H2

デブリ衝突損傷リスク解析ツールに関する最近の機能拡充
Latest Expansion of Tactical Utilities for Rapid ANalysis of Debris on Orbit Terrestrial

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デブリ衝突損傷リスク解析ツール(TURANDOT)は宇宙機設計支援ソフトウェアである。このソフトウェアを、より多くのユーザーが安心して利用できるツールとするために、過去2年間にわたって複数のベンチマークテストを実施した。また、直近ではユーザーの利便性を高めるために入力支援機能を大幅に強化中である。TURANDOT に関連する 2012 年度～2014 年度の活動状況を報告する。

TURANDOT

デブリ衝突損傷リスク解析ツールに関する
最近の機能拡充

Latest Expansion of <u>T</u>actical <u>U</u>tilities for <u>R</u>apid <u>AN</u>alysis of <u>D</u>ebris on <u>O</u>rbit <u>T</u>errestrial

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6th Space Debris Workshop
@JAXA/Chofu, 2014/12/17~2014/12/19

Contents

- Introduction
- What is TURANDOT
- Validation
- New function
- Demonstration

Estimated Annual Collision

- 800km Altitude

Debris Size	0.1~1mm	1~10mm	1~10cm	10cm<
Collision [1/m^2/year]	100	0.01	0.0001	0.00001
Solution	**Protection**	?	???	Manuever

- Computation by MASTER© by ESA
- Ref. ISSN 1349-113X Proceedings of the 5th Space Debris Workshop

Kinetic Energy @ Collision

- Is common object small enough?
- Ex. 3g/cm^3, 1mm^3, 16km/sec
  - 3g x 0.1cm x 0.1cm x 0.1cm = 0.000003kg
  - 0.5 x 0.000003kg x (16km/sec)^2 = 768 J

- 800 J concentrate on 1mm^2, in <μsec.
  - Easy to penetrate spacecraft structure

Kinetic Energy @ Collision

- Cube object, 3g/cm^3, 16km/sec, 2015/1/1~2024/12/31
- Collision Frequency is Estimated by MASTER-2009©+TURANDOT (Normal to orbit direction)
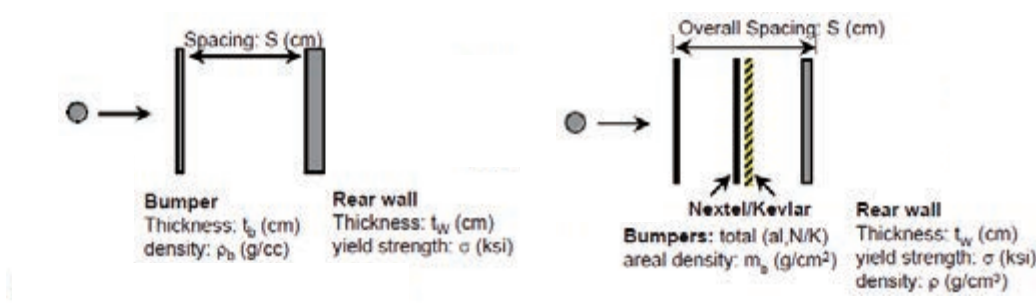
Debris Size [mm]	0.01~0.1	0.1~0.316	0.316~0.5	0.5~1
Collision Frequency [1/m^2/year]	646 (1/day)	67 (1/week)	0.6 (1/year)	0.13 (1/decade)
Kinetic Energy	<0.77J	<24J	<96J	<768J

