Simulation of Debris Creation in hypervelocity Impact

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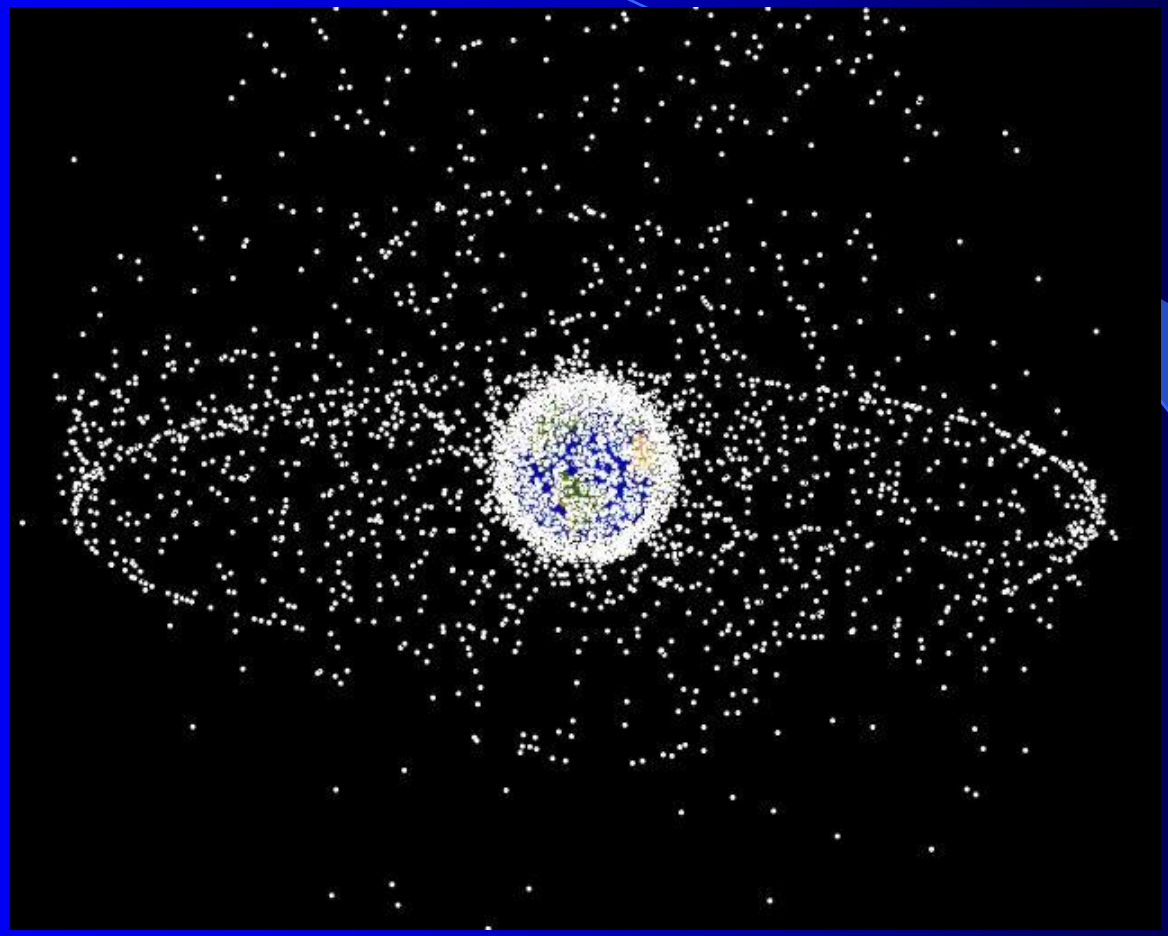
OUTLINE

1. Background
2. Software to simulate hypervelocity impact and typical applications
3. Simulation for orbital object break up (debris creation) in hypervelocity collision
4. conclusions

1. backgound

- Orbital debris is increasely concerned because of
  more aerospace activities
  manned spacecraft
- As the large relative velocity, a fatal damage could be occured if a spacecrafts is impacted by debris even with very small mass.

- debris > 10 cm ~ 20,000 objects
- debris 1 ~ 10 cm a million
- debris < 1 cm tens of million



The resouces of space deberis

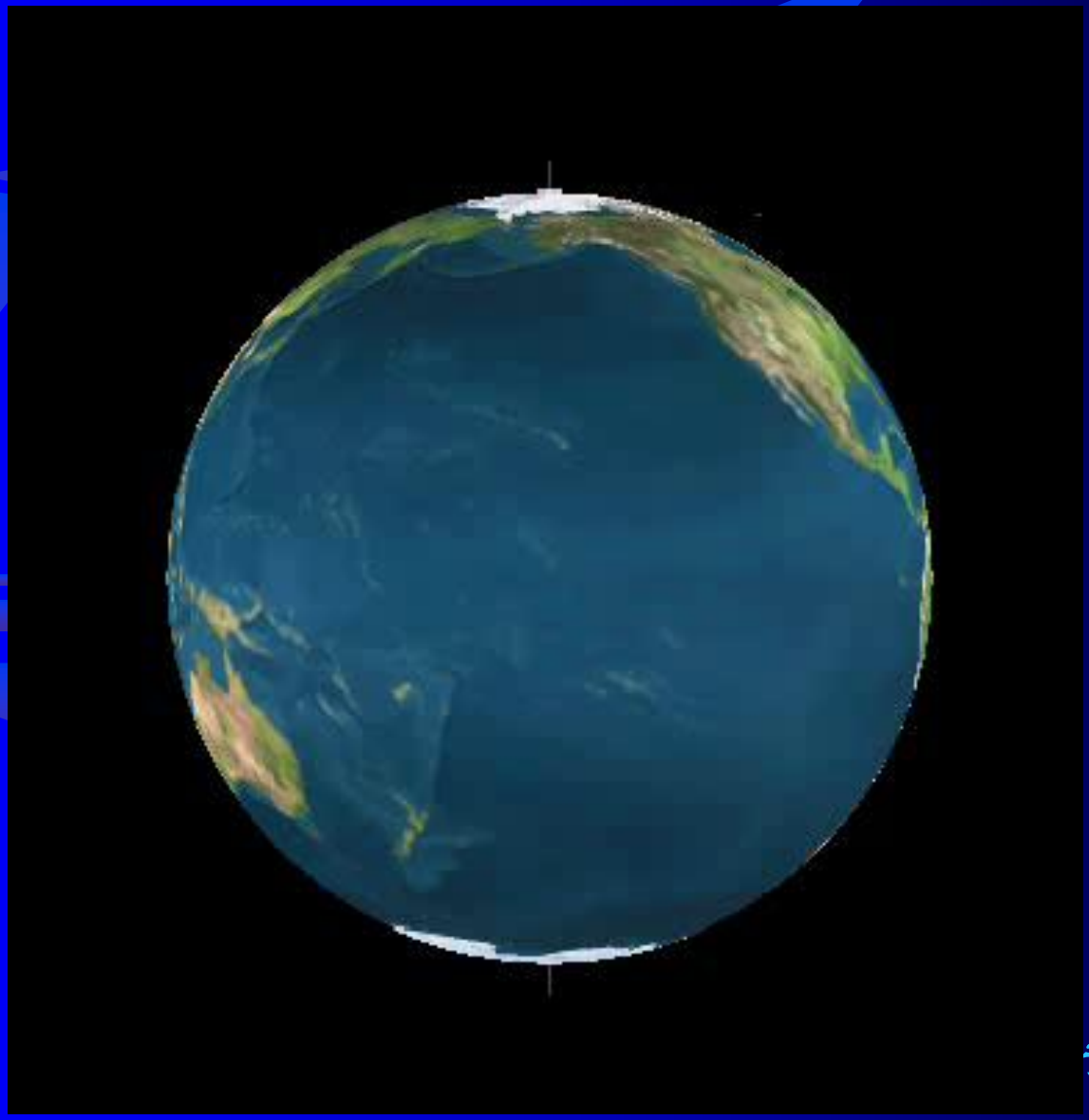
(1) human aerospace activities

- Seperation of satellite from luanch vehicle
- Sapce orperation
- last stage of luanchers
- satellites without function (out of use)

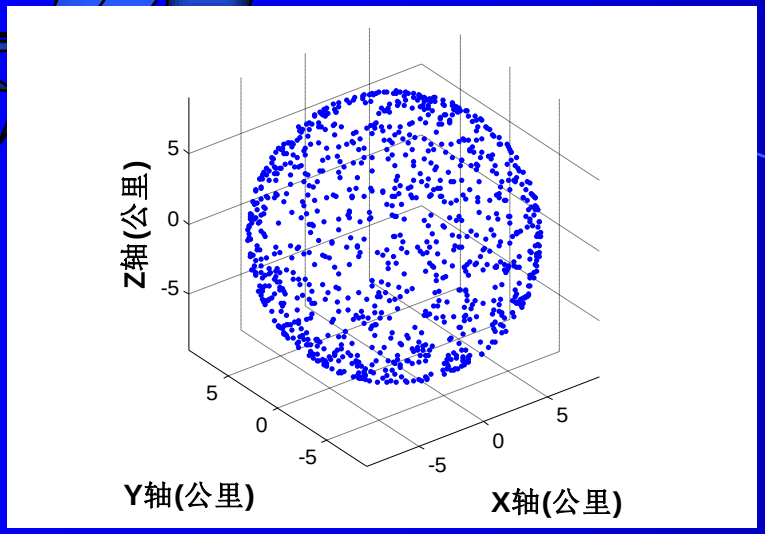
(2) Collision between orbital objects,

10 cm debris collision ---- new debris cloud containing more than one million fragments 1 mm in size and larger can be created.

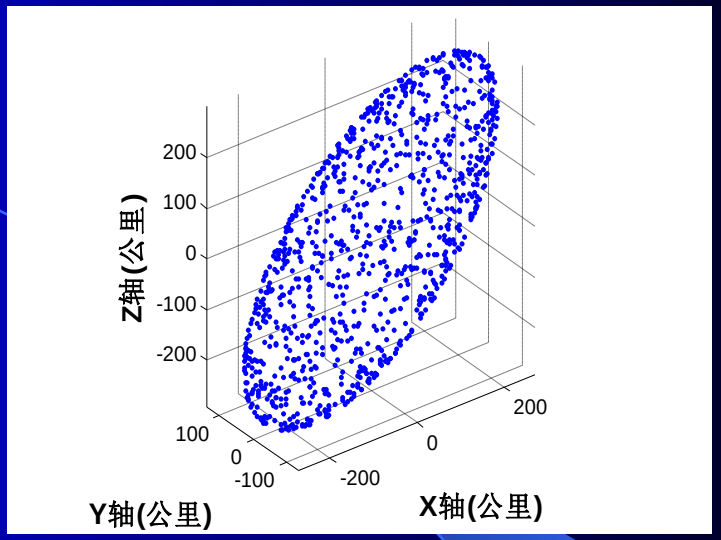
1.Simulation of debris cloud evolution



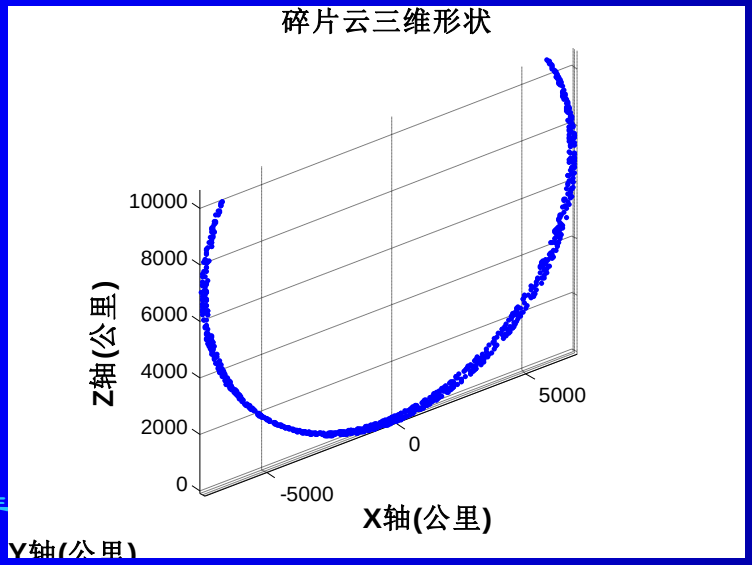
The evolution procedure of given debris cloud



