UNIVERSITÀ
DEGLI STUDI
DI PADOVA

FRAGMENTATION MODELS FOR HYPERVELOCITY IMPACT

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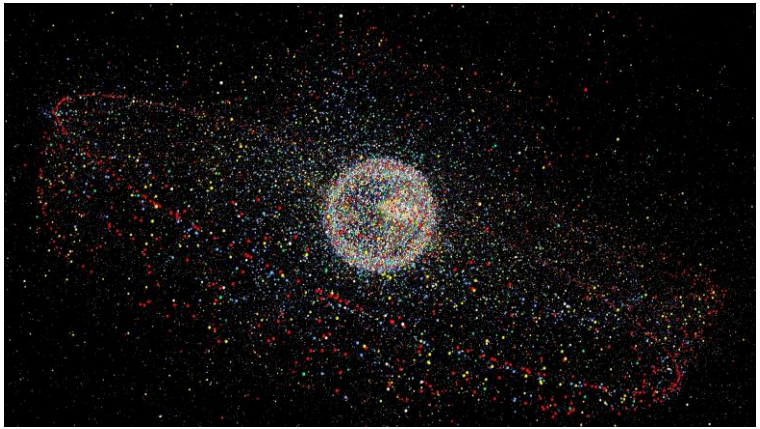
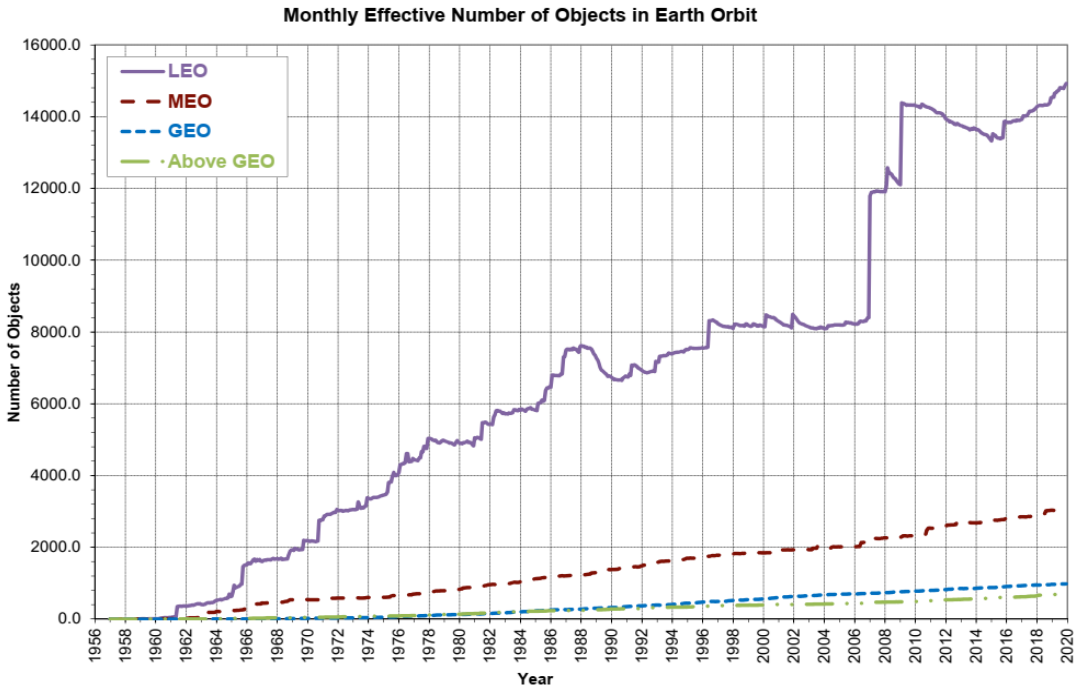
Outline

