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Modeling Large-scale Drop Impact: Splash Criteria and Droplet Distribution

Sandia National Laboratories
Albuquerque, NM, USA

Korea University
Seoul, South Korea

Alexander L. Brown, Ph.D.
(505) 844-1008
albrown@sandia.gov

Richard A. Jepsen, Ph.D.
(505) 284-2767
rajepse@sandia.gov

Sam S. Yoon, Ph.D.
82-2-3290-3376
skyoon@korea.ac.kr

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Fire Science & Technology

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

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Primary Goal:

To provide model development guidance aimed at predicting large-scale liquid impact dynamics.

Methods:

- **New Large-scale Testing Including:**
  - Data from meter scale tank impact.
  - 10 cm sphere drop-tower tests.
  - New model development based on new and old data
- **Towards Improved Impact Models**
  - Comparisons with new data and models.
  - Some development effort for oblique impacts.
  - New model deployment in Vulcan fire simulation code.

Very Large-scale (~1 m) Water Slug Impact Tests

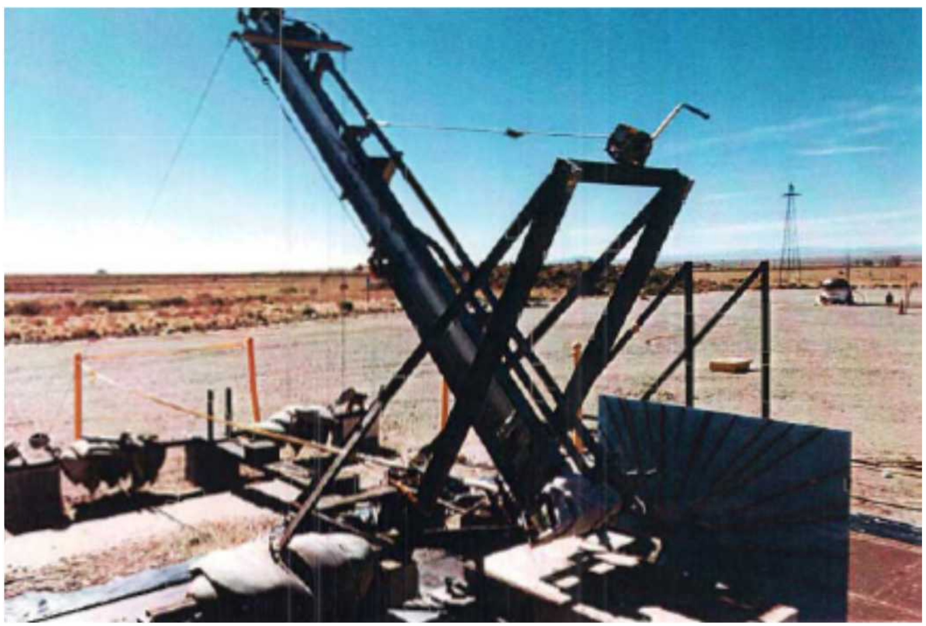
Investigate large scale (We~10^8) fuel tank impact and dispersion

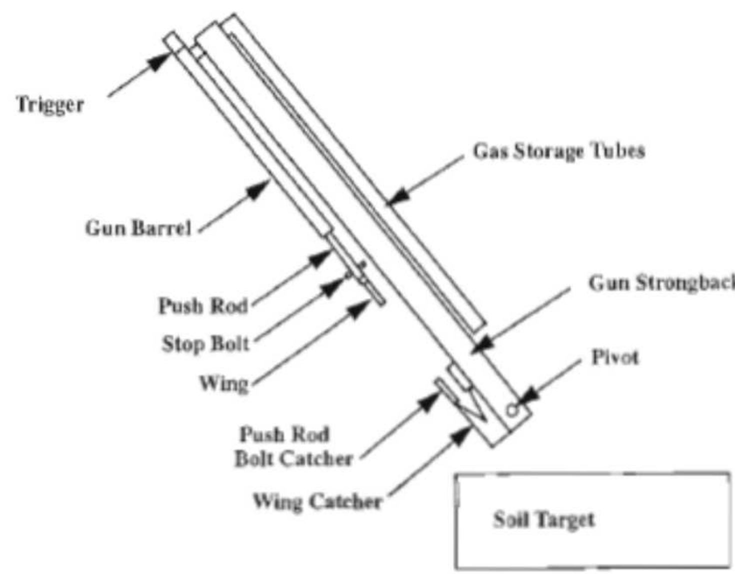
•Rocket propelled tank

•Impact unyielding wall

Tieszen's Angled Impact

- **Tests were designed to examine the splash of liquid from mock aircraft wing tank impacts.**
- **Soil and hard surface impacts were examined.**
- **Reports provide extensive data including recovered mass, and surface mass distribution.**





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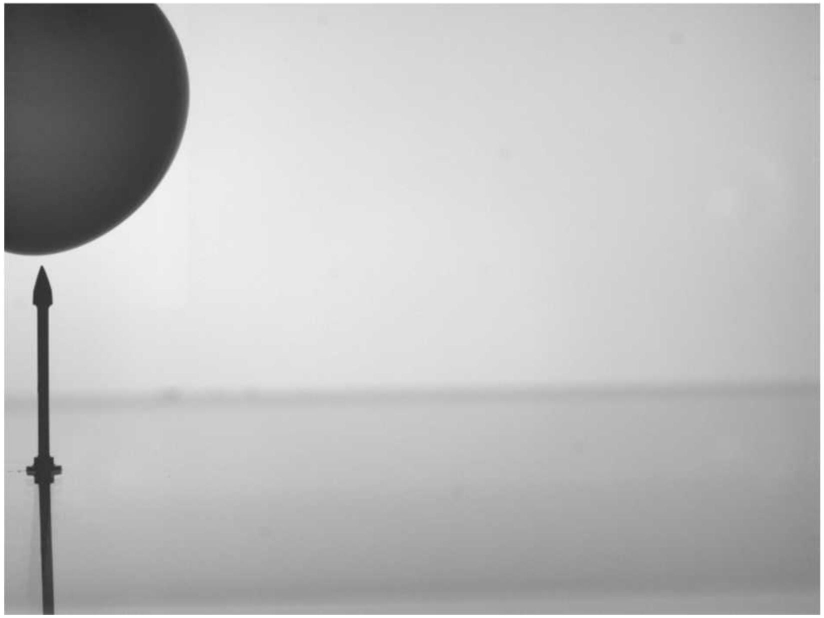
Large Scale (10 cm) Sandia Drop-tower Tests