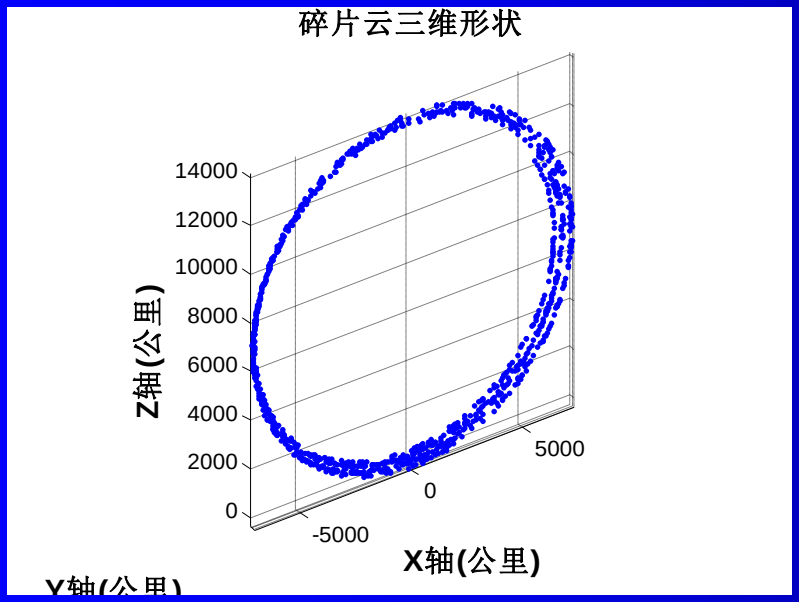
Spherical 60s,

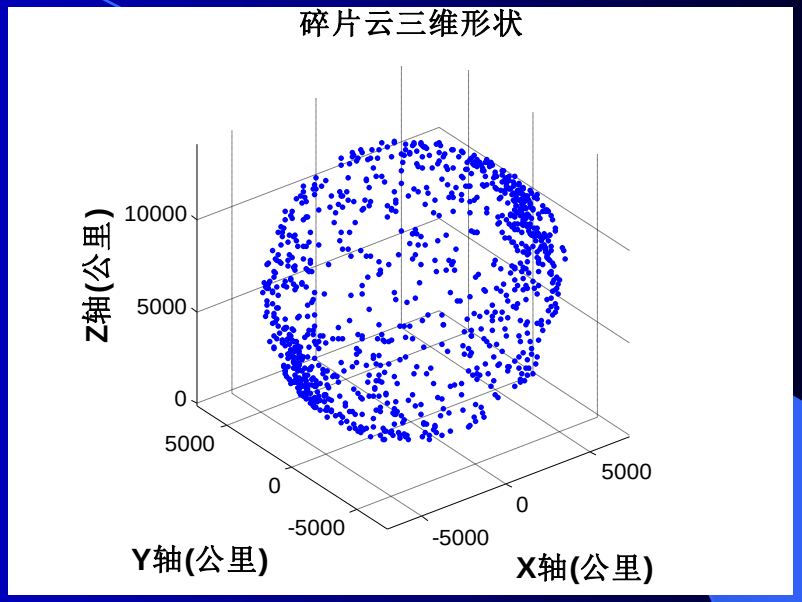


Ellipsoidal
1800s，4500s，18000s



Funiform
9h，12h，60h





Gyroidal

1d，several d，>10d

Omnidirectional filling

2y（LEO)

NASA Model for debris creation

$$N_{\geq Lc}(Lc) = 0.1(MV)^{0.75} L_c^{-1.71}$$

- NASA model is built based on the test and space surveillance data.

- NASA Model cannot consider the material property and the configurations of impact objects.

2. Software to simulate hypervelocity impact and typical applications

Hypervelocity Impact (V > 1 km/s)

Available Commercial software

Autodyn 2D and 3D

LS – Dyna

Hypervelocity impact

Fragment: sphere diameter 9.53mm, 1.2g；
Target : plate thickness 2.2mm
Impact velocity : 6.64km/s.

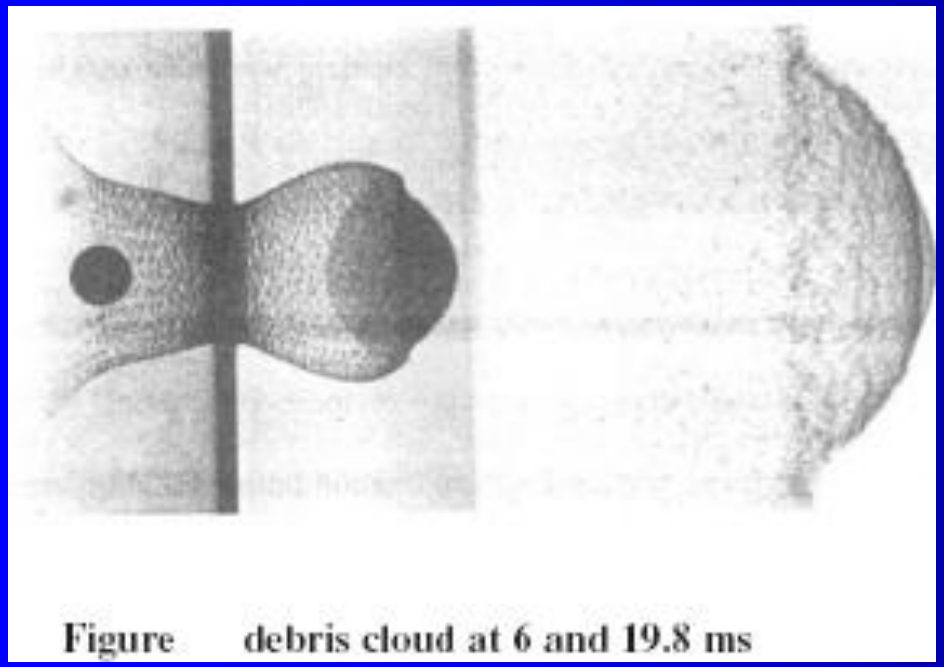
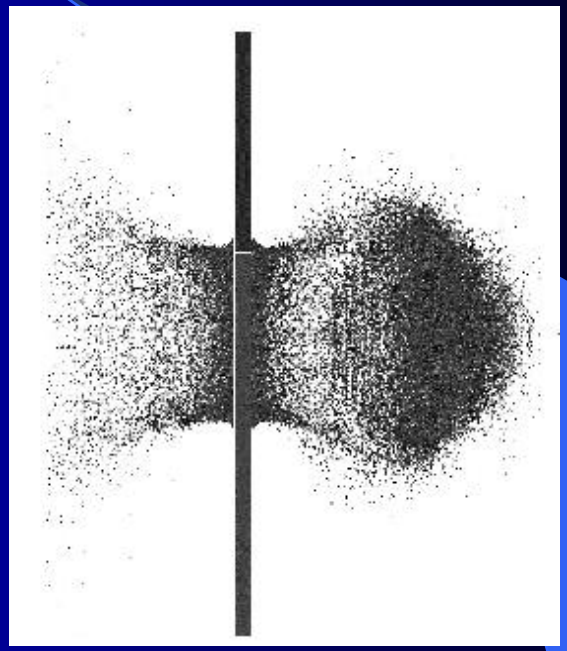
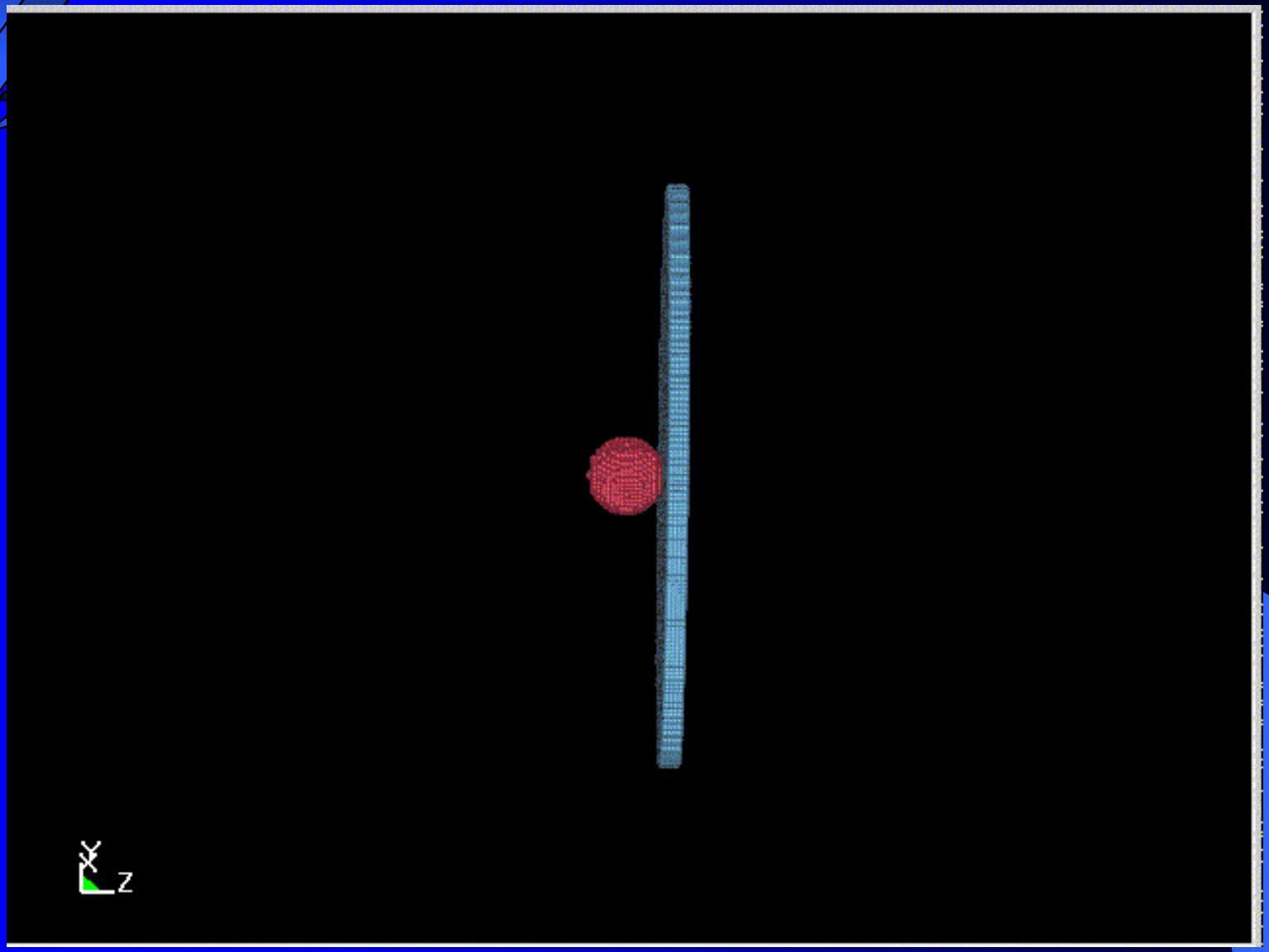


