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Non-Cylindrical Mine Drop Experiment

Dr. Peter C. Chu, LT Charles Allen
Naval Postgraduate School
Dr. Peter Fleischer
Naval Oceanographic Office

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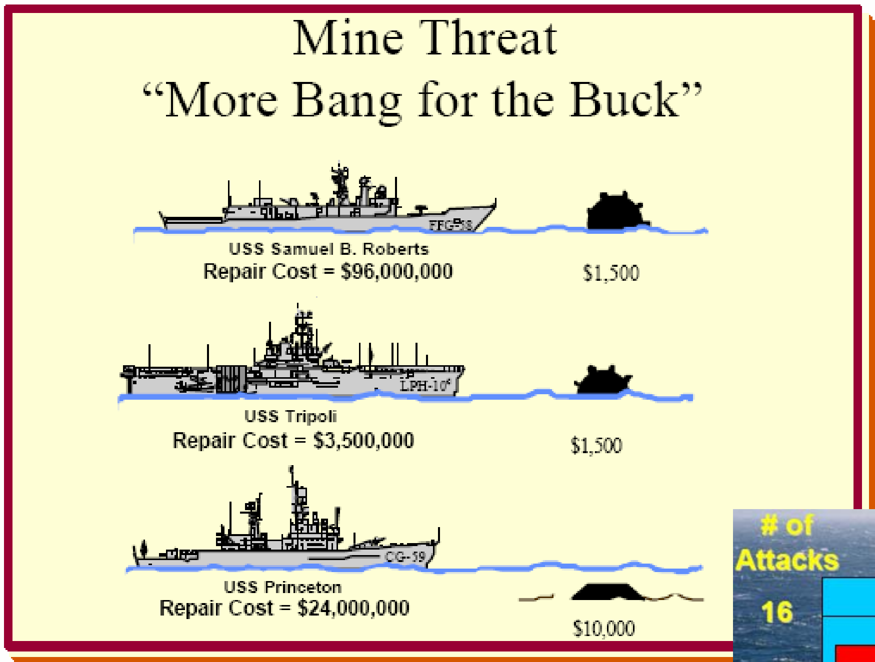
Purpose of the Study

- Increase the operational effectiveness of IMPACT35 through the study and characterization of real-world naval mines.

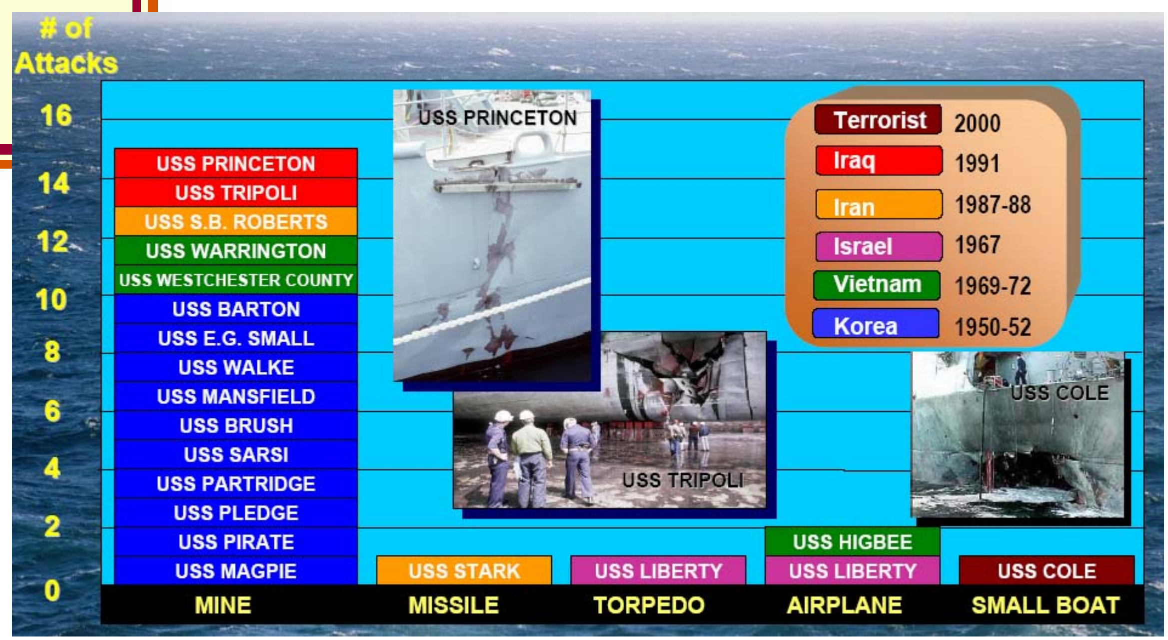
Brief History

- Mine Warfare
- Mine Impact Burial Prediction Models
- Mine Countermeasure Systems

Big Bang for the Buck



The Poor Man's Navy



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Mine Countermeasure

- Mine Countermeasure operations are difficult.
- Time is the target not equipment or people
- Most mines possess complex magnetic, acoustic, and pressure triggering.
- Significant challenges still remain in the surveillance, reconnaissance, detection, and neutralization of mines.
- The primary challenge is to determine exactly where the waiting mines are located
- Attempting to obtain accurate data of potential enemy shores may not be easy

Impact Burial Prediction Model (IBPM)

1-Dimensional IBPM developed in 1980 by Arnone and Bowen (improved later by Satkowiak in 1988)

- Primary Weakness: Assumes a cylindrical shape with a constant mine orientation as it falls.