10 cm liquid slug impacts were done at Sandia's 185 ft drop tower

Large Scale (10 cm) Sandia Drop-tower Tests

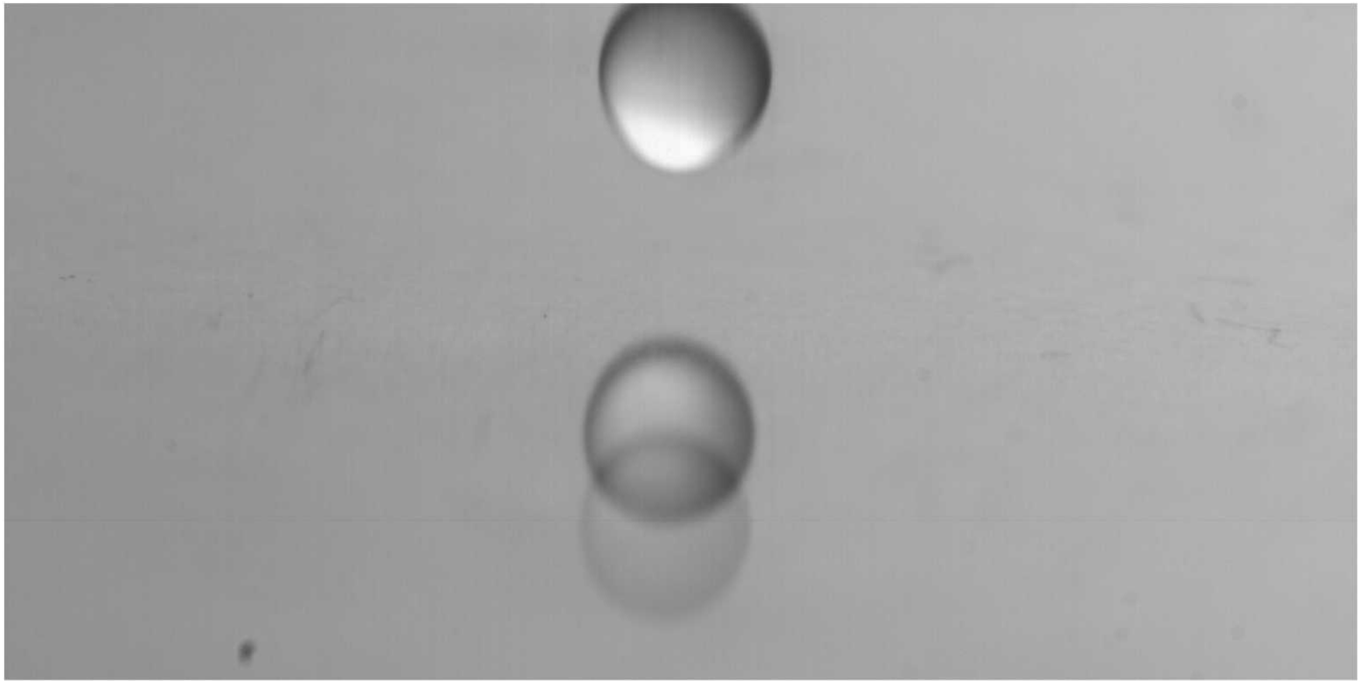
10 cm liquid slug impacts were done at Sandia's 185 ft drop tower