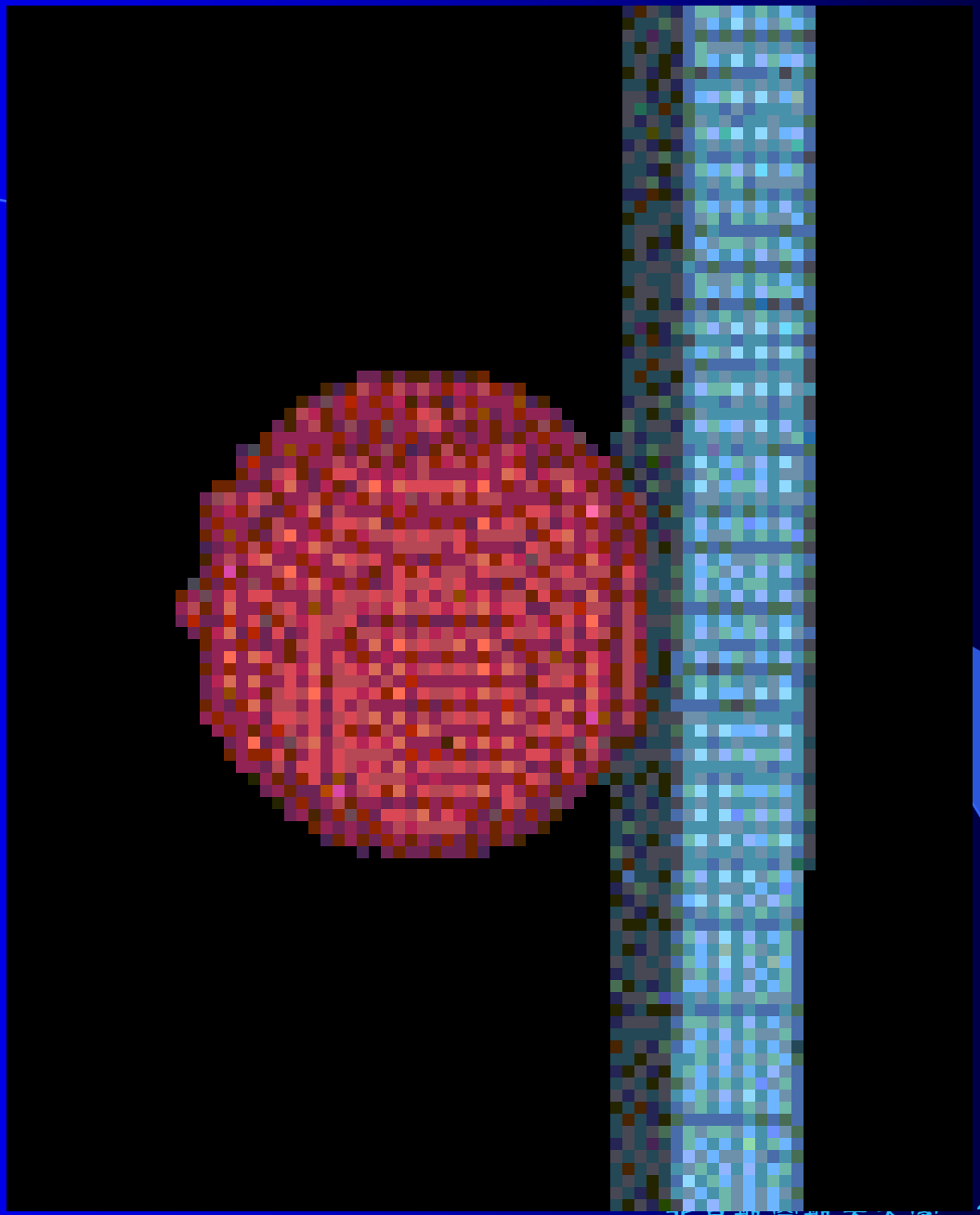
Figure debris cloud at 6 and 19.8 ms



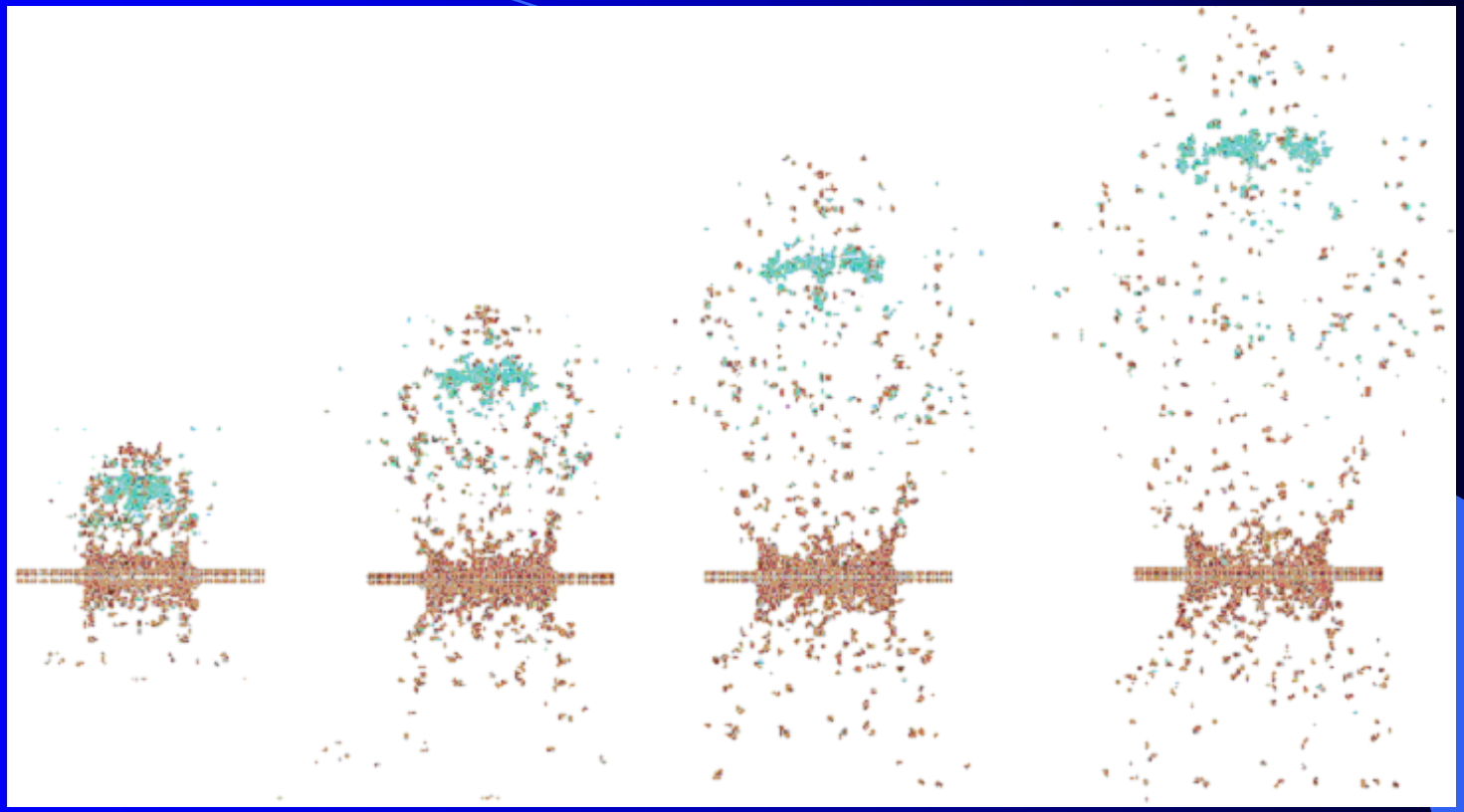
Experiment phenomenon **computational simulation**



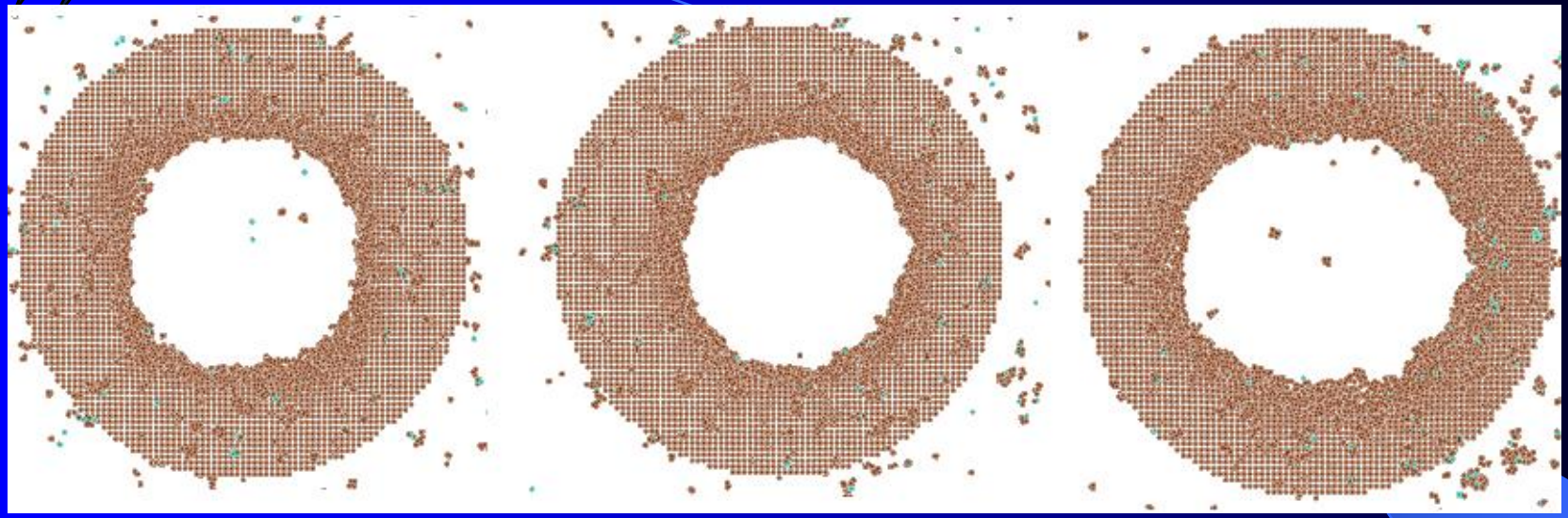
SPH simulation principle



Hypervelocity impacting with LS-Dyna



a)5μs b)10μs c)15μs d)20μs



Damage after impact

Typical Study with LS-Dyna or Autodye

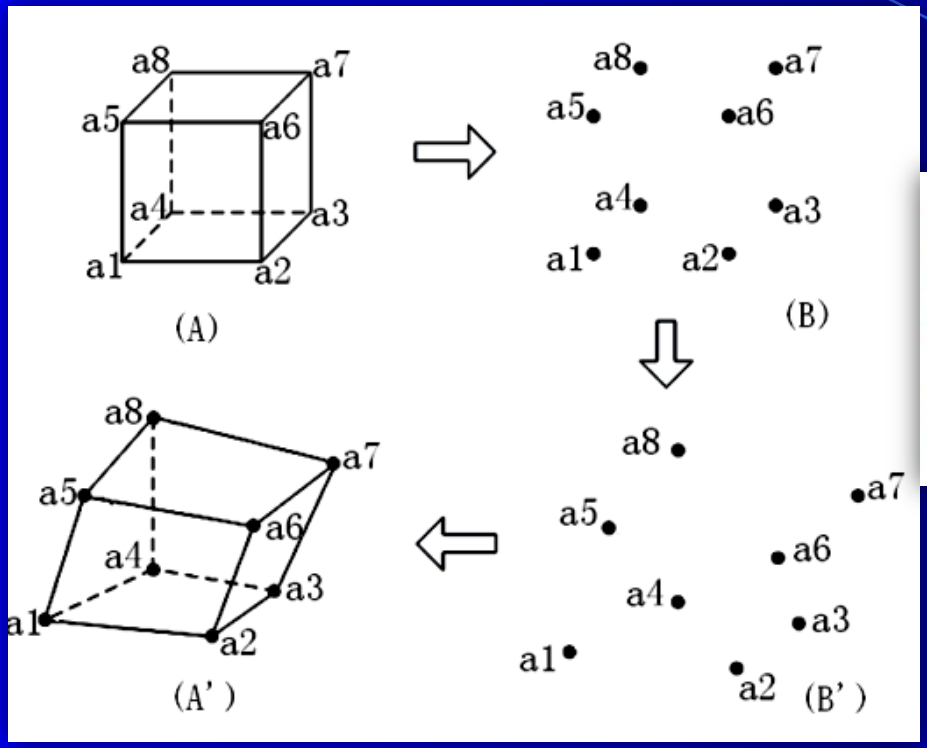
- Simulating the phenomena of impact with different bullet velocities, shooting angles, mass and sizes.
- Estimating the critical damage conditions for space structure, and used for protecting design.

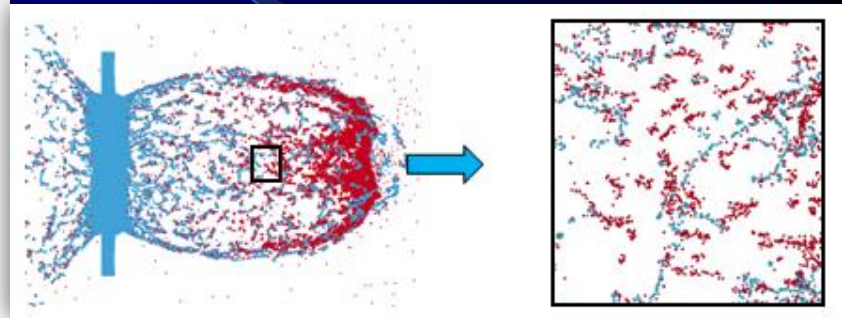
This work use it to simulation the body break up in hypervelocity impact

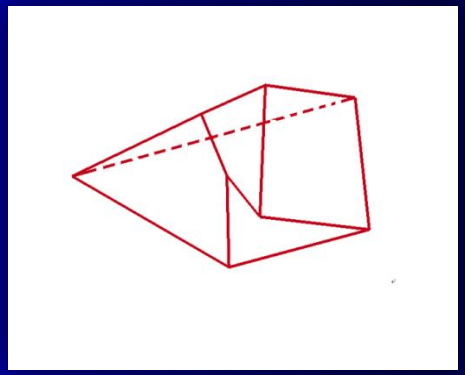
Then to estimate the number of debris with special sizes.