IBPM

- 2-Dimensional Model (IMPACT 28) developed by Hurst in 1992.

- Contained two momentum equations (in x- and z-directions) and a moment of momentum equation (in the y-direction).

- Able to predict the mine’s COM position in the x-z plane and the rotation about the y-axis.

Advances of IBPM

- 2-Dimensional Model Weakness: Very difficult to include fluid motion, as any fluid motion in the y-axis broke the two-dimensional plane.
- Latest iteration of IBPM, IMPACT 35, is <u>3-D</u>.
- With full physics, the model contains three momentum equations and three moment of momentum equations, predicting the mine's COM position in x,y, and z space and the rotation around all three axes.
- Significant improvement of three-dimensional modeling over two-dimensional.

Full Physics of IBPM

Momentum Equation:

$$\frac{d}{dt}\begin{bmatrix} u \\ v \\ w \end{bmatrix} = -\begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix} + \frac{\mathbf{F}_b + \mathbf{F}_h}{\rho\Pi}$$

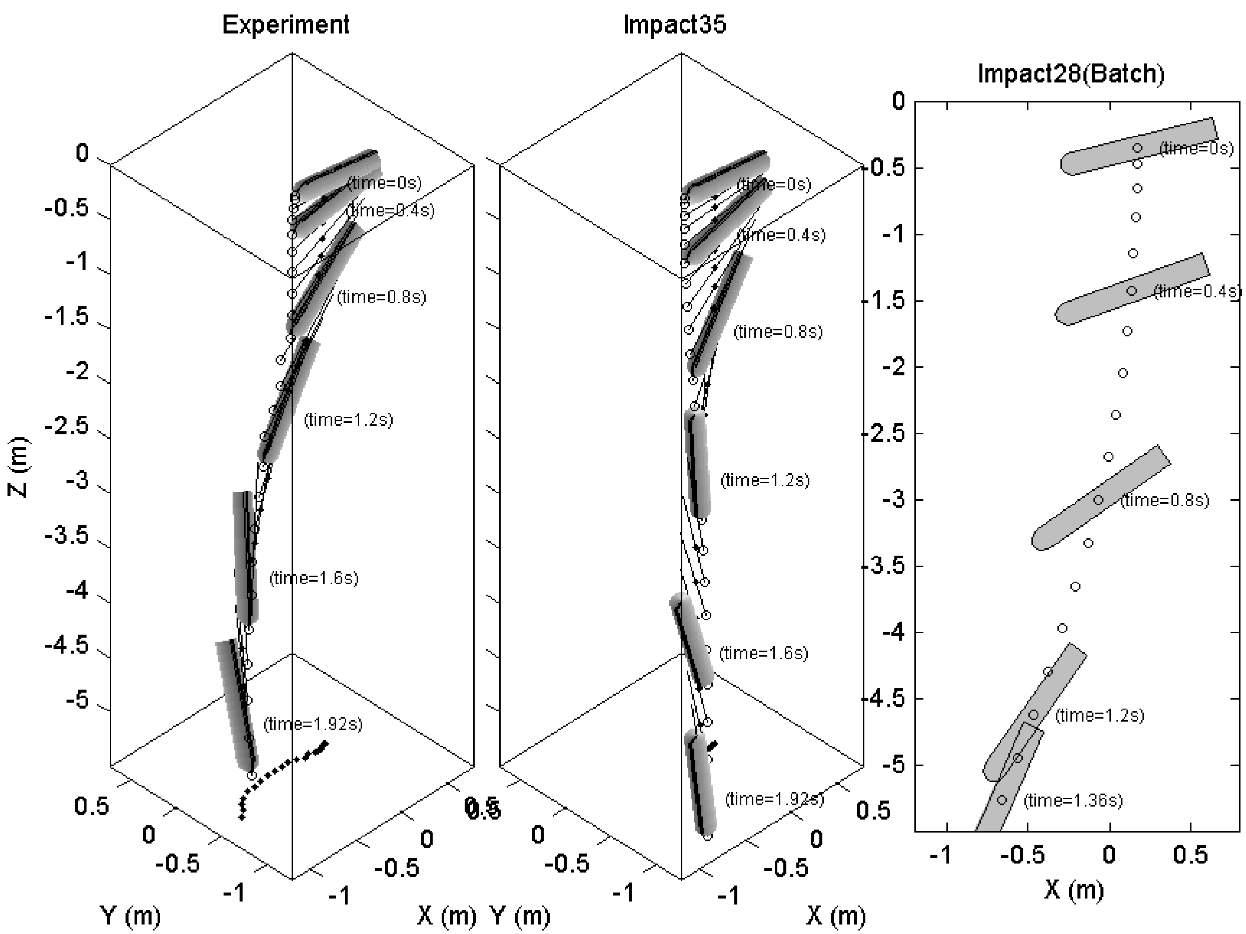
g is the gravitational acceleration
Π is the shape volume
ρ is the rigid body density
$\rho\Pi = m$, is the shape mass
$\mathbf{F}_h$ is the hydrodynamic force
$\mathbf{F}_\mathrm{b} = -\rho_w\Pi$ is the buoyancy force
ρ_w is the water density.

Moment of Momentum Equation

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

$\mathbf{M}_b$ and $\mathbf{M}_h$ are the buoyancy and hydrodynamic force torques.

