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Indra Deimos

25/03/2025

Reliability challenges with the use of COTS in development of platforms for Small Satellite missions

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ACCEDE | ESCCON

2025

Seville - Spain
25 to 27th March

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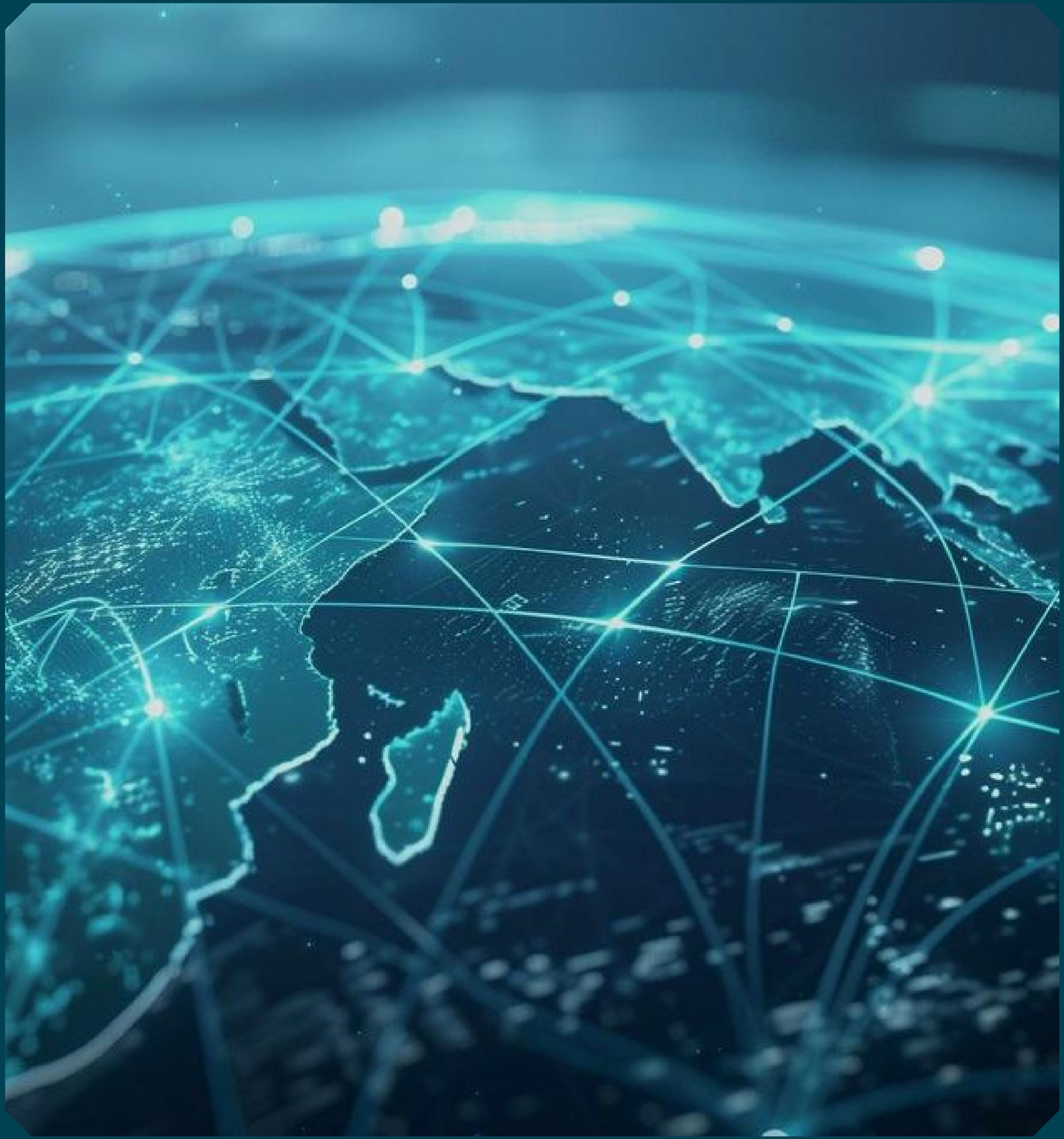

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01

“Traditional” vS “New” Space

COTS utilization

What is a Commercial off-the-shelf (COTS) item?

