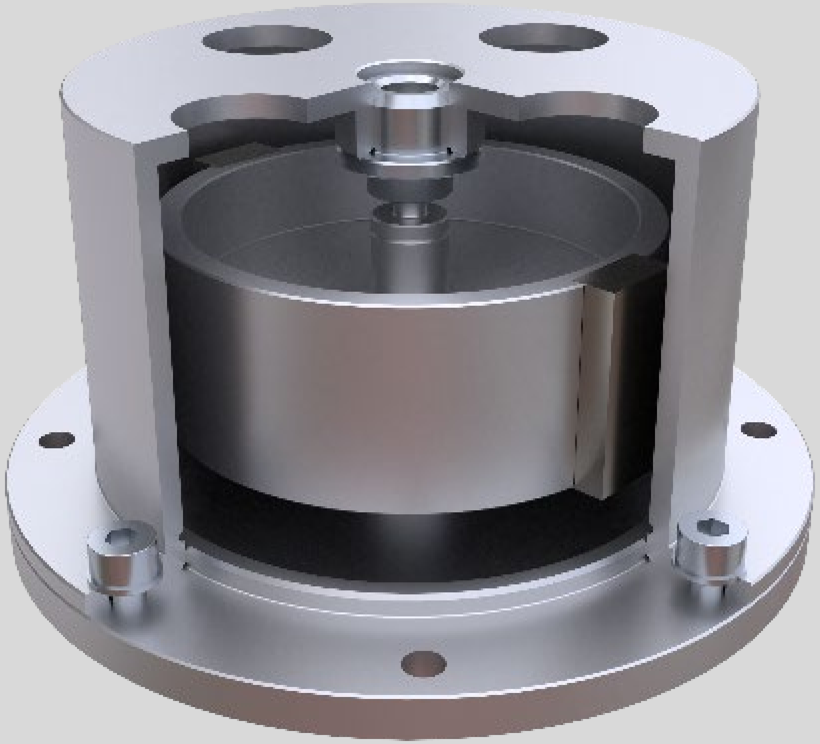

Detumbler

A passive device for postmortem detumbling in LEO

17th ESA Workshop on Avionics, Data, Control and Software Systems (ADCSS 2023)

Towards zero-debris AOCS and GNC systems

November 14th, 2023

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This document contains Technical Information :

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Contents

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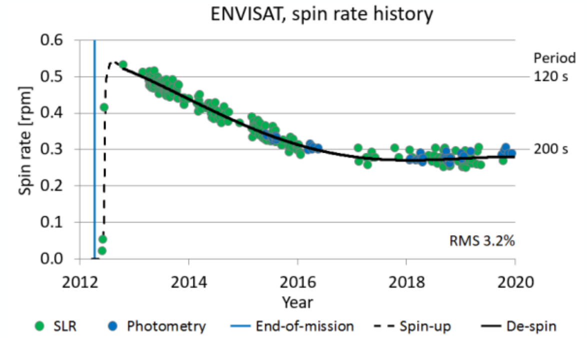
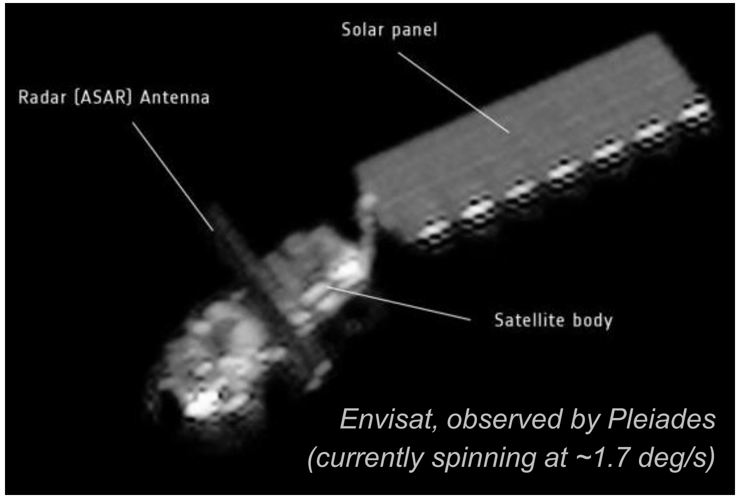
2. Requirements and sizing
3. Performance simulation campaigns
4. Detumbler technology developments
5. Conclusions and perspectives

Context = space sustainability



At stake :

- **Sustainability** of LEO orbits (Kessler syndrome)
- Especially with (and *within*) **mega-constellations**

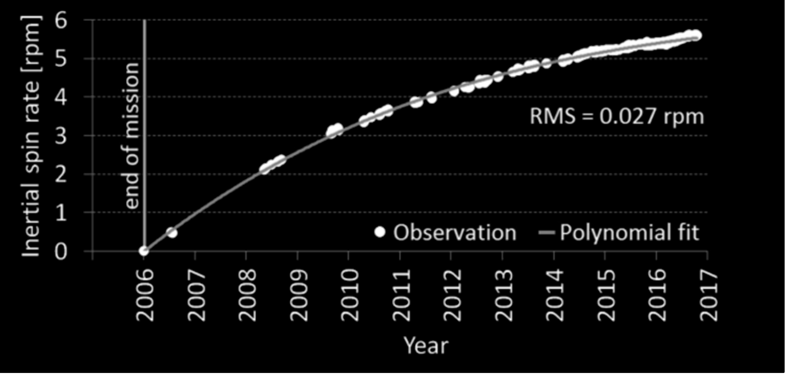


Envisat, observed by Pleiades (currently spinning at ~1.7 deg/s)