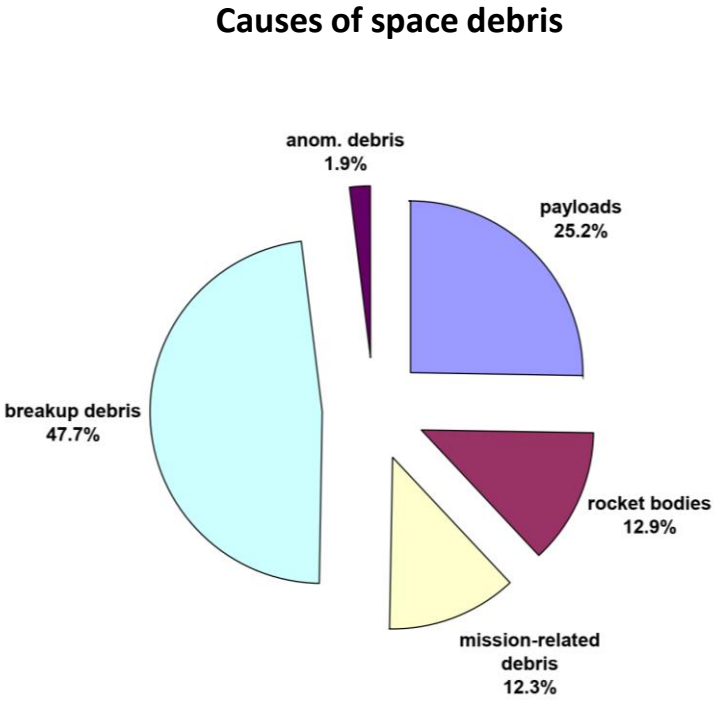
- Research background
- Satellite breakup models
- Fragmentation model
- Research tasks and methodologies
- Works up to now
- Future works



Orbital space debris

➢ Orbital space debris & Breakup events





➢ Satellite breakup models

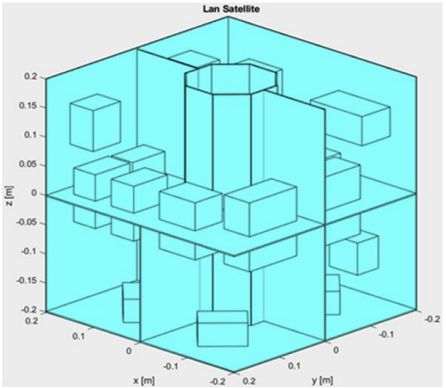
- **Empirical models**
  - ✓ NASA SBM
  - ✓ CARDC SBM

- **Semi-empirical models**
  - ✓ IMPACT
  - ✓ FAST
  - ✓ CST(CISAS)

- **Size distribution**
- **Velocity distribution**
- **Area-to-mass distribution**

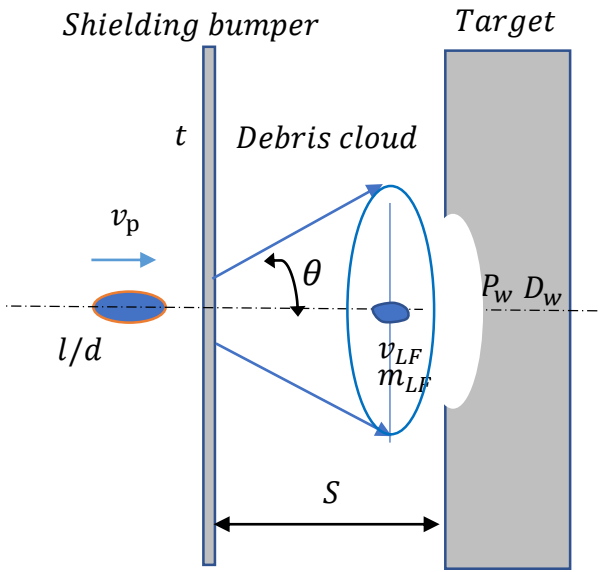
CST

- **Fragmentation algorithm**
- Fragments tracking algorithm
- Structure response



Fragmentation model

- **Small-scale model**
- **A dual-wall structure**



➢ Impact condition

- Projectile shape ratio l/d
- Impact velocity v_p, (Valid range:3km/s-7km/s)
- Impact inclination angle
- Material of projectile and target:(Aluminum to Aluminum)

➢ Thin-plate fragmentation model

- Perforated hole: d_h/d
- Largest central fragment: m_{LF}, v_{LF}.
- Spray angle of debris cloud: θ
- Mass, velocity distribution of fragments: N_m and N_v
- Edge velocity of debris cloud.

