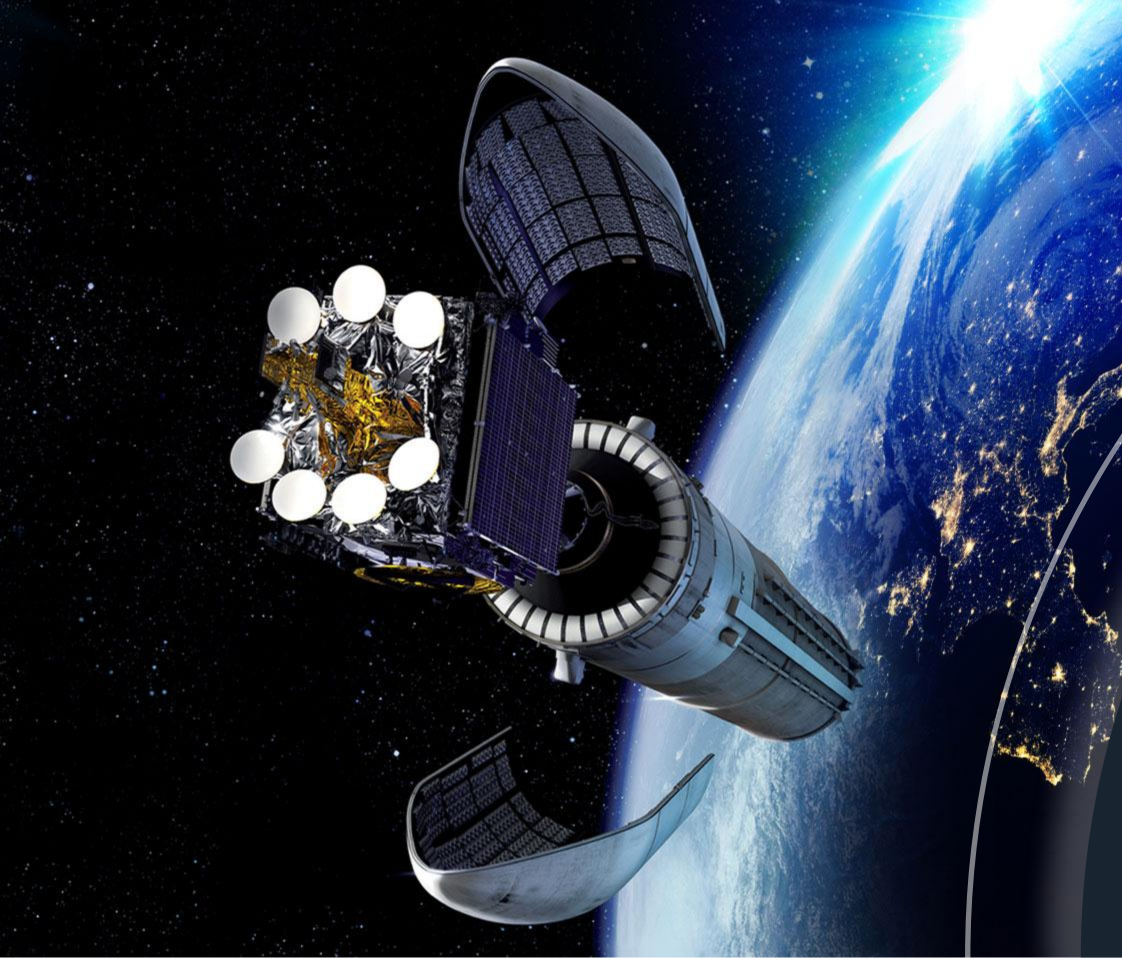


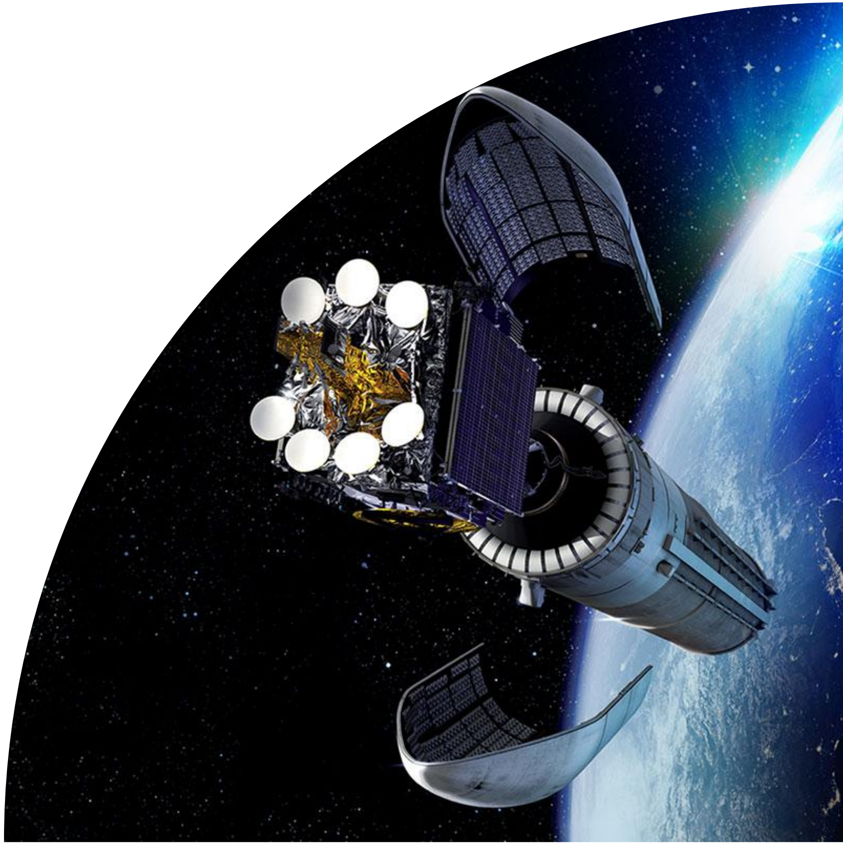
Debris Workshop – ESTEC
October 2018

Feasibility Study of Active Debris Mitigation for Mega Constellations

ThalesAlenia Space
a Thales / Leonardo company

Table of contents

Study logic



Study

ITT ESA 8815 Managed by Robin Biesbroek

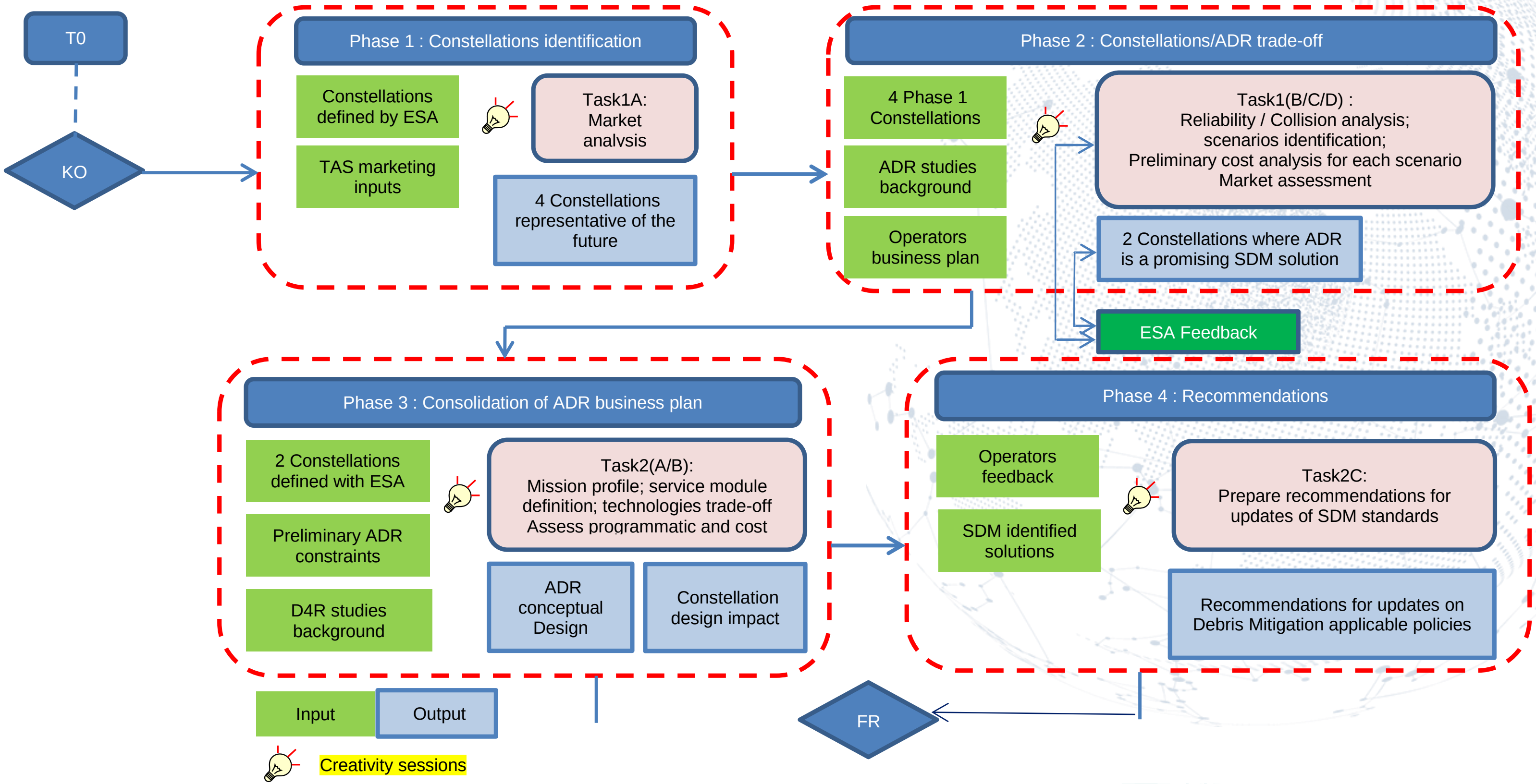
GSP funded contract

Thales in France and Thales in Italy team

- Carole Billot, Raphael Hache, Isabel Moore, Andrea Sita
- Mauro Pasquinelli, Maria Valeria Catullo, Simona Ferraris

- 12 months study
- KO end April 2017

Logic



T0
KO
Phase 1 : Constellations identification
Constellations defined by ESA
TAS marketing inputs
Task1A: Market analysis
4 Constellations representative of the future
Phase 2 : Constellations/ADR trade-off
4 Phase 1 Constellations
ADR studies background
Operators business plan
Task1(B/C/D) : Reliability / Collision analysis; scenarios identification; Preliminary cost analysis for each scenario Market assessment
2 Constellations where ADR is a promising SDM solution
ESA Feedback
Phase 3 : Consolidation of ADR business plan
2 Constellations defined with ESA
Preliminary ADR constraints
D4R studies background
Task2(A/B): Mission profile; service module definition; technologies trade-off Assess programmatic and cost
ADR conceptual Design
Constellation design impact
Phase 4 : Recommendations
Operators feedback
SDM identified solutions
Task2C: Prepare recommendations for updates of SDM standards
Recommendations for updates on Debris Mitigation applicable policies
FR
Input
Output
Creativity sessions

Reference constellations

Goal to have a portfolio with significant differences on the following key parameters :

- Number of satellites
- Altitude
- Type of propulsion

Others parameters deducted from the knowledge of the existing projects

MEGA 1000
- 1080 sat of 200 kg – Elec
- 20 planes 54 sat – 85°/1100 km
- 20 Launch/year - 18sat/LV

