How to survive a cliff jump: throw something!

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Questions, questions!

Why did he throw the knife?

Does throwing something beforehand actually help cushion the impact?

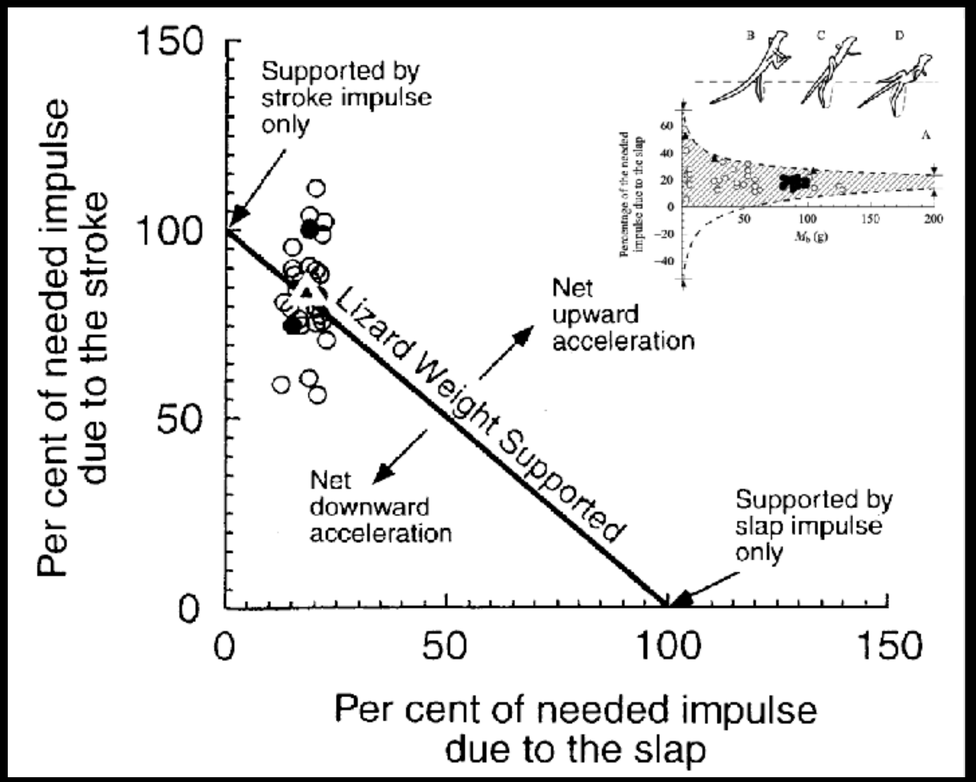
The short answer: (Drumroll please!)

YES!

(if you time it right of-course!)

Why is impact force important?

Basiliscus basiliscus



Basilisk lizards use impact impulse to walk on water!

Apollo-15 splashdown

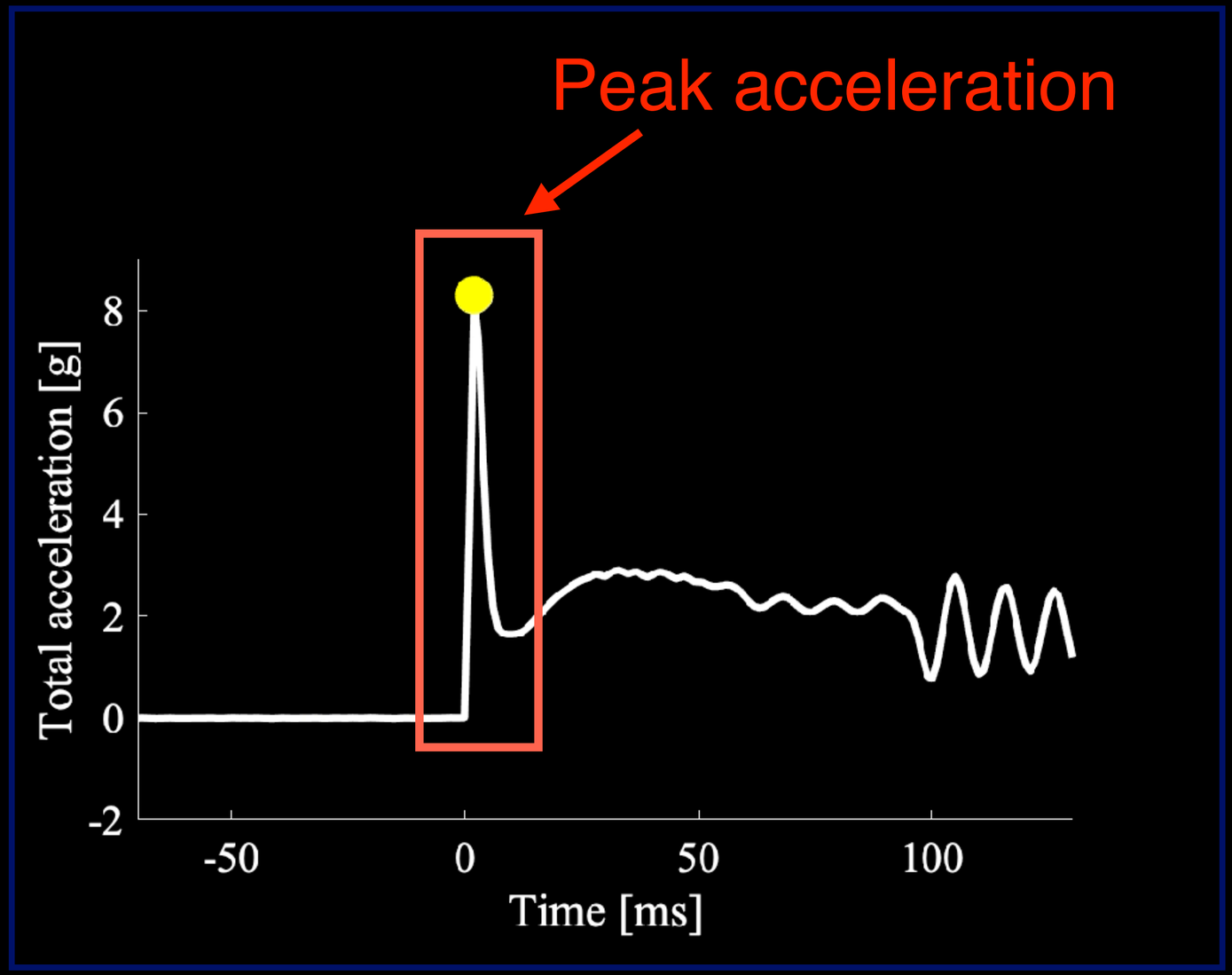
Can be fatal for water landing aero-structures, off-shore and ocean rigs etc.

