Development of the Navy's 3D Mine Impact Burial Prediction Model (IMPACT35)

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Sponsored by ONR Coastal Geosciences (Code 321)

Sixth International Symposium on Technology and the Mine Problem, NPS, Monterey, CA 93943, May 10-14, 2004

References

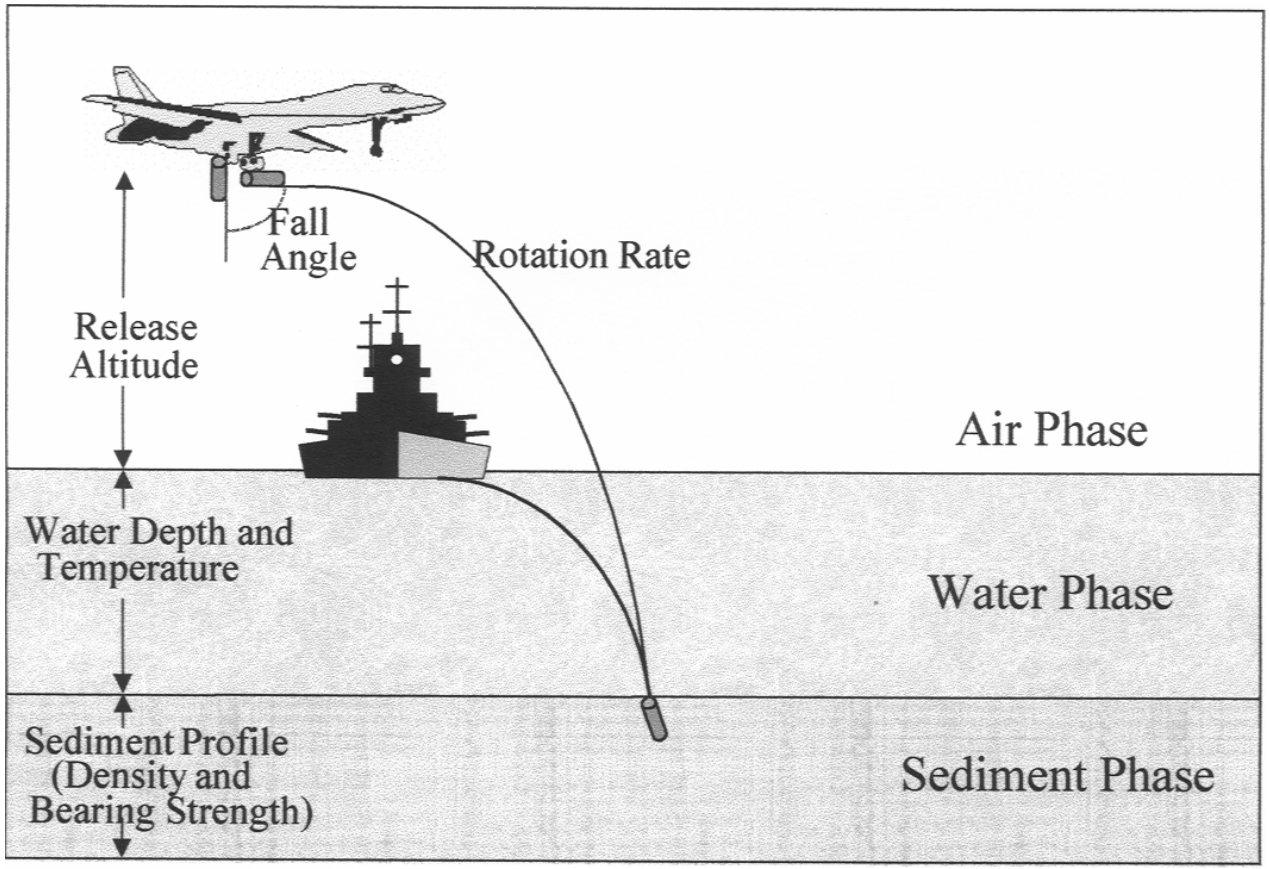
- Chu, P.C. and C. Fan, 2004: Three dimensional rigid body impact burial prediction model. **Advances in Fluid Mechanics**, 6, 43-52.

- Chu, P.C., C.W. Fan, A.D. Evans, and A. Gilles, 2004: Triple coordinate transforms for prediction of falling cylinder through the water column. **Journal of Applied Mechanics**, in press.

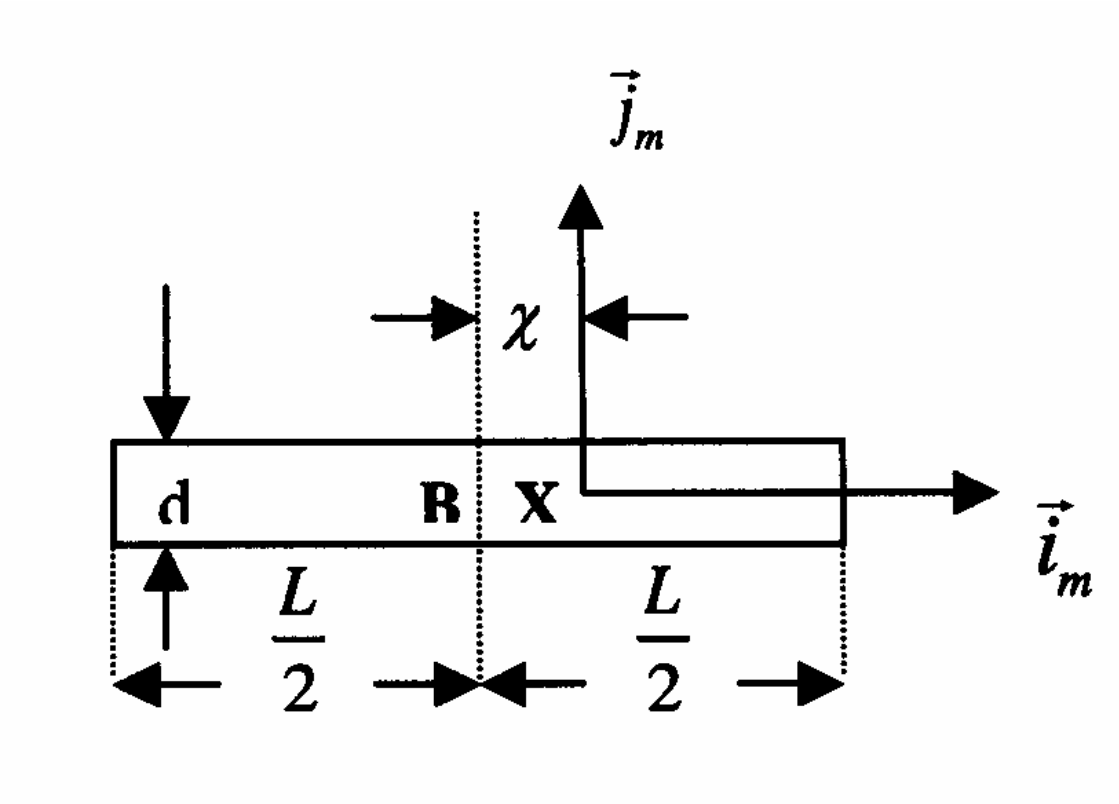
- Chu, P.C., and C.W. Fan, 2004: Prediction of falling cylinder through air-water-sediment columns. **Journal of Applied Mechanics**, in revision.