- **Both water and glycerin were tested**
- ***We* ranged from 10^4 to 10^6**



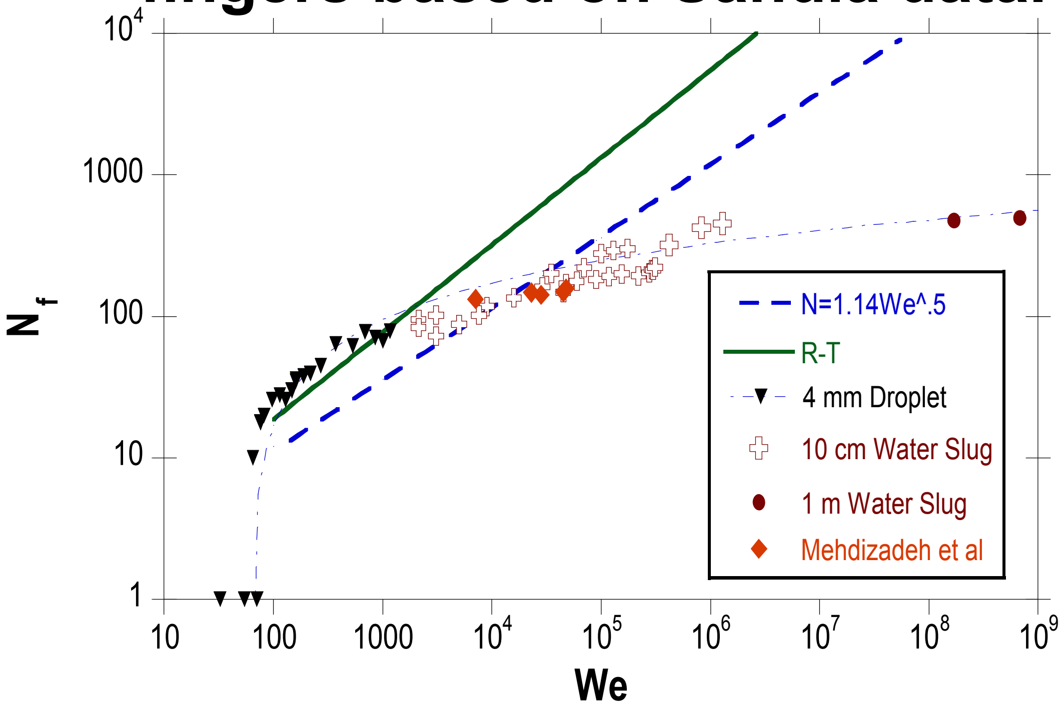
4 mm Sandia Drop Tests

Small scale testing done for a variety of fluids at We 10^2 to 10^4



Finger Correlation

- **Number of fingers is thought to relate to the emergence of secondary drops, and is therefore important.**
- **Yoon et al.[1] describe a more robust correlations for fingers based on Sandia data.**



$$N_f = -92.0 + 57.0 \log(We)$$

[1]Yoon, S.S., Jepsen, R.A., Nissen, M.R., O'Hern, T.J., "Experimental investigation on splashing and nonlinear fingerlike instability of large water drops," *Journal of Fluids and Structures*, 23:101-115 (2007).

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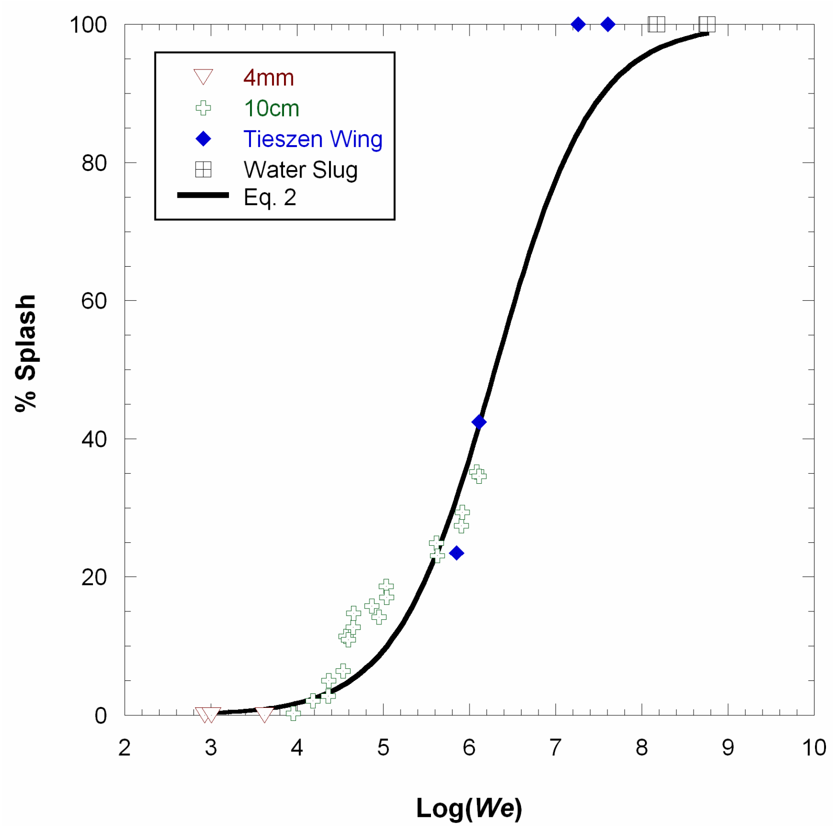
Residual Mass Correlation

- Splash mass fraction or percent is seldom reported in the literature.
- We present a logistic fit based on our data that is applicable to water and similar fluids.



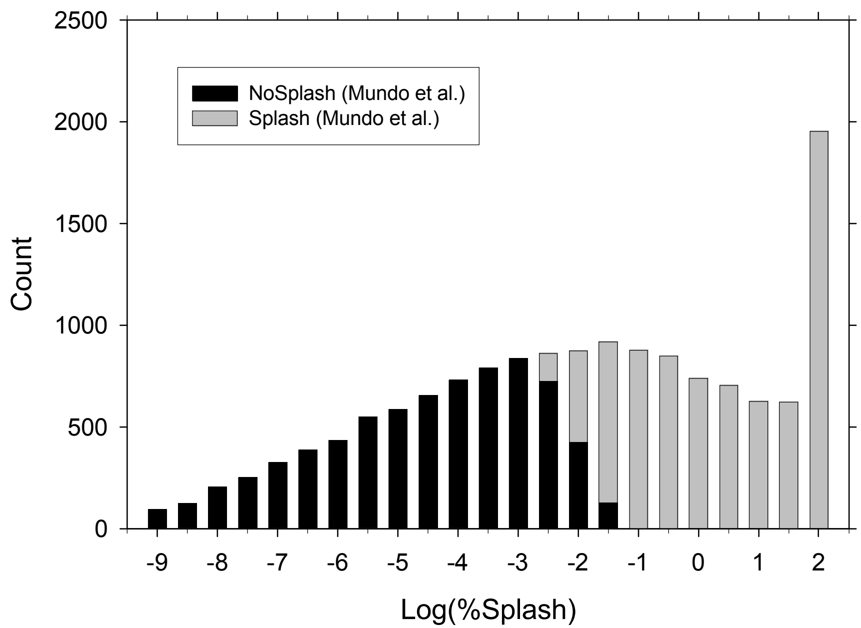
Eq. 2: $$\%Splash = \frac{100We}{We + 10^6}$$