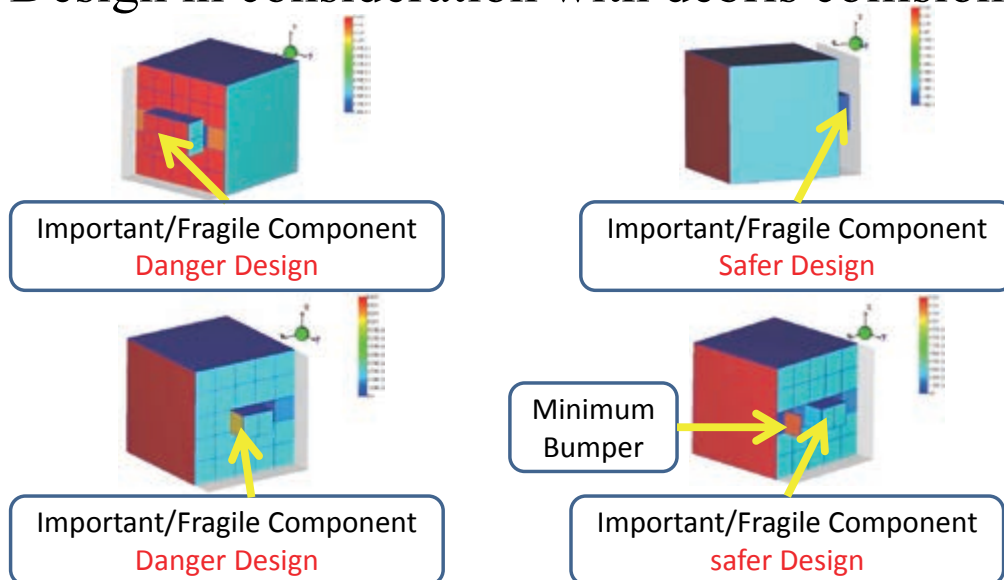# Protection Design

- Debris Bumper : Effective & Expensive

  – Ref. IADC Protection Manual v5.0

Protection Design

- Design in consideration with debris collision
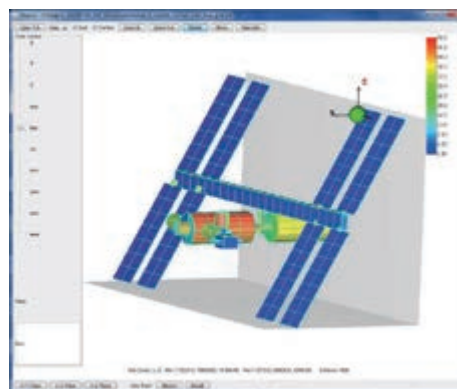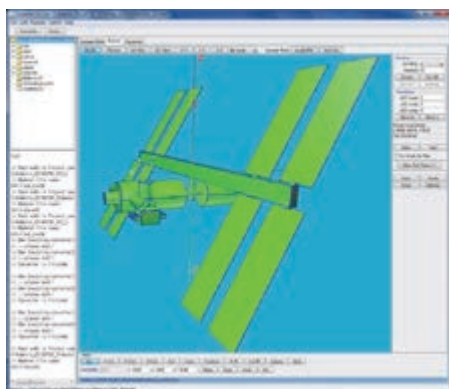
History

- April, 2007~Feb., 2009
  - "Collision <u>Probability</u>" Analysis Tool
- April, 2009~Feb., 2011
  - "Collisional <u>Damage</u>" Probability Analysis Tool
- April, 2011~Feb., 2012
  - Including "MASTER-2009"
- April, 2012~
  - Detail Modifications & Validations

Functions I

- GUI
  - Integrated Analysis Environment
  - Satellite modeling
  - Grid generation

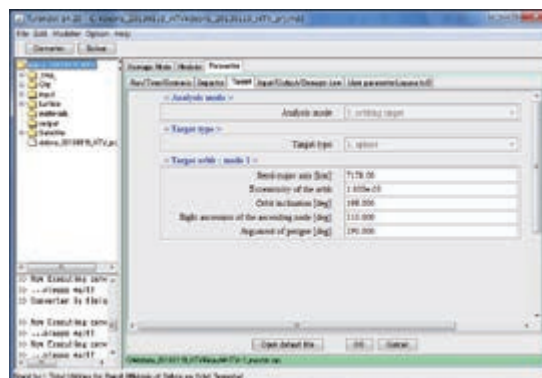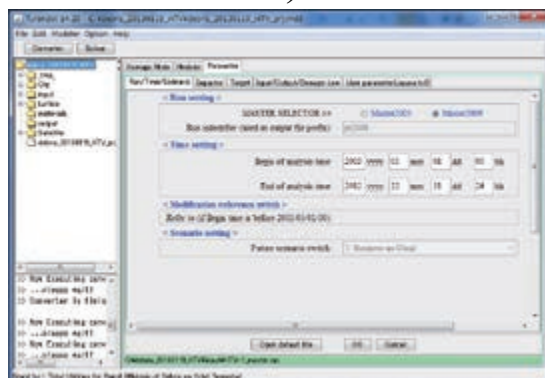 - Acknowledgement for Kurihara, M.

