National Aeronautics and Space Administration

COMPARISON of ORSAT and SCARAB Reentry Analysis Tools for a Generic Satellite Test Case

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ORSAT SCARAB Description

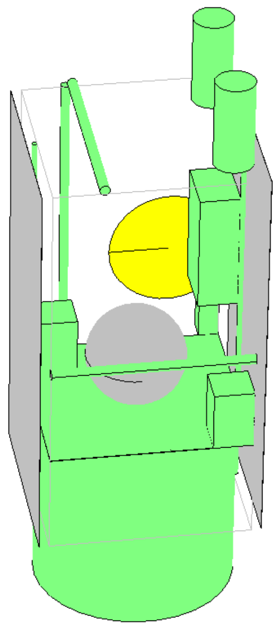
- **NASA ORSAT**
  - "Object-oriented" model
    - Reentering spacecraft are modeled as a set of simplified geometric shapes
      - Spheres
      - Cylinders
      - Boxes
      - Flat Plates
  - 3 degrees-of-freedom equations of motion
    - Stable attitude
    - No assumed lift
  - Aerodynamic and aerothermodynamic models based on shape, motion and Knudsen number dependant functions for drag and heating
  - Thermal analysis with a 1-D heat conduction model
  - Assumed break-up altitude of 78 km

- **ESA SCARAB**
  - "Spacecraft-oriented" model
    - Reentering spacecraft modeled as close to real geometry as possible using triangular panelized surfaces
  - 6 degrees-of-freedom equations of motion
    - Integration of attitude motion
  - Aerodynamic and aerothermodynamic models based on local panel methods
  - Thermal analysis with 2-D heat conduction model
  - Break-up model based on stress and structural integrity checks

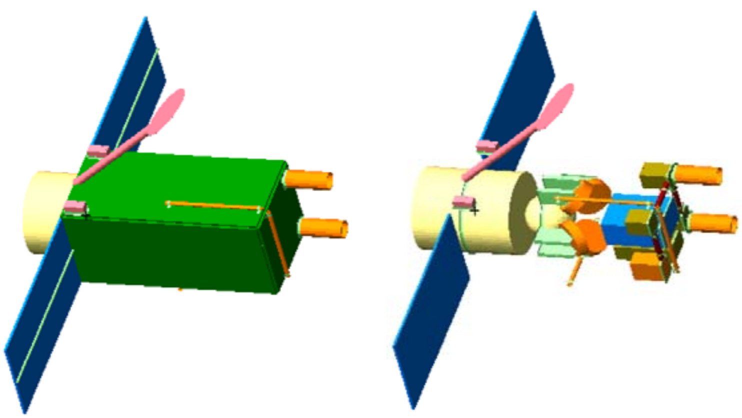
Previous Comparisons

- **1998 – 1999 IADC**
  - Comparison of 1 meter diameter spheres
    - Materials consisted of Titanium, Aluminum, and Iron
  - Results were in good agreement
- **2002-2003 ROSAT**
  - Compared results for a complete, real spacecraft (~2400 kg mass)
    - Assumed uncontrolled, naturally decaying reentry
  - Showed significant difference in predicting surviving debris casualty area (DCA)
    - ORSAT DCA = 13.62 m^2
    - SCARAB DCA = 31.78m^2
  - Differences attributed to:
    - Different material properties
    - Different fragmentation processes
    - Differences in the simulation and assumptions of attitude dynamics
- **2004 -2005 4th European Conference on Space Debris**
  - Test Matrix of simple Geometries
    - Spheres
    - Cylinders (L/D: 2 and 5)
    - Boxes (L/W: 2 and 5)
  - 4 Materials; Aluminum, Titanium, and 2 types of Graphite Epoxy
  - Results were in good agreement
    - Deviation for surviving mass < 0.2%

