Contents

Preface xv
Acknowledgements xvii
Author xix
Nomenclature xxi

1. Introduction 1
1.1 Development of Marine Vehicles, Structures and Facilities 2
1.2 Types of Marine Vehicles, Structures and Facilities 2
1.2.1 Transportation 3
1.2.2 Defence 4
1.2.3 Resource Exploitation 5
1.2.3.1 Living Resources 5
1.2.3.2 Mineral Resources 6
1.2.3.3 Renewable Energy 7
1.2.3.4 Fossil Fuels 8
1.2.4 Tourism, Recreation and Sports 10
1.2.5 Land–Sea Interface 12
1.2.6 Support Services 12
1.3 Design Definition and Marine Environment 13

2. Marine Environment 17
2.1 Oceans 17
2.1.1 Ocean Bottom 18
2.1.2 World Water Resources 19
2.1.3 Straits and Waterways 21
2.1.4 Freshwater Resources 23
2.2 Properties of Water 24
2.2.1 Physical Properties 24
2.2.2 Density 25
2.2.3 Temperature Distribution in the Oceans 26
2.2.4 Transmission of Electromagnetic Radiation in Water 27
2.2.5 Salinity 27
2.2.6 Sound Properties in Water 29
2.3 Atmosphere 29
2.3.1 Coriolis Effect 31
2.3.2 Atmosphere Circulation 31
2.4 Ocean Circulation 32
2.4.1 Ekman Spiral 33
2.4.2 Geostrophic Flow 33
2.4.3 Gyres 34
2.4.4 Thermohaline Circulation 35
2.4.5 Circulation in Basins other than Deep Ocean 35
2.4.6 Tides 35
2.4.7 Ocean Currents 36

2.5 Ocean Waves 38
2.5.1 Potential Theory of Water Waves 39
2.5.2 Regular Waves 42
2.5.3 Irregular Waves 42
2.5.4 Energy Spectrum 44
2.5.5 Representation of an Irregular Seaway 46
2.5.6 Shallow Water Waves 47
2.5.7 Seiches 48
2.5.8 Storm Surges 48
2.5.9 Tsunamis 48
2.5.10 Internal Waves 48

3. Design Process 51
3.1 Mission Requirement 51
3.2 Market Study 51
3.2.1 Identifying Customer Needs 52
3.2.2 Product Design 54
3.2.3 Relate Product to Enterprise 54
3.2.4 Promotion 55
3.3 System Design 55
3.3.1 Features of a Marine Product 56
3.3.2 Sustainability 57
3.3.3 Subsystems and System Components 57
3.3.4 System Integration 59
3.4 Design Process 60
3.4.1 Sequential Design Process 60
3.4.2 Concurrent Engineering in Design 61
3.4.3 Point-Based Design 63
3.4.4 Set-Based Design 63
3.5 Design Stages 64
3.6 Information Generation and Management 66
3.7 Communication 67
3.8 Design Tools 67
3.8.1 Data Collection and Statistical Analysis 68
3.8.2 Scientific Knowledge Base and Computer Software 68

4. Engineering Economics 71
4.1 Interest Relationships 71
4.2 Economic Criteria 75
4.2.1 Net Present Value 76
4.2.2 Required Income 77
4.2.3 Internal Rate of Return or Yield 78
4.2.4 Permissible Price 78
4.2.5 Payback Period 78
4.3 Economic Complexities 78
4.3.1 Loan 79
4.3.2 Stage Payment 79
4.3.3 Subsidy 79

