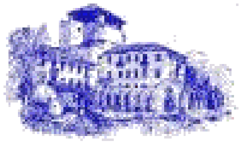
UNCLASSIFIED



Development of IMPACT35
- 3D Model -

Peter Chu, C. Fan, and NPS Students (U.S. Naval Officers)

Naval Postgraduate School

Peter Fleischer, Ron Betsch

Naval Oceanographic Office

Phil Valent

Naval Research Lab

Fourth Annual ONR Mine Burial Prediction Workshop

Woods Hole, MA, April 12-14, 2004

UNCLASSIFIED

References

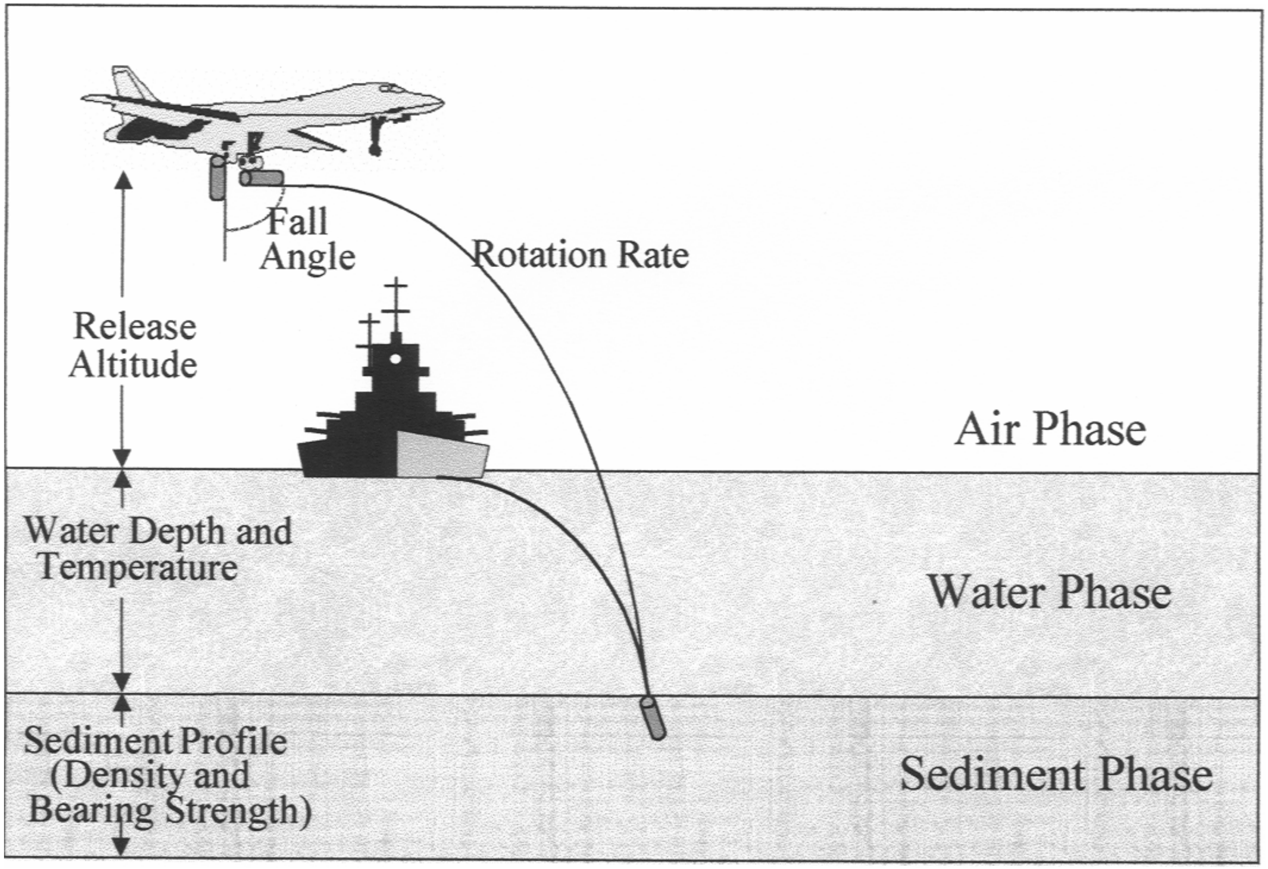
- Chu, P.C., C.W. Fan, A.D. Evans, and A. Gilles, 2004: Triple coordinate transforms for prediction of falling cylinder through the water column. **Journal of Applied Mechanics**, in press.

- Chu, P.C., A. Evans, A. Gillis, T. B. Smith, and V. Taber, 2004: Development of the Navy's 3D mine impact burial prediction model (IMPACT35). **Sixth International Symposium on Technology and Mine Problem**, NPS, Monterey, May 9-13, 2004.

