Solid Propellant Autonomous DE-Orbit System [SPADES]

Solid Propellant Rocket Motor development

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SPADES introduction

SPADES is:

- Cross-cutting system to support the compliance of future missions with the space debris mitigation requirements.

- Builds upon previous work and serves as a start point for future developments from ESA side in the area of solid propulsion de-orbit systems

SPADES introduction

SPADES could serve on:

(Main design drivers)

1. **Larger LEO satellites**, usually with hydrazine propulsion systems, that shall re-enter in a controlled way;

2. **Upper stages and jettisoned components** (e.g. SYLDA, SPELTRA) from GTO, to re-enter them in a controlled way / remove them from orbit immediately;

3. **Small satellites in LEO** without propulsion system, to make sure these re-enter within 25 years

4. **Multiple Active Debris Removal missions**, where clusters of solid rocket motors provide space debris with the required velocity increment for controlled deorbit.

SPADES introduction

SPADES could serve on:

5. **GEO satellites**, for re-orbiting them to graveyard orbits (0 degrees inclination. For GEO these are stable orbits)
6. **MEO satellites**, for re-orbiting them to graveyard orbits (higher inclination orbits. For MEO these are not all stable orbits)

SPADES introduction

SPADES can be tailored to specific needs:

1. Provide **basic velocity increment** for de-orbiting (only the SRMs)
2. **Autonomously de-orbit a spacecraft when control of the spacecraft has been lost** (a complete system with SRMs, avionics, thermal control, communication etc.)

NOTE: the SPADES system is installed in the satellite prior to launch.

SPADES introduction

This presentation:

1. Focus on the propulsive aspects of the system

2. Single motors and cluster configuration

1. Size of standardized solid rocket motor that is still adaptable to specific needs

2. System level comparison with other propulsive systems

BACKGROUND

1. ESA programs shall comply with IPOL and French space law:
    - Reenter within 25 years
    - Risk of casualties on ground shall be less than 1/10000
2. A possible way to deal with the issues of space debris is by introducing a velocity increment to the object In order to de-/re-orbit it. The introduction of these velocity increments has since the dawn of the space age in 1957 been realized with help of rocket technology
3. The main advantages of a solid propellant based system are the reliability, simplicity, relatively high specific impulse, high density impulse, relatively high thrust and the facts that the system could be made autonomous, due to its low power requirement and short operation time.

BACKGROUND

4. IPOL also excludes the release of particulate matter in orbit → Aluminium free propellant is being developed.

5. No Al_2O_3 → Hard particles damaging other spacecraft

6. No liquid Aluminium deposit on the nozzle rim inside the motor or may form a pool of molten Aluminium inside the motor, when submerged nozzles are being used.

7. Lower combustion temperature and therefore / also a lower eroding effect on motor parts such as e.g. throat, nozzle and TVC systems.

8. Lower specific impulse due to absence of aluminium might be compensated by larger possible expansion ratios

BASICS of de-/re-orbiting

De-orbiting (controlled)

1. Choose re-entry position above an unpopulated area
2. Uncontrolled de-orbit can still be performed if the object raises a casualty risk on ground $<10^{-4}$.
3. Swift de-orbit reduces in-orbit time of the decommissioned spacecraft
4. The chance of being hit by other objects
5. Decreased chance that batteries, tanks etc. might explode.
6. No need to implement means to passivate the spacecraft
7. Reduces tracking needs
8. Reduces the number of avoidance manoeuvres by other satellites
9. (Autonomous) system allows all liquid propellant to be used for the mission itself / commercial activities

BASICS of de-/re-orbiting

Re-orbiting

1. (Autonomous) system allows all liquid propellant to be used for the mission itself / commercial activities
2. Development can easily spin off from de-orbiting since re-orbiting does not impose the major design drivers.

MOTOR GENERAL DESIGN

Motor clustering

1. With standardized motors, different numbers of motors could be clustered in order to deliver the desirable total impulse that matches the needs to deorbit from a particular orbit with a particular satellite mass.
2. Cheaper to produce,
3. Standardized,
4. Simple, easily adaptable and easy to manufacture.
5. Lower overall thermal protection mass

→ How many different motor designs are necessary?

MOTOR GENERAL DESIGN

Motor clustering

The range in required total impulses is just too large for a single motor design

- Satellites ranges from 10000 kg to 25 kg
- Orbit ranges from even more than 800 km to even less than 400 km

Analysis showed that at least two motor designs were required, but that it was best to complement this with a third standardized motor design.

In principle, a standard intermediate motor would be capable, in a reduced-length (“chopped” motor), to de-/re-orbit small satellites

