectra (Jonswap or Bretschneider)

The transfer function of the roll moment due to waves is required



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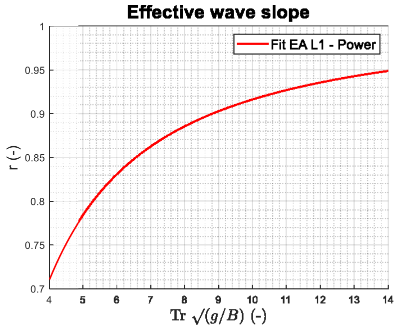
Wave excitation moment

- Neglecting diffraction, the wave exciting roll moment may be defined by the usage of the **effective wave slope function**:

$$r(\omega) = \frac{M_{FK}(\omega)}{\Delta g GM k \zeta_a}$$



$$M_{FK}(\omega)$$

Strip-theory on the actual vessel

Simplified methods (Level 2 EA & DSC)

Regression analysis (Rosano et al. 2024)

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Fin stabilizing moment

$$\ddot{\phi} + 2\alpha\dot{\phi} + \beta|\dot{\phi}|\dot{\phi} + \omega_0^2\phi = m_{waves}(\omega_e t) + m_{fins}(t)$$

- Two types of simulations:
  1. *At anchor*
  2. *Underway*

At zero speed were determined:

- Motor loads (Mz) and torque requirements
- Stabilizing forces (Fy)
- Geometric features for optimized fin design:
  - Fin area
  - Fin Aspect Ratio (AR)
  - Endplates

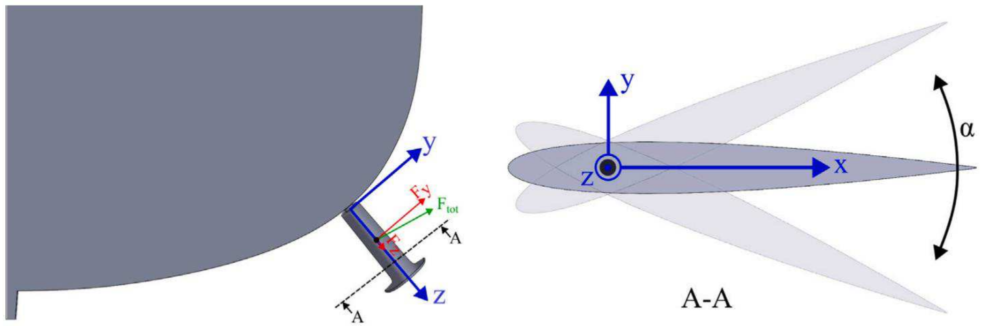

Fig. 2. Fin coordinate system and schematic movement description.

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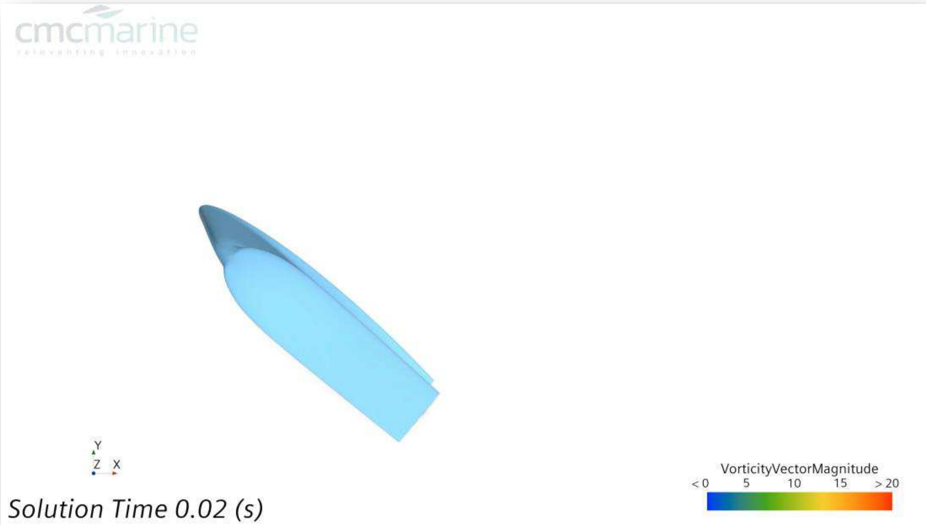
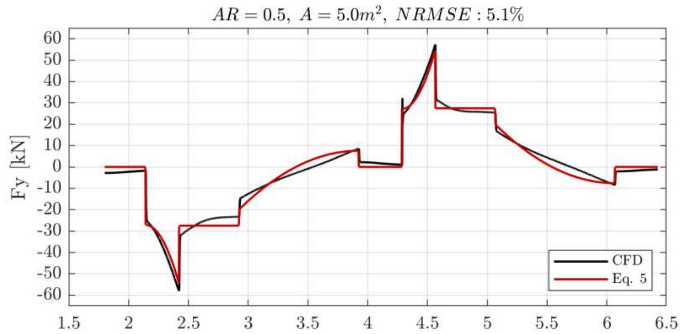
Fin stabilizing moment