Glasheen, J. W., & McMahon, T. A. (1996). A hydrodynamic model of locomotion in the basilisk lizard. *Nature*, *380*(6572), 340-342.

Image taken from NASA archive

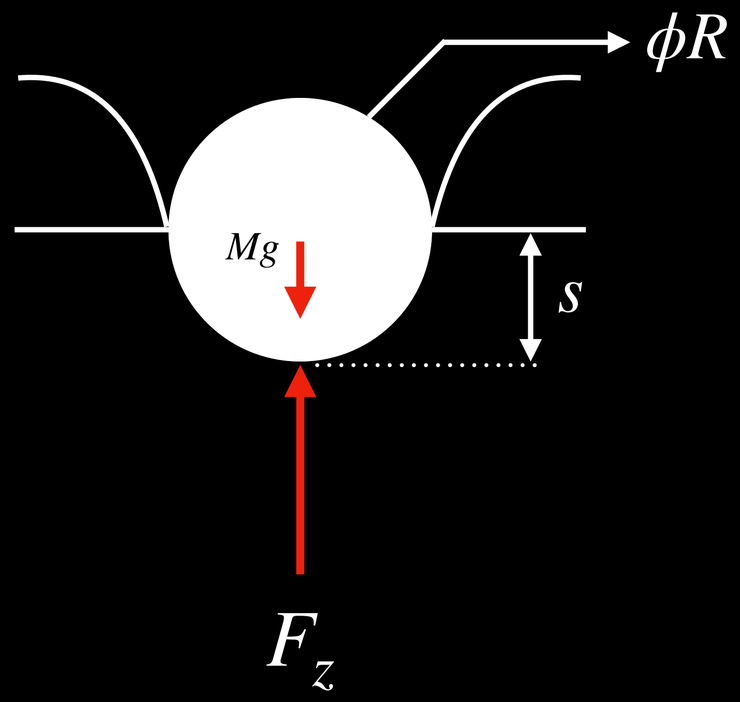
Seddon, C. M., & Moatamedi, M. (2006). Review of water entry with applications to aerospace structures. *Int. J. of Impact Engineering*, *32*(7)

Quiescent case



Acceleration data from embedded accelerometer

Hydrodynamic Force acting on Sphere



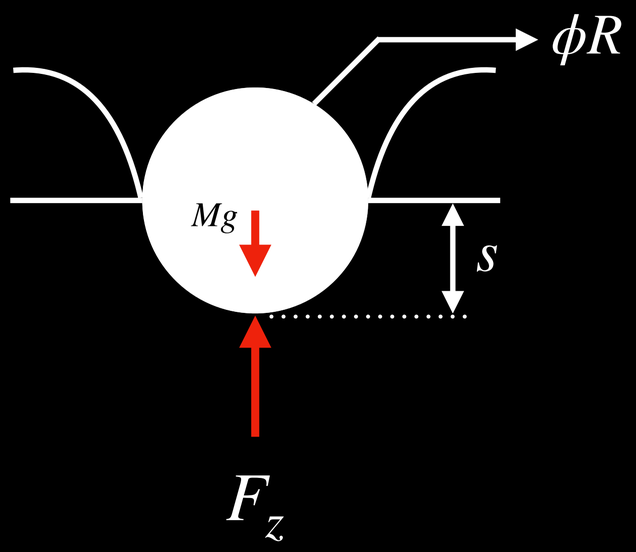
$$C_d = \frac{2}{\rho\pi R^3}\frac{1}{(1+\frac{m}{M})^3}\frac{dm}{db}$$

$$F_z = -M\frac{dU}{dt} = \frac{U_o^2}{R}\frac{1}{(1+\frac{m}{M})^3}\frac{dm}{db}$$