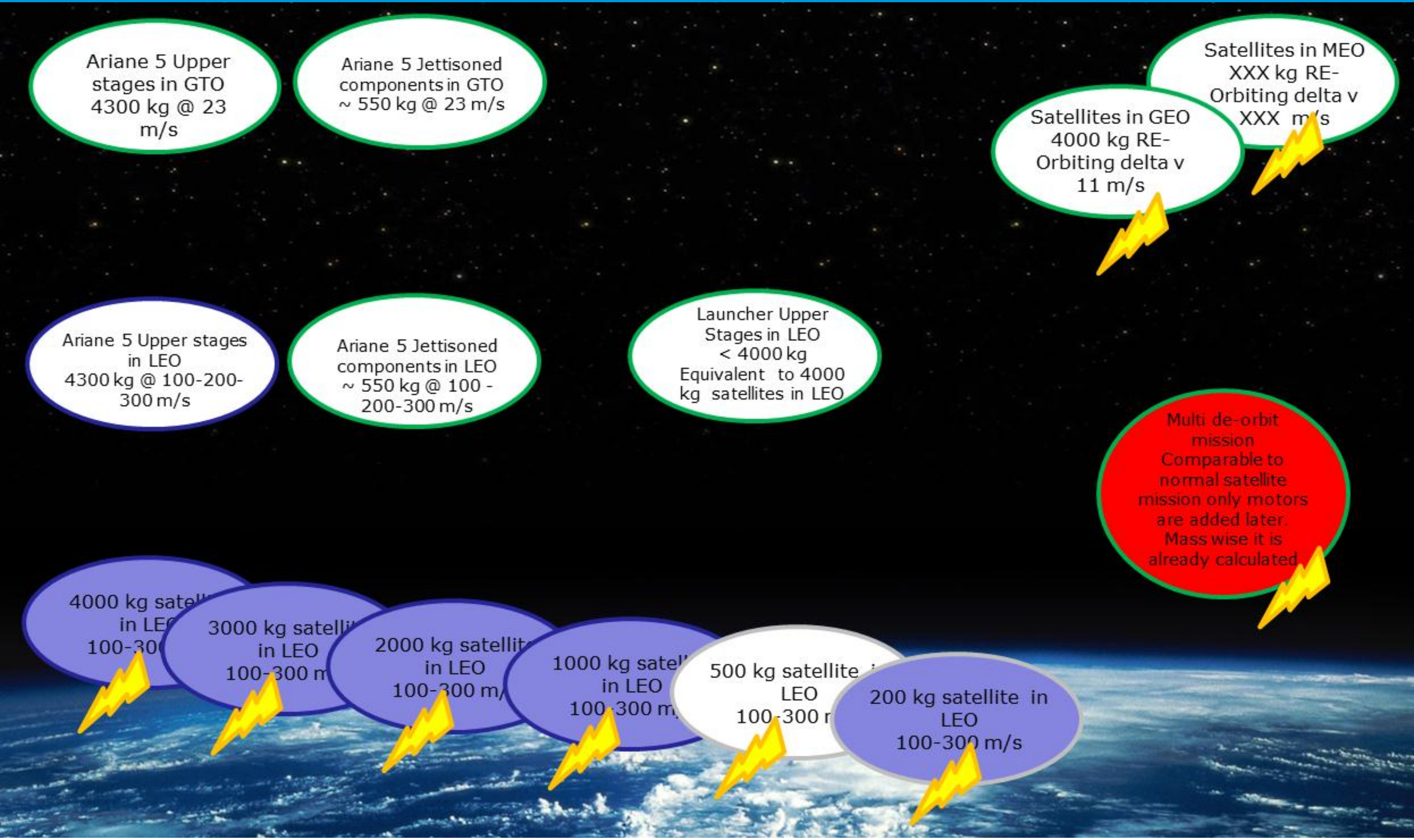
MOTOR GENERAL DESIGN

Risk analysis showed that too large clusters would bring the reliability of the system down to levels below those of liquid propulsion systems.

Therefore the number of motors that are clustered together should not go above ≈ 8.

Clusters with more than 8 motors could still be used but, then the SPADES system can not claim highest reliability anymore.

MOTOR SIZING



Ariane 5 Upper stages in GTO
4300 kg @ 23 m/s

Ariane 5 Jettisoned components in GTO
~ 550 kg @ 23 m/s

Satellites in MEO
XXX kg RE-Orbiting delta v
XXX m/s

Satellites in GEO
4000 kg RE-Orbiting delta v
11 m/s

Ariane 5 Upper stages in LEO
4300 kg @ 100-200-300 m/s

Ariane 5 Jettisoned components in LEO
~ 550 kg @ 100 - 200-300 m/s

Launcher Upper Stages in LEO
< 4000 kg
Equivalent to 4000 kg satellites in LEO

Multi de-orbit mission
Comparable to normal satellite mission only motors are added later.
Mass wise it is already calculated

