Aeolus Assisted Reentry

A successful story

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Aeolus Reentry Flight Control Team
ESA Space Debris Office Team
ESRIN/ESOC Communication Teams

2023 CLEAN SPACE INDUSTRY DAYS
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ESTEC

Background of Aeolus Reentry

- Aeolus was not designed to perform a ***controlled reentry*** because its SRR took place before the entry into force (*i.e. March 2014)* of ESA's *Space Debris Mitigation Policy for Agency Projects ESA/ADMIN/IPOL(2014)2*

- Without any intervention, Aeolus would have reentered in an **uncontrolled mode** with a **global casualty risk** (i.e. **$1.71 \cdot 10^{-4}$**) higher than the current policy threshold of **10^{-4}** (i.e. 1 over 10,000)

- During the reentry, the satellite would have broken up and around 20% of the satellite mass would have survived and reached Earth's surface: estimated **17 fragments,** average total mass of **223 kg,** average fragment mass of 12.9 kg**.** The heaviest fragment could have been up to 186.0 kg

- As part of the Aeolus Reentry Working Group activities, a Legal Analysis was performed which concluded that although Aeolus was **not legally bound** to the current Policy, ESA had **the best effort obligation** to minimise any casualty caused by Aeolus reentry with the objective to achieve the current target of **10^{-4}**.

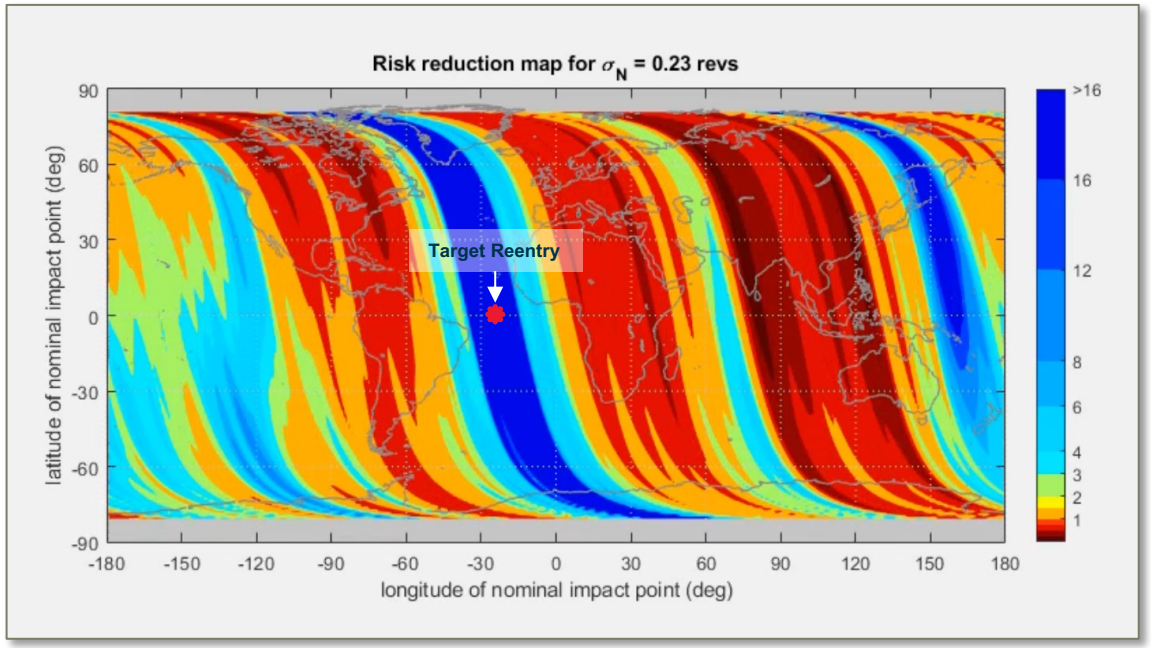
ATV Break-up (Credits: ESA)

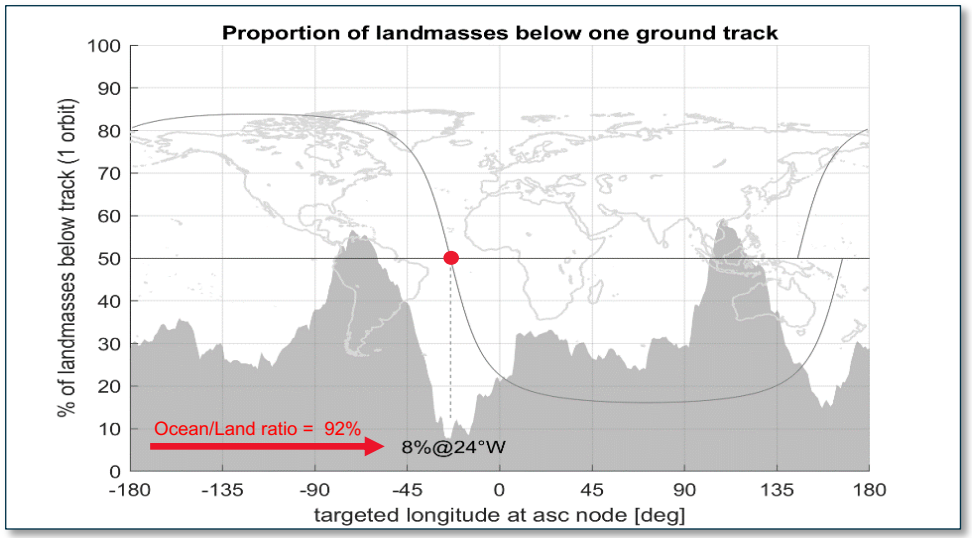
Fuel tank from unknown satellite (Credits: Enver ESOP / ESA)

Background of Aeolus Reentry

- The analysis carried by Aeolus Reentry Working Group demonstrated that Aeolus could be reentered through an *innovative assisted* approach (i.e., semi-controlled) that would also **reduce** the original global casualty risk and, retroactively, bring Aeolus to **be compliant** with the current space safety regulations.