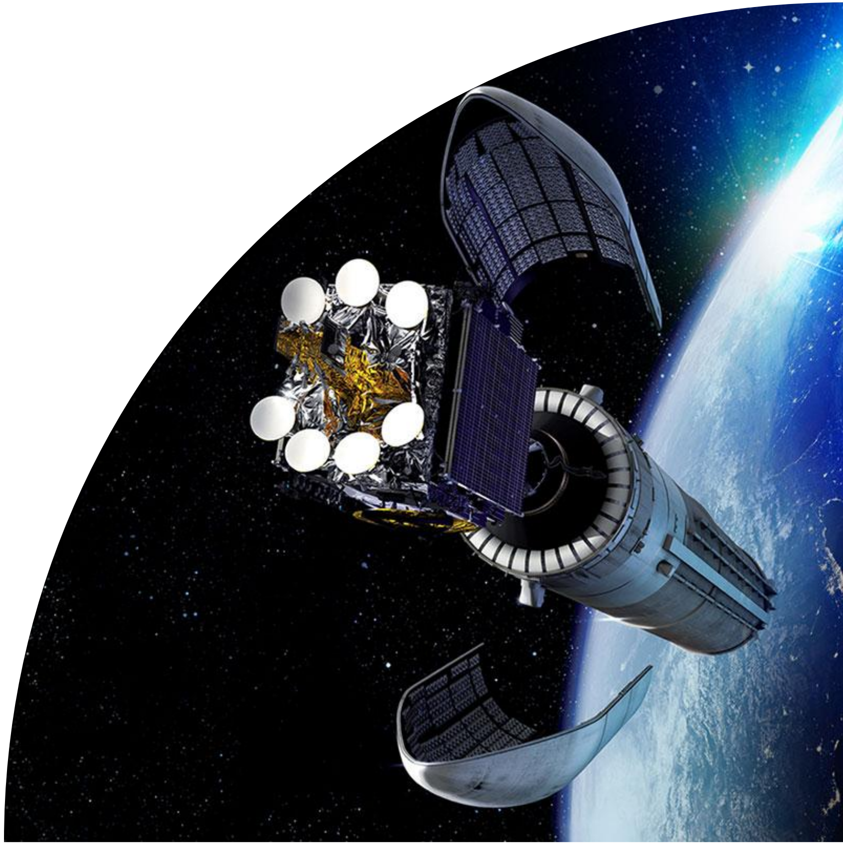
MEGA 200
- 200 sat of 1000 kg - Chemical
- 10 planes 20 sat – 85°/1100 km
- 5 Launch/year – 10 sat/LV

TAS 3200
- 3200 sat of 380 kg - Chemical
- 2*32 planes 50 sat – 53°/820 km
- 26 Launch/year – 25 sat/LV

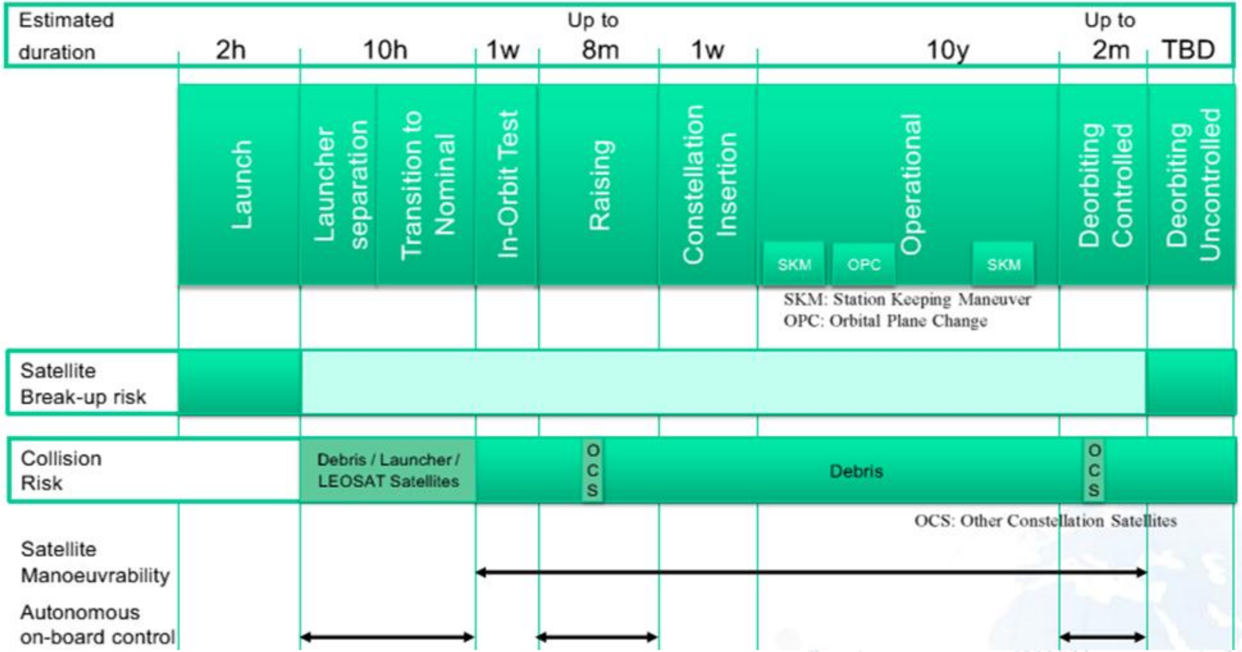
TAS 100
- 108 sat of 1200 kg – Elec
- 6 planes 18 sat – 90°/1400 km
- 6 Launch/year – 8 sat/LV