4000 kg satel
in LE
100-30

3000 kg satelli
in LEO
100-300 m

2000 kg satellit
in LEO
100-300 m/

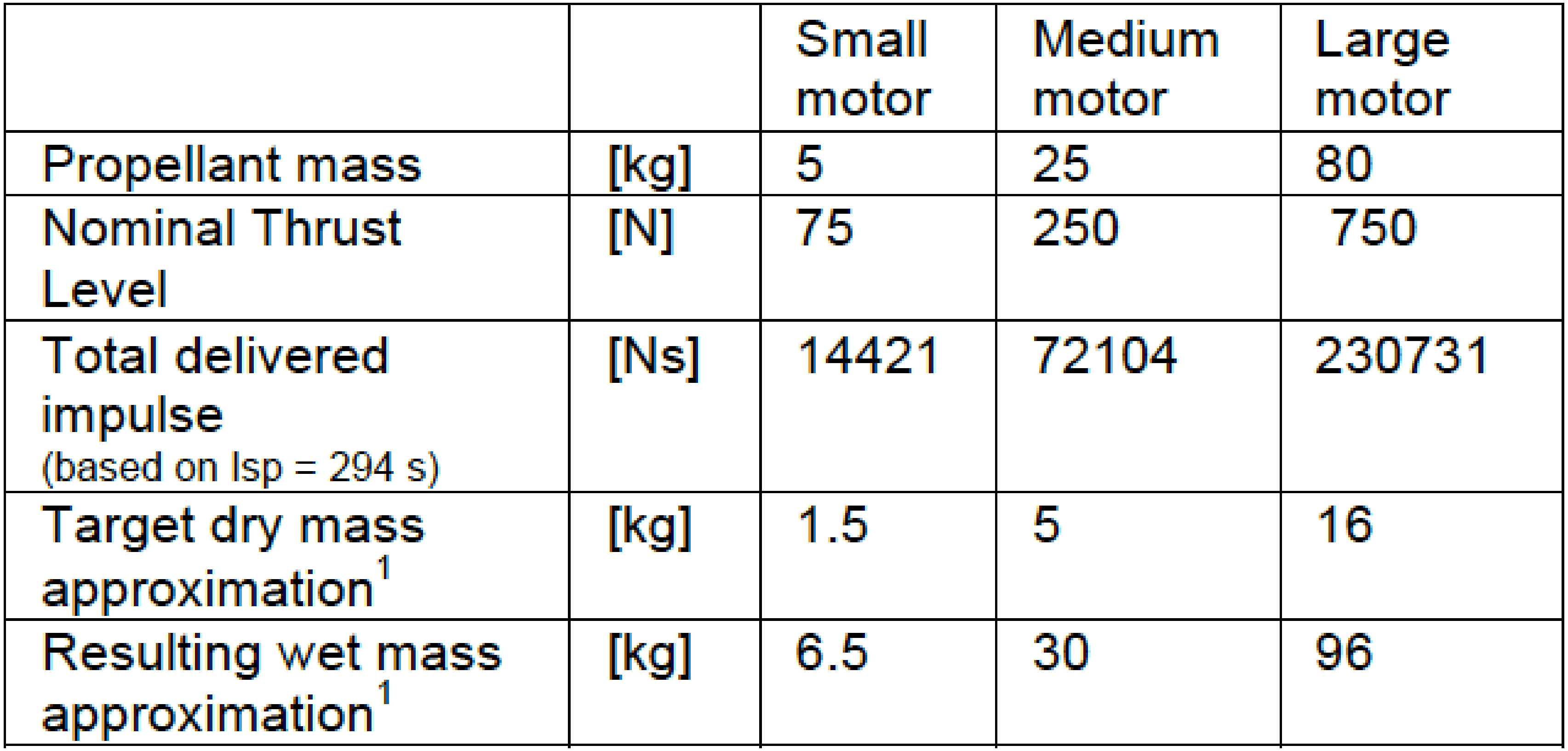
1000 kg satel
in LEO
100-300 m

500 kg satellite
LEO
100-300 r

200 kg satellite in
LEO
100-300 m/s

Variety of missions to be de-orbited or re-orbited.

MOTOR SIZING

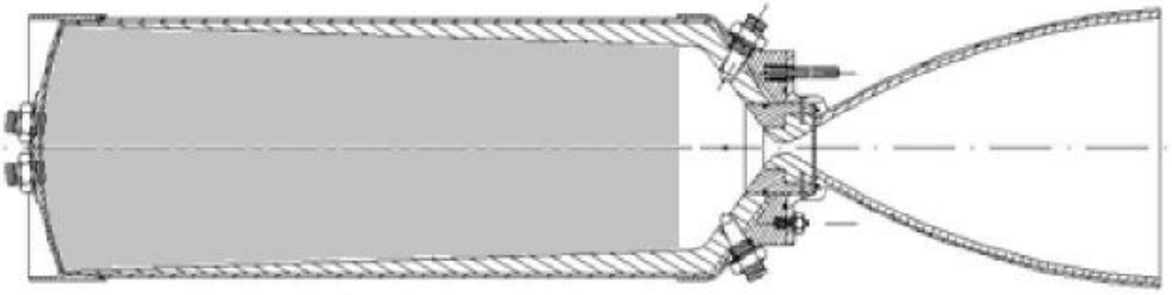


		Small motor	Medium motor	Large motor
Propellant mass	[kg]	5	25	80
Nominal Thrust Level	[N]	75	250	750
Total delivered impulse (based on Isp = 294 s)	[Ns]	14421	72104	230731
Target dry mass approximation[1]	[kg]	1.5	5	16
Resulting wet mass approximation[1]	[kg]	6.5	30	96

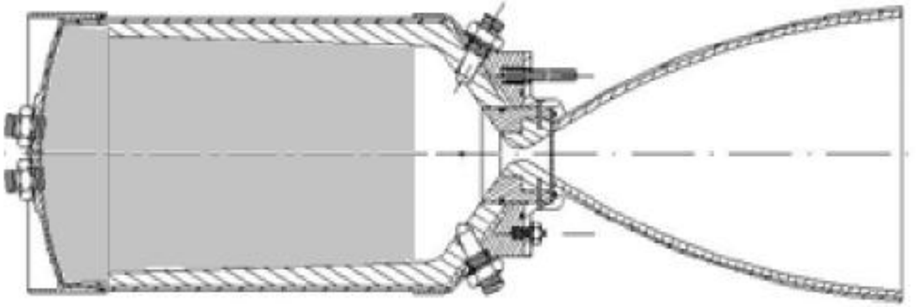
Standardized cluster motor characteristics

MOTOR ADAPTATION

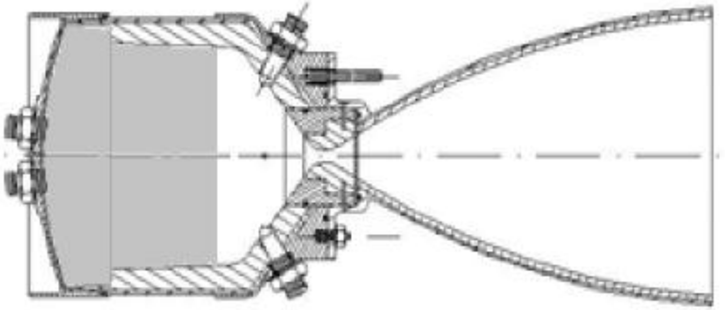
Conceptual design of a solid propellant de-orbit motor (top),



