STARDUST

PUSHING THE BOUNDARIES OF SPACE RESEARCH TO SAVE OUR FUTURE

Computer Graphics for Space Debris

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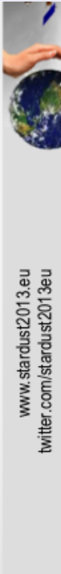
SEVENTH FRAMEWORK PROGRAMME

MARIE CURIE ACTIONS

Outline



- ✓ Introduction
- ✓ Methodology
- ✓ Test Cases
- ✓ Results
- ✓ Conclusions and Future Work

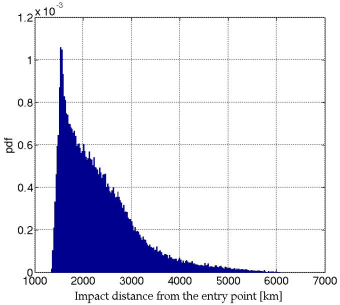
Motivation

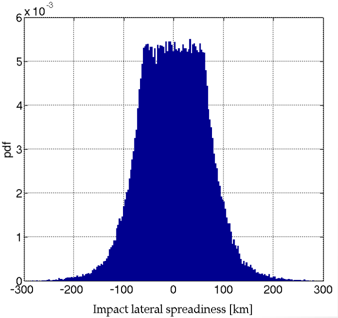
- ✓ Re-entering objects post a risk on ground through:
    - ⋆ Direct impact
    - ⋆ Radioactivity
    - ⋆ Chemical (e.g unused hydrazine)
- ✓ Re-entering objects will rise due to increased space activity
- ✓ End-of-life analysis model re-entry and determines the risk on the ground
    - ⋆ Compliance with NASA and ESA regulations for future missions

Artist's impression of satellite re-entry

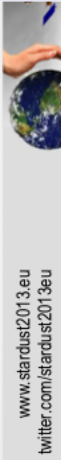
Motivation

- ✓ Atmospheric re-entry is complicated by the large uncertainties in the trajectory of an object as it re-enters.
- ✓ The involved uncertainties require a probabilistic approach
  - ⋆ Probabilistic analysis is accurate but expensive
  - ⋆ Accurate but quick estimation of the aerodynamics and aerothermodynamics is necessary for such analysis



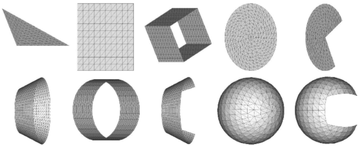


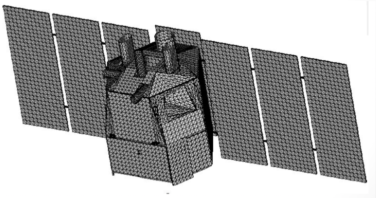
Mehta et. al., 2015



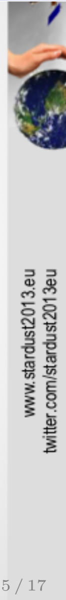
Problem Description

- ✓ Goal: To develop a tool for quick and accurate estimation of aerodynamic and aerothermodynamics for re-entry of debris objects.
- ✓ Existing re-entry tools can be classified as either object-oriented or spacecraft oriented
  - ⋆ Both use primitive shapes such as sphere, boxes, cylinder, and cones to create complex geometries





Koppenwallner et. al., 2005

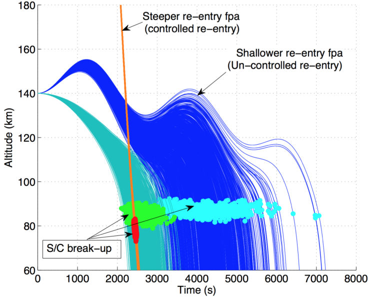


Problem Description

✓ Object-oriented tools assume total break-up at a certain altitude

- ⋆ Break-up altitude is either pre-defined or is condition based
- ⋆ Primitives are tracked individually and combinations of primitives are not modeled

✓ Shading and visibility analysis is required for aerodynamic and aerothermodynamic computations



Monte Carlo analysis performed with the DEBRIS suite

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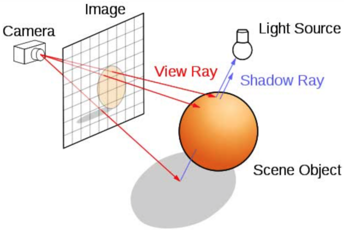
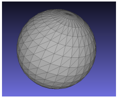
Ray Tracer

