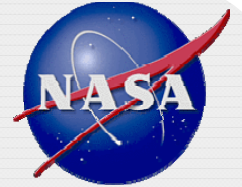National Aeronautics and Space Administration

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

PEDAS1-0021-10

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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

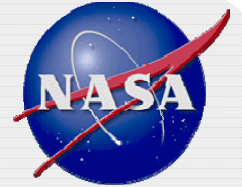    - Assumed break-up altitude of 78 km

- **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

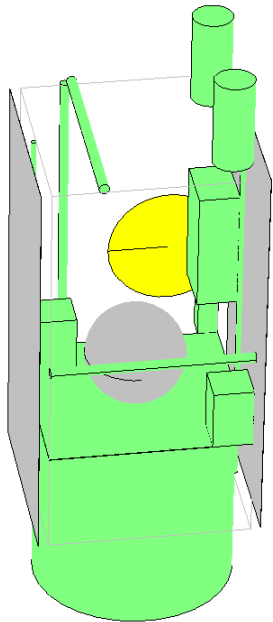    - Break-up model based on stress and structural integrity checks
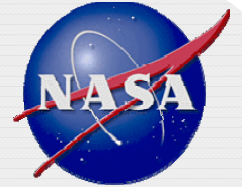
# Previous Comparisons

- **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 = 31.78$m^2$
  - 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
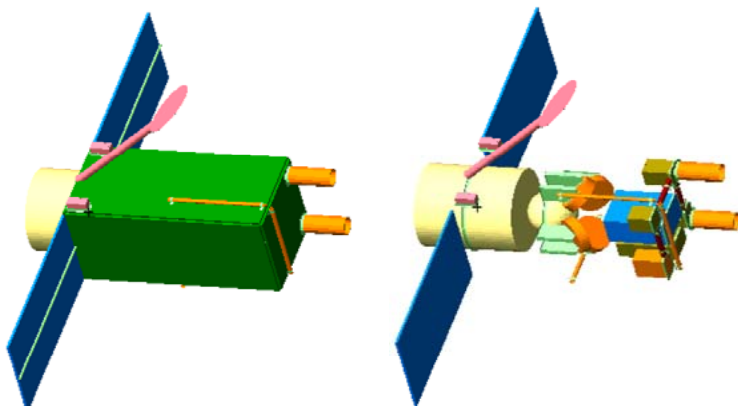    - Deviation for surviving mass < 0.2%

# 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
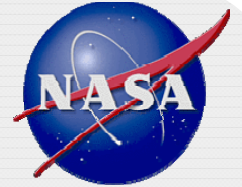
# Modeling Results

- **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
    - A DCA 10.949 m$^2$ higher
    - 6.31 kg more surviving mass
    - 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
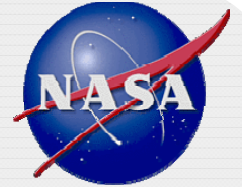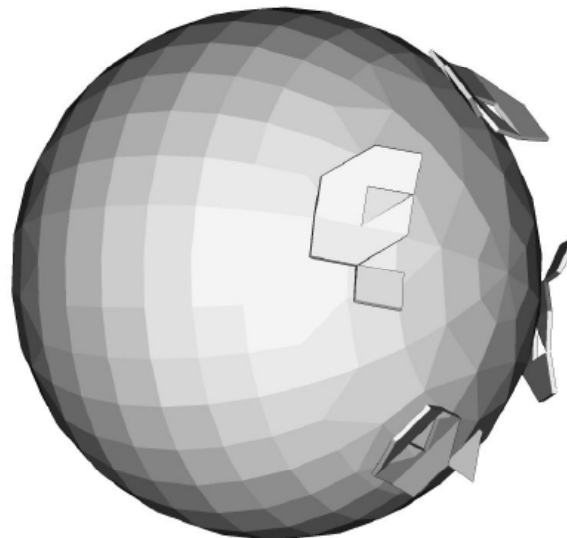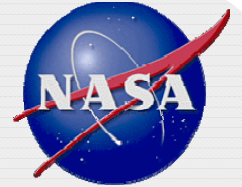
# Modeling Results Comparison

