Cost versus Reliability and Safety trade-off considerations for Systems with very long in-flight storage lifetime; a case study for Graveyard/ Deorbiting Systems

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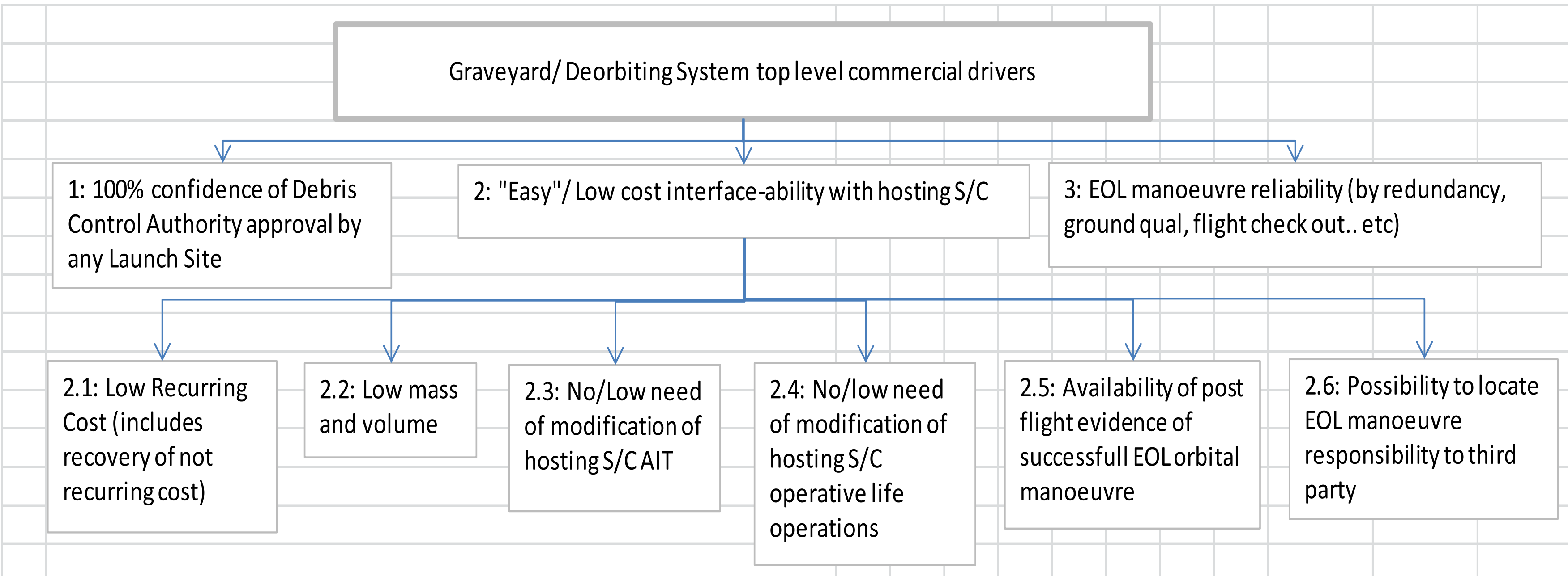
Top level commercial drivers and identification of conflict situations



Top level commercial drivers and identification of conflict situations

		1	2.1	2.2	2.3	2.4	2.5	2.6	3
1	100% confidence of Debris Control Authority approval by any Launch Site		**C**	no	no	**C**	no	**tbd**	no
2.1	Low Recurring Cost (includes recovery of not recurring cost)			**CC**	**C**	no	**CC**	**C**	**CC**
2.2	Low mass and volume				no	no	**C**	no	**C**
2.3	No/Low need of modification of hosting S/C AIT					no	no	no	**tbd**
2.4	No/low need of modification of hosting S/C operative life operations						no	**C**	**CC**
2.5	Availability of post flight evidence of successfull EOL orbital manoeuvre							no	no
2.6	Possibility to locate EOL manoeuvre responsibility to third party								no
3	EOL manoeuvre reliability (by redundancy, ground qual, flight check out.. etc)								

Legenda: C= conflicting req's; CC= strongly conflicting req's; no= not conflicting req's

Mission characteristics

<u>I - Long pre-operative flight storage time (and combined with orbital environmental conditions)</u>

This mainly for the graveyard mission in GEO, where nowadays communication operative missions lifetime are significantly exceeding 15 years.