$$F_{y,actuated} = \quad \rho \left(k_{a1} A^{na1} AR^{na3}\, \omega|\omega| + k_{a2} A^{na2} AR^{na4}\, \dot{\omega} \right)$$





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Ocean Engineering 314 (2024) 119745

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Research paper

Hydrodynamic model of active fin stabilizers at zero advancing speed

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https://www.sciencedirect.com/science/article/pii/s002980182403083x?via%3dihub

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Case study

Case study – Fast attack craft

- NAVAL MISSION: TAP (Transit And Patrol), SAR (Search and Rescue), SUW (SUrface Warfare), Replenishment at Sea (RAS)

	Units	Value
L_{WL}	(m)	65
B_{WL}	(m)	7.90
T_m	(m)	2.85
Δ	(t)	620
GM	(m)	1.02
T_r	(s)	6.4
$V_{service}$	(kn)	20
V_{max}	(kn)	35
Hull	-	Steel
Superstructure	-	Aluminium

The pictures here are for visualization purposes only

https://www.navalnews.com/naval-news/2021/12/indonesia-launched-its-5th-kcr-60m-fast-attack-craft/

https://www.dearsan.com/en/products/naval-vessels/fast-attack-craft-fac-65

https://www.fincantieri.com/globalassets/prodotti-servizi/navi-militari/m-10-16_fast_attack_craft_f.pdf

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Electrically-driven anti-roll fins

- Compared to a traditional hydraulic unit electrically-driven fins are:
  - smaller size of the unit
  - fewer components
  - easier and faster to install
  - faster in their movements
  - reduced maintenance
- Integrate rudder and fin angle to minimize heel angle in turn
- Control system to keep the route

Operability limits

NATO STANAG 4154

STANAG 4154
(Edition 3)

STANDARDIZATION AGREEMENT (STANAG)

SUBJECT: COMMON PROCEDURES FOR SEAKEEPING IN THE SHIP DESIGN PROCESS

Application	Performance Limitations		
	Motion	Limit*	Location
Recommended Criteria	Motion Sickness Incidence (MSI)	20% of crew @ 4 hrs	Task Location
	Motion Induced Interruption (MII)	1/min	Task Location
	Relative Wind	35 kts	Task Location if on Weather Deck
Default Criteria	Roll	4°	
	Pitch	1.5°	
	Vertical Acceleration	0.2g	Bridge
	Lateral Acceleration	0.1g	Bridge
	Relative Wind	35 kts	Flight deck

*Note: Roll, pitch and acceleration limits are given in terms of root-mean-square amplitude.

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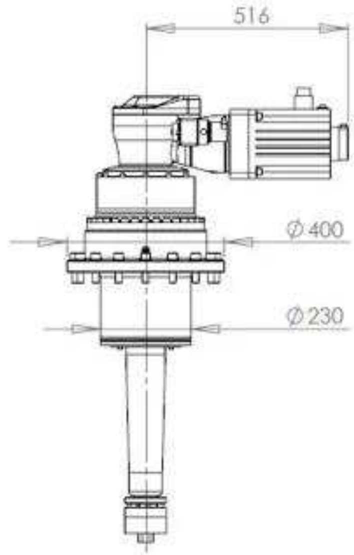
Case study – Solution #1

	Units	Value
Fin area	(m^2)	2 x 1.60
AR	(-)	0.58
α_{max}	(deg)	25
$\dot{\alpha}_{max}(at\ anchor)$	(deg/s)	80
$\dot{\alpha}_{max}(underway)$	(deg/s)	30
Power	(kW)	4 x 5
Actuator weight*	(kg)	245
Material	-	Steel