Active debris removal is currently (near-)infeasible

- business model hampered by **huge technical challenges**
- exacerbated by the possibility of a **tumbling target**

TOPEX-POSEIDON runaway tumbling after decommissionning



Causes of post-mortem tumbling

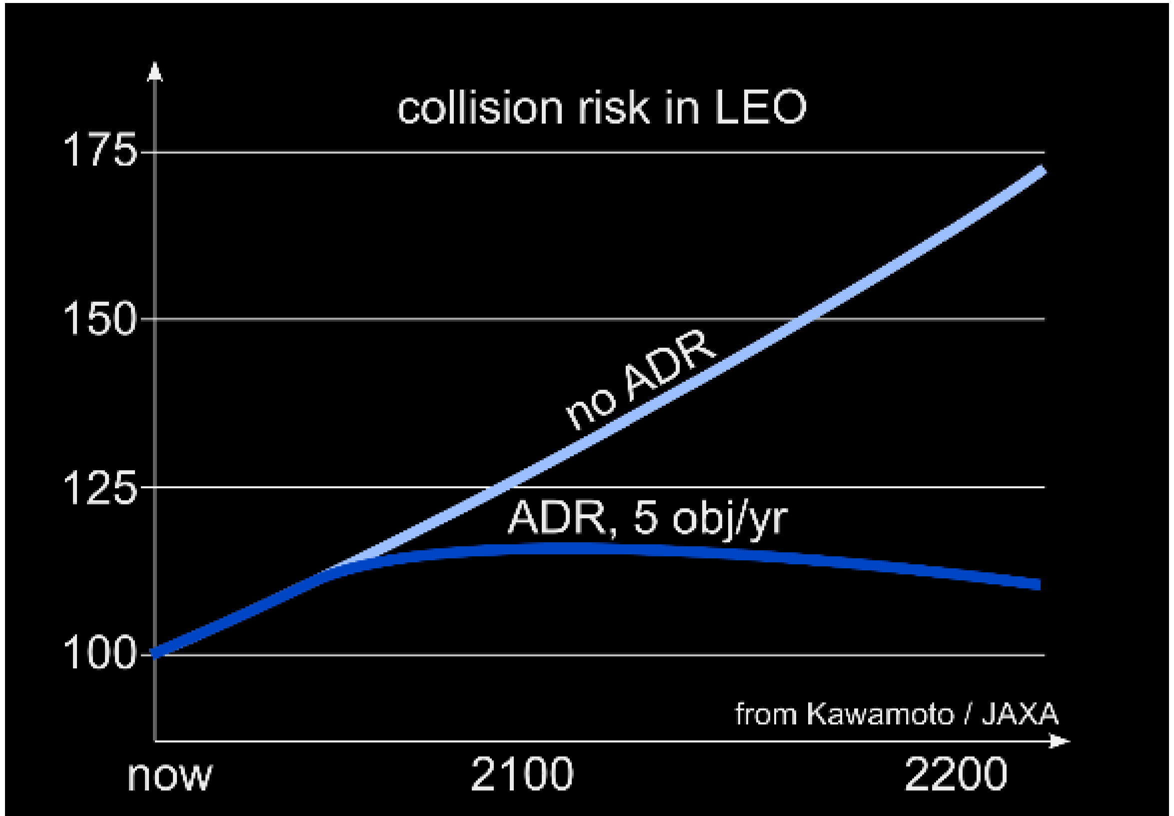
- Sudden **fatal failures or impact events**
  – e.g. Envisat (~1.7 deg/s)
- **Spontaneous** self-tumbling (after proper decommissioning)
  – e.g. Topex-Poseidon self-accelerated to 33 deg/s

Making Active Debris Removal Feasible

- Postmortem **detumbling / anti-tumbling** function
  - to kill initial rates passively
  - to prevent spontaneous spin-up
  - angular rates remain low (< 0.2 deg/s)

- Active debris removal **much less challenging**
  - smaller chaser
  - safer proximity operations
  - simpler grabbing system
  - smoother capture

- Expected benefits: direct and indirect
  - earlier technical **feasibility** of active removal
  - **key enabler** for commercially viable active debris removal