- Chu, P.C., A. Gilles, and C.W. Fan, 2004: Experiments of falling cylinder through water column. **Experimental Thermal and Fluid Sciences**, in revision.

Hydrodynamic Characteristics



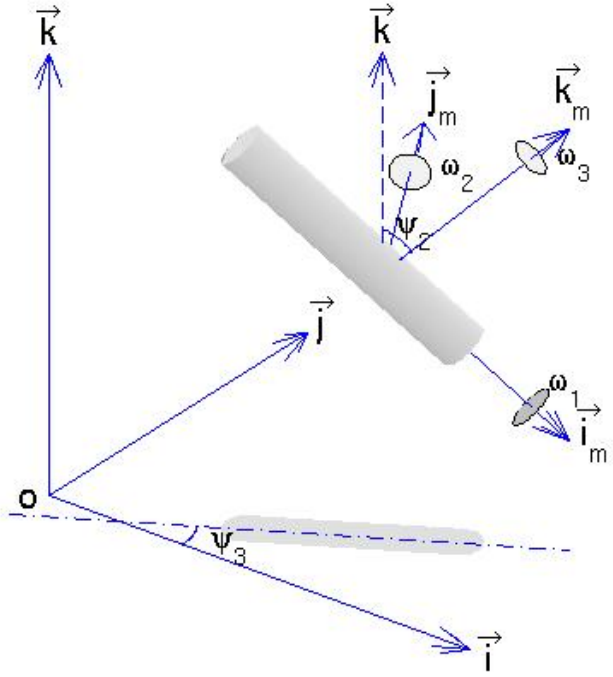
Cylinder: X (COM), B (COV)



Triple Coordinate Transform

- Earth-fixed coordinate (E-coordinate)
- Cylinder's main-axis following coordinate (M-coordinate)
- Hydrodynamic force following coordinate (F-coordinate).

E and M Coordinate Systems



$$\mathbf{j}_M = \mathbf{k} \times \mathbf{i}_M, \qquad \mathbf{k}_M = \mathbf{i}_M \times \mathbf{j}_M$$

E-Coordinate, $F_E(O, \mathbf{i}, \mathbf{j}, \mathbf{k})$

- COM Position: $\mathbf{X} = x\mathbf{i} + y\mathbf{j} + z\mathbf{k}$,
- Translation velocity:

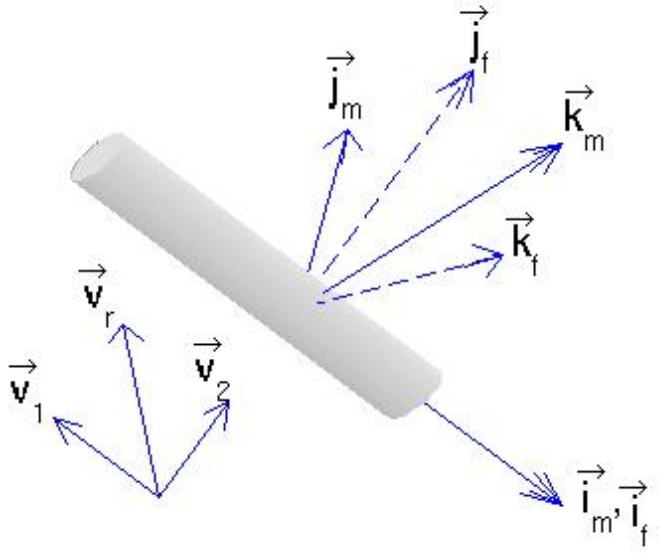
$$d\mathbf{X}/dt = \mathbf{V}, \quad \mathbf{V} = (u, v, w)$$

Transform Between E- and M-Coordinate Systems

$$
{}^{E}_{M}\mathbf{R}(\psi_2,\psi_3) \equiv \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}:
$$

$$
= \begin{bmatrix} \cos\psi_3 & -\sin\psi_3 & 0 \\ \sin\psi_3 & \cos\psi_3 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\psi_2 & 0 & \sin\psi_2 \\ 0 & 1 & 0 \\ -\sin\psi_2 & 0 & \cos\psi_2 \end{bmatrix},
$$

F-Coordinate System



E- and F-Coordinate Transform

$$\mathbf{i}_F = \mathbf{i}_M = \begin{bmatrix} r_{11} \\ r_{21} \\ r_{31} \end{bmatrix}, \qquad \mathbf{j}_F = \mathbf{V}_2 / |\mathbf{V}_2|, \qquad \mathbf{k}_F = \mathbf{i}_F \times \mathbf{j}_F.$$

$$\overset{E}{F}\mathbf{R}(\psi_2, \psi_3, \phi_{MF}) \equiv \begin{bmatrix} r_{11} & r'_{12} & r'_{13} \\ r_{21} & r'_{22} & r'_{23} \\ r_{31} & r'_{32} & r'_{33} \end{bmatrix},$$

Momentum Equation in E-Coordinate System

$$\frac{d}{dt}\begin{bmatrix} u \\ v \\ w \end{bmatrix} = -\begin{bmatrix} 0 \\ 0 \\ \left(1-\rho_w/\bar{\rho}\right)g \end{bmatrix} + \frac{1}{\bar{\rho}\Pi}\begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix},$$

Moment of Momentum Equation in M-Coordinate System

$$\mathbf{J} \cdot \frac{d\boldsymbol{\omega}}{dt} = \mathbf{M}_b + \mathbf{M}_h \,,$$

Inertial terms are small

M-Coordinate

The moment of gyration tensor for the axially Symmetric cylinder is a diagonal matrix

$$\mathbf{J} = \begin{bmatrix} J_1 & 0 & 0 \\ 0 & J_2 & 0 \\ 0 & 0 & J_3 \end{bmatrix},$$