3. Simulation for break up in hypervelocity collision

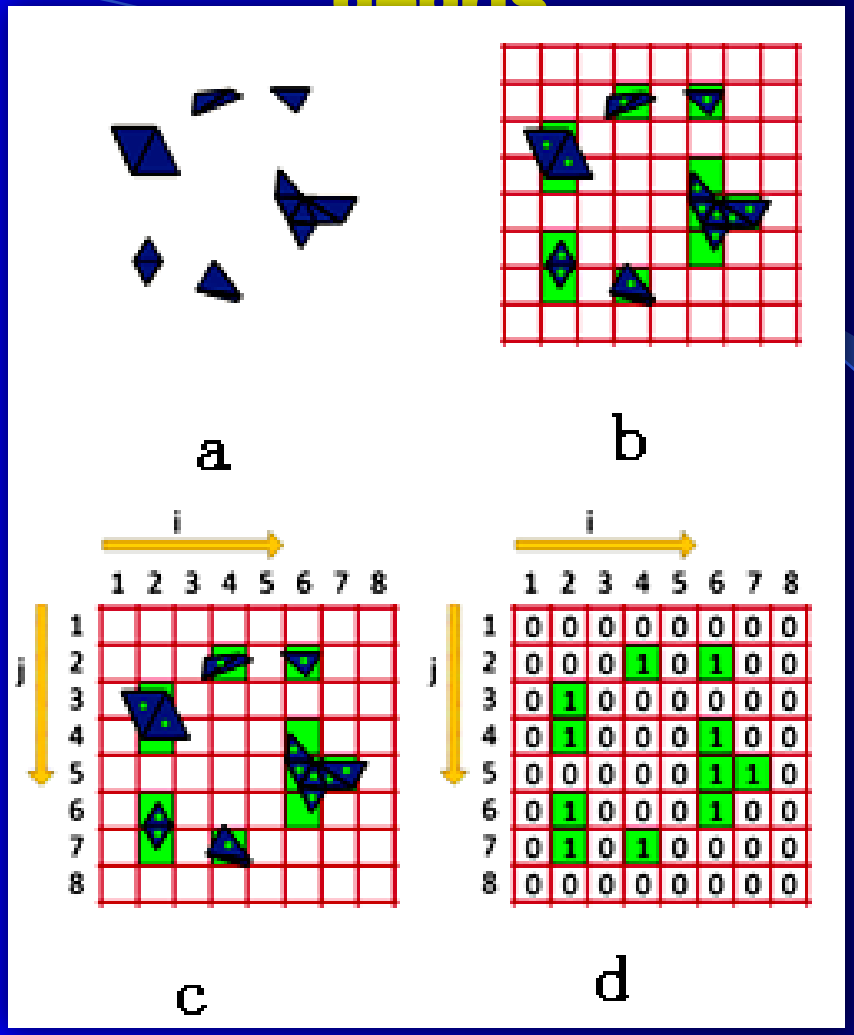
Use FEM Mesh to establish SPH particles



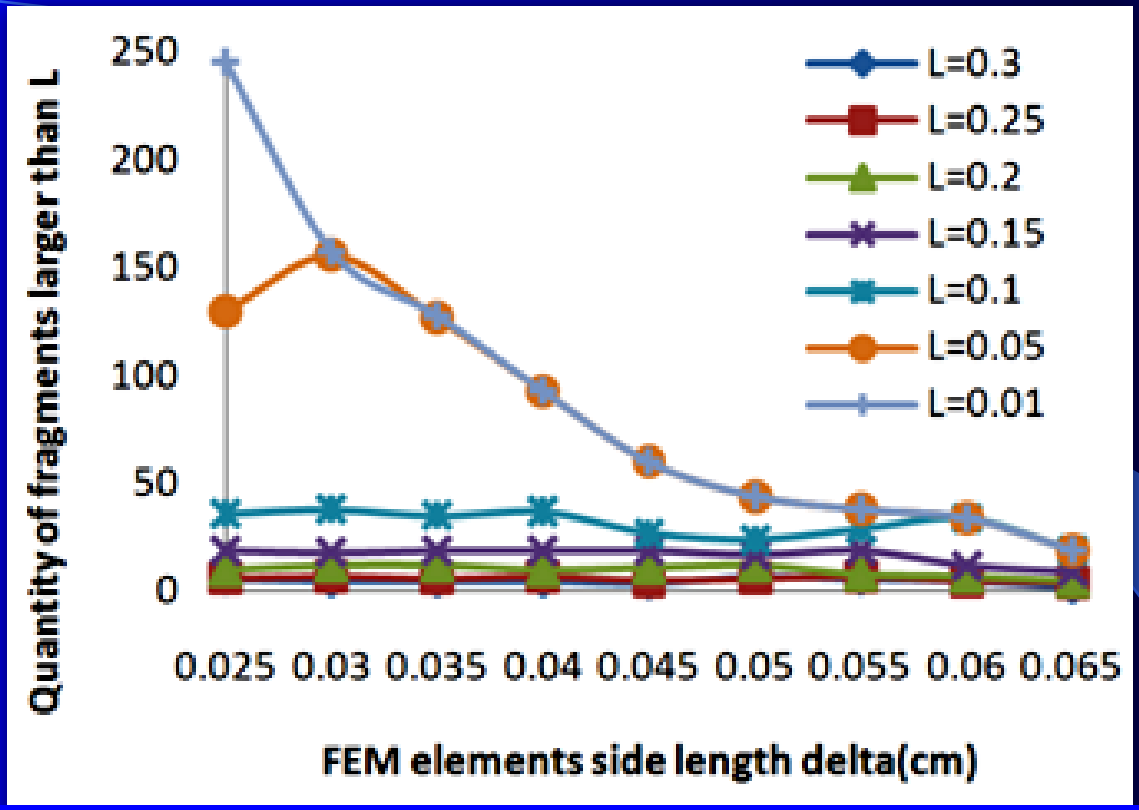




Use 0-1 drawings to statistic number of debris

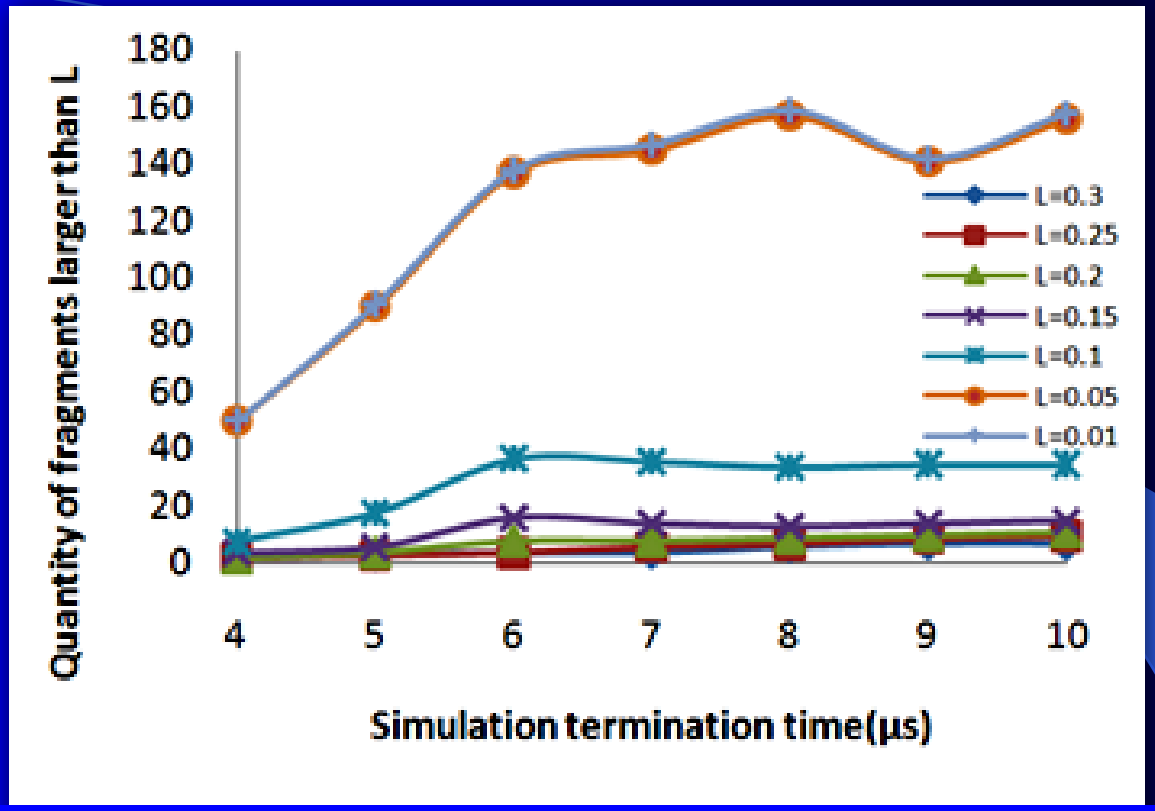


Parameters Determination



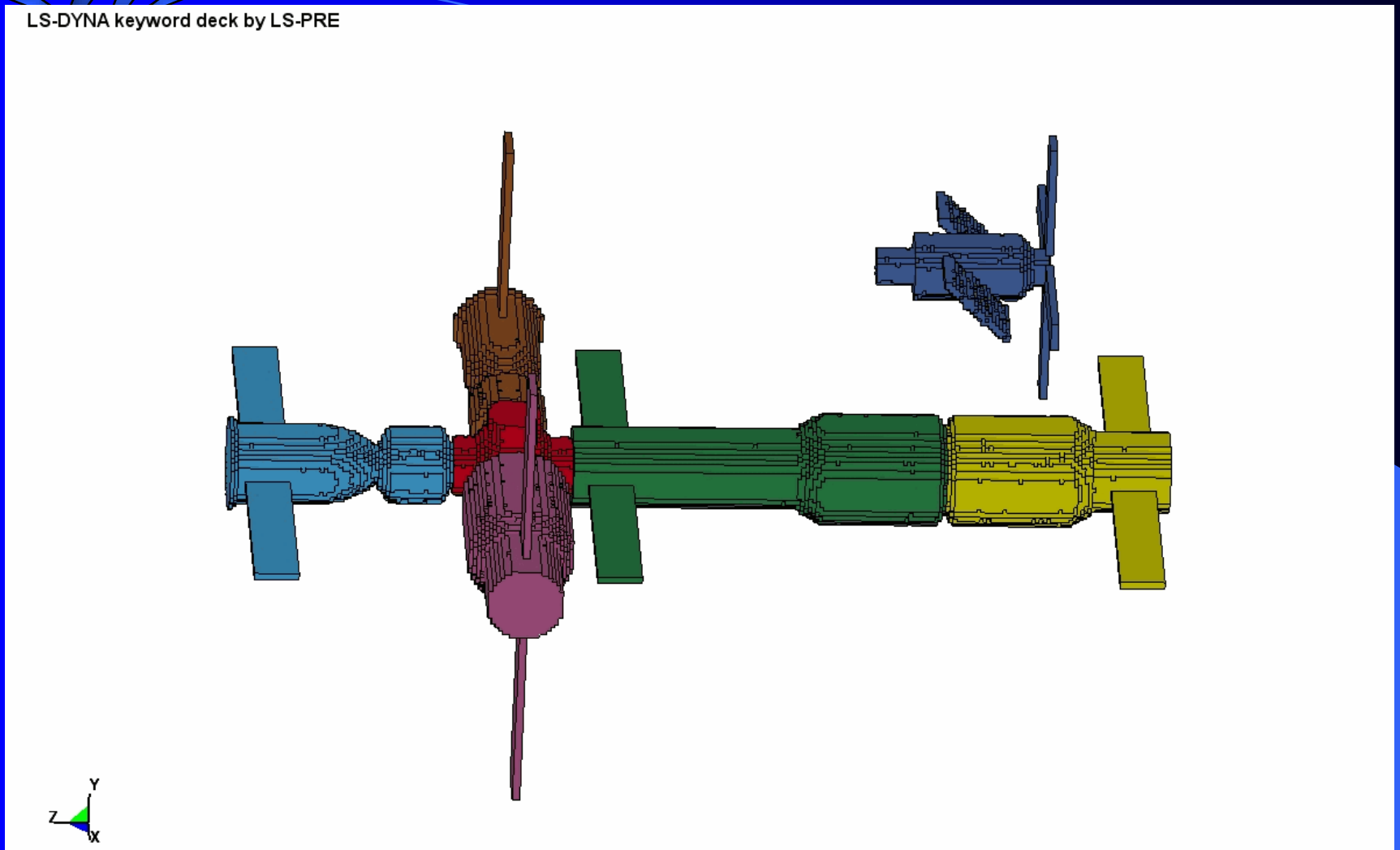
Debris size vs FE mesh size

Parameters Determination

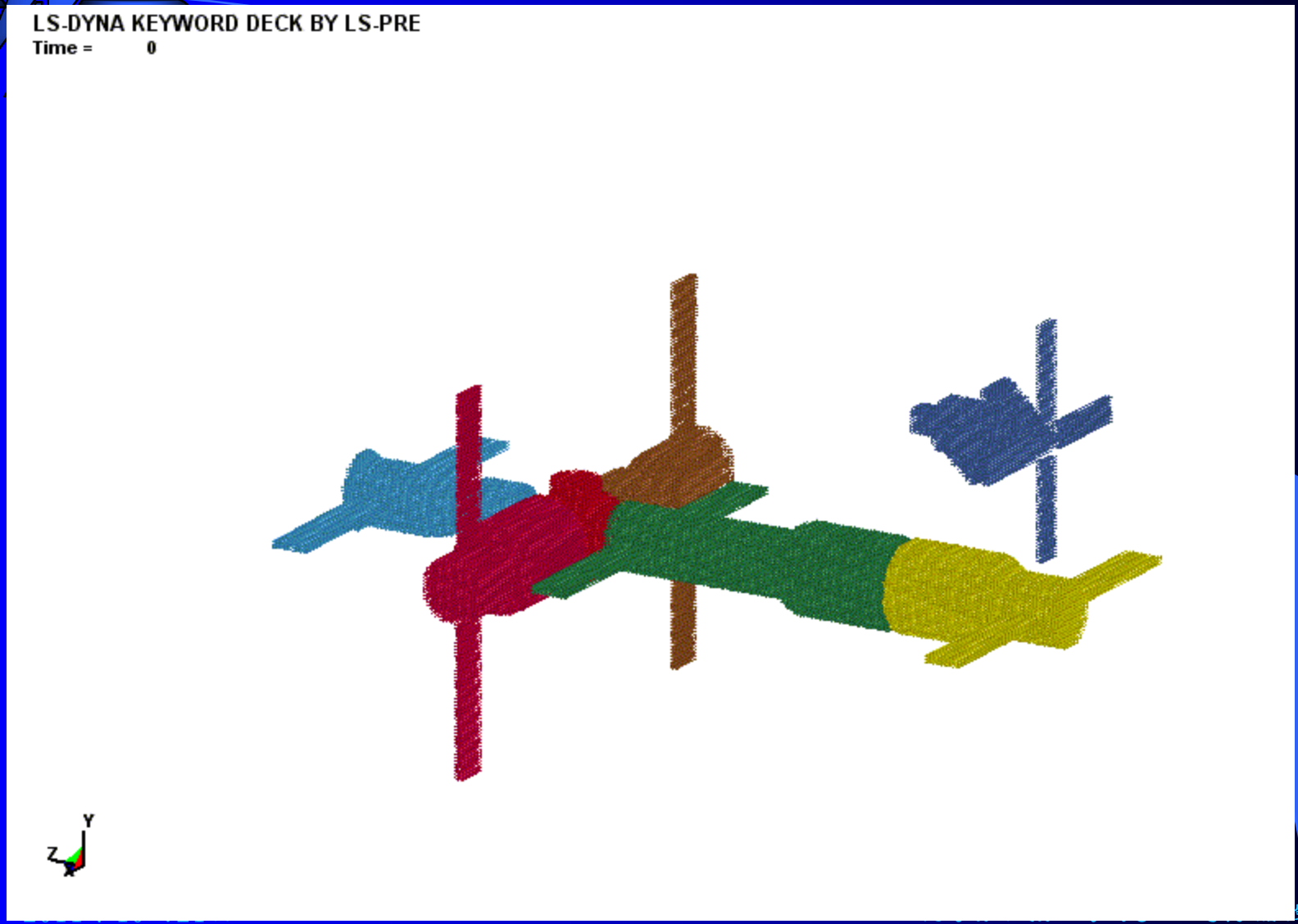


Debris size vs simulation time

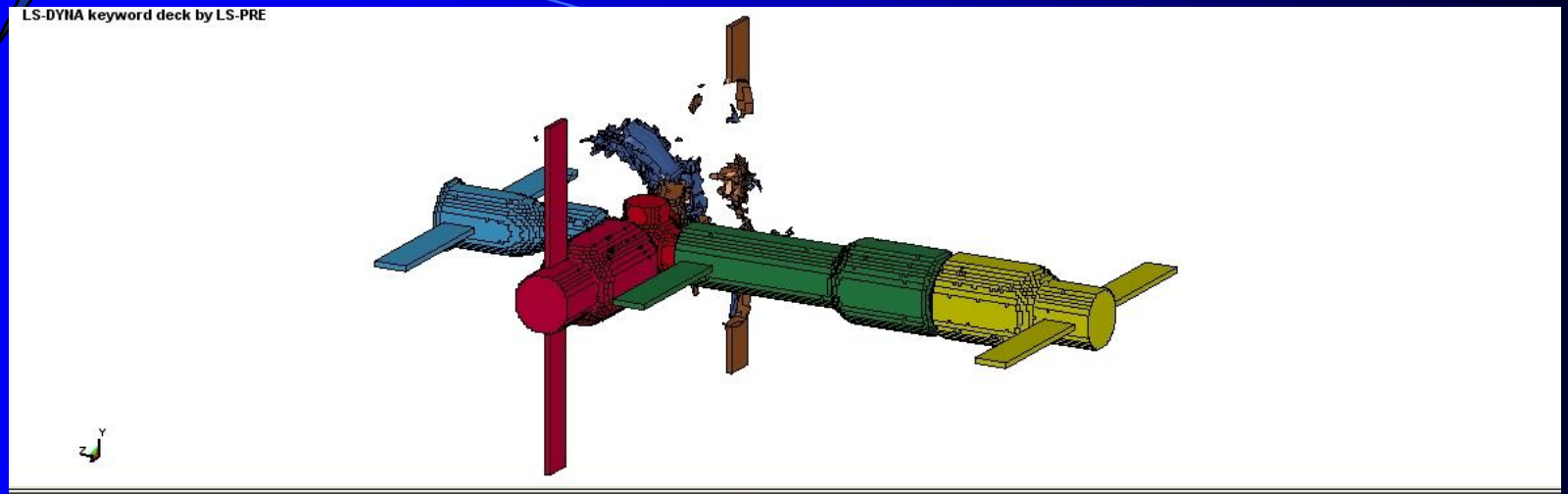
Simulation example of hypervelocity collision