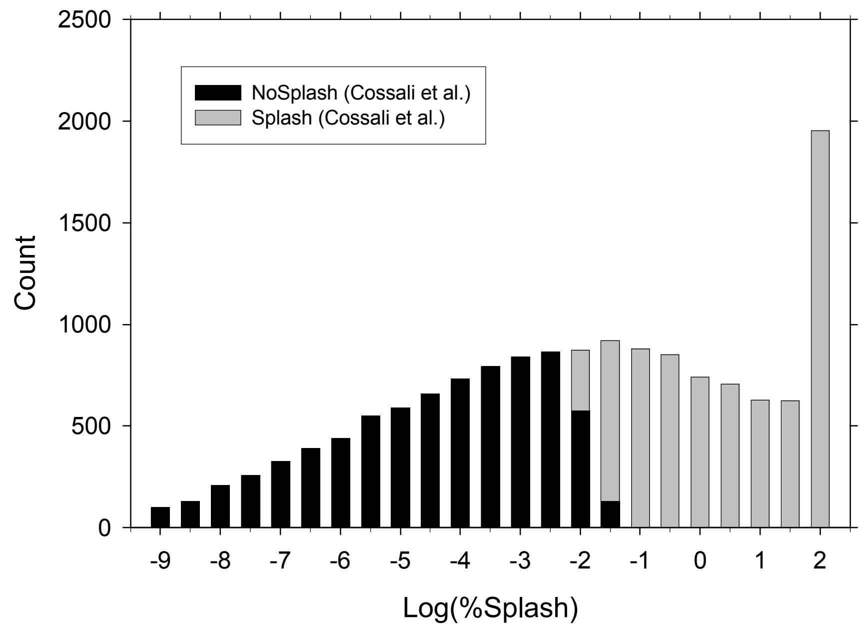
Residual Mass Correlation Comparison

Our water impact correlation for splash mass compares favorably with two existing literature models for determining the presence of splash.

Other fluid (fuels) comparisons are similar.

Glycerin appears moderately different.





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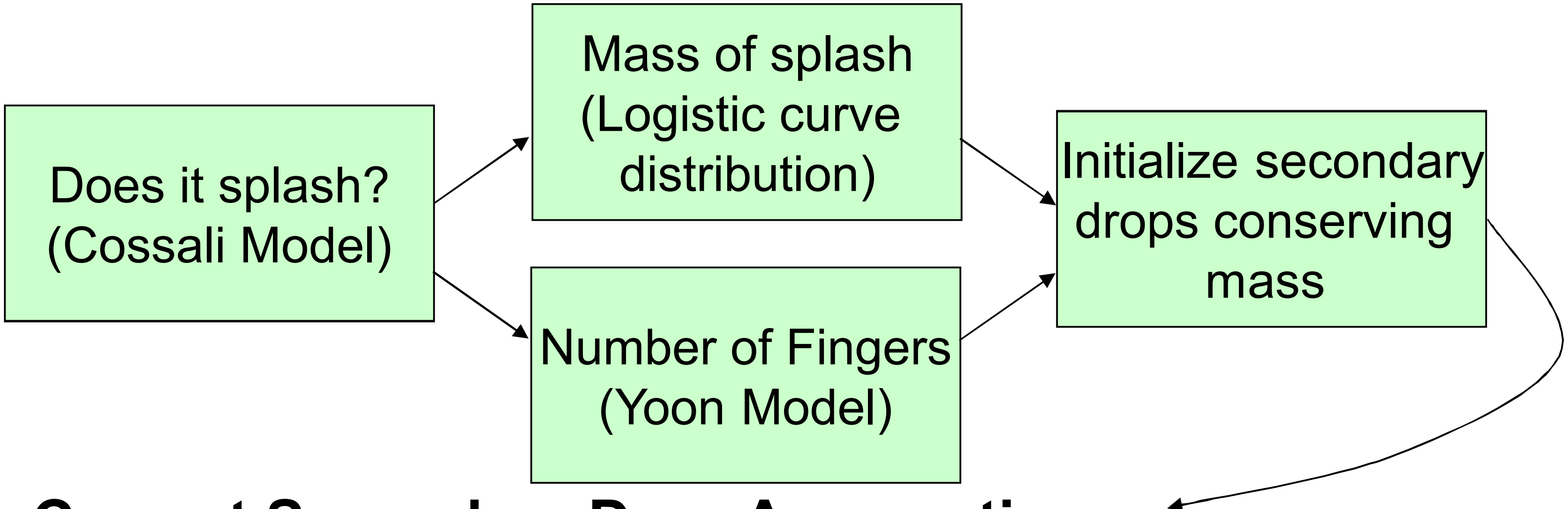
Glycerin Drop Results

- Remarkably, a *We = 2e5* glycerin drop exhibits *no fingers* and *no splash*. (Rich, please provide additional or new video/stills)
- A *We = 1e6* glycerin drop did splash.
- This result defies most literature correlations found.

Impact Splash Model Logical Implementation



Current Secondary Drop Assumptions:

- **Number of secondary drops = number of fingers**
- **Secondary drops are of equal size**
- **Secondary droplet speed = primary drop speed**
- **Drops are distributed equally around impact point**
- **Randomly distributed between θ = 1, 15º elevation**