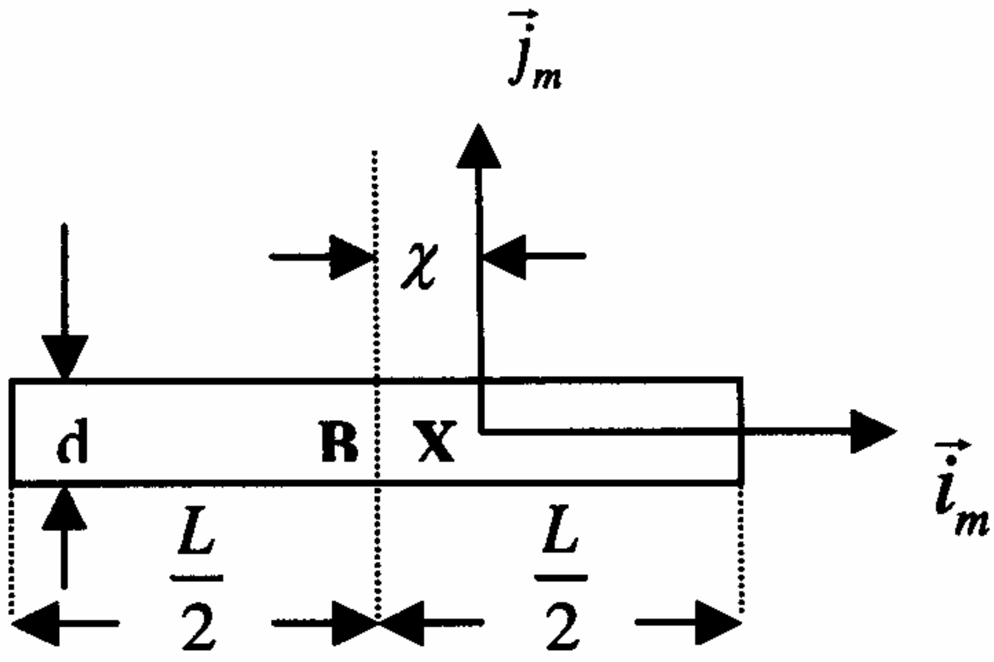
- Chu, P.C., and C.W. Fan, 2004: Prediction of falling cylinder through air-water-sediment columns. **Journal of Applied Mechanics**, in revision.

- 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



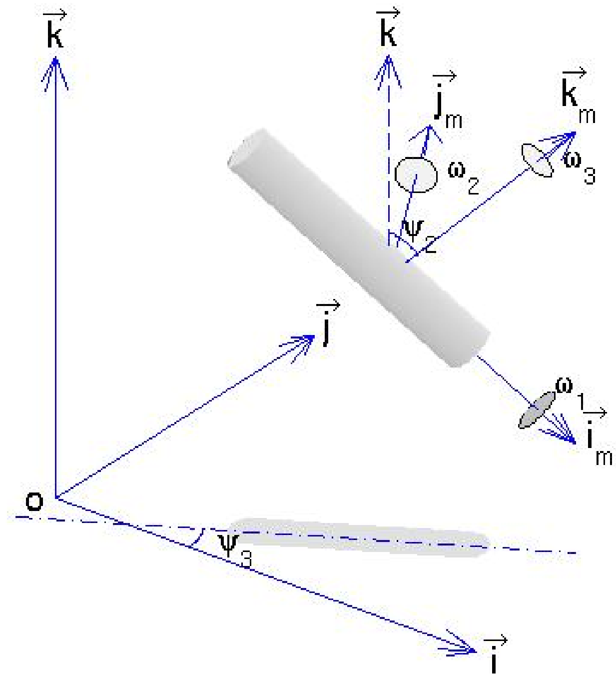
Cylinder: X (COM), B (COV)



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:

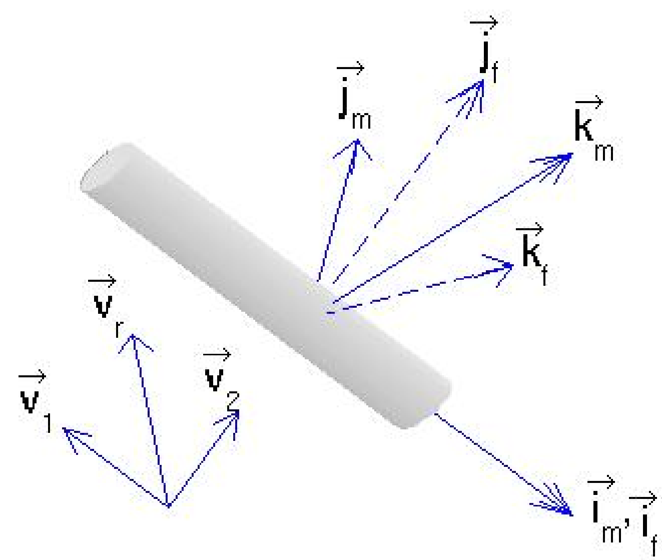
$$d\mathbf{X}/dt = \mathbf{V}, \quad \mathbf{V} = (u, v, w)$$

Transform Between E- and M-Coordinate Systems

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

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

F-Coordinate System



E- and F-Coordinate Transform

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

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

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

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

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

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

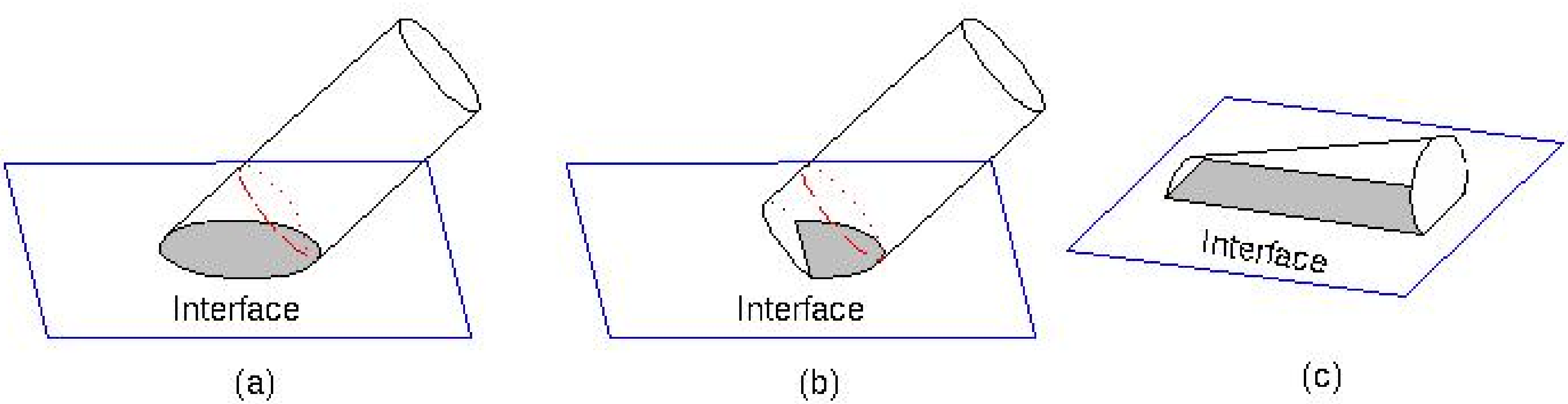
$$\frac{d}{dt}\begin{bmatrix}\omega_2 \\ \omega_3\end{bmatrix} = -\mathbf{B}\cdot\begin{bmatrix}\omega_2 \\ \omega_3\end{bmatrix} + \boldsymbol{\alpha}_2 ,$$

