NASA Upper Atmosphere Research Satellite (UARS) Re-entry Prediction and Analysis

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INTERNATIONAL SYMPOSIUM ON
SUSTAINABLE SPACE DEVELOPMENT AND UTILIZATION FOR HUMANKIND
ORBITAL SPACE DEBRIS – CHALLENGES & OPPORTUNITIES

1-2 March 2012
Upper Atmosphere Research Satellite

- Launched: 12 September 1991 inside STS-48
- Deployed: 15 September 1991
- International Designator: 1991-063B
- U.S. Satellite Number: 21701
- Dry mass: 5668 kg
- Initial Operational Orbit: 575 km by 580 km, 57 deg inclination
- Decommissioned: 15 December 2005 after maneuvering into a shorter-lived disposal orbit
  - Residual orbital lifetime reduced by ~ 20 years
Orbital History of UARS

Operational orbit, 1991-2005

Maneuver to disposal orbit and decommissioning, December 2005
The two principal and not completely independent influences on reentry prediction accuracy are atmospheric density and vehicle stability.

1. Atmospheric density varies over the planet and can be significantly affected by solar activity within a short period.
   - Solar activity can also adversely affect the operation of ground-based radars, leading to less accurate tracking information.

2. Changes in vehicle stability are not uncommon during the final days prior to reentry due to increased average atmospheric density.
   - The initiation or change of tumbling modes can result in a change in the vehicle’s drag profile, which, in turn, can affect the time and location of reentry.
U.S. Reentry Predictions

• The official source of reentry predictions for uncontrolled space objects is USSTRATCOM’s Joint Space Operations Center (JSpOC).

• Normal procedure is for TIP (Tracking and Impact Prediction) messages to be prepared and released to the public (via the Space-Track.org website) at the following intervals:
  
  – T – 4 days, T – 3 days, T – 2 days, T – 1 day, T – 12 hours, T – 6 hours, and T – 2 hours

• TIP messages provide the best estimates of reentry time and location but have large uncertainties. Even at T – 2 hours, the uncertainty of reentry time is on average +/- 25 minutes for nearly circular orbits. This equates to +/- 12,000 km on the Earth.

• A final, post-reentry assessment message is normally issued within a few hours of reentry.
Average of 47 Objects Reentering from Near Circular Orbits

Sample Size: 47 Spacecraft and Rocket Bodies

- Official
- Actual
- 10% of Time to Go
UARS Reentry Predictions

- Predicted vs. Actual ReEntry Time (hours)
- Official Uncertainty
- 10% of time to go
- 20% of Time to Go

Hours Before ReEntry:
-96 to 0
UARS Reentry Predictions

Predicted - Actual ReEntry Time (hours)

Hours Before ReEntry

- Predicted-Actual
- Official Uncertainty
- 10% of time to go
- 20% of Time to Go
High confidence post-flight assessment is that UARS reentered the Earth’s atmosphere at 14.1° S and 170.1° W at 04:00 GMT on 24 September 2012.

UARS Groundtrack, 03:30 – 04:00 GMT, 24 September 2011
Probability of Reentering Over the Ocean

Global Fraction of Land Distributed by Latitude

% of the Earth's Surface that is Land at Given Latitude
Probability of Reentering Over the Ocean

Probability of Satellite Reentry Over Land
as a Function of Orbital Inclination

Fraction of Earth's Surface that is Land beneath Satellite's Orbit

Orbit Inclination [deg]
• NASA’s highest fidelity software program for reentering satellites is called ORSAT: Object Reentry Survival Analysis Tool. The program:

  – Assesses spacecraft, launch vehicle stage, and other man-made space object component survivability during atmospheric entry from sub-orbital, orbital, and deep space trajectories.

  – Assesses human casualty risk associated with uncontrolled reentries.

  – Characterizes surviving debris footprints associated with controlled reentries for the purpose of avoiding inhabited regions and the Antarctic permanent ice pack.

• ORSAT has supported many NASA, DoD, and other domestic and foreign programs during the past two decades.
Basic Components of UARS

Starboard View

Port View
NASA conducted a detailed reentry risk assessment for UARS in 2002.

- Number of potentially hazardous objects expected to survive: 26
- Total mass of objects expected to survive: 532 kg
- Estimated human casualty risk (updated to 2011): ~1 in 3200

<table>
<thead>
<tr>
<th>Object Description</th>
<th>Material</th>
<th>Qty.</th>
<th>Type</th>
<th>Initial mass (kg)</th>
<th>Impacting mass (kg)</th>
<th>Impacting vel. (m/s)</th>
<th>Impacting K. E. (klf)</th>
<th>Downrange (km)</th>
<th>Debris casualty area (m²)</th>
<th>Impacting cross section area (m²)</th>
<th>Mass/CS area (kg/m²)</th>
<th>Impacting ballistic coeff. (kg/m²)</th>
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<tbody>
<tr>
<td>HGA gimbal &amp; retention</td>
<td>Titanium</td>
<td>1</td>
<td>Cyl.</td>
<td>98.81</td>
<td>27.03</td>
<td>43.91</td>
<td>26.07</td>
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<td>Box</td>
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<td>158.30</td>
<td>44.02</td>
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<td>0.928</td>
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</tbody>
</table>

**TOTALS**: 26 objects, total mass 607.92 kg, total mass 532.38 kg, estimated human casualty risk ~1 in 3200.

Note: Totals account for quantity while the value listed in the table accounts for only one object.
Downrange Spread of Surviving Debris

Note: Darkened objects indicate that Initial Temperature = 300 K and/or Oxidation Efficiency = 0.5 were changed based on reasonable assumptions.

Surviving Components
Summary

• No NASA or USG human casualty reentry risk limits existed when UARS was designed, built, and launched.

• Time of reentry estimates were within normal limits

• NASA, the USG, and some foreign space agencies now seek to limit human casualty risks from reentering space objects to less than 1 in 10,000.

• UARS was a moderate-sized space object. Uncontrolled reentries of objects more massive than UARS are not frequent, but neither are they unusual.

• Since the beginning of the space age, there has been no confirmed report of an injury resulting from reentering space objects.