The Cost of New Space

Space Cost Engineering (SCE2022), ESA ESTEC, The Netherlands, 15-16 September 2022

Authors:

Elisabetta Lamboglia (ESA)
Cost Engineer
Climate and Sustainability Coordinator

Nigel Drenthe (ESA)
Cost Engineer

Vedant Paul Mogha (ESA)
YGT in the ESA Cost Engineering section

Outline and Introduction

ESA lesson learnt from ***New Space*** ***relates to:***

- The boost of involvement of the private and commercial sectors
- A new technical, quality , and programmatic approach to Space

The following slides reflect the impact of this fast-evolving domain, for:

1) **Satellites implementation.** Comparison between New Space and traditional ESA space missions in terms of cost. We consider a large traditional ESA mission as a benchmark, in comparison with costs of several ESA New Space missions
2) **Small launchers**. We also tackle small launch vehicles current developments, cost estimating

1. The Cost of ESA New Space satellites

New Space – ESA Precursors

PROBA

Spacecraft

PROBA, renamed PROBA-1, is a Belgian satellite launched atop an Indian Polar Satellite Launch Vehicle by ISRO on 22 October 2001. The satellite was funded through the ESA's MicroSat program. This small boxlike system, with solar panel collectors on its surface, has remarkable image-making qualities. Wikipedia

Launch date: October 22, 2001 at 6:53 AM GMT+2

Orbit height: 615 km

Speed on orbit: 7.5 km/s

Cost: 15.6 million EUR (2007)

Manufacturer: Verhaert Space NV

Launch site: Satish Dhawan Space Centre First Launch Pad

Launch mass: 94 kg (207 lb)

PROBA-2

Spacecraft

PROBA-2 is the second satellite in the European Space Agency's series of PROBA low-cost satellites that are being used to validate new spacecraft technologies while also carrying scientific instruments. Wikipedia

Launch date: November 2, 2009

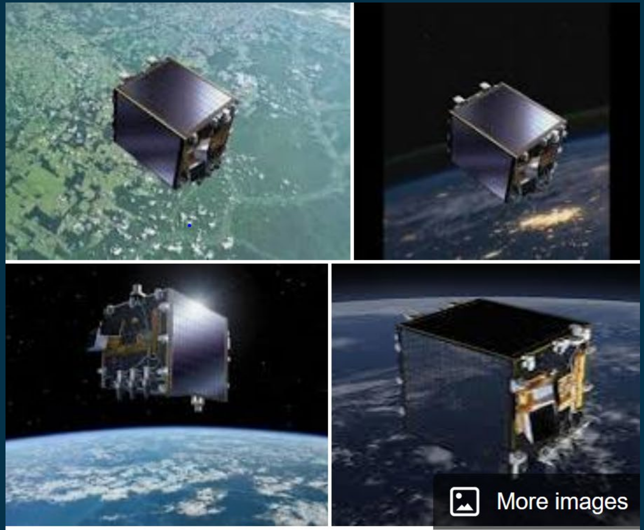
Orbit height: 720 km

Manufacturer: Verhaert Space NV

Dimensions: 0.60m x 0.70m x 0.85m

Launch mass: 120 kilograms (260 lb)

Mission duration: 2 years (planned) 12 years, 10 months and 10 days (in progress)



PROBA-V

Spacecraft

PROBA-V, or PROBA-Vegetation, is a satellite in the European Space Agency's PROBA series. It was launched in 2013 with a predicted usable lifetime between 2.5 and 5 years. Wikipedia

Launch date: May 7, 2013

Orbit height: 820 km

Launch mass: 158 kilograms (348 lb)

Mission duration: 2.5–5 years

Period: 101.21 minutes

PROBA-3

Spacecraft

Proba-3 is a technological demonstration mission by the European Space Agency devoted to high precision formation flying to achieve scientific coronagraphy. It is part of the series of PROBA satellites that are being used to validate new spacecraft technologies and concepts while also carrying scientific instruments. Wikipedia

Launch date: 2023

Dimensions: CSC: 1.1 by 1.8 by 1.7 metres (3.6 ft × 5.9 ft × 5.6 ft); OSC: 0.9 by 1.4 metres (3.0 ft × 4.6 ft)

Launch mass: CSC and OSC in stack: 550 kilograms (1,210 lb)

Rocket: PSLV-XL (baselined)

Manufacturer: S/C: SENER/QinetiQ/EADS CASA/GMV/SPACEBEL ASPIICS: CSL

Mission duration: 2 years (nominal)

Reference system: Geocentric

Satellites implementation. Mission characteristics & assumptions

The analysis conducted provides a relative cost sensitivity analysis (as a percentage) between different types of ESA missions to assess the cost of New Space

This first analysis integrates the following group of missions derived from financial proposals and preliminary cost estimates:

- REF - Large sat operational EOP: Reference mission- PhB2/AdvCD/CD/E1 financial proposal
- Case 1- Cubesat <20kg : PhB/CD/E1 financial proposal
- Case 2 - Small sat <60 kg : PhB/CD/E1 financial proposal
- Case 3 - Small sat 100 kg : Phase A/B cost estimate
- Case 4 - Small sat 100-150 kg : PhB/CD/E1 financial proposal
- Case 5 - Small sat 150 kg : CDF (phase 0) study cost estimate
- Case 6 - Small sat 260 kg : CDF (phase 0) study cost estimate

PFM: Non-recurring cost comparison for Totals

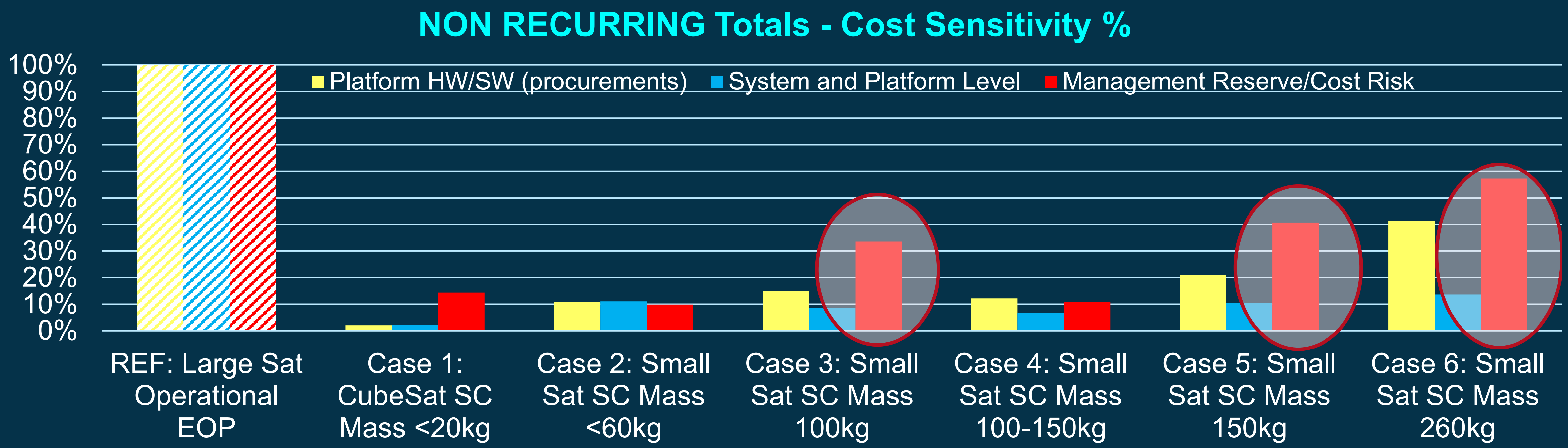
Remarks:

- We observe a trend- **Platform HW/SW & System and platform level** costs raise as the mass of the SC increases.
- We observe case 3, case 5 and case 6 are outliers from the trend observed. This can be justified by the fact that they are derived from preliminary cost estimates, thus higher risk margins due to mission uncertainty.

Financial Proposal: Case 1, 2, 4

Phase A/B cost estimate: Case 3

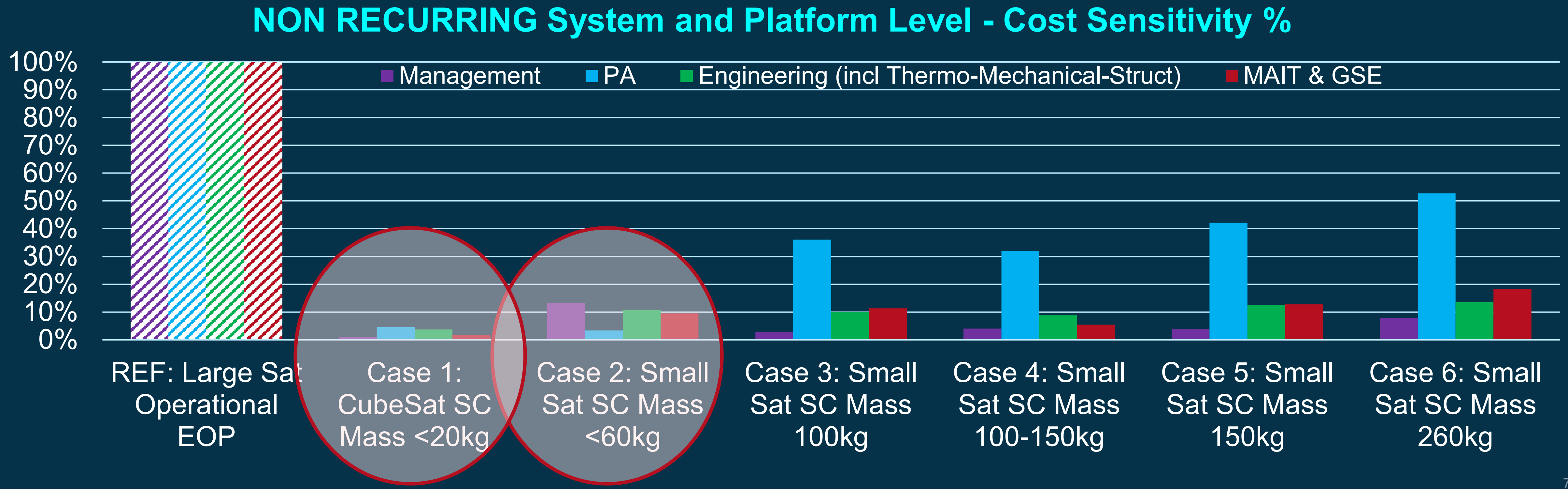
Phase 0 Cost estimate: Case 5, 6



PFM: Non-recurring cost comparison for System and Platform

Remarks:
- For case 2, we observe the lowest % of cost dedicated to PA&S. This cost is included in Project Management.
- The case 1 cost is an average of 3 SCs- one PFM and 2 FMs. To be noted that this PFM cost might be slightly underestimated.

Financial Proposal: Case 1, 2, 4
Phase A/B cost estimate: Case 3
Phase 0 Cost estimate: Case 5, 6



PFM: Non-recurring cost comparison for HW/SW

Remarks:

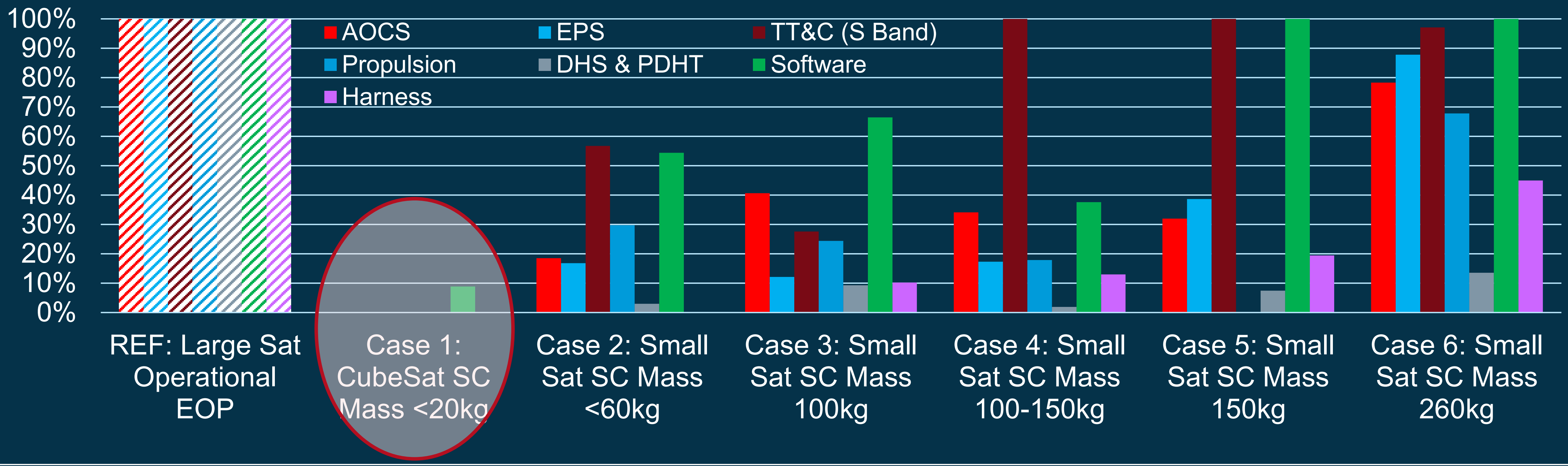
- For case 1:
  - The costs for HW/SW is integrated in engineering. Thus, are missing from the subsystem hardware costs.
  - PDHT is valid for large platforms but not for small platforms.
  - New Space missions have light procurement approach with equipment procurement in house by the Prime.

