Table of Content

1. Introduction **1**

2. Objectives of the study **3**
2.1. Final objective . . . 3
2.2. Secondary objectives . . . 3

3. Scope of the study **4**

4. The linearized model of ship's dynamical response **5**
4.1. The dynamic model of ship rolling . . . 5
4.2. The dynamic model of ship rolling with a U-Shaped Anti-Roll tank incorporated 7
4.3. Model validation . . . 12
4.4. Parametric analysis . . . 15
4.5. The optimization problem to select the most efficient ART . . . 17

5. Excitation model: White Noise case **19**
5.1. Lyapunov equation . . . 20
5.2. State space: Generalized formulation . . . 21
5.3. Lyapunov solution: Generalized formulation . . . 22
5.4. Lyapunov solution applied to the Ship case and the Ship-plus-ART case . . . 23
5.4.1. Lyapunov solution for the ship without ART (single DoF) . . . 23
5.4.2. Lyapunov solution for the ship with an ART implemented (two DoF) 24
5.5. Optimization for white noise excitation input . . . 25

6. Excitation model: Filtered Power Spectral Density case **26**
6.1. Power spectral densities of the ocean . . . 27
6.2. Linear filter of minimum squares . . . 29
6.3. Theory of realization: The filter tuning . . . 30
6.4. State space and Lyapunov formulation of the filter . . . 32
6.5. Determination of the filter: Couplement of Lyapunov systems . . . 33
6.5.1. Filter coupling for the ship without an ART (single DoF) . . . 33
6.5.2. Filter couplement for the ship with an ART implemented (two DoF) 35
6.6. Optimization approach for realistic wave slope excitation . . . 36

7. Methodology: Proposed framework for the optimization of the design of U-shaped Anti-Roll tanks under stochastics seas **38**

8. Case of study: Optimization of a U-Shaped ART for a specific ship **43**

8.1. Characteristics of the ship chosen for the case of study: Offshore Patrol Vessel (OPV) . . . 43
8.2. Ocean properties and OPV's operation predicted environment . . . 43
8.3. Fitting tune parameters of the Filter . . . 46
8.4. Optimization of the ART for the OPV characteristics . . . 46
8.5. Results . . . 47
8.5.1. ART Optimum design . . . 48
8.5.2. Responses of the system for different scenarios and manouvering . . . 49

9. Analysis and Discussion **56**

10. Conclusion **59**

Bibliography **61**

11. ANNEXES **62**

Annexes **63**

Annex A. Annex A: Parameters and keywords of this study **63**
A.1. Parameters . . . 63
A.1.1. Design parameters for the ship + U-shaped ART system . . . 63

Annex B. Annex B: Frequency Response Function and Response Amplitude Operators fundamentals **64**

Annex C. Annex C: U-shaped ART basic schematics **65**

Annex D. Annex D: Convention of ship maneuvering reference system **66**

Annex E. Annex E: Roll reduction of the OPV for all sea states **67**

Annex F. Annex F: The U-shaped Anti-roll tank stabilisation phenomena **72**
F.1. Operation principle of a U-shaped Anti-roll tank . . . 72
F.2. Variation Of dynamic response for different design parameters . . . 75
F.2.1. Design variability . . . 75
F.2.1.1. Variability of the length of the U-shaped ART . . . 75
F.2.1.2. Variability of the width of the lateral reservoirs . . . 76
F.2.1.3. Variability of the height of the conduct between reservoirs . . . 76
F.2.2. Other operational variabilities . . . 77