# Liquid Impingement Erosion:
# Modeling Droplet Impacts onto Elastic Solids

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# Outline

- Milestones
- Introduction
- Methodology
- Results
- Progress to date
- Potential for continuation of current work

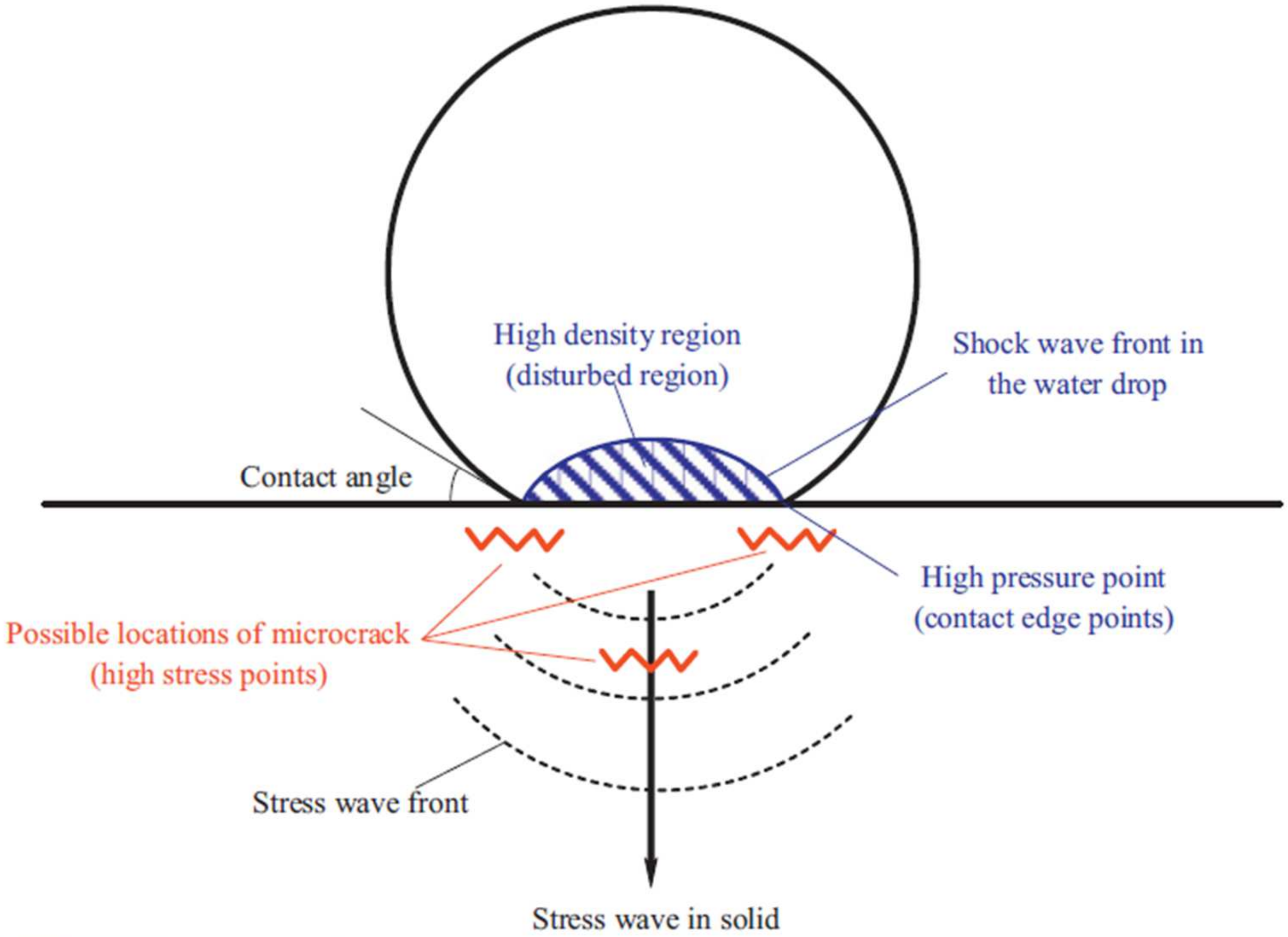
# Key milestones

- **Incompressible FSI Model**:
  → incompressible VOF coupled with elastic solid solver
  → 2-way coupling approach

