H2

デブリ衝突損傷リスク解析ツールへの ORDEM 3.0 導入

Introduce an analysis feature using ORDEM 3.0 to the 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．本ツールは宇宙機表面を詳細な格子に分割し，デブリに対する宇宙機自身の遮蔽を考慮した上で，各部位のデブリ衝突頻度を解析する．さらに，任意の宇宙機部位について，宇宙機表面材料と弾道方程式を設定することで，損傷リスクも評価可能である．弾道方程式については，標準的と考えられているモデルをデフォルトとして与えるほか，ユーザが任意のモデルを生成して解析に利用することが可能である．また，これまで軌道上デブリフラックスのデータベースとして MASTER-2009 と ORDEM 2.0（ORDEM2000）を利用してきたが，ORDEM 3.0 によるフラックスも利用できるように機能を拡張した．ORDEM 3.0 で与えられるフラックスは，天球を Igloo と呼ばれる 614 に分割した領域で与えられるが，天球を約 1 平方度毎に分割した 41,258 の領域に Igloo との立体角比に従ってフラックスを再分配して解析に利用している．この講演では，本ツールの概要と機能拡張について紹介する．

The Tactical Utilities for Rapid ANalysis of Debris on Orbit Terrestrial(Turandot) supports design of spacecraft. This software is capable of prediction of spacecraft damage probability by collisional debris including shielding effect of the spacecraft itself. Turandot was expanded in order to use ORDEM 3.0 as well as MASTER-2009 and ORDEM2000 as database of debris flux. This presentation introduces overview and feature expansion of the Turandot.

TURANDOT

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7th Space Debris Workshop
@JAXA/Chofu, 2016/10/18~2016/10/20

Contents

- Introduction
- What is TURANDOT
- Validation
- New function(ORDEM 3.0)
- Demonstration

Introduction

M/OD risk assessment tools	
BUMPER II	NASA
ESABASE2 / DEBRIS	ESA
COLLO, BUFFER	TSNIIMASH
MDPANTO	DLR
SHIELD	QinetiQ
MODAOST	CAST
TURANDOT	JAXA

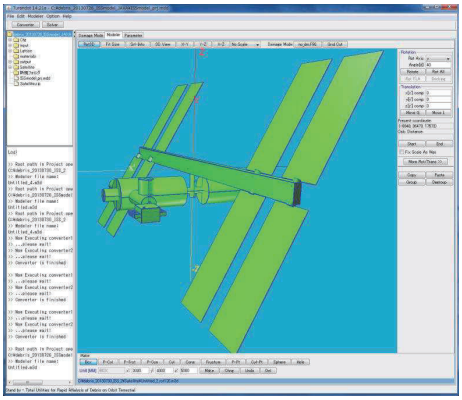
IADC Protection Manual(Version 7.0), IADC-04-03
https://www.nasa.gov/centers/johnson/techtransfer/technology/MSC-23774-1-bumper.html
Update of the ESA Space Debris Mitigation Handbook, ESA Contract 14471/00/D/HK

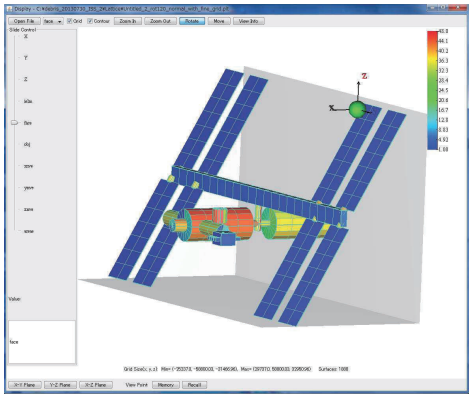
About Turandot

- Turandot supports design of spacecraft.
- This software is capable of prediction of spacecraft damage probability by collisional debris including shielding effect of the spacecraft itself.
- April, 2007~
  - "Collision Probability" Analysis Tool
  - "Collisional Damage" Probability Analysis Tool
  - Including "MASTER-2009"
  - Detail Modifications & Validations