Financial Proposal: Case 1, 2, 4

Phase A/B cost estimate: Case 3

Phase 0 Cost estimate: Case 5,6

NON RECURRING HW/SW - Cost Sensitivity %

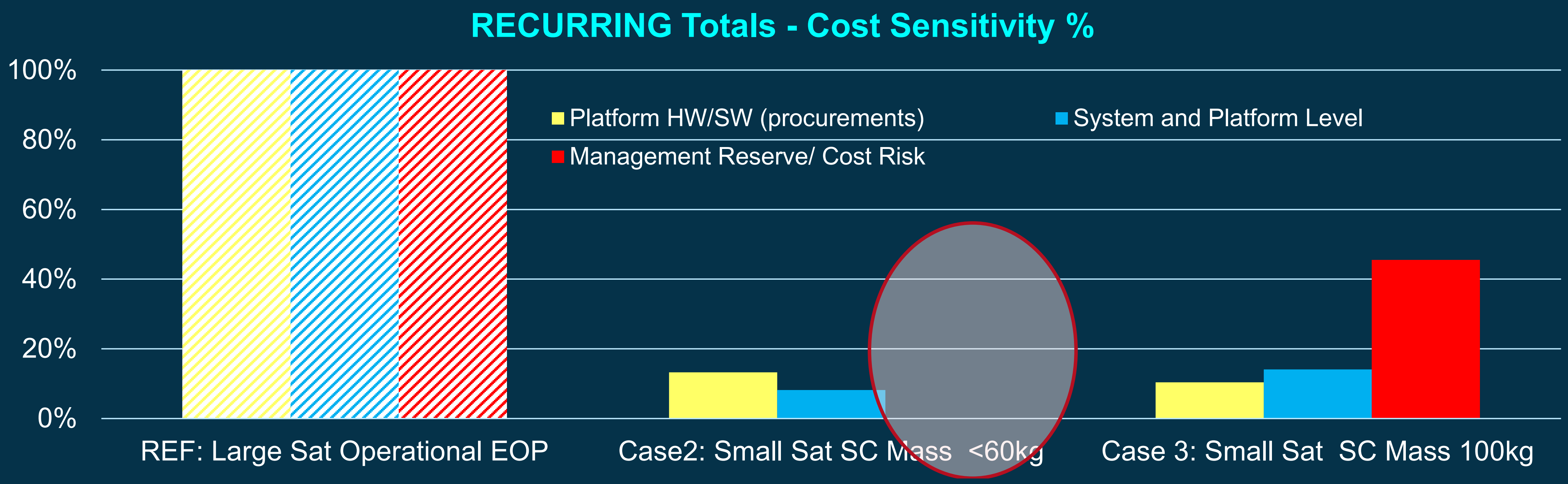


FM2: Recurring cost comparison for Totals

Remarks:

- For case 2, management reserve/cost risk is considered in the PFM Management Risk.

Financial Proposal: Case 1, 2, 4
Phase A/B cost estimate: Case 3
Phase 0 Cost estimate: Case 5, 6



FM2: Recurring cost comparison for System and Platform

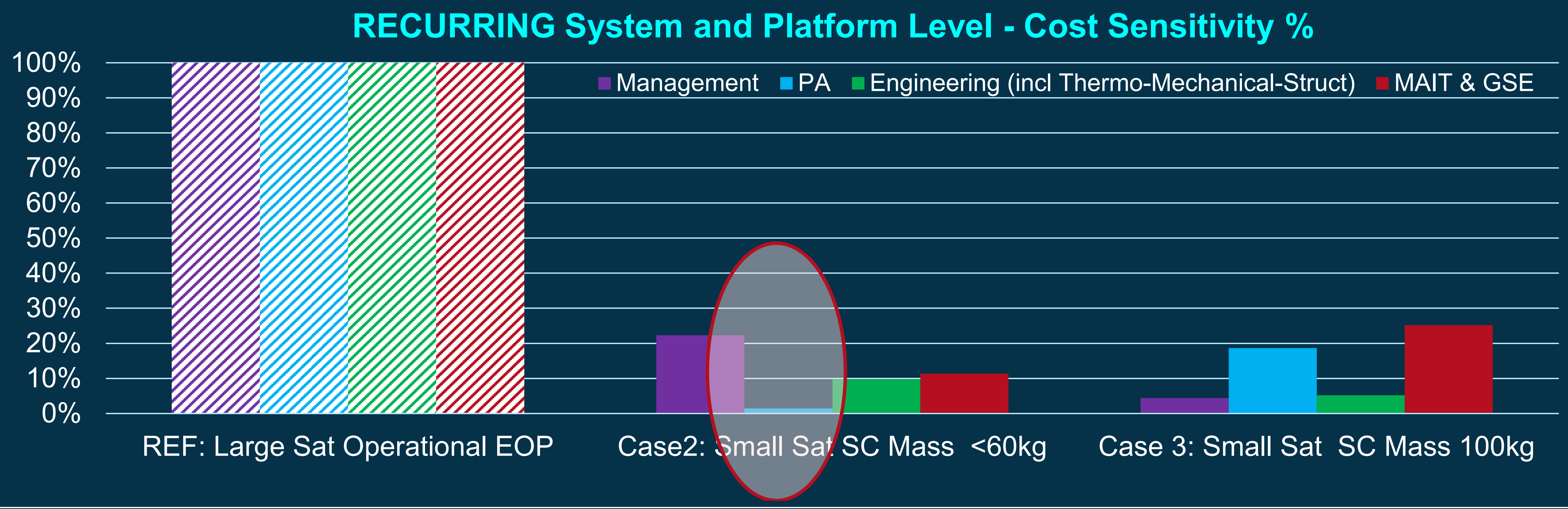
Financial Proposal: Case 1, 2, 4

Phase A/B cost estimate: Case 3

Phase 0 Cost estimate: Case 5, 6

Remarks:

- We observe that case 2 is from a Financial proposal as compared to case 3 is from a Phase A/B Cost estimate. PA&S for case 2 is low due to SAME reason as for PFM (integrated in Project Management)



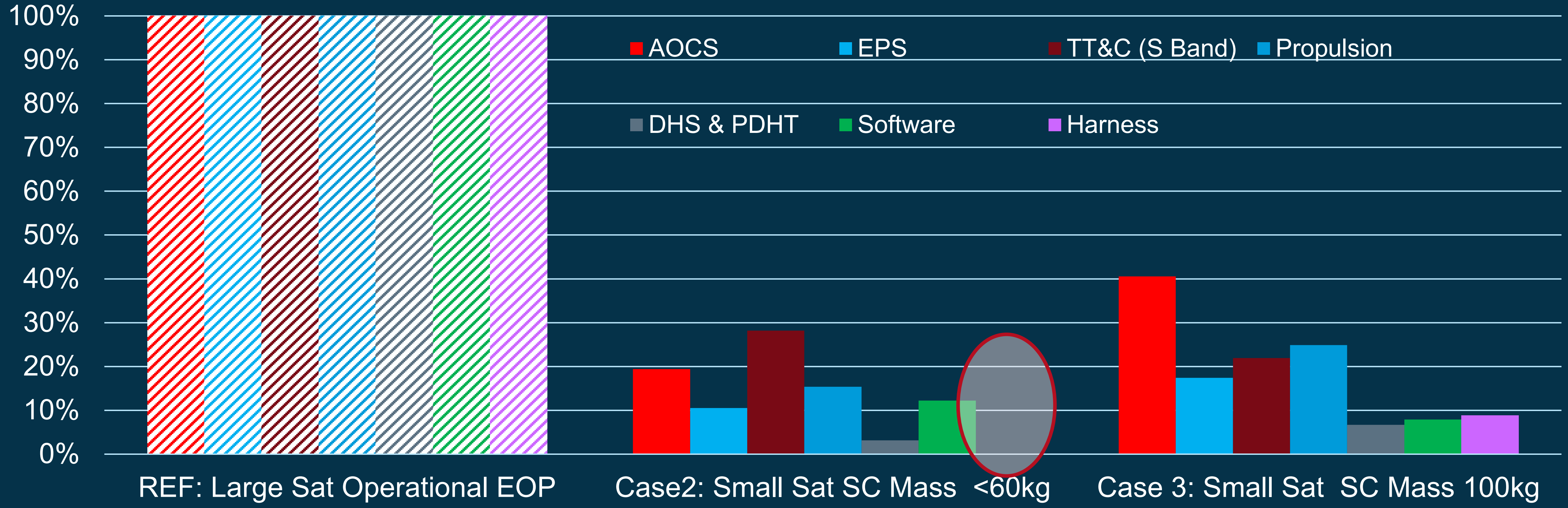
FM2: Recurring cost comparison for HW/SW

Remarks:

- The Harness for case 2 is embedded in the system level.

Financial Proposal: Case 1, 2, 4
Phase A/B cost estimate: Case 3
Phase 0 Cost estimate: Case 5, 6

RECURRING HW/SW - Cost Sensitivity %



2. The trends and cost of New Space for small launchers

Small launch worldwide

Vehicles in development, ≤1000kg to LEO

Adapted 2021 survey, Niederstrasser

Small launch is dominated by the United States and China in terms of number of companies launching <1000kg to LEO

Vehicles in operation, <1000kg to LEO

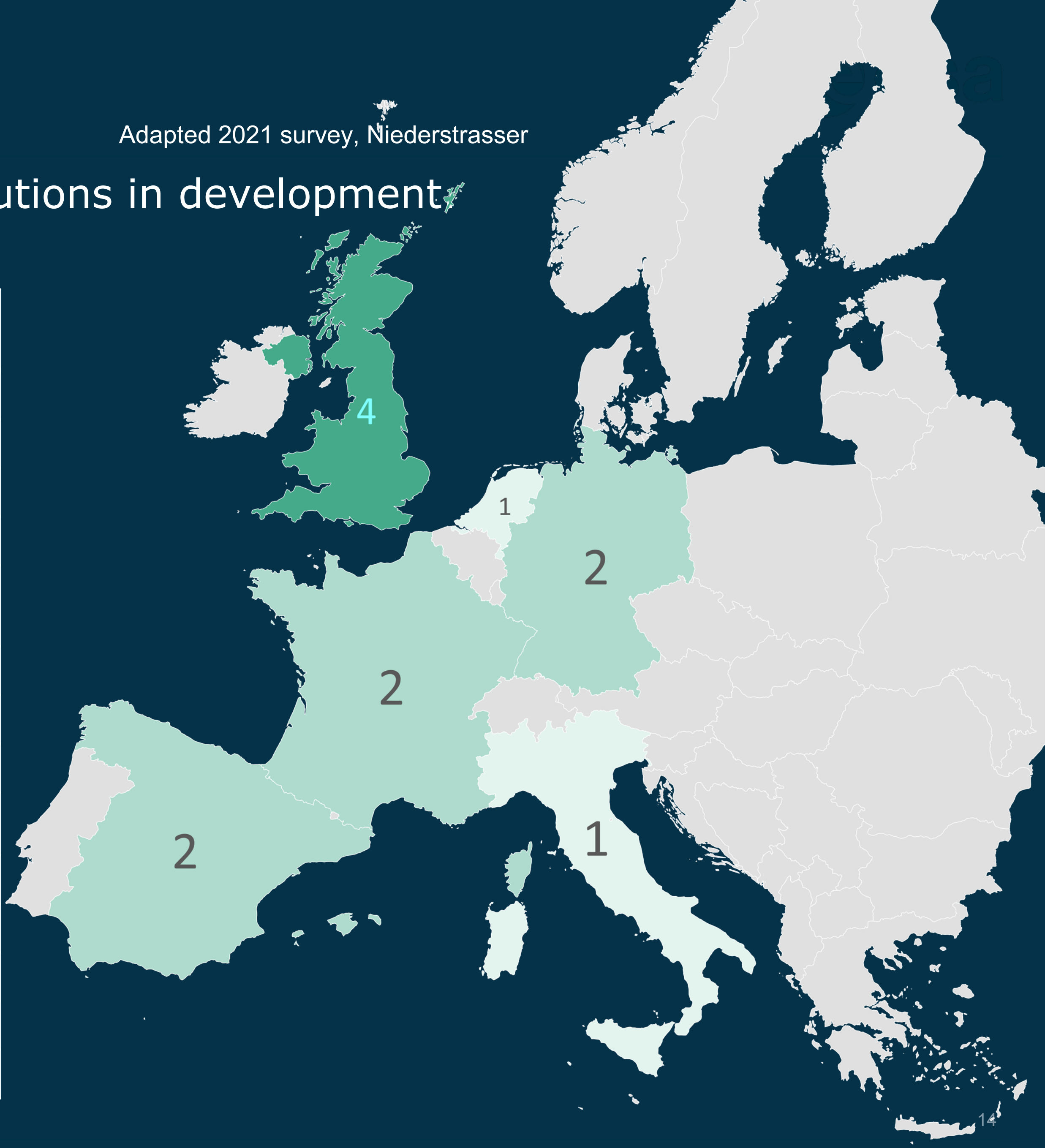
Organization	Vehicle Name	Country	First Launch
Northrop Grumman	Pegasus XL	USA	1990
Northrop Grumman	Minotaur I	USA	2000
China Aerospace Science and Technology Corporation	Chang Zheng 11	China	2015
ExPace	Kuaizhou-1A	China	2017
China Aerospace Science and Technology Corporation	Kaituozhe-2	China	2017
Rocket Lab	Electron	USA/New Zealand	2018
iSpace	Hyperbola-1	China	2019
China Rocket Co, Ltd	Jielong 1	China	2019
Galactic Energy	Ceres-1	China	2020
Virgin Orbit	LauncherOne	USA	2021