Active Debris Removal will be crucial in preventing Kessler syndrome

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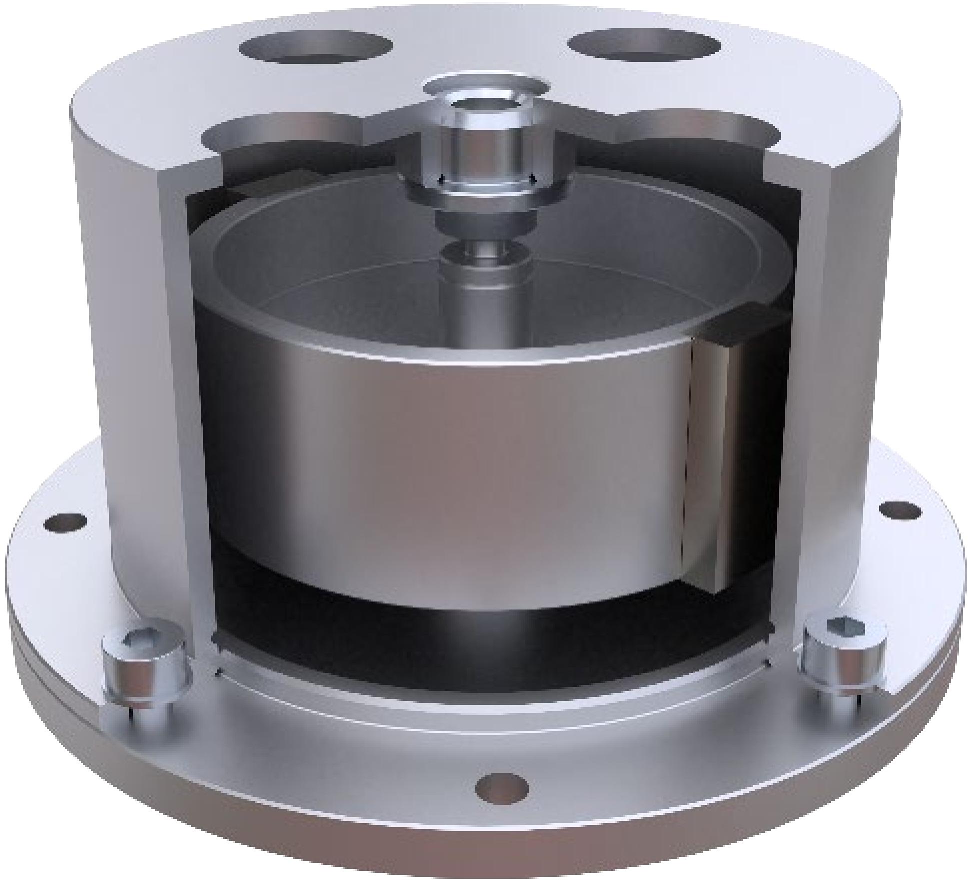
Operating principle of the DETUMBLER

Description of device

- Fully passive mechanism
- Rotor fitted with magnets
- Rotor free to pivot inside aluminum housing (stator)
- Stator is attached to satellite structure

Operating principle

- rotor tends to stay aligned with geomagnetic field
  – acts like a compass
- if satellite is tumbling
  – differential rate rotor/stator
  – rotor magnets moving close to conductive wall
  – eddy currents in the stator
  – resistive viscous torque slow down the rotation



3D rendering, cutout view

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Intended missions, performance requirements

Altitude range: [500 – 1200 km]

Spacecraft sizes

- cover the widest range with a single design
- key parameter = satellite inertia
- choice for initial detumbler design: [50 – 5000 kg.m²]
  - covers more than 95% of satellites in flight
  - corresponds to satellites up to ~1.5 tons

Performance requirements

- detumbling time-constant < 100 days
- saturation rate > 3 deg/s

=> viscous damping coefficient: k_v = 1 mNms/rad

Innocuity requirements (during satellite mission)

- disturbance torque < 50 µNm => M < 1.6 Am²
- magnetic disturbances < 3 µT (B_0/10)

Mechanical and environment requirements

- size < 5 cm in diameter and height, mass < 100 grams
- dry friction < 5 µNm, testable under 1g
- temperature range [-100, +80 °C]
- lifetime > 20 years (target 100 years)

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Sizing approach

Analytical approximations

- ideal geometry / dimensional analysis

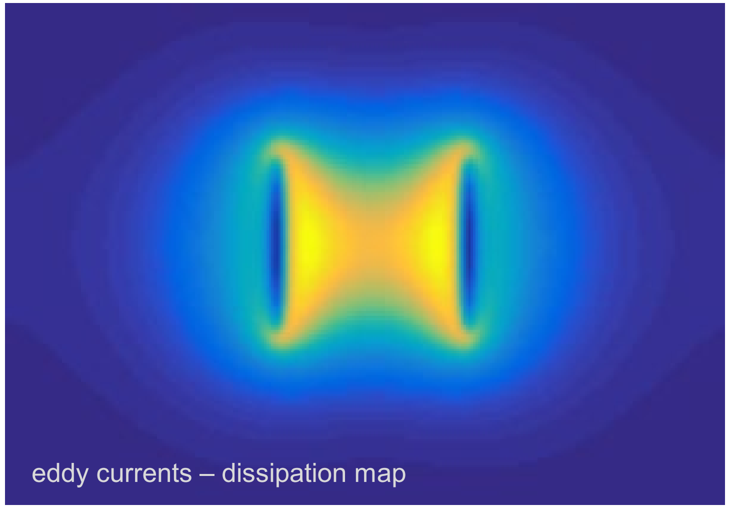
$$k_v^\infty = \frac{V B_r^2 r^2}{4\rho}$$