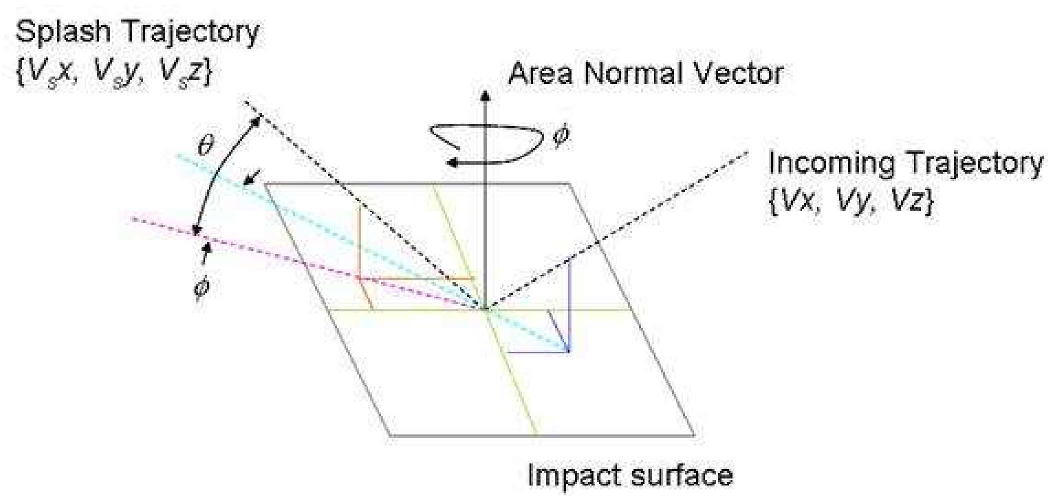
Angled Drop Impact Evaluation

- **A non-perpendicular impact results in different finger and mass distributions**

Proposed Method:

A function exists *f(ψ,r)* such that:

$$\frac{N}{N_{total}} = \frac{\int_0^{\phi} \frac{1}{2} f(\psi, r) d\psi}{\int_0^{2\pi} \frac{1}{2} f(\psi, r) d\psi}$$



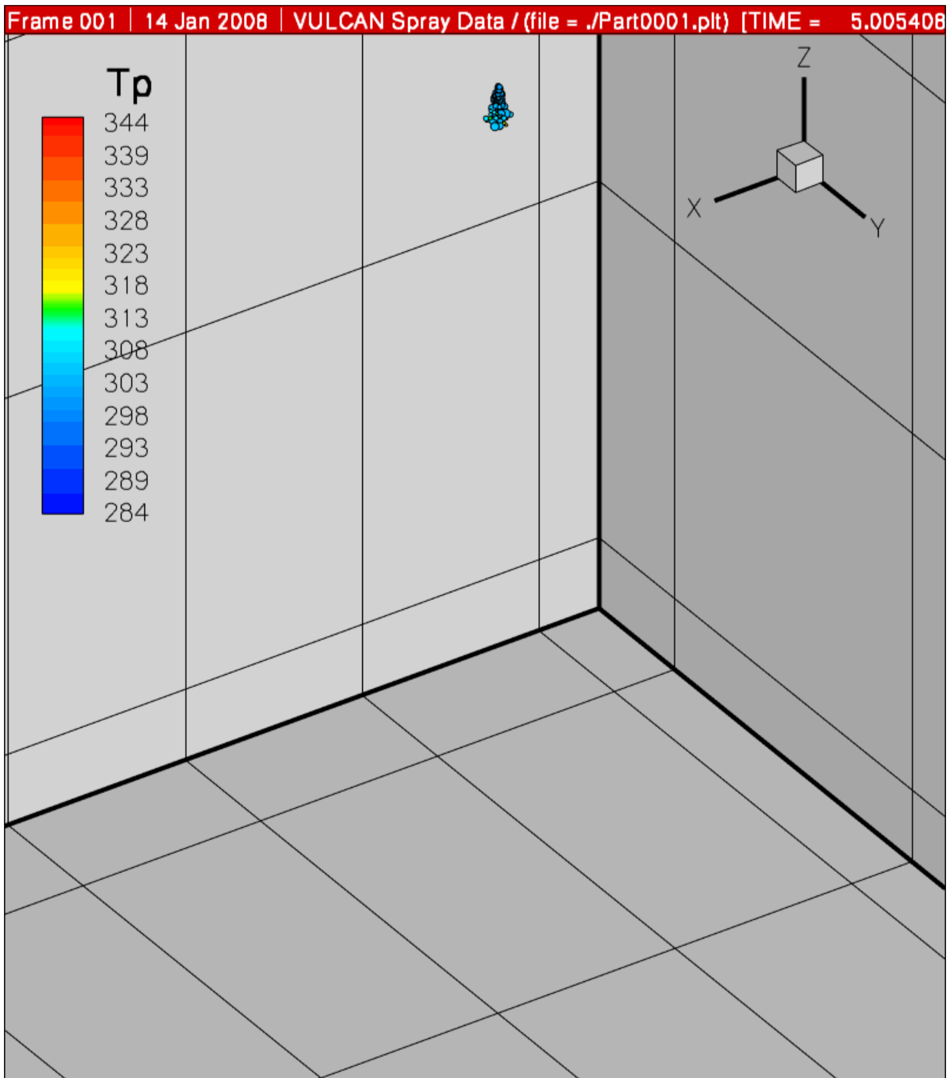
where:

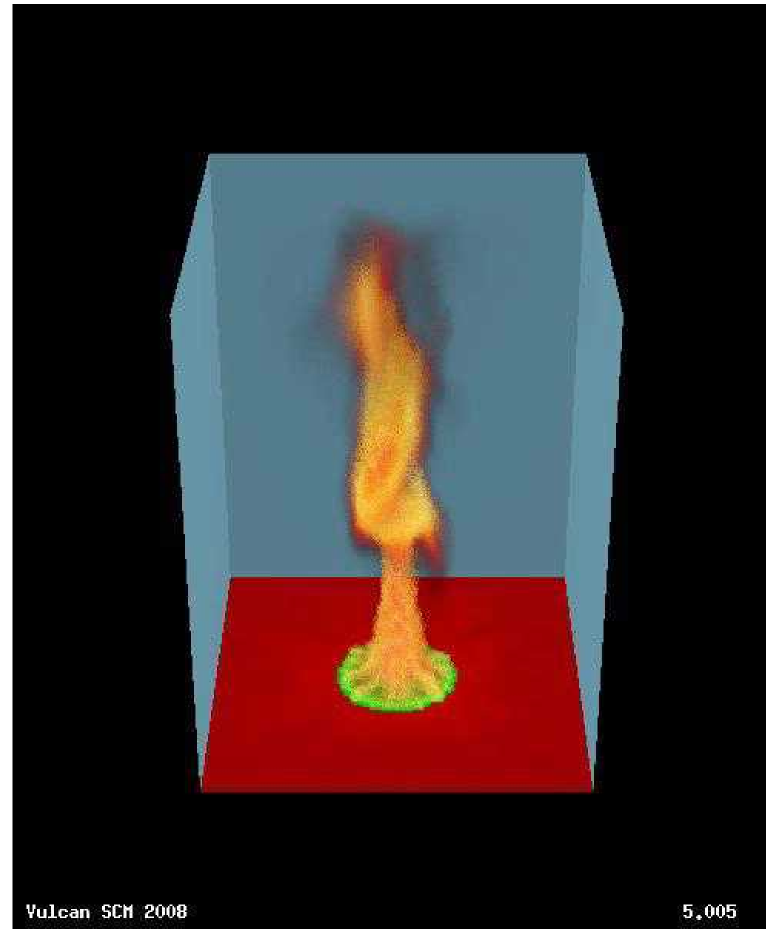
$$r = V_{perp} / V_{total}$$

We can then use knowledge of *N*, *N*$_{total}$ and *r* to solve for ϕ with an appropriately defined function, the development of which is a current pursuit.

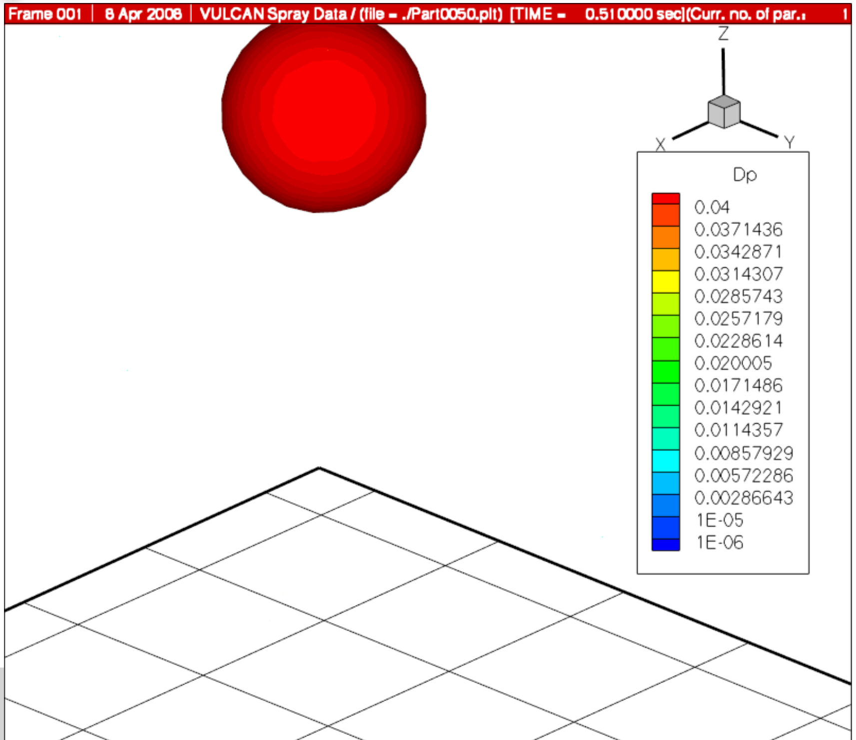
Application 1: Suppression Fire Spray

Suppression spray shows impact drops. Fire calculations are consistent with data in suppression time.