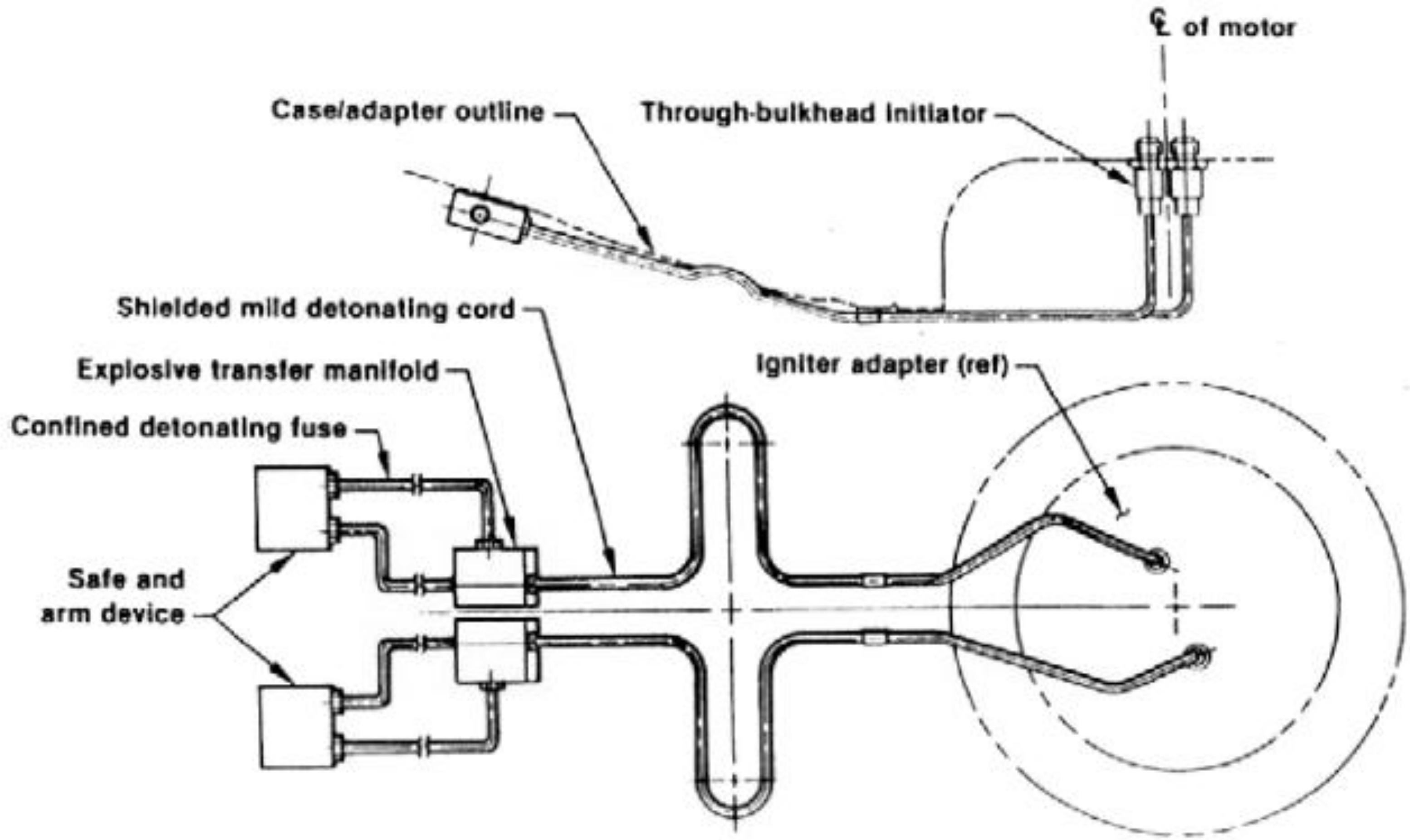
Adapted motor with intermediate propellant grain length (centre)



Adapted motor with shortest propellant grain length (bottom)



MOTOR ADAPTATION



Example of an ignition chain

SPADES SYSTEM requirements

SPADES shall be able to perform a safe controlled de-orbit or re-orbit of the host system according to the Space Debris mitigation requirements from ESA IPOL using Solid Rocket Motors.

SPADES shall be designed to be capable to de-/re-orbit different space objects from different Earth orbits. (LEO, MEO, HEO, GTO, GEO, Lagrange Points)

SPADES shall be able to de-/re-orbit the host object after any end-of-life scenario, except after a fragmentation event.

The mission requirements of the host mission shall not be altered due to the use of SPADES.

SPADES SYSTEM requirements

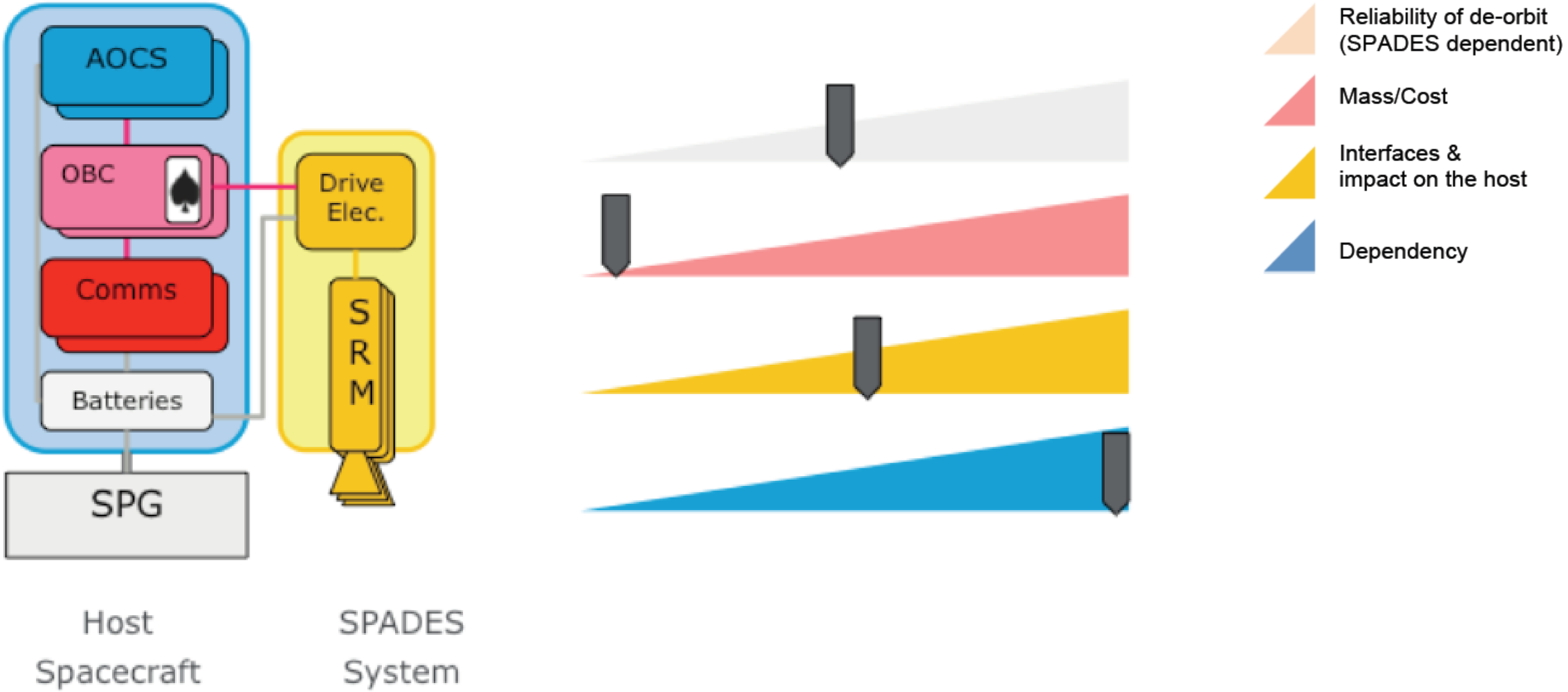
SPADES shall only be activated through dedicated ground command.

