# Contents

## 1 Wings in Ground Effect
- Introduction ............................................. 1
- Marine Transport and WIG Development ............ 2
- Alternative Technologies .............................. 3
  - The Hydrofoil ....................................... 4
  - The SES ............................................. 4
  - The Hovercraft ..................................... 5
- Ground Effect for Higher Service Speed ............ 6
- Some WIG Technical Terms .......................... 7
  - Ground Effect ..................................... 8
  - Dynamic Air Cushion ............................... 8
  - Static Air Cushion .................................. 9
- Basic Principles of Ground Effect .................... 9
- Types of WIG .......................................... 15
- Classic WIG .......................................... 16
- PARWIG .................................................. 17
  - PARWIG Attributes ................................ 22
  - PARWIG Limitations ................................ 22
  - Military Applications ............................. 23
  - Civil Applications .................................. 25
- Dynamic Air Cushion Craft (DACC) ..................... 25
- DACC Characteristics ................................ 27
- DACC Applications .................................. 27
- Dynamic Air Cushion Wing-in-Ground Effect Craft (DACWIG) .......... 27
- DACWIG Attributes .................................. 29
- DACWIG Applications ................................ 32

## 2 WIG Craft Development
- Introduction .......................................... 33
- Russian Ekranoplan Development .................... 33
  - KM or “Caspian Sea Monster” ...................... 42
  - UT-1 .................................................. 45
  - Orlyonok and Lun ................................... 45
3 **Longitudinal Force Balance and Trim**

Introduction .................................................. 95
Operational Modes ............................................ 96
Running Trim .................................................. 98
Centres of Effort and Their Estimation .................. 102
  Introduction ................................................. 102
Longitudinal Centres of Forces Acting on WIG Craft .... 103
  Centre of Buoyancy (CB) .................................. 103
  Centre of Hydrodynamic Force Acting on Hull and Side Buoys 103
  Centre of Static Air Cushion Pressure (CP) ................ 104
  Centre of Aerodynamic Lift of a Single Wing Beyond the GEZ 104
  Centre of Lift of WIG Main Wing with Bow Thrusters in Ground Effect Zone .................................. 104
  Centre of Lift of a Whole WIG Craft Operating in GEZ .... 106
Influence of Control Mechanisms on Craft Aerodynamic Centres 106
Longitudinal Force Balance .................................. 109
  Condition for Normal Operation of a WIG in Various Operation Modes ............................................. 109
  Inherent Force-Balance Method ............................ 111
4 Hovering and Slow-Speed Performance

Hovering Performance Requirements
- Manoeuvring and Landing
- Low-Speed Operations
- Hump Speed Transit and Take-Off into GEZ
- Seakeeping

PARWIG Theory from the 1970s

Static Hovering Performance of DACWIG and DACC
- Configuration of a DACC or DACWIG

Measures for Improving Slow-Speed Performance
- Inflatable Air Bag
- Skirt
- Laminar Flow Coating on the Bottoms of Hull and Side Buoys
- Hard Landing Pads

5 Aerodynamics in steady Flight

Airfoil Fundamentals

An Experimental Investigation of Airfoil Aerodynamics
- Nomenclature
- Basic Model
- Model Tests

Discussion
- Drag
- Lift–Drag Ratio
- Pitching Moment
- Conclusion

WIG Aerodynamic Characteristics
- Factors Influencing WIG Aerodynamic Characteristics
- Bow Thruster with Guide Vanes or Jet Nozzle
- Special Main-Wing Profile
- Aspect Ratio
- Other Measures

6 Longitudinal and Transverse Stability
Main-Wing Airfoil and Geometry ........................................ 192
Influence of Flaps ......................................................... 192
Tailplane and Elevators .................................................. 193
Centre of Gravity .......................................................... 193
Influence of Ground Effect on Equilibrium ......................... 194
Influence of Bow Thrusters with Jet Nozzle or Guide Vanes .... 194
Automatic Control Systems ............................................... 195
Stability Analysis .......................................................... 195
Static Longitudinal Stability in and Beyond the GEZ ............ 197
Operating Beyond the GEZ ................................................ 198
Basic Stability Equation .................................................. 199
Wing Pitching Centre ....................................................... 200
Pitching Pitching Centre .................................................. 201
Flying Height Pitching Centre ............................................ 203
Estimation of Balance Centres ........................................... 204
Static Longitudinal Stability Criteria ................................... 206
Requirements for Positive Static Longitudinal Stability ......... 207
Static Transverse Stability of DACWIG in Steady Flight ........ 210
WIG Operating in Weak GEZ ............................................. 213
Transverse Stability Criteria ............................................. 215
Transverse Stability at Slow Speed ...................................... 216
Transverse Stability During Turning .................................... 216
PARWIG Transverse Stability ............................................ 217
Dynamic Longitudinal Stability over Calm Water .................. 217
Basic Assumptions .......................................................... 218
Basic Motion Equations ................................................... 218
Transient Stability During Transition Phases ....................... 222