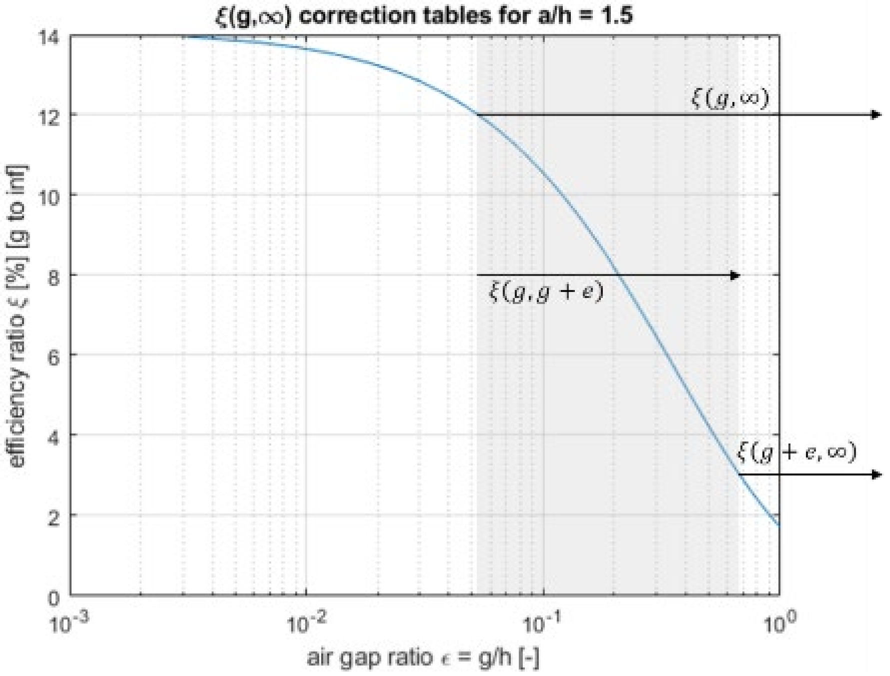
Numerical simulations

- 3D shape of magnetic field for magnets
- numerical 2D Maxwell-Faraday solver (eddy currents)
- correction tables wrt. analytical formulation
  - edge effects / aspect ratios
  - air gap size / wall thickness

Experimental verification

- test on simplified 1-D mockup
- test on representative breadboard
- characterization tests on actual prototype





Final specifications

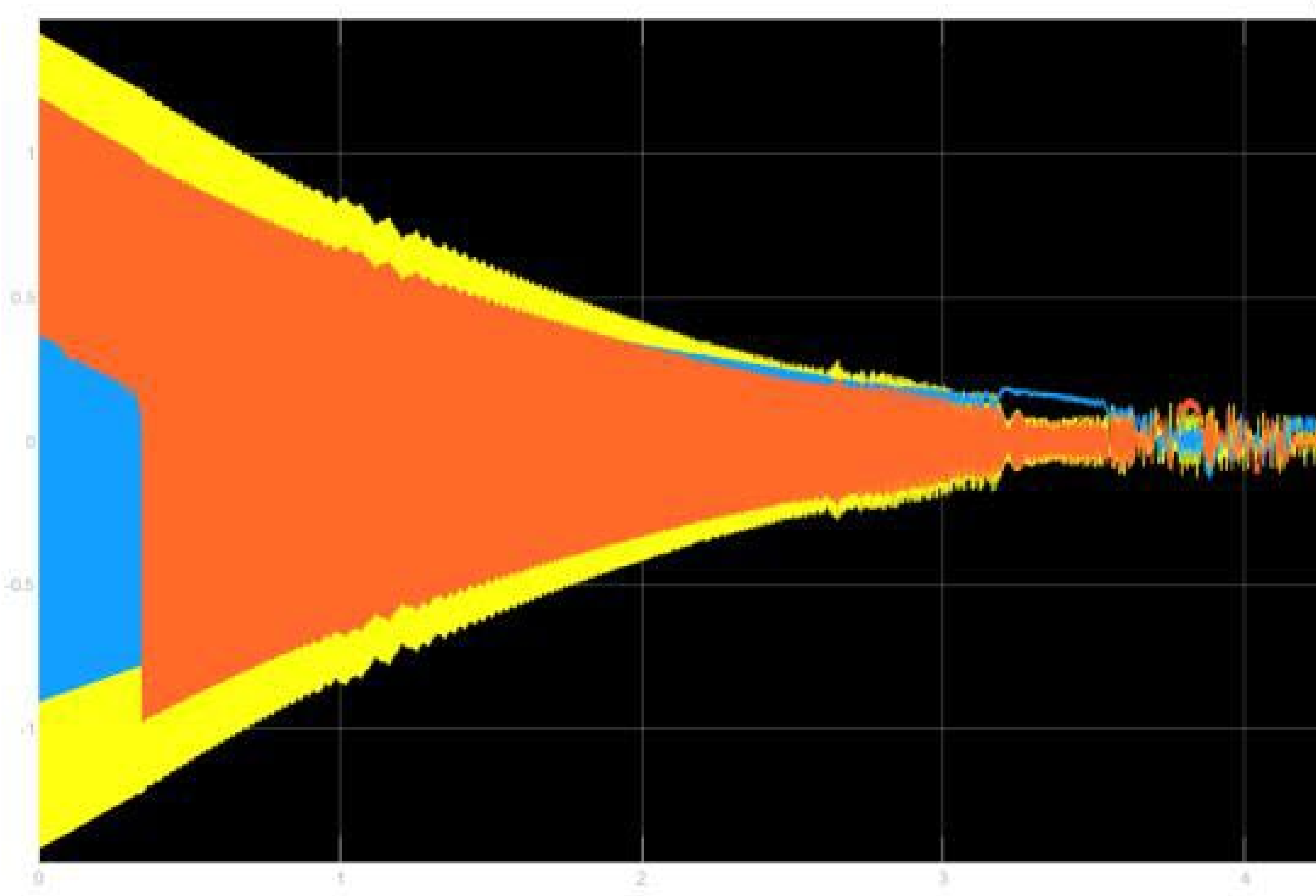
Mass	< 100 grams
Size	h50mm ⌀60mm
Orbits	up to 2000 km, all inclinations
Satellite inertia	up 5000 kg.m² (~1.5 tons)
Detumbling time	< 300 days
Damping ratio	up to 1 mNms/rad
Magnetic moment	< 1.6 Am²
Dry friction	< 5 µNm (goal 1 µNm)
S/C rate after detumbling	< 0.2 deg/s
Service life	> 20 years (target = 100 years)
Temperature range	−100° C to + 80°C
Power	0W (100% passive)
Disturbance torque on S/C	< 50 µNm
Accommodation constraints	> 40 cm from MAG
Units needed per S/C	1