- The **Atlantic Ocean Corridor** – around the reentry target location of [**0, 25W ± 10 Deg]** - was identified to be the best and most robust solution for the reentry, compatible with Aeolus orbits and its space and ground segment capabilities



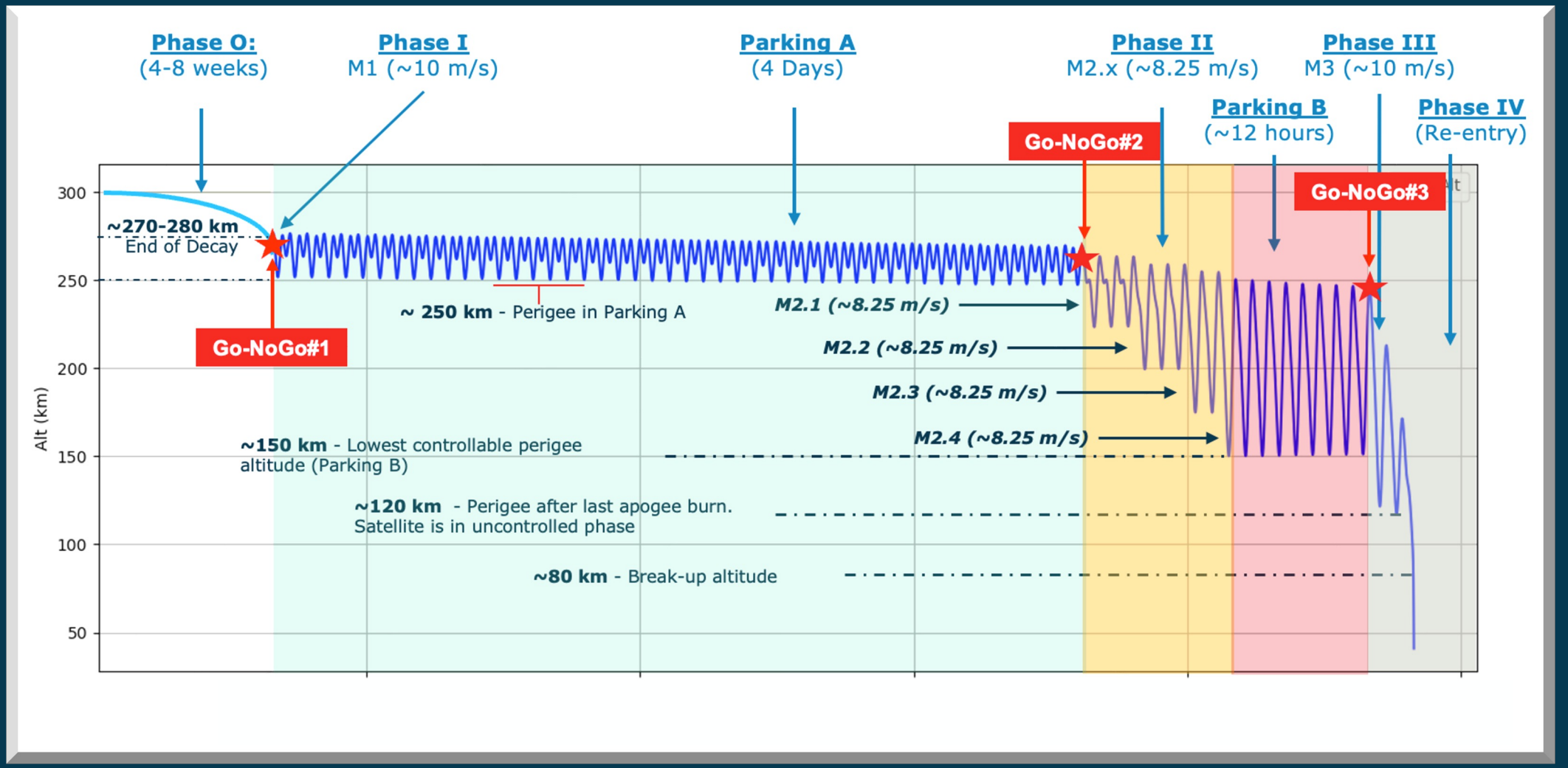


- The analysis concluded that the reentry dispersion was **0.23 rev. (1σ) ± 9,200 km** around the target location (**GOAL: 0.5 rev**.)

- The estimated **global casualty risk** was reduced to **$4.0 \cdot 10^{-6}$** (i.e. **x42 better** than the uncontrolled case) (**GOAL: < 1/10,000**)

- A full assisted reentry timeline was built which foresaw also solutions to fall back into the *uncontrolled scenario* in case of unexpected failure or abortion of the *assisted reentry*