Functions I

- GUI
  - Computation condition setting
  - Requirement from Databases　(MASTER & ORDEM)

Functions II

- No Domestic Database!
  - MASTER-2005 & ORDEM2000
  - <u>MASTER-2009 & ORDEM2000</u>

$$flux_{\text{ORDEM}} = flux_{\text{MASTER}} \cdot K \qquad if\ 1 < K$$

$$flux_{\text{ORDEM}} = flux_{\text{MASTER}} \qquad if\ K < 1$$

$$K = \frac{F_{\text{ORDEM}}}{\displaystyle\int_{4\pi} f_{\text{MASTER}} \cdot d\Omega}$$

Functions III

- Damage Probability
  - Users' Definition
  - Fortran 95 like

Functions III

20141219_Debris_WS_MUSE   13

Comparison with MASTER-2009©

- Flux computing function of MASTER-2009©

- Fluxis for 6 Faces of a cube
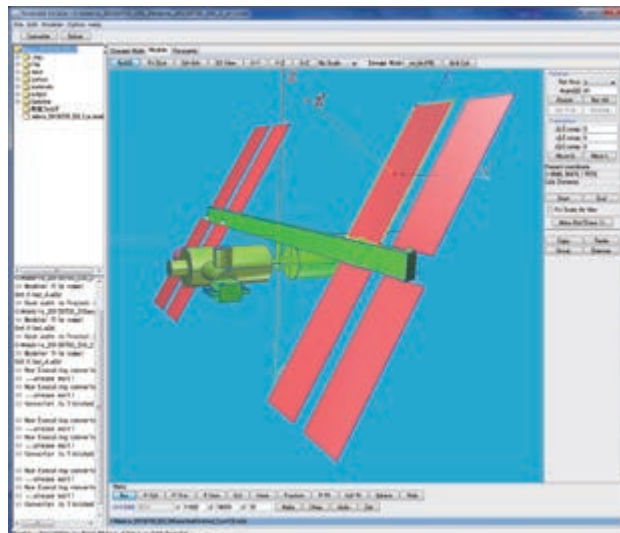
20141219_Debris_WS_MUSE   14

Result

Condition		TURANDOT	MASTER-2009	Error
a) 0.1mm<d	Debris	6.3672	6.3678	0.0%
	Meteoroid	1.1050×10	1.1088×10	0.3%
b) 1cm<d	Debris	1.5014×10^{-5}	1.5354×10^{-5}	2.2%
	Meteoroid	8.9217×10^{-7}	8.6510×10^{-7}	3.1%

- Good agreement
- TURANDOT is reasonable

BLE Validation(1)
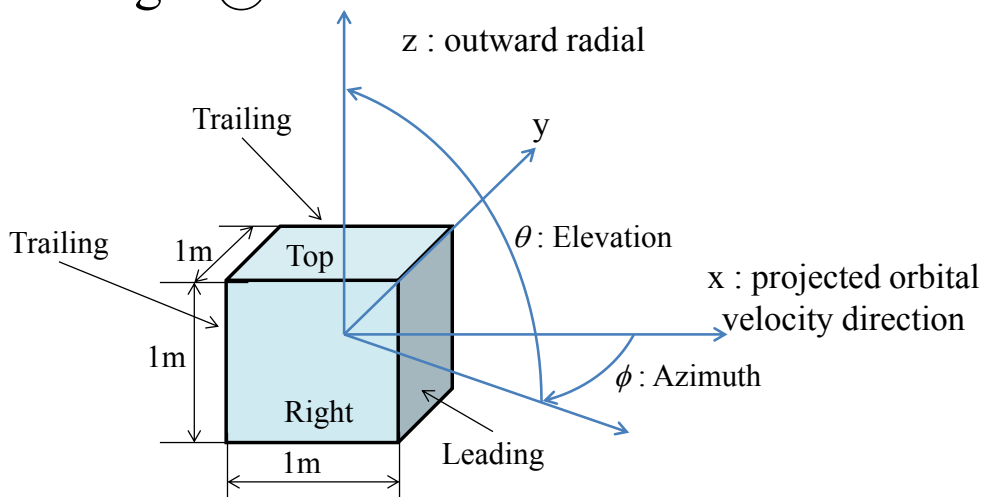
- MASTER-2005©
- Earth oriented attitude
- 2002/01/01~2002/12/31
- 0.001m<d<0.1m
- 85 debris flux data from "expl.cpe" as No.1001, 2001,…, 85001
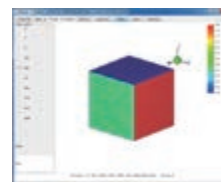 - 1 debris flux from every 1000 debris flux

BLE Validation(2)