As per “ECSS-S-ST-00-01 rev.1”

2.3.61 commercial off-the-shelf

equipment, including hardware and associated software or procedures, that is commercially available from current industry inventory

[ISO 14625:2007]

NOTE In common usage, COTS equipment is understood to not be manufactured, inspected or tested in accordance with military or space standards. COTS equipment is generally cheaper and easier to procure, yet has associated risk in terms of quality and performance in the space environment.

What is a Commercial off-the-shelf (COTS) item?

As per “NASA-STD-8739.10”

Commercial: A classification for an assembly, part, or design for which the item manufacturer or vendor establishes performance, configuration and reliability, including design, materials, processes, and testing pursuant to market forces rather than by enforceable compliance to a government or industry standard.

Off-The-Shelf Hardware: Assembly, part, or design that is readily available for procurement, usually to catalog specifications, without the necessity of generating detail procurement specifications for the item.

“Traditional space” satellites main characteristics

“Traditional space” **target** SC:

- Deploy functions strategic for governments-society and prime science.
- Extreme reliability and robustness in space environment for long and safe service life. “Failure-is-not-an-option” ideally.

“Traditional space” **needs**:

- Tight engineering, product/quality assurance and MAIT requirements.
- Manufacturers with highly specific competences for the design and construction.
- High customization and low industrialization.
- Large size and weight. Expensive launch ticket.

High costs and long development times.

COTS items for the “traditional space” market

- COTS items are used when they bring a necessary technological advantage to fulfill the mission, unavailable elsewhere.
- Cost and availability is never the driver. The cost and time to assess if they are usable negate those factors.
- In the European industry, assessment of acceptability, and required adaptations, are defined in the ECSS system. For example:

ECSS-Q-ST-20-10C
8 October 2010

Space product assurance

Off-the-shelf items utilization in space systems

ECSS-Q-ST-60-13C Rev.1
12 May 2022

Space product assurance

Commercial electrical, electronic and electromechanical (EEE) components

“New space” satellites main characteristics

“New space” **needs**:

- Relaxed engineering, product/quality assurance and MAIT requirements.
- Access to manufacturers less specialized in space applications.
- High standardization/industrialization of equipment used for satellites.
- Reduced and standardized size and weight. Cheaper launch ticket.

“New space” **target** SC:

- Functions limited by “new space” market offering and trends.
- SC itself is not the sole purpose of its production, also “learning” from it.
- Short service life and higher acceptable risks allows a reduced reliability and robustness in space environment.

“Low” costs and “short” development times.

COTS items for the "new space" market

- **Cost and availability** is the first driver for their usage.
- COTS items bring **desirable state-of-the-art characteristics**, like allowing the shrinking of the equipment to fit standardized sizes keeping complex performances, etc.
- For the product/quality risks associated , each "new space" actor has a different "recipe" on what shall be addressed and how, and what can be accepted at a risk. Sharing this "recipe" is against the commercial interest of these "actors". There is not an external body of standards to guide. Inhomogeneous and shady product/quality assurance provisions explains partially a larger rate of failure compared with "traditional space": ranging roughly 25-40% (REF 1, REF2).

02

COTS EEE parts main characteristics

Space EEE parts market main characteristics

Reduced # manufacturers - No competition **+** Small number of customers – *ad hoc* production **+** Long production and testing times **+** Small market – Low priority for manufacturers **=**

-Two-digits % cost of satellite [REF 3]
-Critical path in the development

UNAFFORDABLE FOR NEW SPACE
COTS NEEDED

Space EEE parts market

Generic and Detailed Performance Specifications specific for space applications
Qualified Parts and Manufacturers Lists

- Mechanical Robustness
- Thermal Robustness
- Reliability
- Radiation Robustness

Required characteristics for space applications

Mechanical robustness of COTS EEE parts?

Space application origin: orbital launch.
-Thrust.
-Aero drag.
-Separation stages.

Test methods:
-Variable frequency vibration.
-Random vibration.
-Mechanical shock.
-Constant Acceleration.