- **Compressible FSI Model**:
  → compressible VOF solver with a rigid substrate
  → 1-way coupling approach

- **FSI model validation**:
  → Comparison with existing analytical data

# High speed drop impact




Li et al., 2008

# Governing equations, compressible fluid

Continuity: $$\frac{\partial \rho_f}{\partial t} + \nabla \cdot (\rho_f V_f) = 0$$

Momentum: $$\frac{\partial (\rho_f V_f)}{\partial t} + \nabla \cdot (\rho_f V_f \otimes V_f) = \nabla \cdot \sigma_f + \rho_f g$$

Equation of state: $$\rho_f = \rho_{f_0} + p_f \psi$$

Fluid stress tensor: $$\sigma_f = -p_f I + \mu_f \left( \nabla V_f + \nabla V_f^{\,T} \right)$$

# Equation of state

- Air: Ideal gas law @ isothermal condition

$$\rho_f = \rho_{f_0} + p_f \psi, \quad \psi : compressibility\ factor$$

$$\rho_{f_0} = 0, \psi = \frac{1}{RT} \approx 10^{-5} \Rightarrow p = \rho RT$$

- Water: Tait's equation of state

$$\frac{p_f + B}{p_a + B} = \left( \frac{\rho_f}{\rho_{f_0}} \right)^N$$

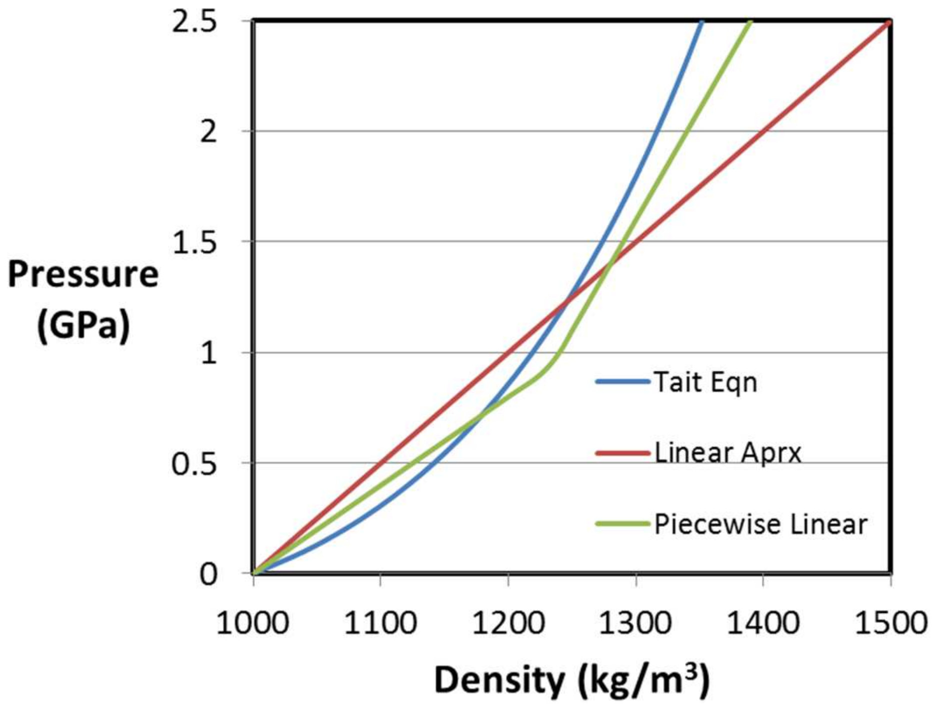
$$B = 300MPa,\ p_a = 0.1MPa,\ N = 7.415$$

- Linear approximation:

$$\rho_f = \rho_{f_0} + p_f \psi$$

$$\rho_{f_0} = 1000, \psi = 10^{-7}$$

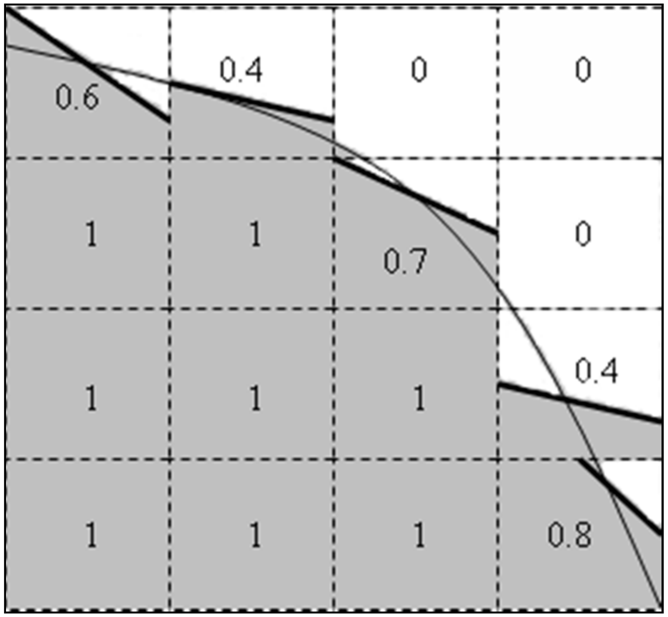
$$\rho_f = \rho_{f_0} + p_f \psi$$



# Volume of Fluid method

- Liquid volume fraction:

$$\begin{cases} \alpha_l = 0 & \textit{Gas phase} \\ 0 < \alpha_l < 1 & \textit{Interface} \\ \alpha_l = 1 & \textit{Liquid phase} \end{cases}$$




- VOF Advection:

$$\frac{\partial \alpha_l}{\partial t} + \nabla.(V_f \alpha_l) = 0$$

- Interface Reconstruction method:
  *Piecewise Linear Interface Calculation (PLIC)* of Youngs (1982)

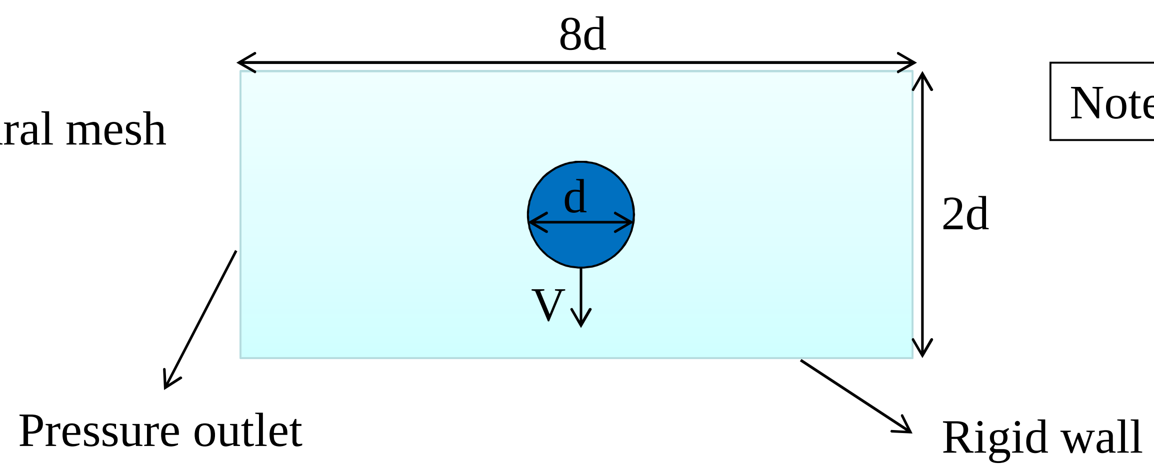
# Numerical scheme

- Solver: compressible VOF
- Segregated solver and fixed system of grids
- 2nd order accuracy in space and time
- Pressure-velocity coupling → Pressure-Implicit with Splitting of Operators (PISO) method
- Adaptive time step based on CFL initially set to 0.1