BASELINE REENTRY TIMELINE



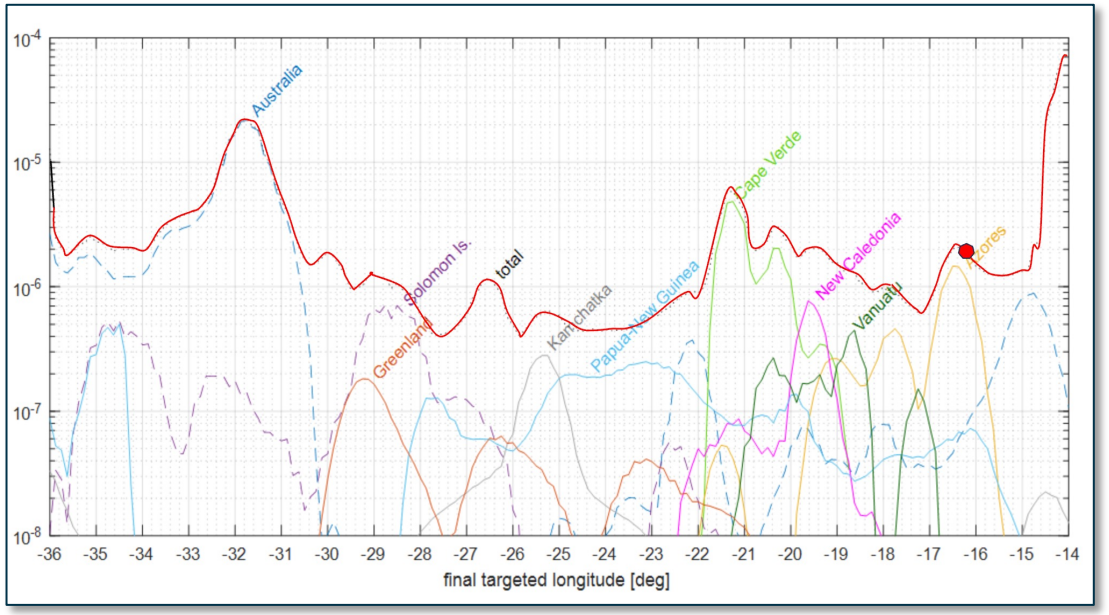
Major Challenges

PHASE I – To lower the Perigee to 250KM

- **GPS fundamental for the calibration and OD**. After both critical manoeuvres, GPS monitor triggered, leading to a reconfiguration to GPS-B. The second GPS monitor also triggered but did not lead to a Safe Mode thanks to the update of FDIR settings. A more robust solution was found before the execution of the next set of critical manoeuvres which allowed to start the next phase

PHASE II – To lower the Perigee to 150KM

- A **severe onboard AOCS "anomaly"**, including GPS and RCS reconfiguration, occurred while slewing to nominal attitude, leaving the satellite without any attitude control and arriving at *Troll Station* with severe mispointing of around 100 deg (i.e. satellite almost upside down). Recovered in a short time (i.e. <10') with additional FDIR settings were disabled.
- **Increased fuel consumption** (excessive attitude thrusting) due to high drag which also increased the final perigee height to 160km. Resolved by switching to the *Optimum Equilibrium Attitude*



PHASE III – To lower Perigee to 120KM

- Executed one single large maneuver of **12.3 m/s**
- Maneuver execution monitored over Svalbard, Kiruna and Inuvik, confirming good performance
- Goodbye to Aeolus: last TC **@15:43z**; last TLM received **@15:10z** - 28th July 2023
- Transition to Space Debris Office Coordination

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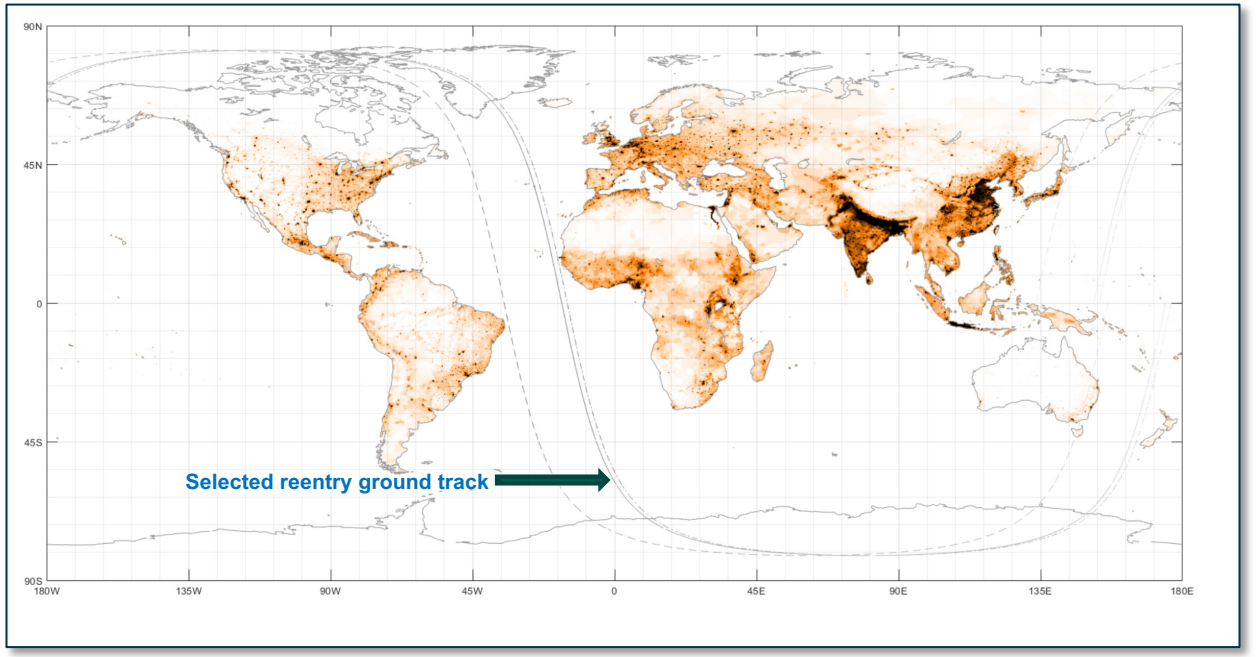