Shiffman et. al. (1945) reports $C_d \approx 1$ at $b = s/R \approx$ 0.1-0.2, later experimentally validated by Moghishi (1981)

m being the added fluid mass

Hydrodynamic Force acting on Sphere



$$C_d = \frac{2}{\rho\pi R^3}\frac{1}{(1+\frac{m}{M})^3}\frac{dm}{db}$$

$$F_z = -M\frac{dU}{dt} = \frac{U_o^2}{R}\frac{1}{(1+\frac{m}{M})^3}\frac{dm}{db}$$

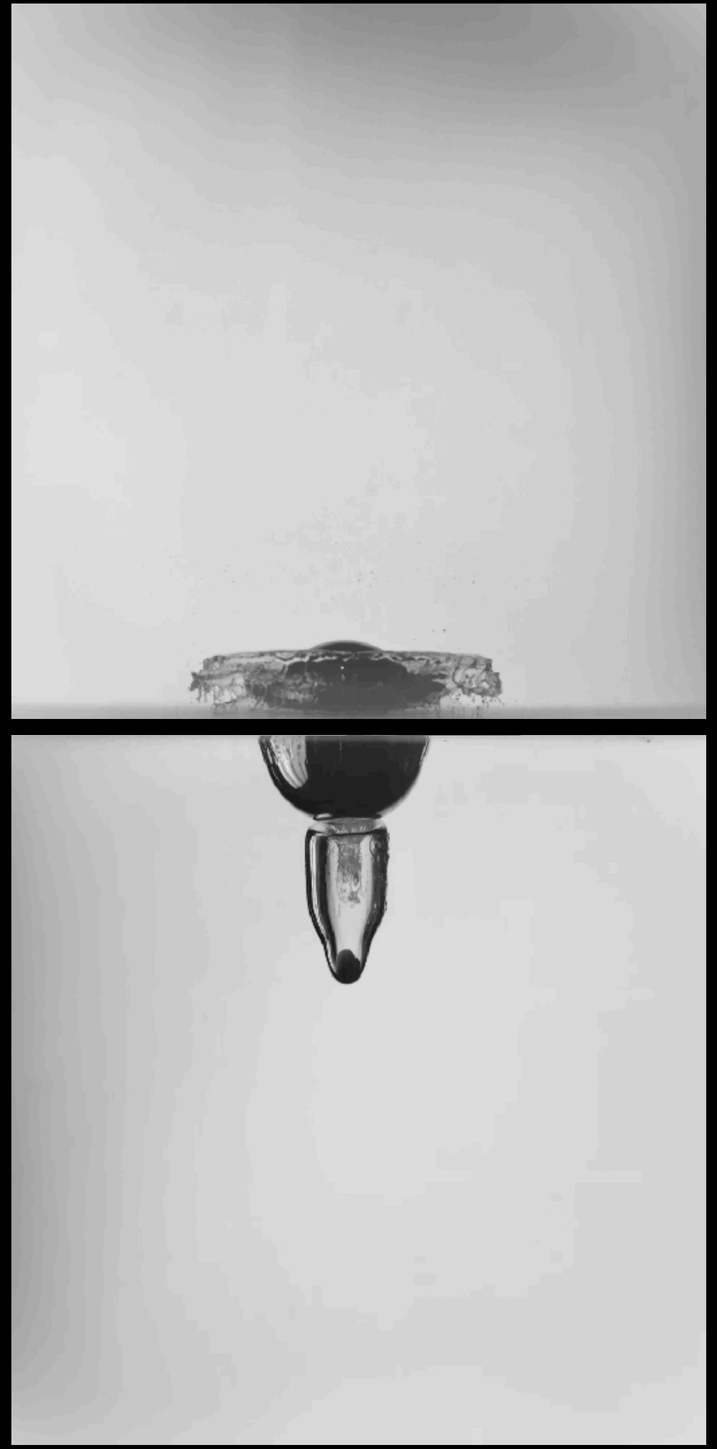
We learn two things:

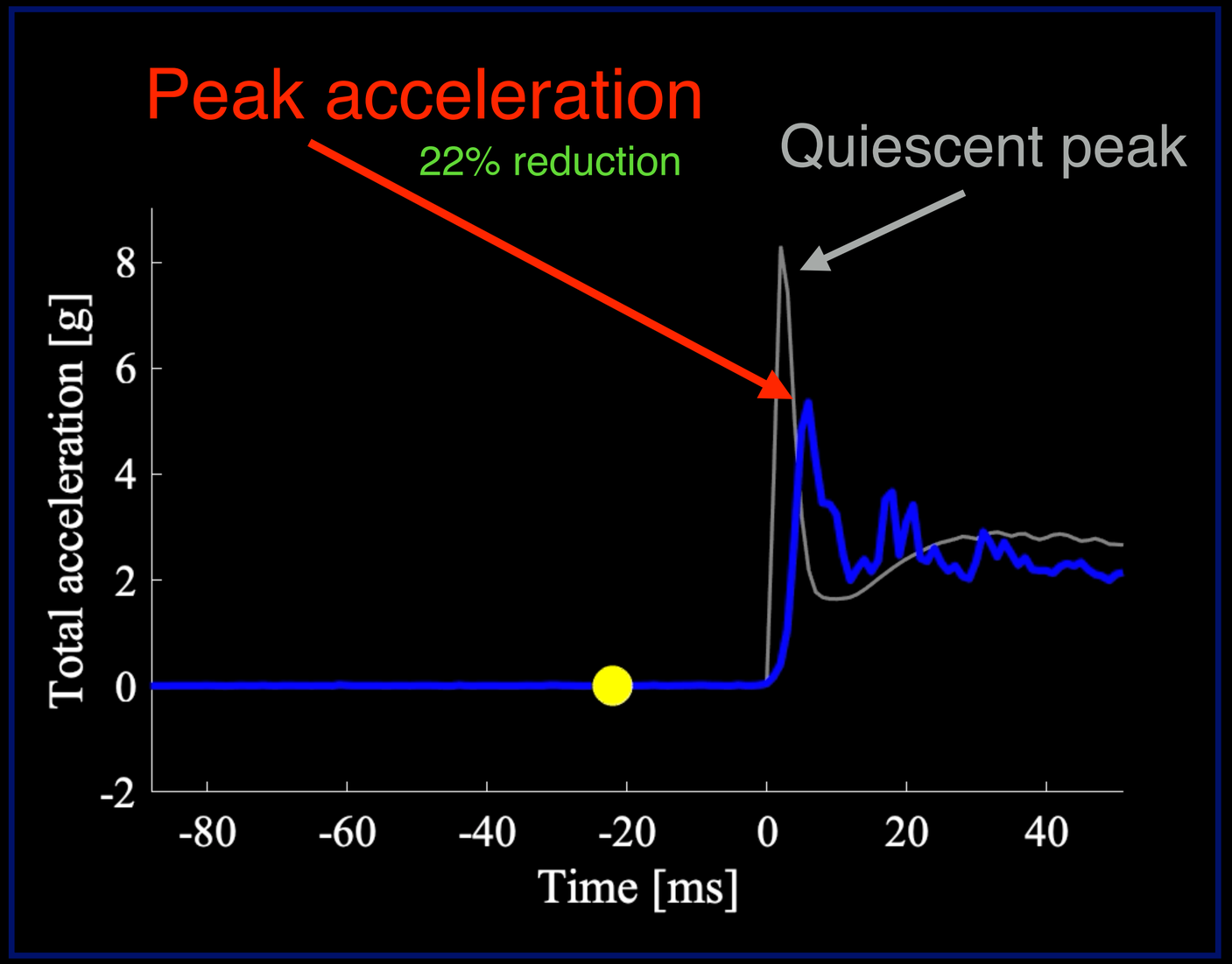
- $C_d \sim 1$ **contributes to the high peak impact force**
- $F_z \sim \frac{dm}{db}$

$$F_z \sim \frac{dm}{db}$$

Dependence on $\frac{dm}{db}$ gives us an opportunity to reduce F_z !!

Throwing something before might help!




Peak acceleration
22% reduction
Quiescent peak
Total acceleration [g]
8
6
4
2
0
-2
-80
-60
-40
-20
0
20
40
Time [ms]

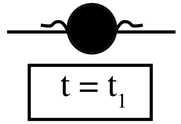
We can use cavity characteristics to predict consecutive sphere entry modes!

Ideal candidate would be the pinch-off time, predictable through the Eq.

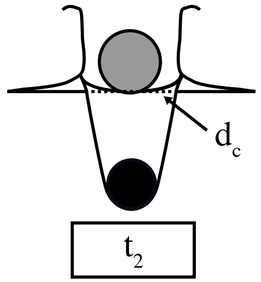
$$t_p = \beta\sqrt{\frac{d_1}{2g}}$$

We propose a new non-dimensional parameter: The ‘Matryoshka’ number (Mt)

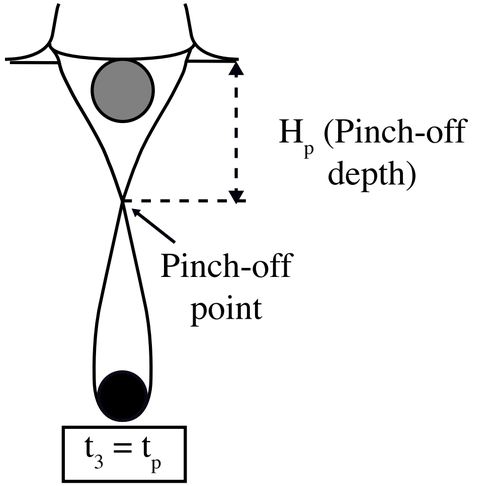
Duclaux, V., Caillé, F., Duez, C., Ybert, C., Bocquet, L., & Clanet, C. (2007). Dynamics of transient cavities. Journal of Fluid Mechanics, 591, 1-19.



