Maneuverability towing tank experiments with manifold models; part 1: static test

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MANEUVERABILITY TOWING TANK EXPERIMENTS WITH MANIFOLD MODELS – PART I: STATIC TESTS

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Introduction: Main characteristics of a manifold

- Metallic structural arrangement installed on the seabed

- **Function:** Integrates multiple submerged systems (e.g., production system, pressure control system, pipes and oil wells)

- A complex device - High manufacturing and installation costs

- **Installation methods:** vertical direction, PIM
Introduction: Pendular Installation Method (PIM)

- Developed by Petrobras (2002)
- Controlled pendulous motion to the seabed
  - Advantages:
    √ Reduces risks of resonance, safer, and economical
  - Disadvantage:
    √ Free–fall condition in the firsts steps of PIM, so it requires the prediction of the structure trajectory
- Necessity of studies on PIM forces and movements:
  - Experimental studies → towing tank tests
Objectives

• **Obtainment and comparison of the maneuverability of 3 dummy manifold models:**
  
  o **Simplified Model:** Influence of geometrical simplifications for analysis
  
  o **Detailed Model:** Reproduce most of the details of the dummy manifold
  
  o **Top Plate Model:** Influence of the installation of external device

**Two-part work:**

  o **Part I – Static drift tests:** Reynolds Sensitivity Study and Drift tests [3]

  o **Part II – Forced oscillation tests:** Pure Sway, Pure Yaw and Yaw with Drift tests

**PS.:** Tests conducted on pitch (XZ) and roll (YZ) planes, but only **XZ plane** shown for simplification purposes.
IPT’s Towing Tank

- Model towed by a *Planar Motion Mechanism* device (PMM)
  - Allows the set and maintains the desired drift angles
- Model rigidly attached to the PMM by a stiff vertical structure
- 6 DoF load cell
- Same test assembly in Part II [6]
Part I Test Methods

REYNOLDS SENSITIVITY TESTS

- **Objective:** Ensure flow around the model in fully developed condition (hydrodynamic coefficients do not change in function of the test velocity)
- **Method:** Varies tow velocity until load cell limit, using few important inclination angle

DRIFT TESTS

- **Objective:** Obtain the hydrodynamic coefficients for all inclination angles
- **Method:** Maintain the defined tow velocity, with several fixed inclinations angles per run
Test Method: Part I Tests Schematics

- **Drift Tests**: constant tow velocity with several of inclination angles, from 0° to 360°
Test Method: Drift Test Example
Dummy manifold main characteristics

- Load cell attached next to model CG: avoid excessive inertia loads on results
- CR defined at the CG

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full Scale</td>
</tr>
<tr>
<td>Total length (L)</td>
<td>16.6</td>
</tr>
<tr>
<td>Total width (B)</td>
<td>8.5</td>
</tr>
<tr>
<td>Total height (H)</td>
<td>4.7</td>
</tr>
<tr>
<td>CS distance (d)</td>
<td>1.9</td>
</tr>
</tbody>
</table>
Manifold Models

SIMPLIFIED
External geometry simplification

DETAILED
Most of the details of the dummy

DETAILED w/ TOP PLATE
Installation of external device
Analysis Method: Data Reduction

- Data obtained by mean values of the interval filtered results [6]

- **Data Reduction**: reduction of the forces and moments into coefficients:
  
  \[
  CF_i = \frac{F_i}{\frac{1}{2} \cdot \rho \cdot V_{tow}^2 \cdot A_p}
  \]
  
  \[
  CM_i = \frac{M_i}{\frac{1}{2} \cdot \rho \cdot V_{tow}^2 \cdot A_p \cdot L_M}
  \]

- **Lateral Velocity**: projection of the velocity on the model lateral axis (X axis for pitch)
  
  \[
  v_l = V_{tow} \cdot \sin(\beta - \beta_{ref})
  \]
Analysis Method: Forces and Moments Models

- **Classic model**: hydrodynamic forces and moments are function of the movement variables (lateral velocity in static drift tests)

- We can calculate [10] hydrodynamic derivatives through polynomial regression

\[
X(v_l) = X_0 + X_{vv} \cdot v_l^2 + X_{vvv} \cdot v_l^4 + O(v_l^6)
\]
\[
Y(v_l) = Y_v + Y_{vv} \cdot v_l^3 + O(v_l^5)
\]
\[
N(v_l) = N_v + N_{vv} \cdot v_l^3 + O(v_l^5)
\]
CS for the Hydrodynamic Derivatives

- For the **standard naval coordinate system** \( \rightarrow \) \( X \) - main resistance; \( Y \) - lateral direction, then for the **towing tank** \( \rightarrow \) \( X \) - tow direction; \( Y \) - transversal direction
Results: Reynolds Sensitivity Study