* Including electric motor

Stabilization while underway
&
1 couple of fins



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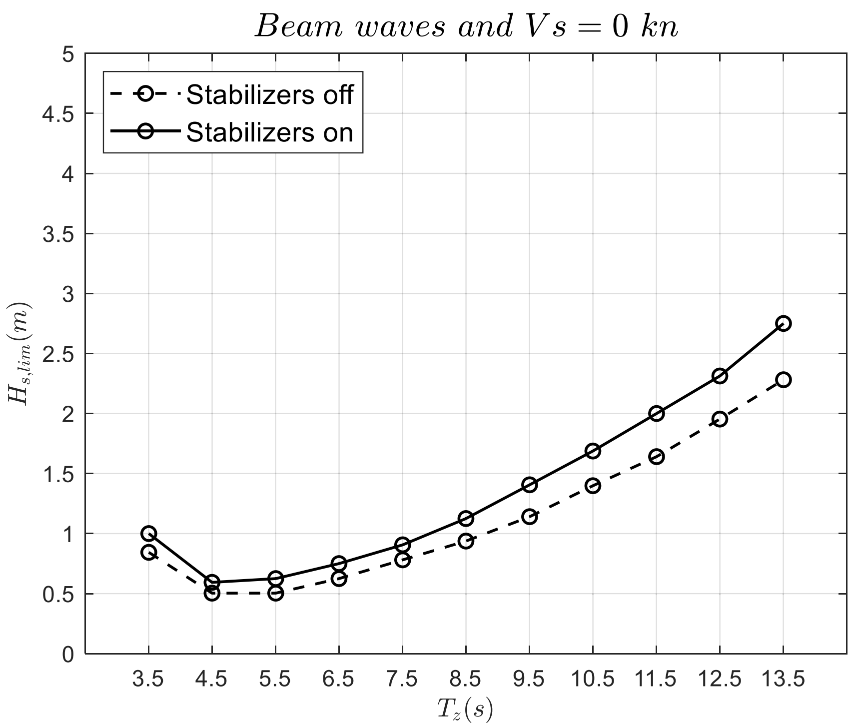
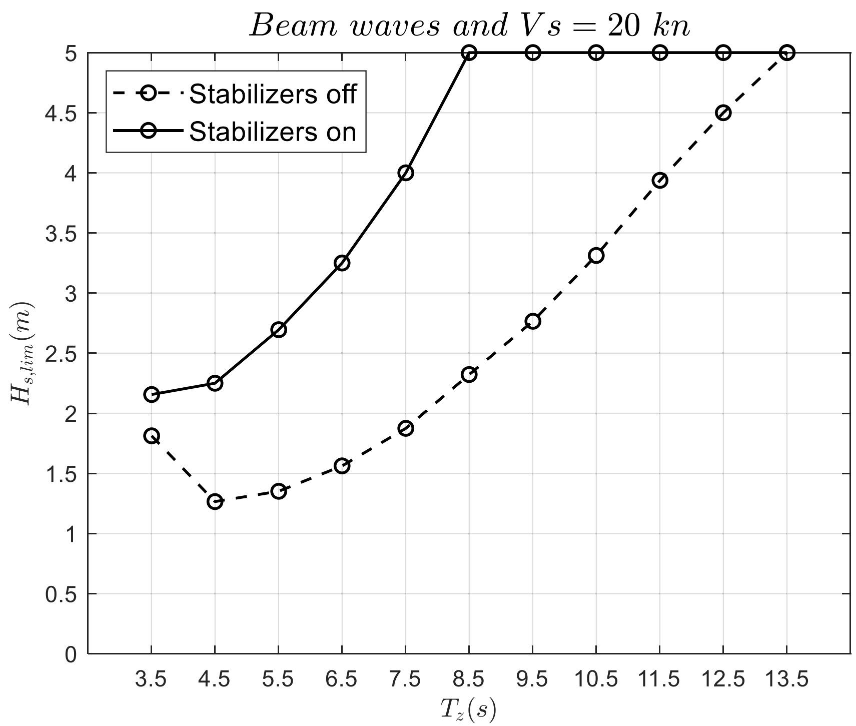
Case study – Solution #1