# Domain & boundary conditions

Uniform hexahedral mesh
Grid size = d/20

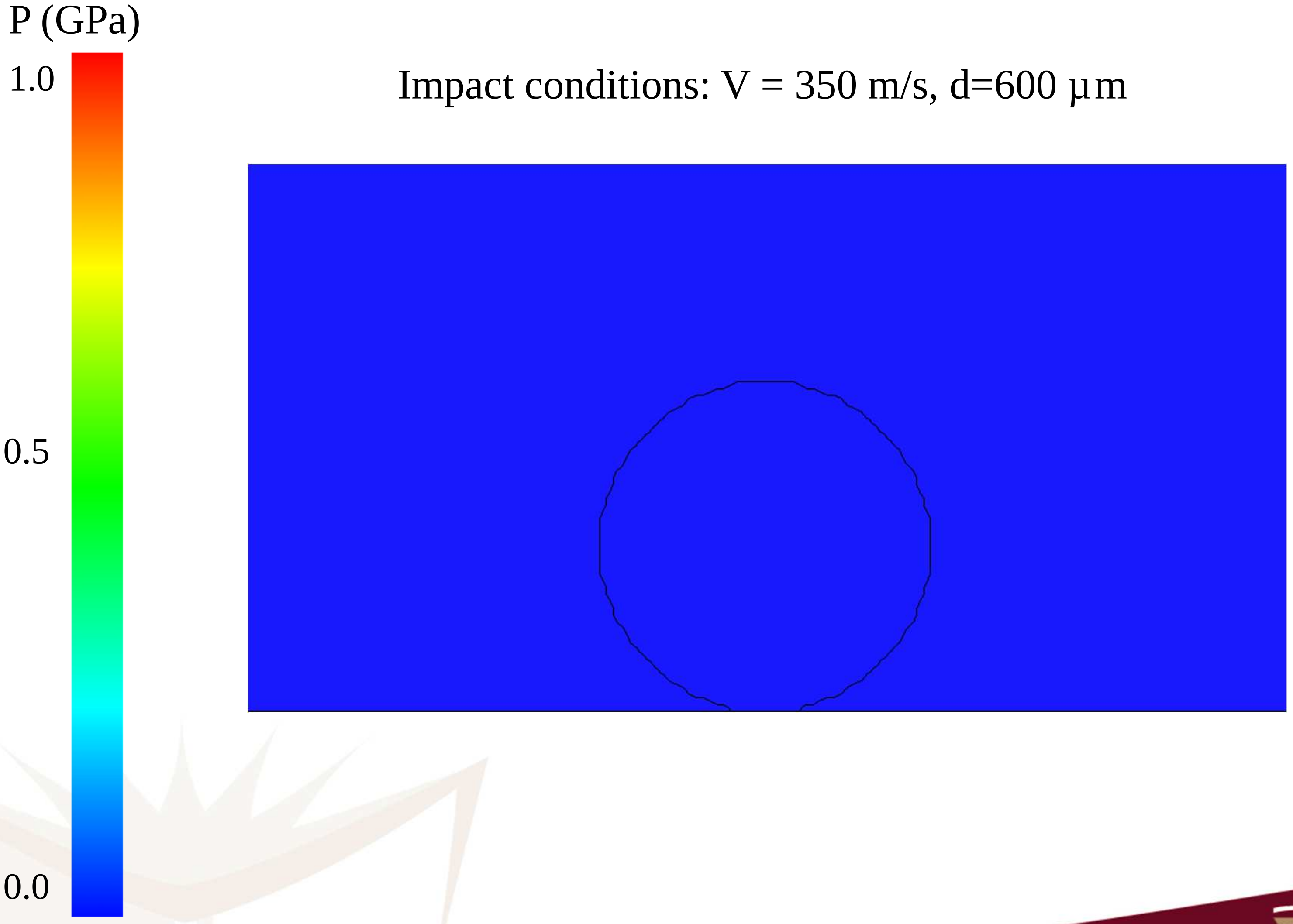
Note: not to scale




| Fluid initial properties | Air | Water |
|---|---|---|
| Density (kg/m$^3$) | 1 | 1000 |
| Kinematic viscosity (m$^2$/s) | 1.48e-05 | 1e-06 |
| Surface tension (N/m) | - | 0.07 |

