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Wave Effect on Underwater Bomb Trajectory with Application to Mine Neutralization

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This project was sponsored by ONR
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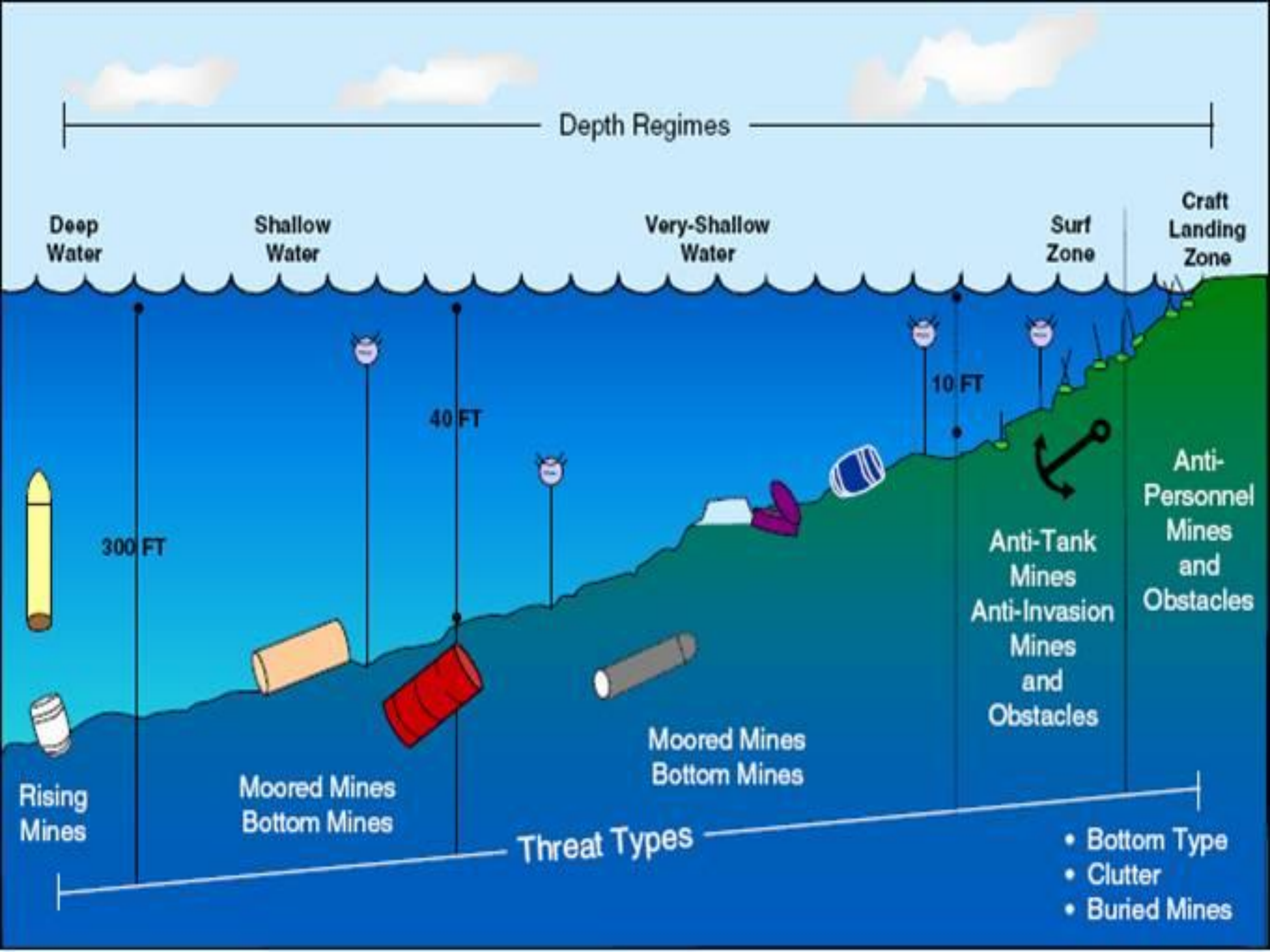
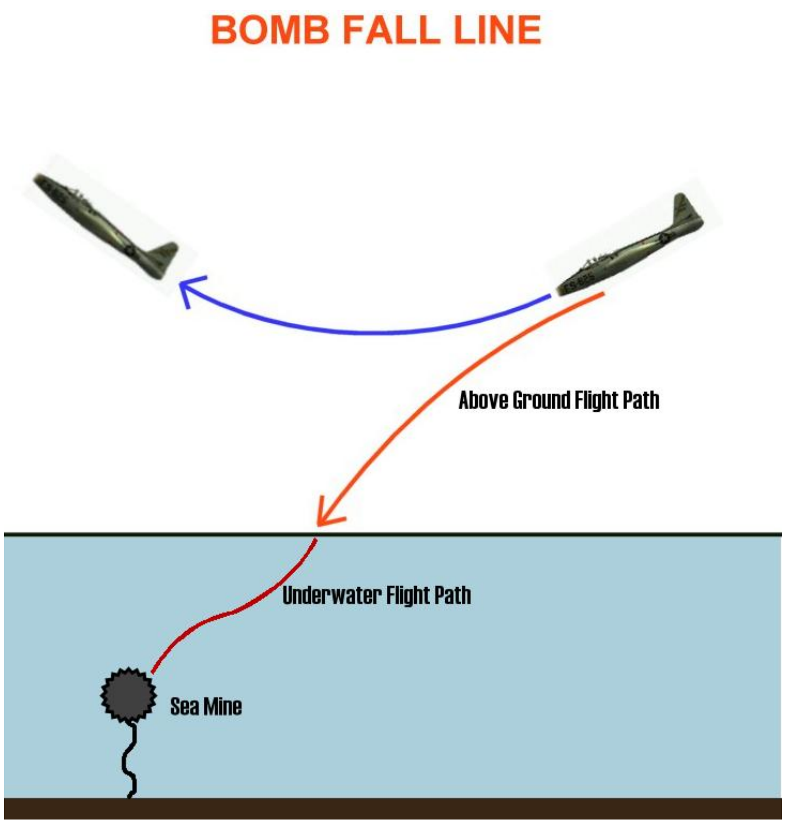
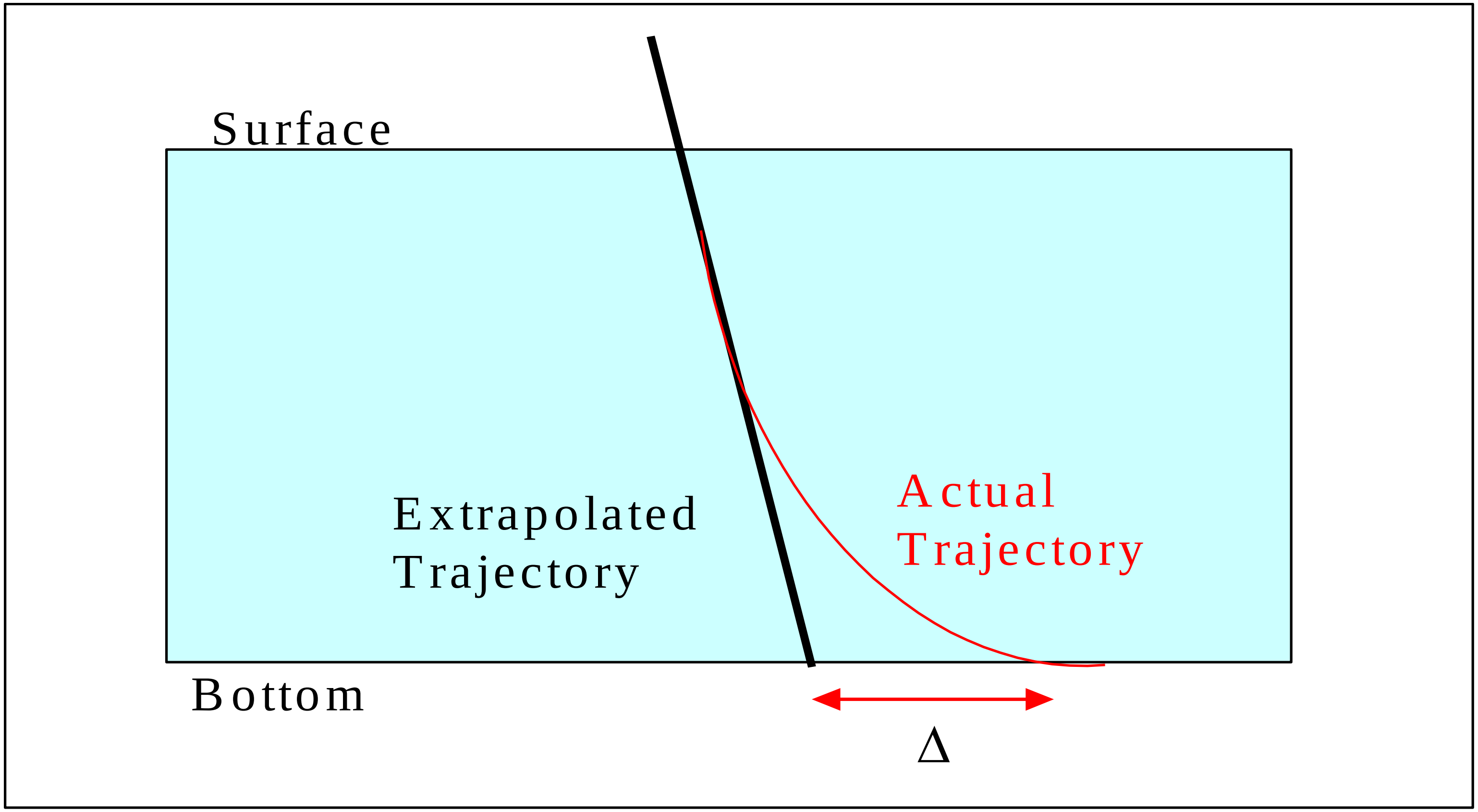