Mechanical robustness is also a concern for the COTS EEE parts original markets

Integrated Circuits	ESCC-9000	AEC-Q100	COTS vs space
Random vibration	NA	NA	-
Variable f. vibration	MIL-STD-883 TM 2007 Condition A	JESD22-B103	Greater acceleration
Mechanical shock	MIL-STD-883 TM 2002 Condition B	JESD22-B110	Same profile and repetition Lesser axes
Constant acceleration	MIL-STD-883 TM 2001 Condition A/B	MIL-STD-883 TM 2001 Condition D/E	Greater acceleration Lesser axes

Differences can be covered with delta-evaluation at EEE part, compliance with actual mission conditions predicted by analysis and/or environmental testing at equipment level.

Thermal robustness of COTS EEE parts?

Space application origin: orbital effects.
-Shade-Exposure Sun phases.
-Variable operating temperatures.
-Stringent highest/lowest operating temperatures.

Test methods:
-Thermal Shock.
-Temperature Cycling.
-High/Low temperature performance measurement 100%.

Thermal robustness is also a concern for the COTS EEE parts original markets

Integrated Circuits	ESCC-9000	AEC-Q100	COTS vs space
Thermal shock	MIL-STD-883 TM 1001 Condition B	NA	-
Temperature cycling	MIL-STD-883 TM 1010 Condition C (100 cyles)	JESD22-A104 and Appendix 3 (500 to 1500 cycles)	Larger temperature range and cycles
H/L temperature measurement.	Chart F3 and Detail specification 100% each lot	Electrical distribution Defect Screening Tests AEC Q100-009 AEC Q001+Q002+Q003	Characterization and sampling

Differences can be covered with delta-evaluation at EEE part, compliance with actual mission conditions predicted by analysis and/or environmental testing at equipment level.

Reliability of COTS EEE parts?

Space application origin:
-Demonstration of high reliability.
-Impossibility of maintenance.

Test methods:
-Burn-in
-Operating Life.
-Wafer Lot Acceptance

Reliability is also a concern for the COTS EEE parts original markets.

Integrated Circuits	ESCC-9000	AEC-Q100	COTS vs space
Wafer Lot Acceptance	Chart F2A	Group D	No TID aspect
Burn-in	Chart F3-100% each lot, 240h	AEC Q100-008-Early Life Failure Rate Sampling (x800), no failures, as technology qualification, 48h	No systematic and 100%, less time.
Operating Life Test	MIL-STD-883 TM 1005, 2000h*45parts	JESD22-A108, 1000h*77parts	Slightly less accumulated time

Differences can be covered with delta-evaluation at EEE part, testing at board level (only covering burn-in) or accept a decreased reliability due to the shorter mission times and higher acceptable risks..

Radiation Hardness Assurance of COTS EEE parts?