4.3.4 Escalation 80
4.3.5 Depreciation 80
4.3.6 Taxes 81
4.4 Cash Flow Calculation 82
4.5 Building Cost Estimation 83
4.5.1 Material Cost 83
4.5.2 Labour Cost 84
4.5.3 Direct Cost 84
4.5.4 *Indirect Expenses* 85
4.5.5 Production Quantum 85
4.5.6 Production Rate 88
4.5.7 Financial Complications 88
4.5.8 Labour Rate 89
4.5.9 Stages of Building Cost Estimation 89
4.5.9.1 Pre-Contract Cost Estimation 89
4.5.9.2 Pre-Contract Cost Estimation of Value-Added Structures and Vehicles 91
4.5.9.3 Contractual Cost Estimation 91
4.5.9.4 Actual Costing 91
4.6 Determination of Price 91
4.7 Design versus Tendering and Contract 95
4.8 Engineering Economics Application to Ship Design 96
4.8.1 Ship-Operating Economics 96
4.8.2 Application to Ship Design 96
4.8.3 Comparison of Alternative Designs 98
4.8.4 Uncertainties in Ship Design 100
4.8.5 The Optimal Ship 103

5. Vehicle Parameter Estimation 109
5.1 Ship Nomenclature 109
5.2 Controlling Equations for Preliminary Estimation of Main Parameters 113
5.3 Data Collection and Analysis for Parameter Estimation 114
5.4 Approximate Semi-Empirical Relationships for Parameter Estimation 117
5.4.1 Midship Area Coefficient 119
5.4.2 Water Plane Area Coefficient 119
5.5 Basic Ship Method of Parameter Estimation 120
5.6 Preliminary Performance Estimate 120
5.6.1 Vertical Centre of Buoyancy, *KB* 123
5.6.2 Moment of Inertia of Water Plane 123

6. Stability of Floating Bodies 125
6.1 Bonjean Curves and Hydrostatics 125
6.2 Stability at Small Angles 128
6.3 Stability at Large Angles 132
6.3.1 Righting Lever of Floating Bodies 132
6.3.2 Righting Lever of Submerged Bodies 139
6.3.3 Free-Surface Effect 139
6.3.4 Grain Shifting Moment due to Carriage of Bulk Dry Cargo 140

6.4 Intact Stability Requirements 141
6.5 Effect of Parametric Changes on Stability 142
6.5.1 Effect of Change of Breadth on Stability 143
6.5.2 Effect of Change of Depth on Stability 143
6.5.3 Effect of Change of Form 143
6.6 Discussion on Stability 144
6.7 Damaged Stability 146
6.8 Safety and Subdivision 149

7. Hydrodynamic Design 151
7.1 Resistance 151
7.1.1 Components of Total Resistance 151
7.1.2 Shallow-Water Effects 160
7.1.3 Methodical Series 162
7.1.4 Resistance Estimation by Statistical Method 164
7.1.5 Resistance Estimation of Submersibles 164
7.1.6 Experimental Fluid Dynamics 166
7.1.7 Computational Fluid Dynamics 169
7.2 Propulsion 172
7.2.1 Power Transmission 175
7.2.2 Cavitation 177
7.2.3 Selection of Screw Propeller Parameters 180
7.2.4 Selection of Propeller Type 184
7.3 Seakeeping 190
7.3.1 Ocean Waves and Ship Motions 191
7.3.2 Prediction of Seakeeping Behaviour 192
7.3.2.1 Numerical Estimation 192
7.3.2.2 Experimental Prediction 194
7.3.2.3 Statistical Prediction 195
7.3.3 Effect of Ship Parameters on Seakeeping 196
7.3.4 Control of Ship Motion 200
7.3.4.1 Bilge Keel 201
7.3.4.2 Outriggers or Removable Stabilizers 201
7.3.4.3 Antiroll Tanks 201
7.3.4.4 Active Antiroll Tanks 202
7.3.4.5 Stabilizer Fins 202
7.3.4.6 Translating Solid Weight 203
7.3.4.7 Gyroscopic Stabilizers 203
7.3.4.8 Rudder Roll Stabilization 203
7.3.4.9 Maglift Stabilizers 203
7.4 Manoeuvrability 203
7.4.1 Manoeuvring Trials 204
7.4.1.1 Turning Circle Manoeuvre 205
7.4.1.2 Zig-Zag Manoeuvre 206
7.4.1.3 Manoeuvres to Determine Course Stability 207
7.4.1.4 Stopping Manoeuvres 207
7.4.1.5 Other Effects during Turn 207