➢ Thick target penetration depth model

➢ Damage response model

$$\frac{P_W}{D_W} = F(t/d, l/d, S/d, v_p/c, \rho_p/\rho_t, \rho_p/\rho_w)$$

Research tasks and methodologies(1)

➢ Investigation on projectile shape effects

- SPH numerical simulation with AUTODYN code
- Characterization investigation of shape effects on impacting fragmentation

➢ Fragmentation model development

- Semi-empirical fragmentation model for satellite structure & material
- Local and global damage response model

➢ Programming of new fragmentation model

- Programming with MATLAB
- Incorporation into CST and calibration

➢ Experimental calibration and validation

- Hypervelocity impact experiment with two-stage gas gun

Research tasks and methodologies(2)

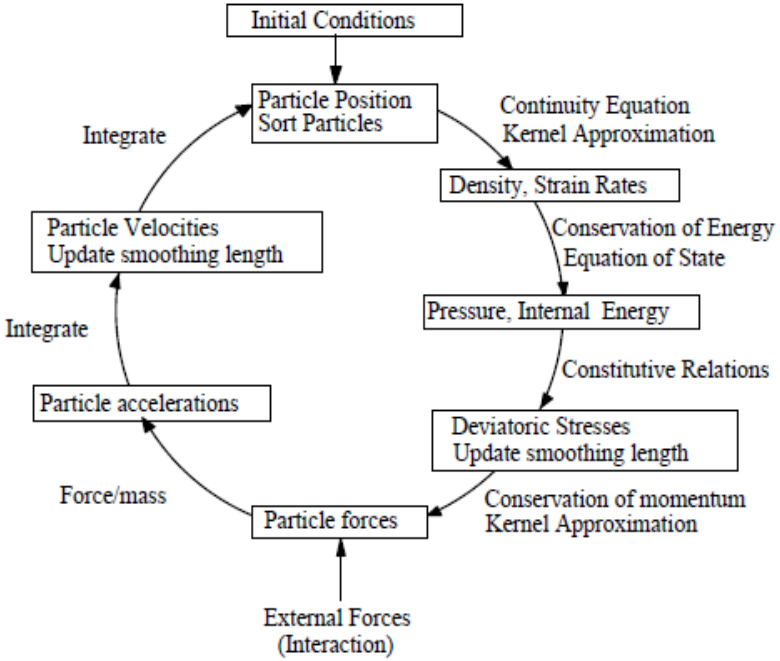
Smooth Particles Hydrodynamics - SPH simulation

- Gridless Lagrangian method
- Extreme deformation and high pressure condition

➢ **Equation of state**
- Mie - Gruneisen EOS
- Tillotson EOS
- Shock EOS

➢ **Material strength model**
- Johnson cook
- Steinberg-Guinan

➢ **Failure model**
- Grady criterion
- Maximum stress criterion



Works up to now

- Literature review activities and research scheme refinement
- Investigation on characteristics of projectile shape effects
  - Debris cloud characteristics of shaped projectile
  - Damage effectiveness in terms of shape ratio
- Preliminary works on fragmentation model development
  - Perforation hole size prediction model
  - Central large fragment model
  - Penetration depth model
  - Debris cloud spray-angle model

Works on fragmentation model (1)

Perforation hole model

Maiden CJ, McMillan AR.
AIAAJ 1964;2(11).

$$\frac{D_h}{d_p} = 2.4 \cdot \frac{v}{c} \cdot \left(\frac{t_b}{d_p}\right)^{2/3} + 0.9$$

Nysmith CR, Denardo BP.
NASA TN D-5492, 1969.

$$\frac{D_h}{d_p} = 1.46 \cdot v^{0.5} \cdot \left(\frac{t_b}{d_p}\right)^{0.45}$$

Shape effect consideration

$$d_E = d_p \cdot f^a$$

$$f = l/d_p$$

$$\frac{D_h}{d_p} = f^{a_0} \cdot 2.4 \cdot \frac{v}{c} \cdot \left(\frac{t_b}{d_p}\right)^{2/3} + 0.9 \cdot f^{a_1}$$

$$\frac{D_h}{d_p} = 1.46 \cdot v^{0.5} \cdot \left(\frac{t_b}{d_p}\right)^{0.45} \cdot f^b$$