Test Sat Design



Early generic satellite concept sketch by ORSAT Team



SCARAB model for generic satellite

- **Joint Development between ORSAT Team at JSC and the SCARAB Team at HTG**
  - 35 unique objects representing simplified models of typical satellite components
  - Approximately 400 kg mass
    - ORSAT – 391.641 kg • SCARAB – 401.531 kg
    - Difference +9.89 kg (+2.53% w.r.t. ORSAT mass)
    - Differences result from 3 primary effects
      - ➢ SCARAB requires all connection elements to be modeled
      - ➢ Material densities are slightly different
      - ➢ Masses in SCARAB are calculated based on the mass of the triangular panels each object is comprised of
  - Initial trajectory conditions
    - Altitude – 122 km • Velocity – 7.41 km/s
    - Inclination – 52° • Flight Path Angle – -0.1°
  - Environmental Conditions
    - Zonal Harmonics up to J4
    - Earth Flattening
      - ➢ Eccentricity of Earth = 0.08182
    - U.S. Standard 1976 Atmosphere

Modeling Results

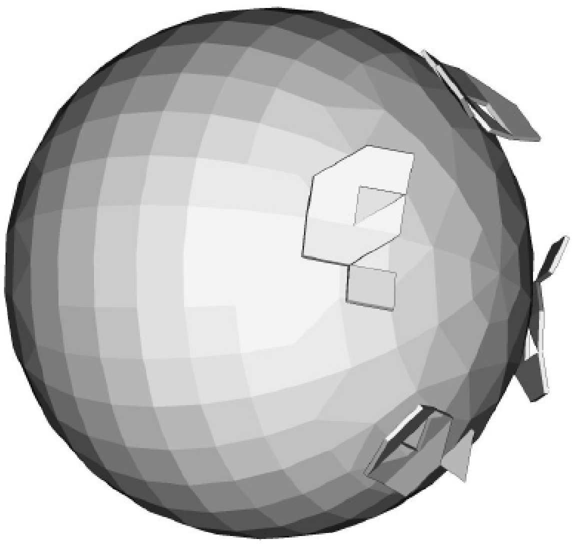
- **ORSAT**
  - 21 Surviving components representing a mass of 47.22 kg (12.1%) DCA = 15.377 m^2
    - Debris footprint begins at 678 km (LH2 Tank) and ends at 849 km (Command Box)
      - Footprint Length = 171 km
- **SCARAB**
  - 6 Surviving components representing a mass of 40.91 kg (10.19%) DCA = 4.428 m^2
    - Debris footprint begins at 744.53 km (LH2 Tank) and ends at 1013.1 km (Battery Box Contents)
      - Footprint Length = 268.7 km
- **Differences**
  - Compared to SCARAB, ORSAT Predicts:
    - 15 more surviving objects
    - 6.31 kg more surviving mass
    - A DCA 10.949 m^2 higher
    - A Footprint 97.57 km shorter beginning 66.53 km sooner
- **Surviving fragments can be divided into 3 areas for study**
  1. Objects which survive in both codes
     - There are five of these objects; LH2 Tank and (4) RWA Flywheels
  2. Objects which only survive in one code
     - Command box survives only in ORSAT
  3. Objects which survive differently
     - The Battery Cells and Battery Box Frames survive in both codes, but in different ways

Modeling Results Comparison

- **Objects Surviving in Both Codes**

	ORSAT			SCARAB		
Object	Surviving Mass (kg)	DCA (m^2)	Downrange (km)	Surviving Mass (kg)	DCA (m^2)	Downrange (km)
LH2 Tank	10.000	1.088	678	9.958	1.088	744.53

  - LH2 Tank
    - 0.5 m titanium spherical tank
    - Only significant difference is the downrange distance
      - ORSAT components decelerate faster due to kinetic energies which result from lower mass (e.g. modeling only tank, not including brackets)
      - Tank represents heel (shortest downrange distance) of debris footprint for both codes