Moment of Momentum Equations

$$\frac{d\omega_1}{dt} = -a_1\omega_1 ,$$

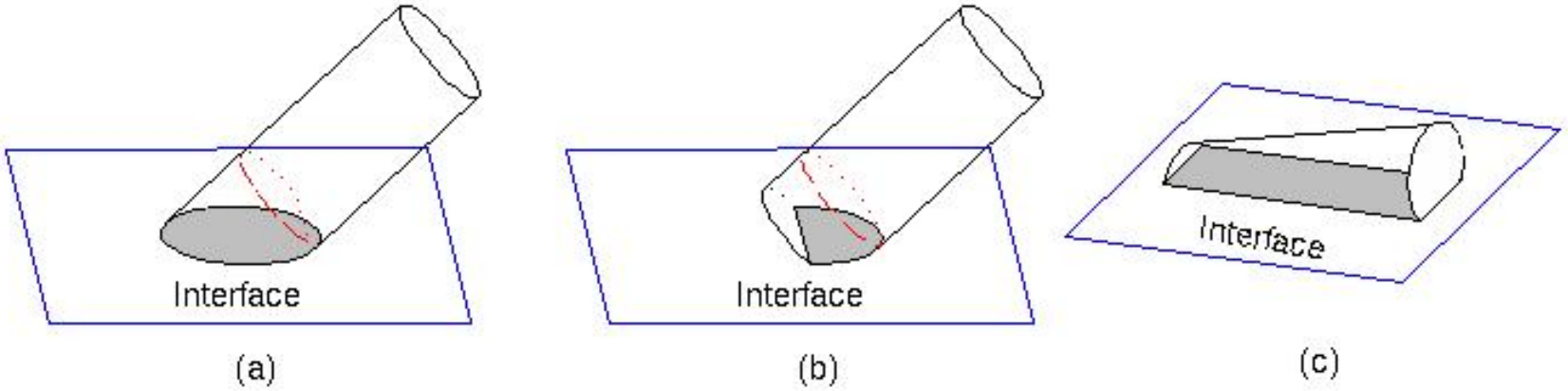
$$\frac{d}{dt}\begin{bmatrix}\omega_2\\ \omega_3\end{bmatrix} = -\mathbf{B}\cdot\begin{bmatrix}\omega_2\\ \omega_3\end{bmatrix} + \boldsymbol{\alpha}_2 ,$$

F-Coordinate

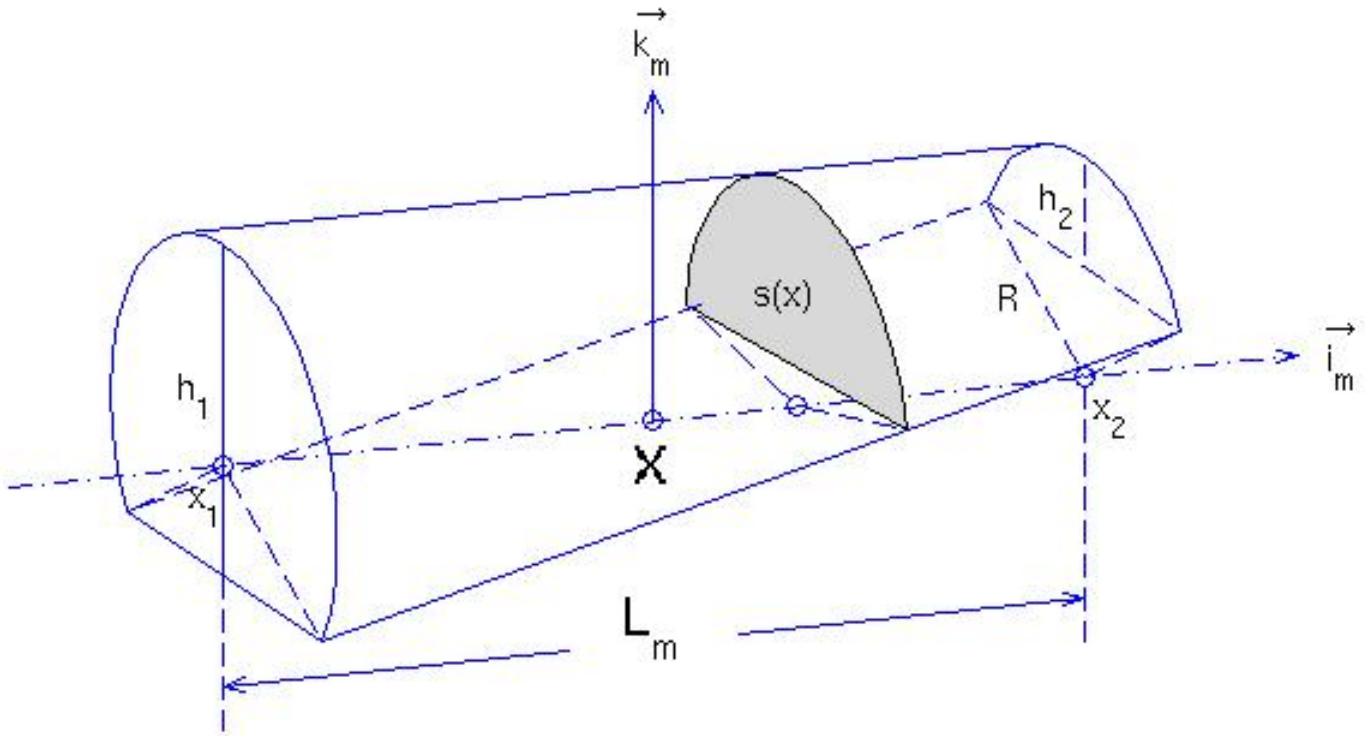
Hydrodynamic forces (drag and lift)
are easily calculated.

$$\mathbf{M}_{v1} = -C_{m1}\omega_1 \mathbf{i}_F, \quad C_{m1} \equiv \pi\mu L d^2 .$$