Simulator setup

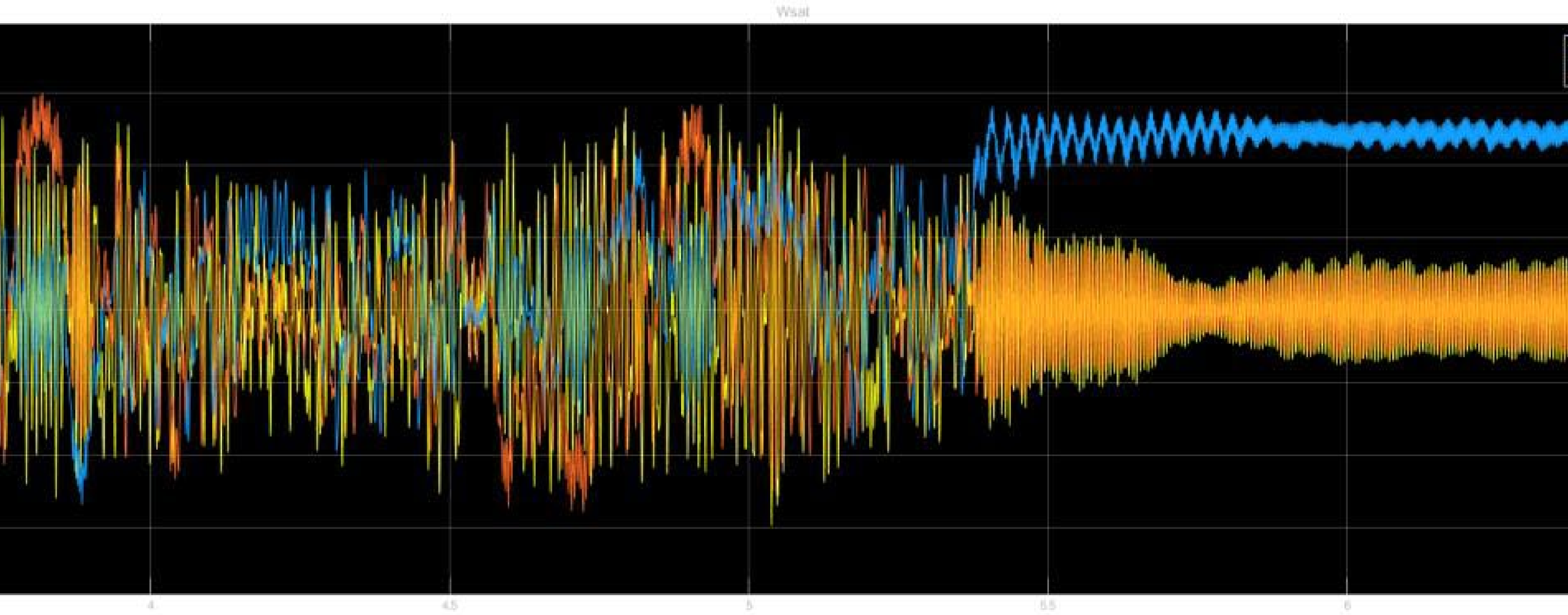
Simulation objectives
- demonstrate detumbling and antitumbling capacity
- very long simulation time (several months of real time)
- very tiny disturbances (numerical sensitivity)