Functions I

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

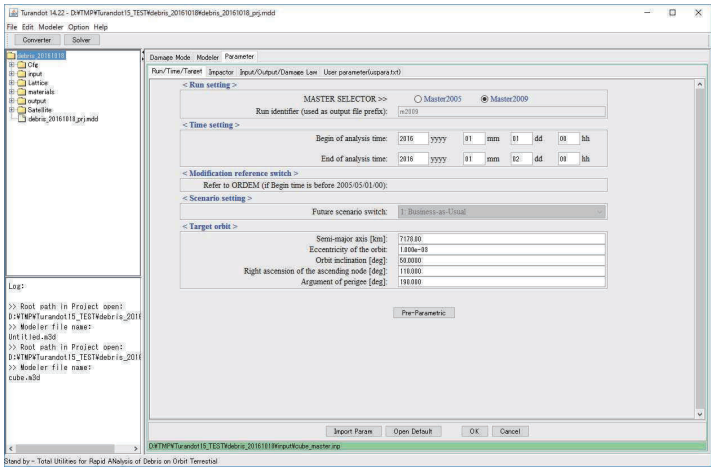




Acknowledgement for Kurihara, M.

Functions I

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



Functions II

- MASTER-2009(MASTER-2005) & ORDEM 2.0(ORDEM2000)

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

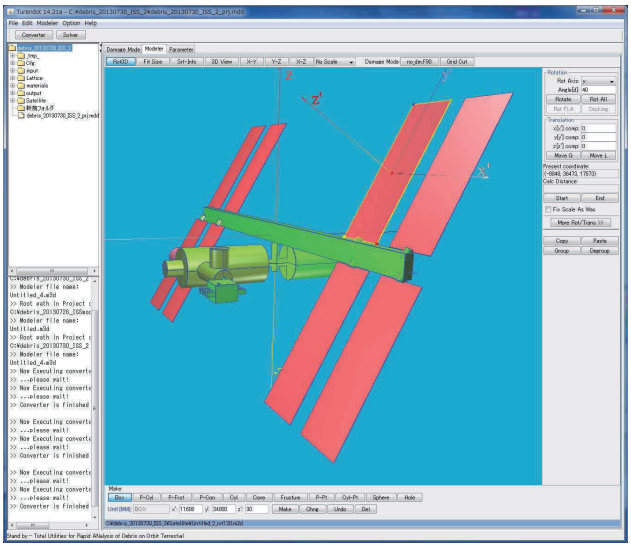
$$f_{\mathrm{ORDEM}} = f_{\mathrm{MASTER}} \qquad \text{if } K < 1$$

