Das EU-Projekt LEOSWEEP: Entsorgung von Weltraummüll mit Ionenstrahlen

XXIV. EA OTPIP Mühlleithen 2017

Andreas Neumann, DLR Göttingen
Inhalt

- Müll im Weltraum
- Das Projekt LEOSWEEP
- DLR Part im Projekt
- EP Testanlage des DLR mit Diagnostik-Systemen
- Einige Ergebnisse
- Zusammenfassung und Ausblick
Space debris encompasses both natural (meteoroid) and artificial (man-made) particles. Meteoroids are in orbit about the sun, while most artificial debris is in orbit about the Earth. Hence, the latter is more commonly referred to as orbital debris. Orbital debris is any man-made object in orbit about the Earth which no longer serves a useful function. Such debris includes nonfunctional spacecraft, abandoned launch vehicle stages, mission-related debris and fragmentation debris.

There are more than 20,000 pieces of debris larger than a softball orbiting the Earth. They travel at speeds up to 28,000 km/h, fast enough for a relatively small piece of orbital debris to damage a satellite or a spacecraft. There are 500,000 pieces of debris the size of a marble or larger. There are many millions of pieces of debris that are so small they can’t be tracked.

Trajectories of space debris objects in Earth orbit. Courtesy of ESA.
All human-made space objects result from the near-5000 launches since the start of the space age. About 65% of the catalogued objects, however, originate from break-ups in orbit – more than 240 explosions – as well as fewer than 10 known collisions. Scientists estimate the total number of space debris objects in orbit to be around 29,000 for sizes larger than 10 cm, 670,000 larger than 1 cm, and more than 170 million larger than 1 mm.

Any of these objects can cause harm to an operational satellite. For example, a collision with a 10 cm object would entail a catastrophic fragmentation of a typical satellite, a 1 cm object will most likely disable a spacecraft and penetrate the International Space Station shields, and a 1 mm object could destroy subsystems. Scientists generally agree that, for typical satellites, a collision with an energy-to-mass ratio exceeding 40 J/g would be catastrophic.
Catalogued Space Objects

Source: Space Debris and De-Orbiting, Dr. Manfred Wittig, MEW-Aerospace UG
Scientific models estimate the total number of space debris objects in Earth orbit to be in the order of (ESA):

- > 10 cm: 29000
- > 1 cm: 670000
- > 1 mm: > 170 million
Space Debris Objects

![Graph showing the distribution of space debris objects by altitude. The graph peaks at two notable events: Iridium-Cosmos Breakup and Fengyun-1C Breakup.]
Space Debris Impact Simulation

Impact at 6.8 km/s: 56,500 J

Image courtesy of ESA
Space Debris Impact on Windows

Impact chip
Released 12/05/2016 9:00 am
Copyright ESA/NASA

The European-built Cupola was added to the International Space Station in 2010 and continues to provide the best room with a view anywhere. In addition to serving as an observation and work area when the crew operates the Station’s robotic arms, it also provides excellent views of Earth, celestial objects and visiting vehicles........

ESA astronaut Tim Peake took this photo from inside Cupola last month, showing a 7 mm-diameter circular chip gouged out by the impact from a tiny piece of space debris, possibly a paint flake or small metal fragment no bigger than a few thousandths of a millimetre across. The background just shows the inky blackness of space.

An impact crater on one of the windows of the Space Shuttle Challenger following a collision with a micrometeoroid during STS-7, 1983, source:
http://www.orbitaldebris.jsc.nasa.gov/photogallery/gallarypage/sts7crack.jpg,
http://www.orbitaldebris.jsc.nasa.gov/photogallery/photogallery.html
Vega Launch

http://spaceflightnow.com/vega/vv02/launchtimeline.html
Reentry of Space Objects

Satellite Reentries in 2014

- More than 600 satellites, launch vehicle upper stages and other debris were recorded by U.S. Space Surveillance Network in 2014
  - 86 satellites
  - 49 upper stages
  - 467 debris objects

- High Reentry Rate due to Solar Maximum in 2014

- Total mass was more than 100 tons
LEOSWEEP: EU FP7 Project

- Ion Beam Shepherd (IBS) concept
- Ion beam provides an efficient and low-risk contactless manipulation of the debris to be deorbited
- Key milestones:
  - detailed understanding of the physics underlining the concept
  - identification of key technological challenges and concrete solutions
  - assessment of the concept capability in dealing with large-scale removal operations
  - development of ground-based laboratory experiments
  - definition of a clear technology and policy development roadmap
  - pre-phase A design of a small technology demonstration mission
  - exploitation and dissemination of the proposal outcomes

- Partners:
LEOSWEEP: EU FP7 Project

Source: LEOSWEEP Website:

https://leosweep.upm.es/en
LEOSWEEP Activities

- Space Dynamics Group (SDG), Technical University of Madrid (Universidad Politécnica de Madrid: UPM)

- ITM Ukraine, Sputter Investigations
LEOSWEEP: EU FP7 Project

DLR measurement tasks:

- Thruster beam divergence
- Impulse transfer on test target
- Plasma parameters
DLR Site Göttingen

