Results of the IAASS Re-entry Analysis Test Campaign 2012

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IAASS Launch and Re-entry Safety Workshops

- 1st Workshop, Huntsville (2010)
- 2nd Workshop, Kourou (2010)
- 3rd Workshop, Paris (2011)
- 4th Workshop, Wallops (2012)
- 5th Workshop, Montréal (2013)

- Participants:
  - ESA, NASA, CNES, FAA, USAF, HTG, ASTOS Solutions, APT Research, ACTA, Aerospace Corporation, Aerospace Concepts

- Re-entry test cases
  - ATV fragments, Delta-II Second and Third Stage
  - UNC, Columbia tanks
  - Delta-II Second Stage, GENSAT
General Purpose

- To promote cooperation, collaboration, and data exchange between re-entry analysis tools developers and operators
- To compare assumptions, methodology, and results
- To identify areas of improvement
- To provide commonly accepted recommendations for harmonization
- To improve the reliability of on-ground risk predictions
Analysis Tools

Object oriented approach

Parent:

Set of child fragments with simple geometric shapes

3 DoF re-entry analysis

SESAM 1.1a (ESA)
ASTOS/DARS 7.0.3 (ESA)
DEBRISK 2.04.10 (CNES)

S/C oriented approach

Complete panelized 3D model of arbitrary shape

6 DoF re-entry analysis

SCARAB 3.1L (ESA)
Delta-II Second Stage

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Credits: NASA, Tulsa World, Aerojet
## Fragment List and Material Properties

<table>
<thead>
<tr>
<th>Name</th>
<th>Shape</th>
<th>No. of fragments</th>
<th>Width/Diam. [m]</th>
<th>Length [m]</th>
<th>Height [m]</th>
<th>Mass [kg]</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent</td>
<td>Cylinder</td>
<td>1</td>
<td>1.8</td>
<td>6.3</td>
<td>0.0</td>
<td>924.343</td>
<td>-</td>
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<td>PropTan</td>
<td>Cylinder</td>
<td>1</td>
<td>1.7</td>
<td>2.7</td>
<td>0.0</td>
<td>267.675</td>
<td>A316</td>
</tr>
<tr>
<td>ThrustC</td>
<td>Cylinder</td>
<td>1</td>
<td>0.44</td>
<td>0.6</td>
<td>0.0</td>
<td>45.8</td>
<td>Inconel</td>
</tr>
<tr>
<td>GasTan1</td>
<td>Sphere</td>
<td>2</td>
<td>0.41</td>
<td>0.0</td>
<td>0.0</td>
<td>10.056</td>
<td>TiAl6V4</td>
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<tr>
<td>GasTan2</td>
<td>Sphere</td>
<td>2</td>
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<td>0.0</td>
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<td>30.548</td>
<td>TiAl6V4</td>
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<tr>
<td>Nozzle</td>
<td>Cylinder</td>
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<td>1.0</td>
<td>1.6</td>
<td>0.0</td>
<td>99.594</td>
<td>CFRP</td>
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<td>EngSup</td>
<td>Cylinder</td>
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<td>0.3</td>
<td>0.43</td>
<td>0.0</td>
<td>52.175</td>
<td>AA7075</td>
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<tr>
<td>GuideEl</td>
<td>Box</td>
<td>8</td>
<td>0.5</td>
<td>0.45</td>
<td>0.1</td>
<td>10.337</td>
<td>AA7075</td>
</tr>
</tbody>
</table>

### Additional Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>SCARAB*</th>
<th>SESAM</th>
<th>ASTOS/DARS</th>
<th>DEBRISK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting Temperature [K]</td>
<td>1650</td>
<td>1650</td>
<td>1650</td>
<td>1644</td>
</tr>
<tr>
<td>Spec. Heat Capacity [J/kg/K]</td>
<td>460-715</td>
<td>611.5</td>
<td>611.5</td>
<td>460.6</td>
</tr>
<tr>
<td>Spec. Heat of Melting [kJ/kg]</td>
<td>274</td>
<td>274</td>
<td>274</td>
<td>286.098</td>
</tr>
<tr>
<td>Emissivity [-]</td>
<td>0.08-0.62</td>
<td>0.591</td>
<td>0.591</td>
<td>0.35</td>
</tr>
</tbody>
</table>
Delta-II Second Stage Initial Conditions