Modeling Results Comparison

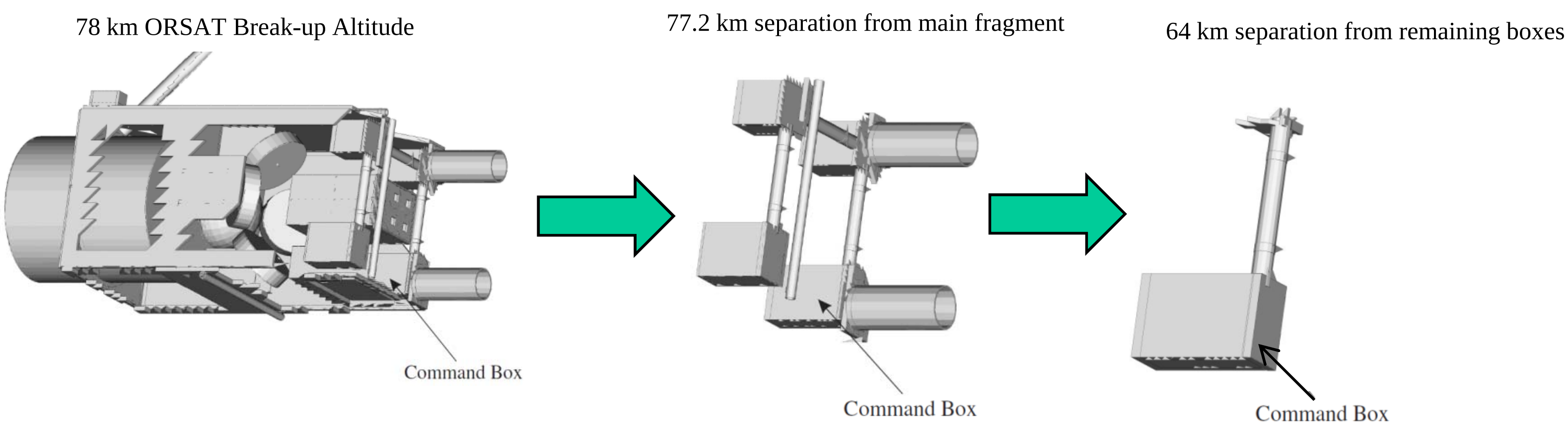
- **Objects Surviving in Both Codes**

	ORSAT			SCARAB		
Object	Surviving Mass (kg)	DCA (m^2)	Downrange (km)	Surviving Mass (kg)	DCA (m^2)	Downrange (km)
Flywheel 1	3.136	0.750	703	3.313	0.584	799.28
Flywheel 2	3.136	0.750	703	3.313	0.584	767.16
Flywheel 3	3.136	0.750	703	3.313	0.584	773.79
Flywheel 4	3.136	0.750	703	3.313	0.584	791.28

  - Reaction Wheel Assembly Flywheel
    - 0.3 m diameter X 0.01 m thick titanium disk
    - Flywheels illustrate a diversion in modeling approach
      - ORSAT's "object oriented" method for modeling the components treats duplicate components such that the flywheels experience identical reentry scenarios
      - SCARAB "S/C oriented" approach models the trajectory and ablation of flywheels individually as they break apart from the parent object at different times
    - DCA difference is a result of differing method for determining area
      - ORSAT uses maximum cross section for disks
      - SCARAB uses mean cross section
    - Downrange distance variance is a result of differing masses as SCARAB predicts the shaft to remain attached and ORSAT does not

Modeling Results Comparison

- **Objects which only survive in one code**
  - ORSAT predicts the command box to survive
    - Impacts with a mass of 3.89 kg (15.6% of original mass) and a DCA of 0.691 m^2
  - Differences between ORSAT and SCARAB fragmentation modeling make the source of the prediction difference difficult to identify
    - ORSAT begins modeling reentry of the command box at 78 km break-up of parent S/C
    - SCARAB has a more complex fragmentation history (below):



  - In addition, the ORSAT analysis also shows that > 96% of the total energy required for this object to demise is absorbed, and that it will be predicted to demise if the oxidation heating efficiency is increased