Lower sphere impacts the free surface



Upper sphere passes free surface line



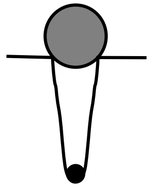
Pinch-off time of the cavity

Definition of Matryoshka number:

$Mt = (t_2 - t_1)/ t_p$

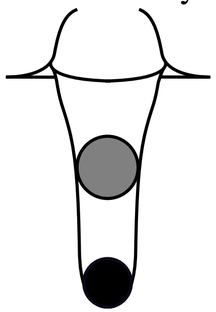
Mt < 1

On cavity



$d_c / d_2 < 1$

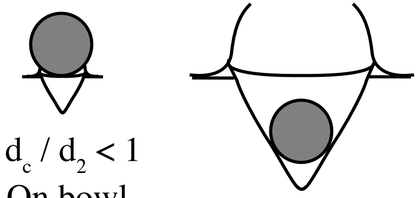
Inside cavity



$d_c / d_2 > 1$

Mt > 1

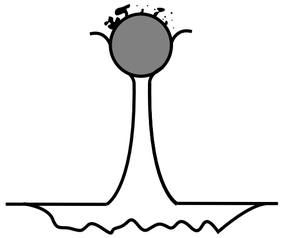
Bowl

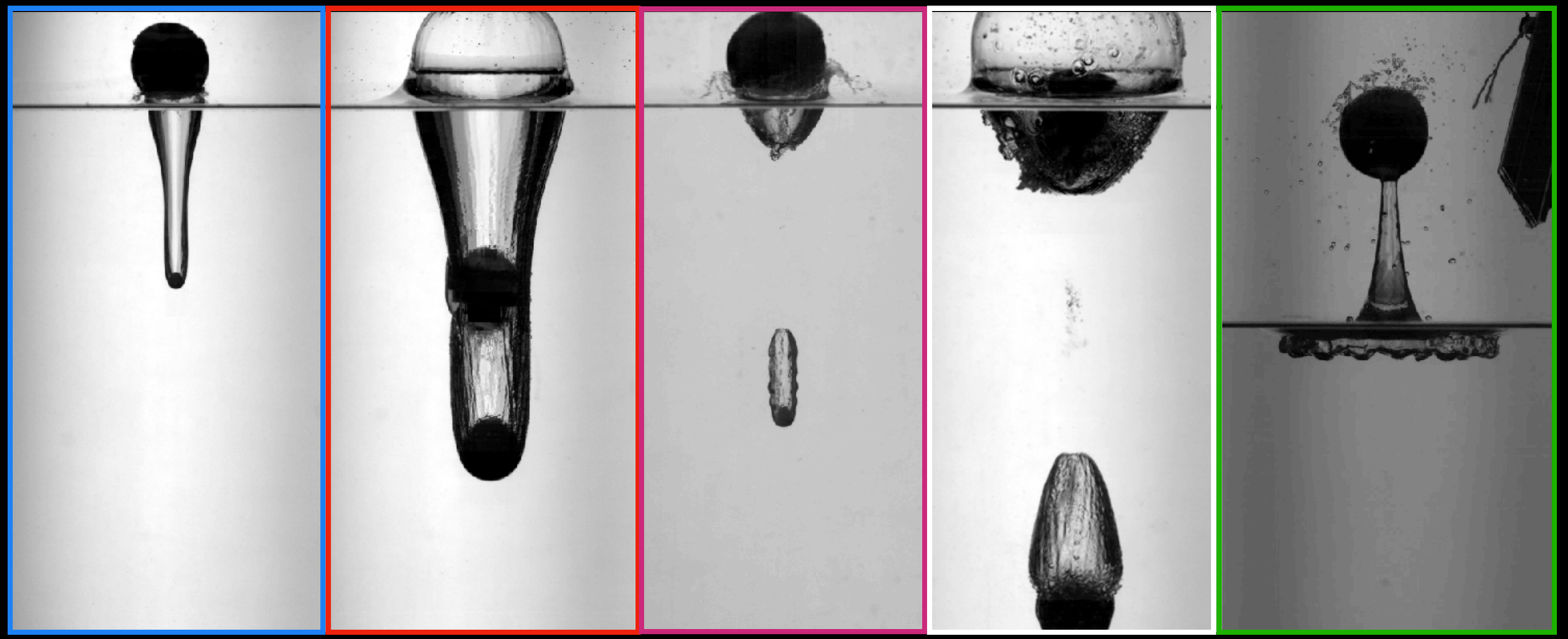


$d_c / d_2 < 1$
On bowl

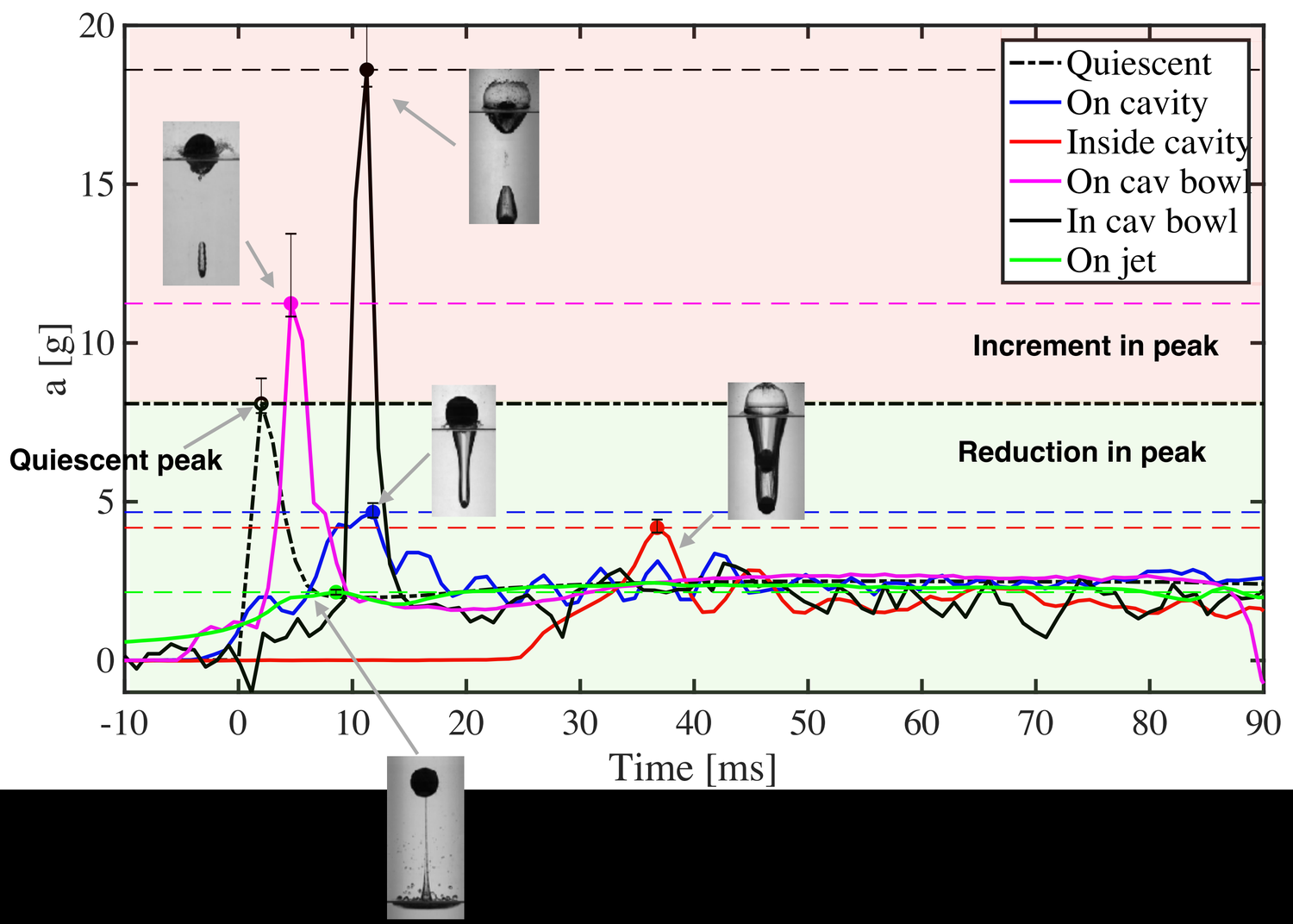
$d_c / d_2 > 1$
Inside bowl