2D Versus 3D IBPM
NRL/NSWC-Caderock Experiment 2001



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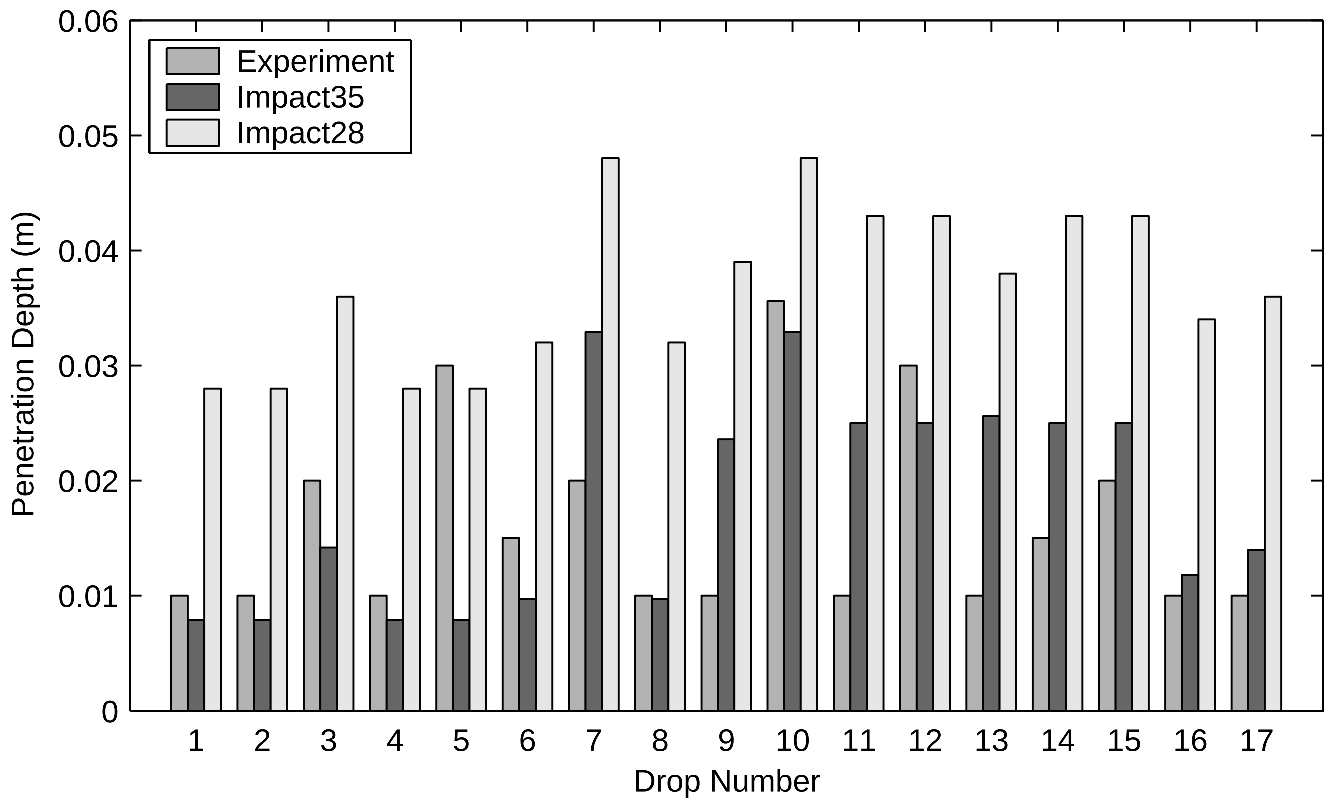
2D Versus 3D Burial Depth Prediction Using NPS MIDEX Data



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Weakness of 3D IBPM (IMPACT35)

- There is but one significant weakness of this 3-D model: Assumes the shape is CYLINDRICAL.

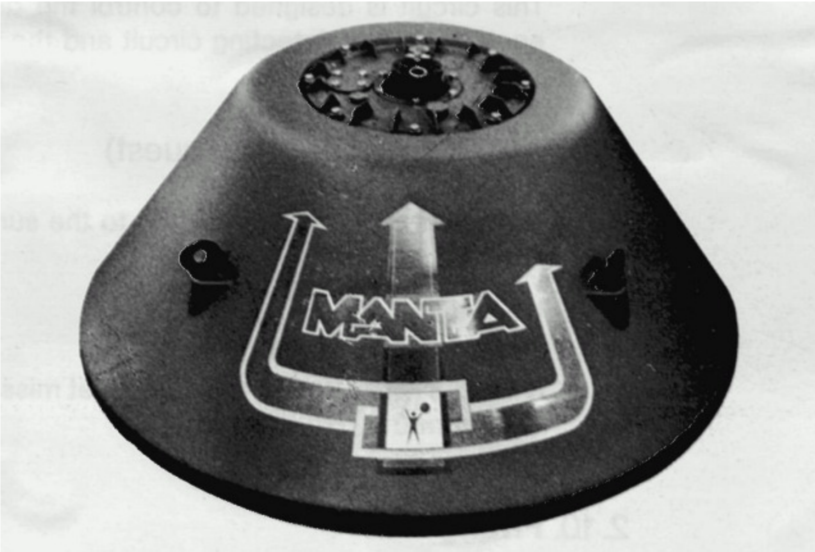
- If the model is to be used operationally, this is a big problem as the most widely-used bottom mines such as the Manta and the Rockan are not cylindrical.

- Determination of the hydrodynamic force and torque for non-cylindrical mines is crucial, but there is no existing formulae for these.

Non-Cylindrical Mine Shape

- Direct continuation of IBPM testing process
- Use of scaled models representing real-world, non-cylindrical shapes to gather water-phase trajectory data.
- Ultimate goal is to make data available for follow-on IBPM modeling work.
- Four shapes tested : Sphere, “Gumdrop,” Manta, and Rockan.