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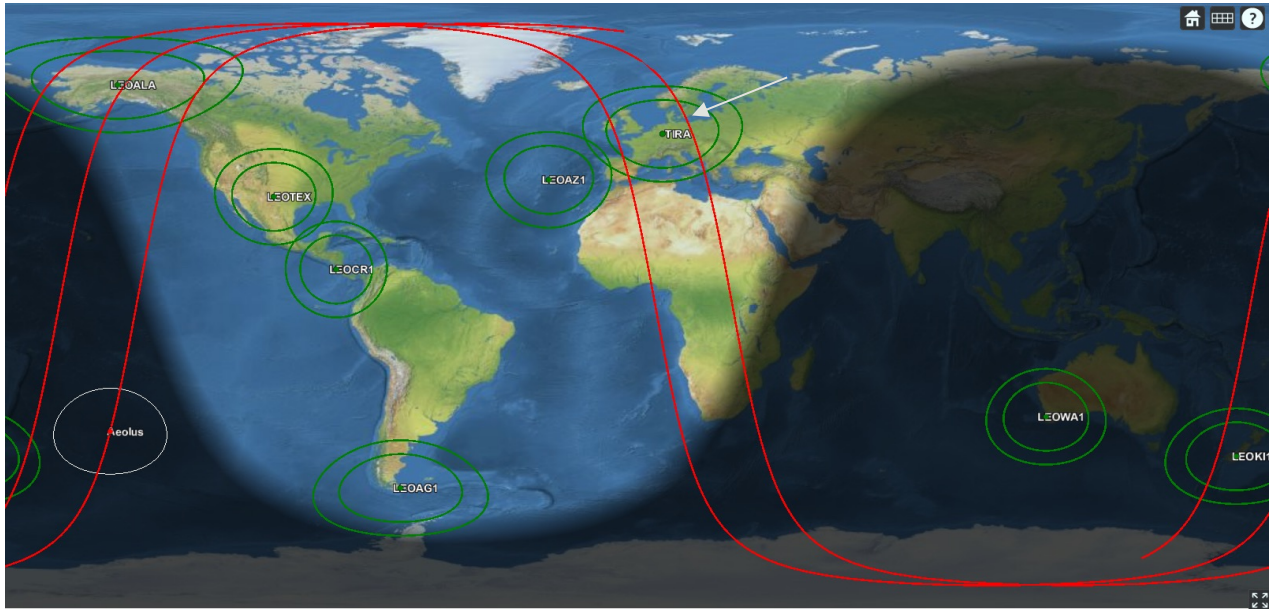
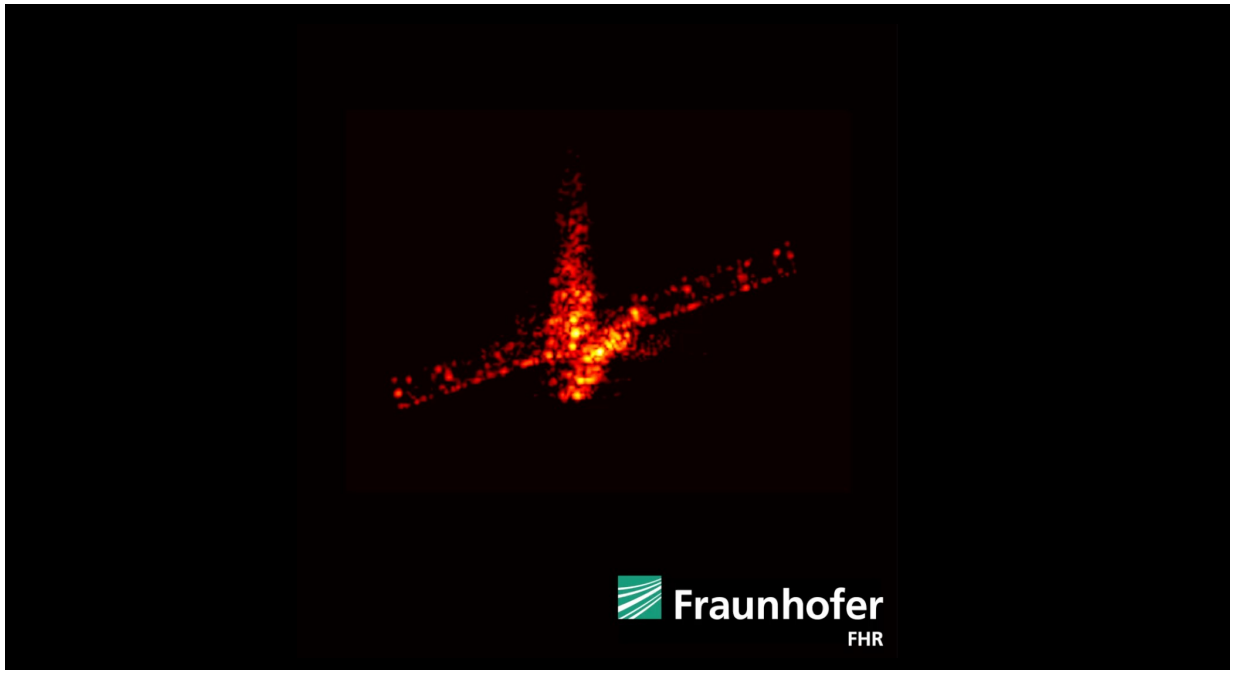
Phase IV: Reentry

- Coordinated by the the Space Debris Office, several international organizations (**IADC, USSPACECOM, EU-SST, Leolabs** and **TIRA)** supported the reentry of Aeolus, providing tracking data when satellite was in the visibility of their network
- **TIRA** from the Fraunhofer Institute for the High Frequency Physics and Radar Techniques (Germany) could observe the satellite after the last contact and following the last M3 burn.