SPADES shall comply with the safety engineering requirements of ECSS-ST-Q-40C, which means a dual failure tolerance for functions that might cause a catastrophic event.

→

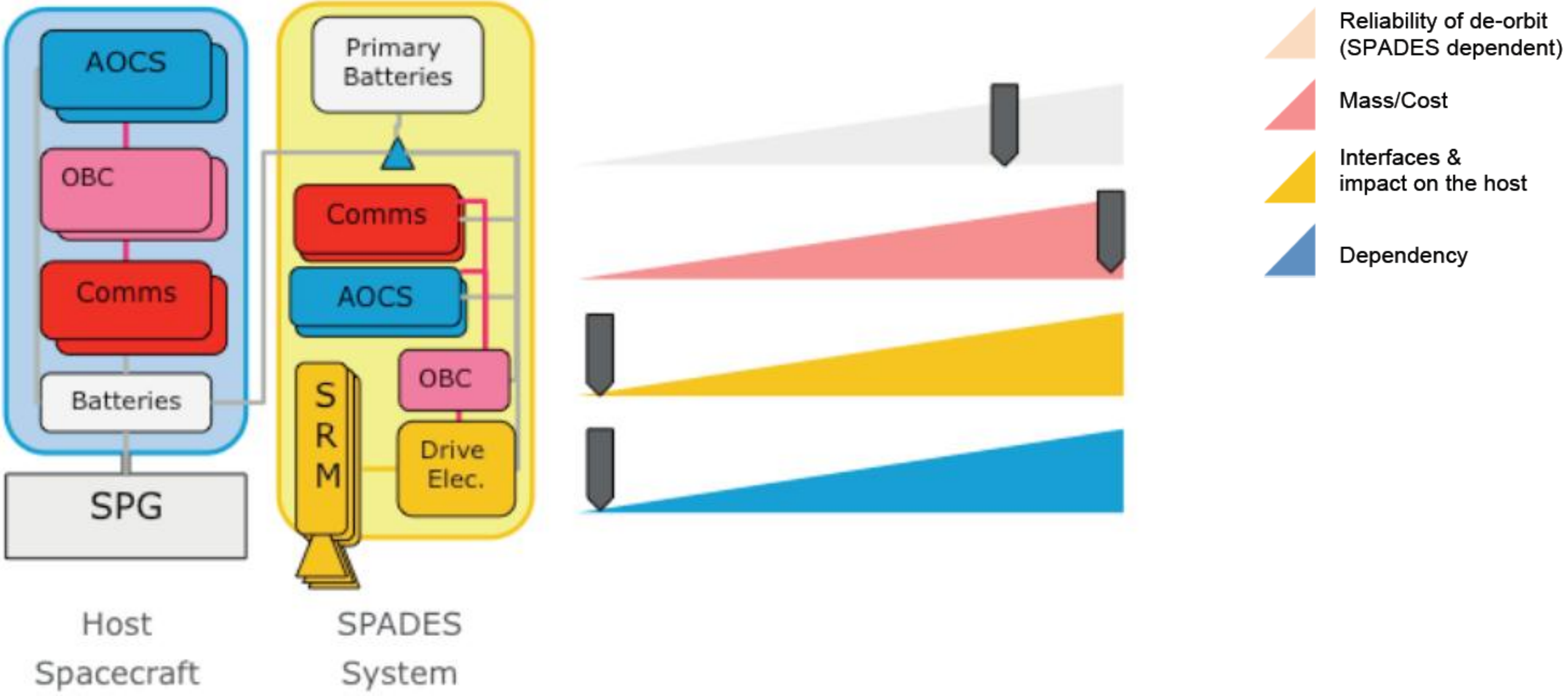
Based on these requirements the study team designed a system that, similar to the clustered rocket motors, would be modular. That way the system can be built in a way that it is less or more dependent on host spacecraft systems according to the customer wishes.