Employees: 450
Size of site: 55 945 m²

Research institutes and facilities:
- Institute of Aerodynamics and Flow Technology
- Institute of Aeroelasticity
- Institute of Propulsion Technology, Turbines department
- The Engineering Systems House (ESH)
- Technology Marketing
- Aeronautics Program Management
- Training - Cooperative State University
- German-Dutch Wind Tunnels (DNW), "Goettingen and Koeln" business unit
- DLR_School_Lab Göttingen
- Central Archive in DLR
Vacuum chamber: 12m long, 5m diameter
Distance thruster-chamber walls as large as possible
Plume and plume impingement for EP thrusters with up to 25-50kW
EP T lifetime tests, operation with different gases
Performant measurement equipment for ion beam profile measurements also in the backflow, + thrust and thrust vector measurement
Continuous pumping speed to allow background pressures < 10^{-4} mbar
LHe boost pump (under development)
Operation customer oriented, stable/reference conditions
**DLR Facility**

**Thruster Stand**
- Stand structure not connected to chamber wall
- 3 posts anchored to concrete foundation

**Mass Spectrometer**
- Separated by gate valve from chamber
- Up to 200 amu
- Usable for leak detection

**IR Cameras**
- On flexible support for changing view direction
- Range: -20° – 900° C
C-Shaped Beam Scanner (CSB)

- 15 Faraday cups (FC) at 0.7m pointing at thruster
- Vertical: 8° distance, 112° coverage
- Total horizontal scan angle > 180°
- FC’s can operate as energy analyzer (RPA)
- 2-4 deg/s scanning speed
- 16 channel data acquisition

Examples of Faraday cups

CSB and MPBS in vacuum chamber
Example of a CSB Measurement

- Scan of RIT10/37 thruster plume with CSB
- Beam divergence is small (<8°)
Beam Scanner Systems

Multi-Purpose Beam Scanner (MPBS)
- Stainless steel arm
- 1.5m from thruster exit
- Speed: up to 2°/s
- Horizontal scan angle > 180°
- Designed for 10kg load
- Mounting platform for multiple instruments
- Can carry emissive probe, Langmuir probe, Faraday cups, IR camera, RPA

Long Distance Beam Scanner (LDBS)
- 2 linear rails (2-7m from thruster stand)
- Scanning area: 3m horizontal, 1m vertical
- 2 Faraday cups with different apertures
- Control software can perform various kinds of scans (X, Y, XY, timeseries @ one point)
Example of LDBS Measurement

- Measurement with DLR RIT10/37 @ 18mA, 9.9.2015
Beam Divergence

The ion beam shape can often be approximated by a circular symmetric Gaussian function with an offset:

\[ I(x) = I_0 + C_0 \cdot \exp \left\{ -\frac{(x-x_0)^2}{2\cdot\sigma^2} \right\} \]

The fit parameters are:

\[ I_0, \ C_0, \ \sigma, \ x_0 \]

Assuming a circular symmetry, and that \( I(x) \) passes the center:

- 90\% of beam power corresponds to \( R_{90} = 2.15 \cdot \sigma \)
- 95\% of beam power corresponds to \( R_{95} = 2.45 \cdot \sigma \)
Force on Target Measurement

Task: Intercept beam with force measurement system
Force on Target Measurement

**ITBS, Impulse Transfer Balance System**
- Range: 0-50mN
- Working in vacuum
- Lightweight
- Intercept a significant part of the beam: 2m?
- Target options
- Low sputtering
- First Test Campaign with RIT10/37
LEOSWEEP Testing at DLR

- Measurement systems installation and tests in May & June 2015 with RIT10/37
- ITBS construction and tests in 2015, ready in October 2015
- LEOSWEEP ITT thruster
- Arrival at DLR in November 2015
- ITT Testing in November 2015 to March 2016
Data Analysis and Results by DLR

- Force on Target Measurement: Checking the Method with DLR RIT10/37
- Beam Scan: 1800V, 18mA, 1mN
- Gaussian fit: $\sigma = 328\text{mm}$
- Assumption: 1mN in beam cone
- Force on 600mm target: 0.31mN
- Equals about: 0.032g
- Measurement: 0.020g
WP8 Data Analysis and Results by DLR

- LEOSWEEP Impulse Transfer Thruster ITT
- Confidential, sorry…

LEOSWEEP Impulse Transfer Thruster developed by TransMIT GmbH, Giessen under testing in the frame of LEOSWEEP project in DLR electric propulsion test facility STG-ET, Göttingen
Data Analysis and Results by DLR

- Influence of magnetic field on ion beams
- Magnetic field inside DLR chamber is equal to Earth magnetic field
- Experiment with DLR RIT
- Only ions! No neutralizer
- Measured beam deviation
Ion Beam Shepherd for Asteroids

LEOSWEEP Project Outcome

- Mission design proposed and optimized
- Spacecraft design proposed
- Legal framework was investigated
- ITM: exposure of samples to Xe+ ions (E>100eV) with material of Cyclone-3 third stage coating on basis of the accelerated life test procedure has confirmed its adequacy and efficiency
- Thruster has been build, issues were addressed
- Thruster tested for divergence and impulse transfer at DLR
- Project dissemination
- Project terminated in December 2016
Summary

Space debris issues

LEOSWEEP EU FP7 Project

DLR EP Test Facility

Measurement systems: thrust balance, beam scanner, others

Some results

Next debris removal project?
Vielen Dank für Ihre Aufmerksamkeit


Förderung: LEOSWEEP, EU FP7