- TIRA captured several radar images of the satellite and its rotation
- Only 0.18s time offset vs. FD computed orbit
- Imaging possible even with low elevation (11deg)
- Orbit Determination was possible and allowed SDO to perform a preliminary reentry prediction for **18:48 UTC** already at **17:19 UTC** and very close to final location

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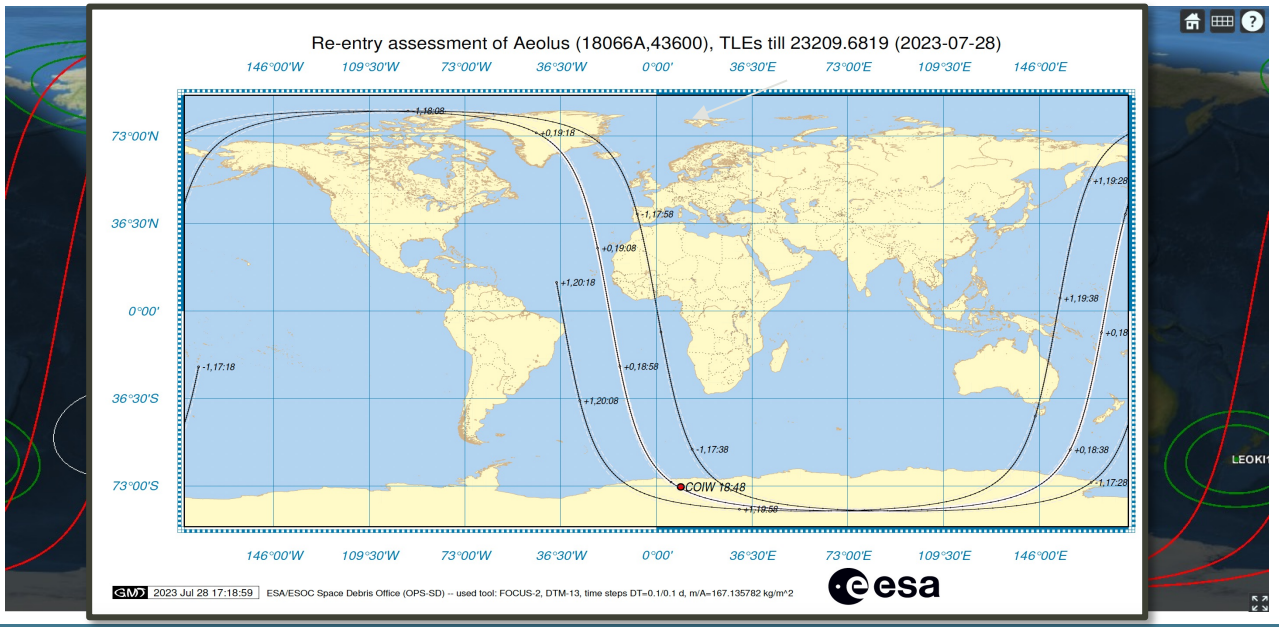