7 Calm Water Drag and Power .......................................... 225
Introduction ............................................................... 225
WIG Drag Components .................................................... 230
WIG Drag Before Take-Off ............................................... 231
Hump Drag and Its Minimisation ....................................... 231
Estimation of the Craft Drag Before Take-Off ....................... 234
WIG Drag After Take-Off .................................................. 239
Drag of WIG After Take-Off ............................................. 239
Powering Estimation for WIG ............................................. 243
Performance Based on Wind-Tunnel Test Results of Model .... 244
with Bow Thrusters in Operation ....................................... 244
Estimation of WIG Total Drag .......................................... 245
Drag Prediction by Correlation with Hydrodynamic Model .... 246
Test Results ............................................................... 246
Influences on Drag and Powering Over Calm Water ............. 249
Hull-Borne Mode ........................................................... 250
Transit Through Main Hump Speed (Fn = 2–4) ..................... 250
During Take-Off (Fn = 4.0–8.0) ........................................ 250
Flying Mode ............................................................... 251

8 Seakeeping and Manoeuvrability .................................. 255
   Introduction .................................................................. 255
   Differential Equation of WIG Motion in Waves .......... 256
      Coordinate Systems ................................................. 256
      Basic Longitudinal Differential Equations of DACWIG
      Motion in Waves ...................................................... 256
   Seakeeping Model Tests .............................................. 259
   Manoeuvrability and Controllability ......................... 267
   WIG Control in Flight ................................................. 268
      The Influence of a Wind Gust on the Running Trim of WIG
      in Steady Flight ........................................................ 270
      Nonlinear Analysis of WIG Motion ......................... 271
      Special Cases of Craft Motion .................................. 273
      Manoeuvring in Hull-Borne Mode ......................... 275
   Take-Off Handling in Waves ...................................... 275
   Turning Performance ................................................. 276
   Operation of WIG Craft in Higher GEZ ..................... 280

9 Model Tests and Aero-hydrodynamic Simulation ........ 283
   Introduction .............................................................. 283
   Experimental Methodology ........................................ 284
      Static Hovering Experiments on a Rigid Ground Plane 284
      Model Tests in a Towing Tank ................................. 284
      Model Experiments in a Wind Tunnel .................... 285
      Radio-controlled Model Tests on Open Water and Catapult
      Model Testing Over Ground .................................... 285
   WIG Model Scaling Rules ......................................... 286
   Scaling Parameters for WIG ........................................ 286
      Reynold’s Number .................................................... 286
      Euler Number ($H_q$) and Relation to Cushion Pressure Ratio 294
      Wind-Tunnel Testing .............................................. 294
      Bow Thruster or Lift Fan Non-dimensional Characteristics
      of DACC and DACWIG ............................................ 297
      Froude Number, Fn ................................................ 299
      Weber Number, We ................................................ 299
      Other Scaling Terms for Towing Tank Test Models ...... 300
      Structural Simulation .............................................. 301
   Scaling Criteria ....................................................... 301
   Model Test Procedures .............................................. 302