Mitigation methods

- Problematic & ADR functional



Problematic of megaconstellation operational lifetime



Solution

ADR multi missions

ADR among constellation

ADR single shot

Reliability increase

- Design
- Redundancy
- In-space maintenance
- EOL kit on-board

Deorbitation and natural re-entry

- 25 years
- 5 years

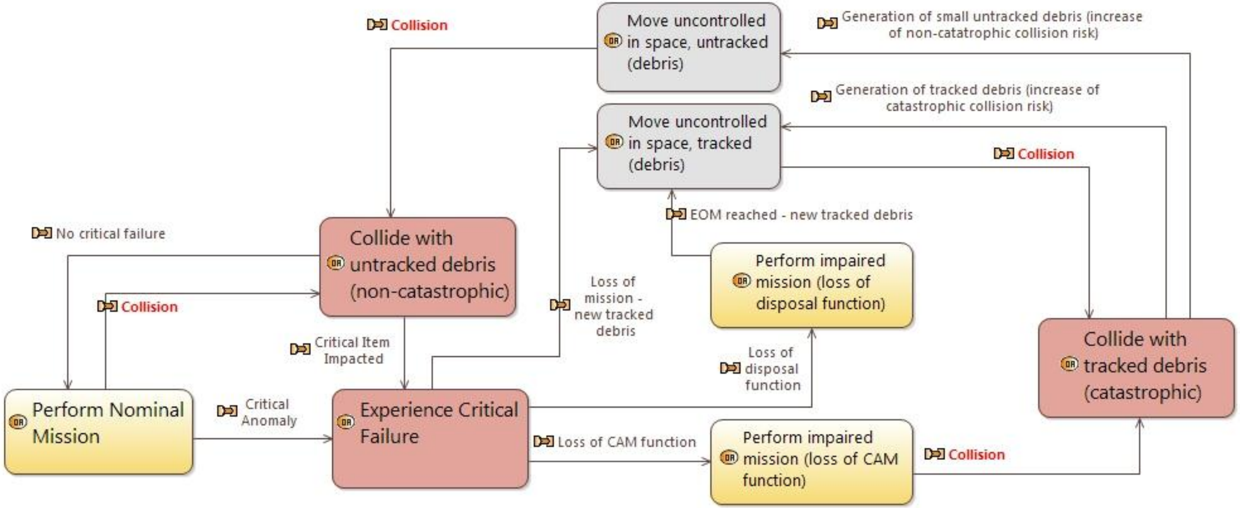
Reorbitation

Deorbitation and controlled re-entry

Deorbit kit plugged by chaser/remover

ADR to reduce collision risk and debris generation

Satellites May Experience Collisions → **Collision Risk Analysis**

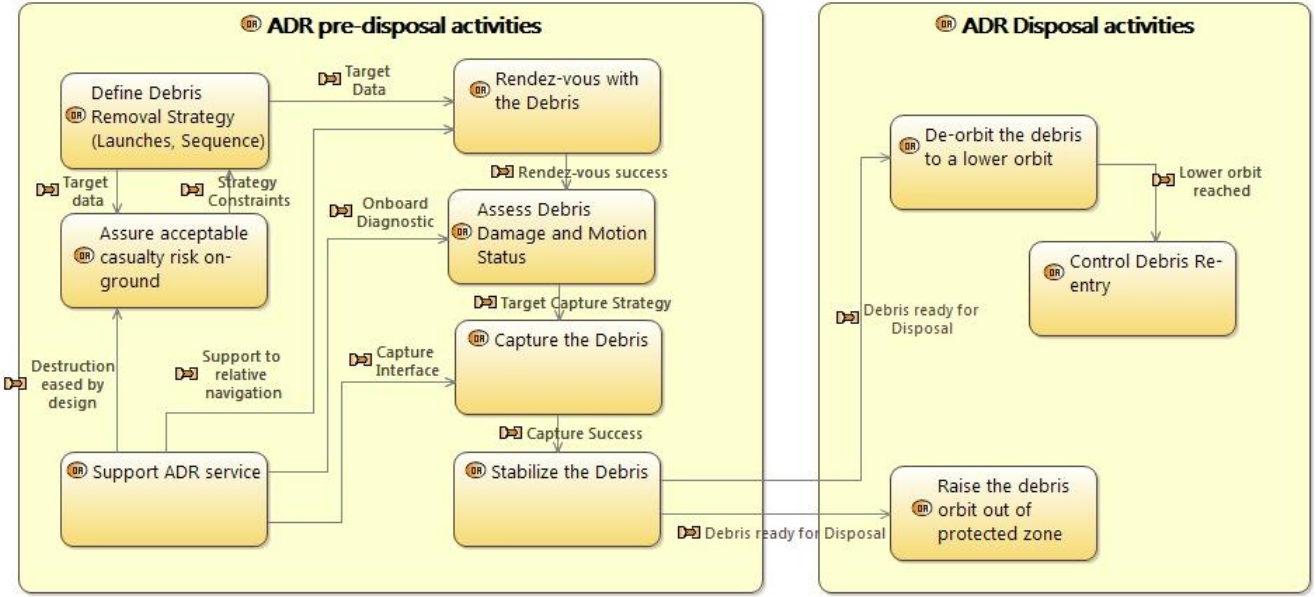