- Osculating state vector from last TLE data set (SGP4):
  - Epoch: Jan. 22, 1997 09:02:32.420 UTC
  - Semi major axis: 6495.30524 km
  - Eccentricity: 0.002241
  - Inclination: 96.57158 deg
  - RAAN: 344.69854 deg
  - Arg. of perigee: 98.30452 deg
  - True anomaly: 262.00863 deg

- Initial attitude state vector (SCARAB):
  - Roll/pitch/yaw angle: 0 deg
  - Roll/pitch/yaw rates: 0.05/0.2/-0.1 deg/s

- Initial Temperature: 300K

- Corresponding geodetic state vector:
  - Altitude: 119.160504 km
  - Longitude: 87.273238 deg
  - Latitude: 0.31315034 deg
  - Velocity: 7.89959411 km/s
  - Flight-path angle: -0.12406669 deg
  - Flight azimuth: 99.9874818 deg
  - Flight heading: -9.9874818 deg
Some Tool Specific Settings

• SCARAB:
  - Zonal harmonic terms up to J8
  - MSISE-90 atmosphere model (F10.7=73, F10.7(90d)=76.8, Ap=6)
  - Solar radiation pressure/heating included
  - Third body perturbations (Sun and Moon) included
  - HWM-93 wind model

• SESAM:
  - Zonal harmonic terms up to J2
  - US-Standard 76 atmosphere model
  - Breakup altitude 78 km

• DEBRISK:
  - Zonal harmonic terms up to J2
  - CIRA88-MSI86 atmosphere model (F10.7=F10.7A=140, Ap=48)
  - Breakup altitude 78 km

• ASTOS:
  - Zonal harmonic terms up to J4
  - MSISE-00 atmosphere model (F10.7=150, F10.7(90d)=150, Ap=4)
  - Solar radiation pressure/heating not included
  - Third body perturbations (Sun and Moon) not included
  - No wind assumed
Propellant Tank Result Comparison
Trajectories

SESAM 1.1a
DEBRISK 2.04.10
ASTOS 7.0.3
SCARAB 3.1L

Altitude [km]

Longitude [deg]

Latitude [deg]

0 60 120
0 60 120
0 60 120
Propellant Tank Result Comparison
Atmospheric Densities

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![Graph showing atmospheric densities comparison](image-url)

- SCARAB (MSISE-90)
- SESAM (US76)
- DEBRISK (CIRA88-MSI86)
- ASTOS (NRL-MSISE-00)

Altitude [km]
Density [kg/m³]
Rel. Density [-]
Propellant Tank Result Comparison
Velocities

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Propellant Tank Result Comparison
Temperatures (I)

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Temperature [K]

Altitude [km]

200 400 600 800 1000 1200 1400 1600 1800

Temperature [K]

Cylinder
Tail Sphere
Bow Sphere
Overall Mean

Cylinder
Tail Sphere
Bow Sphere
Overall Max
Propellant Tank Result Comparison
Temperatures (II)
Summary

The benchmark test case based on the re-entry of the Delta-II Second Stage has permitted to make a first step in comparing technical details between re-entry analysis tools.

The tools used in this comparison were SCARAB, SESAM, ASTOS, and DEBRISK.

Differences in re-entry trajectory and temperature evolution results for the propellant tank have been identified.

Differences in user inputs and tool settings have also been identified.
Conclusions

• The identification of the reason for the differences in the results was difficult.
• It was observed that the tool users make different assumptions in certain inputs (e.g. atmosphere models, materials properties).
• It was also observed that some differences may arise from different implementations of aerothermodynamic and aerodynamic models inside the software.
• Because of this, it is very difficult to determine proper causal correlation between inputs, methods and the result variations.
• It is also possible that some factors have contradicting effects, and are ultimately not noticeable because they compensate each other.
Outlook

For future comparisons, the number of parameters influencing the results should be limited.

As much as possible, there should be a decoupling between the differences caused by inputs, and differences caused by the tools themselves.

As a first step, it would be recommendable to harmonize the inputs (e.g. use the same atmospheric conditions and material database).

More results are expected from other tools during the Fifth IAASS Launch and Re-entry Safety Workshop in Montréal 2013.

With the resulting discussion, it is foreseen that a revised benchmarking case will be proposed, together with a clear definition of the output content of the tools.

Concentrating on simple geometric shapes (instead of a full spacecraft) could be beneficial to compare the tools' internal methods.