- Tests with $\beta_{\text{ref}} = 90^\circ$ made for all the 3 models
- Model symmetry: X force and Y moment close to zero for $\beta_{\text{ref}}$

Maximum velocities:
- Simplified: 0.45 m/s
- Detailed: 0.50 m/s
- Det. w/ Top Plate: 0.30 m/s

Maneuvering Tests Adopted Velocities:
- Simplified: 0.40 m/s
- Detailed: 0.40 m/s
- Det. w/ Top Plate: 0.20 m/s
Results: Drift Tests for X force

- Almost null response around 90° and 270°: X force is the lift (tow direction from top to bottom)
- Maximum responses around 0° and 180° for the 2 first models: X force is the drag (tow direction from side to side)
- Similar curves: Simplified and Detailed models
- Different responses for the Top Plate model: maximum responses around 30° and 120°
Results from Drift Tests for Z force

- Maximum responses around 90° and 270°: Z force is the drag (tow direction from top to bottom)
- Almost null response around 0° and 180°: Z force is the lift (tow direction from side to side)
- Similar curves for Simplified and Detailed models
- Larger responses For the Top Plate model: specially on 270°; maximum responses around 30°, 120° and 270°
  - Exception: lower response around 90°
Results: Drift Tests for Y moment

- For 90° and 270°: almost null response - symmetry and inclination direction against the top
- For the Top Plate model: larger responses - maximum responses around 30°, 120° and 225°
Free-Run Test Results
Results: Simplified Model Maneuver Analysis

- \( X(v_l) = X_0 + X_{vv} \cdot v_l^2 + X_{vvv} \cdot v_l^4 + O(v_l^6) \)
- \( Y(v_l) = Y_v + Y_{vvv} \cdot v_l^3 + O(v_l^5) \)
- \( N(v_l) = N_v + N_{vvv} \cdot v_l^3 + O(v_l^5) \)

<table>
<thead>
<tr>
<th>Simplified Model</th>
<th>X</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>X0</td>
<td>-1,63</td>
<td>Yv</td>
<td>-0,36</td>
</tr>
<tr>
<td>Xvv</td>
<td>-1,54</td>
<td>Yvv</td>
<td>0,264</td>
</tr>
<tr>
<td>Xvvvv</td>
<td>9,72</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results: Detailed Model Maneuver Analysis

- \( X(v_l) = X_0 + X_{vv} \cdot v_l^2 + X_{vvvv} \cdot v_l^4 + O(v_l^6) \)
- \( Y(v_l) = Y_v + Y_{vvv} \cdot v_l^3 + O(v_l^5) \)
- \( N(v_l) = N_v + N_{vvv} \cdot v_l^3 + O(v_l^5) \)

<table>
<thead>
<tr>
<th>Detailed Model</th>
<th>X</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>X0</td>
<td>-1,55</td>
<td>Yv</td>
<td>-0,28</td>
</tr>
<tr>
<td>Xvv</td>
<td>-1,57</td>
<td>Yvvv</td>
<td>0,604</td>
</tr>
<tr>
<td>Xvvvv</td>
<td>9,51</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results: Top Plate Model Maneuver Analysis

\[ X(v_l) = X_0 + X_{vv} \cdot v_l^2 + X_{vvvv} \cdot v_l^4 + O(v_l^6) \]

\[ Y(v_l) = Y_v + Y_{vvv} \cdot v_l^3 + O(v_l^5) \]

\[ N(v_l) = N_v + N_{vvv} \cdot v_l^3 + O(v_l^5) \]

<table>
<thead>
<tr>
<th>Detailed Model with Top Plate</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>X0</td>
<td>-1,47</td>
<td>Yv</td>
<td>0,953</td>
</tr>
<tr>
<td>Xvv</td>
<td>-4,17</td>
<td>Yvvv</td>
<td>-0,44</td>
</tr>
<tr>
<td>Xvvvv</td>
<td>6,35</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results from Maneuvering Analysis

- **SIMPLIFIED**
- **DETAILED**
- **DETAILED WITH TOP PLATE**

**Graphs showing force and moment data vs. lateral velocity for simplified and detailed models with and without a top plate.**
Conclusions

- All the manifold models had their static directional stability maintained.
- **Simplified** and **Detailed** models had similar maneuverability behaviors:
  - Almost identical forces and moment curves - similar maneuvering coefficients curves as well.
  - Shows that geometrical simplifications to manifold models has low influences in the maneuver behavior - **reasonable alternative for maneuvering studies**
- **Detailed model with top plate** presented higher forces and moments on almost all inclination angles.
- Drag and stability of the Top Plate model is notably superior.
References


Acknowledgments
Thank You

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