SPADES SYSTEM modularity, basic package



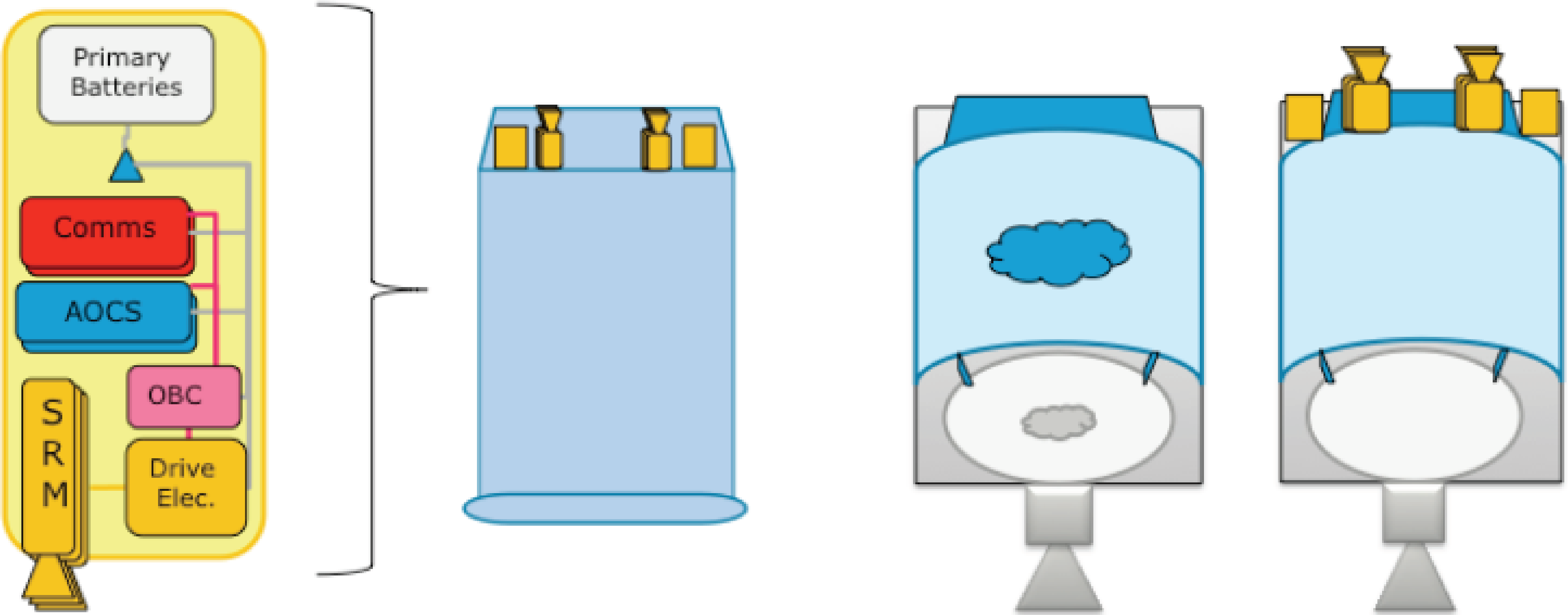
SPADES basic package applied to small spacecraft.

SPADES SYSTEM modularity, full independent



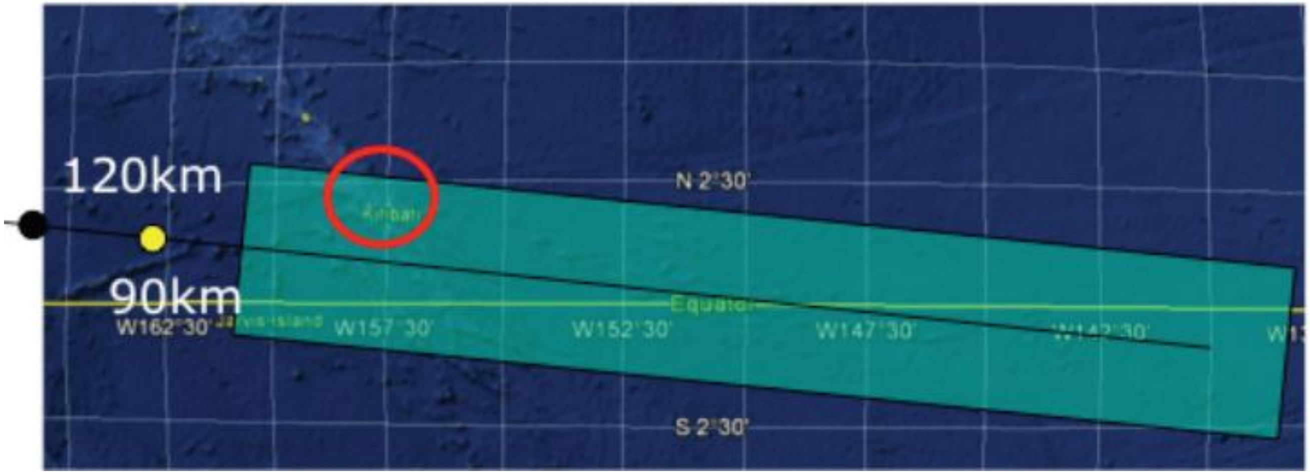
The SPADES full independent package applied to large spacecraft

SPADES SYSTEM upper stages, sylda speltra

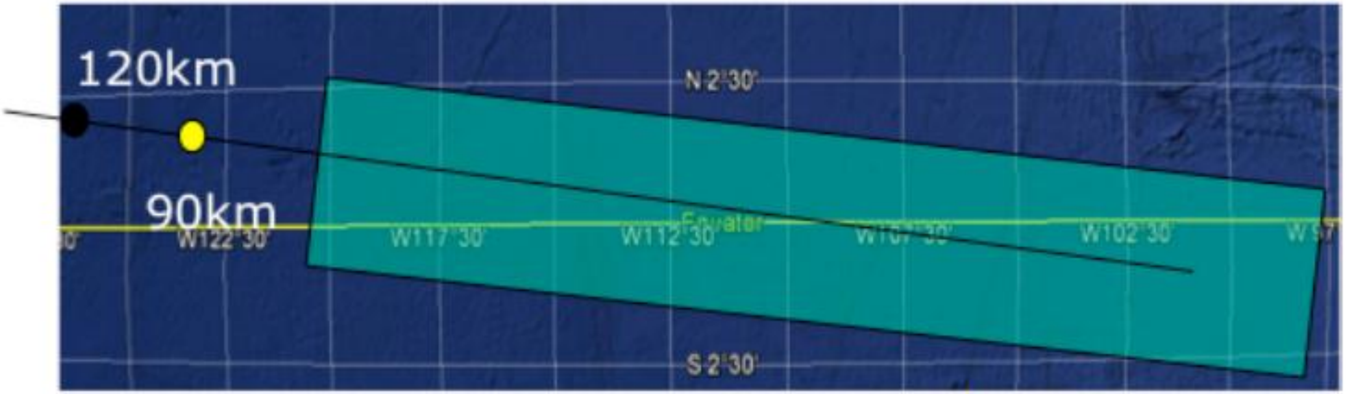


De-orbiting SYLDA or SPELTRA (left) and an upper stage (right)