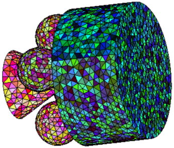
- ✓ The standard choice of tool for visibility analysis is the Ray-Tracer
  - ⋆ Computationally expensive
  - ⋆ Highly dependent on mesh resolution
- ✓ True C_D values for calculating errors are computed using standard ray-tracer
  - ⋆ Analytical model for aerodynamics and aerothermodynamics are applied to visible triangles

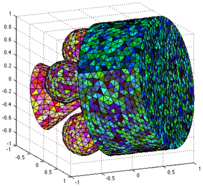


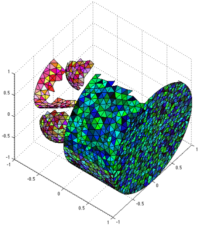


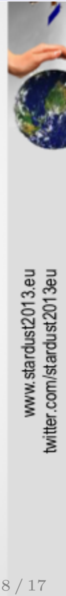
Pixelator

- ✓ The method uses 2D pixel data to determine visible part of the object
  - ⋆ Assign randomly generated unique colors in the RGB spectrum to each triangular facet
  - ⋆ Take screen-shot to obtain *c.data*
  - ⋆ Triangles with colors in *c.data* are visible
- ✓ Limited by number of unique colors in RGB spectrum
- ✓ Implemented in MATLAB, takes only a fraction of a second
  - ⋆ Standard ray-tracer in *C* language takes between 1-2 seconds



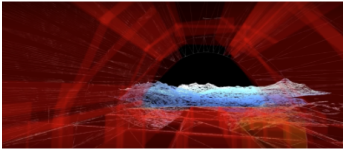


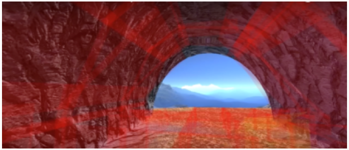




Voxelator

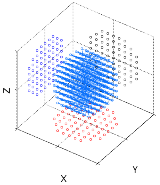
- ✓ A novel method for visibility analysis (based on Voxelization) has been developed
- ✓ Voxelization is derived from state-of-the-art computer graphics methods
  - ⋆ Voxels are 3D equivalent of pixels in 2D images
- ✓ Voxelization avoids the complex process of mesh generation

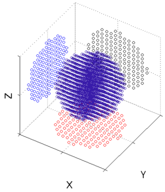


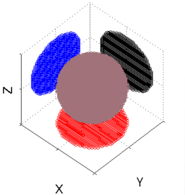


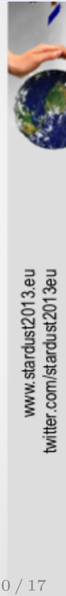
Voxelator

- ✓ Voxelized primitives are used to create complex shapes
  - ⋆ Primitives currently modeled are a sphere, a box, a cylinder, and a cone
- ✓ The tool computes visibility factors for each primitive
  - ⋆ Visibility factor is defined as the fraction of an object visible based on the projected area
  - ⋆ $C_{D_{total}} = \sum_{i=1}^{N} V_i C_{D_i}$
- ✓ Assumptions include:
  - ⋆ random tumbling
  - ⋆ pre-computed aerodynamic and aerothermodynamic databases for primitives





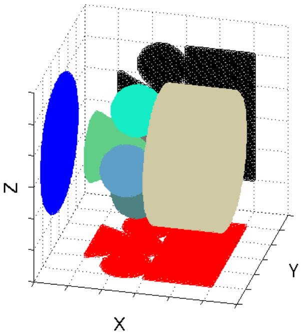


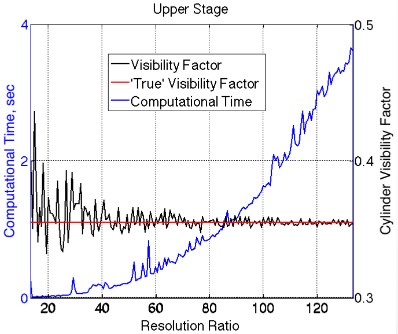


Upper Stage

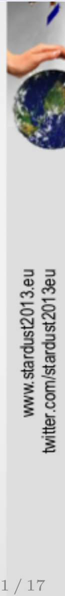
✓ Resolution study is performed to determine optimal resolution ratio