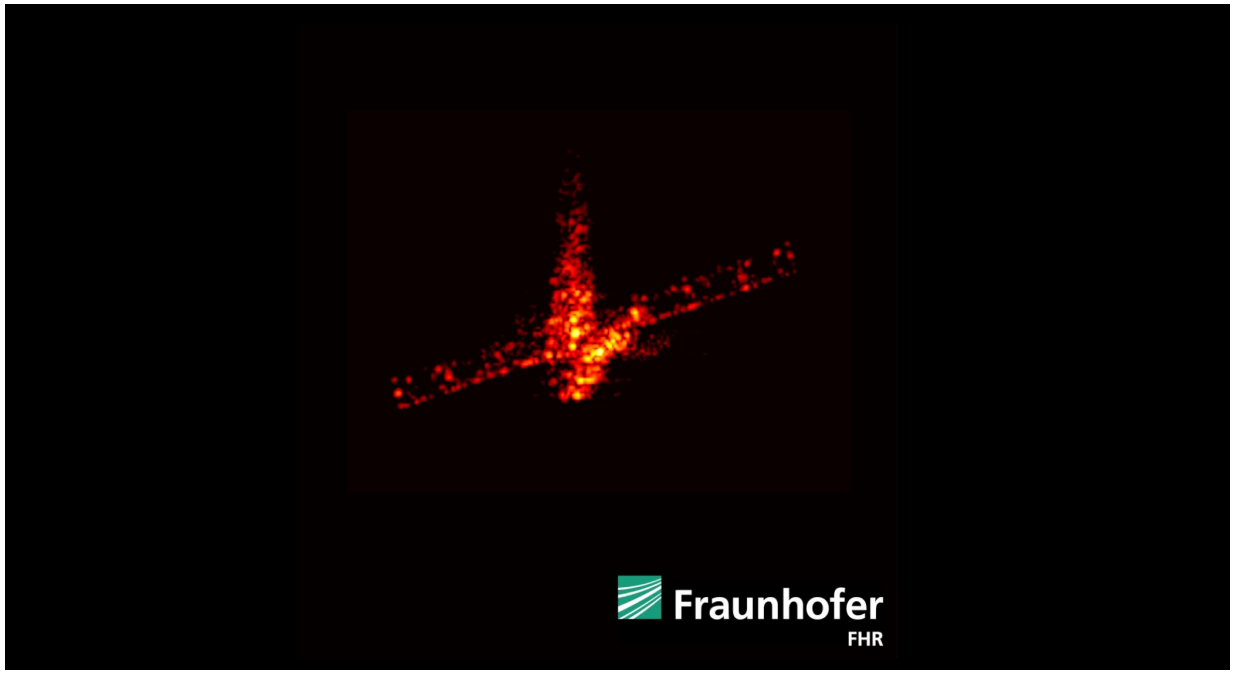

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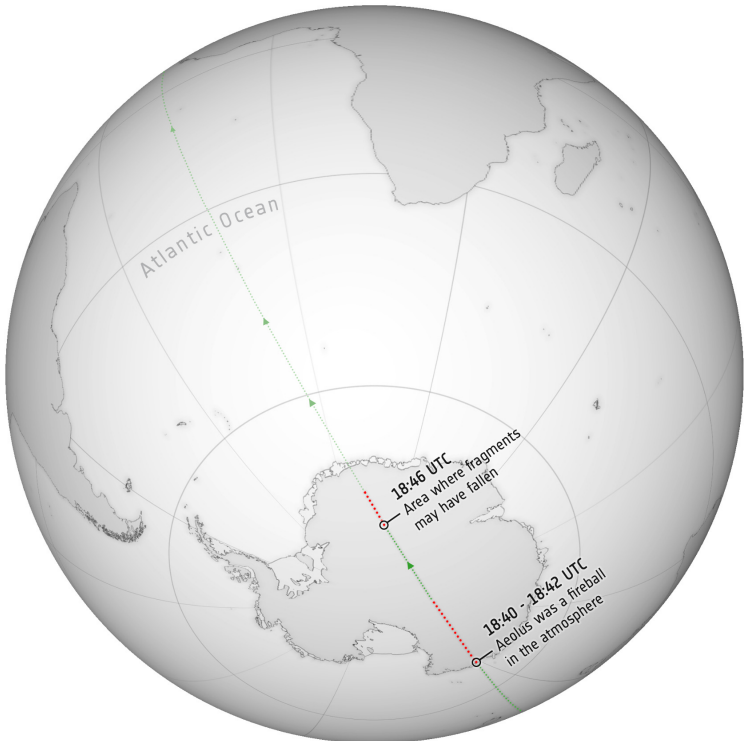
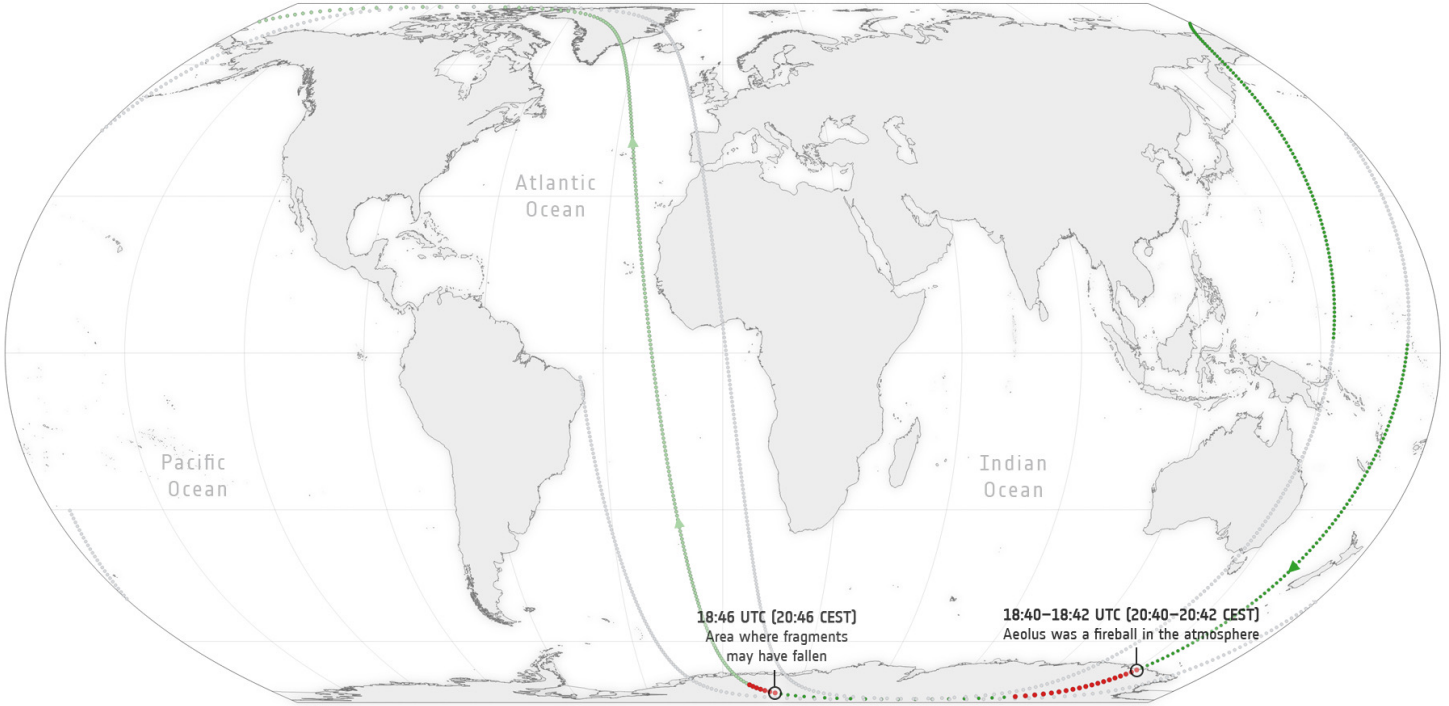