- ## Objects Surviving in Both Codes

| Object | ORSAT | | | SCARAB | | |
|--------|-------|-------|-------|--------|-------|-------|
| | 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
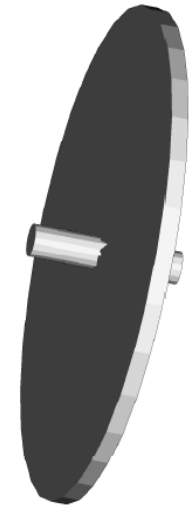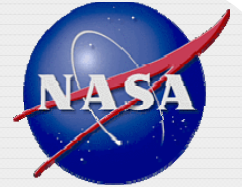
# Modeling Results Comparison

- **Objects Surviving in Both Codes**

| Object | ORSAT | | | SCARAB | | |
|---|---|---|---|---|---|---|
| | 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 |

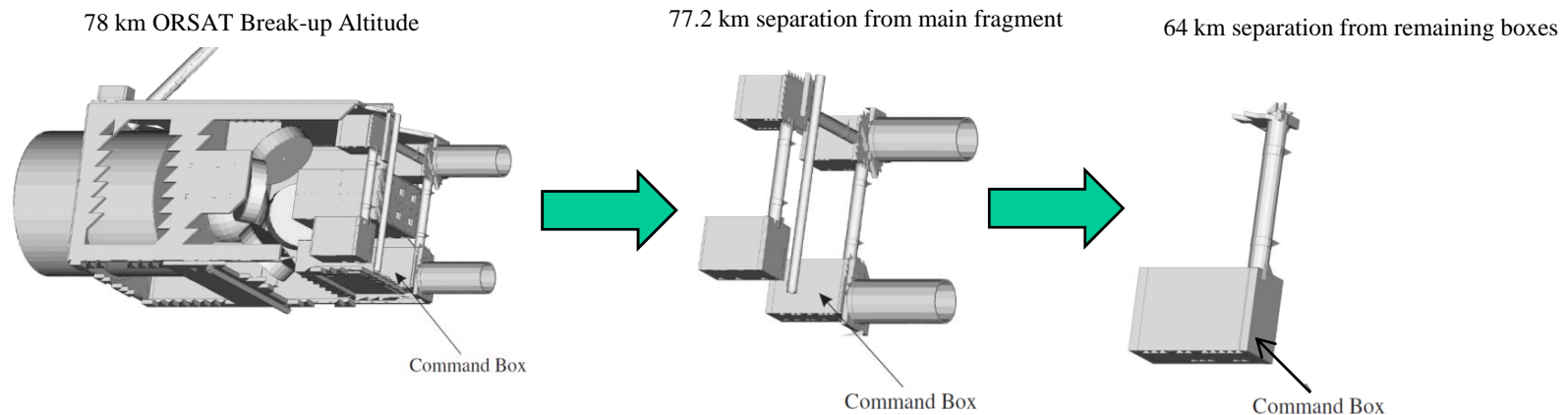- Reaction Wheel Assembly Flywheel
  - 0.3 m diameter X 0.01 m thick titanium disk
  - Flywheels illustrate a  diversion in modeling approach
    - ORSAT's "object oriented" method for modeling the components treats duplicate components such that the flywheels experience identical reentry scenarios
    - 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
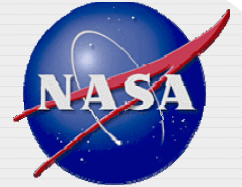
# Modeling Results Comparison

- **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):

78 km ORSAT Break-up Altitude          77.2 km separation from main fragment          64 km separation from remaining boxes



Command Box          Command Box          Command Box

  - 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
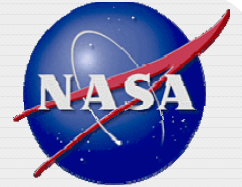
# Modeling Results Comparison

- **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
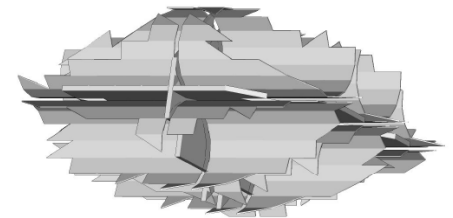
# Modeling Results Comparison

- **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
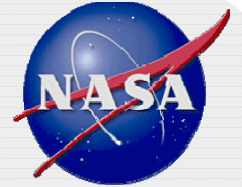
# Modeling Results Comparison

- **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 (m²) | 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 m²
  - 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 m² (2.12% w.r.t. ORSAT) when considering only objects surviving in both codes
    - ➤ Difference is 0.807 m² (13.37%) when the command box is included
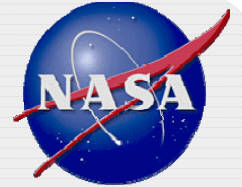
# Conclusions

- **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