7.4.2 Manoeuvring Standards 209
7.4.3 Estimation of Manoeuvring Characteristics 210
7.4.3.1 Free Running Model Experiments 211
7.4.3.2 Captive Model Experiments 212
7.4.3.3 Numerical Simulation 212
7.4.3.4 Statistical Analysis 212
7.4.3.5 System Identification–Based Prediction 213
7.4.3.6 Manoeuvring Devices 214
7.4.4 Design Considerations for Controllability 217
7.4.4.1 Environment 217
7.4.4.2 Effect on Hull Parameters 218

8. Hull Form Design 219
8.1 Hull Form Characteristics 222
8.1.1 River Vessels 222
8.1.2 Yachts 225
8.1.3 Semi-Planing and Planing Vessels 225
8.1.4 Catamaran Vessels 228
8.1.5 SWATH Vessels 229
8.1.6 Seagoing Vessels 231
8.1.6.1 Midship Section Design 231
8.1.6.2 Bow Profile and Forward Section Shape 232
8.1.6.3 Bulbous Bow 233
8.1.6.4 Forward Section Flare above Water 234
8.1.6.5 Inverted Bow or X-Bow 235
8.1.6.6 Sectional Area Curve 235
8.1.6.7 Load Water Line 236
8.1.6.8 Stern Forms 236
8.2 Geometrical Design 239
8.2.1 Principal Parameters of the Hull Form 240
8.2.2 Form Parameter Approach 240
8.2.3 Lines Distortion Approach 242
8.2.4 Standard Series Approach 244
8.3 Computer-Aided Design of Hull Form 245

9. Machinery System 249
9.1 Main and Auxiliary Machinery and Equipment 249
9.2 Energy Consumption Pattern 254

10. Structural Design 261
10.1 Marine Structural Material 262
10.1.1 Structural Steel 263
10.1.2 Aluminium 265
10.1.3 Titanium 266
10.1.4 Fibre-Reinforced Plastics 267

10.2 Loads on Marine Structures and Vehicles 271
10.2.1 Static Loading and Vertical Bending Moment 271
10.2.2 Wave Bending Moment 272
10.2.3 Horizontal Bending Moment 273
10.2.4 Torsional Moment 273
10.2.5 Static External Hydrostatic Load 273
10.2.6 Static Internal Load 274
10.2.7 Dynamic External Load due to Waves 274
10.2.8 Dynamic Loading 276
10.2.9 Miscellaneous Loading 276
10.2.10 Operational Loads 277
10.2.11 Loads due to Ship Handling 278
10.3 Structural Layout 280
10.3.1 Bending Stress on Hull Girder 282
10.3.2 Shear Stress 285
10.3.3 Buckling Stress 287
10.3.4 Stiffened and Unstiffened Plate Panels 288
10.3.5 Continuity and Structural Alignment 288
10.3.6 Stress Concentration 290
10.4 Structural Design 292
10.4.1 Rule-Based Design 293
10.4.2 Direct Calculation-Based Design 294
10.4.3 Reliability-Based Design 295
10.4.4 Corrosion Allowance 299
10.4.5 Fatigue in Marine Structure 300

11. Layout Design 303
11.1 Cargo Spaces 308
11.1.1 General Cargo 309
11.1.2 Solid Bulk Cargo 311
11.1.3 Liquid Bulk Cargo 312
11.1.3.1 Crude and Product Oil 312
11.1.3.2 Chemical Cargo 314
11.1.3.3 Liquefied Gas 316
11.1.4 Unitised Cargo 322
11.1.4.1 Containers 323
11.1.4.2 Roll-On/Roll-Off Cargo 325
11.2 Liquid Non-Cargo Spaces 327
11.3 Working Spaces 329
11.3.1 Machinery Spaces 329
11.3.2 Working Spaces on the Open Deck 331
11.3.3 Navigation and Control Spaces 332
11.3.4 Space for Stores and Spares 333
11.4 Accommodation Spaces 335
11.5 Ergonomics in Layout Design 338
11.5.1 Lighting and Visual Comfort 338
11.5.2 Interior Environment 338
11.5.3 Vibration 340