- Cube, $(1m)^3$
- Damaged@1cm<d

z : outward radial

Trailing

y

Trailing

1m Top

θ : Elevation

1m

x : projected orbital velocity direction

Right

ϕ : Azimuth

1m Leading

BLE Validation(3)

- Direction vector of debris flux

$$\mathbf{v}_{debri} = \begin{pmatrix} \cos\theta\cos\phi \\ -\cos\theta\sin\phi \\ \sin\theta \end{pmatrix}$$

- Normal vectors of the cube surfaces

Name	Nomal Vector
Leading	(1,0,0)
Trailing	(-1,0,0)
Left	(0,1,0)
Right	(0,-1,0)
Top	(0,0,1)
Bottom	(0,0,-1)

BLE Validation(4)

- Collision Probability for unit time

$$P_{\text{collision}} = \sum_{0 < \mathbf{V}_{debri} \cdot \mathbf{V}n} \mathbf{V}_{debri} \cdot \mathbf{V}n \times \textit{flux}$$

- For Damage Probabillity, including "condition",

$$P_{\text{damage}} = \sum_{\substack{0 < \mathbf{V}_{debri} \cdot \mathbf{V}n \\ \textit{if contidion=true}}} \mathbf{V}_{debri} \cdot \mathbf{V}n \times \textit{flux}$$

BLE Validation(5)

- Result

	MASTER2009 +MS-Excel©	TURANDOT
Leading	9.95E-09	9.95E-09
Trailing	1.21E-12	1.21E-12
Left	1.24E-09	1.24E-09
Right	5.62E-09	5.62E-09
Top	5.49E-12	5.49E-12
Bottom	3.04E-11	3.04E-11

- Good agreement

Validation

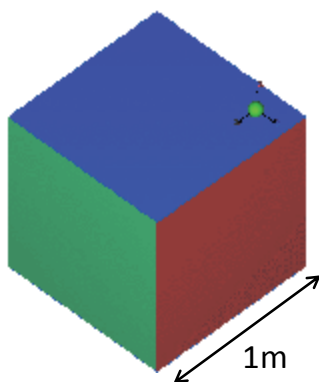- IADC（Inter-Agency Space Debris Coordination Committee）Benchmark
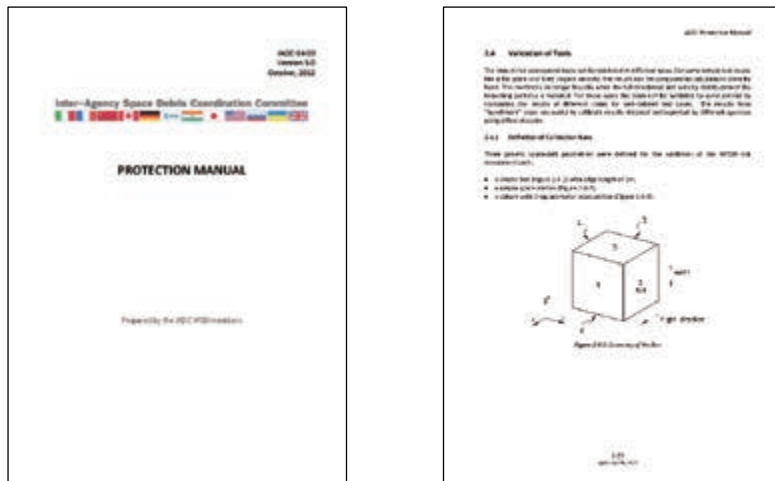
IADC Benchmark

1) Cube　　　　　2) Sphere　　　　　3) Station

1m

Cross section 1m^2

3m

1m

2m

1m
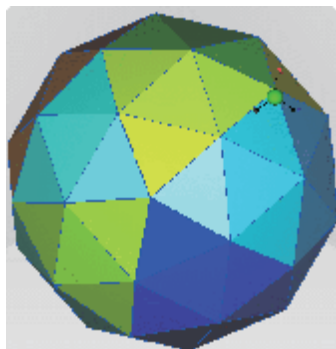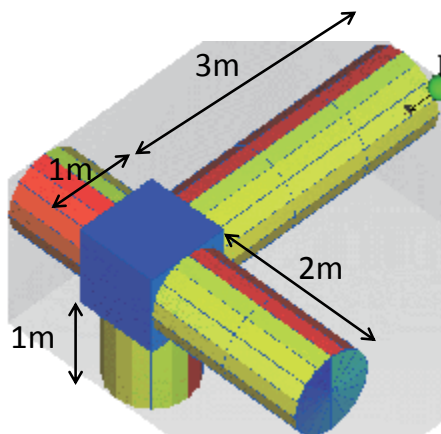
Orbit Parameter Input Support (1)