SPADES SYSTEM upper stages, sylda speltra

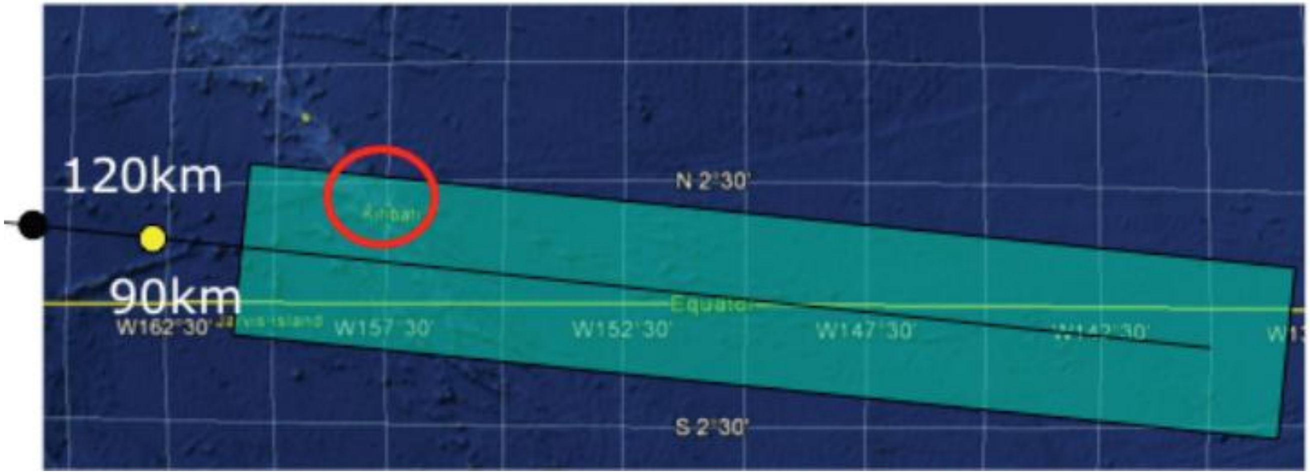


Typical impact footprint for GTO Apogee de-orbit burn (Kourou launched Ariane 5ME)



Typical impact footprint for GTO 3rd Apogee de-orbit burn

SPADES SYSTEM upper stages, sylda speltra



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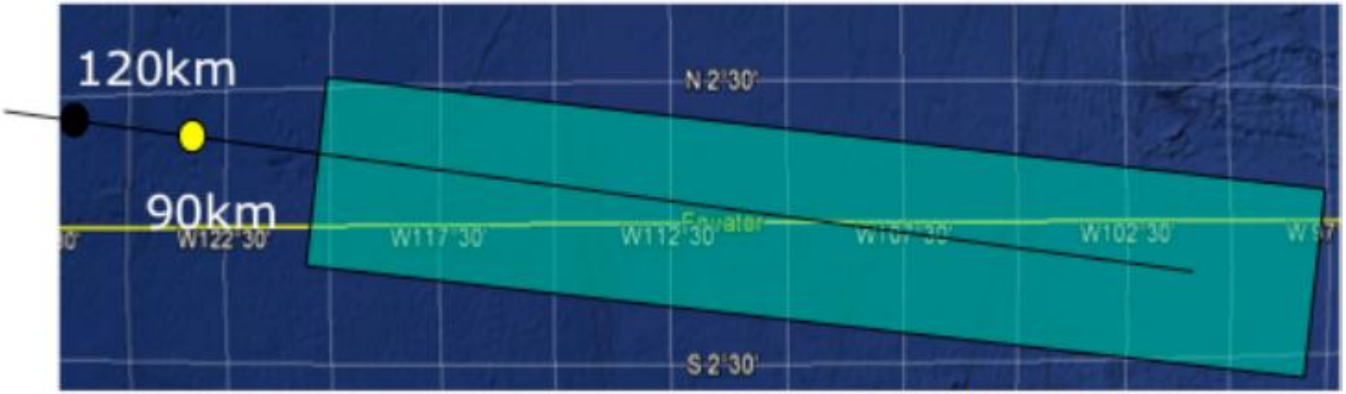
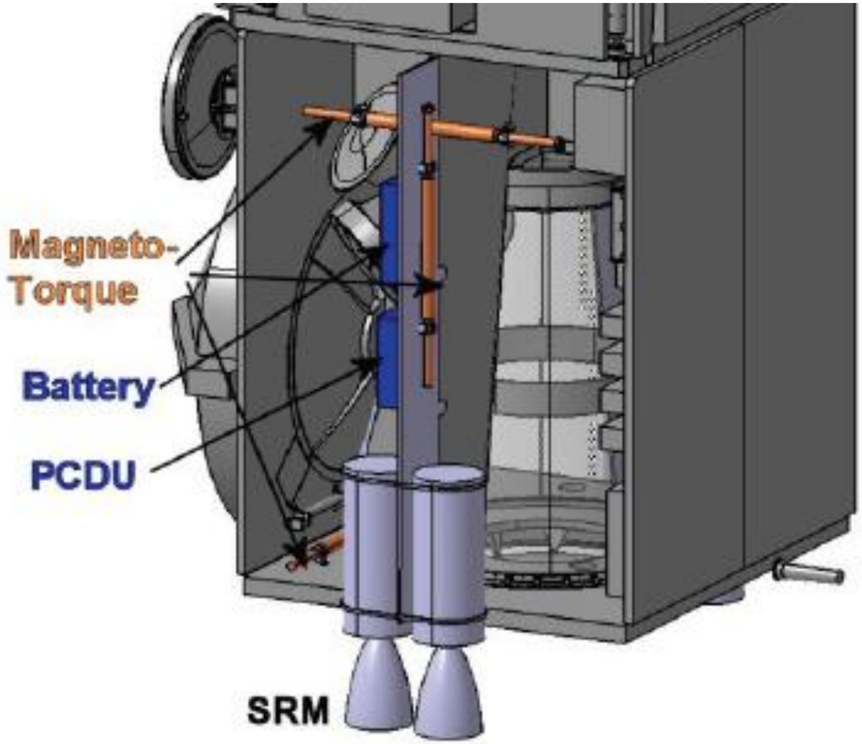