Depth Regimes
Deep Water
Shallow Water
Very-Shallow Water
Surf Zone
Craft Landing Zone
300 FT
40 FT
10 FT
Rising Mines
Moored Mines Bottom Mines
Moored Mines Bottom Mines
Anti-Tank Mines Anti-Invasion Mines and Obstacles
Anti-Personnel Mines and Obstacles
Threat Types
• Bottom Type
• Clutter
• Buried Mines

Mine Neutralization Using Bomb

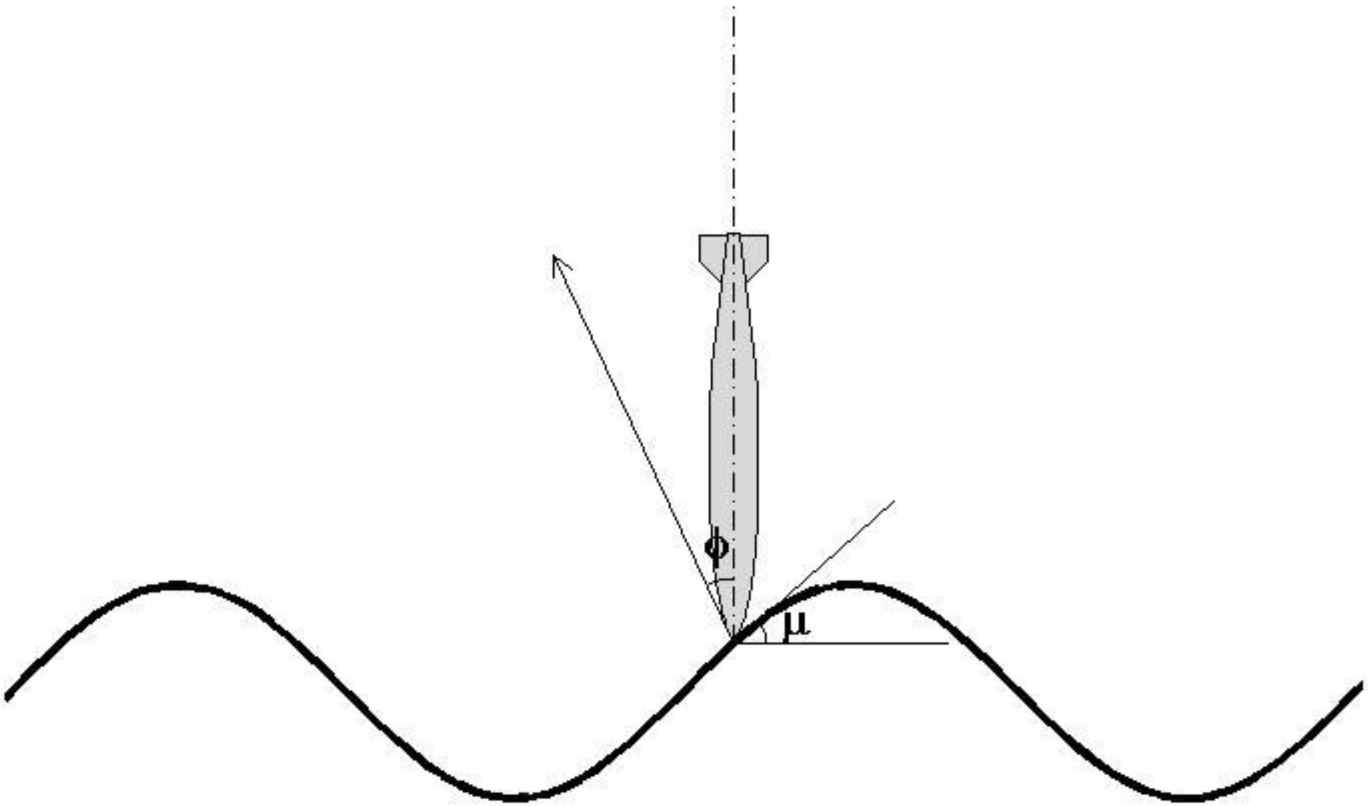




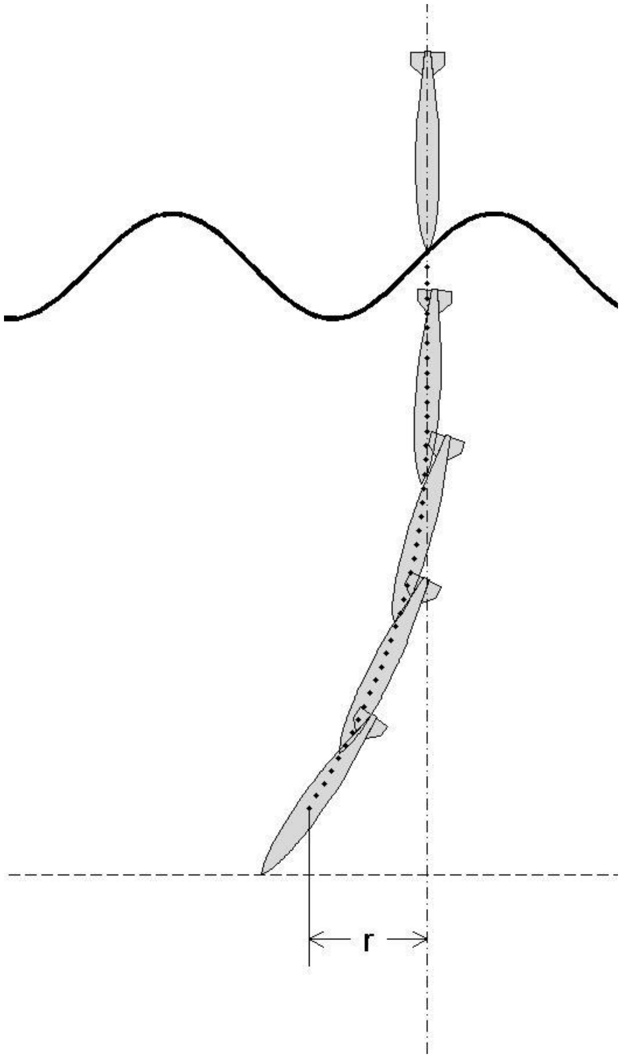
For effective mine clearance

$\Delta < 7$ ft (2.1 m)

The Technology Transition Agreement (TTA) between the Office of Naval Research and the Navy states that the "trajectory deviation from the flight path (velocity vector) should not exceed 7 ft (2.1 m) (approximate) for water depths of 10-40 ft (3-12.2 m)" (Humes 2007).

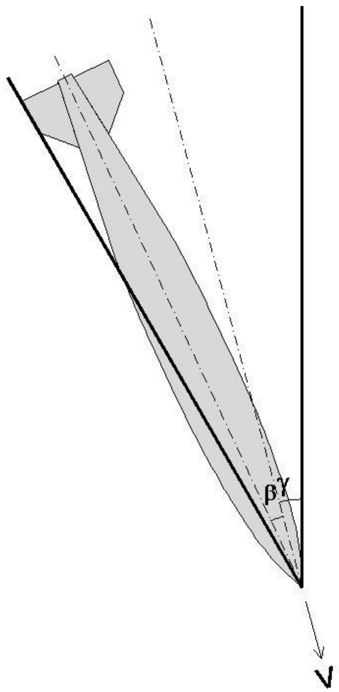

φ
μ

Navy’s Standard

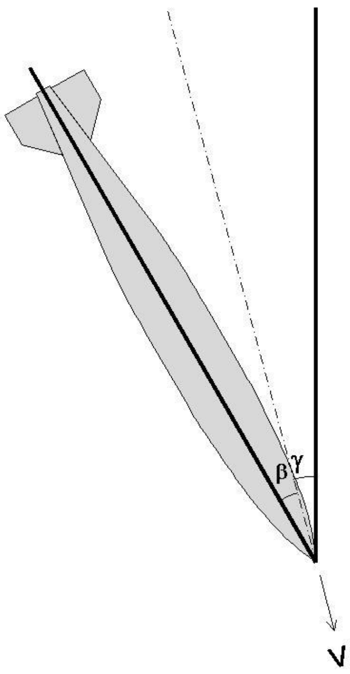


r < 2.1 m (i.e., 7 ft)