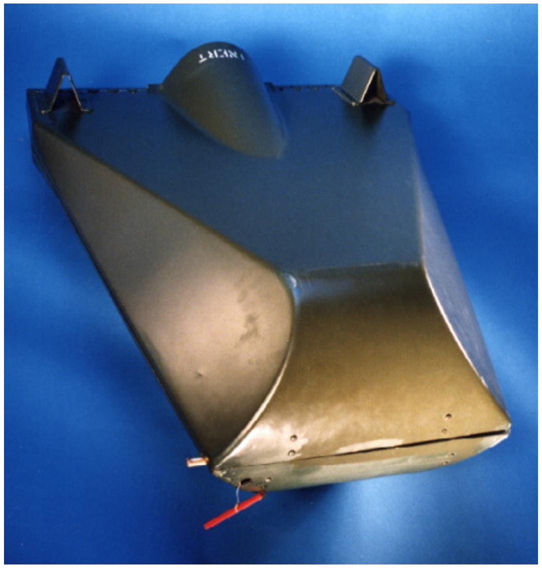
The Italian Manta



Diameter:	**0.980 m**
Height:	**0.440 m**
Weight:	**220 kg**
Charge:	**130 kg (HBX-3)**
Operating Depth:	**3-100 m**

- Anti-invasion bottom mine.
- Glass-Reinforced Plastic (GRP) casing
- Triggered acoustically or magnetically
- Shelf life:30 years
- Active life: 17 months

The Swedish Rockan



Length: **1.015 m**
Width: **0.800 m**
Height: **0.385 m**
Weight: **190 kg**
Charge: **105 kg (Cemtex)**
Operating Depth: **5-100 m**

- Anti-invasion bottom mine
- Acoustic and magnetic triggering.
- GRP “gliding” case.
- Anechoic coating

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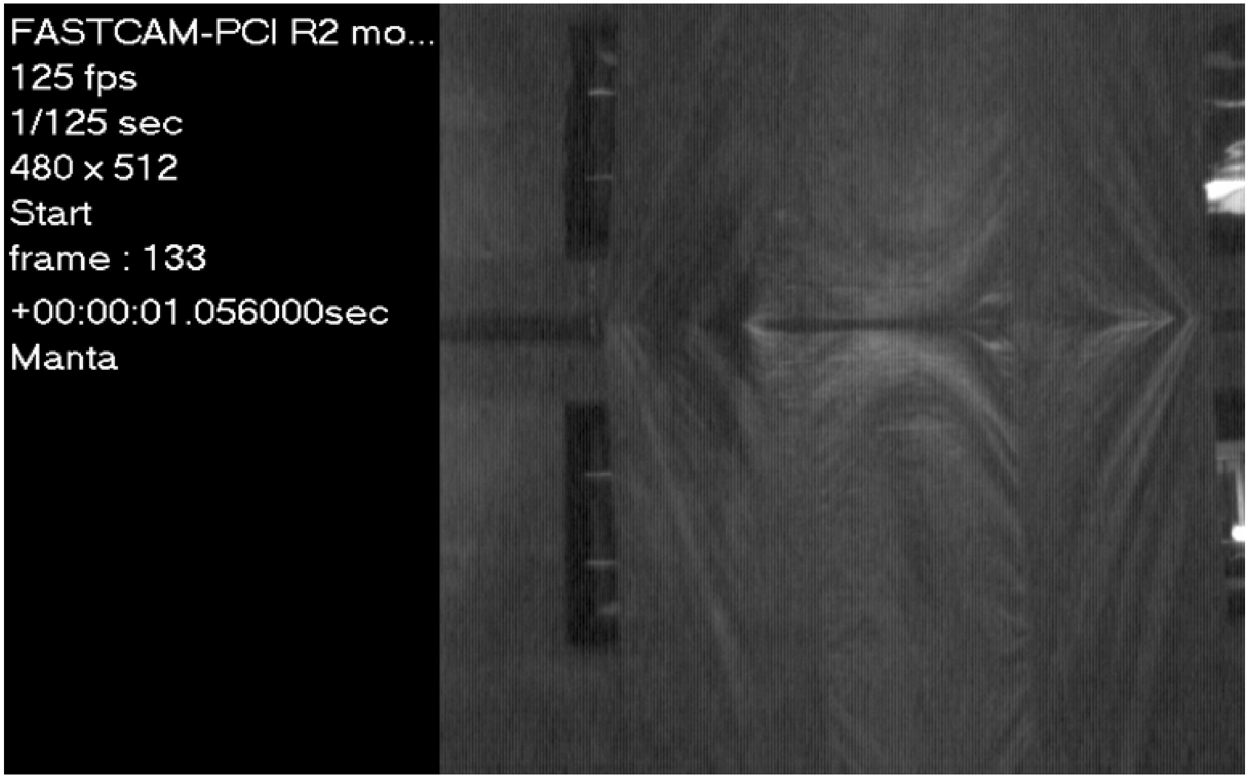
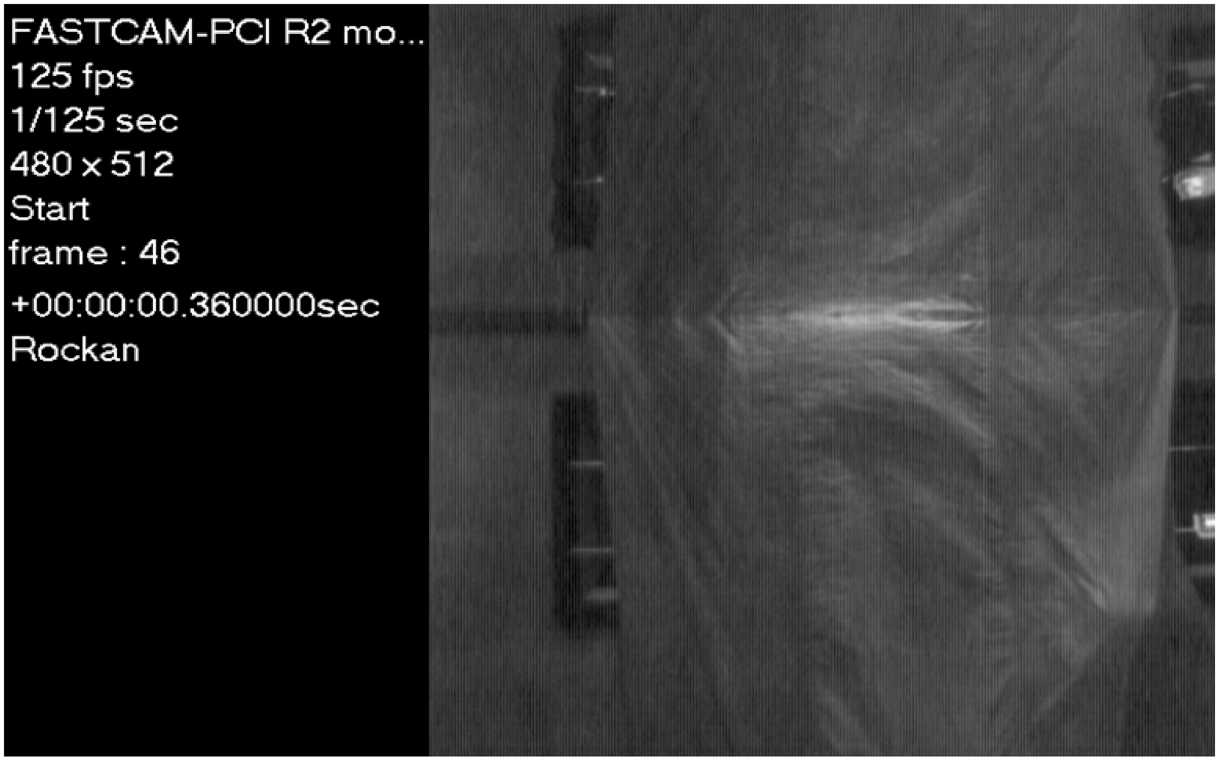
Manta