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

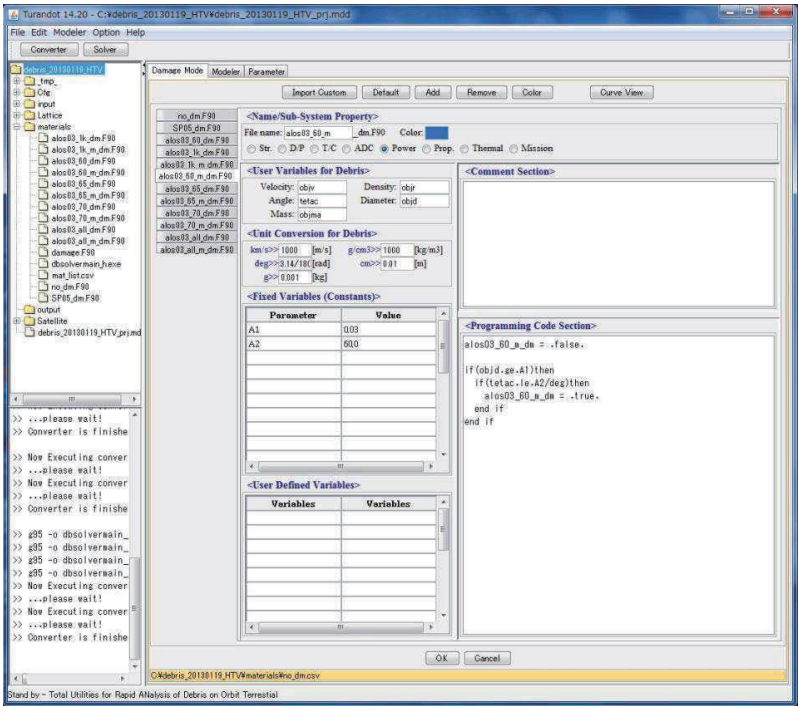
$$f : \mathrm{flux}$$

Functions III

- Damage Probability
  - Users' Definition
  - Fortran 95 like

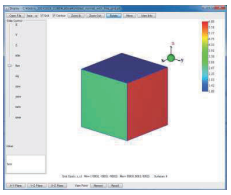


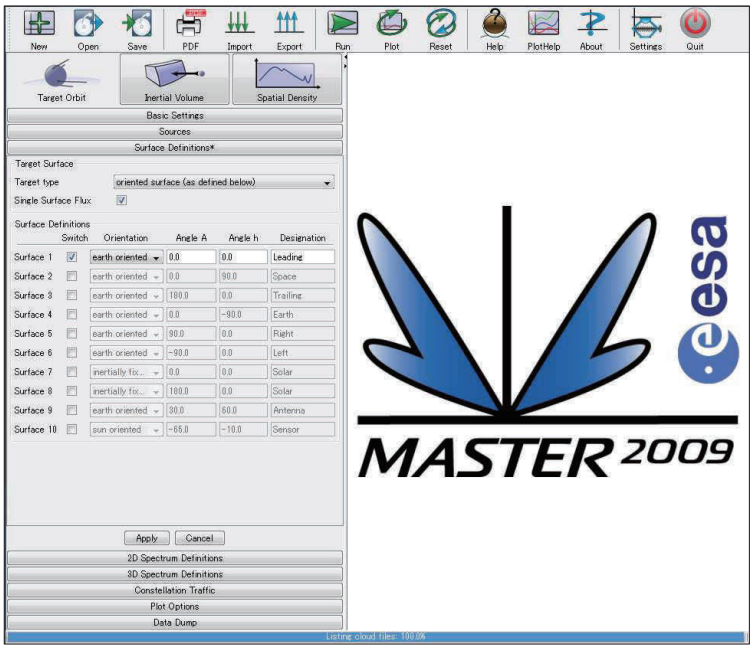
Functions III



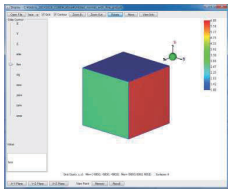
Comparison with MASTER-2009©

- Flux computing function of MASTER-2009©
- Fluxes for 6 Faces of a cube





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%

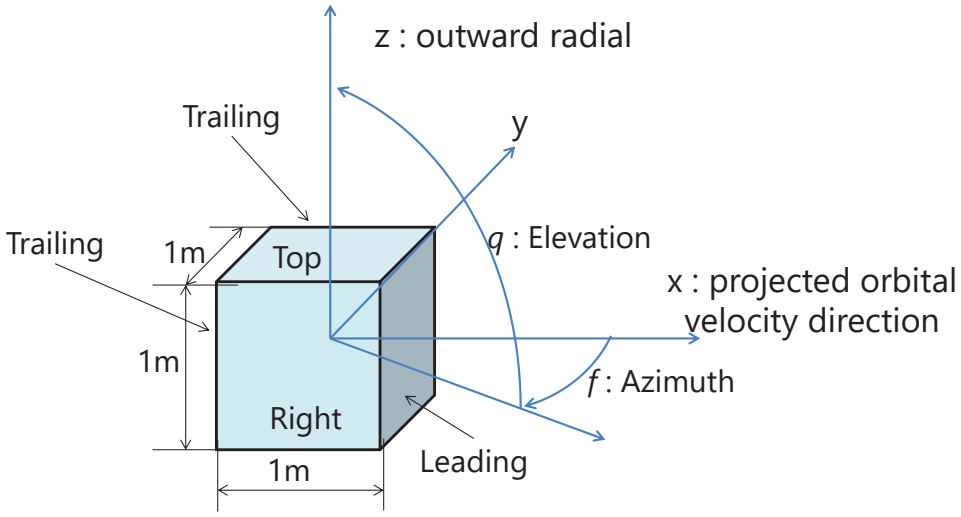
- Good agreement
- TURANDOT is reasonable