Air Cavity

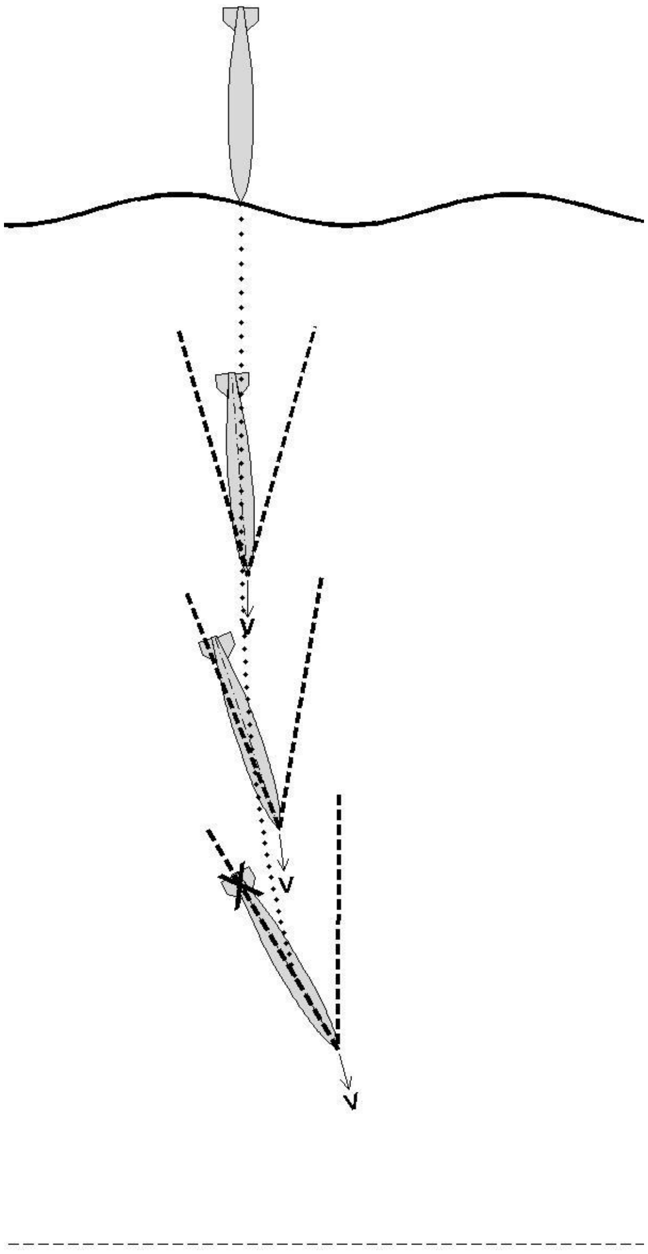


Inside the cavity



Hitting the cavity wall → Tail Separation

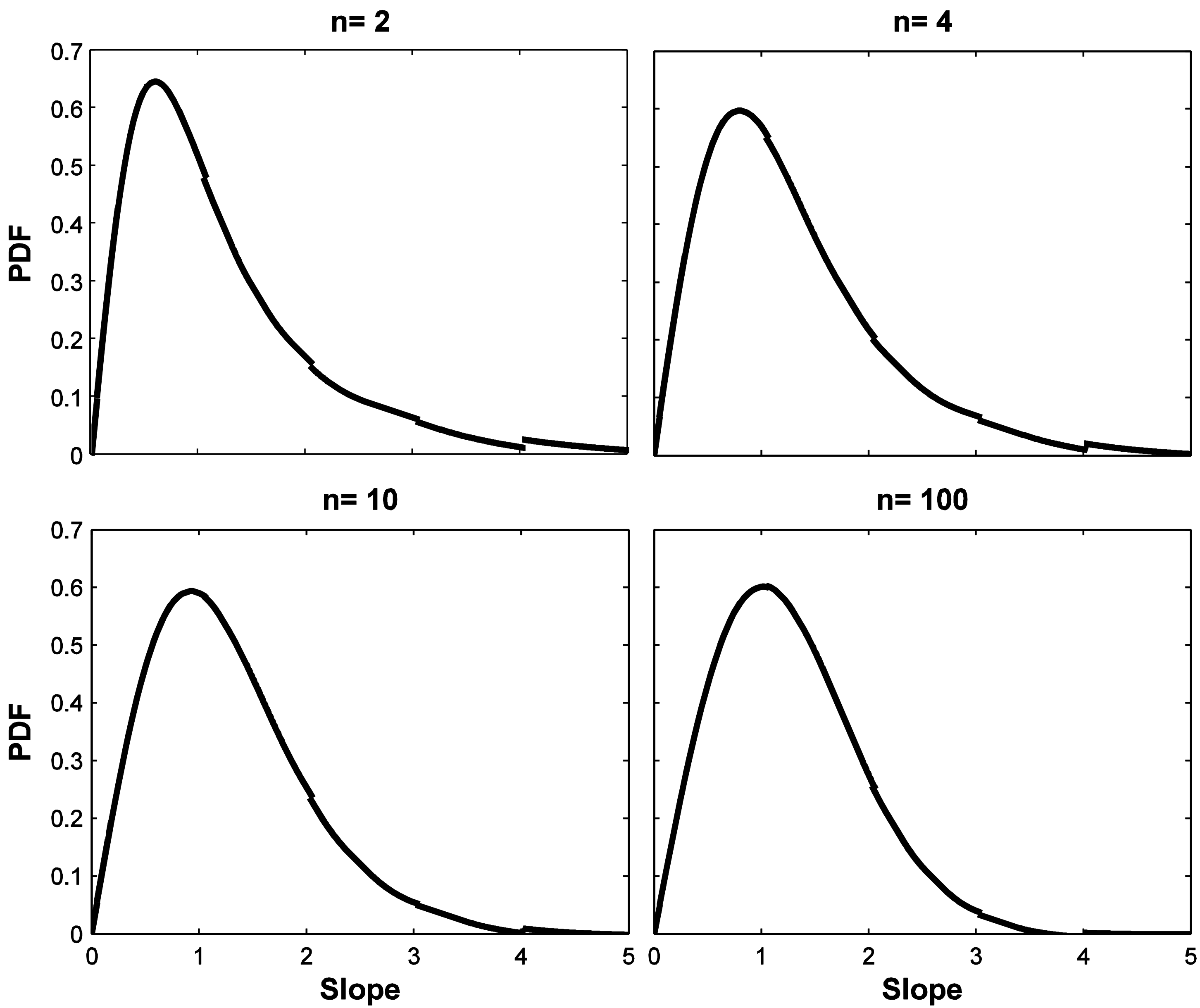
Surface slope affects
the tail separation and the
trajectory