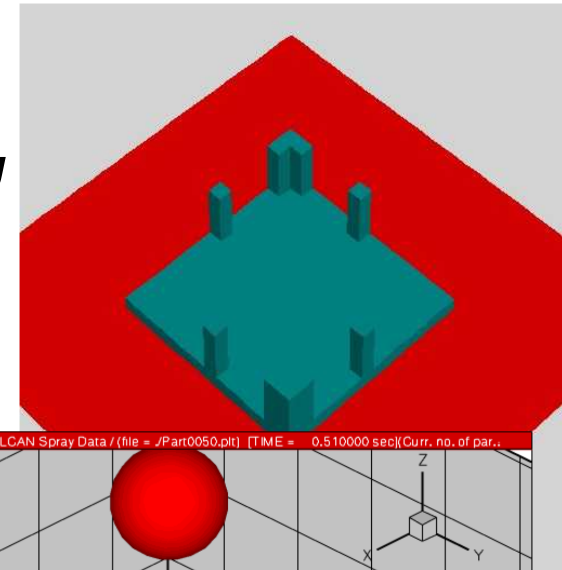


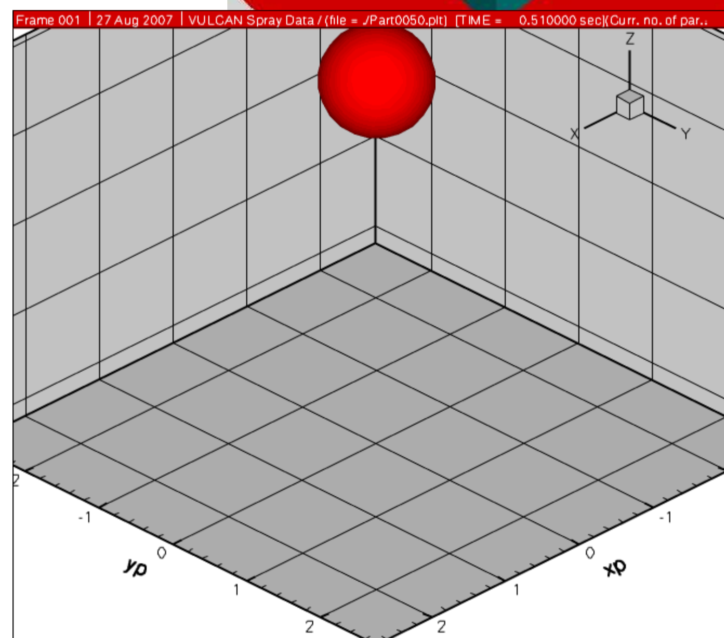


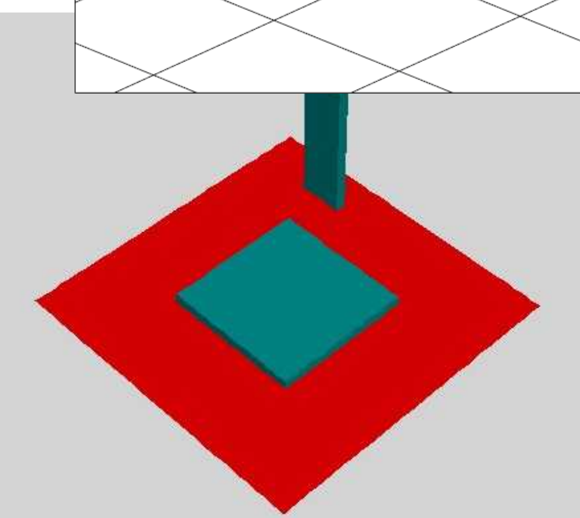
Application 2: Two Surface Impact Tests



Model performs well for *challenging* cases: Angled impact (left) and oblique obstacles with tertiary impact (right).







All cases assume 4 cm diameter initial drops released every 0.5 seconds: Relative particle sizes are significantly oversized in the videos so the spray drops are visible.

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Summary

- We present new water impact data that were used to generate a correlation for mass evolved on drop impact.
- The correlation is consistent with existing models for the presence of splash.
- The glycerin 10 cm drop results defy most existing correlations.
- A general method for impact splash modeling is presented.
- A general method for distributing fingers for oblique impacts is presented.
- Additional work is needed for droplet size variations, secondary velocity, and the oblique weighting function.
- Several example predictions are shown illustrating the current model performance.

Acknowledgements

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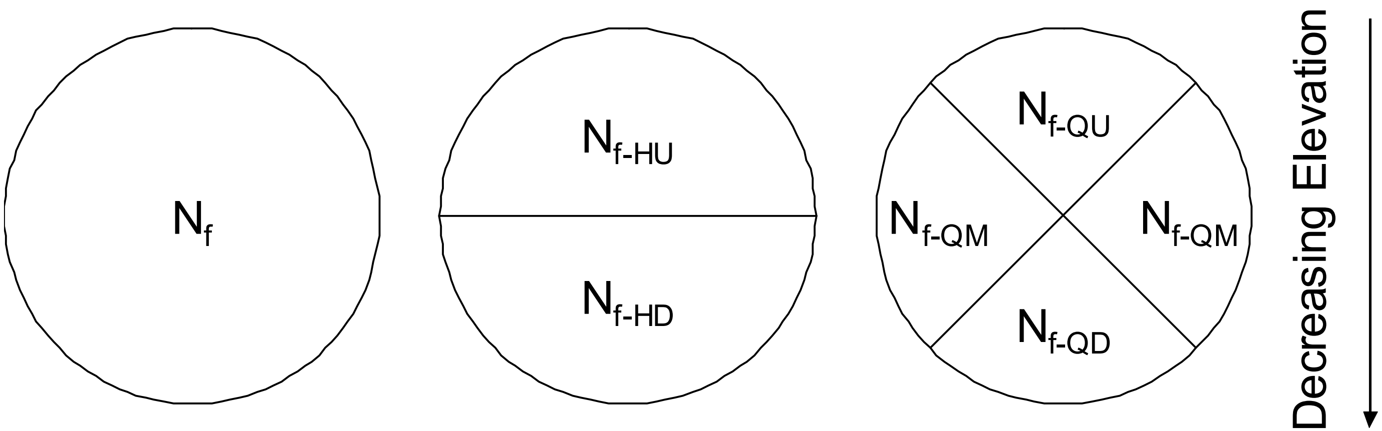
Extra Viewgraphs

Oblique Impact Details

Oblique impact data were extracted from photographic finger counts for the whole drop, two hemispheres, and three quadrants.

Function constants are determined from dimensionless number of fingers (N/N_f), and show reasonable self-similarity for the range of drops analyzed thus far.