BLE Validation(1)

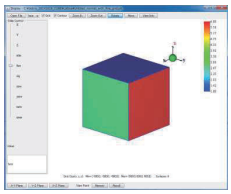
- MASTER-2005©
- Earth oriented attitude
- 2002/01/01~2002/12/31
- 0.001m<d<0.1m
- 85 debris flux data from “expl.cpe” as No.1001, 2001,..., 85001
  - 1 debris flux from every 1000 debris flux

BLE Validation(2)

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



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

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

- For Damage Probabillity, including "condition",

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

BLE Validation(5)

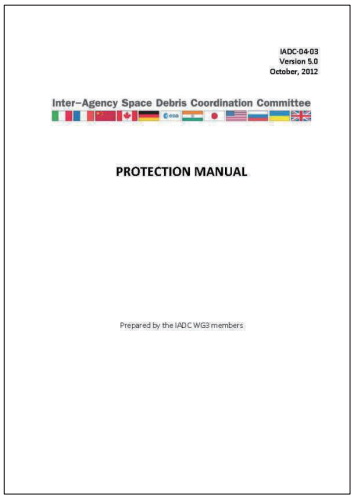
- Result

	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

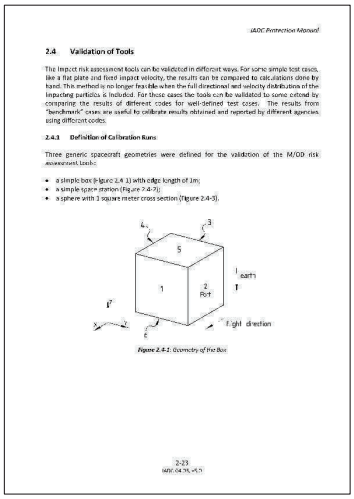
- IADC（Inter-Agency Space Debris Coordination Committee）Benchmark


IADC-04-03
Version 5.0
October, 2012

Inter-Agency Space Debris Coordination Committee

PROTECTION MANUAL

Prepared by the IADC WG3 members


IADC Protection Manual

2.4 Validation of Tools

The impact risk assessment tools can be validated in different ways. For some simple test cases, like a flat plate and fixed impact velocity, the results can be compared to calculations done by hand. This method is no longer feasible when the full directional and velocity distributions of the impacting particles is included. For those cases the tools can be validated to some extend by comparing the results of different codes for well-defined test cases. The results from "benchmark" cases are useful to calibrate results obtained and reported by different agencies using different codes.

2.4.3 Definition of Calibration Runs

Three generic spacecraft geometries were defined for the validation of the M/OD risk assessment tools:

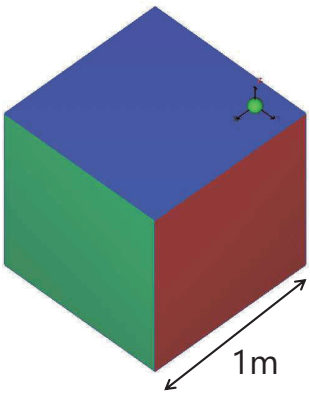
- a simple box (Figure 2.4-1) with edge length of 1m;
- a simple space station (Figure 2.4-2);
- a sphere with 1 square meter cross section (Figure 2.4-3).