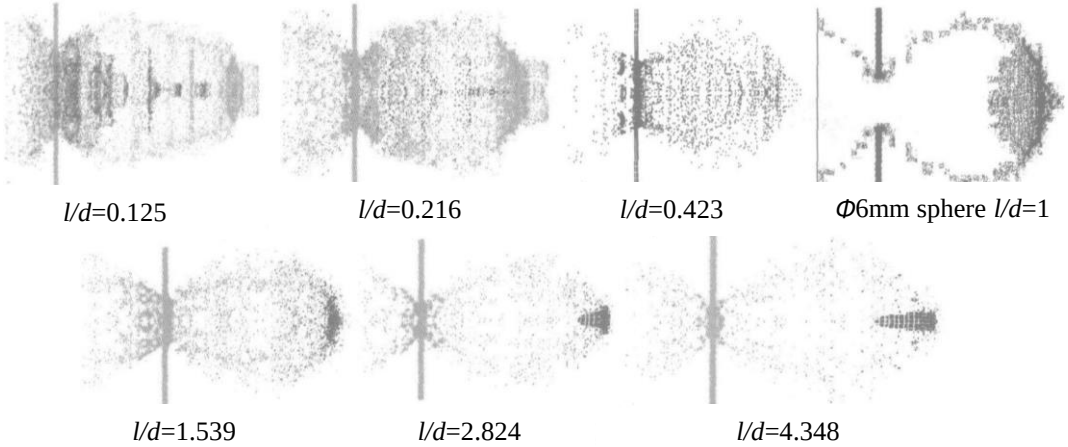
Parameters calibration: Linear regression method

Reference database: Aluminum to Aluminum hypervelocity impact at 3.7km/s~10.4km/s

- Experiment data from: *Scott A. Hill. Inter. J Impact Engng 30(2004).*
- Simulation data from: *Schonberg WP. NASA CR-4486, Washington, DC, 1993.*

Debris cloud spray-angle analytic model

Projectile: Al-2A12, bumper: Al-2A12, impact velocity: 5km/s, time: t=10us.



Analytic model form

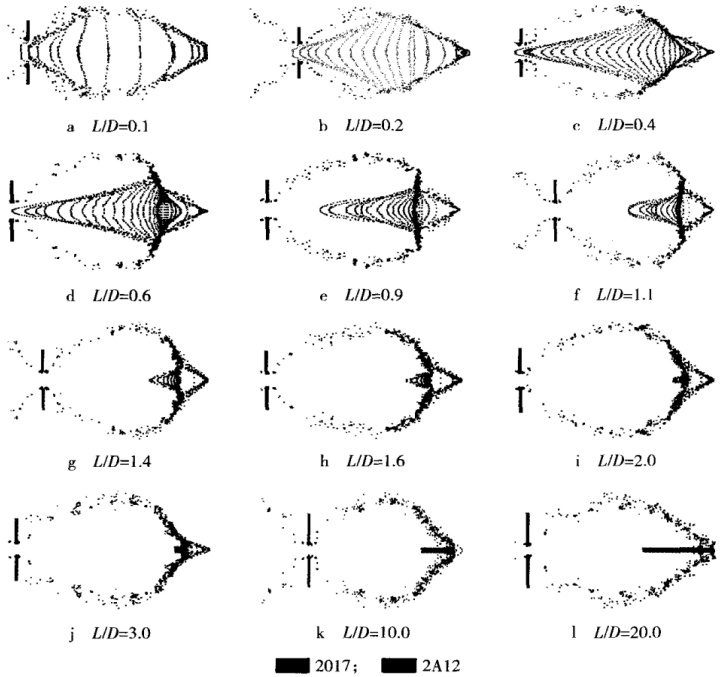
$$\theta \propto f(v/v_c) \cdot f(t_b/d_p) \cdot f(l/d_p)$$

$$\theta = c_0 \cdot \left(\frac{v}{v_c}\right)^{c_1} \cdot \left(\frac{t_b}{d_p}\right)^{c_2} \cdot f^{c_3} \cdot c_4{}^{-(f-1)/c_5}$$

Works on fragmentation model (3)

Central large fragment model

Projectile: Al-2017, bumper: Al-2A12, impact velocity: 5km/s, time: t=20us.