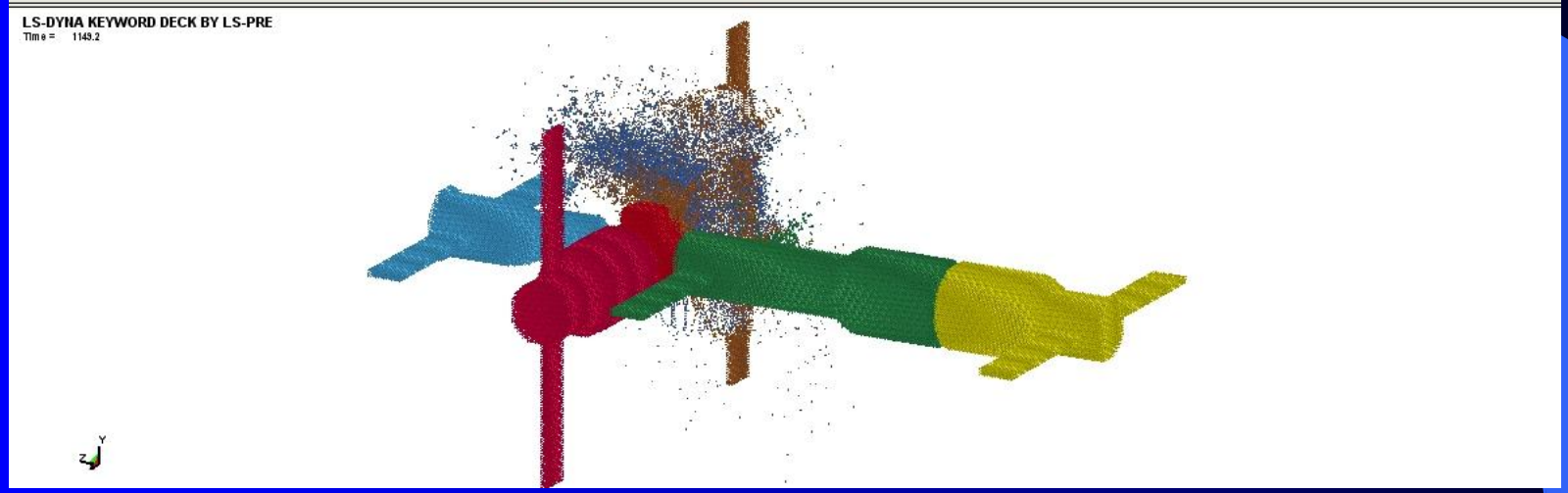


Non-central hypervelocity collision

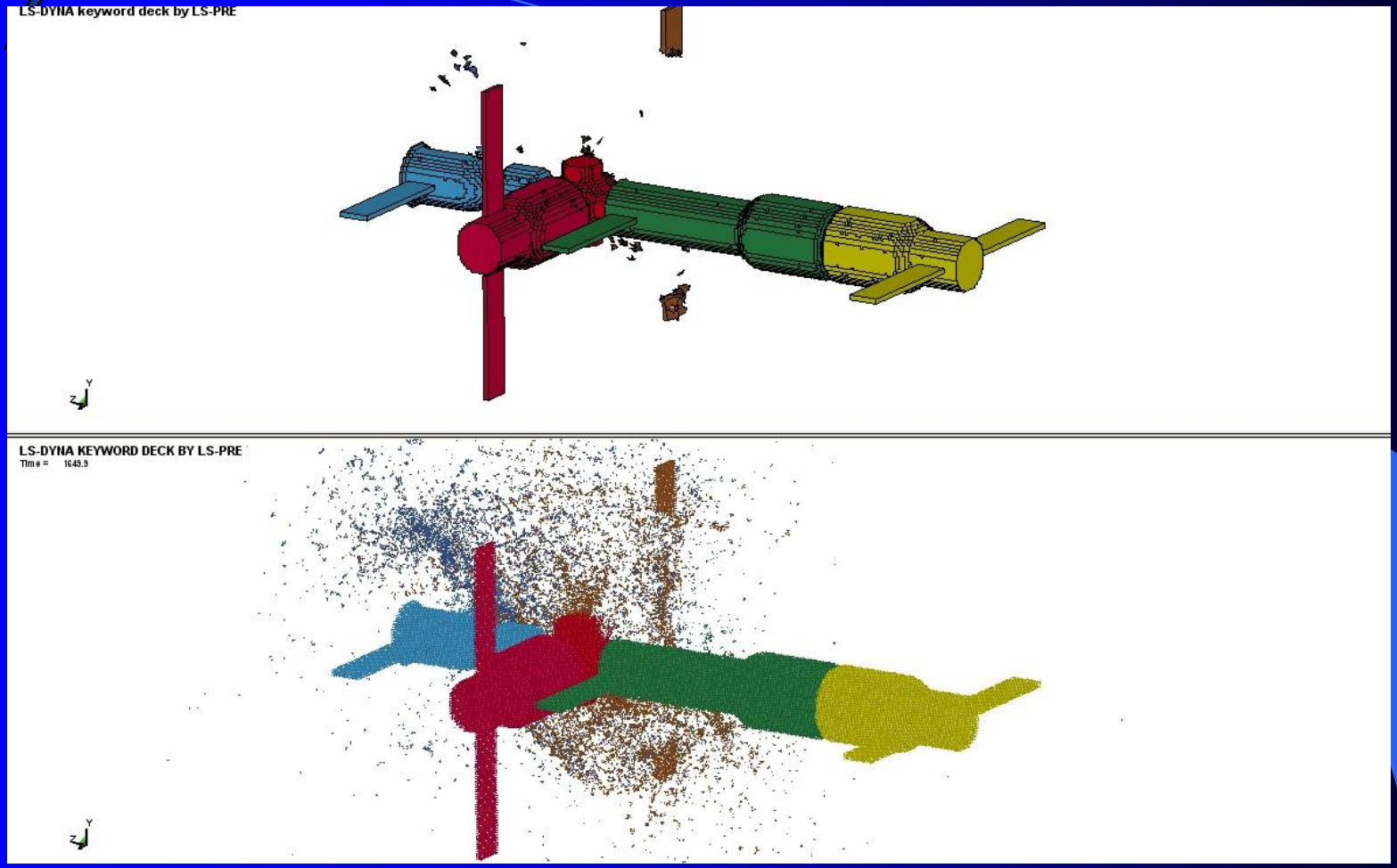


Non-central hypervelocity collision

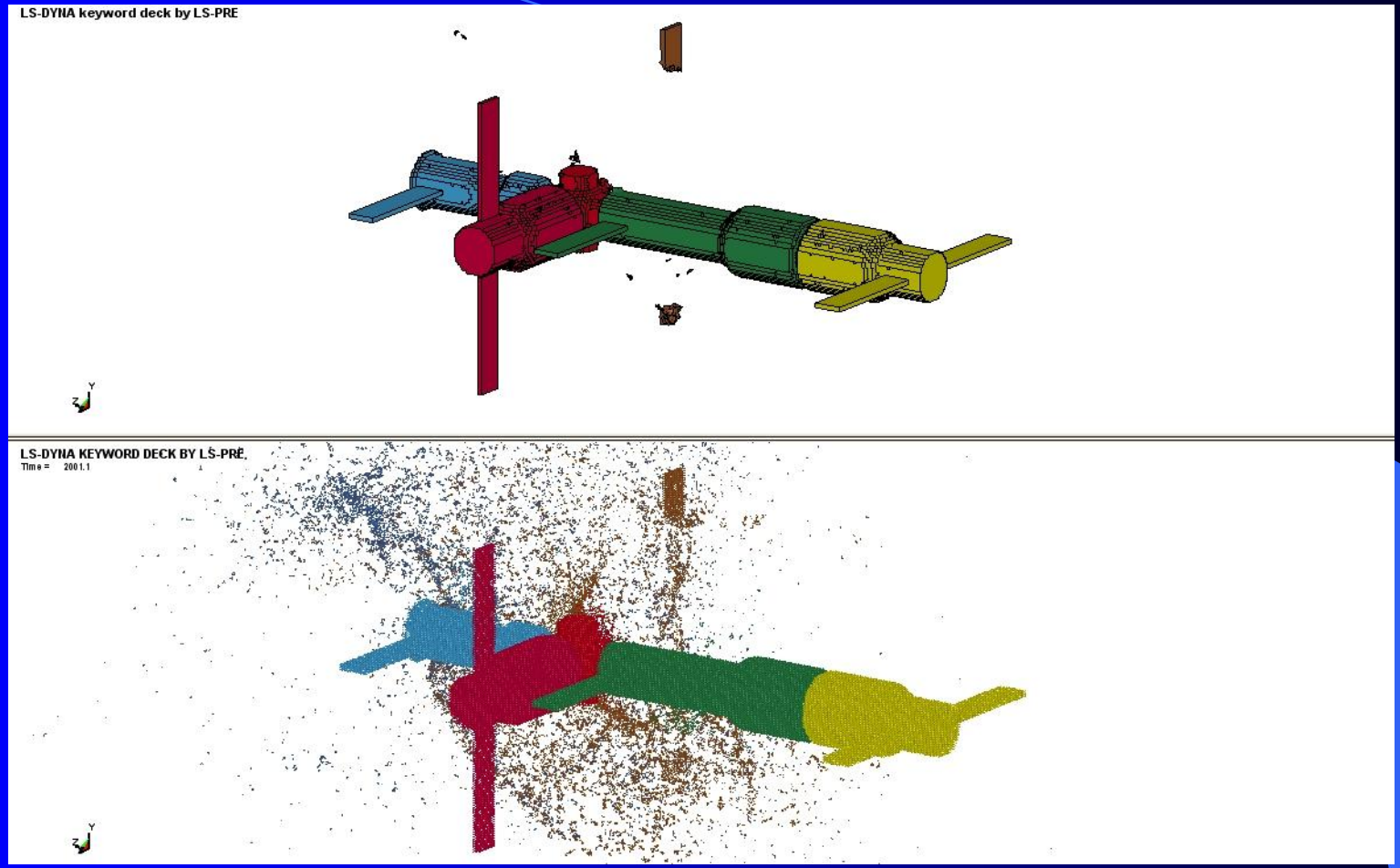




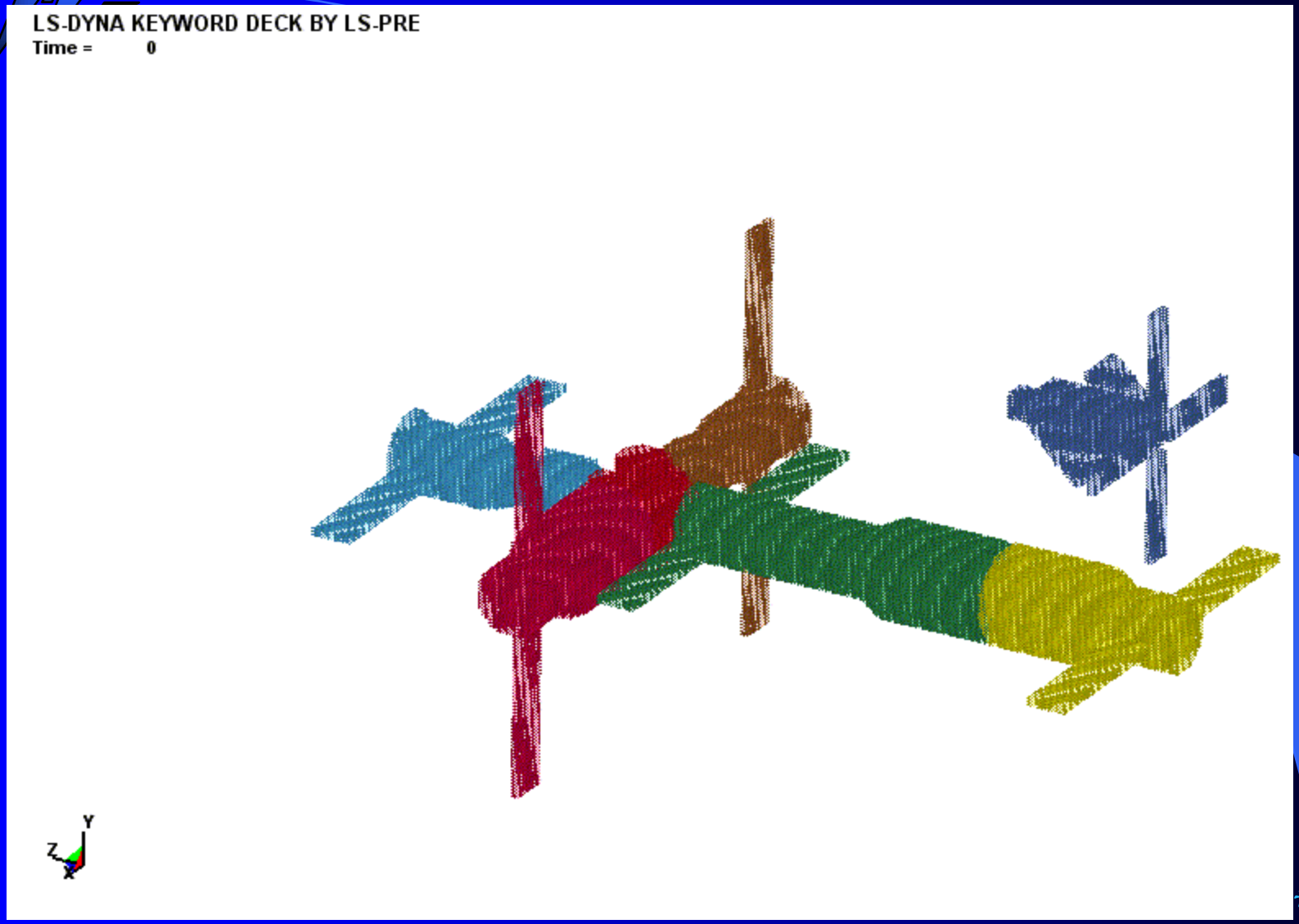
Non-central hypervelocity collision



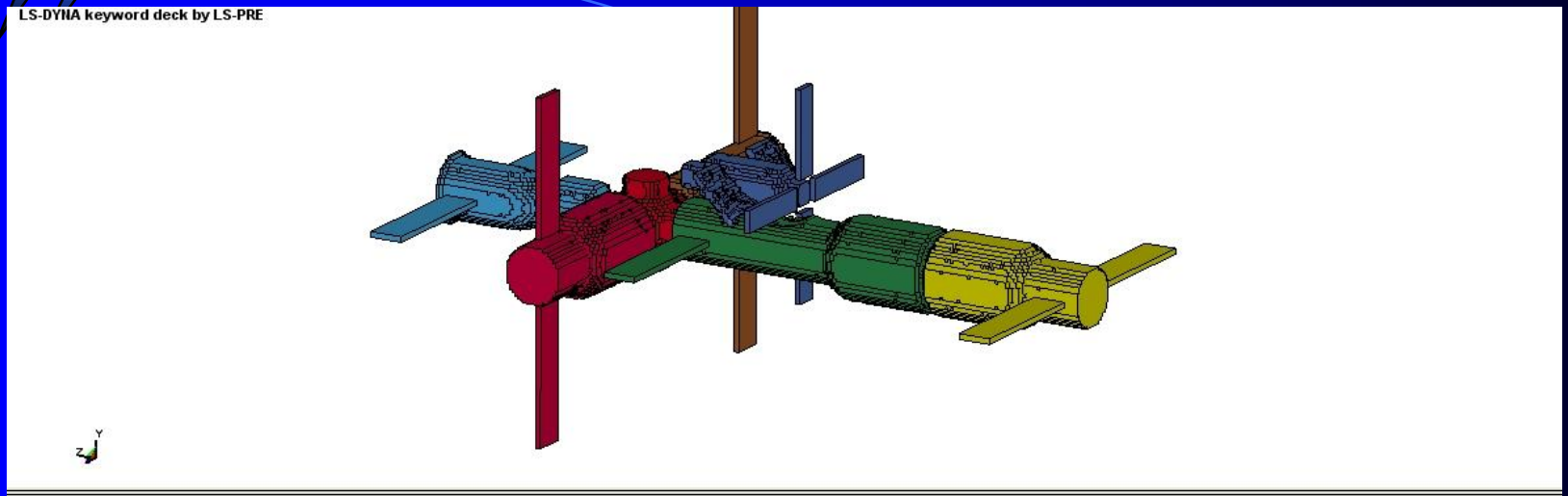
Non-central hypervelocity collision

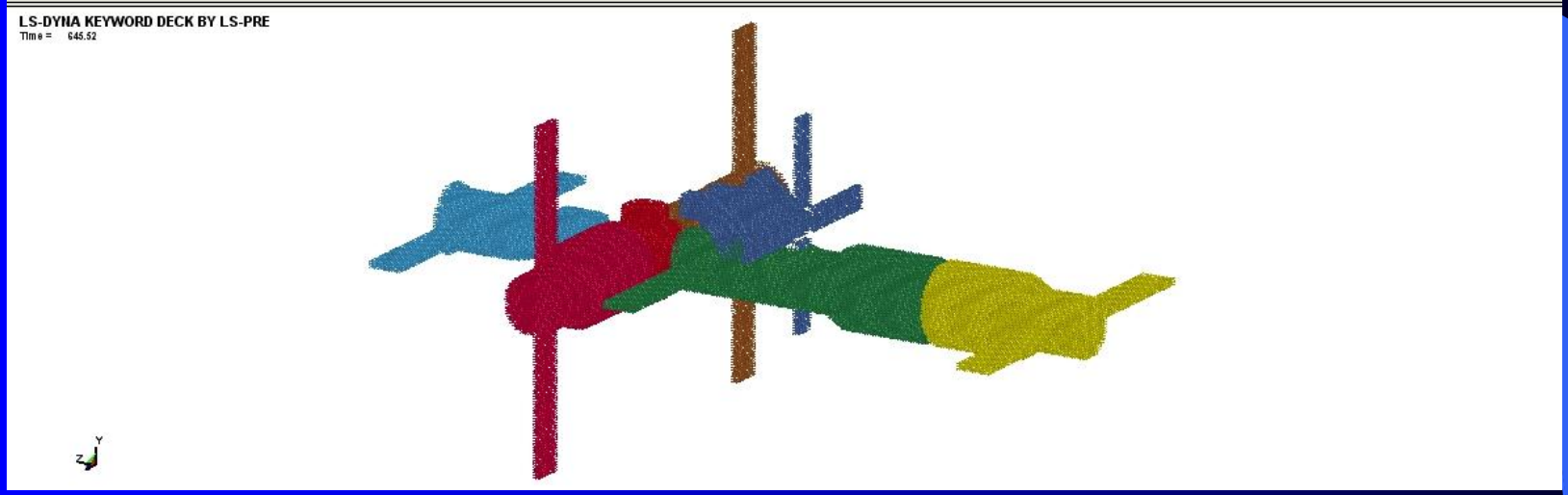


Central hypervelocity collision

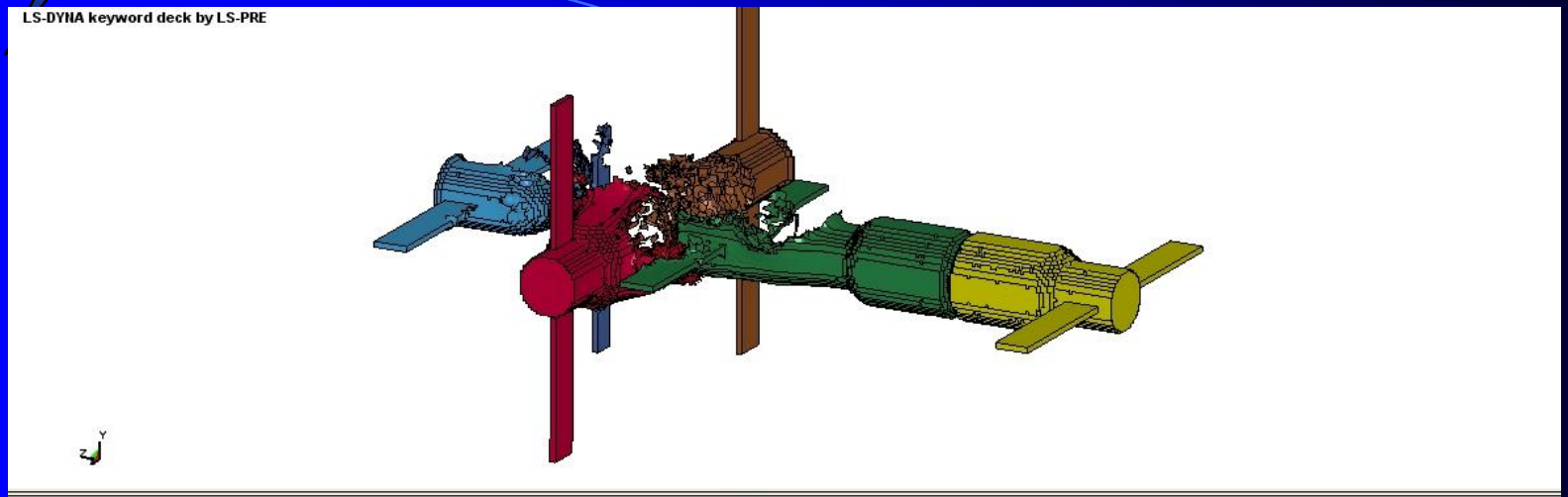


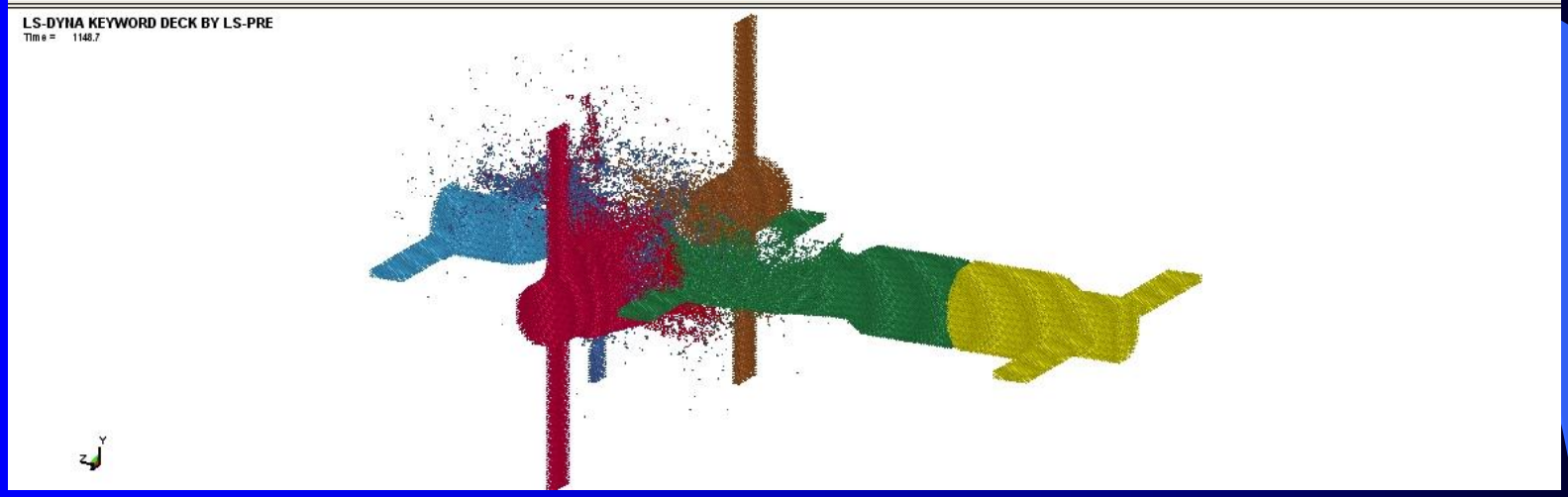
Central hypervelocity collision



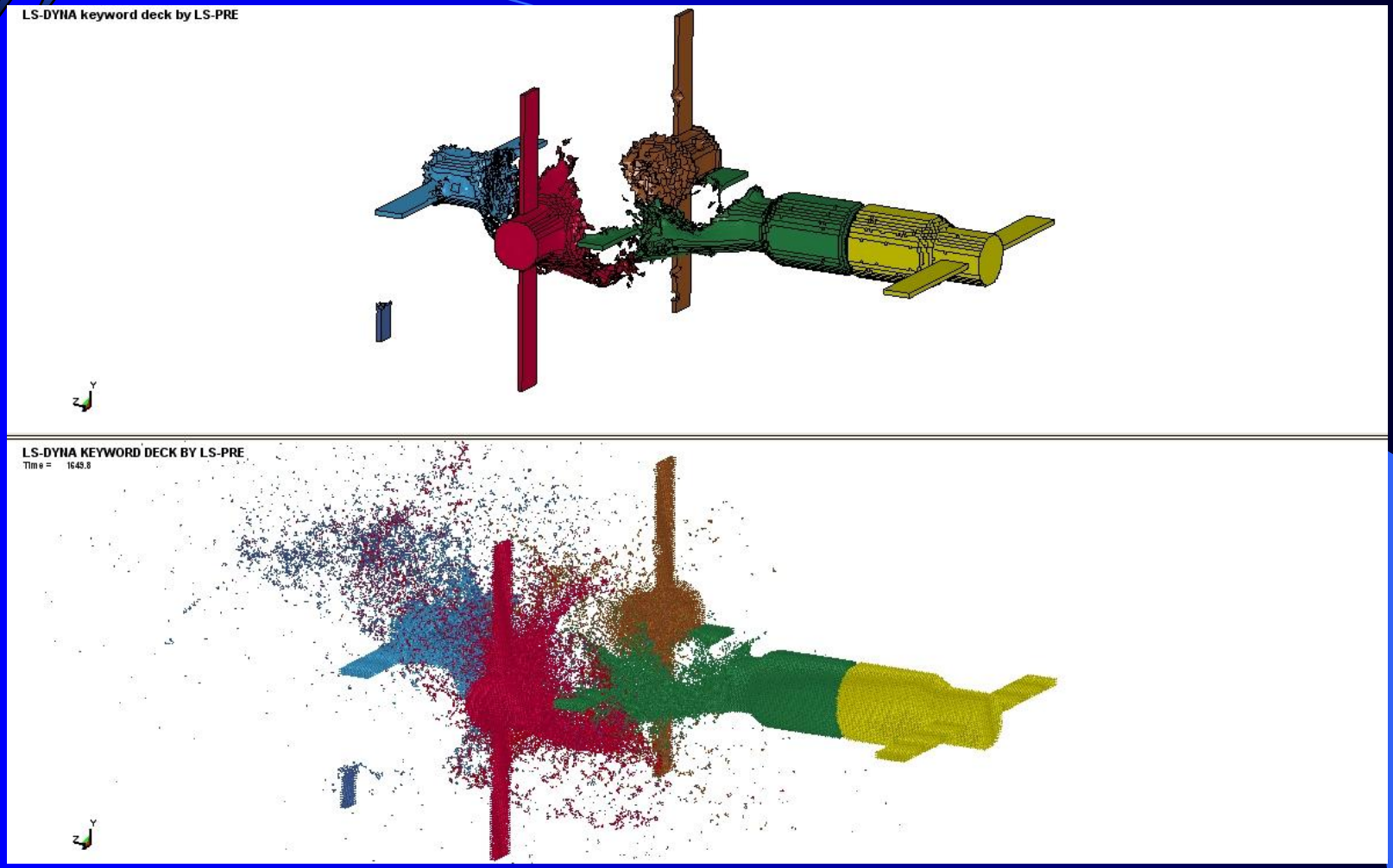


Central hypervelocity collision

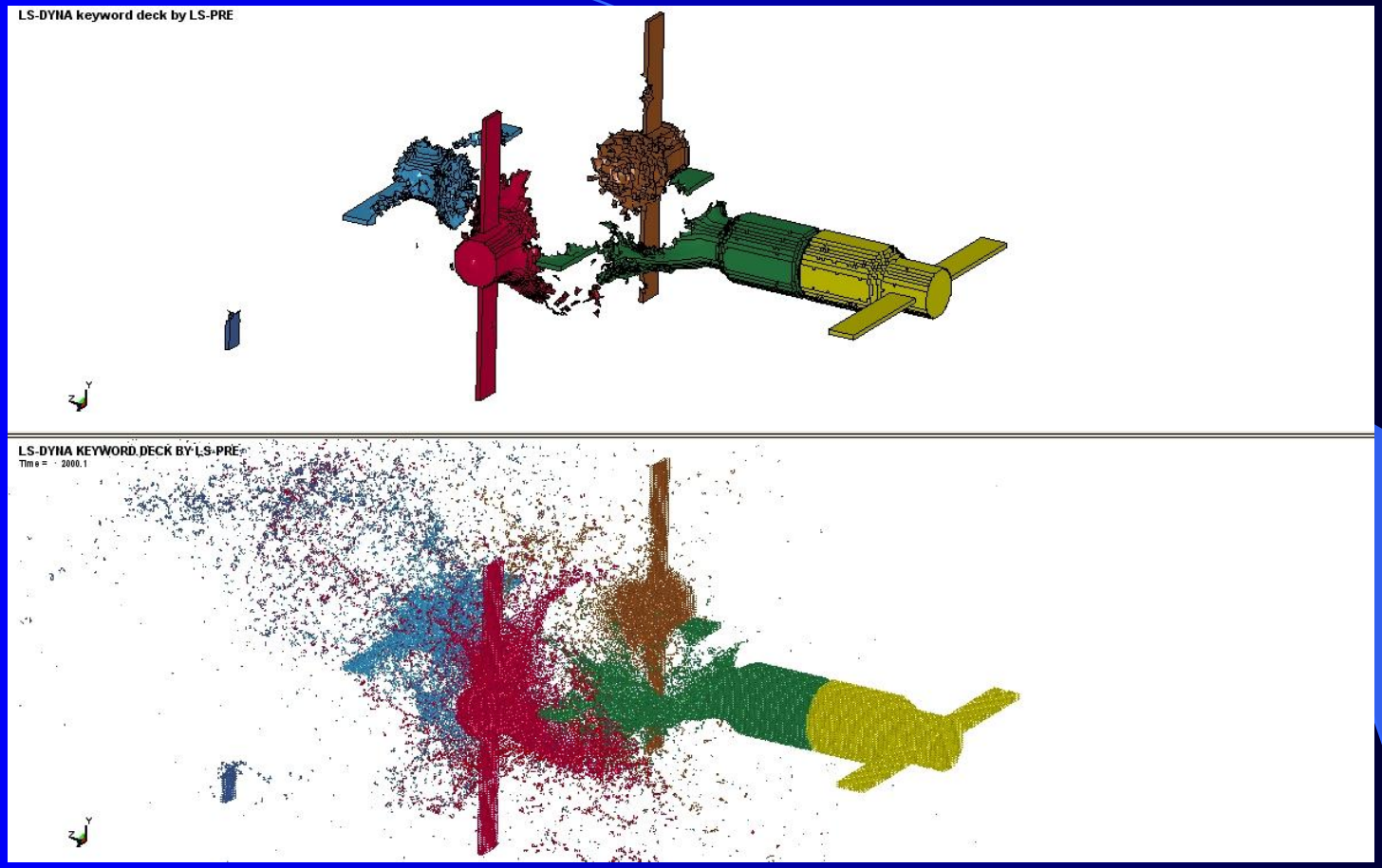




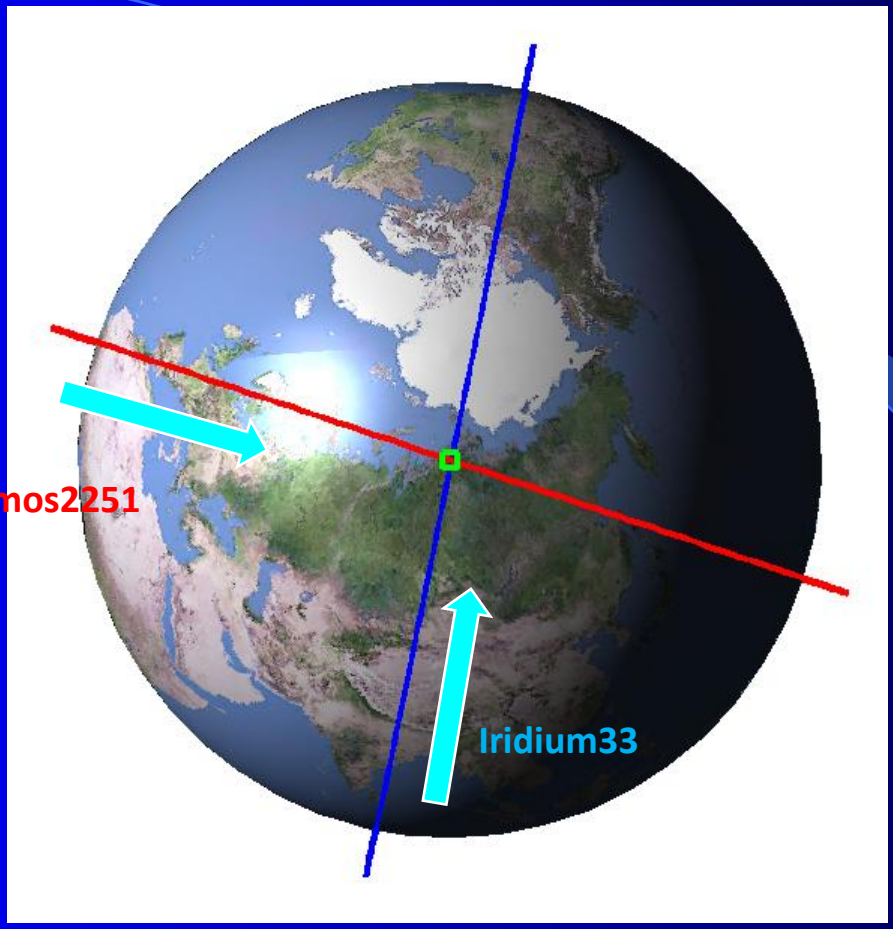