Simulator setup
- Orbit model
- Representative magnetic field model
- Disturbance torques (SRP, gravity gradient, …)
- Detumbler model
  - Including rotor dynamics

Performance indicators
- Angular rate
- Momentum
- Kinetic energy



Simulation example (magnetic capture)

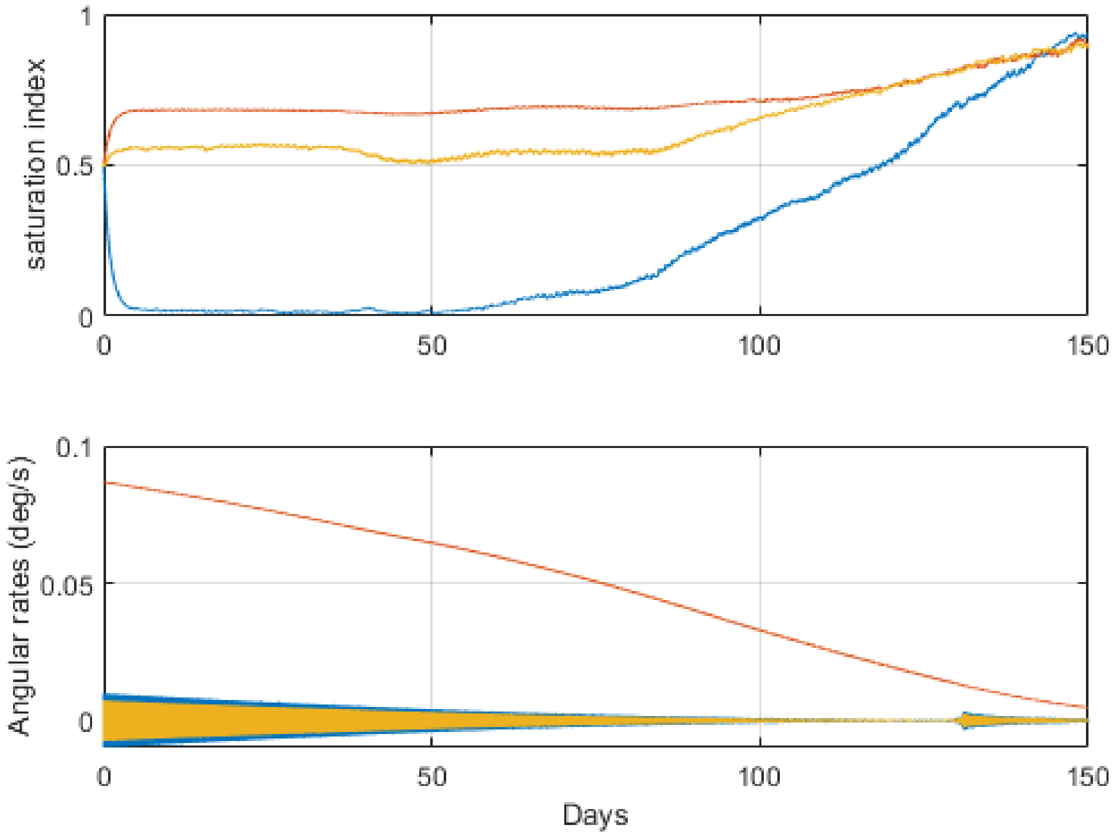


Behaviour analyses

Three classes of converged state
- gravity gradient capture
- magnetic bias capture
- chaotic alternation

Saturated regime
- at high tumbling rates, magnetic torque < viscous torque
- rotor no longer follows B
- confirmation that it does not prevent detumbling

Antitumbling efficiency
- verify capacity to prevent spontaneous spinup
- (from accumulation of asymmetric SRP torque)