On Worthington jet



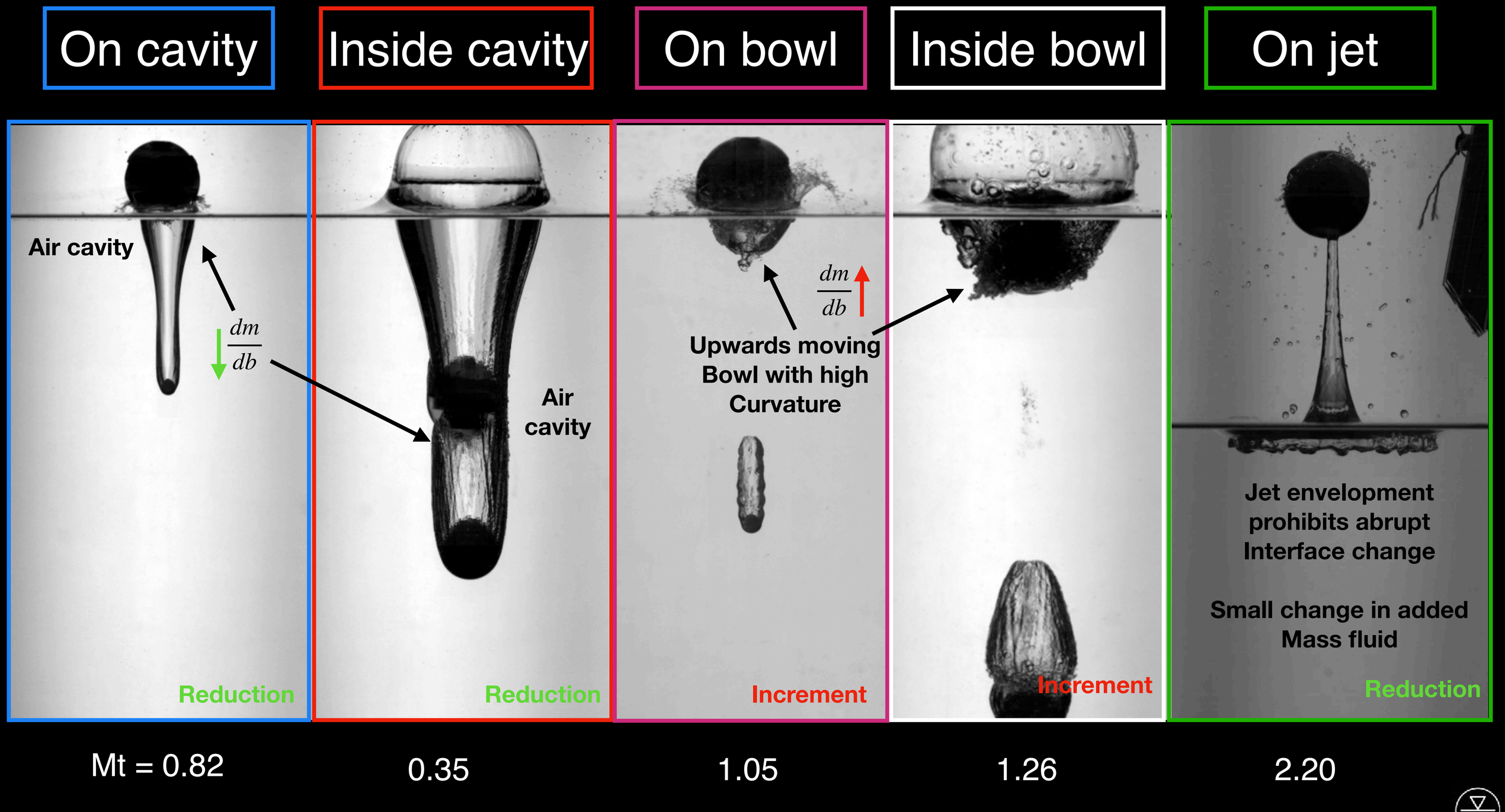

On cavity
Inside cavity
On bowl
Inside bowl
On jet
Mt = 0.82
0.35
1.05
1.26
2.20
Mt < 1
Mt > 1

Acceleration plot

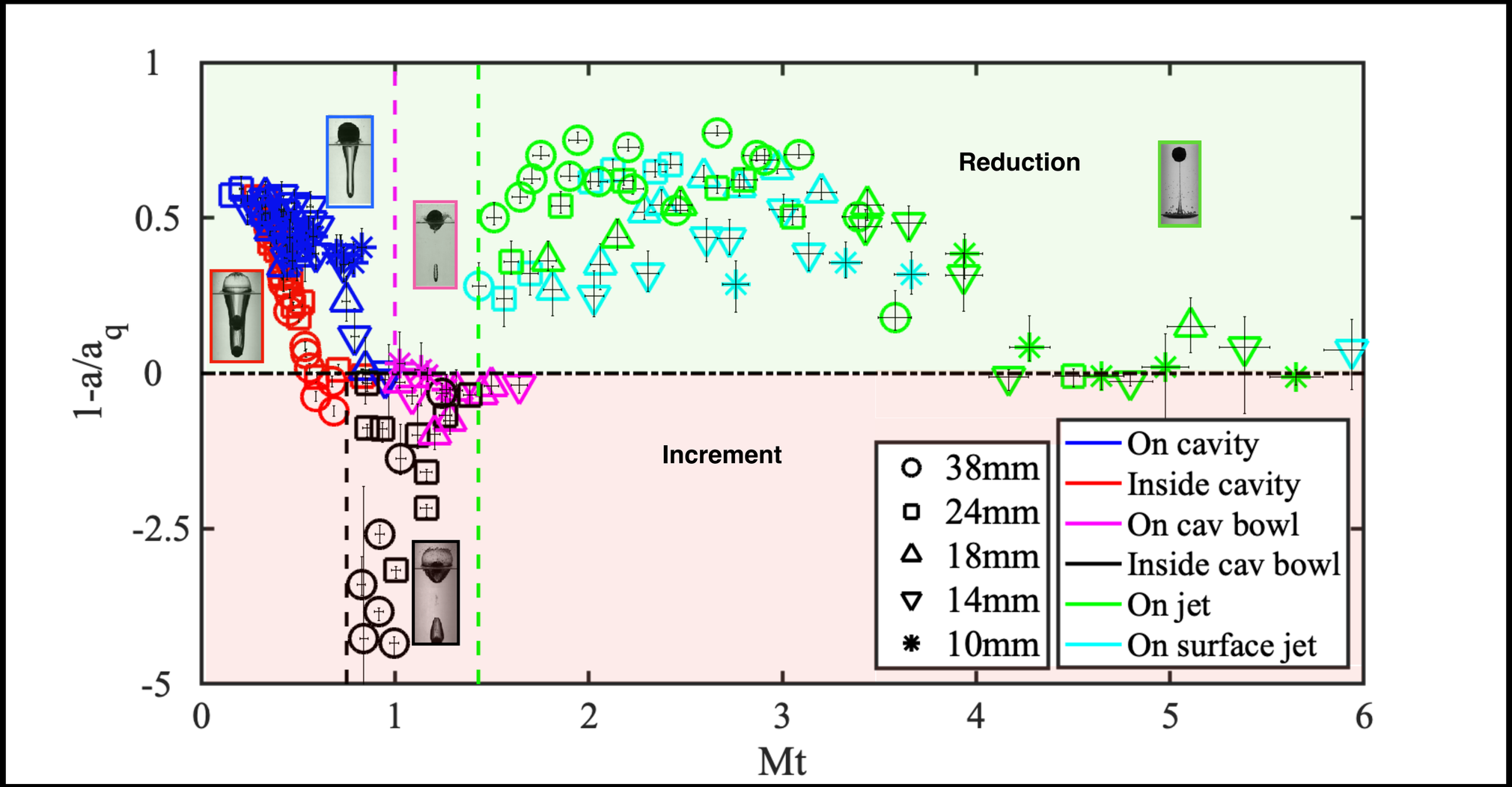


Mt < 1: Cavity cases lead to significant reduction!

