Mine Drop Experiment (MIDEX)

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Republic of Korea minesweeper *YMS-516* is blown up by a magnetic mine, during sweeping operations west of Kalma Pando, Wonsan harbor, on 18 October 1950.

From http://www.history.navy.mil/photos/events/kowar/50-unof/wonsan.htm
Acknowledgements

• Chenwu Fan
• Marla Stone
• ET1 Adam Dummer
• George Jaksha
• Prof. Chu
Overview

• Mine Warfare Overview
• Important Environmental Parameters for MCM Operations
• Impact Burial Prediction Model
• Mine Drop Experiment Overview
• Hydrodynamic Theory
• Data Analysis
• Conclusion
• Questions
A Shift in Operational Focus

- Breakdown of Soviet Union Forced Change in U.S. Navy Mission Requirements.
- Primary Guiding Documents: … From the Sea, Forward … From the Sea, Operational Maneuver from the Sea.
- Shift in Mission Focus from Open Ocean to the Littoral.
- Greatest Threat to U.S. Forces Operating in the Littoral: the Naval Mine.
Naval Mine Characteristics

Characterized by:

- **Method of Delivery**: Air, Surface or Subsurface.
- **Position in Water Column**: Bottom, Moored or Floating.
- **Method of Actuation**: Magnetic and/or Acoustic Influence, Pressure, Controlled or Contact.

- Composed of metal or reinforced fiberglass.
- Shapes are Typically Cylindrical but Truncated Cone (Manta) and Wedge (Rockan) shaped mines exist.
Naval Mine Threat

Inexpensive Force Multiplier

Roberts (FFG-58), Tripoli (LPH-10), Princeton (CG-59)
Damages $125 Million; Mines Cost $30K

Widely Available

• Over 50 Countries (40% Increase in 10 Yrs)
  • Over 300 Types (75% Increase in 10 Yrs)
  • 32 Countries Produce (60% Increase in 10 Yrs)
  • 24 Countries Export (60% Increase in 10 Yrs)

Numerous Types

WWII Vintage to Advanced Technologies
(Multiple Sensors, Ship Count Routines, Anechoic Coatings Non-Ferrous Materials)
Important Environmental Parameters for MCM Operations

- Water Properties
- Weather
- Beach Characteristics
- Tides and Currents
- Biologics
- Magnetic Conditions
- Bathymetry (Bottom Type)
Impact Burial

- Mine Impacting Bottom will Experience a Certain Degree of “Impact Burial (IB)”.
  - Highest Degree of IB in Marine Clay and Mud.
  - IB Depends on Sediment Properties, Object’s Impact Orientation, Shape and Velocity.

- MCM Doctrine Provides only a Rough Estimate of IB.

<table>
<thead>
<tr>
<th>Bottom Composition</th>
<th>Predicted Mine Case Burial %</th>
<th>Bottom Roughness</th>
<th>Bottom Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock</td>
<td>0</td>
<td>Smooth Moderate Rough</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>MUD OR SAND</td>
<td>0 TO 10</td>
<td>Smooth Moderate Rough</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>10 TO 20</td>
<td>Smooth Moderate Rough</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>25 TO 75</td>
<td>Smooth Moderate Rough</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>75 TO 100</td>
<td>All</td>
<td>C</td>
</tr>
</tbody>
</table>
Development of Navy’s Impact Burial Prediction Model (IBPM)

- IBPM was designed to calculate mine trajectories for air, water and sediment phases.
- Improved IBPM (Satkowiak, 1987-88) – With Rotation.
- Final Improvements made by Hurst (1992):
  - More Accurately Calculates Fluid Drag and Air-Sea and Sea-Sediment Interface Forces.
  - Treats Sediment as Multi-Layered.
Impact 25

• Main Limitations:

1. Model assumes mine body is of uniform density, thus center of buoyancy coincides with center of mass.


• If a mine’s water phase trajectory is not accurately modeled, then IB predictions will be wrong.

• Recent sensitivity studies by (Chu et al., 1999, 2000, Taber 1999, Smith 2000) have only focused on sediment phase calculations.
MIDEX

- MIDEX designed to examine the uniform density assumption of IMPACT 25, namely what effect a varying center of mass will have on a mine shape’s water phase trajectory.

- Controlled Parameters:
  1. Drop Angles: 15°, 30°, 45°, 60°, 75°.
  2. Center of Mass Position.
  3. L/D ratio (constant).
  4. $V_{\text{init}}$ (to some extent).