<u>II – Existence of failure cases with potential population safety hazard (deorbiting)</u>

Both controlled and semi-controlled Earth Re-Entry manoeuvre are characterized by failure cases where anomalies on Propulsion or Attitude and Orbit Control HW/ SW could result in Earth footprint on populated areas with consequent risk of casualties.

<u>III- Existence of failure cases with potential direct damaging of third party properties (both Deorbiting and Graveyard)</u>

Typical of Graveyard manoeuvre is the case where, again, anomalies on Propulsion or Attitude and Orbit Control HW/ SW could result in impact on other GEO S/C or in satellite fragmentation so leading to a significantly higher probability of new collisions in the GEO protected zone. No specific limitation of such failure scenario seems defined by actual norms.

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Typical Trade-Offs definition and approach

- **TO1:** Deorbiting / Graveyard module functionally independent, or utilizing host SC H/W
- **TO2:** Deorbiting / Graveyard module physically independent, or with its HW integrated within the hosting SC
- **TO3:** More complex vs simpler (less performing) design; equipment and system levels
- **TO4:** Improvement of reliability by using extended qualification vs use of redundancy
- **TO5:** Reliability vs total cost (recurring)
- **TO6:** Trade Off for defining the detailed content of the in-flight check-out and the ranges of test results that can consent the execution of the EOL manoeuvre as planned
- **TO7:** Reliability calculation based on absolute worst cases, or on expected figures plus justified, quantitative margin (need to avoid non homogeneous review by the Launch Site Authorities)

TO1: Deorbiting / Graveyard module functionally independent, or utilizing host SC H/W

Legenda: +++: strongly preferred; +: preferred; -= not preferred

Trade Off Options	Recurring cost	Not Recurring cost (1)	Schedule and AIT	Host SC easy IF & intrusivity	Easy of approval/ qualif.	Mass and Volume	Debris respons. focusing
Functionally independent wrt hosting SC	---	+++	+++	+++	+++	---	+++
Partly utilizing hosting SC capabilities	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Utilizing at max extent hosting SC capabilities	+++	-	--	---	--	+++	---

Notes:

(1): with consequent impact on recurring cost as well

(2): it depends from the detail of the residual equipment integration within hosting SC

TO4: Improvement of reliability by using extended qualification vs use of redundancy

Legenda: +++: strongly preferred; +: preferred; -= not preferred

Trade Off Options	Recurring cost	Not Recurring cost (1)	Schedule and AIT	Host SC easy IF & intrusivity	Easy of approval/ qualif.	Mass and Volume	Debris respons. focusing
Max use of extended qualification	+++	---	+	Na	-	++	Na
Intermediate approach	(2)	(2)	(2)	Na	(2)	(2)	(2)
Max use of redundancy	---	+++	-	na	+	--	Na

Notes:

(1): with consequent impact on recurring cost as well

(2): it depends from the detail of the residual equipment integration within hosting SC

