Space Debris Reentry Hazards

William Ailor, Ph.D., The Aerospace Corporation

Chair, Space Hazards Technical Committee, International Association for the Advancement of Space Safety (IAASS)

Presented to Scientific &Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space

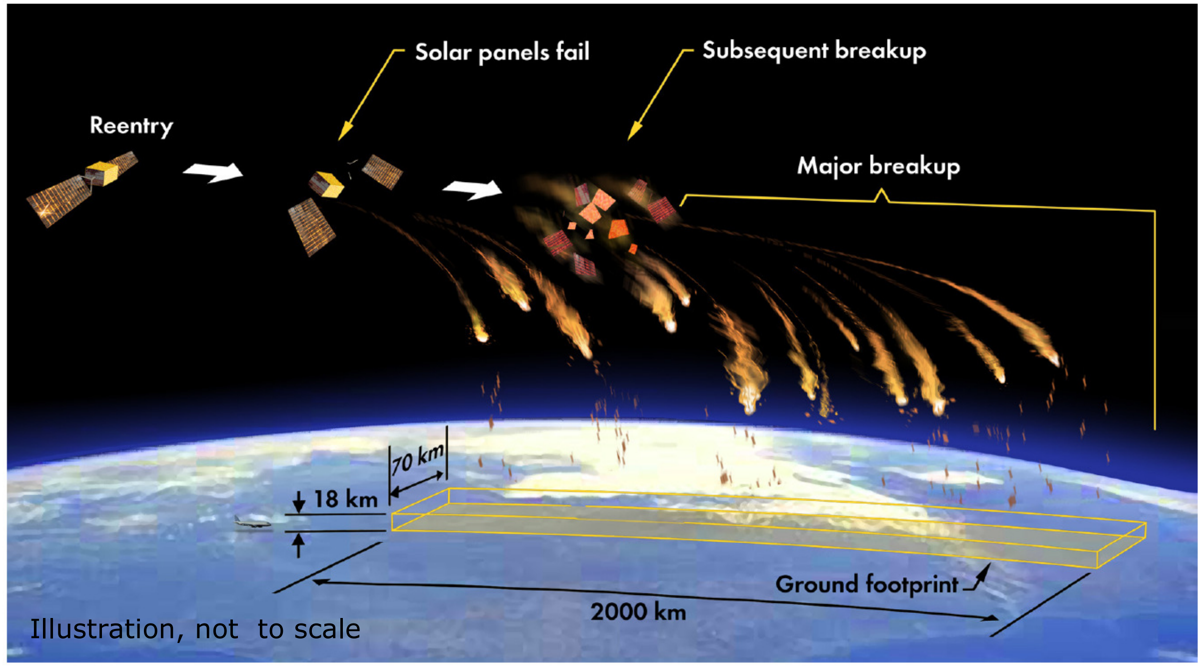
February 2012

Space Debris

- Over 20000 tracked objects (objects larger than 10 cm diameter)
  - *1000 operating satellites*
  - *Over 13000 tracked objects in Low Earth Orbit (LEO)*
- Reentry of larger, uncontrolled objects can be a hazard to people and property
- ~40 large debris objects (objects >800 kg) reenter randomly per year
  - *Dead satellites (e.g., UARS, Phobos-Grunt)*
  - *Launch stages*
- Reentry is recommended end-of-mission disposal option for LEO objects
  - *Directed reentry to safe area for objects with casualty expectation exceeding defined limit (1×10^{-4} in the U.S.)*
  - *Random reentry acceptable for objects with lower risk*
- Many large objects in LEO lack capability to control reentry location
  - *Launched before requirement in place*
  - *Mission ended prematurely*

Reentry Breakup Basics

- Space hardware reenters at very shallow angle (<1 degree)
- ~40 objects weighing more than 1 ton reenter randomly per year
- Major breakup at ~78 km
- 10 to 40% of dry mass on orbit survives and impacts the Earth's surface; poses hazard to people and property
- Debris spread over long, thin ground footprint