Figure 2.4-1: Geometry of the Box

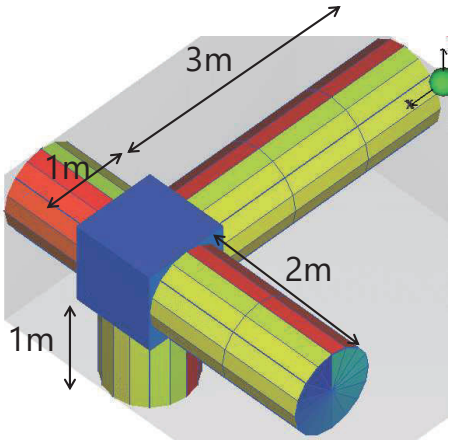
2-23
IADC-04-03, v5.0

IADC Benchmark

1) Cube 2) Sphere 3) Station



Cross section 1m^2



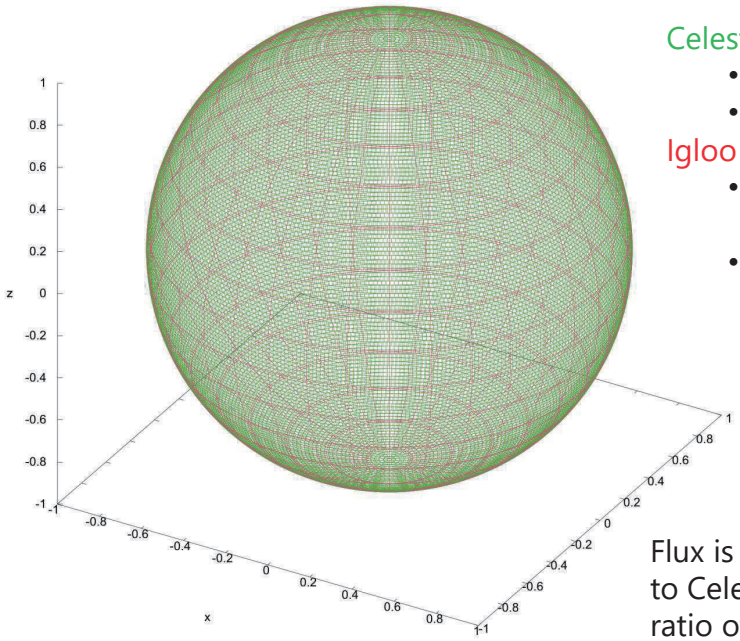
ORDEM 3.0

Table 2-1: Feature Comparison of ORDEM 2.0 and ORDEM 3.0

Parameter	ORDEM 2.0	ORDEM 3.0
Spacecraft & Telescope/Radar analysis modes	Yes	Yes
Time range	1991 to 2030	2010 to 2035
Altitude range with minimum debris size	200 to 2000 km (>10 μm) (LEO)	100 to 40,000 km (>10 μm)* (LEO to GTO) 34,000 to 40,000 km (>10 cm) (GEO)
Orbit types	Circular (radial velocity ignored)	Circular to highly elliptical
Model population breakdown by type & material density	No	Intacts Low-density (1.4 g/cc) fragments Medium-density (2.8 g/cc) fragments & microdebris High-density (7.9 g/cc) fragments & microdebris RORSAT NaK coolant droplets (0.9 g/cc)
Model cumulative size thresholds (*fiducial points*)	10 μm, 100 μm, 1 mm, 1 cm , 10 cm, 1 m	10 μm, 31.6 μm, 100 μm, 316 μm, 1 mm, 3.16 mm, 1 cm, 3.16 cm, 10 cm, 31.6 cm, 1 m
Flux uncertainties	No	Yes
Total input file size	13.5 MB	1.25 GB
Meteoroids	No	No**

NASA Orbital Debris Engineering Model ORDEM 3.0 - User's Guide, NASA/TP-2014-217370, p.5

Celestial Grid and Igloo



Celestial Grid
- about 1 deg^2 (0.3 msr)
- 41,258 cells

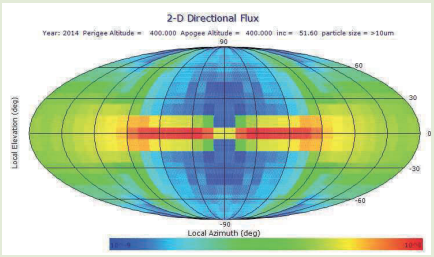
Igloo
- 10 deg (in azimuth) x 10 deg (in elevation)
- 614 cells

Flux is redistributed from Igloo to Celestial Grid according to ratio of solid angle.