F-Coordinate

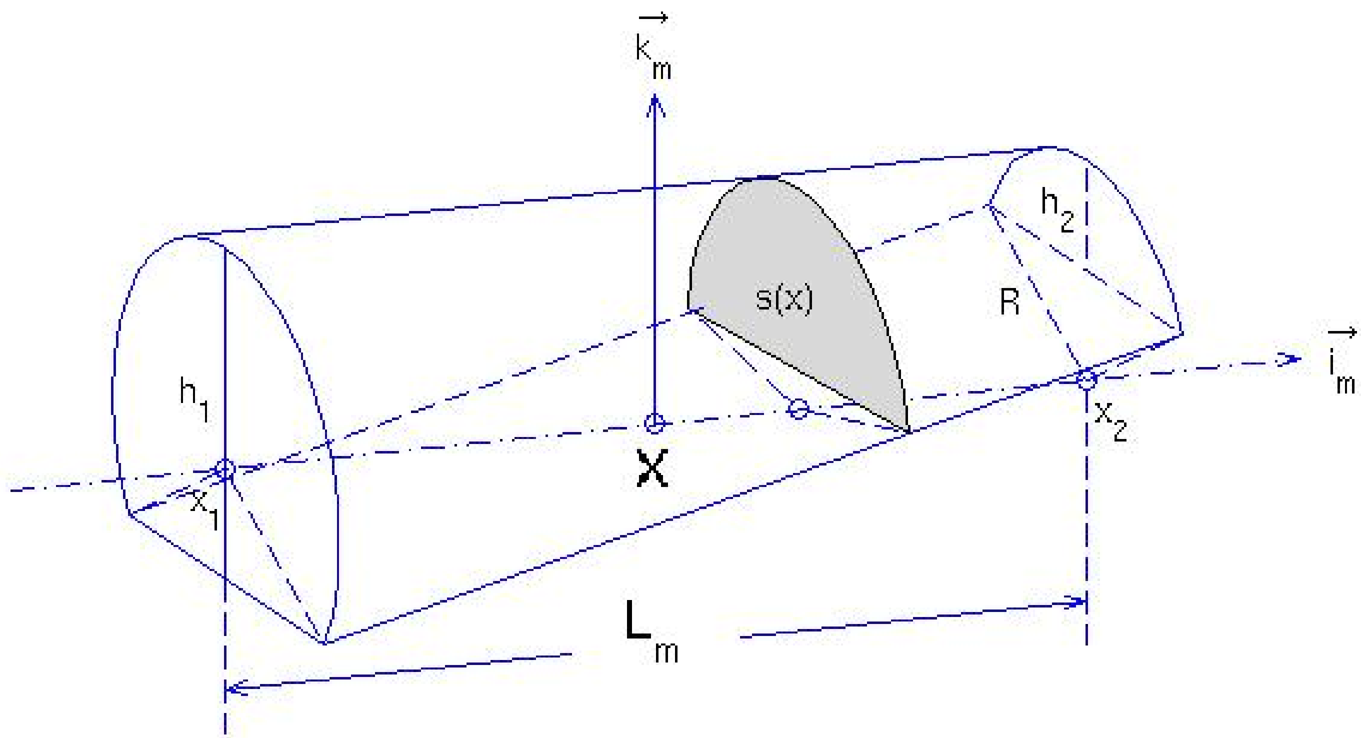
Hydrodynamic forces (drag and lift) are easily calculated.