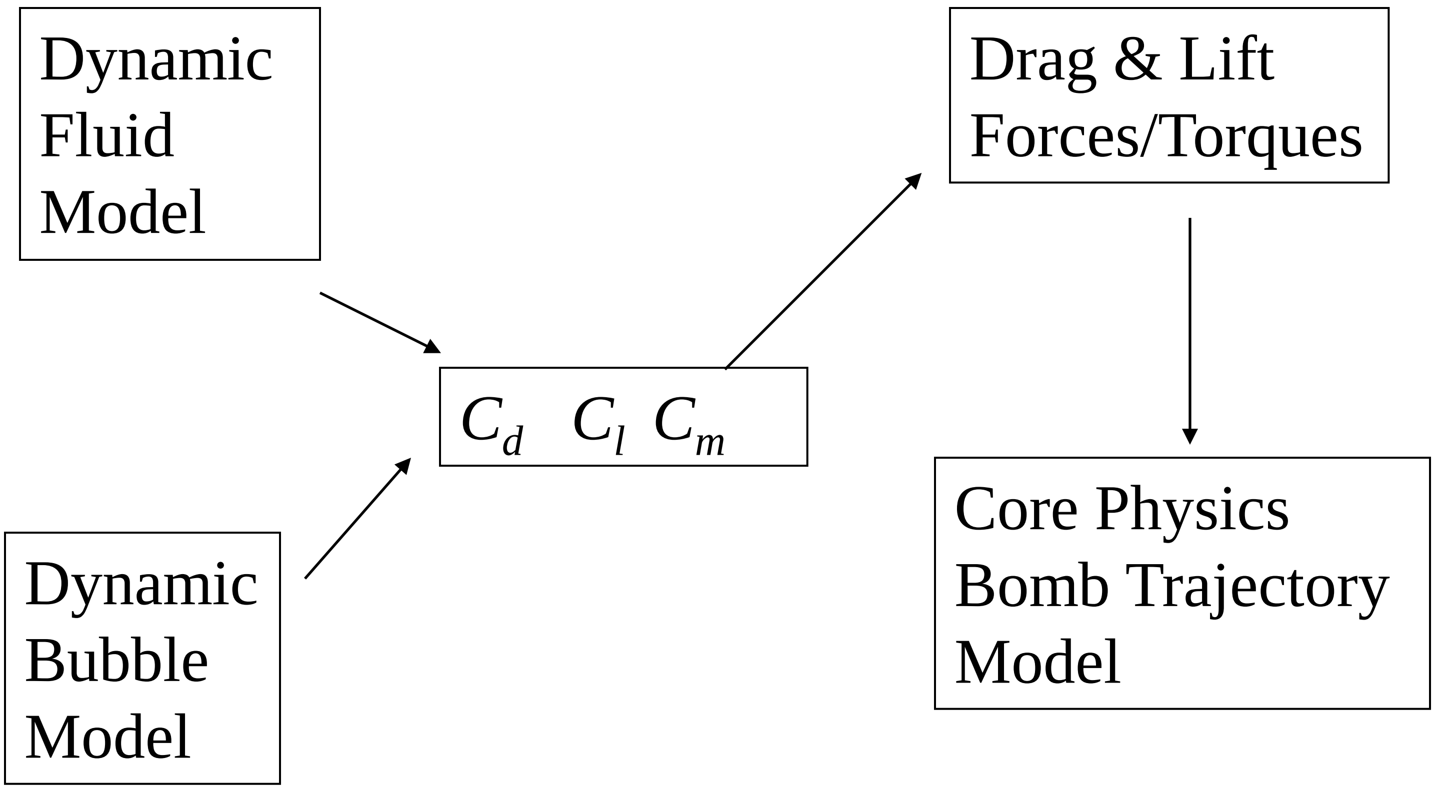
Probability Density Function (PDF) of Ocean Surface Slope

$$p(s) = \frac{n}{(n-1)} s \left[1 + \frac{s^2}{(n-1)} \right]^{-(n+2)/2}$$

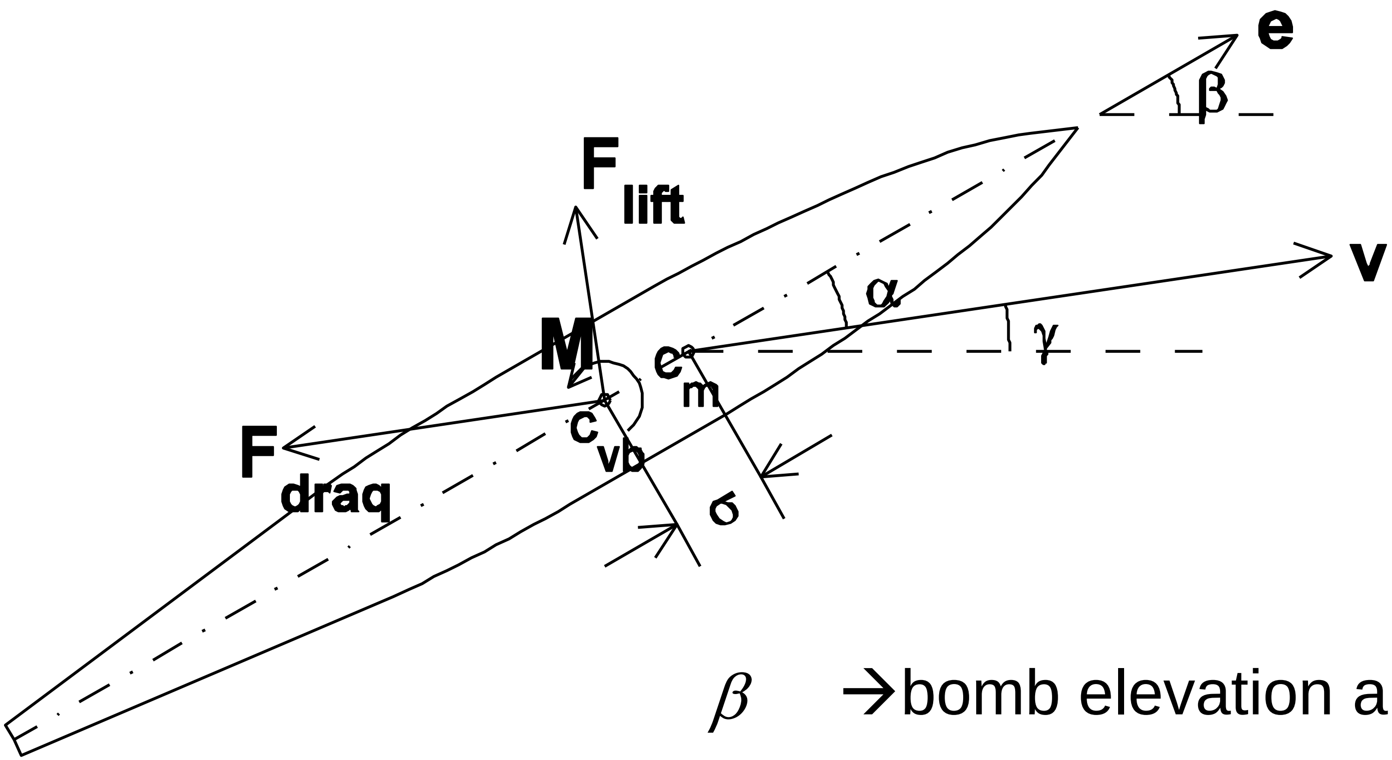
s → scaled slope, *n* → peakedness coefficient


n= 2
n= 4
n= 10
n= 100
PDF
PDF
Slope
Slope
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
1
2
3
4
5

6-FOF Bomb Trajectory Model



Dynamical Determination of Drag/Lift Coefficients



β → bomb elevation angle

γ → bomb velocity angle

α → attack angle

Definitions of $(C_d \;\; C_l \;\; C_m)$

$$f_{drag} = \frac{1}{2} C_d \rho A_w V^2$$

$$f_{lift} = \frac{1}{2} C_l \rho A_w V^2$$

$$M_{trav} = \frac{1}{2} C_m \rho \Pi_w V^2$$

Π_w → Underwater volume

A_w → Underwater area

Theoretical Base

$$m\frac{d\mathbf{V}}{dt} = \left(\rho\Pi - m\right)g\mathbf{k} + f_{drag}\mathbf{e}_d + f_{lift}\mathbf{e}_l$$

$$\mathbf{I} \bullet \frac{d\mathbf{\Omega}}{dt} = \mathbf{r}_v \times \mathbf{f}_b + \mathbf{r}_f \times \left(\mathbf{f}_{drag} + \mathbf{f}_{lift}\right) + \mathbf{M}_r$$

Here, **V** is the translation velocity of COM,

$\mathbf{\Omega}$ is the angular velocity.