Typical impact footprint for GTO 3rd Apogee de-orbit burn

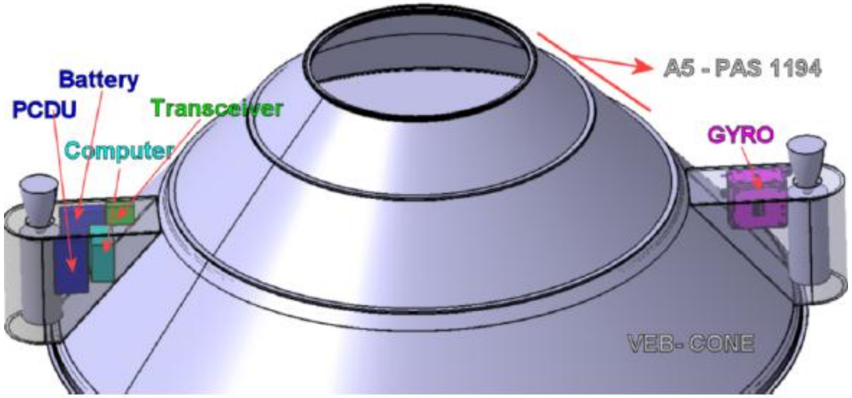
3rd Apogee de-orbit burn: 23 m/s EOL of upper stage de-orbit burn 200 m/s + 73 m/s

SPADES SYSTEM in LEO

SPADES LEO 800 km SSO – fully independent			
Mass	Host	dry	1336 kg
		wet (excl. adapter)	1429 kg
	SPADES	dry	139 kg
		wet	246 kg
AOCS	Sensors	6 x Fine sun sensors	
		2 x Gyro	
		2 x Magnetometer	
	Actuator	3 x Magnetic torquers	
		TVC	
Prop.	Solid propellant system		
	4/2 cluster (4 SRMs, 2 firing simultaneously)		
	Providing de-orbit Δv of 216 m/s with a < 0.04 g		
Power	Automatically activated in case of host power bus failure		
	Battery	Li-SOCl$_2$ primary battery	
		48 cells (8s6p) (1 redundant string)	
		Total energy: 643 Wh	
	Bus	15 V regulated bus	
Comm.	All S-Band system		
	2 x Transceiver		
	2 x fixed LGA for 4π coverage		
Thermal	MLI, heaters, black paint, SSM, radiator, heat switch		
	Internal (inside host) configuration for improved thermal conditions		
DHS	OBC	OSCAR based	
Structure	Support rings, adapter and support plates, brackets, interface rings		



SPADES SYSTEM in GTO



SPADES GTO – fully independent			
Mass	Host	dry	5533 kg
	SPADES	dry	89 kg
		wet	136 kg
AOCS	Sensors	4 x Fine sun sensors	
		1 x Gyro	
Prop.	Solid propellant system		
	2 SRMs (firing simultaneously)		
	Providing de-orbit Δv of 30 m/s with a < 0.04 g		
Power	Automatically activated at launch or at end of the nominal mission		
	Battery	Li-SOCl_2 primary battery	
		48 cells (8s6p) (1 redundant string)	
		Total energy: 1210 Wh	
	Bus	15 V regulated bus	
Comm.	All S-Band system		
	2 x Transceiver		
	2 x fixed LGA for 4π coverage		
Thermal	MLI, heaters, black paint, SSM, radiator, heat switch		
DHS	OBC	OSCAR based	
Structure	Accommodation on the cone between VEB-ESC and Ariane 5 adaptor PAS 1194VS		
	Interface plates, closing panels		

SPADES SYSTEM comparison

		Δ Mass			Cost change [%]	Reliab. change [%]
		Total [kg]	Dry [kg]	Prop. [kg]		
Small LEO reference satellite < 200 kg	Added Hydrazine	24	16.2	8	110	94
	SPADES	14	8.4	6	108	98
	Bi-Prop	N/A	N/A	N/A	N/A	N/A
Medium LEO 1000 kg - 2000 kg reference satellite	Added Hydrazine	328	168	160	107	94
	SPADES	165	59	106	103	98
	Bi-Prop	272	197	75	109	97
Large LEO > 2000 kg reference satellite	Added Hydrazine	754	246	508	107	94
	SPADES	450	115	335	106	96
	Bi-Prop	488	255	233	112	97

SPADES development roadmap

Contracts have been issued and are being issued

“Performance Assessment of Aluminium Free Solid Propellant”.

Has been issued.

“Solid Propellant De-Orbit Motor Engineering Model (EM) Development”

The objective of the activity is to design, manufacture, test, document and deliver three engineering or pre-qualification models of a solid propellant rocket motor, including its ignition system for de-orbiting satellites.

“Thrust Vector Control Systems for solid propellant de-orbit motors”

The objectives of the activity is to investigate, select, design, build and deliver a thrust vector control mechanism for solid propellant de-orbit motors and to perform a cold gas demonstration of it’s capabilities.

CONCLUSIONS main

1. **Solid propulsion combines high performance with low cost, and allows to expand the autonomy of the deorbit function.**

2. **Solid rocket motors for de-orbiting applications shall be cigarette burning, which allows for motor length adaptation (chopping) for easy customizing of the motor-delivered-total impulse.**

3. **De-orbiting LEO satellites with deployed appendages, is driving for motor / cluster design.**

4. **A minimum of 2, but preferably complemented with a small 3rd, standardized motor designs are required to be able to de-orbit the complete range of applicable spacecraft.**

CONCLUSIONS main

5. De-orbiting of other objects (large jettisoned launcher components, upper stages, GEO spacecraft) would require aforementioned motors to be chopped, which is relatively easy and incorporated in the design.

6. The de-orbit burn for Ariane 5 GTO jettisoned components / upper stages can take place in the favorable 3rd apogee (23 m/s), avoiding land mass.

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