Analytic model forms

- **Size prediction model:**

$$\frac{d_f}{d_p} \propto f\left(\frac{v}{v_{FR}}\right)\cdot f\left(\frac{l}{d_p}\right) \propto f\left(\frac{v}{c}\right)\cdot f\left(\frac{l}{d_p}\right)\cdot f\left(\frac{t_b}{d_p}\right)$$

$$\frac{d_f}{d_p} = a_0\cdot\left(\frac{v}{c}\right)^{a_1}\cdot\left(\frac{t_b}{d_p}\right)^{a_2}\cdot\left(\frac{l}{d_p}\right)^{a_3}$$

$$\frac{d_f}{d_p} = a_0\cdot\left(\frac{v}{c}\right)^{a_1}\cdot\left(\frac{t_b}{d_p}\right)^{a_2}\cdot\left(\left(\frac{l}{d_p}\right)^{a_3} + e_0\left(\frac{l-l_e}{d_p}\right)^{e_1}\right)$$

- **Velocity prediction model:**

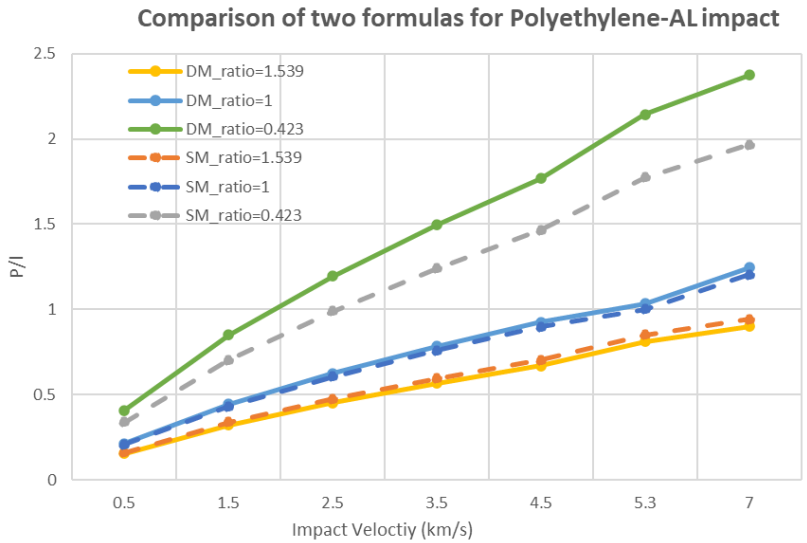
$$\frac{v_f}{v} = b_0\cdot\left(\frac{v}{c}\right)^{b_1}\cdot\left(\frac{t_b}{d_p}\right)^{b_2}\cdot\left(\frac{l}{d_p}\right)^{b_3}$$

Works on fragmentation model (4)

➢ Penetration depth model

Denardo B. P., *Moffett Field, Calif. 94035, Sept. 11, 1968.*

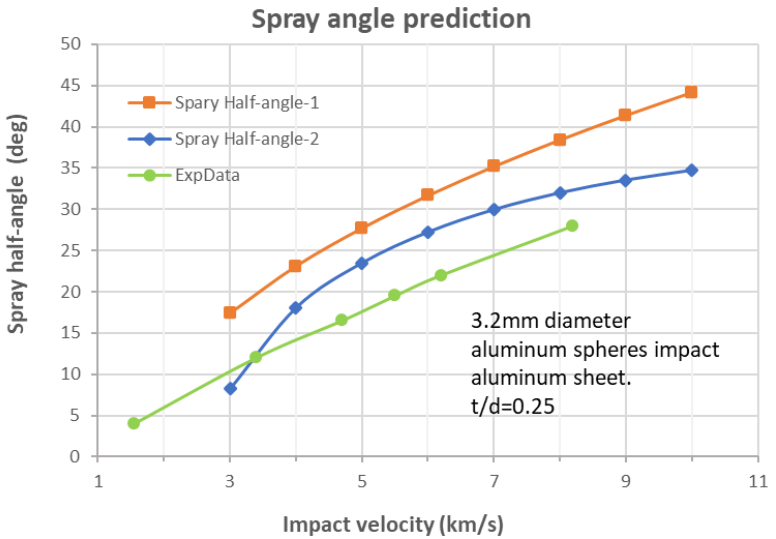
Schafer F. K. , *Impact Engineering. 2001, 26:699-711.*



➢ Debris cloud spray-angle model

Cohen L. J. , *Int. J. Impact Engng, Vol. 17:229-240, 1995*

Francesconi A., *Acta Astronautica 116 (2015) 222–228.*



Future works

(1) SPH simulation research on shape effect issue.

(2) Fragmentation models development based on simulation database.

(3) Investigation on subsequent damage response models.

(4) Fragmentation model programming and incorporation with CST.

(5) Calibration and validation experiments implement.

Thanks for your attention