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

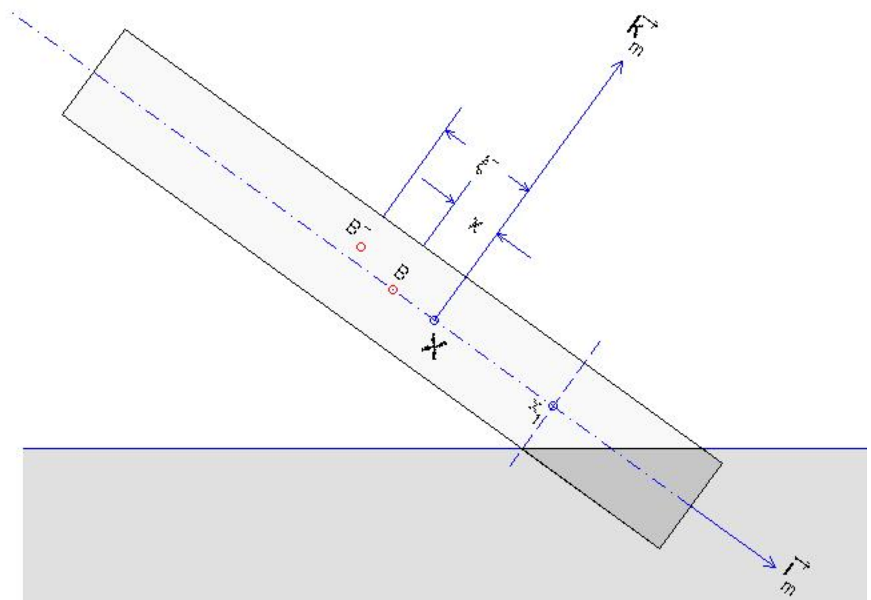
Interfacial Penetration Modeling



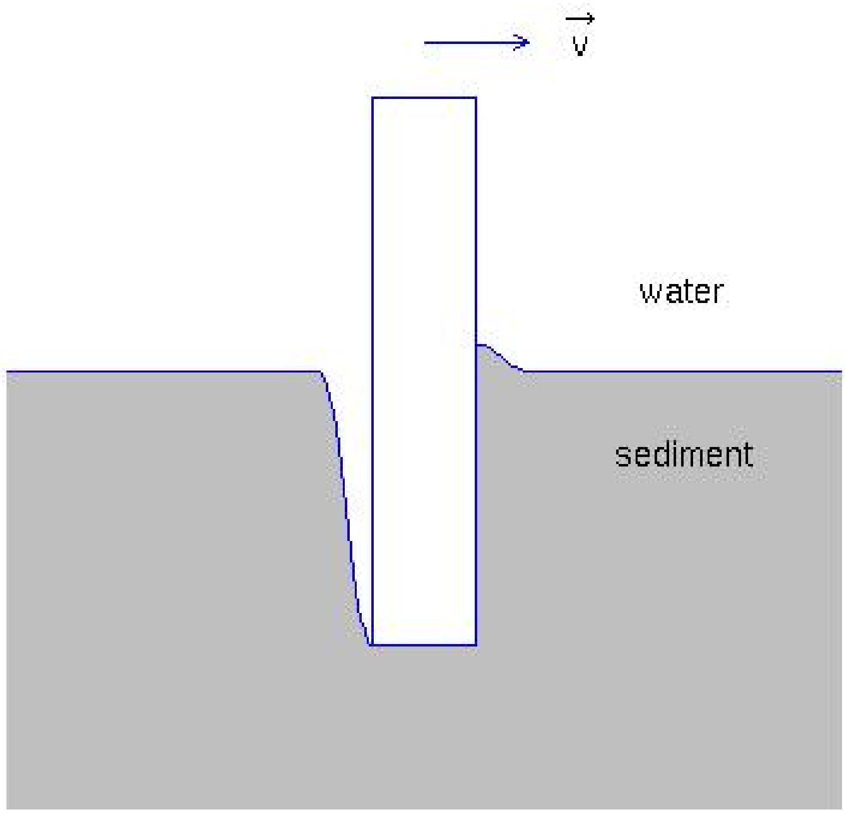
M-Coordinate System



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)