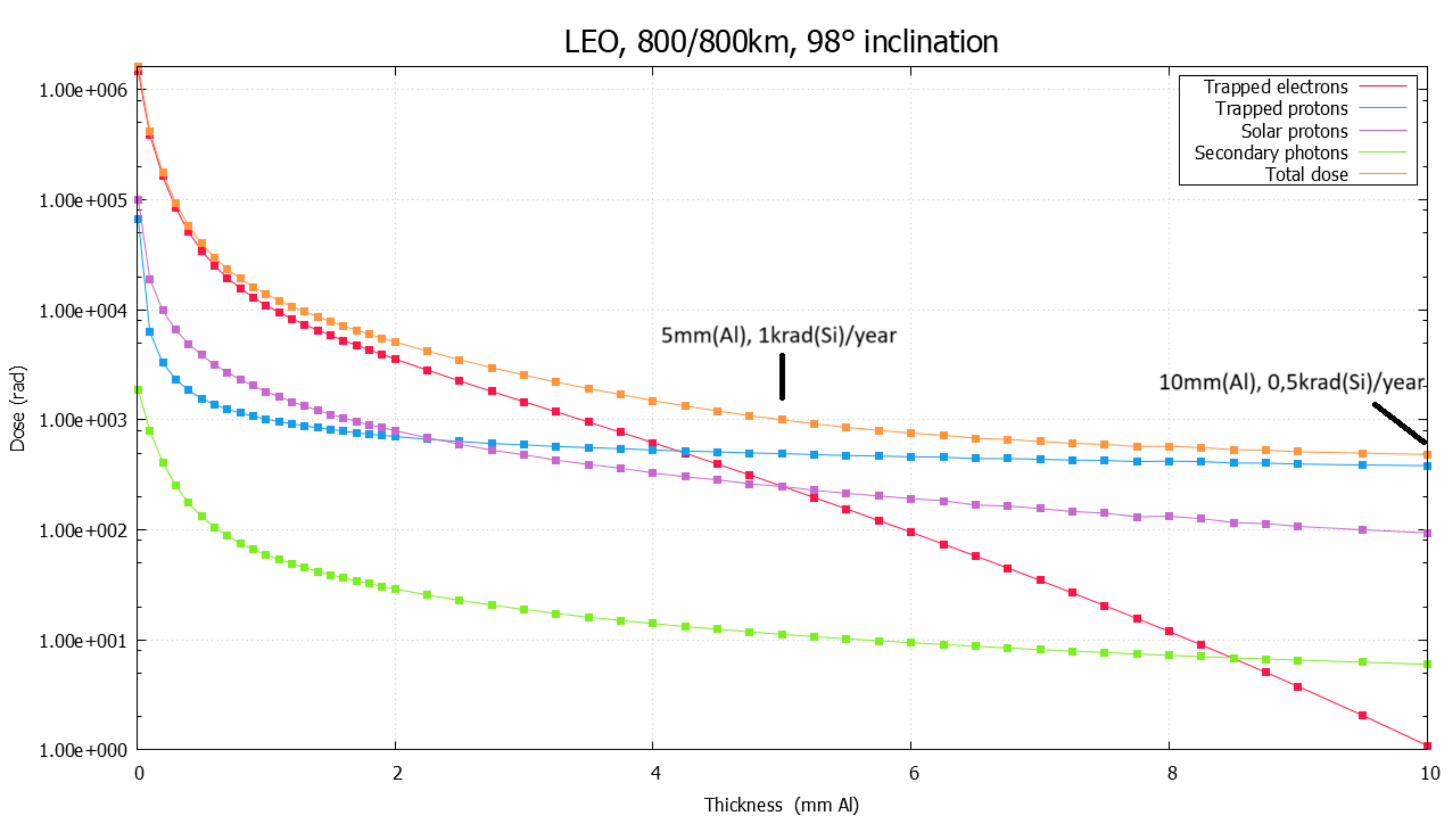
Space application origin: energetic particles
-Long-term/Cumulative effects (created charge trapped in dielectrics and degradation of crystal structure).
-Short term/Prompt effects (sudden charge creation in highly sensitive volumes, with destructive and non-destructive effects).

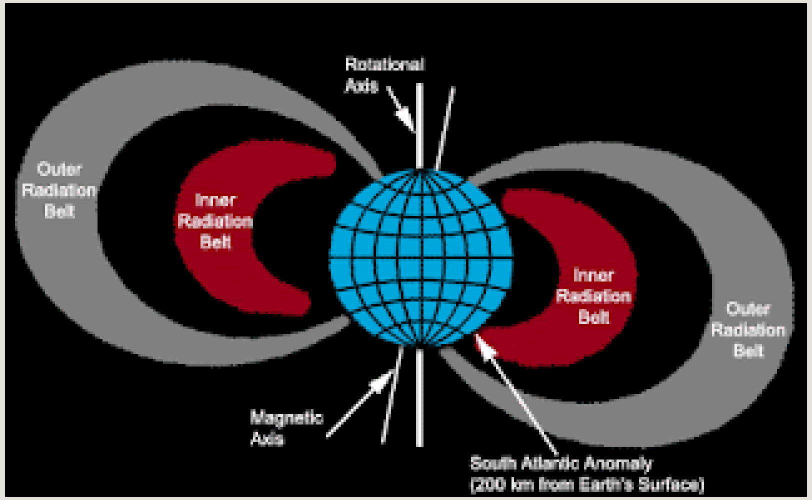
Test methods:
-TID test (electrons/photons)
-TNID test (protons/neutrons)
-SEE test (heavy ions/protons)

RHA is not concern for most COTS EEE parts original markets (industrial/consumer), or it is with a reduced scope (automotive, aeronautics)

Integrated Circuits	ECSS-Q-ST-60-15C	AEC-Q100	COTS vs space
TID test	ESCC-22900	NA	NA
TNID test	ESCC-22500	NA	NA
SEE test	ESCC-25100	JESD89-1/2/3	Limited SRAM and DRAM and mostly SEU

TID/TNID RHA for COTS EEE parts?