- ⋆ Resolution ratio is defined as voxels per unit length

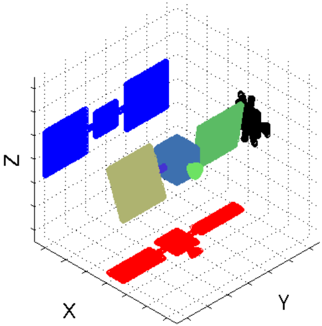


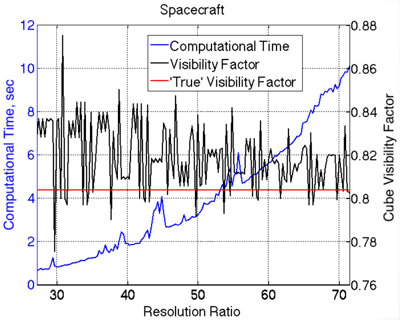


Flow Direction along +ve X: left to right



Generic Spacecraft

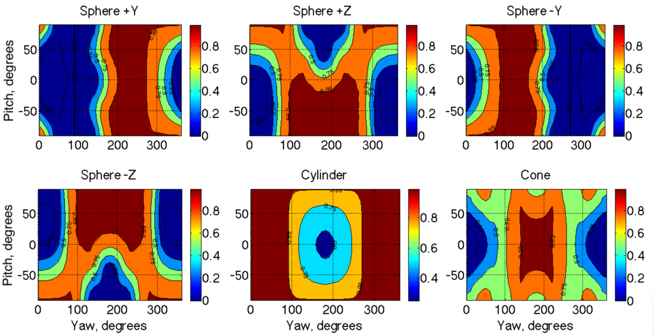


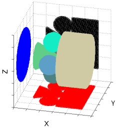


Flow Direction along -ve X: right to left

Upper Stage: Visibility Factors

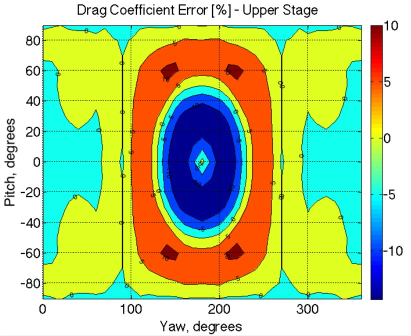
- ✓ Contour map of the visibility factors for 6 primitives as a function of attitude
- ✓ Figure titles represents the primitive and its location



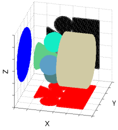


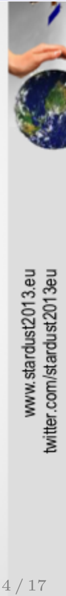
Upper Stage: C_D Error

✓ C_D computed with standard ray-tracer are assumed to be 'true' values

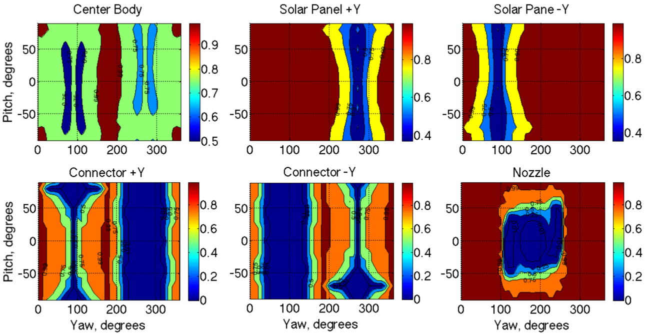


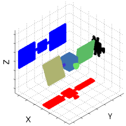
Mean Error: 3.47%

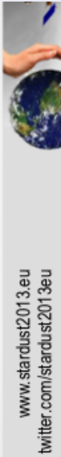




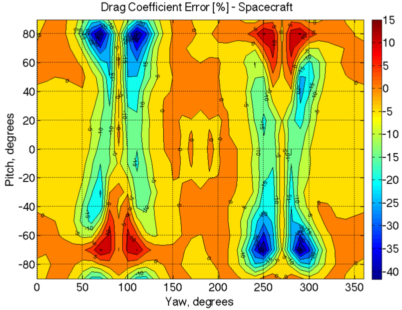
Generic Spacecraft: Visibility Factors



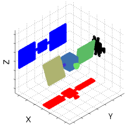


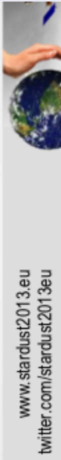


Generic Spacecraft: C_D Error



Mean Error: 4.96%





Conclusions and Future Work

- ✓ Conclusions:
  - ⋆ A new tool based on voxelization has been developed for quick estimation of aerodynamic and aerothermodynamic properties during re-entry
  - ⋆ The mean error in the computed total C_D is less than 5%
- ✓ Future Work
  - ⋆ Addition of more primitive shapes
  - ⋆ Porting over to a faster language such as C/C++. Expected improvement in computational time is between 1-2 orders of magnitude
  - ⋆ Develop the databases for the primitives used. The error in this case will also depend on the interpolation technique used