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Sensitivity analyses

Sensitivity to dry friction

- modest performance degradation below 15 µNm
- sharp decline above 30 µNm

Sensitivity to spacecraft inertia

- confirmation of strict proportionality

Sensitivity to orbit inclination

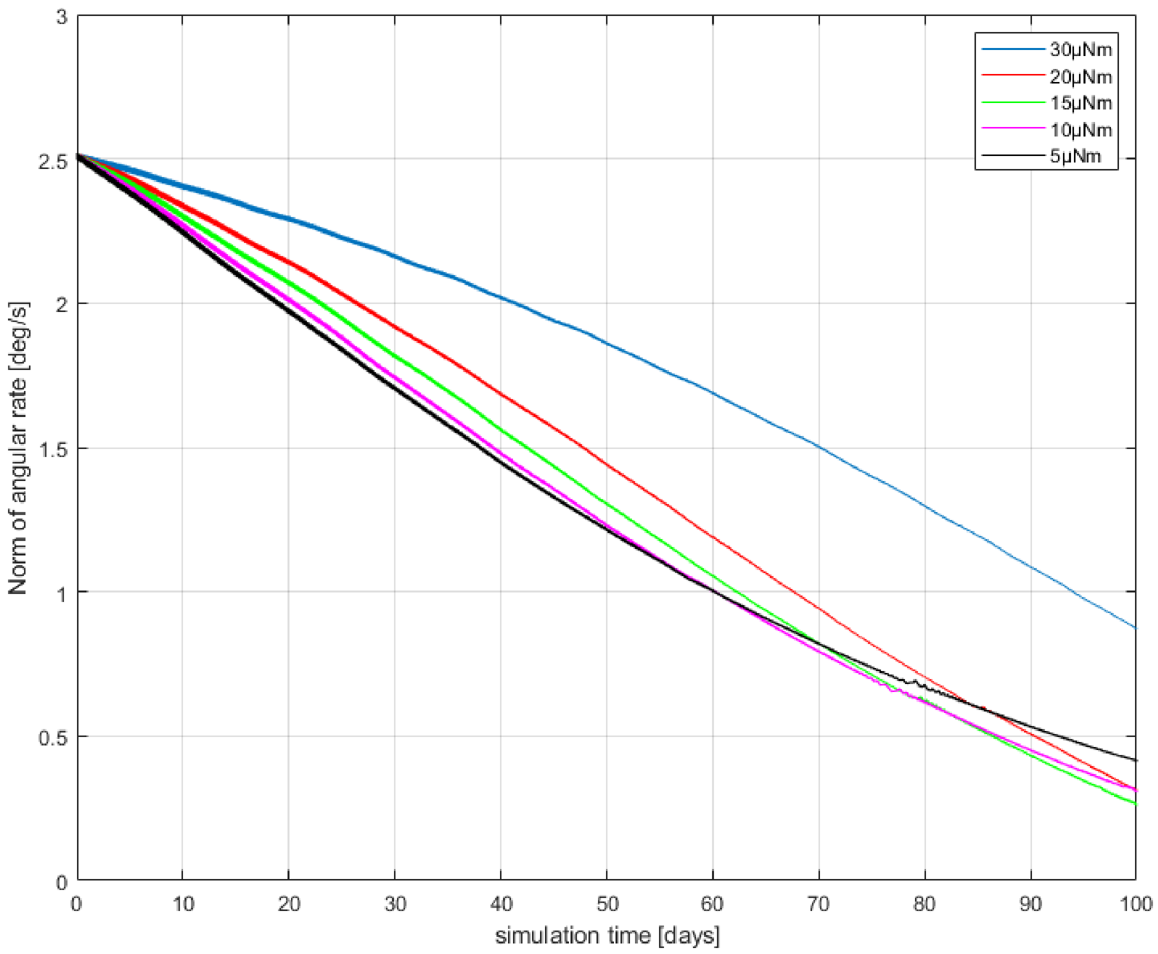
- noticeable increase in detumbling time below 20 deg

Sensitivity to orientation of detumbler inside s/C

- optimum = parallel to max inertia
- approx. 50% penalty when aligned with minimum inertia

Sensitivity to the number of detumblers

- 45% improvement when using 2 at right angles
- 60% improvement when using 3 at right angles



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Statistical performance and robustness campaigns

Parameter	Value or range	Remark
Number of cases	500	
Initial attitude	Random	Uniform on SO(3)
Initial angular rate	1.5 deg/s	Random direction (uniform)
Residual magnetic moment	10 Am²	
Local time of ascending node	[0 24h]	Random uniform
Local bias on magnetic field	[0 5μT]	
Initial rotor angle	[0 360 deg]	
Orbit inclination	[0 100 deg]	
Apogee altitude	[500 1200 km]	
Perigee altitude	[500 1200 km]	
Argument of perigee	[0 360 deg]	
Initial true anomaly	[0 360 deg]	
Satellite inertia Iyy	[1000 5000 kg.m²]	
Satellite inertia Ixx,Izz	[700 4500 kg.m²]	Random scaling factor wrt. Iyy