FASTCAM-PCI R2 mo...
125 fps
1/125 sec
480 x 512
Start
frame : 133
+00:00:01.056000sec
Manta

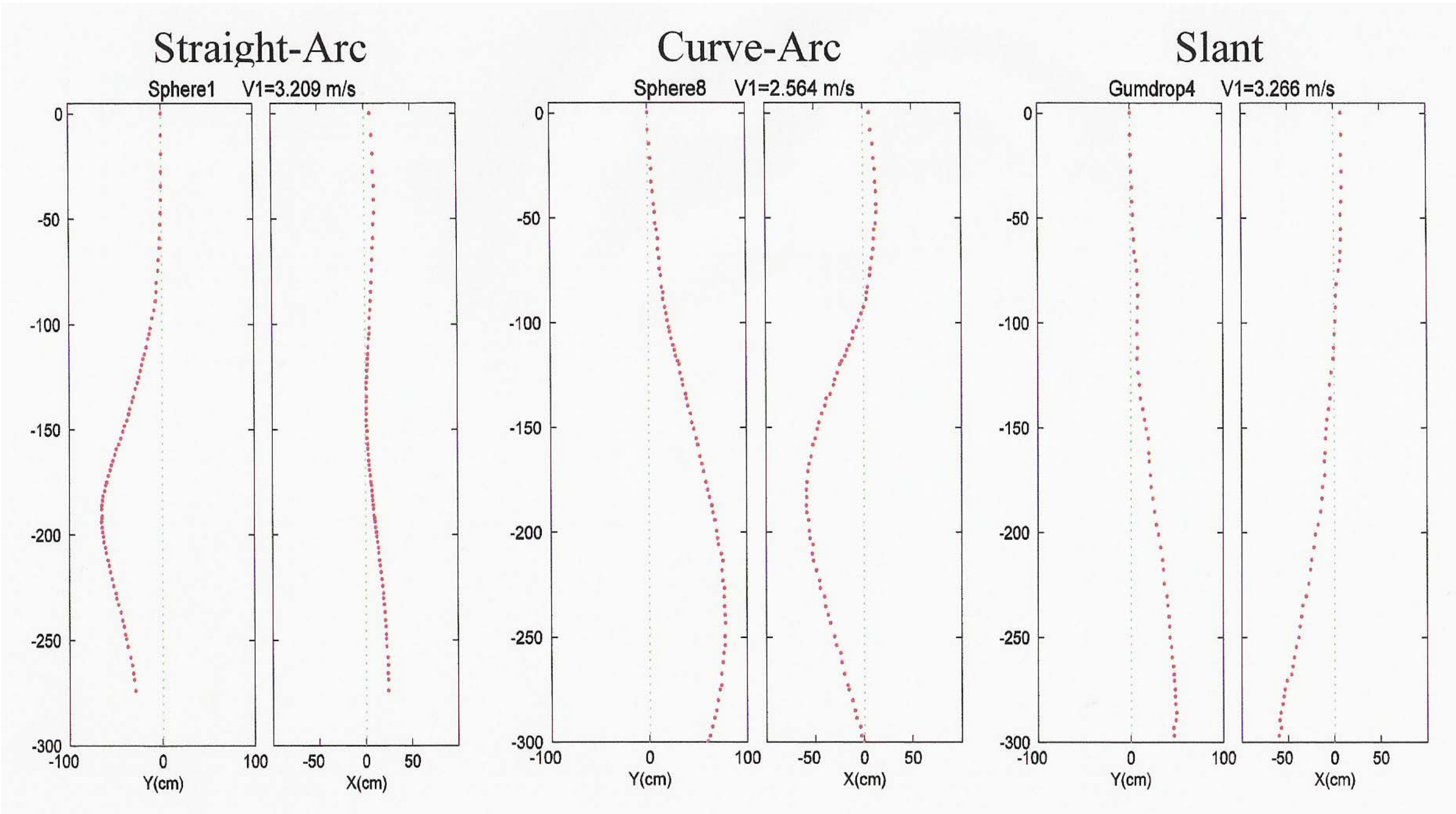
Rockan


FASTCAM-PCI R2 mo...
125 fps
1/125 sec
480 x 512
Start
frame : 46
+00:00:00.360000sec
Rockan

The Sphere and Gumdrop Shapes

Trajectory Pattern	**Description**
Straight-Arc	**The shape follows a vertical path until roughly –100cm, then it follows a smooth arc away from the Z-axis.**