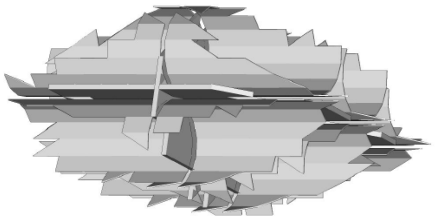
Modeling Results Comparison

- **Objects which survive differently**

  - The battery box and its fragments partially survive in both codes
    - ORSAT assumes the inner frames of the battery box and the battery cells to be separate fragments of the battery box
      - Once the outer box demises, these are assumed reenter individually
    - The SCARAB analysis assumes the battery box, inner frame, and battery cells are strongly attached
      - As portions of the battery box assembly demise, the rest remain connected

  - ORSAT predicts the survival of 3 aluminum frame pieces and 12 nickel batteries
    - Total DCA = 2.798 m^2 and mass of 9.37 kg for aluminum frame pieces
    - Total DCA = 7.8 m^2 and mass of 11.4 kg for battery cells

  - SCARAB predicts 1 surviving component
    - DCA = 1.002 m^2 and mass 17.697 kg
      - Of this mass 11.616 kg are Nickel and 6.081 kg are aluminum



Modeling Results Comparison

- **Objects which survive differently (cont.)**

  – The differences in the battery box survival reveal both striking variances and similarities between the results of the two codes
    - The ORSAT assumption that all of the objects impact separately results in a much higher DCA due the large number of objects impacting
      - ➢ In both codes DCA values include an added area to account for the proximity of a standing person for each individual object
    - If the total mass of each material which impacts the ground is compared the results are quite similar
      - ➢ For the inner frames and battery cells, ORSAT predicts:
        - ☐ 11.4 kg of nickel survives compared to 11.616 kg for SCARAB
        - ☐ 9.37kg of aluminum survives compared to 6.081 kg for SCARAB
    - If the surviving mass of aluminum and nickel in ORSAT are combined into a box shaped fragments with a volume equal to the inner dimension of the parent battery box the following would result
      - ➢ 1 Fragment with an impacting mass of 20.77 kg and a DCA of 1.254 m^2
      - ➢ This is in much better agreement with the SCARAB value

Modeling Results Comparison

- **Looking back at the final results**

	ORSAT			SCARAB	
	Reported Values	Assuming Battery Box Remains Intact	Ignoring Command Box	Reported Values	Using Maximum Area
Surviving Mass (kg)	47.220	**47.220**	43.330	40.91	**40.91**
DCA (m^2)	15.377	**6.033**	5.342	4.428	**5.226**

  – By adjusting some of the methods and assumptions in each code the comparison becomes more clear and results begin to converge
    - Adjust ORSAT results to account for the fused battery cell and inner frame as in SCARAB
      - ➢ Reduces ORSAT DCA by 9.344 m^2
    - Adjust SCARAB cross-sectional area calculation to match those in ORSAT
      - ➢ Use maximum area for RWA Flywheels
      - ➢ Use 0.5*((L*D)+(L*H)) for Battery Box contents
      - ➢ Increases DCA by 0.797
    - The end result is that the DCA's between the codes differ by 0.116 m^2 (2.12% w.r.t. ORSAT) when considering only objects surviving in both codes
      - ➢ Difference is 0.807 m^2 (13.37%) when the command box is included

Conclusions

- **Careful examination reveals that ORSAT and SCARAB arrive at very similar results**
  - Of 33 unique objects modeled both codes strongly agree on 31 of those
    - Predict 29 to demise in a similar fashion
    - Predict 2 (LH2 tank, RWA flywheels) to demise in much the same way
  - Only 2 objects (as modeled in SCARAB) show significant variance
    - For the command box ORSAT's prediction of a high demise factor were very close to the results predicted by SCARAB, and may have demised in ORSAT after evaluating the oxidation effects
- **The large difference in the debris casualty area which resulted form the battery box contents (1 item in SCARAB, 3 unique items in ORSAT) are not an effect of the differing methods employed to model the reentry physics, but are instead a difference in safety philosophy associated with geometric description of components**
- **It is not possible to deem either method as "correct" or better**
  - Either scenario is equally plausable