1 couple of fins





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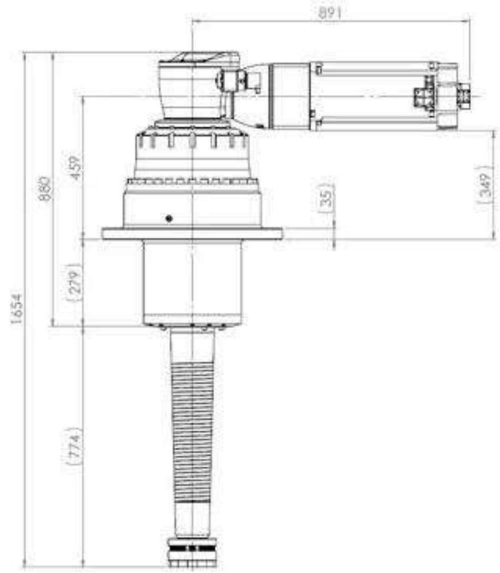
Case study – Solution #2

	Units	Value
Fin area	(m^2)	4 x 3.0
AR	(-)	0.58
$\boldsymbol{\alpha_{max}}$	(deg)	25
$\boldsymbol{\dot{\alpha}_{max}(at\ anchor)}$	(deg/s)	55
$\boldsymbol{\dot{\alpha}_{max}(underway)}$	(deg/s)	30
Power	(kW)	4 x 15
Actuator weight*	(kg)	603
Material	-	Steel