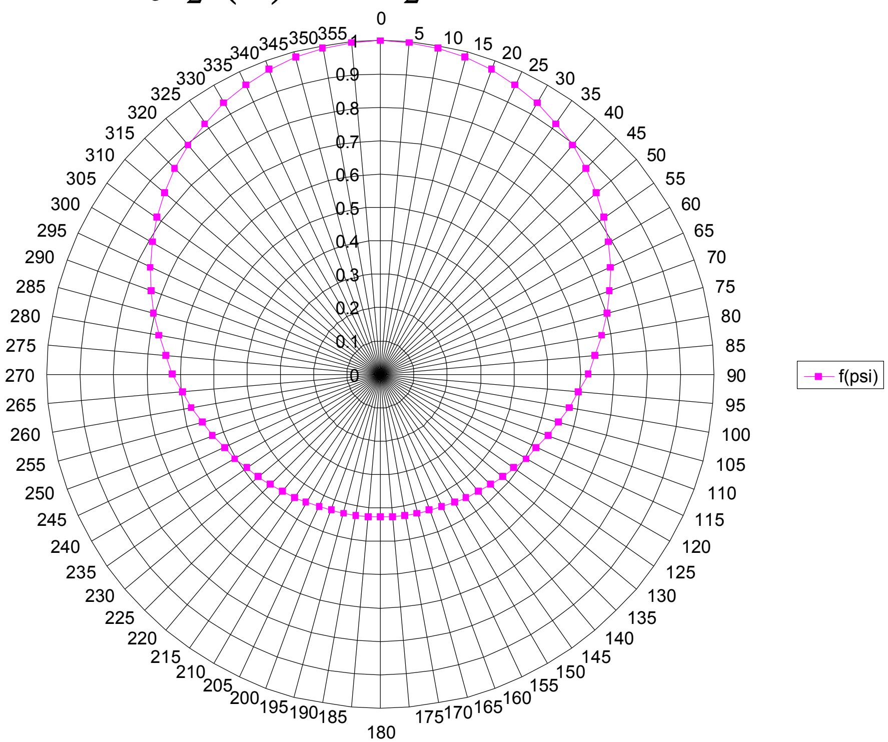


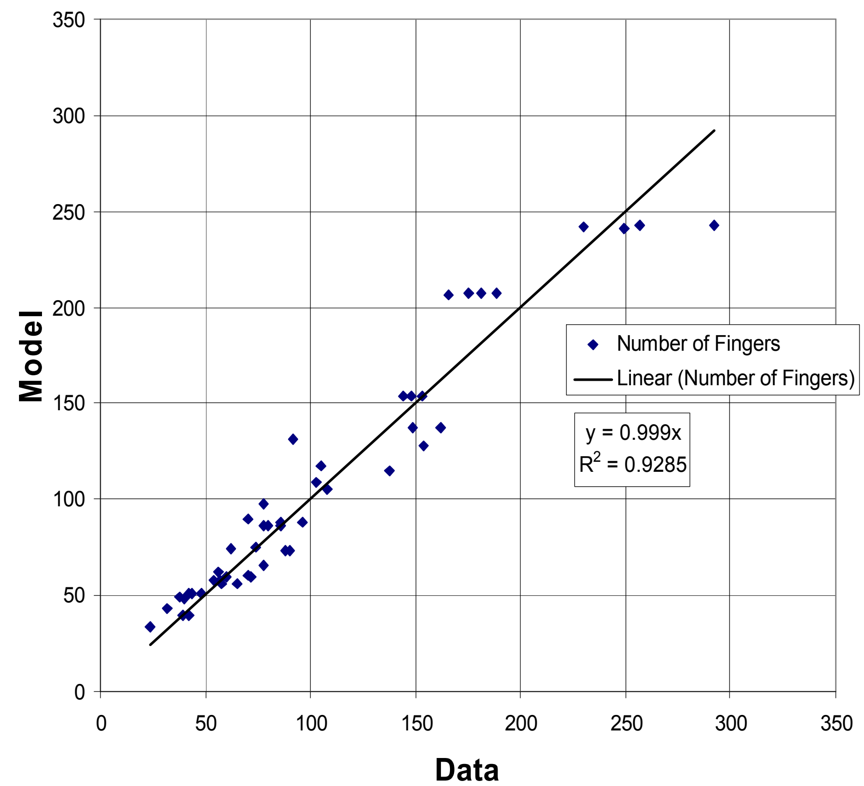
Impact Function

$$f(\psi, r) = 1 - f_1(r)\sin^2\psi - f_2(r)\sin^2\frac{\psi}{2}$$

$$f_1(r) = C_1 r$$

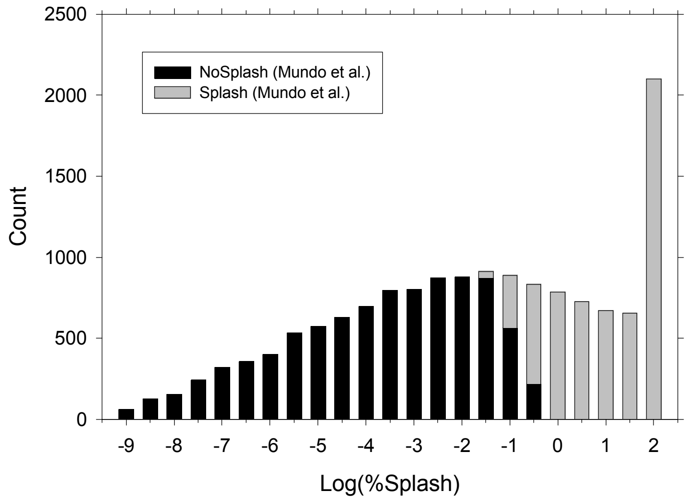
$$f_2(r) = C_2 r$$

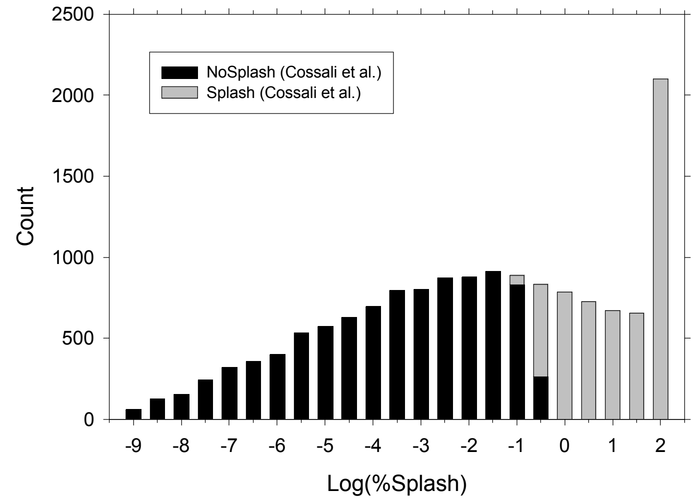




Other Comparison Plots

Glycerin





Gasoline