- Example:
  - SSO
  - 12:00 Local Time on Ascending

RAAN=0°

Red arrow: RAAN

RAAN=45°

RAAN=315°

γ

RAAN=90°

RAAN=270°

RAAN=135°

RAAN=225°

RAAN=180°
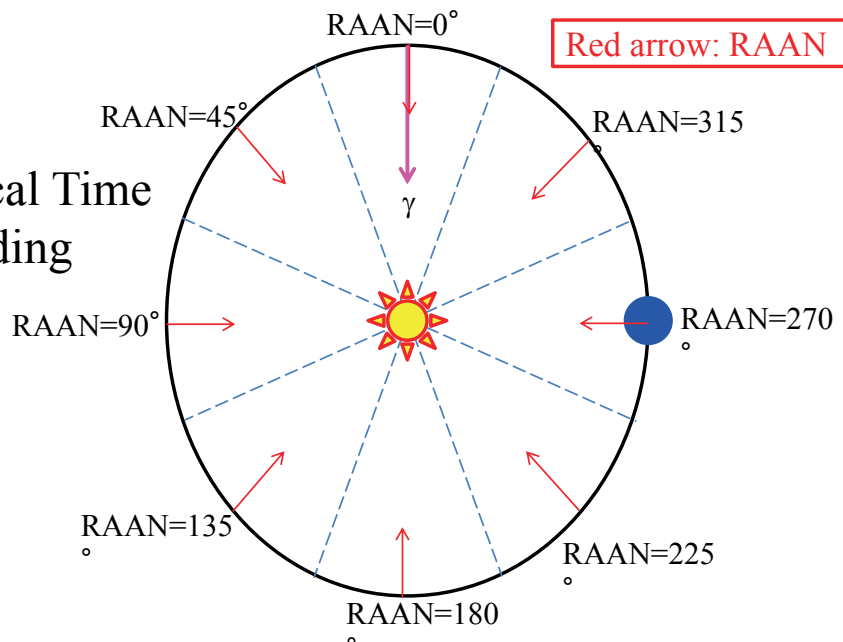
Result

- 2014/01/01~2014/12/31
- Solar Oriented, Cube of $1m^3$
- 1.E-5m < d

	W/O division	8 division	24 division
+X	108	110	105
-X	104	98	93
+Y	109	186	189
-Y	109	180	184
+Z	225	159	159
-Z	224	159	158

- Considerable difference

Orbit Parameter Input Support (2)

- Automatic generation of input parameter
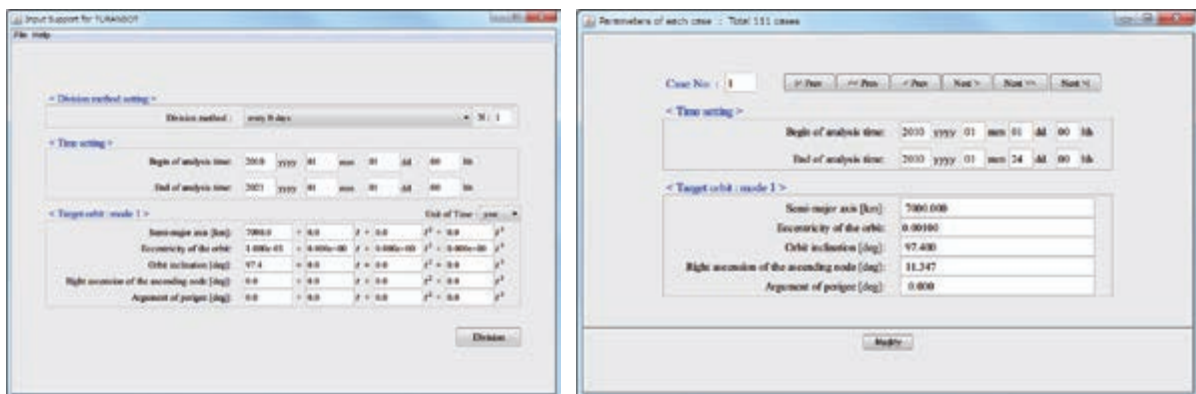
Conclusion

- Validations and benchmarks are conducted.
- Modifications according to the results and users' opinion.
- New assistant functions.