11.5.4 Noise 343
11.5.5 Access and Egress 347

12. Design for Safety 351
12.1 Safety at Sea and Design Application 351
12.1.1 Personal Safety on Board 352
12.1.2 Stability and Safety 352
12.1.3 Motions and Safety 353
12.1.4 Controllability and Safety 354
12.1.5 Fire 354
12.1.6 Hazardous Cargo: Liquefied Gas and Chemical Tankers 356
12.1.6.1 Gas Carriers 356
12.1.6.2 Chemical Tankers 358
12.1.7 Life-Saving Appliances 359
12.1.8 Machinery Failure 361
12.2 Design for Maintenance 363
12.3 Rule-Based Design 367
12.4 Risk-Based Design 370
12.4.1 Step 1: Hazard Identification 370
12.4.2 Step 2: Risk Analysis 371
12.4.3 Human Reliability Analysis 376
12.4.4 Step 3: Risk Control Options 379
12.4.5 Step 4: Cost-Benefit Analysis 379
12.4.6 Step 5: Decision-Making 380
12.4.7 Overall Design Application 380

13. Design for Sustainability 383
13.1 Air Pollution 385
13.1.1 Air Pollution from Diesel Oil Burning Engines 385
13.1.2 Energy Efficiency Design Index 388
13.1.3 Natural Gas as Marine Transportation Fuel 391
13.1.3.1 Physical Properties of Natural Gas 391
13.1.3.2 Storage of Natural Gas 392
13.1.3.3 Emissions from Natural Gas 394
13.1.3.4 NG Engines: Design Implications 394
13.1.4 Alternative Energy Sources for Ship Operation 395
13.1.4.1 Biofuel 395
13.1.4.2 Nuclear Power 395
13.1.4.3 Batteries 396
13.1.4.4 Fuel Cell 396
13.1.4.5 Wind Energy 397
13.1.4.6 Solar Energy 397
13.1.4.7 Other Devices 398
13.1.5 Emission Reduction by Increasing Energy Efficiency 398
13.2 Ocean Pollution 401
13.2.1 Pollution due to Oil 401
13.2.2 Pollution due to Garbage 404
13.2.3 Pollution due to Sewage 404

13.3 Dispersal of Aquatic Species due to Shipping 404
13.3.1 Ballast Water 405
13.3.2 Paints 408
13.4 Underwater Noise 410
13.5 Ship Recycling 410

14. Design for Production 413
14.1 Manufacturing Design 413
14.2 Design for Production 417
14.2.1 Features of Marine Construction Process 418
14.2.2 Producibility 419
14.2.2.1 Producibility Concepts 419
14.2.2.2 Evaluation of Producibility Concepts on Cost 421
14.2.2.3 Integration of Producibility Concepts into Design 421
14.2.2.4 *Feedback for Improvement* 421
14.3 Modularisation 422
14.3.1 Hull Form Modularisation 424
14.3.1.1 An Example 425

15. Decision-Making Process 431
15.1 *Modelling the Optimisation Problem* 433
15.1.1 Problem Formulation 433
15.1.2 Problem Characteristics 433
15.1.3 Solution Methods 436
15.2 Optimisation Techniques 436
15.2.1 Unconstrained Optimisation 437
15.2.1.1 Unconstrained One-Dimensional Search 437
15.2.1.2 Unconstrained *N*-Dimensional Search 437
15.2.2 Constrained Optimisation 438
15.2.2.1 Linear Programming 438
15.2.2.2 Integer Programming 439
15.2.2.3 Constrained Non-Linear Optimisation 439
15.2.3 Dynamic Programming 439
15.3 Heuristic Methods for Decision Support Systems 440
15.3.1 Simulated Annealing 440
15.3.2 Genetic Algorithm 440
15.4 Multiple Criteria Decision-Making 441
15.4.1 Multi-Attribute and Multi-Objective Decision-Making 442
15.5 Decision Support Applications in Ship Design 443

16. Design Management 449
16.1 Creativity and Innovation 449
16.2 Design Integration 451
16.3 Design Management 452

References 455

Index 461