# Generated pressure upon impact

Impact conditions: V = 350 m/s, d=600 μm



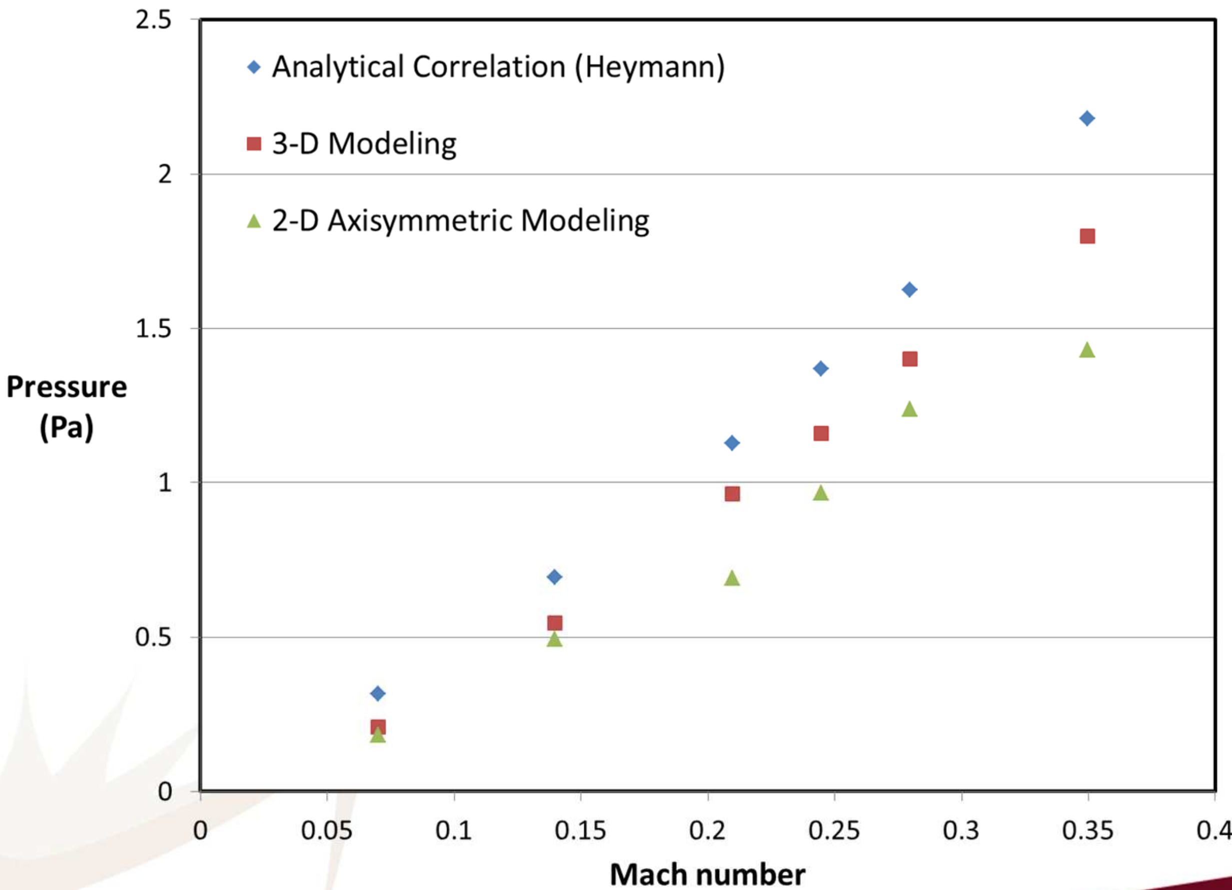
# Test matrix for velocity range

Number of cases = 12

| Simulation Type | Droplet size (μm) | Velocity (m/s) |
|---|---|---|
| 2-D axisymetric | 500 | 100 |
| 3-D | 500 | 200 |
| | | 300 |
| | | 350 |
| | | 400 |
| | | 500 |

# Results, effect of impact velocity

Impact conditions: d=500 µm, V varies
Ma=V/C, C is sound speed in liquid

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# Test matrix for diameter range