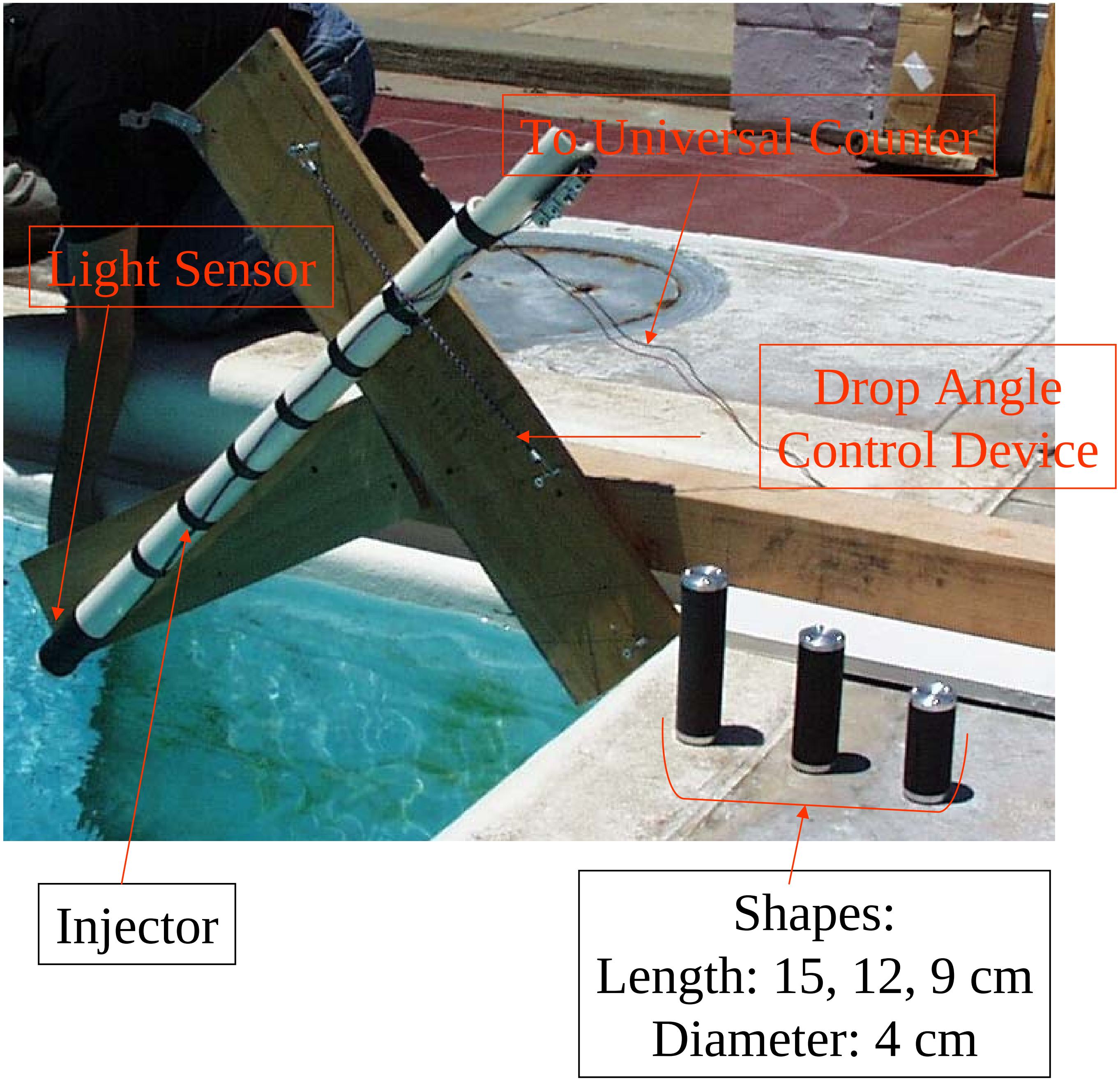
MIDEX

- Cylinder Parameters:

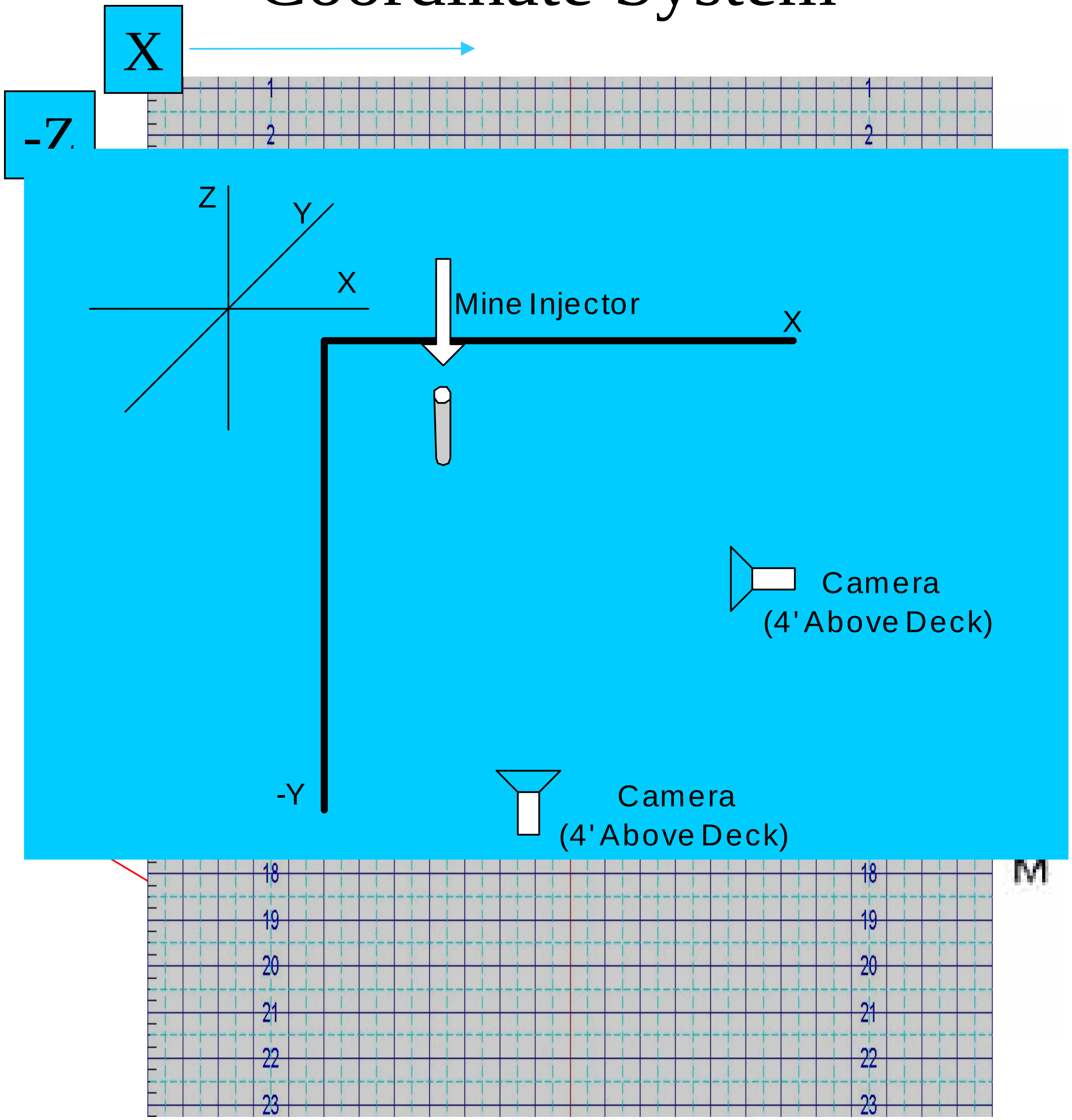
  1. Density Ratio (1.68, 1.70, 1.88)
  2. Center of Mass Position.
  3. L/D ratio.