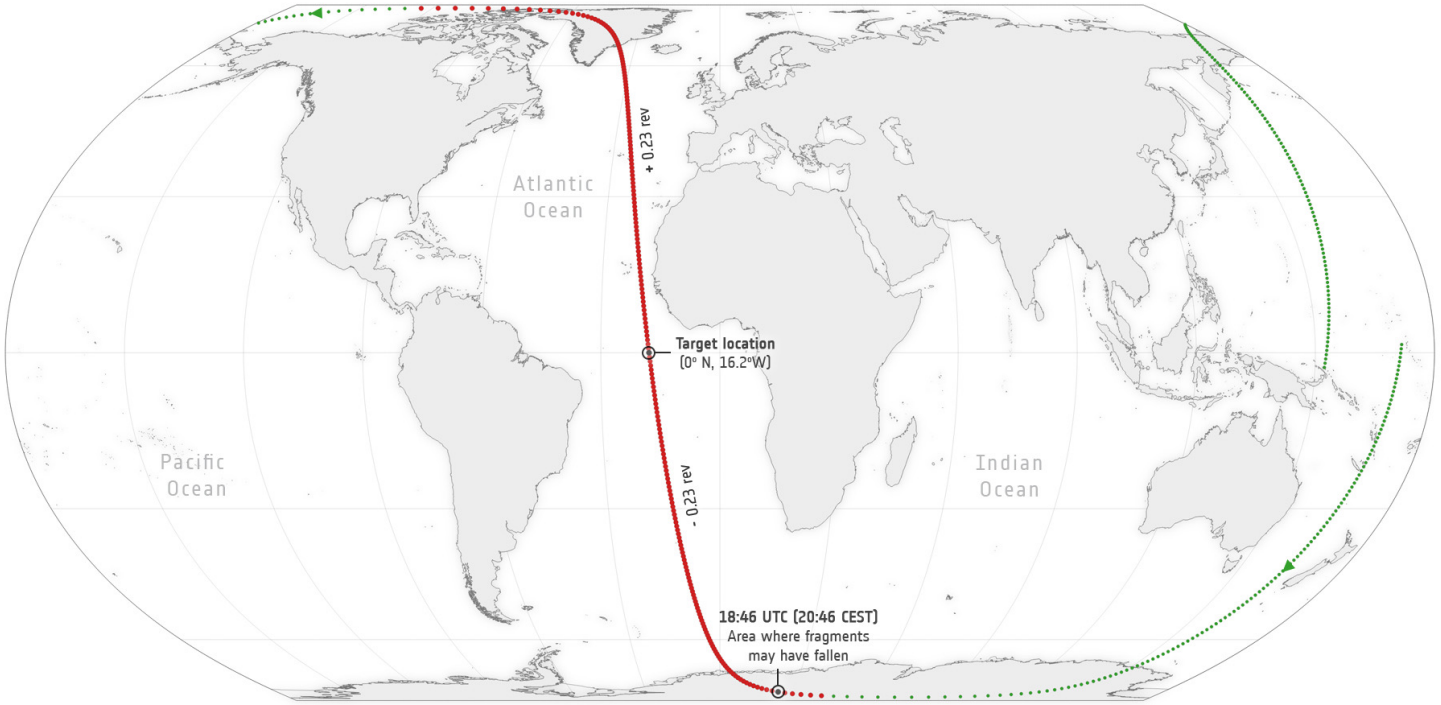


Reentry assessment map
28 July 2023, 18:40–18:46 UTC (20:40–20:46 CEST)

USSPACECOM confirmed reentry @18:46 UTC 28th July 2023 over Antarctica close to entering the Atlantic Ocean on the predicted corridor

Reentry vs. Simulation

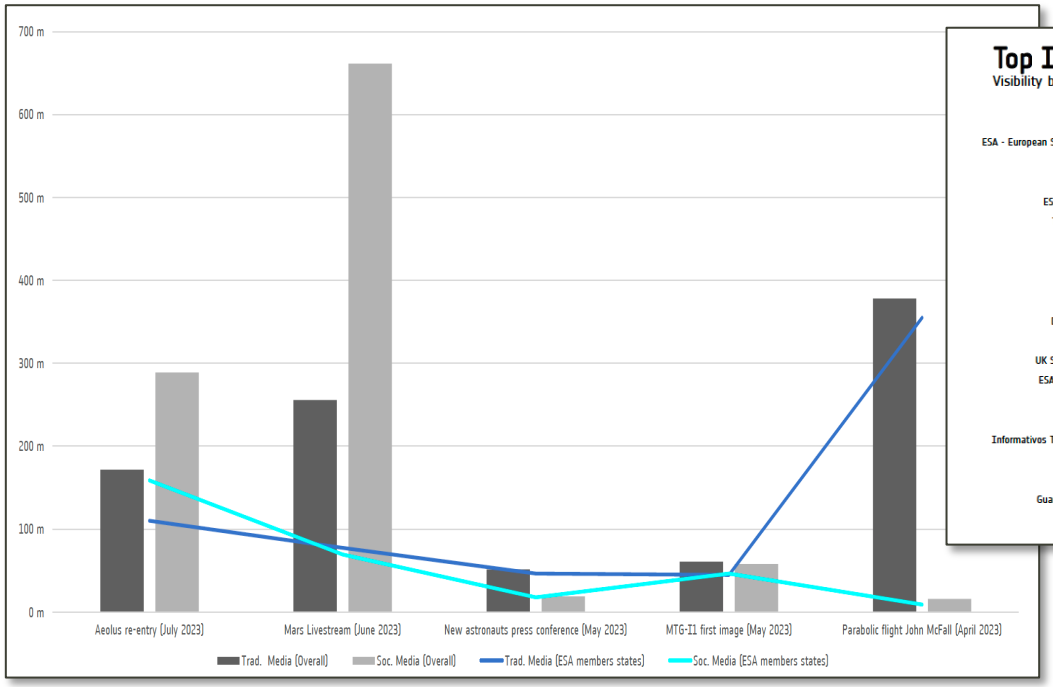
- Aeolus reentered within **0.23 rev. (1σ)** from target location [0, 16.2W]
- The **global casualty risk** was further reduced to **$1.2 \cdot 10^{-6}$**, **150 better than *uncontrolled* and well within ESA's Policy**