Central hypervelocity collision



Central hypervelocity collision

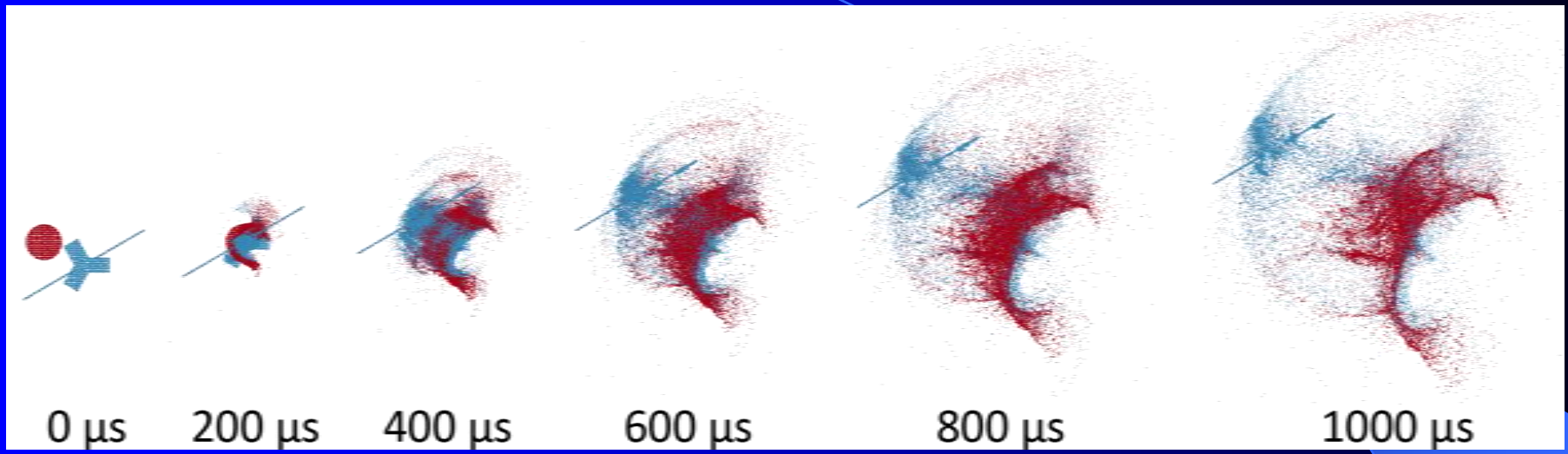


Example for real happened space collision



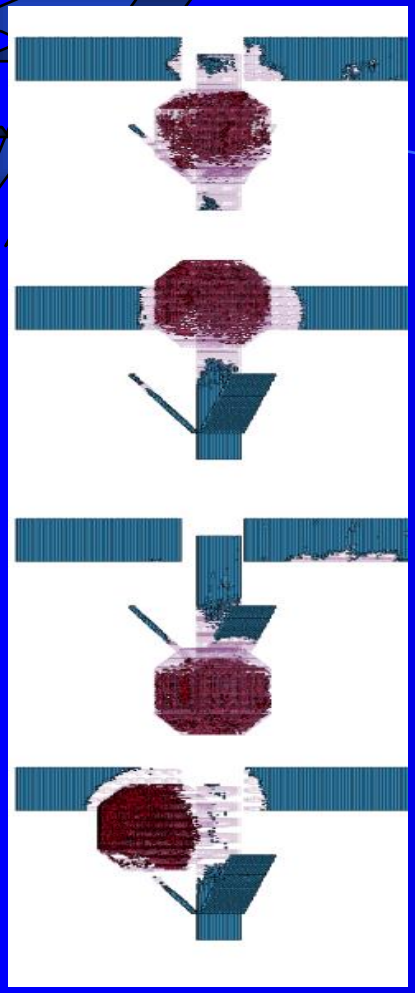
Thanks David Wright for the fig.

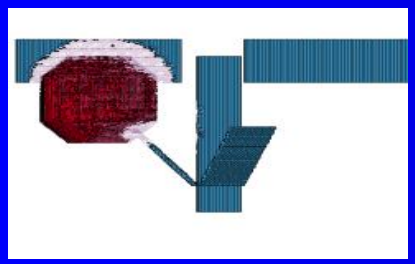
Central impact simulation result (2)

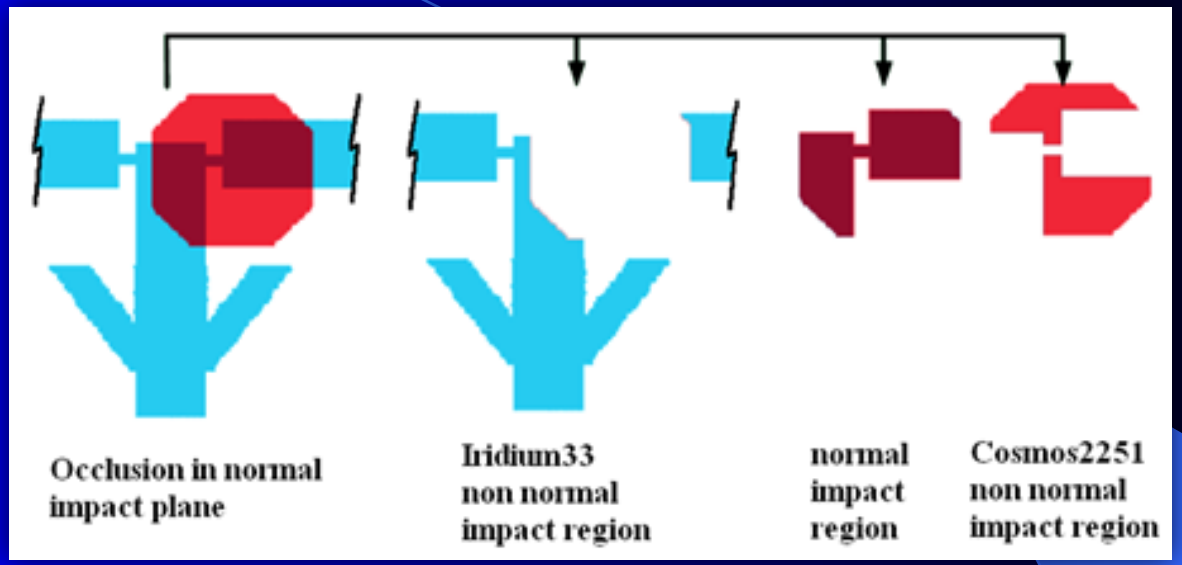


Small fragment view at 0-1ms after the impact

Collision on deffrent position

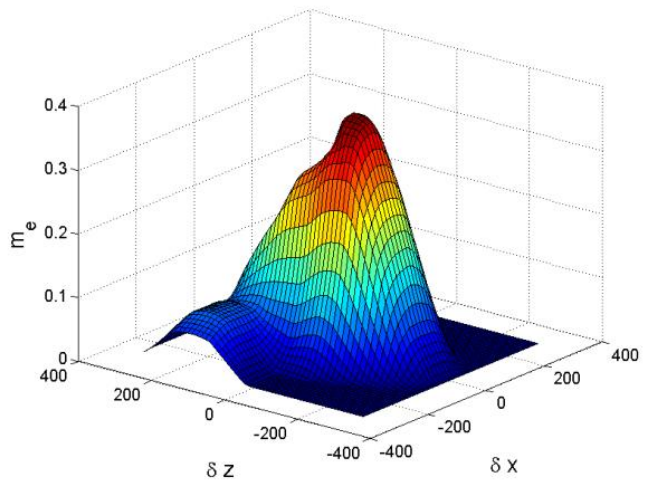


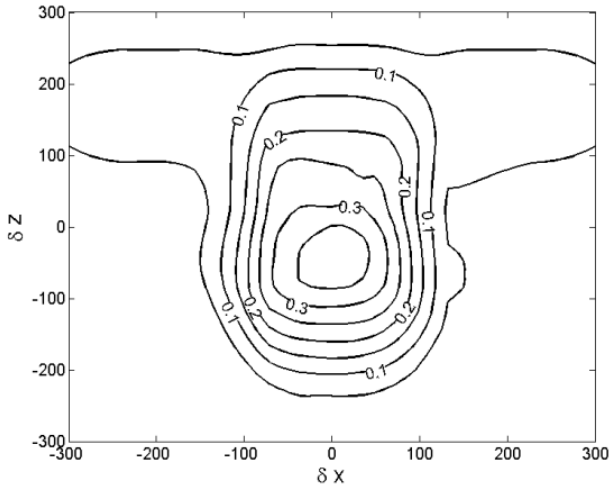




$$m_e = \frac{2\min\left(m_n^C, m_n^I\right)}{m^C + m^I}$$

DENIM distribution





- **Fixing the position of Iridium33 and change the impact location of Cosmos2251 we can get the DENIM distribution.**
- **The maximum number is 0.38.**