Curve-Arc	**The shape follows a curved path in a smooth arc away from the Z-axis.**
Slant	**The shape travels basically in a straight line angled off of the Z-axis/surface intersection.**

Sphere and Gumdrop Shapes
Trajectory Patterns



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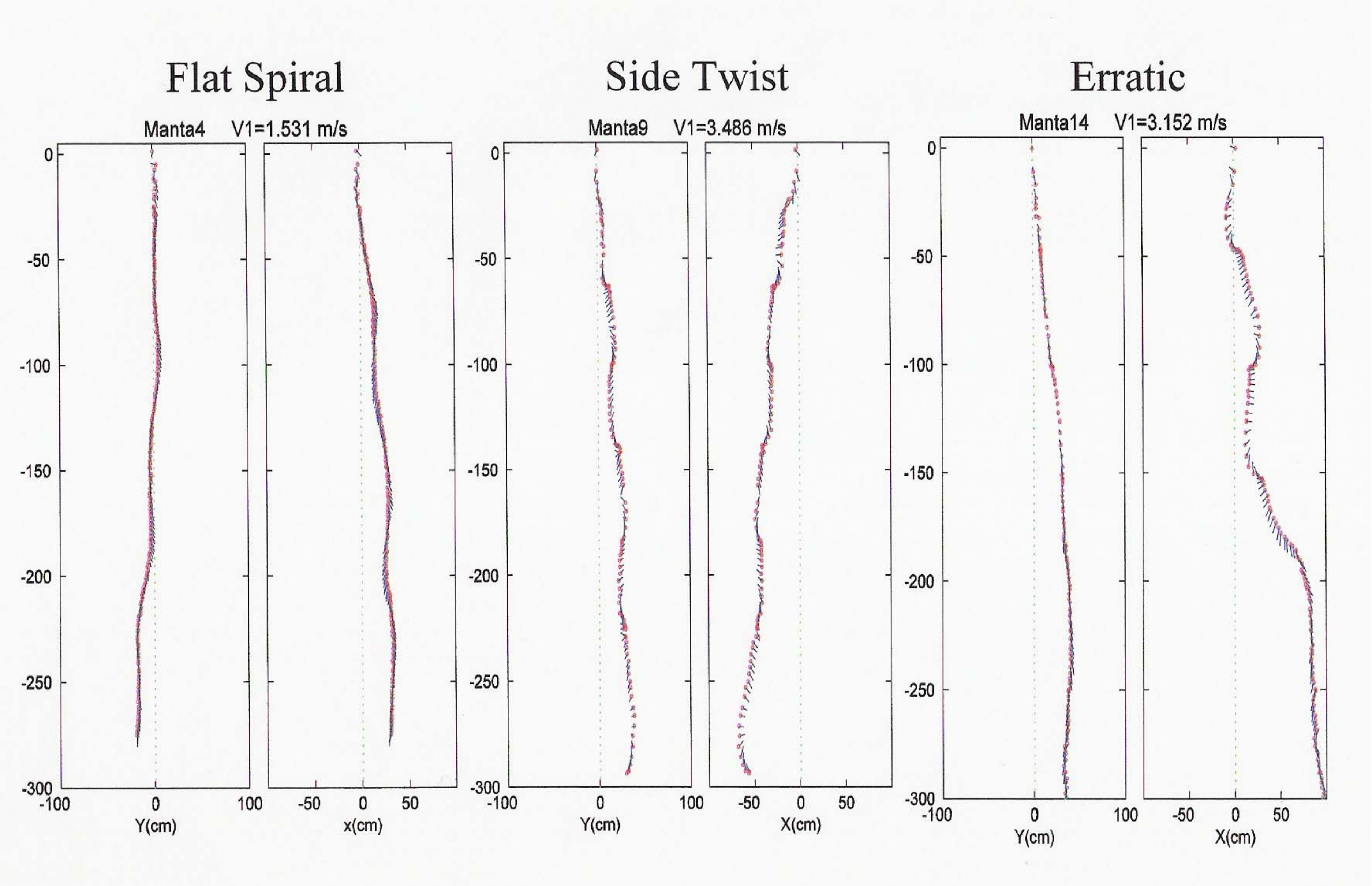
The Manta Shape