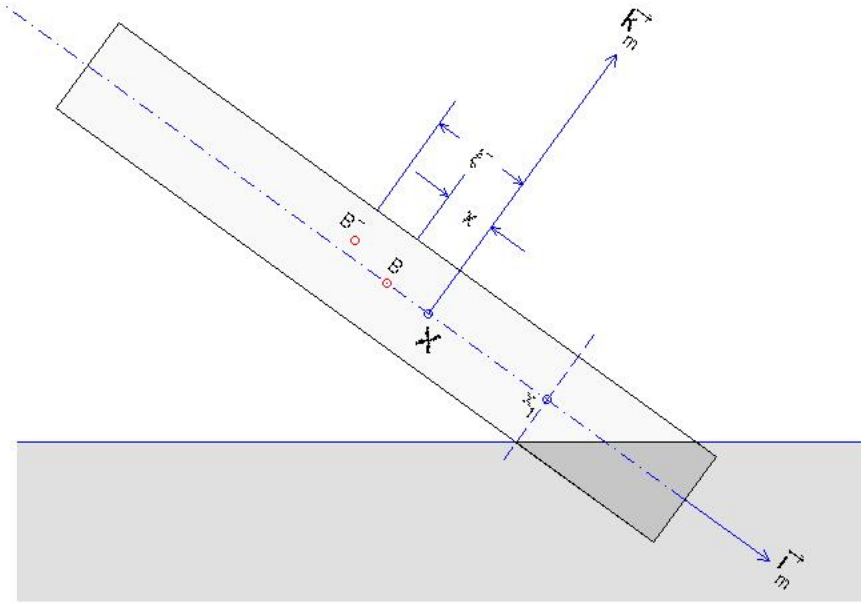
Interfacial Penetration Modeling



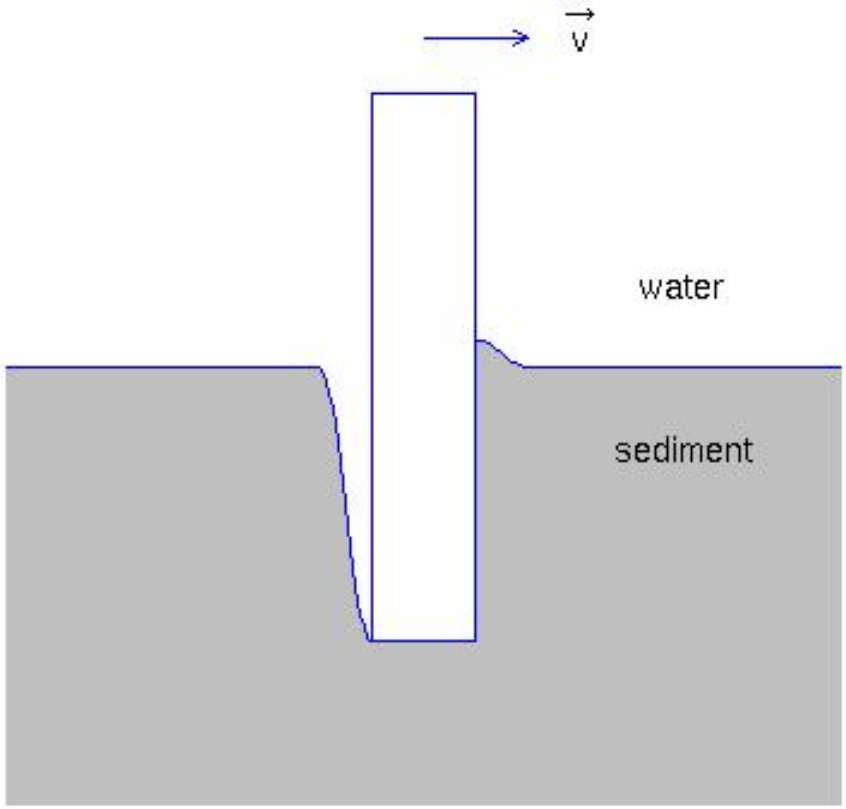
M-Coordinate System



Equivalent Cylinder



Penetration into Sediment



Experiments

- Mine Drop Experiment (MIDEX, 1/20th Scale)
  - June 2001 (NPS Swimming Pool)

- Mine Impact Burial Experiment (MIBEX, Near Full Scale)
  - May 23, 2000 (Monterey Bay, Sand Bottom)