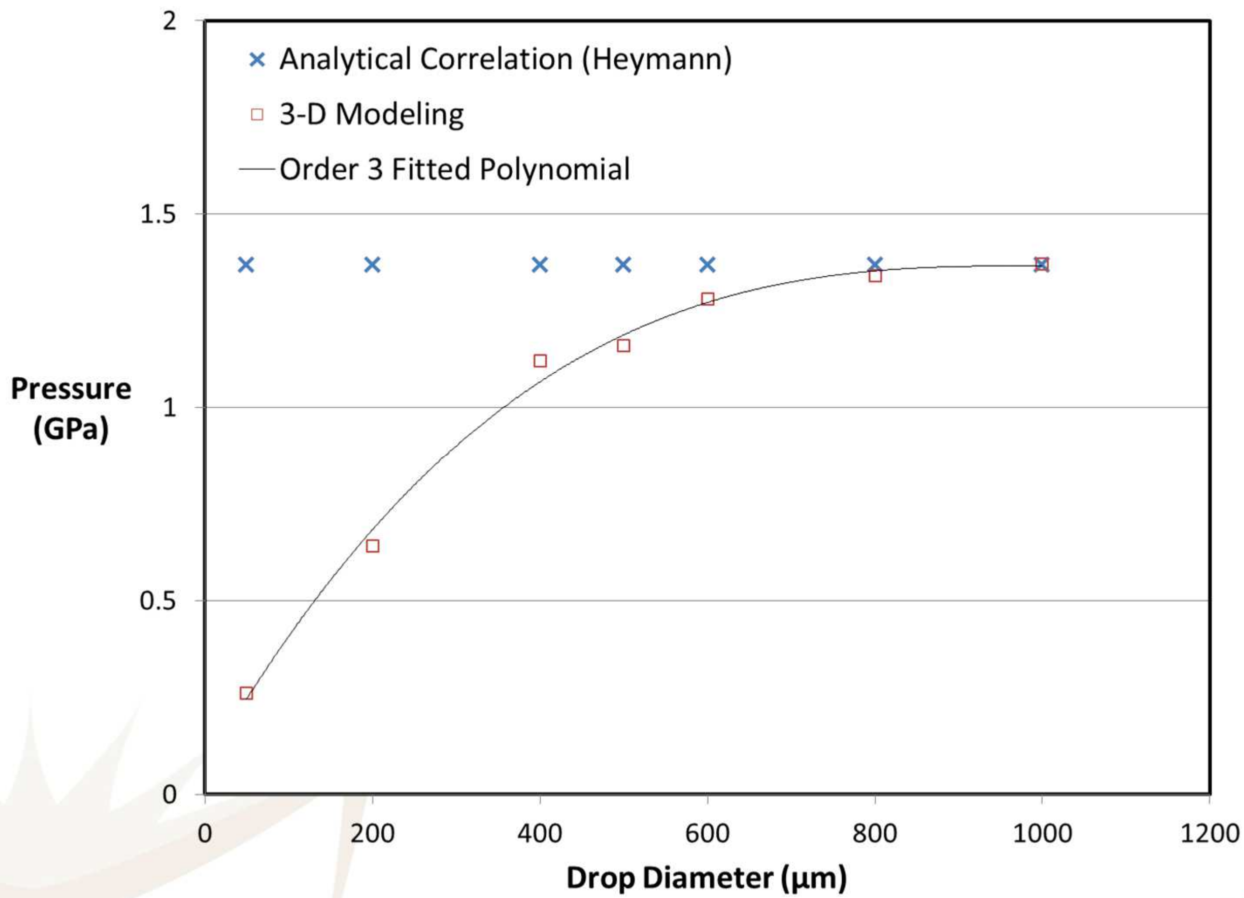
discussed during previous meeting

Number of cases = 7

| Simulation Type | Droplet size (μm) | Velocity (m/s) |
|---|---|---|
| 3-D | 50 | 350 |
| | 200 | |
| | 400 | |
| | 500 | |
| | 600 | |
| | 800 | |
| | 1000 | |

# Results, effect of droplet diameter

Impact conditions: V = 350 m/s, d varies



# Progress to date

- Incompressible Fluid-Solid Interaction model:
  - ✓ 1-way and 2-way coupling methods
  - ✓ 2-D axisymmetric and 3-D model
  - ✓ Impact velocities up to 100 m/s
  - ✓ Droplet size of 500 microns

- Compressible Fluid model:
  - ✓ 3-D model results compared to theoretical data
  - ✓ Impact velocities up to 500 m/s for drop size of 500 µm
  - ✓ Droplet diameter range of 50-1000 µm for impact velocity of 350 m/s

# Deliverables by September 2013

- Compressible fluid modeling:
  - ✓ 3D simulation using compressible VOF model
  - ✓ Impact velocity of 350 m/s
  - ✓ Droplet size range of 50-1000 µm

- Elastic solid modeling:
  - ✓ Ti64 substrate (isotropic and pure material)
  - ✓ Response to the impact pressure generated by the droplet impingement
  - ✓ Resolving the stress components in the solid substrate in elastic mode
  - ✓ Compare the peak stress component with critical material threshold

Thank you!

Questions?

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