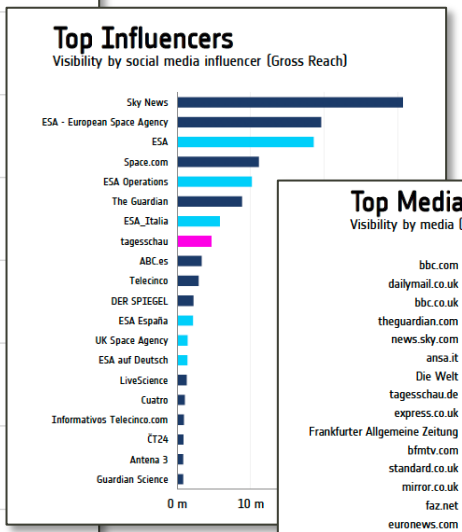


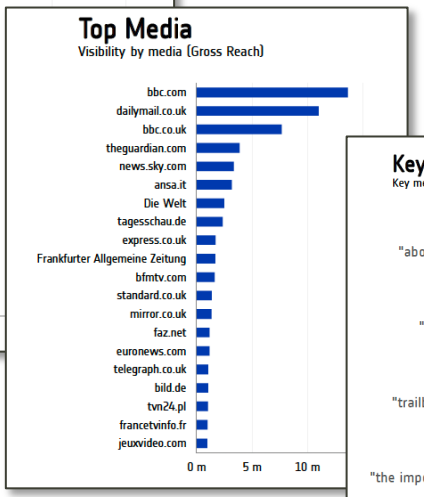
Reentry assessment map
28 July 2023, 18:25–19:40 UTC (20:25–21:40 CEST)

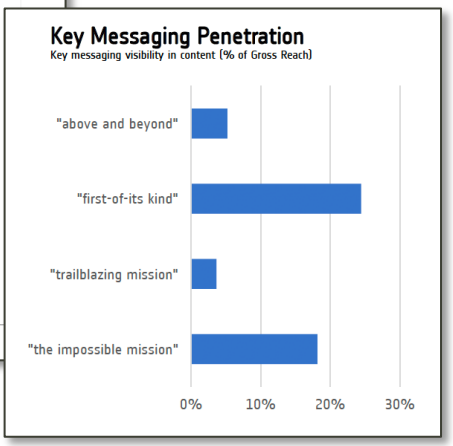
Communication

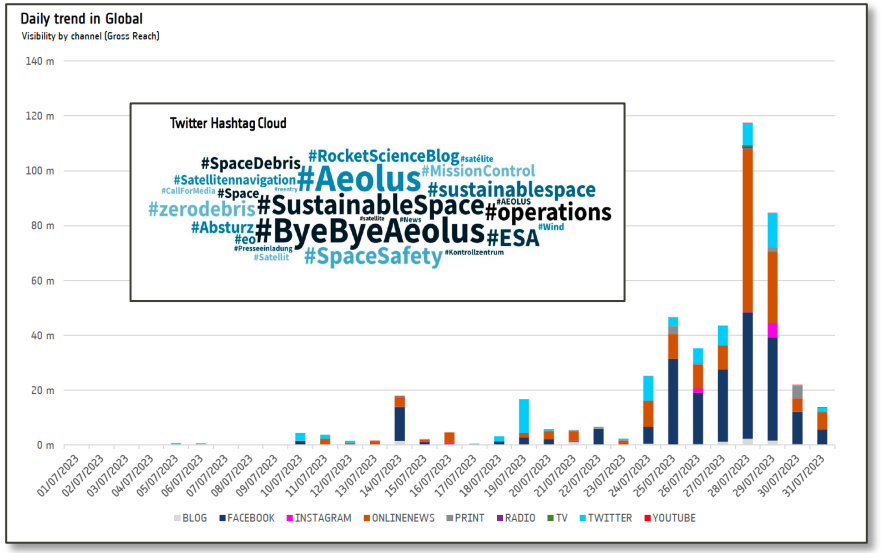
	Traditional Media		Social Media	
	Gross Reach	Volume	Gross Reach	Volume
Global visibility	171.5 M	2.158	288.8 M	2.087

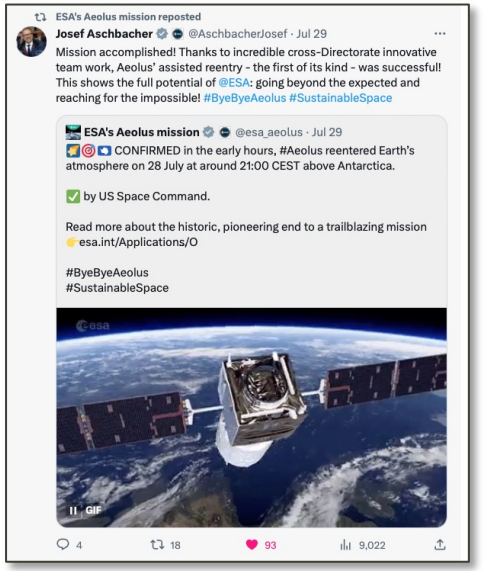












Summary

Aeolus did not have the ability to perform a *controlled* reentry and **did not have** to comply to the ESA's *Space Debris Mitigation Policy*

An innovative reentry *assisted* strategy (i.e. *semi-controlled*) was explored to further reduce the casualty risk by a **factor of 42** and retroactively ensure that Aeolus be compliant with the current space safety regulations. The chosen reentry area was over the Atlantic ocean corridor.

The operations occurred from the 24th to 28th July 2023 with a **successful reentry** over Antarctica **@18:46 UTC 28th July** close to entering the Atlantic ocean on the predicted corridor. The final **global casualty risk** was reduced to **$1.2 \cdot 10^{-6}$**, fully compliant to current policies

It was a tremendous achievement built on imagination, competence, preparation, transparent communication, perseverance, cooperation, fine art of celestial mechanics and, most importantly, thanks to a team spirit facing one of the most complex and stressful operations so far

The Aeolus Reentry Operations Team