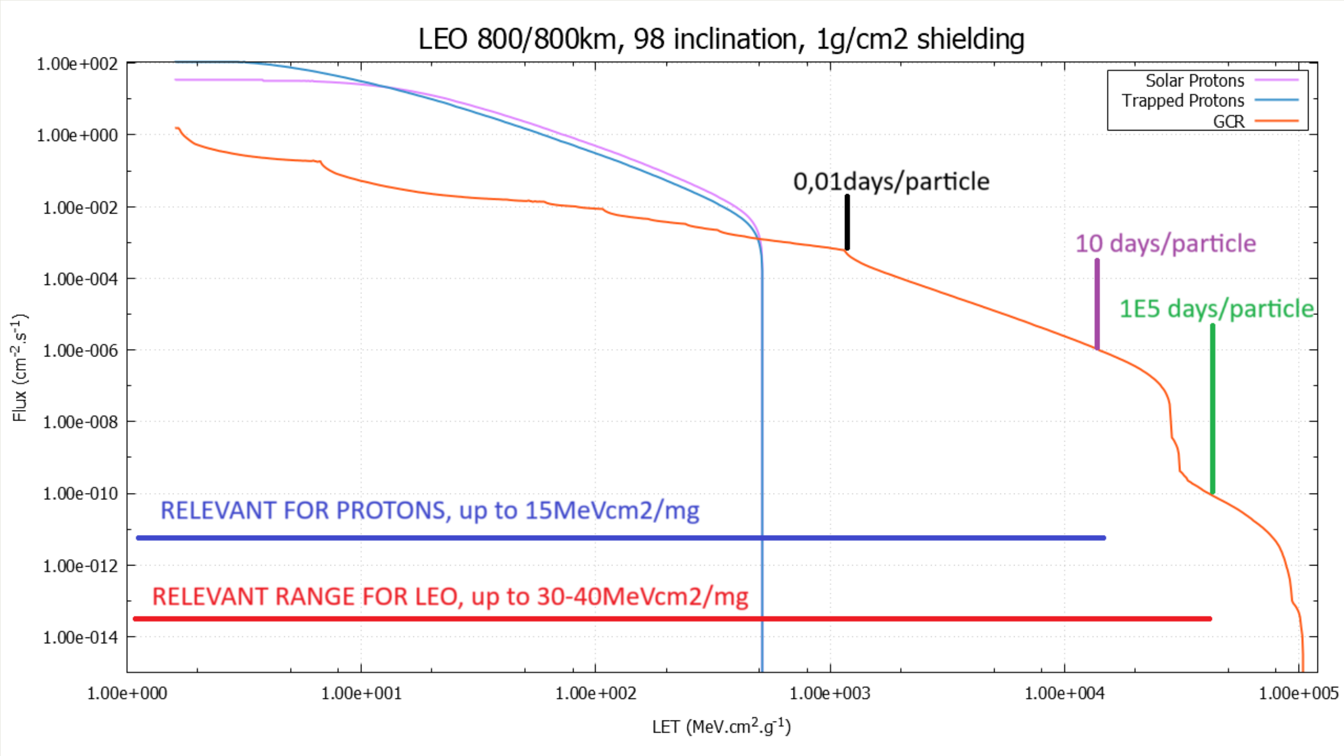




For the most popular LEO, for usual shielding in "new space", TID rate is very low, and TNID is below sensitivity limits for most technologies. Effects on performance are expected minor.

When no TID/TNID tested parts can be used, mitigation is based on board testing or flight without data, both at risk. Flight heritage gathered validates future usage, when flight conditions are representative or worst-case.

SEE RHA for COTS EEE parts?



-LEO, is not relevant for EEE parts with LETth>30*.
-For EEE parts with 15*<LETth<30*, heavy-ions in LEO are moderate relevant as per fluxes.
-For EEE parts with LETth<15*, heavy-ions and protons are high relevant as per fluxes.
*:MeVcm^2/mg

When no SEE tested parts can be used, mitigation is based on board proton testing or flight without data, both at risk. Flight heritage gathered validates future usage, under conditions. Proton testing doesn't cover all the range of interest. Design mitigations SEPEA/SEECA unsecured (tuned to EEE data, not available) or unfeasible (board size, power consumption, etc).