Observation for 10 cm fragment is 1719

Fragments statistics

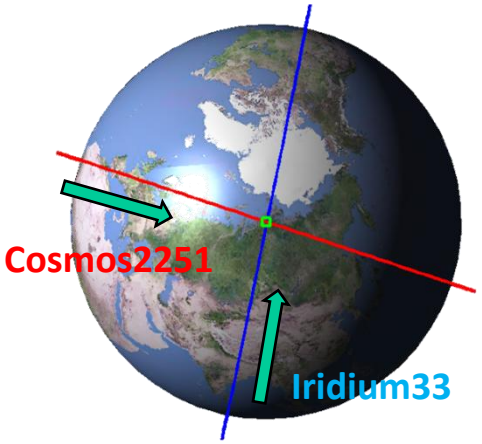
No	δz (cm)	δx (cm)	Cosmos2251 NIM (kg)	Iridium33 NIM (kg)	DENIM	DSFM	DLFM	Fragment amount
1	0	0	589	266	0.36	0.88	0.12	1280
2	0	180	444	117	0.16	0.70	0.30	1288
3	0	-180	261	119	0.16	0.71	0.29	1204
4	-100	80	281	107	0.14	0.64	0.36	759
5	-200	80	238	38	0.05	0.34	0.66	379
6	-12	-36	586	283	0.38	0.89	0.11	1329
7	120	-96	170	79	0.10	0.56	0.44	428
8	84	204	437	76	0.10	0.53	0.47	706
9	48	132	568	151	0.20	0.75	0.25	1403
10	96	-72	331	153	0.20	0.76	0.24	749
11	-48	12	389	226	0.30	0.88	0.12	1537
12	-60	-84	337	225	0.30	0.81	0.19	1330

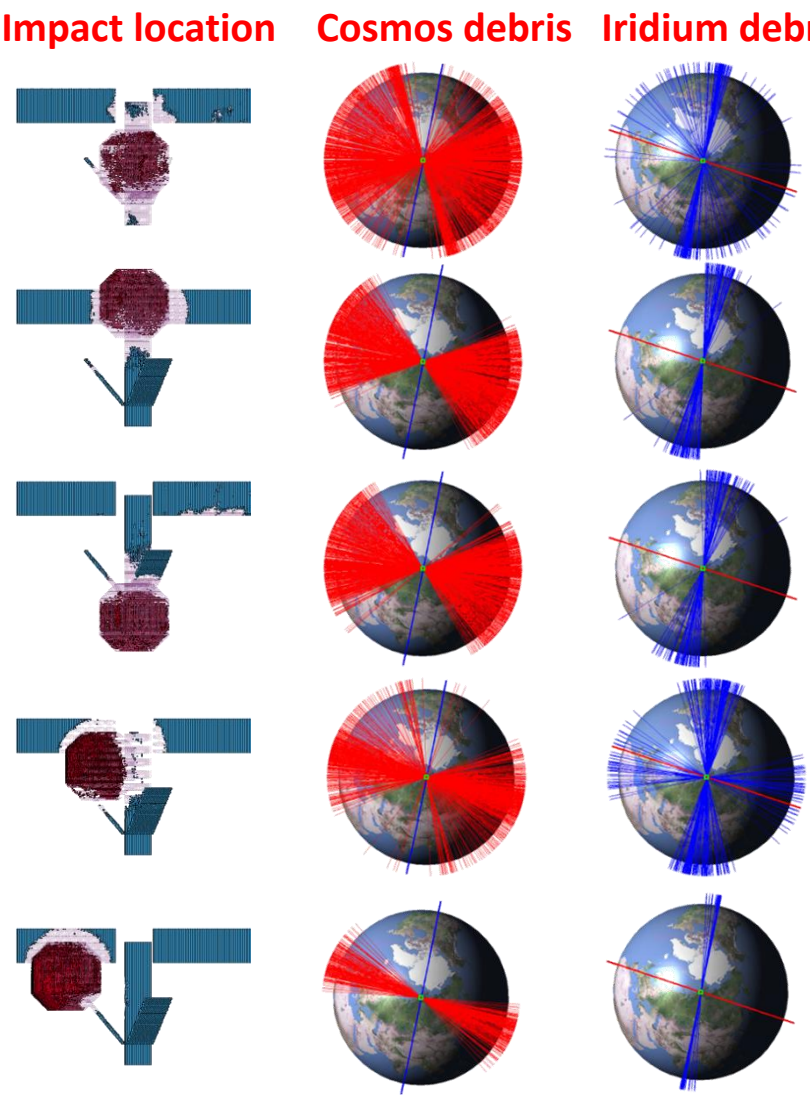
DENIM Dimensionless Equivalent Normal Impact Mass

DLFM Dimensionless Large Fragment Mass

DSFM Dimensionless Small Fragment Mass

Debris orbits considering both large ones and small ones





Debris orbits 1 hour after the collision including debris > 1cm.

It does not need 1-3 years.

Several hours are enough for the debris to spread over all LEOs.

4. Conclusions

(1) The work use SPH method to simulation the orbital object break up in hypervelocity impact.

(2) Compared NASA model, this simulation can consider more situations of object, including materials as well as configurations.

(3) Real happened spacecraft collision simulation is conducted. The result comply to the observation date.

(4) further study should be continue to obtain more effective model.

Thank You for Attention!