Small launch in Europe

Adapted 2021 survey, Niederstrasser

At ≤1000kg to LEO, Europe has 13 small launch solutions in development.
Furthermore, 1 is developed in Canada.

Company	LEO performance	SSO performance	Country
Orbex Prime	-	220kg	UK
Skyrora XL	-	315kg	UK
PLD Space Miura	-	300kg	Spain
HyImpulse SL1	675	400kg	Germany
Venture Orbital Systems Zephyr	-	70kg	France
Pangea Meso	150kg	-	Spain
Dawn Aerospace	250kg	-	Netherlands
B2Space Colibri	200kg	-	UK
Black Arrow Space	-	300kg	UK
ISAR Spectrum	1000kg	700kg	Germany
C6 Launch Systems	-	30kg	Canada
ArianeGroup Maïa	1000kg	-	France
Space Rider	-	800kg	Europe
Vega-C light	-	500kg	Italy



More performant small launch

Other notable European vehicles that exhibit performance ≥1000kg are listed below.

Company	LEO performance	SSO performance	Country
RFA One	1600kg	1350kg	Germany
Polaris Aurora LCT	1150kg	-	Germany
ArianeGroup Maïa extended	1500kg	-	France

ESA Boost!

ESA's boost programme consists of two elements:

1. Commercial space transportation services
    - Co-funding of activities undertaken – specific activities
    - Strict requirements on proof of private funding
    - Activities supported in:
        - Orbital transportation/deployment solutions & services
        - Small launch vehicles

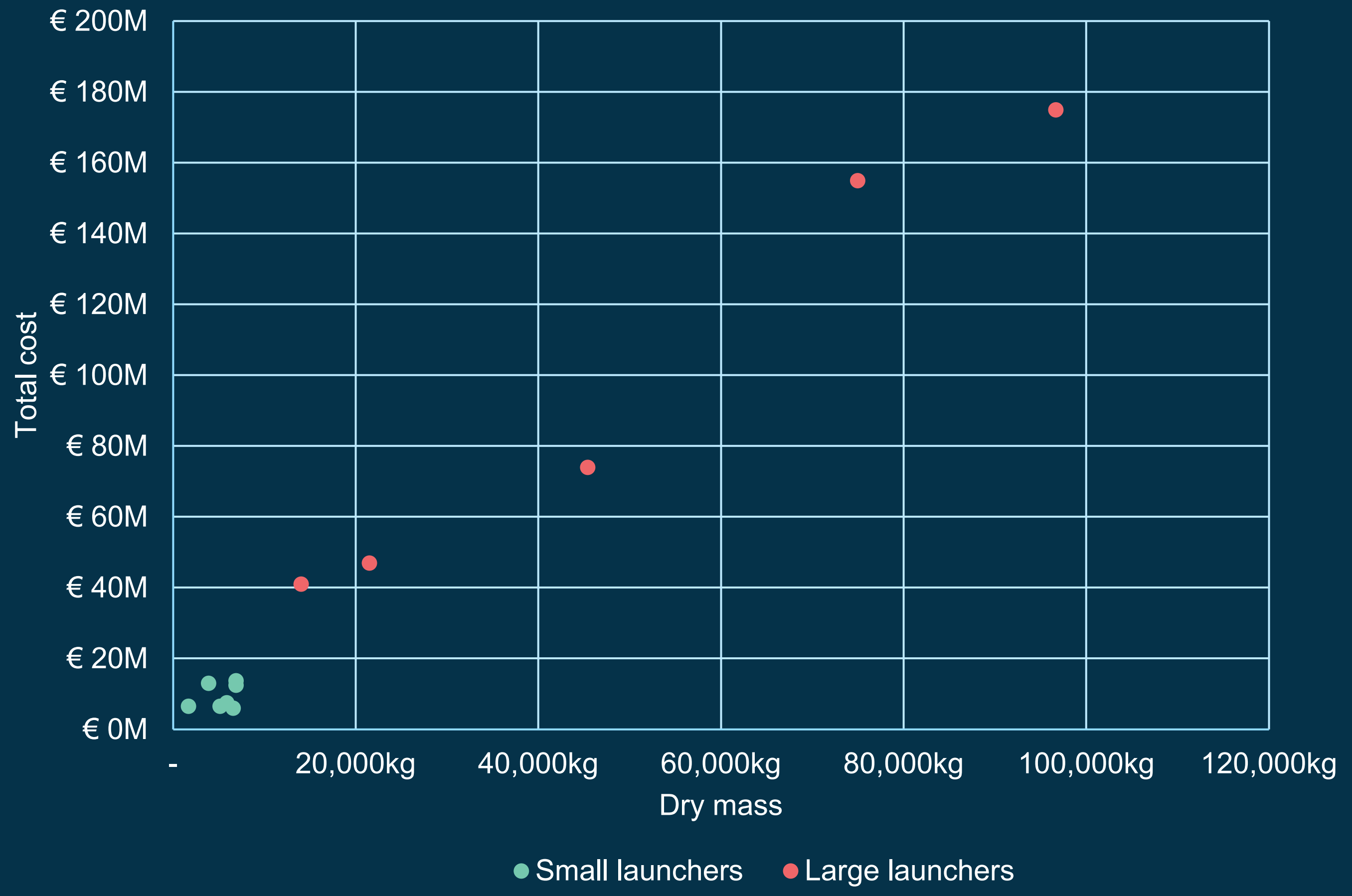
2. Support to participating states
    - Mainly infrastructure-related

General cost trends, how do small launchers fit

As many small launch vehicles in Europe are still in development, any cost analysis is based on to-be-expected costs rather than actuals. First, costs are analysed for dry mass and total cost.