10 Structural Design and Materials ............................... 307
   Introduction ............................................................ 307
   Design Loads ............................................................ 309
      Waterborne and Pre-take-off Loads ......................... 310
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td><strong>Power plant and Transmission</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Introduction</td>
<td>337</td>
</tr>
<tr>
<td></td>
<td>WIG Power Plant Type Selection</td>
<td>338</td>
</tr>
<tr>
<td></td>
<td>Internal Combustion Engines</td>
<td>339</td>
</tr>
<tr>
<td></td>
<td>Turbofan/Turboshift/Turboprop Engines</td>
<td>341</td>
</tr>
<tr>
<td></td>
<td>WIG Application Special Requirements</td>
<td>345</td>
</tr>
<tr>
<td></td>
<td>Marinisation</td>
<td>345</td>
</tr>
<tr>
<td></td>
<td>Altitude Operations</td>
<td>346</td>
</tr>
<tr>
<td></td>
<td>Power Plant Installation Design</td>
<td>347</td>
</tr>
<tr>
<td></td>
<td>Pylon/Nacelle Installation</td>
<td>347</td>
</tr>
<tr>
<td></td>
<td>Engine and System Cooling</td>
<td>348</td>
</tr>
<tr>
<td></td>
<td>Internal Systems Installation</td>
<td>348</td>
</tr>
<tr>
<td></td>
<td>Water Spray</td>
<td>349</td>
</tr>
<tr>
<td></td>
<td>Engine and System Cooling</td>
<td>349</td>
</tr>
<tr>
<td></td>
<td>Ice Protection</td>
<td>351</td>
</tr>
<tr>
<td></td>
<td>Transmission Systems</td>
<td>351</td>
</tr>
<tr>
<td></td>
<td>Drive Shaft</td>
<td>351</td>
</tr>
<tr>
<td></td>
<td>Transmission</td>
<td>352</td>
</tr>
<tr>
<td>12</td>
<td><strong>Lift and Propulsion Systems</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Introduction</td>
<td>355</td>
</tr>
<tr>
<td></td>
<td>Power-Augmented Lift</td>
<td>356</td>
</tr>
<tr>
<td></td>
<td>Independent Lift Systems</td>
<td>359</td>
</tr>
<tr>
<td></td>
<td>Propulsion Systems</td>
<td>361</td>
</tr>
<tr>
<td></td>
<td>Propeller and Ducted Fan Characteristics</td>
<td>363</td>
</tr>
<tr>
<td></td>
<td>Turbofan System</td>
<td>367</td>
</tr>
<tr>
<td></td>
<td>Integrated Lift/Propulsion System</td>
<td>369</td>
</tr>
<tr>
<td></td>
<td>Propulsor Selection and Design</td>
<td>372</td>
</tr>
<tr>
<td>13</td>
<td><strong>Concept Design</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Introduction</td>
<td>373</td>
</tr>
<tr>
<td></td>
<td>General WIG Application Issues</td>
<td>376</td>
</tr>
<tr>
<td></td>
<td>Technical Factors</td>
<td>377</td>
</tr>
<tr>
<td></td>
<td>Operational Factors</td>
<td>379</td>
</tr>
<tr>
<td>Contents</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>WIG Subtypes and Their Application</td>
<td>381</td>
<td></td>
</tr>
<tr>
<td>WIG Preliminary Design</td>
<td>383</td>
<td></td>
</tr>
<tr>
<td>Design Sequence</td>
<td>384</td>
<td></td>
</tr>
<tr>
<td>Functional Specification for a WIG</td>
<td>385</td>
<td></td>
</tr>
<tr>
<td>Design Requirements</td>
<td>388</td>
<td></td>
</tr>
<tr>
<td>Safety Codes for WIG Craft</td>
<td>393</td>
<td></td>
</tr>
<tr>
<td>Basic Concepts</td>
<td>393</td>
<td></td>
</tr>
<tr>
<td>Supplementary Safety Criteria for DACWIG</td>
<td>394</td>
<td></td>
</tr>
<tr>
<td>Setting Up a Preliminary Configuration</td>
<td>396</td>
<td></td>
</tr>
<tr>
<td>Procedure for Overall Preliminary Design</td>
<td>414</td>
<td></td>
</tr>
<tr>
<td>Determination of WIG Aerodynamic and Hydrodynamic Characteristics</td>
<td>414</td>
<td></td>
</tr>
<tr>
<td>WIG Detailed Design</td>
<td>415</td>
<td></td>
</tr>
<tr>
<td><strong>Postscript</strong></td>
<td>417</td>
<td></td>
</tr>
<tr>
<td><strong>Glossary</strong></td>
<td>423</td>
<td></td>
</tr>
<tr>
<td><strong>References and Resources</strong></td>
<td>433</td>
<td></td>
</tr>
<tr>
<td><strong>Subject Index</strong></td>
<td>441</td>
<td></td>
</tr>
</tbody>
</table>
WIG Craft and Ekranoplan
Ground Effect Craft Technology
Yun, L.; Bliault, A.; Doo, J.
2010, XVII, 450 p., Hardcover
ISBN: 978-1-4419-0041-8