There is no existing formulae for calculating C_d C_l C_m for JABS

Diagnostic-Photographic Method → (C_d C_l C_m) for underwater bomb using data from 12th scaled bomb drop experiments at SRI and NPS

Chu, P.C., C.W. Fan, and P. R. Gefken, 2010: Diagnostic-photographic determination of drag/lift/torque coefficients of high speed rigid body in water column. *Journal of Applied Mechanics*, AMSE, **77**, 011015-1

Semi-Empirical Formulas for (C_d C_l)

$$C_d = 0.02 + 0.35 e^{-2\left(\alpha - \pi/2\right)^2} \left(\frac{\mathrm{Re}}{\mathrm{Re}^*}\right)^{0.2} + 0.008\Omega \sin\theta$$

$$\theta = sign\left(\pi - 2\alpha\right)\left(\pi^{2.2} - \left(\pi - \left|\pi - 2\alpha\right|\right)^{2.2}\right)^{\frac{1}{2.2}}$$

$$C_l = \begin{cases} 0.35 \sin\left(\theta_1\right)\left(\frac{\mathrm{Re}}{\mathrm{Re}^*}\right)^{0.2} & if \ \alpha \le \frac{\pi}{2} \\ 0.1 \sin\left(\theta_2\right) - 0.015\Omega\left(\frac{\mathrm{Re}}{\mathrm{Re}^*}\right)^{2} \sin\left(\theta_2^{\,0.85}\right) & if \ \alpha > \frac{\pi}{2} \end{cases}$$

Where $\theta_1 = \pi\left(\frac{2\alpha}{\pi}\right)^{1.8}$ and $\theta_2 = 2\pi\left(\frac{2\alpha}{\pi} - 1\right)^{0.7}$.

