From Sail to Soil – Getting Sailcraft Out of the Harbour on a Visit to One of Earth’s Nearest Neighbours

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Knowledge for Tomorrow

DLR
Why solar sailing? – well, you might as well ask...

Why a 300 kg piggy-back launchable >75 km/s Kinetic Impactor?

Why rendezvous 3 NEAs in <10 years? (sample-return option included)
solar sailing at DLR
– no flight heritage, yet, but not magic either
The December 7th, 1999  DLR/ESA  
Solar Sail Ground Demonstration

(20 m)² push-out boom, hoisted sail

- you need space – the European Astronaut Center hall next to the ISS model
  - Deployment Module: 24 kg
  - CFRP booms (4 x 14m, 101 g/m): 6 kg
  - Sails (20 m)², 4-12 µm foil: 5 kg
  - Dimensions: 60cm x 60 cm x 65cm
The GOSSAMER Roadmap
step 1 – deployment

GOSSAMER-1 – in-orbit deployment demonstrator

- (5 m)$^2$ sail area, all deployment-related mechanisms
- 1-boom, 2-quadrant EM in operation
- 1-boom EQM under construction now for extensive qualification testing to be finished by end of 2015
- proven MASCOT-style concurrent AIV approach
- PFM detailed design progressed beyond PDR
- free-flyer independent spacecraft (really 5-in-1)
- “piggy-back” launch to LEO, <50 kg total
- extensive instrumentation: 6 hi-res video cameras

* IAA-PDC-15-P-20, P. Seefeldt et al, Large Lightweight Deployable Structures …
The GOSSAMER Roadmap

step 2 – control

GOSSAMER-2 – *in-orbit attitude & thrust vector control demo*

- (20 m)$^2$ sail area
- orbit where solar radiation pressure is dominant – high LEO, MEO, GTO
- implementation of several (all?) control methods and all relevant mechanisms
- **find out what’s the best** – 1, 2,..., many combined?
- ~2 years after GOSSAMER-1 flight: requires MASCOT-style concurrent AIV & project management *
- PFM free-flyer for “piggy-back” launch
- mass & undeployed size compatible with ASAP-micro & ESPA envelopes
The GOSSAMER Roadmap

step 3 – proving the principle

**GOSSAMER-3 – all-up proof test science mission readiness demonstrator**

- (50 m)^2 sail area
- initial orbit high enough to spiral out (sail up) – high LEO, MEO, GTO, LTO, L\(^{1/2}\)TO
- applies best control method(s)
- prove that sails can operate science missions successfully
  - *tiny* science payload: imager & sail-environment interaction
- ~2 years after GOSSAMER-2 flight: again, MASCOT-style concurrent AIV*
- PFM free-flyer for “piggy-back” launch
- mass & undeployed size compatible with ASAP-micro & ESPA envelopes
- instrumentation to observe sail ageing in space, as long as it lasts

GOSSAMER-3 quality assurance
– sail monitoring, pointing verification

GOSSAMER-3 – instruments wish list

- a tiny science(...-like) payload to observe sail ageing *
- wide-angle camera to observe sail deployment and long-term foil behaviour and provide proof images for attitude control, pointing stability & accuracy
- sensor to observe interaction of a sail with solar wind’s & geomagnetic field
- sensor to observe plasma, particle and energetic radiation sail environment
- sensor to observe large area foil reflectivity ageing, e.g. thermal equilibrium
- sensor to observe small-scale space weathering mechanisms of foil ageing
- sensor to observe core spacecraft (electronics) electromagnetic signature
- sensor to observe illumination changes and Sun glints off the sail surface
- sensor to register space debris and natural dust impacts on the sail foil

* IAA-PDC-15-P-20, P. Seefeldt et al, Large Lightweight Deployable Structures for Planetary Defence: ...
**Gossamer-3 quality assurance**
- oh! 😊, a ready-made*** instruments package !?