Unsurprisingly, the dry mass is a good predictor for cost.

"You pay for airplanes [or rockets] just as you do for potatoes. The heavier they are, the more expensive they are." - John Boyd



Costs per kilogram of launch vehicle

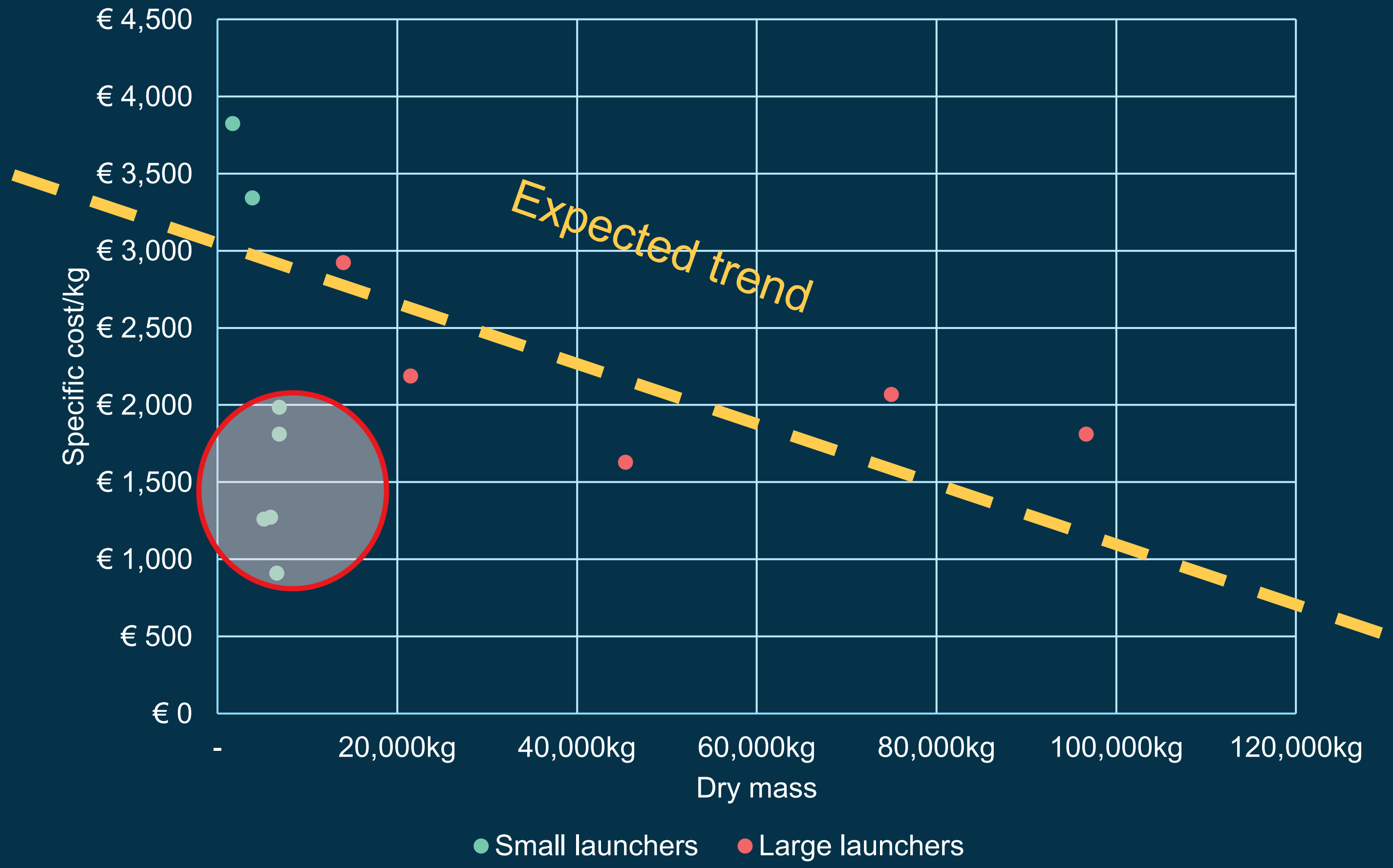
Extensive analysis has already been performed on small launch vehicles' cost per kilogram **to orbit**

However, a more interesting cost engineering metric is the **cost per kilogram of launch vehicle produced**.

Some smaller launch vehicles have lower than usual cost per kilogram of dry mass.

A decreasing trend in dry-mass-specific cost is expected due to the persistent necessity of high-value items such as avionics in *any* rocket

Lower specific cost could signify simpler parts – see analysis in next slide.