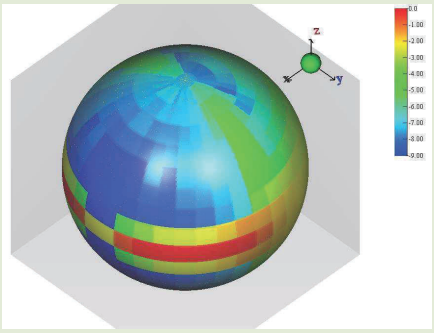
Redistributed flux

Igloo to Celestial Grid

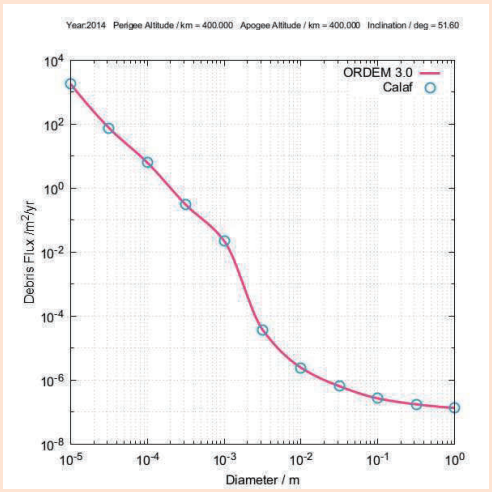
ORDEM 3.0 "2-D Directional Flux" (DIRFLUX_SC.OUT)



Flux distribution based on Celestial Grid

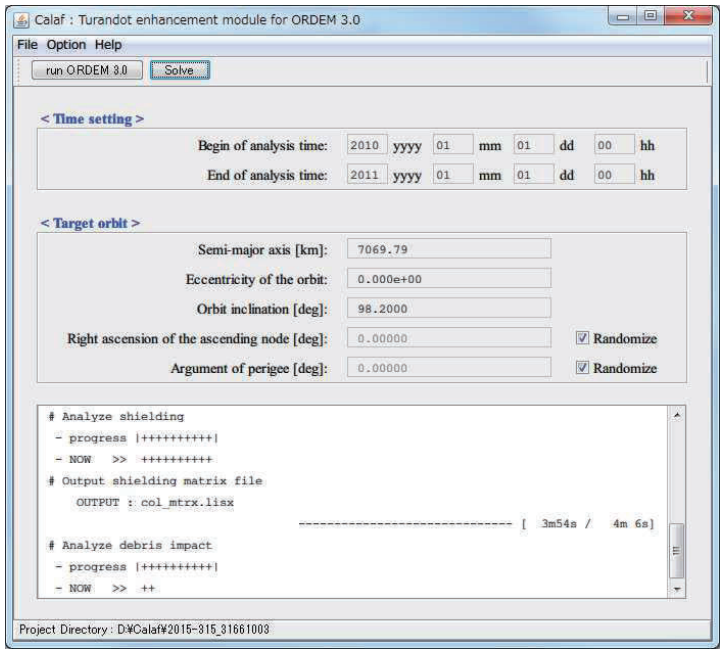


ORDEM 3.0"SIZEFLUX_SC.OUT" and
Cumulative Flux based on Celestial Grid(Calaf)



Year:2014
Perigee Altitude / km = 400.0, Apogee Altitude / km = 400.0,
Inclination / deg = 51.60, RAAN/AoP : random

GUI –for ORDEM 3.0-



Conclusion

- General information about Turandot.
- Turandot was expanded in order to use ORDEM 3.0.