Dynamic issue
Any collision or critical failure modifies the environment, increasing the risk

Satellites May Experience Internal Failures → **Input: 10%** of Probability of Loss of Disposal/CAM functions

Large numbers of satellites, Long Infrastructure Time → Higher Risk

ADR reference operational activities



Different strategies w.r.t. Strategies, Technologies and allocation to:

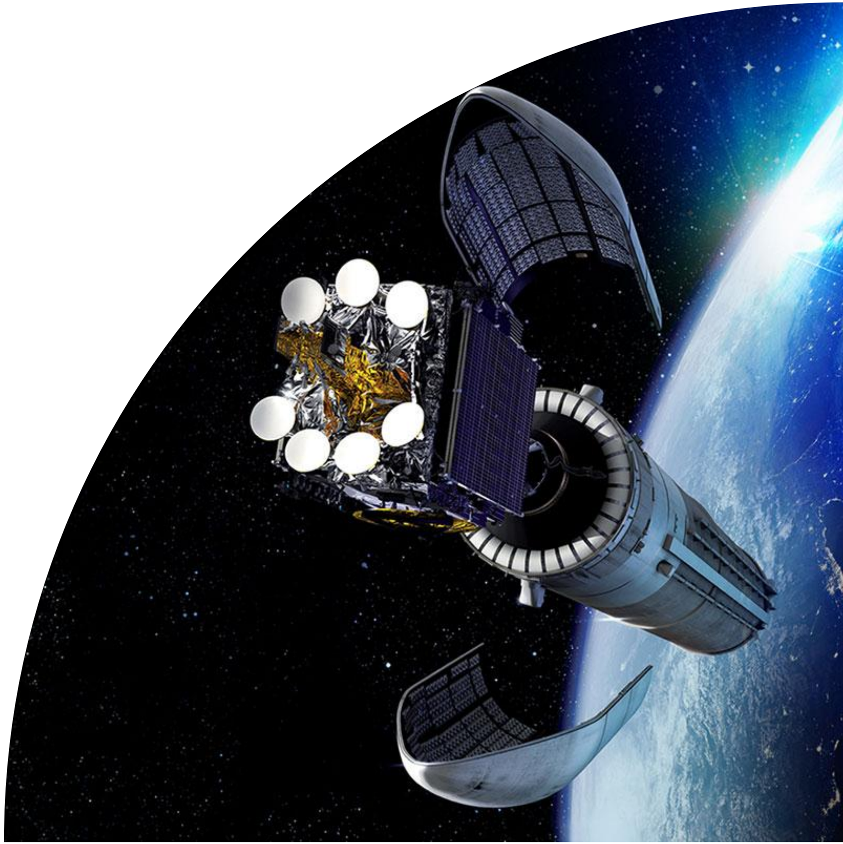
- Constellation system
- ADR system

$$cost_{ADR} = N_{removers} \cdot cost_{remover} + N_{launchers} \cdot cost_{launcher} + cost_{GS} + \Delta cost_{constellation}$$