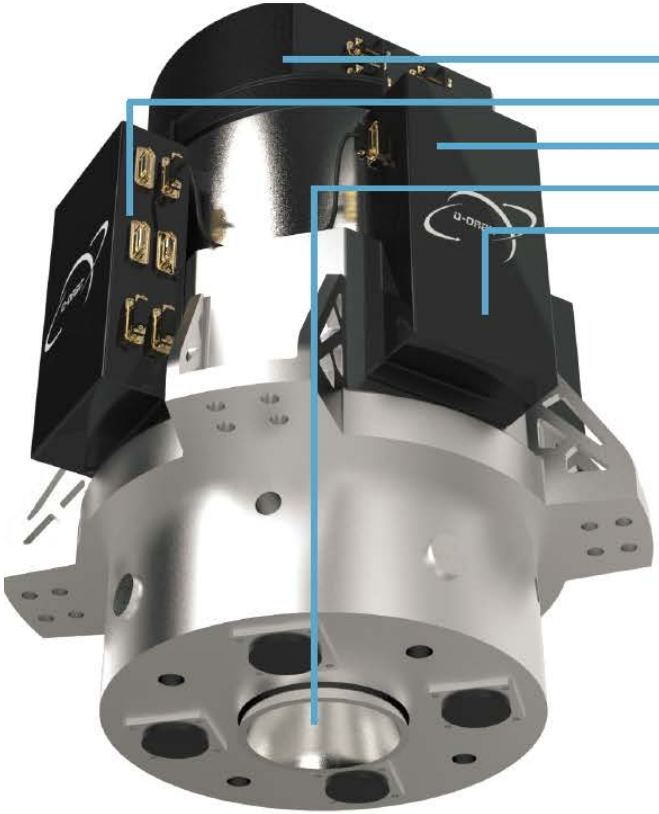
Case study: standardized add-on module for Graveyard/Deorbiting manoeuvre of GEO/LEO host spacecraft (D-Orbit)

TO1	Functionally independent wrt hosting SC	Partly utilizing hosting SC capabilities	Utilizing at max extent hosting SC capabilities	
TO2	Physically independent wrt hosting SC	Partly integrated within the hosting SC	Integrated within the hosting SC	(1)
TO3	Max use of more complex (and more performant) equipment	Max use of simpler design (and additional margins)		
TO4	Max use of extended qualification	Intermediate approach	Max use of redundancy	(2)
TO5	Reliability at the minimum allowed by norms	Higher reliability due to cost of failure		(3)
TO6	Extended in-flight check-out	Intermediate approach	Minimum in-flight check-out	(3)
TO7	Reliability calculation based on absolute worst cases	Reliability calculation based on expected figures plus justified, quantitative margin		(4)

Legenda: Actual design based on Trade Off options in yellow

(1)In order to minimize total mass and volume, approach is to utilize "add-on" independent equipment, but integrated in the host S/C layout
(2) Redundancy utilized where impact on mas and volume is minor only
(3)Trade-off analyses still running
(4)Simultaneous occurrence of worst case independent scenarios is not realistic and leads to very penalizing figures

D-Orbit's Decommissioning System Layout



All D3 classes can be configured with a dedicated Thrust Vector Control and Terminal Attitude Unit

Design

- **Telemetry, Tracking and Command (TT&C)**
- **Electrical Power Subsystem (EPS)**
- **Electro-Explosive Subsystem (EES)**
- **Solid Rocket Motor**
- **Command and Control Unit (CCU)**

Electrical Interfaces

(customizable upon request)

Power Interface	24/28 V
Data Interface	MIL-STD-1553 / CAN / SpaceWire

Quality and Reliability

Compliance with Safety Standard MIL-STD-1573

Components Level	SCC-B to Extended Range
Predicted Reliability	> 0.999
Fail-Safe Architecture	• Single-point-of-failure free • Critical software B-class