- Drop Parameters:

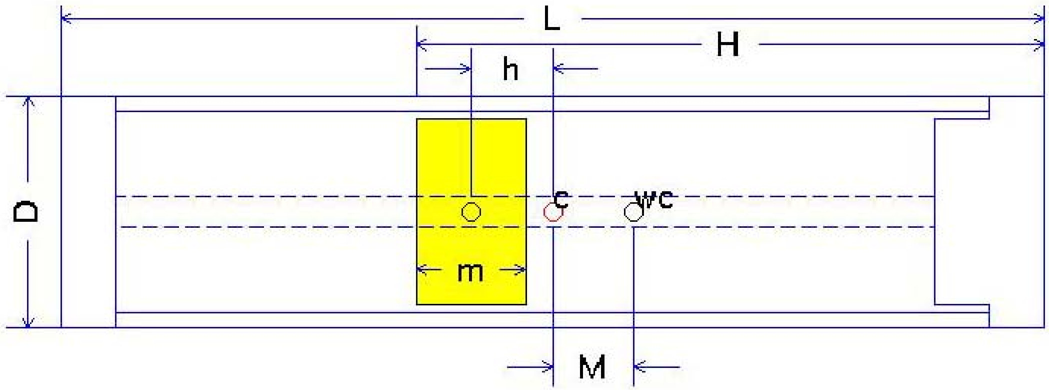
  1. Drop Angles: 15º, 30º, 45º, 60º, 75º.
  2. Release Velocity V_{init}


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 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=12.0726cm D=4cm m=1.7cm
Weight=254.2 g Volume=151.709 cm³ Density=1.6756 g/cm³

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 cm³ Density=1.8786 g/cm³

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

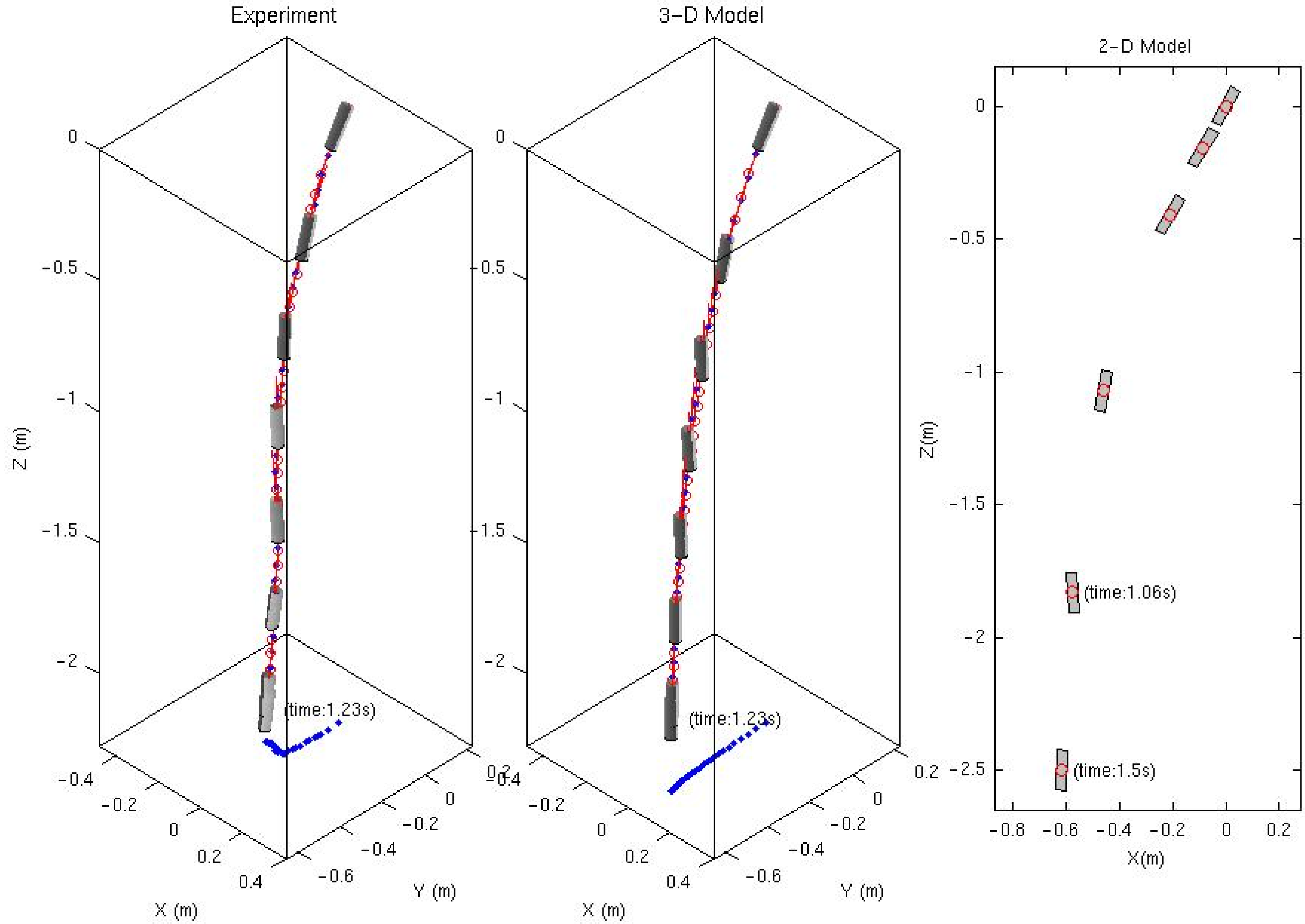
1. Video converted to digital format.
2. Digital video from each camera analyzed frame by frame (30Hz) using video editing program.
3. Mine's top and bottom position determined using background x-z and y-z grids. Positions manually entered into MATLAB for storage and later processing.
4. Analyzed 2-D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

