The 3-Step DLR-ESA Gossamer Roadmap to Solar Sailing

U. Geppert, B. Biering, F. Lura, J. Block, R. Reinhard
- almost countless unfinished, aborted, or failed attempts:

  • GEOSAIL (PHASE A, DLR-ESA, 2008)
  • EUROPEAN SOLAR SAIL DEMONSTRATOR (PHASE B, DLR-ESA, 2006)
  • ODISSEE (DLR-NASA, 1998)
  • ….

All projects aborted/unfinished because of shortage in funding!
How?

- concentrate on a pure technological demonstrator mission with increasing complexity and level of difficulty

- get rid of any scientific payload

- make sure that all Gossamer technologies are scalable

- use materials and technologies that are proved and tested in numerous preceding studies and projects

- take care that the technological success is perfectly documented and communicated to potential users
Gossamer -1: 2013, demonstration of safe deployment of a 5m x 5m solar sail, 320km

Gossamer -2: 2014, deployment of a 20m x 20m solar sail, demonstration of limited orbit and full attitude control, 500km

Gossamer -3: 2015, deployment of a 50m x 50m solar sail, demonstration of full orbit and attitude control, > 10,000km
- thousands of active and dead satellites in 500…1000km

- ~ 600,000 pieces of space debris (>1cm) in 500…1000km

- 340km: lowest perigee of the ISS
### Gossamer: Orbit Selection

#### Atmospheric Drag

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>solar activity high</td>
<td>solar activity low</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>6.47E-02</td>
<td>1.61E-02</td>
<td>2.30E-04</td>
</tr>
<tr>
<td>500</td>
<td>3.02E-03</td>
<td>2.23E-04</td>
<td>2.30E-04</td>
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<tr>
<td>650</td>
<td>4.23E-04</td>
<td>2.77E-05</td>
<td>2.30E-04</td>
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<tr>
<td>800</td>
<td>7.64E-05</td>
<td>9.69E-06</td>
<td>2.30E-04</td>
</tr>
</tbody>
</table>

**Sailing possible for heights > 500km!**

**Fun only above 800km**
Gossamer: Orbit Selection
Inner Radiation Belts

- inner radiation belt: ~650…~6.300km

large fluxes of protons 0.1…50 MeV

large fluxes of electrons < 500keV

\[ 10^9 \text{cm}^{-2}\text{s}^{-1} \approx 160\text{pA cm}^{-2} \]
Gossamer: Orbit Selection
Outer Radiation Belts

- outer radiation belt: ~10,000…~65,000km

- electrons dominate
- fluxes much smaller than in inner belt

Orbits > 10,000km
not as dangerous for sail degradation!
Gossamer: Orbit Selection
Below the Inner Radiation Belt

Fluxes negligibly small but residual atmosphere!
Gossamer: Orbit Selection

for real and non-hazardous sailing:

region between 340km and ~10,000km: off-limits

BUT

(at least for Gossamer-1)

We want to demonstrate *only* the safe deployment!

For being as simple and cheap as possible:

**Gossamer-1 orbit: 320km!**
Gossamer-1

- launch on a Shtil-2.1 in mid 2013 (with QB50)
- orbit: 320km, circular, i=79°
- launch site: Murmansk
- 5m x 5m, 7.6 μm Kapton (Al): sufficient to achieve mission objectives
- sail stays with third stage of rocket, power and telemetry provided by it
- total mass of s/c: 20kg (incl. margin), 45x45x50cm³ container volume
- verification of deployment by at least two wide-field cameras
- deployment: ~ 1 week after launch (after deployment of the 50 CubeSats)
- lifetime of third stage/ deployment system/s/c: ≤ two weeks
Gossamer-1

- satellite bus: integral part of the last rocket stage
  ⇒ supply of power and telemetry

container with sail deployment
Gossamer-1: Distribution of Responsibilities

- Boom technology: DLR Institute of Composite Structures and Adaptive Systems (J. Block)

- Service module: Kayser-Threde (M. Leipold)

- Launch, coordination with QB50: ESA (R. Reinhard)