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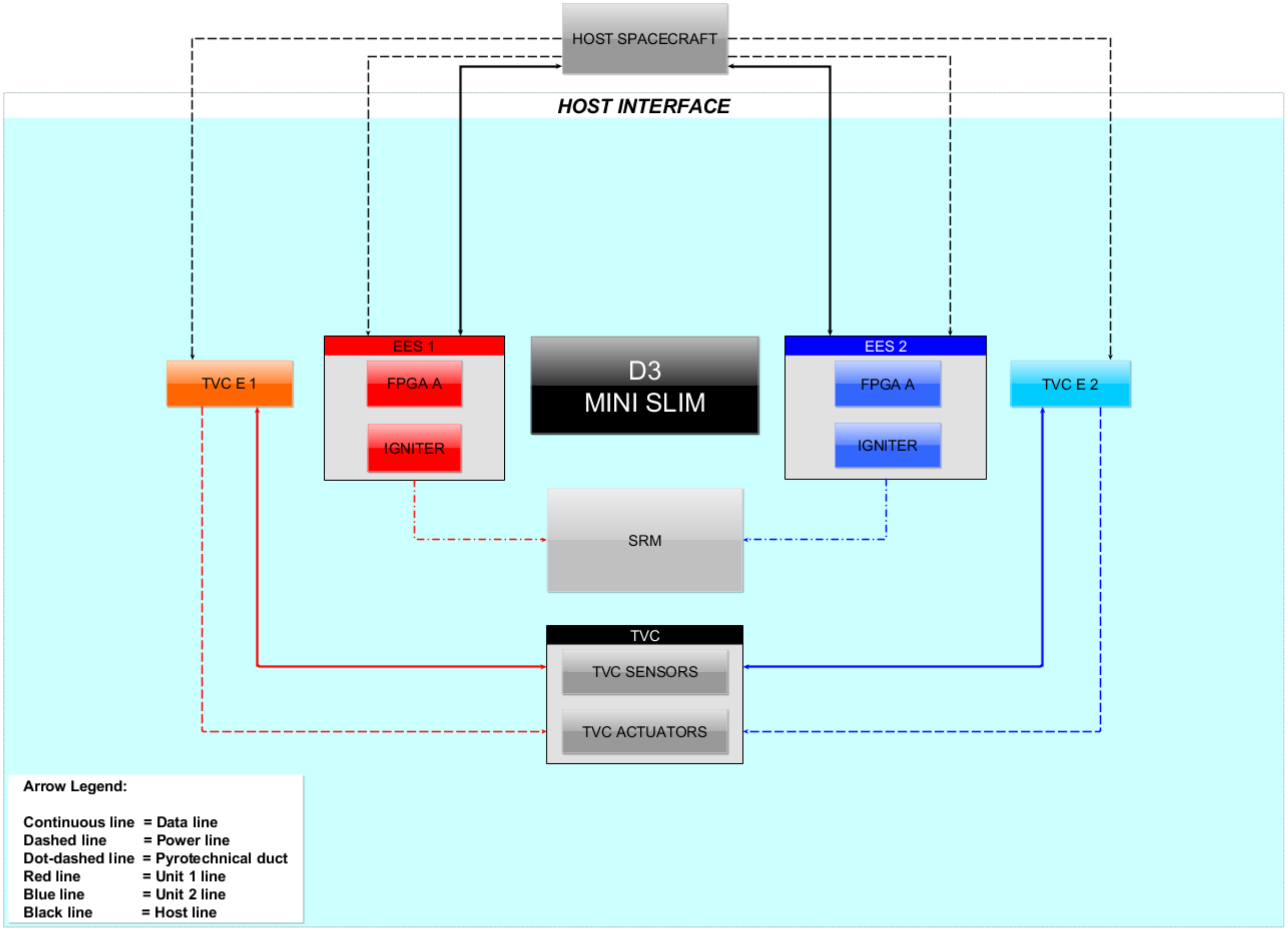
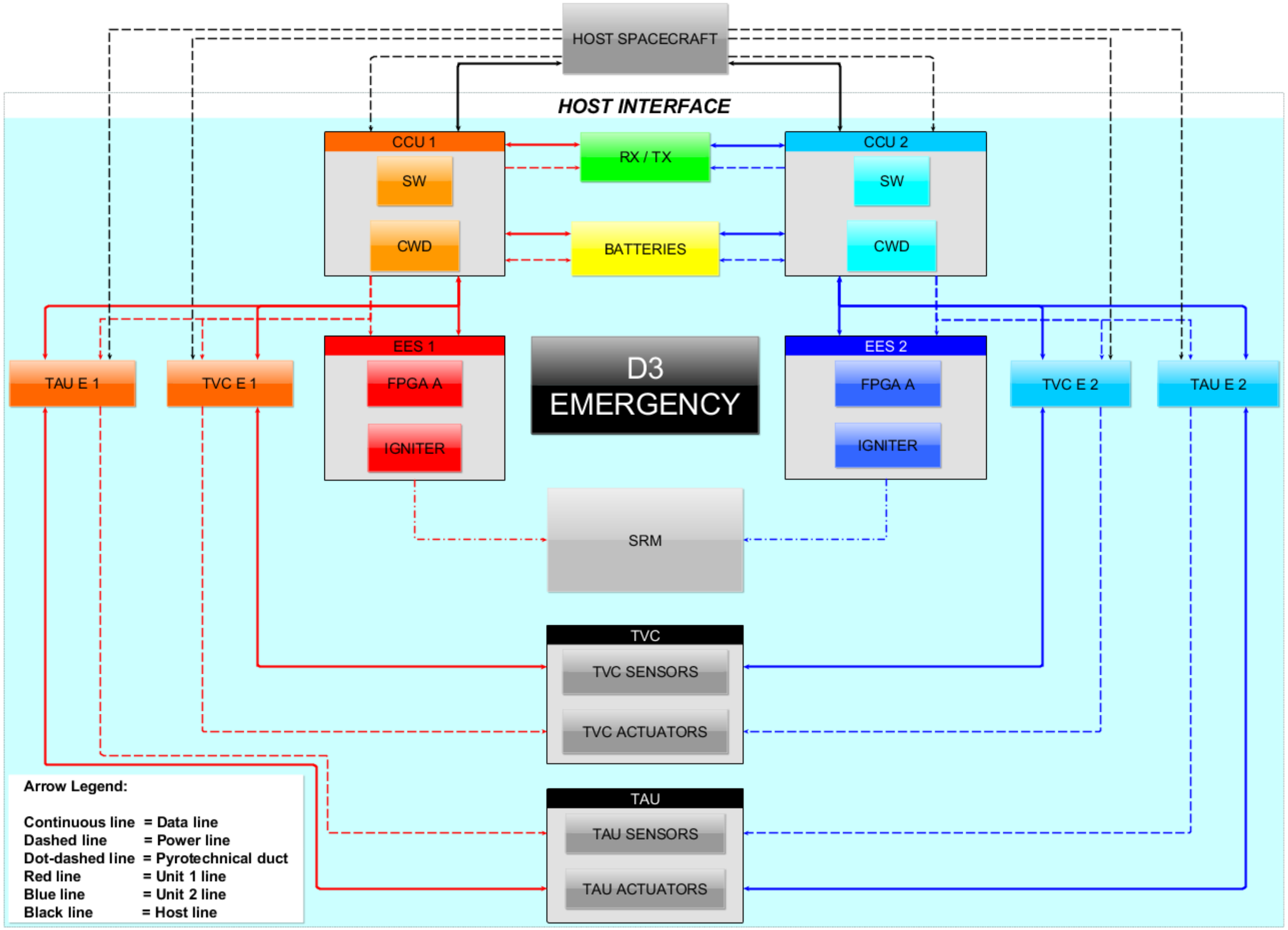
D-Orbit module schematic: Dependent for AOCS, communication, power aspects and computational aspects



Note: Decommissioning module within the blue highlighted area

D-Orbit module schematic: fully authonomous



Note: Decommissioning module within the blue highlighted area

D-Orbit's Decommissioning System Layout

CLASS	Ex. Application	SLIM CONFIGURATION (Basic)		STANDARD CONFIGURATION (with Telemetry, Tracking and Control subsystems)	
		Mass [kg]	Envelope [mm]	Mass [kg]	Envelope [mm]
D3.S20	**200kg/500km**	22	320x320x300	22	320x320x350
D3.C180	**1.1ton/750km**	144	1000x1000x500	146kg	1000x1000x550
D3.C360	**2.4ton/700km**	221	1100x500x900	223	1100x500x1000
D3.MEO	**800kg/23000km**	21	350x350x400	23	350x350x450
D3.GEO	**4ton/36000km**	38	350x350x500	40	350x350x450
D3.GEO	**6ton/36000km**	46	350x350x500	48	350x350x550

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