03

Developing Satellite Systems based on COTS

*Experienced **reliability challenges***

COTS status: an undergoing work

- Although the use of COTS in space is a debated topic since decades, the reality is that it is a young market → **There is no many options yet in the market, and even less well consolidated and reliable options**
- Immaturity of the market entails lack of clear and consolidated processes and/or standards to design, develop and test new components
- The remarkable growth of emerging companies and start-ups joining the space industry brings-up many different ways of thinking and working, which, although being essentially good, makes it more difficult to define such standarizations
- Fast technology evolution makes COTS development to struggle with time-to-market

⬇

- Design process which ignores important topics (SEE, outgassing, magnetisms, redundancy, etc.)
- Insufficient and/or not well focused environmental analysis and testing
- Functionality not fully tested

From requirement-driven to constraints-driven

SC design is contingent upon availability of COTS

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COTS which fullfil **all** the needs are rarely available

Some implications…

- Efforts to “**adapt**” what it is available → it may end up being more expensive and taking much more time than designing it from scratch (and the meaning of COTS is lost again)
- Many times, to cover one need the only available COTS include many other capabilities which are not required → **oversized** systems (because State-of-the-art is not always needed)

COTS is not always synonym of cheaper and faster
Important to analyse if COTS is really what the mission needs

From requirement-driven to constraints-driven

“Adapted” and/or oversized systems

⬇

Reliability issues

- To adapt a COTS implies modifications in its HW, FW or SW. This “invalidates” most of the previous efforts to ensure reliability: mechanical, thermal, radiation robustness is compromised; previous TRL is not fully applicable; etc.
- Oversized COTS usually implies more possible causes/modes of failure, as well as other extra issues such as more complicated thermal management.

When these reliability issues arised and time/cost are already to the limit, mitigation relies on:

QSL and EQSR exercise → identify more likely risks and focus the efforts on them

Tailoring COTS to mission environmental requirements

The task is usually not easy… Barriers to overcome:

1. Incomplete documentation
2. Radiation is frequently disregard
3. EMC is something like black-magic
4. Absence of logbooks – very difficult to know what happened to the unit you have bought before it arrives to your hands
5. Cleanliness is overlooked

Recommendations based on our experience:

- **Spend more time in RFQ process**: do not give anything for granted and put it explicitly
- **QSL and EQSR exercise** to have an overview of the status. If deemed necessary, negotiate a delta-evaluation.
- **Work together** with the manufacturer and make it a reciprocal relationship.

There is a general lack of a clear picture of the mínimum set of analysis and tests to be performed regarding environmental conditions.

ESA tailoring to ECSS [REF 5] gives some guidance, but still too foggy.

04

The need to push into new frontiers

Transfer of knowledge from other industries

- **Surveying COTS from other markets:**
  - ➢ Automotive market: AEC standards, USCAR standards, etc.
  - ➢ Aeronautics market: AQEC standards.
  - ➢ Telecommunications market: Telcordia/Bellcore standards.
  - ➢ “New space” market: branded as “enhanced plastic”, “radiation tolerant”, “hirel plastic”, “rad-hard plastic”, “space enhanced products”, “sub-QML”, etc.
  - ➢ Manufacturers’ standard quality and industrial/consumer grade: investigate EIA/JEDEC standards, CECC-IECQ standards, etc.
  - ➢ Medical market.
  - ➢ Nuclear plants, particle accelerators characterized devices.
- **Take the opportunity to transfer lessons from other industries.**
  - ➢ Specially regarding production, to achieve one of the most challenging goals that “satellite makers” are currently pursuing: deliver hundreds to thousands of satellites, quickly, reliably and affordably. [REF. 4]

New mission classifications

Indra Deimos defines quality and mission assurance levels, with requirements applicable to different products and services, to respond current space market performance, robustness, time to market and cost-driven needs. These levels are based on similar categorizations used by major European and North-American agencies [REF 7].These levels will consider a minimum coverage of product and quality assurance, with a range from higher (Q-Alfa) to lower (Q-Epsilon) as per each mission profile needs, including different reliability, lifetime and environmental conditions and applications.