Sources of Error

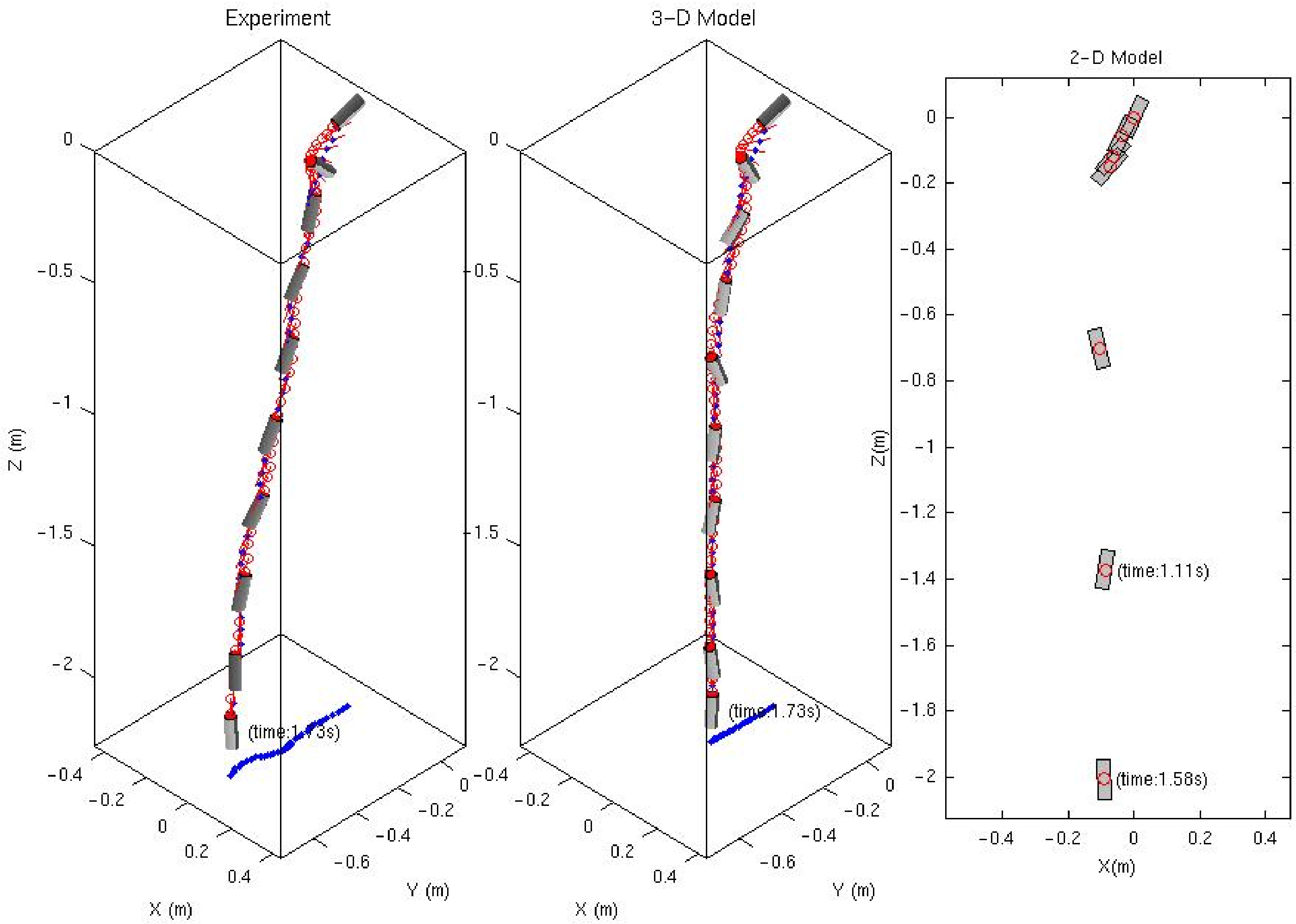
1. Grid plane behind mine trajectory plane. Results in mine appearing larger than normal.
2. Position data affected by parallax distortion and binocular disparity.
3. Air cavity affects on mine motion not considered in calculations.
4. Camera plane not parallel to x-y plane due to pool slope.