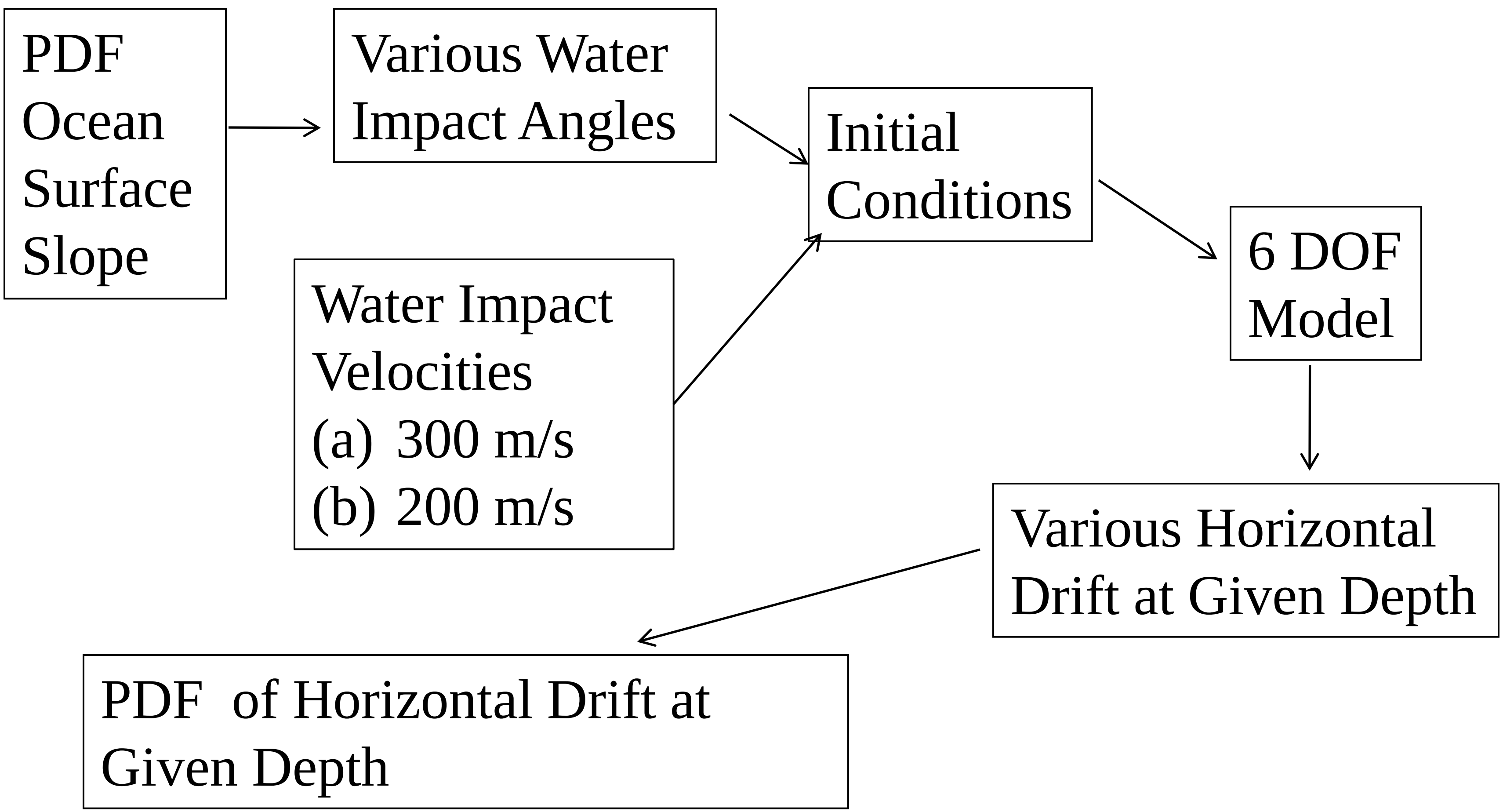
$\mathrm{Re}^* = 1.8 \times 10^7$

Semi-Empirical Formulas for C_m

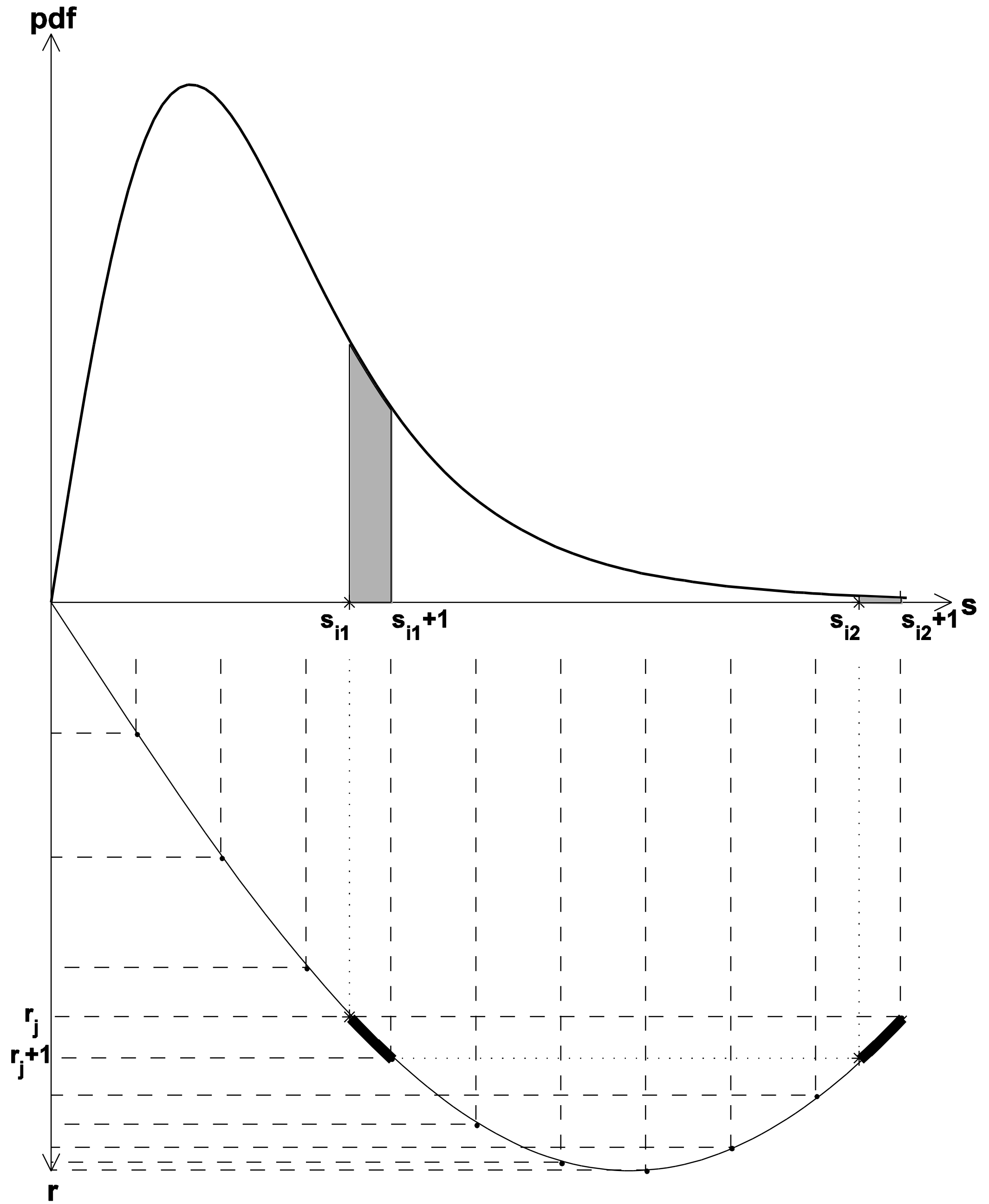
$$C_m = \begin{cases} 0.07\sin(2\alpha)\left(\frac{\mathrm{Re}^*}{\mathrm{Re}}\right)^{0.2} & if\ \alpha \le \frac{\pi}{2} \\ 0.02\sin(2\alpha)\sqrt{\left(\frac{\mathrm{Re}}{\mathrm{Re}^*}\right)} & if\ \alpha > \frac{\pi}{2} \end{cases}$$