Mt > 1: Reduction in on jet case, bowl cases see surprising increment!

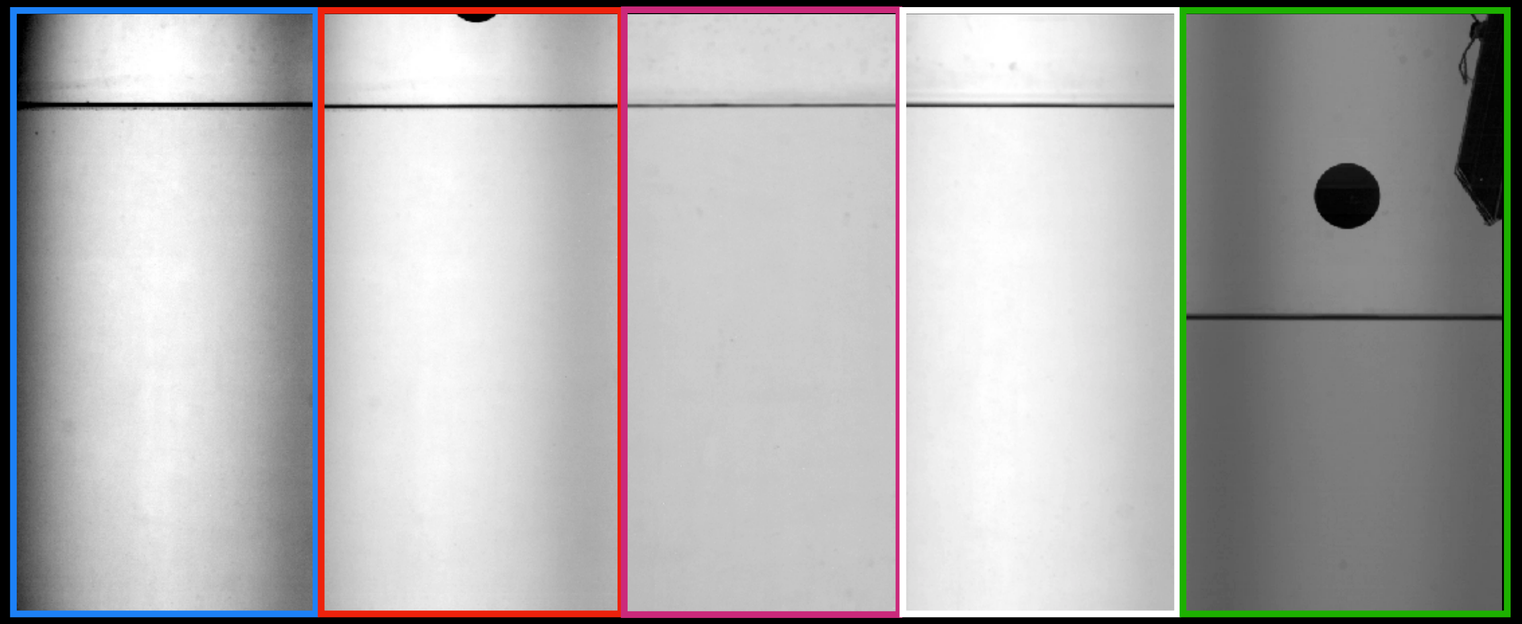

On cavity
Inside cavity
On bowl
Inside bowl
On jet
Air cavity
dm/db
Reduction
Air cavity
Reduction
dm/db
Upwards moving Bowl with high Curvature
Increment
Increment
Jet envelopment prohibits abrupt Interface change
Small change in added Mass fluid
Reduction
Mt = 0.82
0.35
1.05
1.26
2.20

Reduction over the range $0 < Mt < 6$



Summary

5 different two-sphere entry modes



Transitions Mt:

Inside cavity to inside bowl ~ 0.67

On cavity to on bowl ~ 1

Bowl to Worthington jet ~ 1.43

Highest reduction observed:
78%

Highest increment observed:
427%

$$Mt = \frac{\Delta t}{t_p}$$

- Reduction modes: inside cavity, on cavity, on jet
- Increment modes: inside bowl, on bowl

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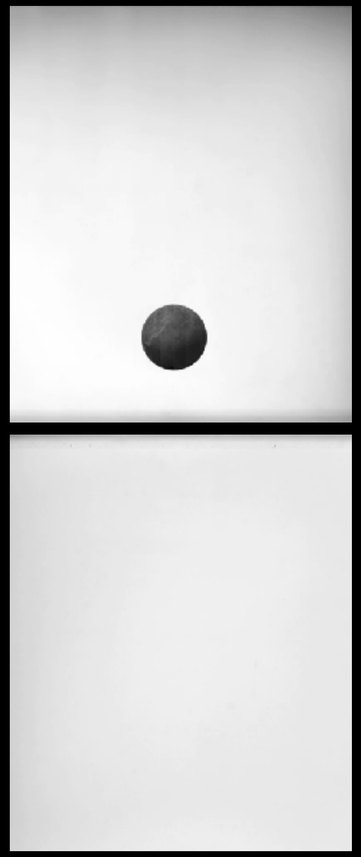

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Thank you!

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