Some Examples of Recovered Debris

Texas, 1997

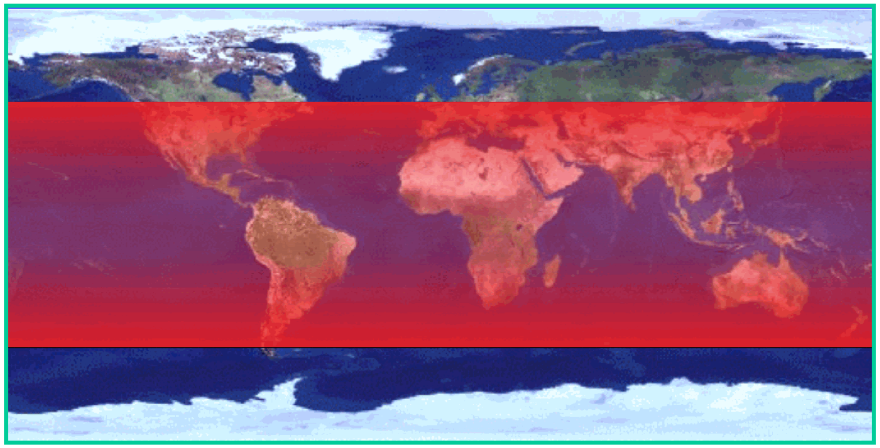
Oklahoma, 1997

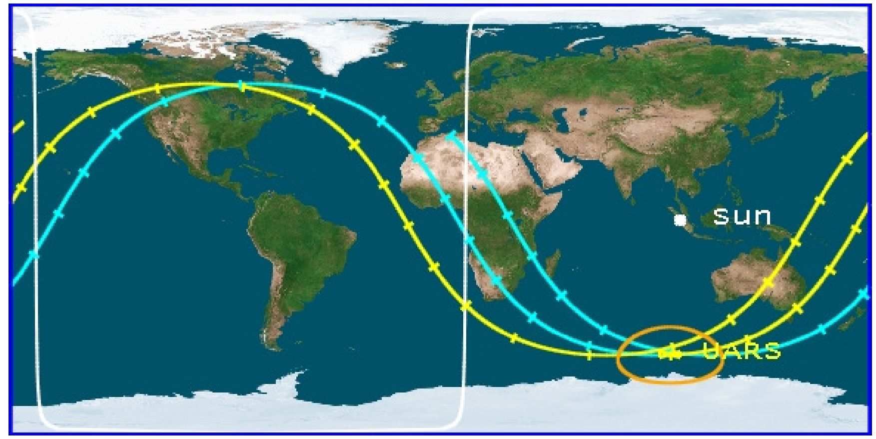
South Africa, 200

Saudi Arabia, 2001

Mongolia, 2010

Estimating Risk





- Models predict number, size, mass of surviving debris
- Debris will fall in latitude band defined by orbit inclination
- Risk estimated for objects with enough kinetic energy to cause injury or death (> 15 Joules in U.S.)
  - *Generally assumes standing human outdoors*
  - *Can include sheltering, rolling, other factors*
- Risk estimated based on population within latitude band

Where will debris land?

Debris impact locations, 1997 Delta II Stage 2 reentry

- Precise location of reentry point (defined altitude prior to breakup) impossible to predict
  - *Generally assume ±10-25% error in **time of reentry** due to atmospheric and drag uncertainties*
  - *Example:*
    - Prediction made with tracking data 1 orbit revolution (90 minutes) from reentry has ±9 minute error
    - Object travelling at 7.5 km/sec x ±9 minutes → ±4050 km uncertainty in reentry location
- Impact point for surviving fragments also impossible to predict
  - *Spread of fragments will depend on where fragments released, flight characteristics of each fragment*
  - *Fragments for Texas reentry impacted many kilometers from each other*
  - *Local wind can be significant factor*

Typical Risks

	Daily Casualty Expectation
Natural Disasters	813 (Deaths, Worldwide, 2010)[1]
Natural Disasters	29 (Deaths, Worldwide, 2009)[1]
Work Accidents	12 (Deaths, U.S., 2009)[2]
Motor Vehicle Accidents	99 (Deaths, U.S., 2009)[2]
Unintentional Poisoning	84 (Deaths, U.S., 2009)[2]
Assault (homicide)	45 (Deaths, U.S., 2009)[2]
Falls	68 (Deaths, U.S., 2009)[2]
Influenza	8 (Deaths, U.S., 2009)[2]
Meteorite Falls	1.1×10^{-4} (Deaths or Injuries, Worldwide, 1800-
Reentry Events	2.7×10^{-5} (Deaths or Injuries, Worldwide)[4]

1 Julie Reed Bell, Seth Borenstein, "2010's World Gone Wild: Quakes, Floods, Blizzard," Associated Press, Dec. 19, 2010 (see http://www.msnbc.msn.com/id/40739667/ns/us_news-2010_year_in_review/t/s-world-gone-wild-quakes-floods-blizzards/).

2 Kenneth D. Kochanek, et al, "Deaths, Preliminary Data for 2009, Vol. 59, No.4," National Vital Statistics Report, U.S. Department of Health and Human Services, March 16, 2011.

3 John S. Lewis, Table, pp176-182, "Property Damage, Injuries, and Deaths caused by Meteorite Falls," **Rain of Iron and Ice**, Perseus Publishing, 1996.

4 Assumes 100 reentries year, each with Expected Casualty of 1×10^{-4} → ($100 \times 0.0001/365 = 2.7 \times 10^{-5}$)

Reentry Breakup Recorder assembly
(recorder is inside heat shield)

Reentry Breakup Recorder during
pre-flight testing

- New instruments recording what happens during breakup and providing precise information on debris impact locations
  - *Reentry Breakup Recorder (REBR) collected data on reentry and breakup of Japan Aerospace Exploration Agency's (JAXA's) HTV-2 vehicle*
  - *Provided latitude and longitude of REBR impact location*
- REBR data will help improve breakup and hazard prediction models
- Future systems may be designed to minimize hazards after reentry ("designed for demise")

Summary

- Over 40 large objects reenter randomly each year
- Variation in Earth's atmosphere due to solar effects and uncertainty in each object's aerodynamics and dynamics makes predictions of exact entry location impossible
- Reentry breakup process disperses components of each object along a long, thin debris footprint
  - After release, each object proceeds independently
  - Distance between objects can be many kilometers
- Risks to humans from each event is very low, but not zero
- New instruments increasing understanding of reentry breakup, may lead to designs of space hardware that minimize hazards for random reentry