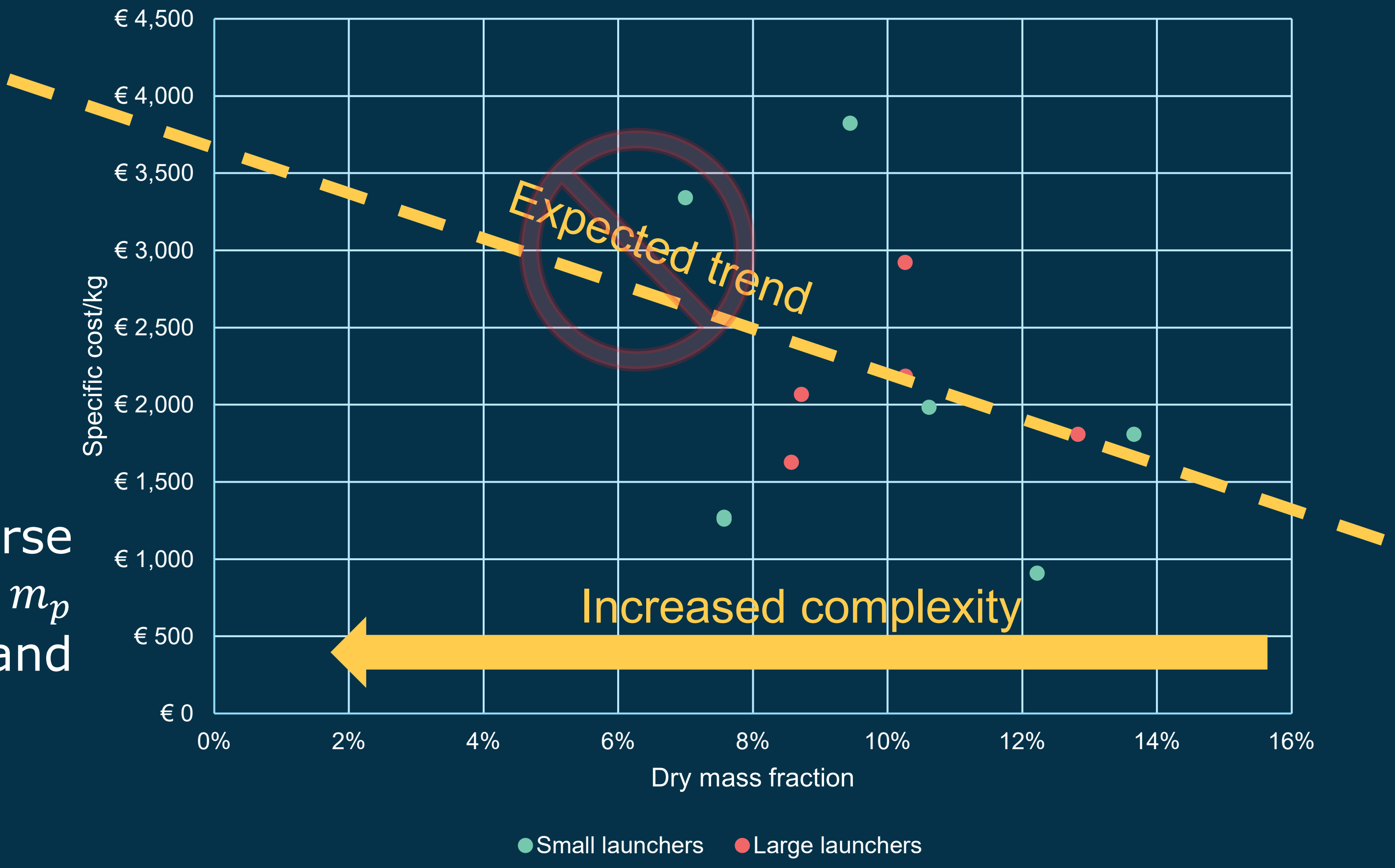
Dry mass fractions as a metric for higher cost?

Dry mass fractions may be seen as a proxy for higher cost. For example, to achieve a good dry mass fraction a design could employ the use of low weight state-of-the-art materials. This would result in higher specific cost.

There seems to be **little relation** between dry mass fractions and specific cost per kilogram - either for small or large vehicles.

Dry mass fraction defined as the inverse of the propellant mass fraction. m_o, m_f, m_p being initial mass, final (empty) mass and propellant mass respectively.

$$1 - \left(\frac{m_0 - m_f}{m_0}\right) = 1 - \left(\frac{m_p}{m_p + m_f}\right)$$

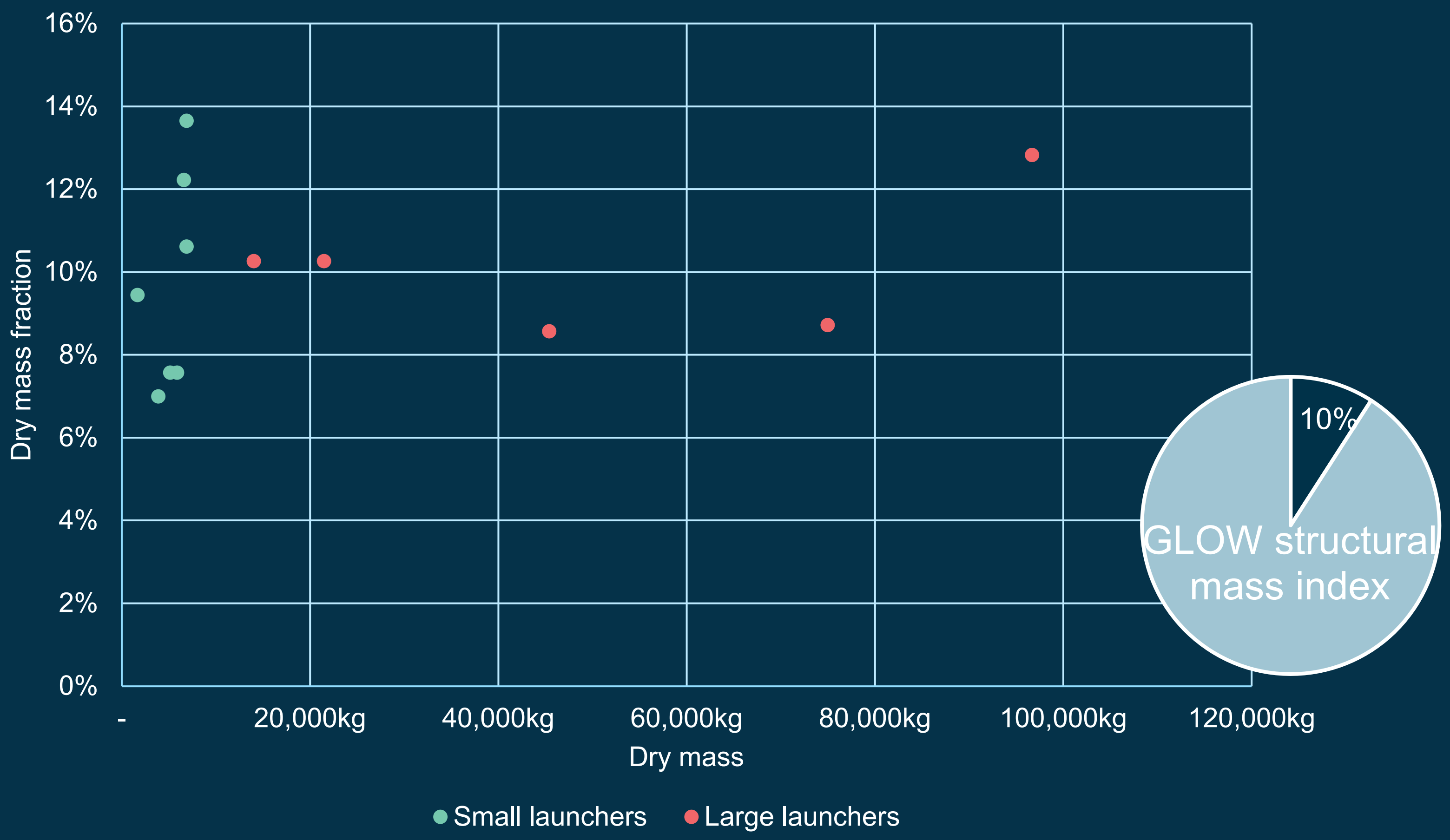


Dry mass fractions for small and large vehicles

A possible source of lower specific costs could be the difference in structural mass index between small and large vehicles.