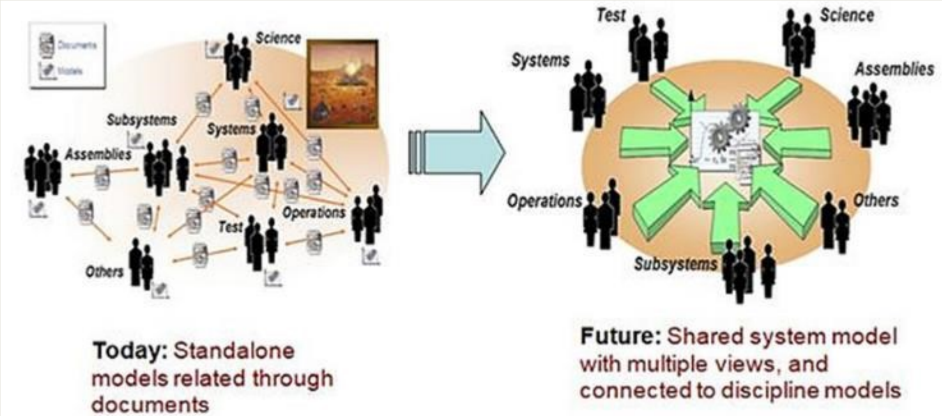
Indra Deimos Class type	Q-Alpha	Q-Beta	Q-Gamma	Q-Delta	Q-Epsilon
Criticality *(for client or Indra Deimos; flagship, strategic, impact, etc.)*	Extremely high	High	Medium	Low	Very low
Safety *(Manned, debris, etc.)*	Very high	High	Medium	Low	Very low
Cost *(for Indra Deimos)*	>xxxM€	xxM-xxM€	xxM-xxM€	xxM-xxM€	<xM€
Lifetime	>10 years	6-10 years	3-6 years	1-3 years	<1 year
Complexity	Very high	High	Medium	Low	Very low

This classification is very useful to define if COTS are suitable or not for the mission, and, if so, which level of reliability/assurance shall/can be requested to them

Adoption of agile working methodologies

Traditionally, system engineering is based on documents, but space systems are becoming too elaborate to manage with documents alone.

Besides, there is a need to **make data more accessible** and to ensure digital continuity throughout the lifecycle of a space mission, across disciplines and throughout supply chains.



Transformation from current practice -Traditional SE to future practice -MBSE Source: (Fosse, 2014).

To **improve process, quality and mission assurance** in the "New" Space paradigm, agile working methodologies, like MBSE and MBMA, need to be adopted

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References

References

1. “Small-Satellite Mission Failure Rates”. NASA/TM—2018– 220034. Stephen A. Jacklin. NASA Ames Research Center.
2. “Small Satellite Trending & Reliability 2009-2018”. 34th Annual Small Satellite Conference. Kara O’Donnell, Gregory Richardson. The Aerospace Corporation.
3. “Guidelines and Metrics for Assessing Space System Cost Estimates”. ISBN 978-0-8330-4023-7. Bernard Fox, Kevin Brancato, Brien Alkire. RAND Corporation.
4. “A REVIEW OF AUTOMOTIVE AND SPACE INDUSTRY PRODUCT DEVELOPMENT PRACTICES”. Proceedings of the International Annual Conference of the American Society for Engineering Management. Moore, James "Tony", ME; Adams, Jim, PhD; Sega, Ronald M, PhD
5. “Guidelines for the utilization of COTS components and modules in ESA”. Ref. ESA-TEC-TN-021473 Issue/Revision 2.0 Date of Issue 16/03/2022
6. NASA SOA Small Spacecraft Technology. *February 2025*
7. NASA Small Spacecraft Body of Knowledge (BoK) - https://www.nasa.gov/smallsat-institute/small-spacecraft-body-of-knowledge/
8. “The path towards increasing RAMS for novel complex missions based on CubeSat technology”. INDRA-DEIMOS contributed paper (PRESS RAMS): A. Cervone et al; CEAS Space Journal; July 2023
9. “SmallSat Mission Confidence Framework (MCF)”. Compilation by INDRA-DEIMOS: F.J. Belmonte; Rev. 02; 24/05/2023


Thank you for your attention!