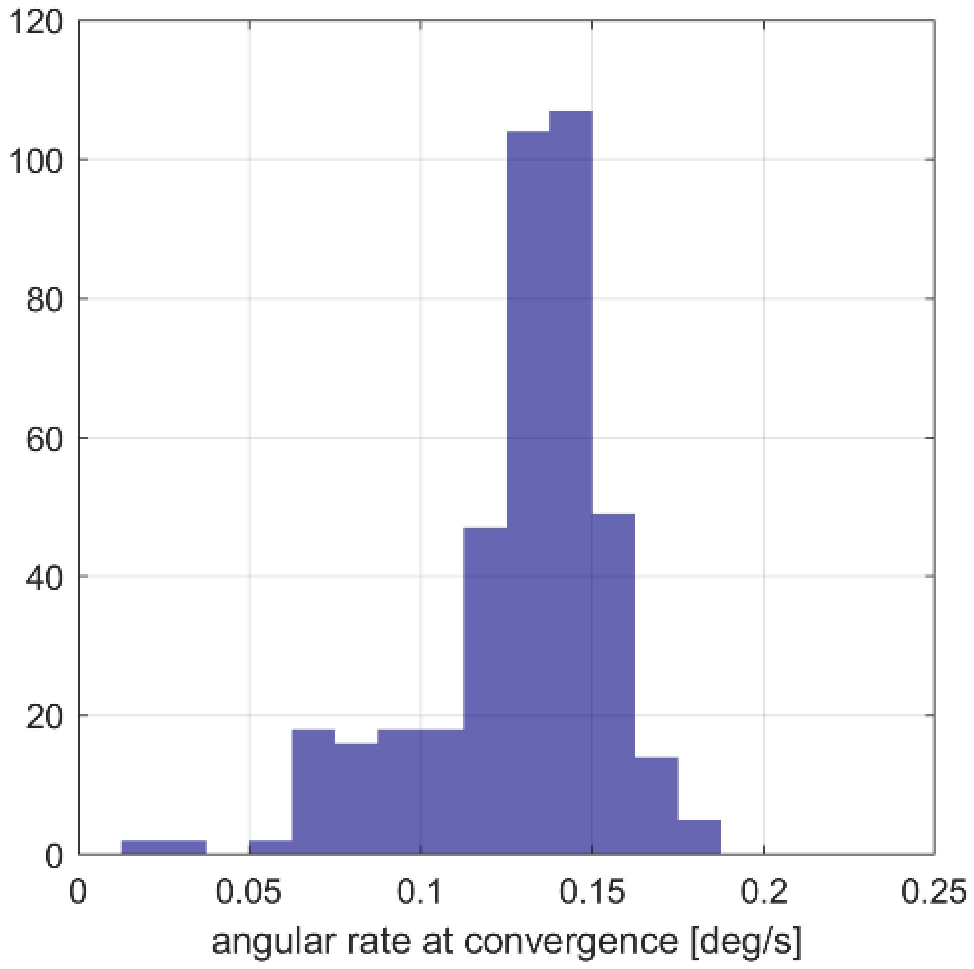
Statistical performance and robustness results

Convergence time
- 70 days on average

Converged angular rate
- consistently below 0.2 deg/s
- average 0.12 deg/s

Inertia and inclination = most influential parameters
- inertia: linear
- inclination: degradation below 20 deg
- effects of the other parameters too small to observe

Detumbling 100% successful
- even for outliers (simulation cutoff time)



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General design approach and technology trade-off

General approach
- simple product, easy to make
- early prototyping and testing
- concurrent prototype to compare options

Design philosophy
- simplest design
- minimize parts and MAIT operations
- very low recurring cost (target = constellations)

Technology trade-off for rotor bearings
- Dry friction is critical to performance
- 3 technological options tested for the bearings
  – All three appear compatible with requirements

- Context of developments = CNES R&D 2021 - 2023

Preliminary environment and performance tests

Vibration and shocks

- Sine vibration:
  - – 24 g on each axis, from 5 to 120 Hz (at 2 octaves/minute)
- Random vibration
  - – 18.4 g RMS axial, 12.8g RMS transverse, in [10 2000Hz]
- Shocks: 20g at 100Hz, 2000g from 2 to 10 kHz

These levels correspond to the Airbus standard requirements for equipment used on LEO earth observation missions

Performance tests were conducted before and after the environment tests

- to verify that no degradation had occurred

Upcoming activities

Further prototyping and tests (R&D CNES)

- Detailed design and manufacturing of EQM(s)
- Formal environment and performance testing
  - – Thermal/vacuum
  - – Vibration/shocks
  - – Acceptance tests: dry friction (before/after)
  - – Performance tests: damping coefficient k_v

In-orbit demonstration opportunities

- Endurosat/Exotrail (8U cubesat with detumbler)
  - – **Launched November 11th, 2023**
  - – In-flight demonstration expected early 2024
- IOD opportunity with CNES (target 2025)
  - – Early definition ongoing

Conclusions and perspectives

Current status

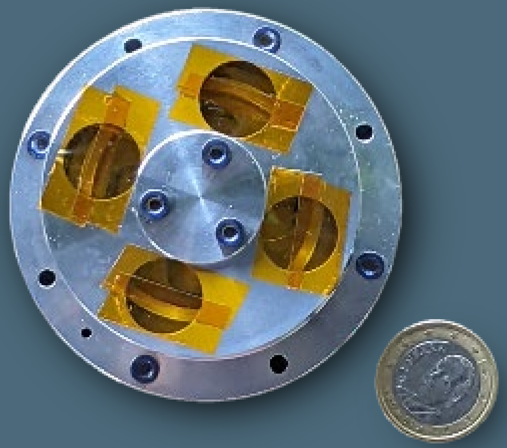
- concept patented
- internal R&D 2020-2021
- joint R&D with CNES 2021-2023 (ongoing)
  - Theoretical background, simulation and sizing tools
  - Experimental validation of key theoretical predictions
  - Functional consolidation via detailed simulation campaigns
  - Verification of innocuity with respect to the host satellite
  - Trade-off on alternative technologies for the rotor bearings
  - Manufacturing of two breadboards
  - Vibration, shock and friction tests
  - Reference sizing and design
- Opportunities : IOD, constellations

TRL 6 by end 2023

First flight models before end 2024

Perspectives: a breakthrough for space sustainability

- prevention of tumbling after end-of-life
- ADR designs and operations much less daunting
- recommendation: detumbler as ‘insurance policy’ in LEO



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Questions?

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