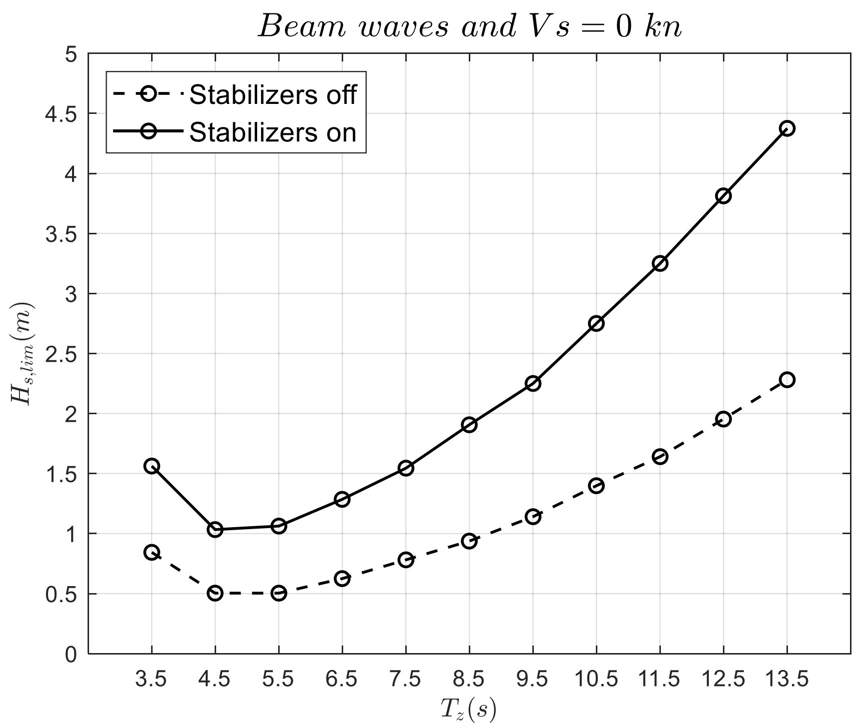
* Including electric motor

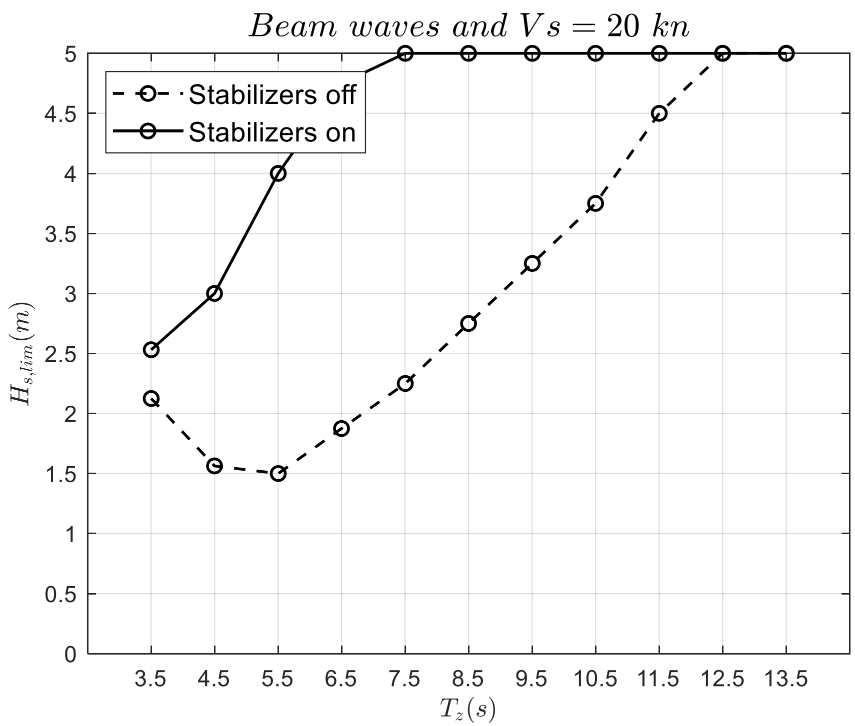
Stabilization at anchor and underway
&
2 couple of fins



Case study – Solution #2

2 couple of fins at anchor
1 couple switched off at 20kn





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Point design analysis

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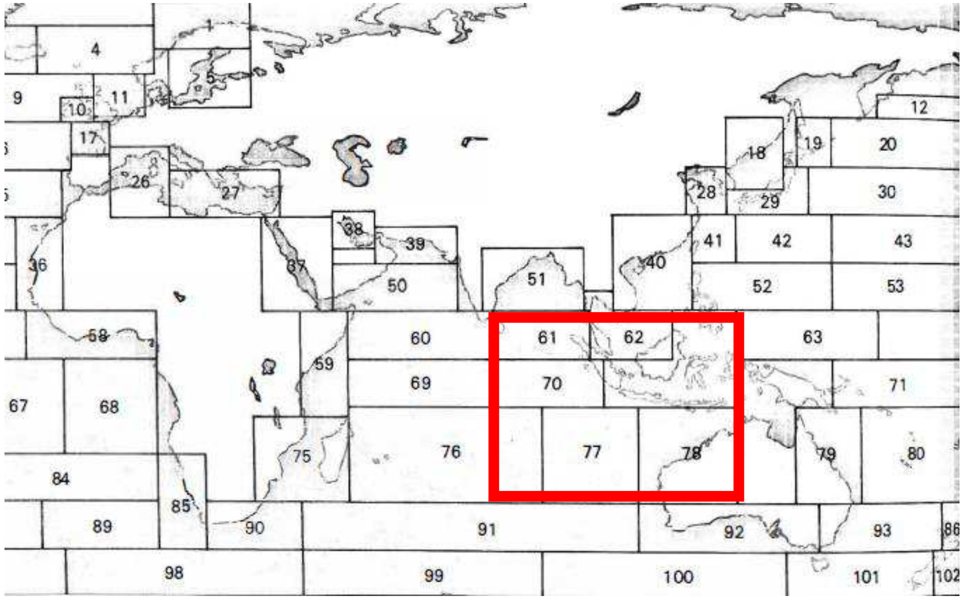
Case study – Point design analysis



Global Wave Statistics (Hogben et al. 1986)

Bretschneider spectrum
Unidirectional beam waves
$T_z = 6.5s$ as most probable zero-crossing period for areas 61, 62, 70, 77 and 78
$H_s = 2.5m$ (SEA STATE 4) and $4.0m$ (SEA STATE 5)

	Units	**Value**
T_z	(s)	6.5
H_s (SS 4)	(m)	2.5
H_s (SS 5)	(m)	4.0
Spectrum type	-	Bretschneider