- Sail and deployment technology: DLR Institute for Space Systems (F. Lura)
Gossamer-1: Boom Technology

carbon fibre:

electrically driven expendable mechanism

coiled on a hub
Marco Straubel
Gossamer-1: Boom Technology

sequence: 2, parabola number: 4

Gravity [m/s²]

Height [m]
Gossamer-1 Sail Container (schematically)
Gossamer-1: Folded and Furled 5m x 5m Sail

roll folding along  
roll folding cross  
coil

fork

19 cm
Gossamer-1: Deployment Demonstration
gradual increase due to increase of the mass of the already pulled-out part and simultaneous decrease of the lever arm (diameter of the sleeve)
Gossamer-1: Deployment Demonstration (cont.)

10s

60s

4 N

0 N
interlock tension

start uncoiling

start tensioning
Gossamer-1: Deployment Demonstration (cont.)

- Never exceeding 4N < 10N limit for bending forces per boom.

(though there was Earth gravitation)

- Next step: verification during parabola flights.
Deorbiting of a sailing area of 5x5 m² of a 150 kg - satellite in comparison with a 1 m² area for periods of high or low solar activity:

<table>
<thead>
<tr>
<th>Orbital Altitude [km]</th>
<th>Live Cycle for Low Solar Activity days/years</th>
<th>Live Cycle for High Solar Activity days/years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>with sail</td>
<td>without sail</td>
</tr>
<tr>
<td>300</td>
<td>1,40/0,00</td>
<td>34,92/0,10</td>
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<tr>
<td>500</td>
<td>94,96/0,26</td>
<td>2373,95/6,50</td>
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<tr>
<td>650</td>
<td>727,90/1,99</td>
<td>18197,54/49,86</td>
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<tr>
<td>800</td>
<td>1985,69/5,44</td>
<td>49642,18/136,01</td>
</tr>
</tbody>
</table>

No attitude control ⇒ alignment of sail?
**Gossamer-2: Mission Objectives**

- successful deployment of a 20m x 20m solar sail

- demonstrate attitude control of the solar sail in a ~500km orbit

- demonstrate limited orbit control (see talk of D. Romagnoli)

  limited: changes of s/c attitude wrt sun ⇒ precise measurement of orbital parameters for different sail attitudes

- gaining first experiences for solar sail propulsion under real environmental conditions

- implementation and testing of a strategy to de-orbit the sailcraft (De-orbiting)
Gossamer-2

- launch in mid 2014 as piggy-back payload
- orbit: determined by mission objectives, at least 500km
- launch vehicle: Shtil-2.1?, tbd

- 20m x 20m, material: tbd, certainly thinner than 7.6μm Kapton

- s/c mass: 57kg (incl. margin), tbc, container volume inside the rocking fairing: 50 x 50 x 60 cm³; acceleration ≈ 0.07mm/s²

- free flying „Inspector“ CubeSat (10 x 10 x 10cm³, 1kg) with a micro-propulsion orbit and attitude control system

- verification of deployment and sail attitudes changes by 4 on board wide field cameras + by wide field camera on board the „Inspector“

- lifetime of the s/c: ~ four weeks, de-orbiting by use of the sail
Gossamer-3: Mission Objectives

- demonstrate successful deployment of a 50m x 50m solar sail in orbit

- demonstrate attitude control of the solar sail

- demonstrate full orbit control

- acceleration $> 0.1 \text{mm/s}^2 \Rightarrow$ if initial orbital altitude is high enough: s/c will be able to leave the Earth gravitational field after $\sim 100$ days

- lunar swing-by after $\sim 600$ days

Real solar sailing
Gossamer-3

- launch as piggy-back in mid 2015

- orbit: 10,000km or higher, inclination: no requirement, vehicle: tbd

- 50m x 50m, < 80kg, container volume 100 x 100 x 100cm³ (tbc)

- free flying „Inspector“ CubeSat as for Gossamer-2

- verification as for Gossamer-2

- a narrow angle camera on board the s/c may provide images of the Earth once the s/c leaves the Earth behind and approaches the Moon
When Gossamer-3 is successfully completed:

SOLAR SAIL PROPULSION WILL BE DECLARED OPERATIONAL:

READY FOR USE ON SPACE SCIENCE MISSIONS!