UNCLASSIFIED

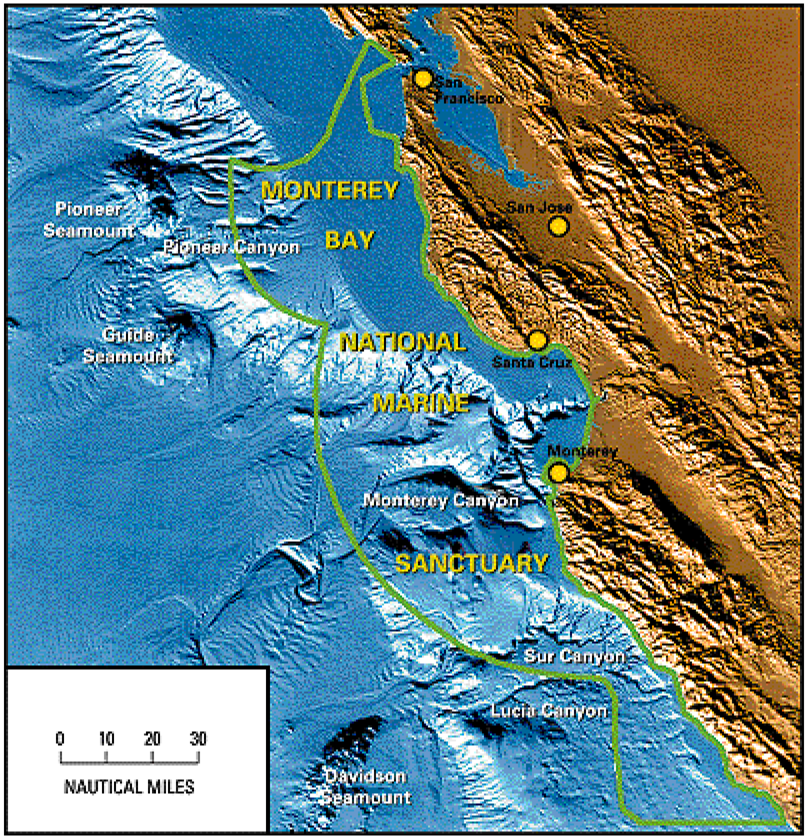
Model-Data Comparison

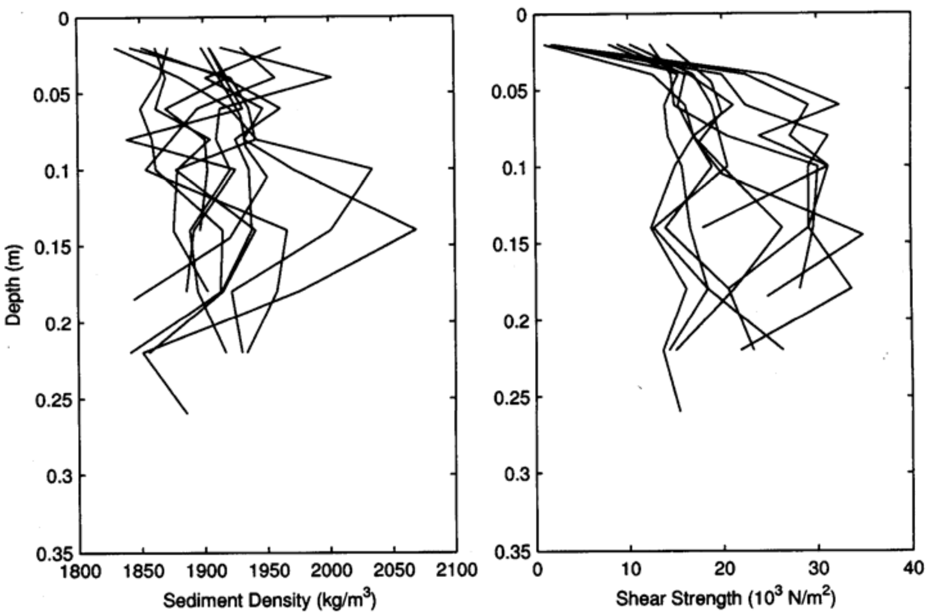


Model-Data Comparison

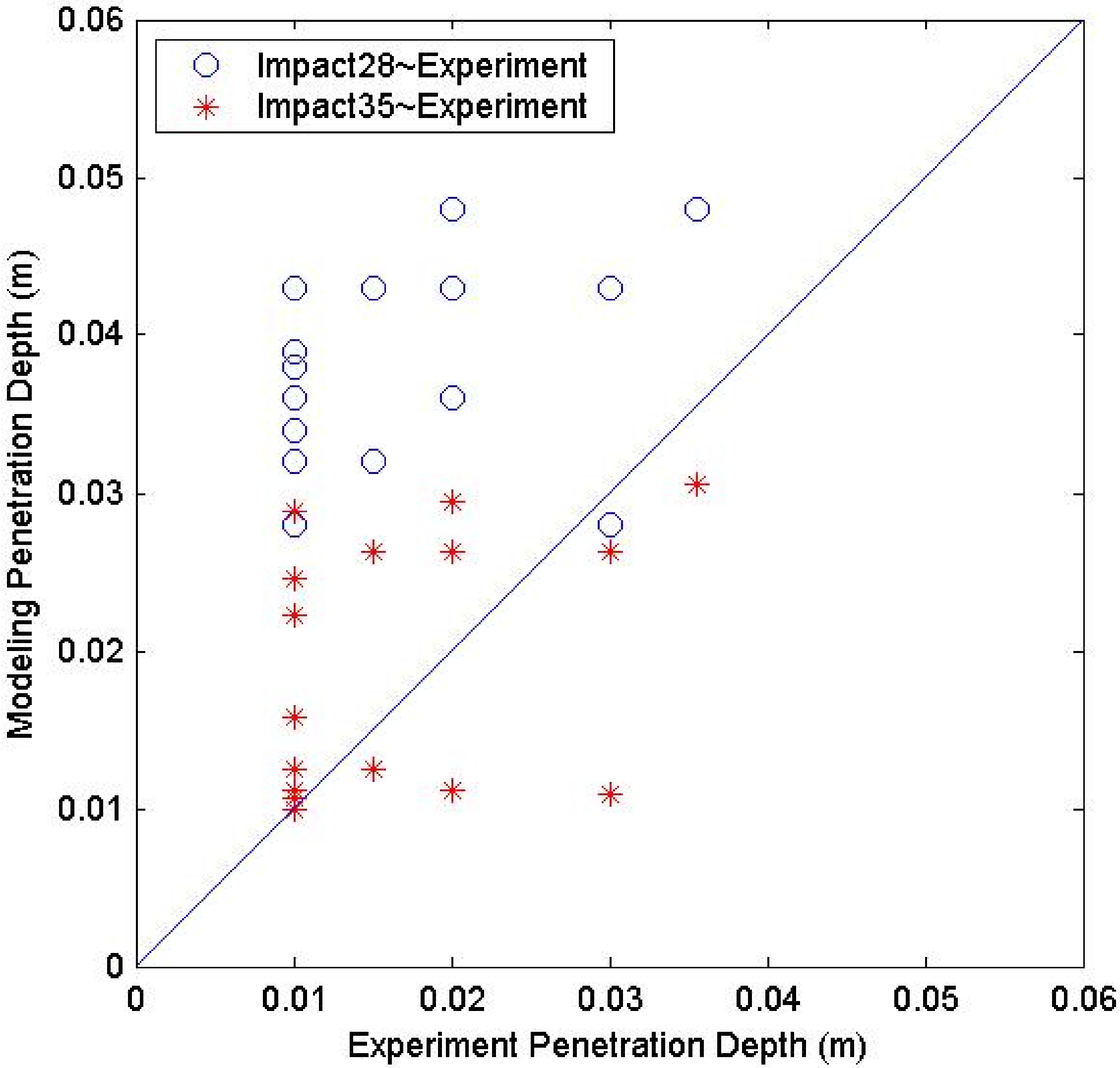


Gravity Cores During MIBEX (5/21/2000)





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 …