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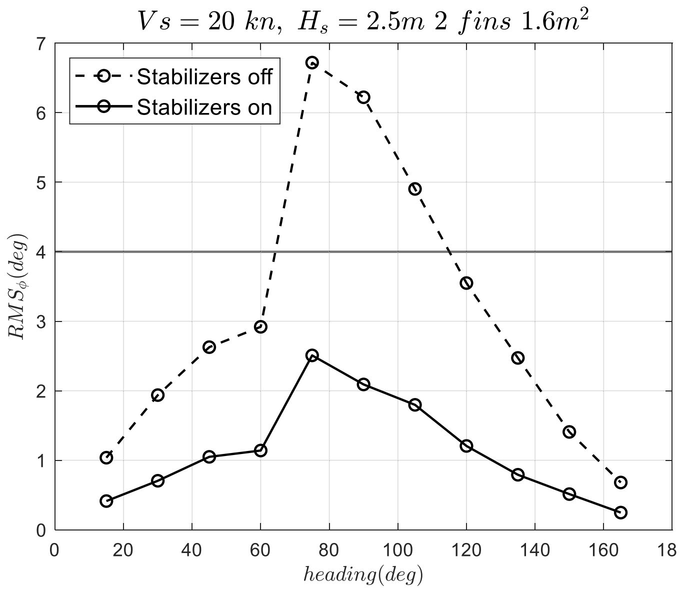
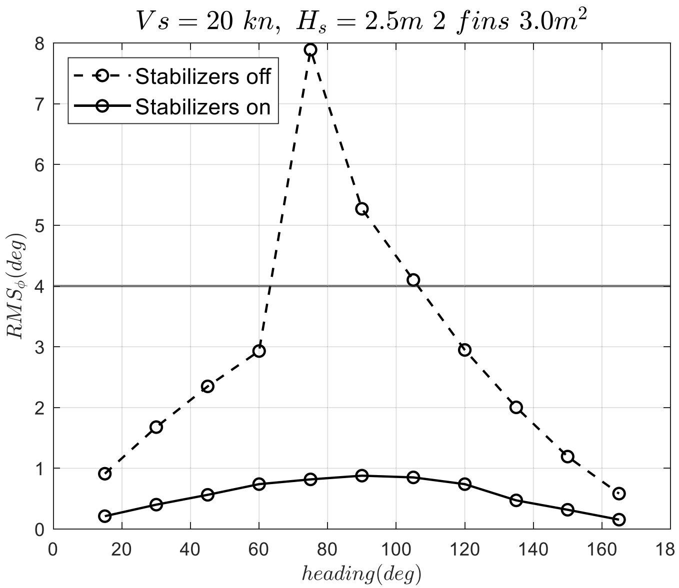
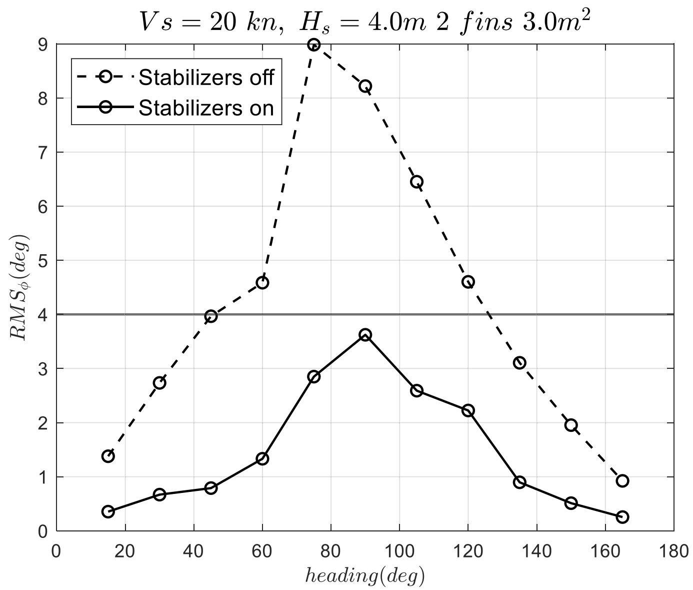
Point design analysis – 20kn

Fin area 1.6m²
1 couple of fins



Fin area 3.0m²
2 couple of fins but 1 couple switched off





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Summary and conclusions

- Application of electrically-driven anti-roll fins for a 65-meters fast attack craft
- Two scenarios are considered:

1. Stabilization at anchor
2. Stabilization while underway

- Operability limits are shown according to NATO STANAG 4154 for beam waves
- If stabilization is required at anchor the number of fins must be doubled as well as the area of each fin
- Point design analysis is shown for any heading and one sea state

Solution	Number of fins	Area single fin (m^2)	Weight actuator (kg)	Power (kW)	Performance at anchor
#1	2	1.6	245	5	POOR
#2	4	3.0	603	15	GOOD

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Acknowledgments

The present study was conducted as part of the research agreeement «Studio di tenuta della nave al mare degli yacht», stipulated between the University of Naples Federico II and CMC Marine.

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Thank you for your attention!