Manta Trajectory Pattern	Description
Flat Spiral	**The shape falls with its bottom side basically parallel to the X-Y plane and following a spiraling path.**
Side Twist	**The shape falls with its bottom side perpendicular to the X-Y plane with the top side turning about the bottom in an alternating clockwise and anti-clockwise motion.**
Erratic	**The shape falls in a flipping combination of side and flat spiraling and twisting.**

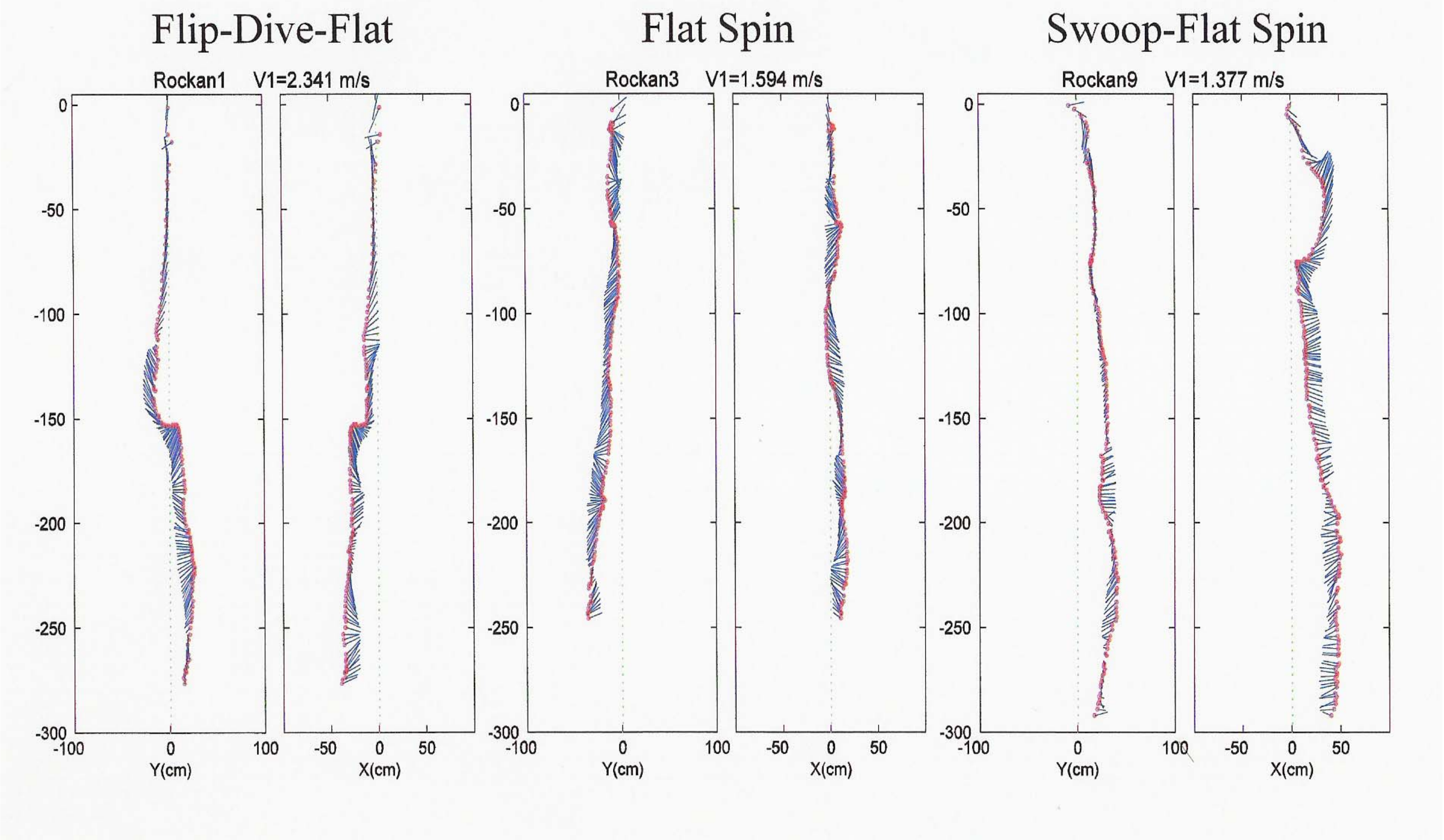
Manta Shape: Trajectory Patterns



The Rockan Shape

Rockan Trajectory Pattern	**Description**
Flip-Dive-Flat	**The shape flips once, goes into a vertical dive and settles into a slowly spinning horizontal orientation for the remainder of the drop.**
Flat Spin	**The shape immediately settles into a slowly spinning horizontal orientation and remains so for the whole of the drop.**
Swoop-Flat Spin	**The shape makes a "U" swooping motion upon entering the water, after which it settles into a slowly spinning horizontal orientation.**

Rockan Shape: Trajectory Patterns



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Trajectory Pattern: Summary

Shape	**Average Time to – 250cm Z**	**Pattern**	**Probability**
Sphere	1.796s	Straight-Arc	0.62
(13 total drops)		Curve-Arc	0.38
		Slant	0.00
Gumdrop	1.462s	Straight-Arc	0.22
(9 total drops)		Curve-Arc	0.56
		Slant	0.22

Trajectory Pattern: Summary

Shape	**Average Time to – 250cm Z**	**Pattern**	**Probability**
Manta	3.703s	Flat Spiral	0.40
(15 total drops)		Side Twist	0.40
		Erratic	0.20
Rockan	4.688s	Flip-Dive-Flat	0.36
(14 total drops)		Flat Spin	0.14
		Swoop-Flat Spin	0.50

-12+ Mb of data for 51 drops.