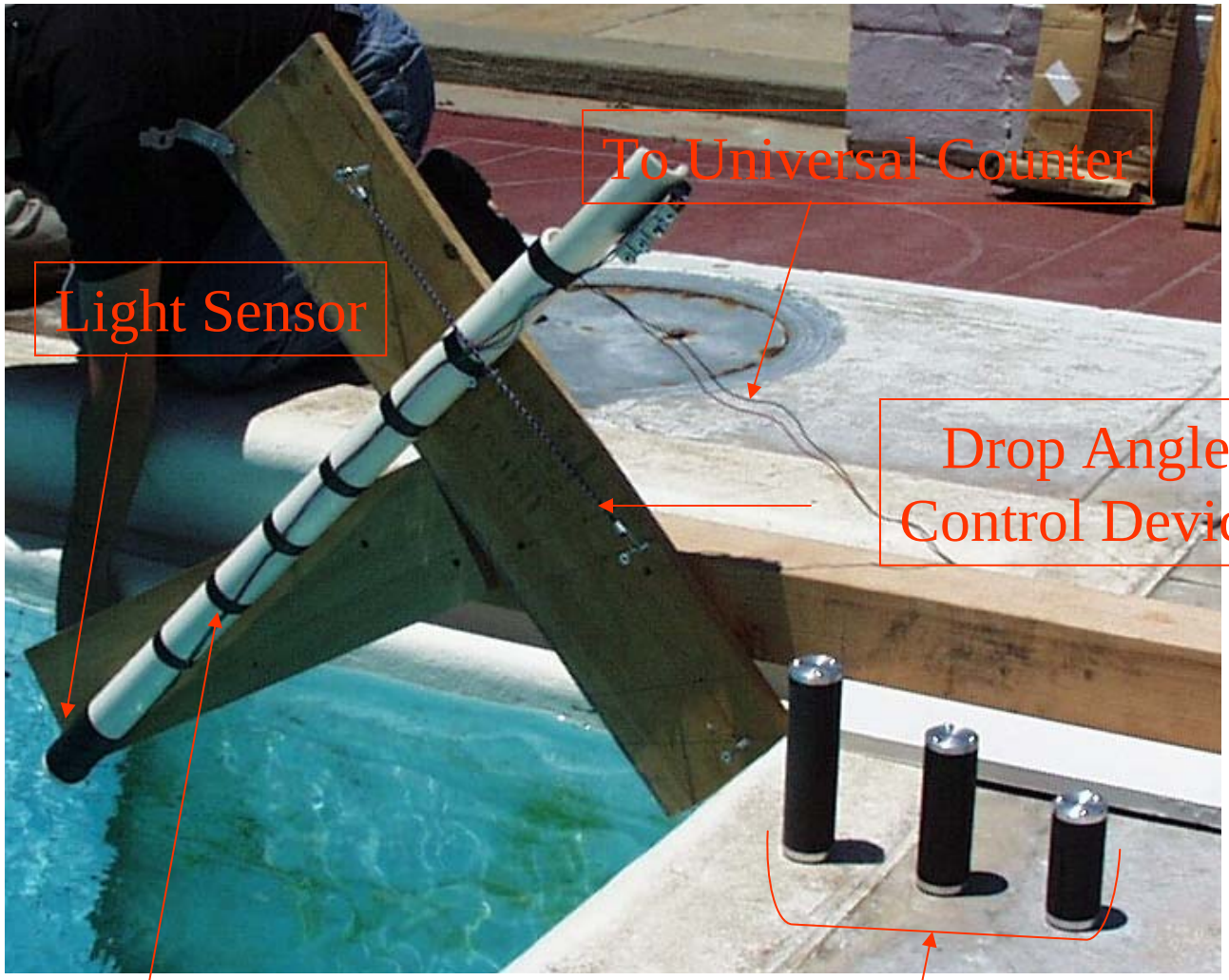
MIDEX

- Cylinder Parameters:

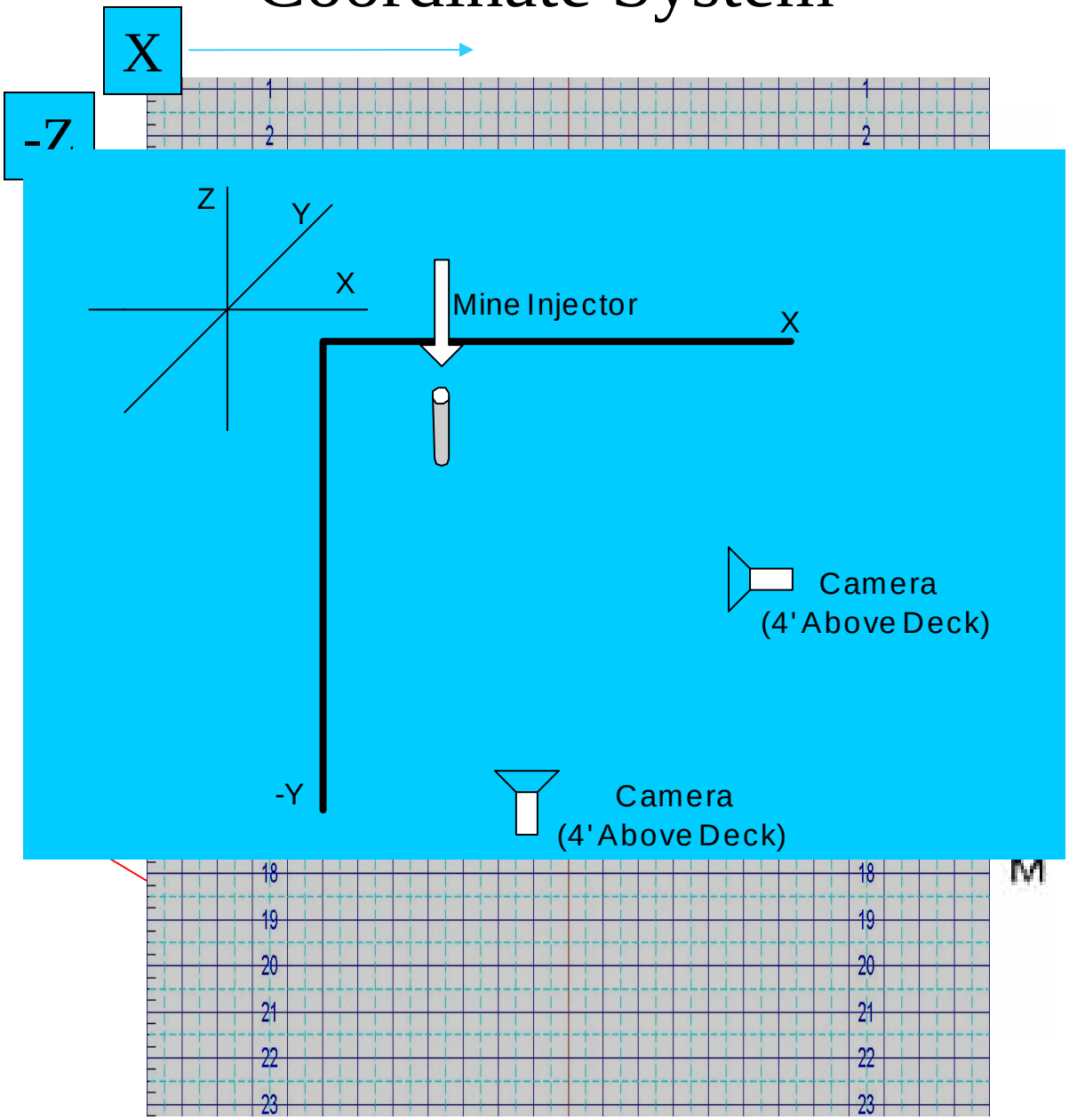
  1. Density Ratio (1.68, 1.70, 1.88)
  2. Center of Mass Position.
  3. L/D ratio.

- Drop Parameters:

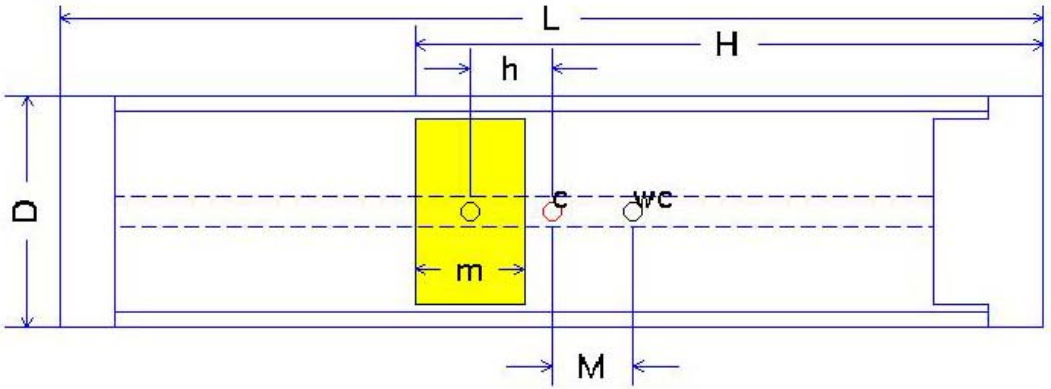
  1. Drop Angles: 15º, 30º, 45º, 60º, 75º.
  2. Release Velocity V_{init}