$\mathrm{Re}^* = 1.8 \times 10^7$

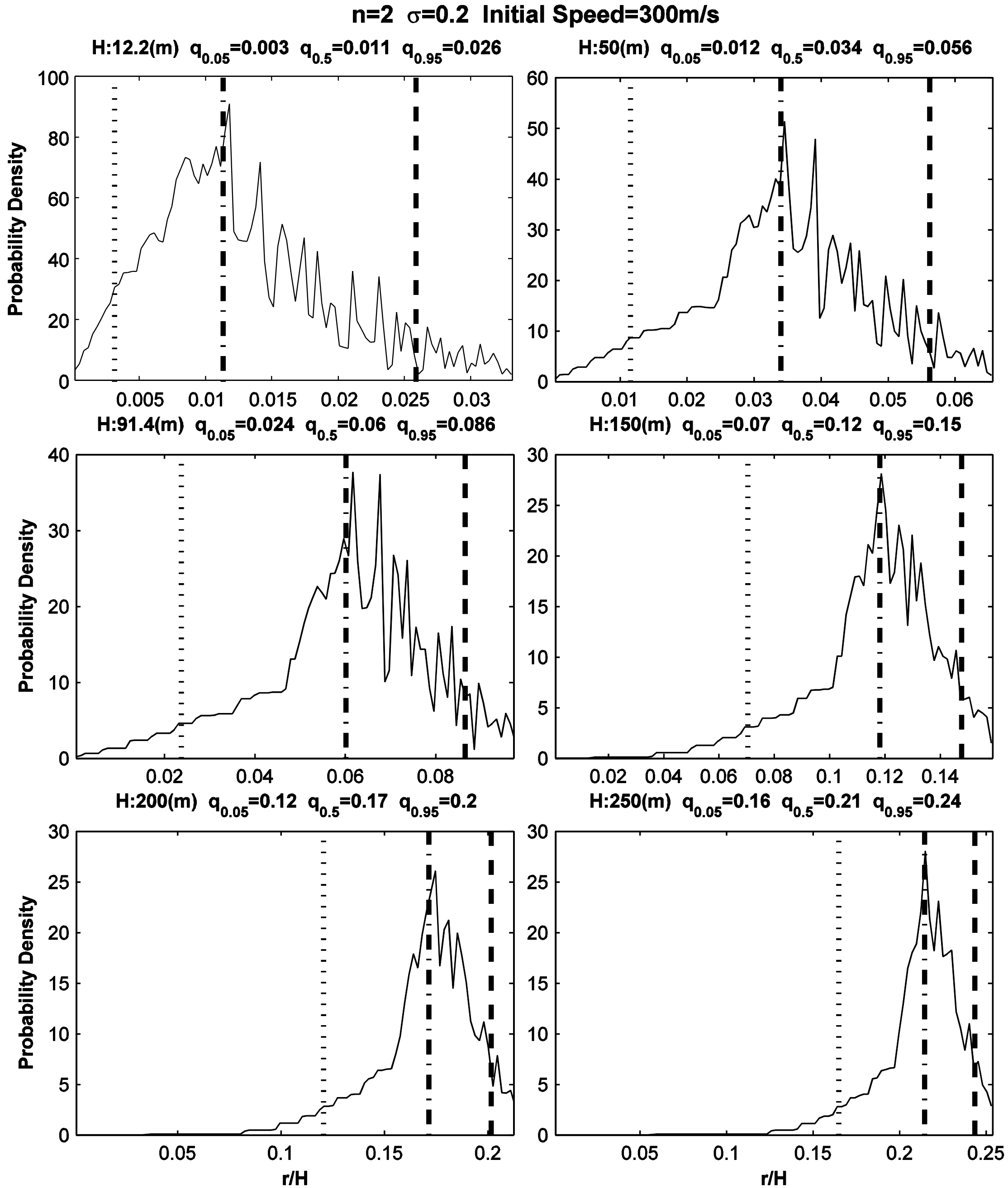
Ensemble Integration of 6-DOF Model



Calculation →
PDF of
Horizontal Drift
at Given Depth



PDF of Horizontal Drift at Various Depths



The median horizontal drift (unit: m) of an underwater bomb at various depths obtained from ensemble integration of the 6-DOF model with various input parameters

Depth (m)	Case 1: V = 300 m/s n = 2 σ = 0.2	Case 2: V = 300 m/s n = 100 σ = 0.2	Case 3: V = 300 m/s n = 2 σ = 1.0	Case 4: V = 200 m/s n = 2 σ = 0.2
12.2 (40 ft)	0.16	0.16	0.37	0.17
50.0 (164 ft)	1.7	1.8	3.1	2.5
91.4 (300 ft)	5.4	5.7	8.6	8.9

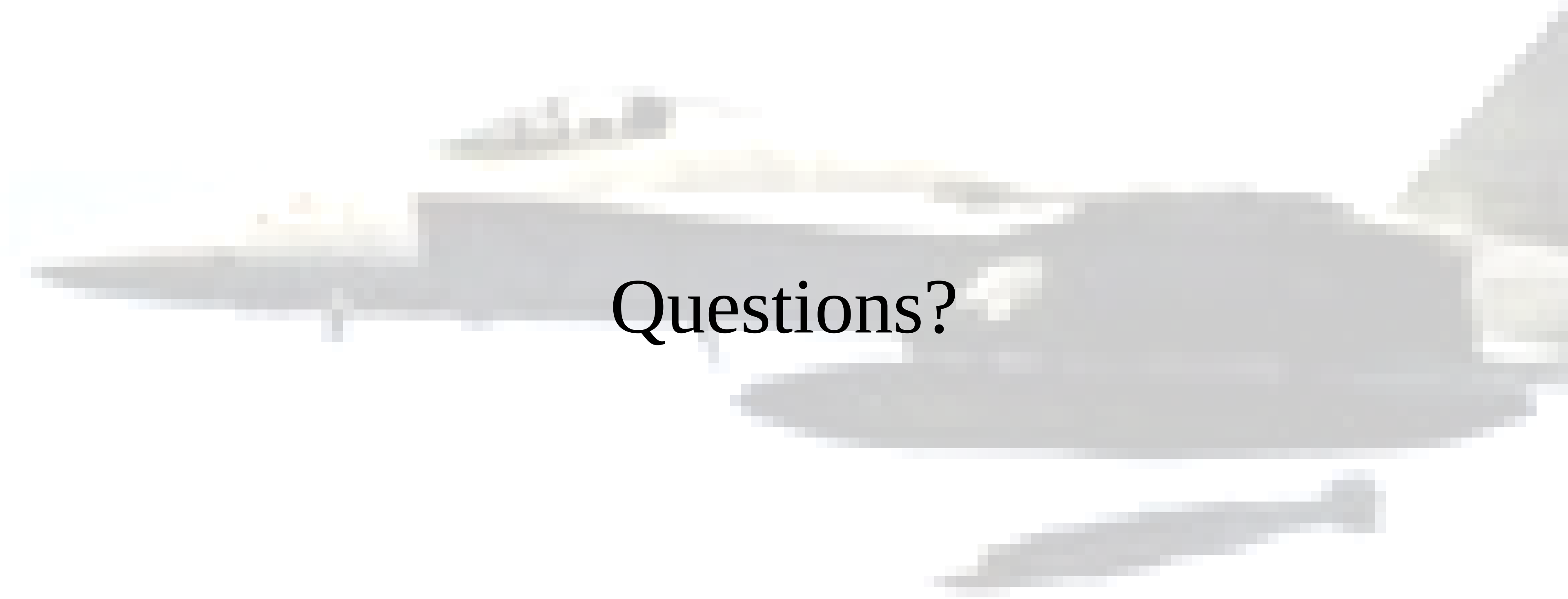
The $q_{0.95}$ values for horizontal drift (unit: m) of an underwater bomb at various depths obtained from ensemble integration of the 6-DOF model with various input parameters

Depth (m)	Case 1: V = 300 m/s n = 2 σ = 0.2	Case 2: V = 300 m/s n = 100 σ = 0.2	Case 3: V = 300 m/s n = 2 σ = 1.0	Case 4: V = 200 m/s n = 2 σ = 0.2
12.2 (40 ft)	0.32	0.27	0.54	0.17
50.0 (164 ft)	2.80	2.55	4.00	3.60
91.4 (300 ft)	7.86	7.40	10.05	10.97

Conclusions

- For very shallow water (VSW, water depth < 40 ft), the horizontal drift of bomb for variety of surface conditions is always less than 7 ft (2.1 m). This confirms the validity of underwater bomb for mine neutralization.

- For shallow water (40 ft < water depth < 300 ft), the validity of underwater bomb for mine neutralization needs more investigation.



Questions?