-- Sample Data Section Below:

Manta	v1=										
2	1.573										
time	pos(x)	pos(y)	pos(z)	el	az	x1	y1	z1	x2	y2	z2
0	0	0	0	0.2489	-0.089	-2.65	0.2366	0.6763	2.65	-0.2366	-0.6763
0.016	1.0266	0.877	-1.9272	0.2283	-0.075	-2.4763	1.14	-1.111	4.5296	0.6139	-2.7435
0.032	-0.0059	1.6109	-5.034	0.5663	0.2217	-1.8329	1.1991	-3.8433	1.8211	2.0226	-6.2248
0.048	1.0642	1.812	-8.8975	0.6146	0.3052	-0.5879	1.2914	-7.6748	2.7164	2.3326	-10.1202
0.064	1.8726	1.7505	-13.0559	0.5801	1.3737	1.6398	0.5842	-12.2765	2.1055	2.9168	-13.8353
0.08	0.4249	1.1682	-17.104	1.1751	2.4841	1.0762	0.6653	-15.1342	-0.2264	1.671	-19.0738
0.096	1.0287	0.4673	-21.2231	1.098	2.9935	2.1314	0.3028	-19.0434	-0.0739	0.6319	-23.4027
0.112	0.4743	0.5906	-22.8637	0.5987	2.7264	1.9202	-0.0467	-21.7856	-0.9717	1.228	-23.9418
0.128	-0.1544	0.9472	-24.8757	0.6953	2.7755	1.7058	0.2341	-23.2136	-2.0146	1.6603	-26.5378
0.144	0.2888	0.695	-26.5979	0.6755	2.73	1.6792	0.0881	-25.3823	-1.1016	1.302	-27.8134
0.16	0.1526	0.8093	-27.673	0.4183	2.8227	1.9877	0.2034	-26.814	-1.6825	1.4152	-28.5321
0.176	1.0865	1.1172	-28.4406	0.5096	2.7333	2.9009	0.3324	-27.336	-0.7278	1.9021	-29.5453
0.192	0.7704	1.3447	-29.3054	0.6743	2.7226	2.1716	0.7207	-28.0793	-0.6309	1.9688	-30.5315
0.208	1.9471	1.0416	-31.5114	1.1301	2.5677	2.5121	0.6763	-30.0848	1.382	1.4069	-32.938
0.224	3.6751	0.8476	-32.5761	1.494	1.5585	3.6729	0.6721	-30.2962	3.6773	1.0231	-34.856
0.24	4.2997	0.7749	-33.505	1.1989	0.5959	3.7704	0.416	-31.8656	4.8289	1.1339	-35.1444
0.256	5.966	1.1659	-33.198	1.03	0.1767	4.6853	0.9372	-31.0315	7.2467	1.3946	-35.3644
0.272	6.4472	1.1568	-33.7435	0.7596	0.352	4.9032	0.5897	-32.1815	7.9912	1.724	-35.3056
0.288	7.509	1.2762	-34.0726	0.8668	0.0167	5.6969	1.2458	-31.9383	9.3212	1.3065	-36.207
0.304	7.1236	1.2602	-34.1381	0.7368	0.0509	5.4868	1.1769	-32.6511	8.7604	1.3436	-35.6251
0.32	7.3128	1.1139	-35.076	0.5785	0.096	5.3566	0.9256	-33.7927	9.2689	1.3022	-36.3593
0.336	7.9869	0.8425	-35.7766	0.4864	0.1469	6.1268	0.5673	-34.7822	9.8471	1.1177	-36.771
0.352	8.6044	0.4401	-36.6309	0.4565	-0.0327	6.1339	0.521	-35.4171	11.0748	0.3592	-37.8447
0.368	9.0886	-0.0097	-37.3031	0.566	-0.0762	6.5638	0.1831	-35.6945	11.6133	-0.2024	-38.9118
0.384	9.2923	0.2361	-37.6281	0.3975	0.0185	7.1699	0.1967	-36.7367	11.4148	0.2754	-38.5194
0.4	9.51	-0.3088	-38.6094	0.2082	0.0255	7.6209	-0.3569	-38.2102	11.399	-0.2607	-39.0086

Conclusions

- Next step of ongoing process to understand and predict the various parameters that affect a mine's water-phase trajectory.
- Observed trajectories were highly variable.
- The Manta and Rockan shapes' trajectories were generally more complex than the Sphere and Gumdrop trajectories.
- The denser Gumdrop shape had the fastest and straightest drops overall.
- Because of important factors, the dispersion of all four shapes' impact points was wide and variable.

Future Work

- More realistic Manta and Rockan mine shapes (with detailed inner modeling)
- Larger scale versions of the Rockan to more closely mimic "gliding."
- Changing the water column (e.g. adding currents or turbulence)

Future Work

- The trajectory information gathered in MIDEX II needs to be compared with the results of IMPACT 35 using the same initial conditions.

- Chaotic features of MIDEX II trajectories should be investigated with instability and predictability analyses.

- Differences and similarities with IMPACT 35 can then be used to generate the next iteration of the IBPM.