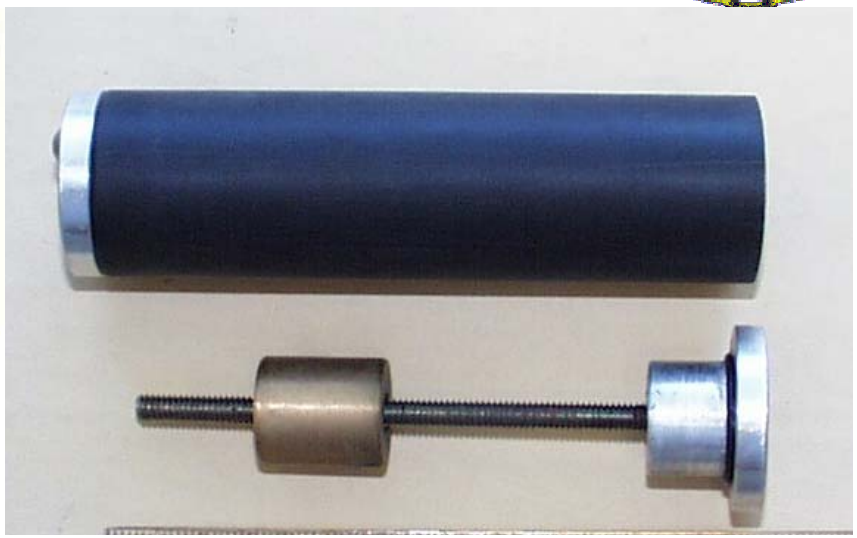

To Universal Counter
Light Sensor
Drop Angle
Control Device
Injector
Shapes:
Length: 15, 12, 9 cm
Diameter: 4 cm

Coordinate System



Center of Mass





MODEL # 1
L=15.1359cm D=4cm m=2.7cm
Weight=322.5 g Volume=190.2028 cm^3 Density=1.6956 g/cm^3

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=12.0726cm D=4cm m=1.7cm
Weight=254.2 g Volume=151.709 cm^3 Density=1.6756 g/cm^3

H:	8.450	6.609	4.768	cm
h:	−1.564	0.277	2.119	cm
M:	0.000	12.145	24.290	mm

MODEL # 3
L=9.1199cm D=4cm m=1.47cm
Weight=215.3 g Volume=114.6037 cm^3 Density=1.8786 g/cm^3

H:	6.662	5.592	4.521	cm
h:	−1.368	−0.297	0.774	cm
M:	0.000	6.847	13.694	mm

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

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.