**MASCOT Flight Spare instruments capabilities**

- Tiny (...) like ;-) science payload**** to observe sail ageing*
- Wide-angle camera to observe sail deployment and long-term foil behaviour and provide proof images for attitude control, pointing stability & accuracy
- Interaction of a sail with solar wind's & geomagnetic field
- Plasma, particle and energetic radiation sail environment
- Large area foil reflectivity ageing, e.g. thermal equilibrium
- Small scale space weathering mechanisms of foil ageing
- Core spacecraft (electronics) electromagnetic signature
- Illumination changes and Sun glints off the sail surface
- Space debris and natural dust impacts on the sail foil

**Gossamer-3 instruments left to be added**
- Additional MAG instrument, 2 sensors spaced by ~1 m at 1 or 2 boom ends
- E.g. Spherical EUV and Plasma Spectrometer (SEPS), 2 on opposite booms
- E.g. Acoustic pick-ups at rigging nodes, structural vibration accelerometers

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**IAA-PDC-15-P-20, P. Seefeldt et al, Large Lightweight Deployable Structures for Planetary Defence: ...**

**IAA-PDC-15-P-64, J.T. Grundmann et al & the MASCOT Team, Mobile Asteroid Surface Scout (MASCOT) -...**

GOSSAMER-3 & MASCOT FS mission events wish list

**minimum mission**
- get launched cheap, deploy & spiral up
- explore & improve sailing skills
- fly-by visit a target on time & look at it right

**nominal mission**
- explore practical flying in Earth-Moon system
- “all-up” navigation accuracy proof test
- low-altitude lunar gravity-assist fly-by

**extended mission**
- transfers to Earth-Sun L₁, L₂ & pole-sitter
- demonstrate spaceweather Displaced- L₁

**extended extended mission**
- fly out to a convenient NEA – coorbital?
- rendezvous & drop MASCOT FS*
- …some grand finale…

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* IAA-PDC-15-04-08, S. Ulamec et al, Relevance of PHILAE and MASCOT in-situ investigations for Planetary Defense
** IAA-PDC-15-P-20, P. Seefeldt et al, Large Lightweight Deployable Structures for Planetary Defence: …
*** IAA-PDC-15-P-64, J.T. Grundmann et al & the MASCOT Team, Mobile Asteroid Surface Scout (MASCOT) –…

additional images: Boeing BSS via Gunter’s SP, M. Langbroek
the GOSSAMER Roadmap for Solar Sailing – an Epilogue

so bring on the lasers, bring on solar-electric propulsion! 😊
... and don’t be shy about megawatts!! ;-)
If GOSSAMER-3 had been launched according to the last Roadmap baseline in ~2020 we’d be on the way to 2015 PDC.

If it had been 2021 PDC, we’d also be on the way.

why?

only Solar Sails can change interplanetary rendezvous targets after launch during cruise phase or other rendezvous in all cases.
Questions?

exploration vehicles (to scale)
Thank you for your attention
– take a look at these posters! 😊

our posters & talks – DLR @ PDC 2015

• IAA-PDC-15-04-08  S. Ulamec et al
  Relevance of PHILAE and MASCOT in-situ Investigations
  for Planetary Defense

• IAA-PDC-15-04-17  J.T. Grundmann et al
  From Sail to Soil – Getting Sailcraft Out of the Harbour
  on a Visit to One of Earth’s Nearest Neighbours

• IAA-PDC-15-P-20  P. Seefeldt et al
  Large Lightweight Deployable Structures for Planetary Defence: Solar
  Sail Propulsion, Solar Concentrator Payloads, Large-scale Photovoltaic Power

• IAA-PDC-15-P-64  J.T. Grundmann et al & the MASCOT Team
  Mobile Asteroid Surface Scout (MASCOT) – Design, Development
  and Delivery of a Small Asteroid Lander aboard HAYABUSA2

• IAA-PDC-15-P-65  C. Lange et al
  Technology and Knowledge Reuse Concepts to Enable Responsive NEO
  Characterization Missions based on the MASCOT Lander

• IAA-PDC-15-P-66  C.D. Grimm et al
  On Time, On Target – How the Small Asteroid Lander MASCOT
  Caught a Ride Aboard HAYABUSA2 in 3 Years, 1 Week and 48 Hours