- Conducted several tests for each drop angle, center of mass position and initial velocity.
Mine Injector

Mine Shapes:
- Length: 15, 12, 9 cm
- Diameter: 4 cm

Light Sensor

To Universal Counter

Drop Angle Control Device
Mine Attitude
(Psi)

Coordinate System

-Z

X

Camera
(4' Above Deck)

Camera
(4' Above Deck)

Mine Injector

X

-7

1

2

1

2

18

19

20

21

22

23

18

19

20

21

22

23
Center of Mass

Defined COM position as:
2 or -2: Farthest from volumetric center
1 or -1
0: Coincides with volumetric center

MODEL # 1
L=15.1359 cm  D=4 cm  m=2.7 cm
Weight=322.5 g  Volume=190.2028 cm³  Density=1.6956 g/cm³
H:  10.380  8.052  5.725 cm
h:  -1.462  0.866  3.193 cm
M:  0.000  18.468 36.935 mm

MODEL # 2
L=12.0726 cm  D=4 cm  m=1.7 cm
Weight=254.2 g  Volume=151.709 cm³  Density=1.6756 g/cm³
H:  8.450  6.809  4.768 cm
h:  -1.564  0.277  2.119 cm
M:  0.000  12.145 24.290 mm

MODEL # 3
L=9.1199 cm  D=4 cm  m=1.47 cm
Weight=215.3 g  Volume=114.6037 cm³  Density=1.8786 g/cm³
H:  6.662  5.592  4.521 cm
h:  -1.358  -0.297  0.774 cm
M:  0.000  6.647 13.694 mm
Hydrodynamic Theory

• Solid Body Falling Through Fluid Should Obey 2 Physical Principles:

1. **Momentum Balance**
\[ \int (dV^*/dt^*) dm^* = W^* + F_b^* + F_d^* \]

2. **Moment of Momentum Balance**
\[ \int [r^* \times (dV^*/dt^*)] dm^* = M^* \]

*Denotes dimensional variables

- \( V^* \rightarrow \) Velocity
- \( W^* \rightarrow \) gravity
- \( F_b^* \rightarrow \) buoyancy force
- \( F_d^* \rightarrow \) drag force

- \( M^* \rightarrow \) resultant moment
Hydrodynamic Theory

- Considering both momentum and moment of momentum balance yields 9 governing equations that describe the mine’s water phase trajectory.

\[
\frac{dV_1}{dt} + \omega_2 V_3 - \omega_3 V_2 = -\frac{C_D \rho_w}{2 \rho_m} |\bar{V}| (V_1 - V_{w1}) + \frac{\rho_m - \rho_w}{\rho_m} \cos \psi_1
\]

\[
\frac{dV_2}{dt} + \omega_3 V_1 - \omega_1 V_3 = -\frac{C_D \rho_w}{2 \rho_m} |\bar{V}| (V_2 - V_{w2}) + \frac{\rho_m - \rho_w}{\rho_m} \cos \psi_2
\]

\[
\frac{dV_3}{dt} + \omega_1 V_2 - \omega_2 V_1 = -\frac{C_D \rho_w}{2 \rho_m} |\bar{V}| (V_3 - V_{w3}) + \frac{\rho_m - \rho_w}{\rho_m} \cos \psi_3
\]

\[
J_1 \frac{d\omega_1}{dt} + (J_3 - J_2) \omega_2 \omega_3 - J_{31} (\frac{d\omega_1}{dt} + \omega_1 \omega_2) = \frac{LM_1'}{g}
\]

\[
J_2 \frac{d\omega_2}{dt} + (J_1 - J_3) \omega_3 \omega_1 - J_{31} (\omega_2^2 - \omega_1^2) = \frac{LM_2'}{g}
\]

\[
J_3 \frac{d\omega_3}{dt} + (J_2 - J_1) \omega_1 \omega_2 - J_{31} (\frac{d\omega_3}{dt} - \omega_2 \omega_3) = \frac{LM_3'}{g}
\]

\[
\frac{d}{dt} \cos \psi_1 = \omega_3 \cos \psi_2 - \omega_2 \cos \psi_3
\]

\[
\frac{d}{dt} \cos \psi_2 = \omega_1 \cos \psi_3 - \omega_3 \cos \psi_1
\]

\[
\frac{d}{dt} \cos \psi_3 = \omega_2 \cos \psi_1 - \omega_1 \cos \psi_2
\]
Hydrodynamic Theory