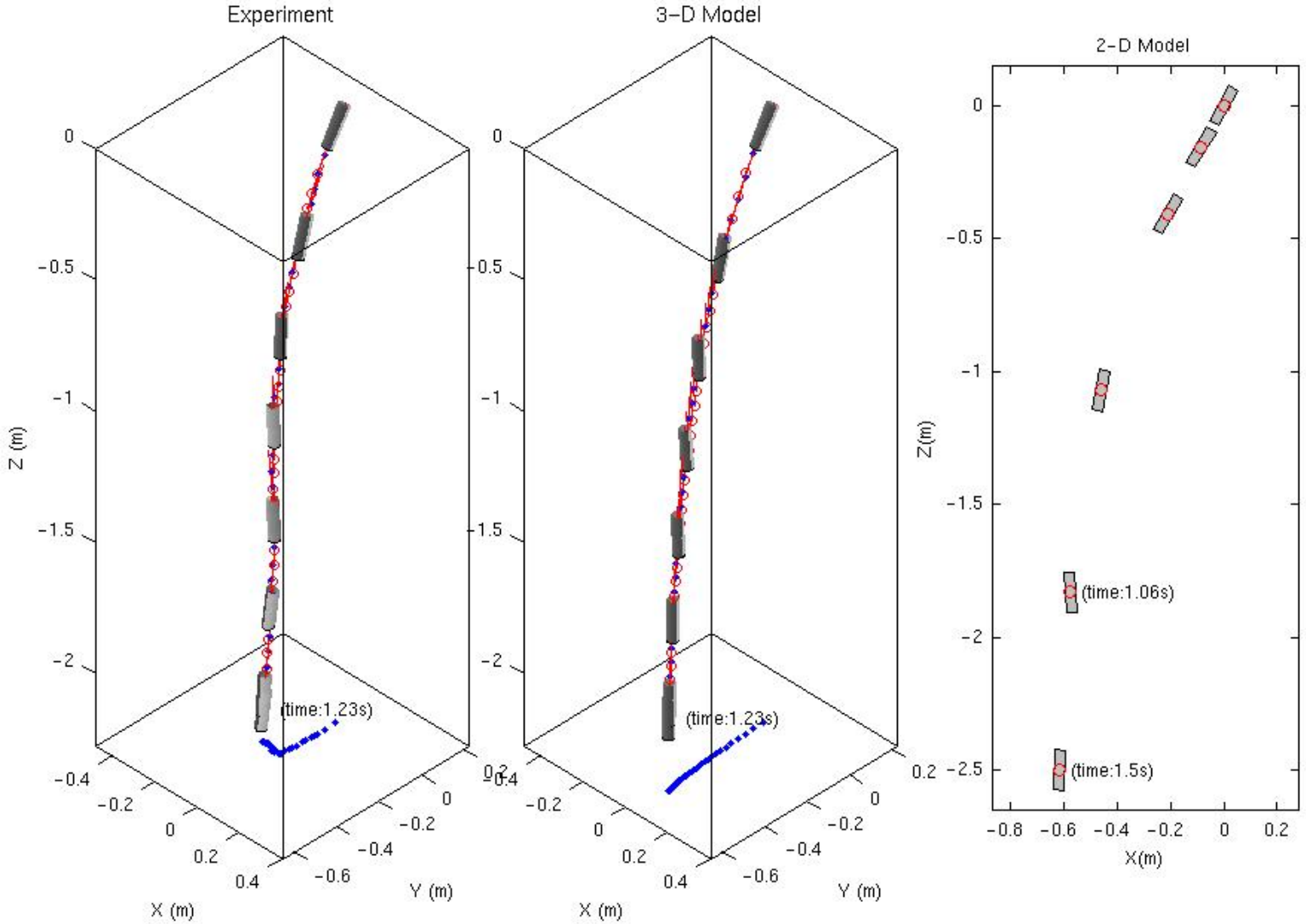
MIDEX

Center of Mass: Position 2

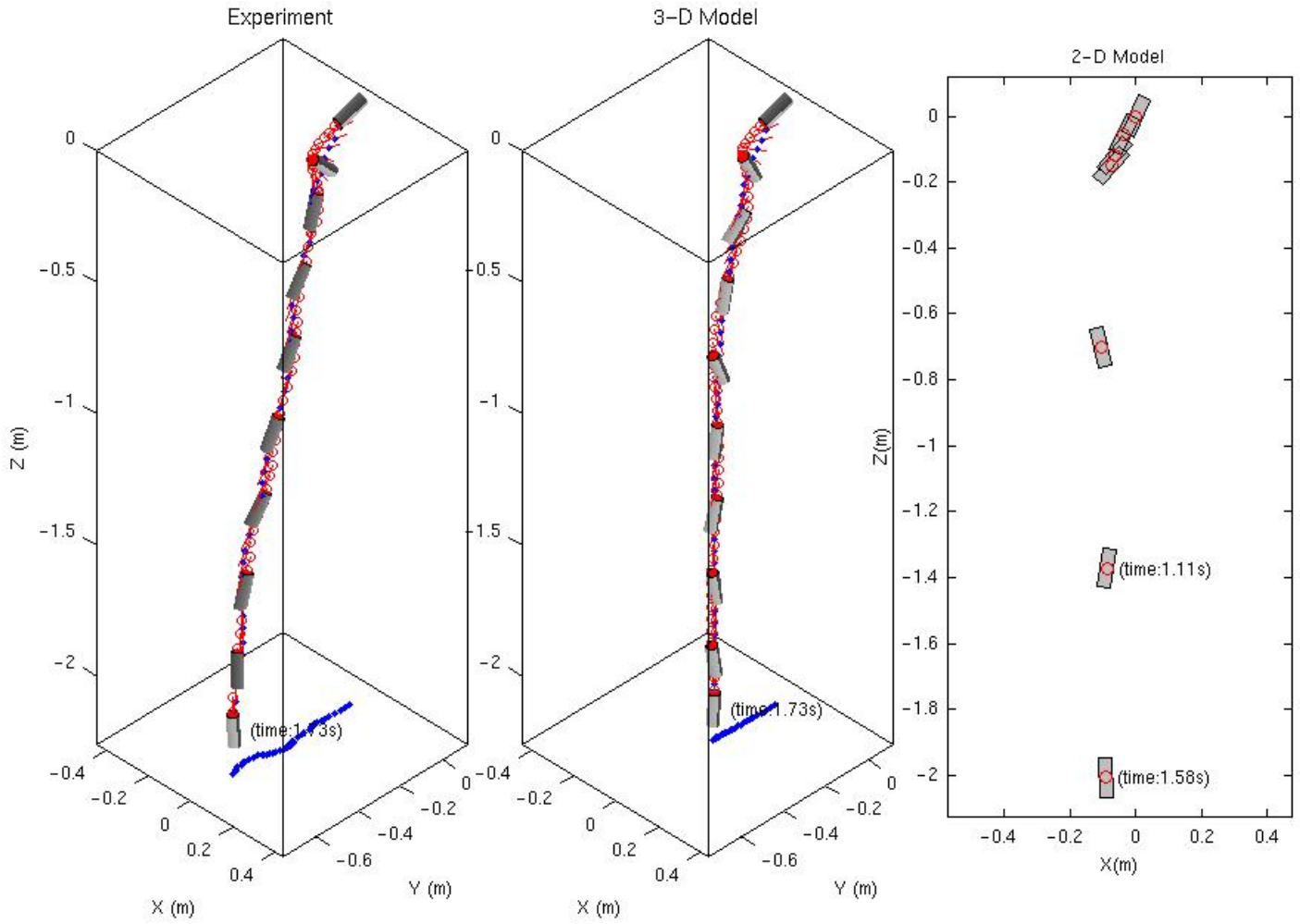
Model-Data Comparison

Model-Data Comparison

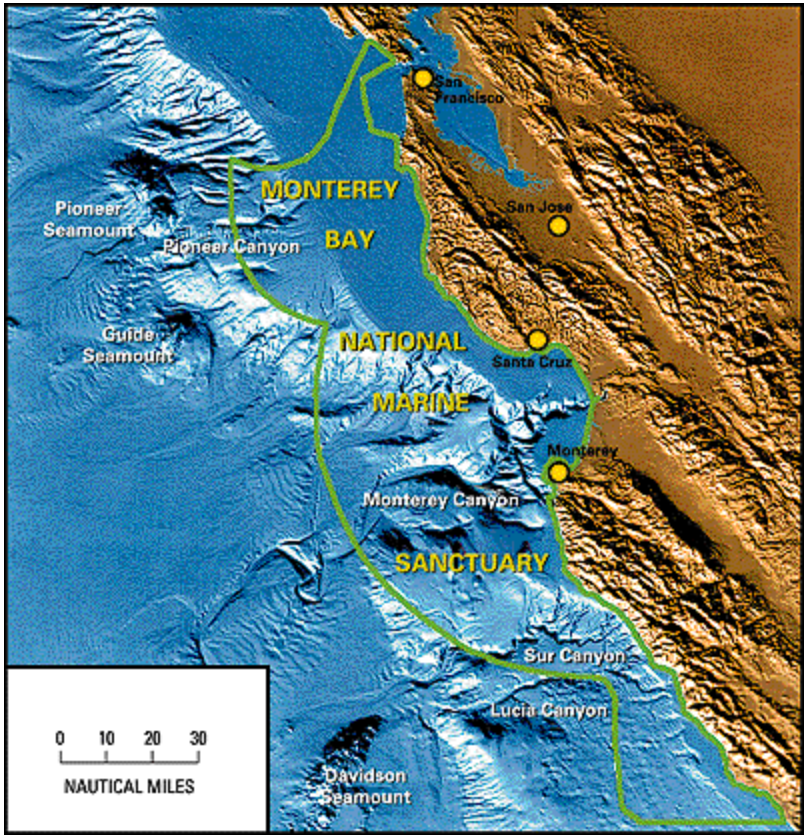
Model-Data Comparison

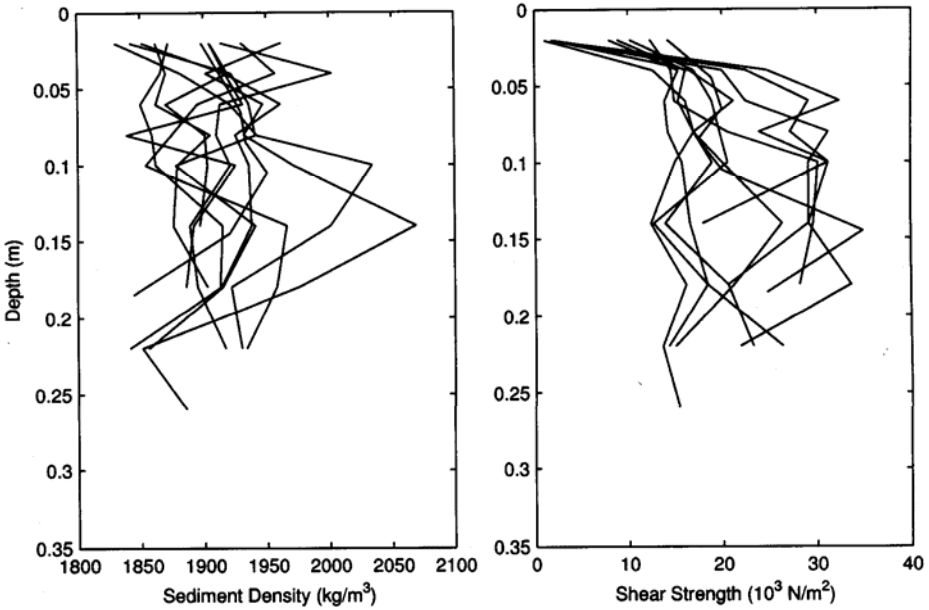


Model-Data Comparison

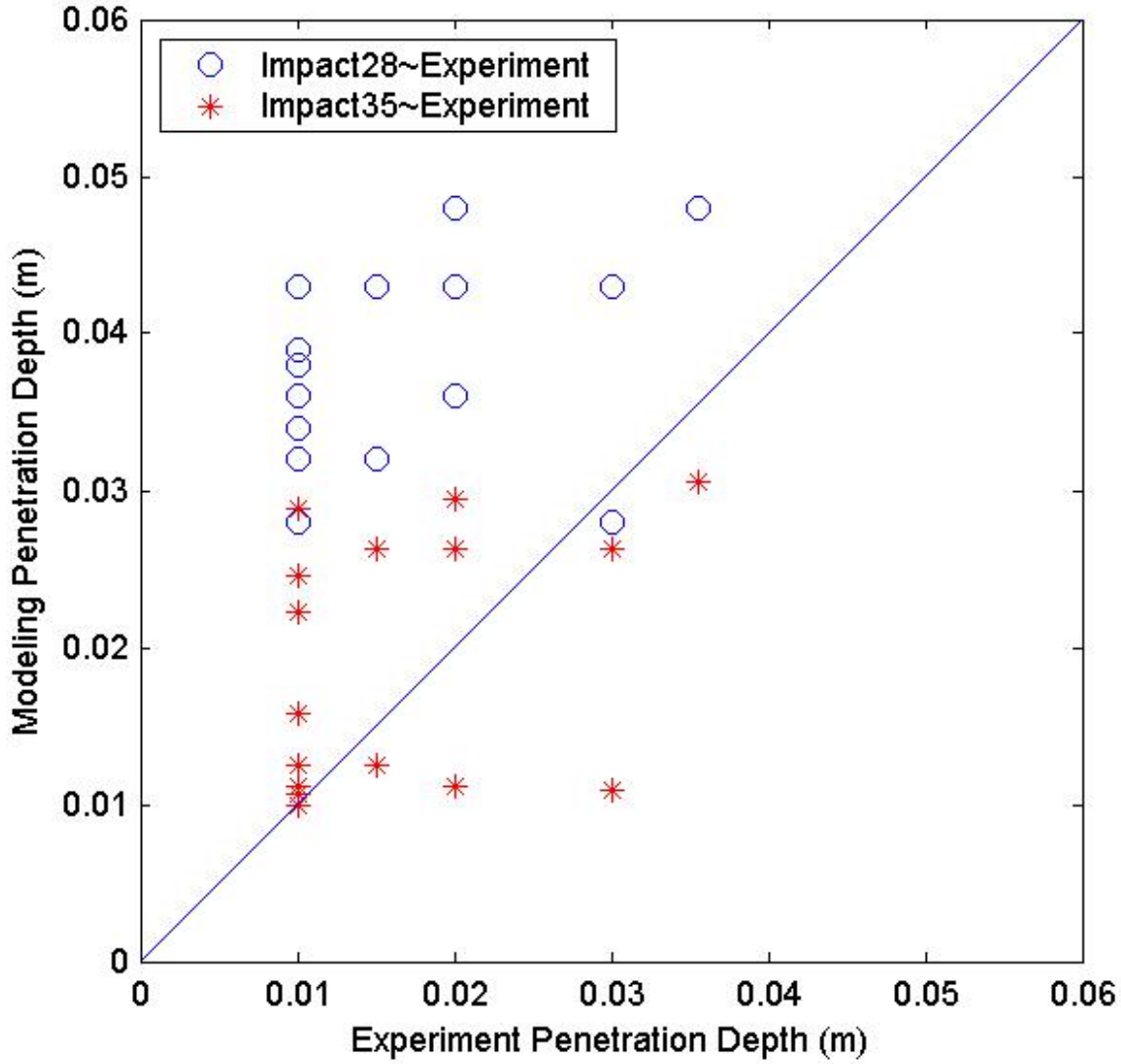


Gravity Cores During MIBEX (5/21/2000)





Model-Data Comparison



Conclusions

- Triple coordinate transform is an effective method to predict 3D movement of cylinder in air, water, and sediment columns.
- Momentum equation (E-coordinate)
- Moment of momentum equation (M-coordinate)
- Hydrodynamic forces and torques (F-coordinate)

Future Work

- (1) Extensive Model Verification
  - NRL (Dr. Phil Valent)
  - JHU-APL (Drs. Alan Brandt, Sarah Rennie)
  - FWG (Dr. Thomas Wever)

- (2) Extension the IMPACT35 for Cylindrical Mines to Naval Operational Mines

  - Korean Mines, Bowen Mines, Psi Mines
  - KW36, KW52, KWDST, KWGE, KWIT
  - Mark36N, Mark52 …