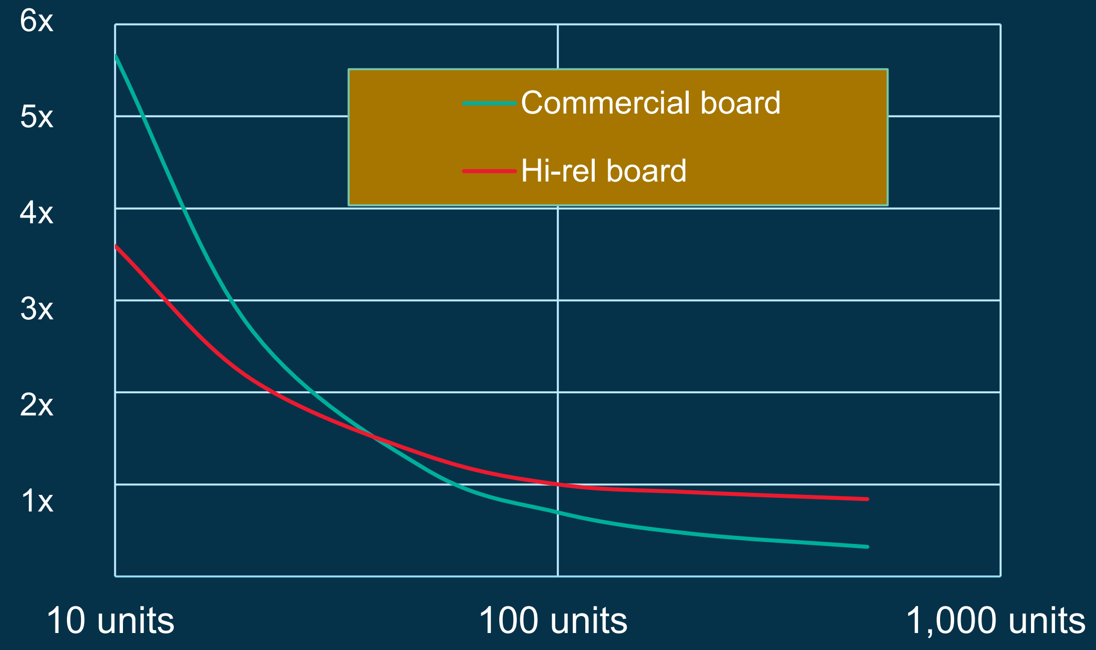
Structural mass indices are **similar** between small and large vehicles.

Conclusion: Cost reduction is not on parts contributing to the structural index → most likely avionics



Example: cost reduction trends for avionics (satellite vs launcher)

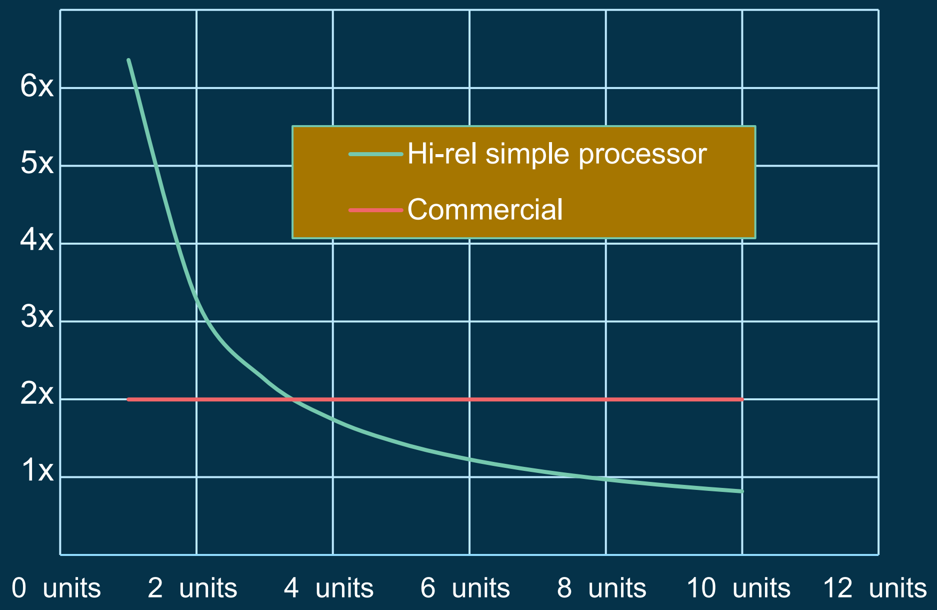
On **electronics board** level, production of >30-50 units is the turning point for using commercial-off-the-shelf components for complex boards



On component-level, cost reduction potential emerges at >X000’s of components.

Other hardware that can benefit from larger volumes application of COTS:

- Simpler processors (X0’s per vehicle):



- Cryogenic valves
- Control valves (X0’s per vehicle)

Conclusions

Satellites

General lesson learnt on the cost engineering trends and domain for New Space satellites:

- First spotted `outliers` have been analyzed and re-considered as fully justified references, based on the nature of the specific mission, technical specificities and the cost estimate mission phase.
- Manpower resources not following the `standard way of thinking’, also affecting some categories (eg: PA) and tendence to co-engineering teams and tasks
- HW/SW cost `embedded` in system cost categories, (eg: engineering)
- New Space missions have light procurement approach with equipment developed in house by the Prime, lowering significantly the cost. As expected.

Small Launchers

- Small launch is dominated by the US and China currently, with the former having most vehicles in development and the latter with most vehicles in operation.
- Generally, small launchers follow the same cost/dry mass trends as larger ones.
- Some launch vehicles exhibit unexpected cost characteristics such as low cost/kg dry mass.
- Uncharacteristic figures are not due to
    - Decreases in structural components complexity
    - Other dry mass fractions in small launch vehicles than larger ones
- Most probable cost gains are from avionics, with COTS becoming interesting at higher volumes.

Thank you!

Elisabetta.Lamboglia@esa.int
Nigel.Drenthe@esa.int
Vedant.Mogha@esa.int