Arnone-Bowen IBPM
Without Moment Equation

Improved IBPM with rotation but without Moment Equation
Hydrodynamic Theory

• By considering both equations mine will exhibit a spiral fall pattern.
Data Analysis

1. Video converted to digital format.
2. Digital video from each camera analyzed frame by frame (30Hz) using video editing program.
3. Mine’s top and bottom position determined using background x-z and y-z grids. Positions manually entered into MATLAB for storage and later processing.
4. Analyzed 2-D data to obtain mine’s x,y and z center positions, attitude (angle with respect to z axis) and u,v, and w components.
Non-dimensional Conversions

- In order to generalize results, data was converted to non-dimensional numbers.

\[ t^* = \frac{dt}{\sqrt{gL}}, \quad V_i^* = \frac{V_i}{\sqrt{gL}}, \quad \frac{L}{D}, \quad \text{COM} = \frac{2\Delta L}{L}, \quad \frac{(x,y,z)}{L}, \quad \frac{(u,v,w)}{\sqrt{gL}} \]
Sources of Error

1. Grid plane behind mine trajectory plane. Results in mine appearing larger than normal.
2. Position data affected by parallax distortion and binocular disparity.
3. Air cavity affects on mine motion not considered in calculations.
4. Camera plane not parallel to x-y plane due to pool slope.
Underwater Video Clip

Center of Mass: Position 2
Drop Angle: 45; L = 15cm; Vi = 2.874m/s; COM: -2

Drop Angle: 45; L = 15cm; Vi = 2.874m/s; COM: -2
Impact Point (All Cases)
Impact Point (All Drop Angles)
Impact Point (By Angle)
Impact Angle Frequency of Occurrence by L
Impact Angle Frequency of Occurrence

Impact Angle Grouped in 5° Bins
Trajectory Patterns

1. Straight
2. Slant
3. Spiral
4. Flip
5. Flat
6. See Saw
7. Combination
Multiple Linear Regression

- General Multiple Linear Regression Equation:
  \[ f_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + \beta_4 x_{4i} + \epsilon_i \]
- Used least squares solution to determine correlation coefficients.
- Input: \( \cos(\text{drop angle}); \ L/D; \ V_{\text{ind}}; \ \text{COM}_{\text{nd}} \)
- Output: \( (x_m, y_m, z_m, \Psi, u, v, w) \)
## Multiple Regression Results

<table>
<thead>
<tr>
<th></th>
<th>$x_m$</th>
<th>$y_m$</th>
<th>$\Psi$</th>
<th>$u$</th>
<th>$v$</th>
<th>$w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>-.0746</td>
<td>-.0546</td>
<td>102.5691</td>
<td>.0040</td>
<td>-.0135</td>
<td>-.9481</td>
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<tr>
<td>$\beta_1$</td>
<td>.1190</td>
<td>-.0828</td>
<td>-13.3508</td>
<td>-.0075</td>
<td>-.0106</td>
<td>-.1080</td>
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<tr>
<td>$\beta_2$</td>
<td>-.0469</td>
<td>-.0798</td>
<td>-.5009</td>
<td>-.0011</td>
<td>.0005</td>
<td>.0295</td>
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<tr>
<td>$\beta_3$</td>
<td>.0372</td>
<td>.0622</td>
<td>1.0437</td>
<td>.0025</td>
<td>.0011</td>
<td>-.0221</td>
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<tr>
<td>$\beta_4$</td>
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<td>.4330</td>
<td>472.2135</td>
<td>-.0090</td>
<td>.0537</td>
<td>-1.2467</td>
</tr>
</tbody>
</table>

- Most important parameter for impact prediction is $\Psi$ (impact angle).

Check of regression equation:

Determine $\Psi$ for case where:

$L=15\text{cm}$, $V_i = 3\text{m/s}$, $\text{COM} = 2$, Drop Angle = $15^\circ$

Yields: $\Psi = 181.2^\circ$

For $\text{COM} = 1$: $\Psi = 136.1^\circ$

For $\text{COM} = 0$: $\Psi = 90.4^\circ$
Conclusion

• COM position is the most influential parameter for predicting a mine’s impact position and angle.
• Final velocities were lowest for COM 0 cases due to the increased effect of hydrodynamic drag.
• Trajectories became more complex as L/D decreased (9 cm mine rotated about z-axis).
• Observed trajectory patterns were more complex than those assumed by IMPACT 25. Accurate representation of a mine’s water phase motion requires both momentum and moment of momentum equations.