Cost of ADR is the cost of keeping clean the operational orbit

Collision Risk

- With Debris
- Among constellation



Risk Evaluation: ESA MASTER 2009 Environment

Evaluation of the risk of losing satellites of constellation caused by impact with untrackable and trackable debris

Untracked debris:

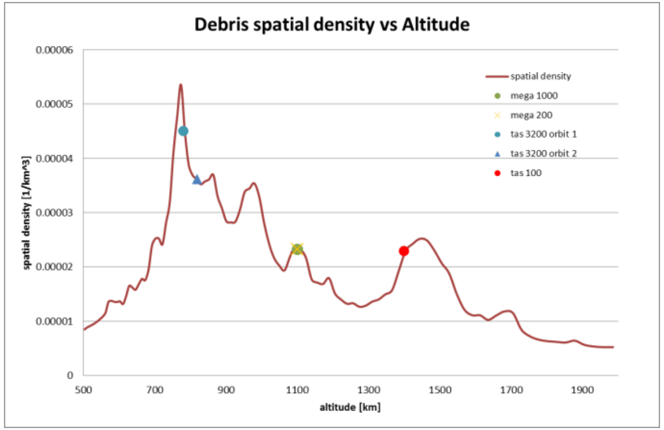
Risk of losing the satellites caused by an impact with untrackable debris **(diameter <10cm):**

- failure of internal items
- failure of external items

Tracked debris:

- Risk of losing the satellites caused by an impact above the **catastrophic threshold (40 J/g)**

Debris environment vs Altitude (ESA MASTER 2009)

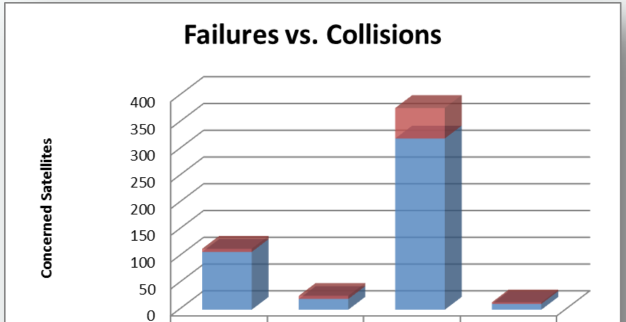


[Collision/sat/year]	MEGA-1000	MEGA-200	TAS-3200 (780km)	TAS-100
Non-catastrophic (operational)	7.94E-04	3.18E-03	2.96E-03	2,4E-03
Catastrophic – Operational	3.57E-06	1.35E-05	5.42E-05	5.39E-06
Catastrophic - Deorbiting	3.36E-06	3.48E-05	9.46E-06	N/A

ThalesAlenia Space
a Thales / Leonardo company

Evaluation of Collisions

Non-catastrophic (first set)



	Mega1000	Mega200	TAS3200	TAS100
mean collisions	6	6	57	3
mean failures	108	20	320	11

Such number can be mitigated by providing adequate MMOD protection and physical configuration

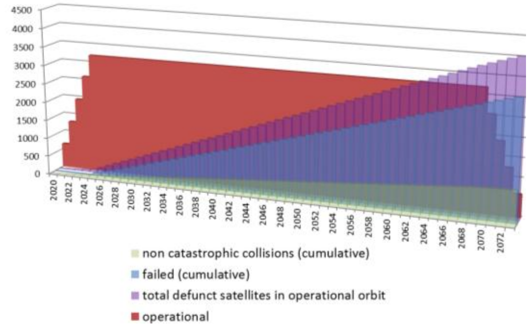
Note: Using 2009 MMOD Environment → Very optimistic

Probability of catastrophic collision between 2 satellites among the constellation not included

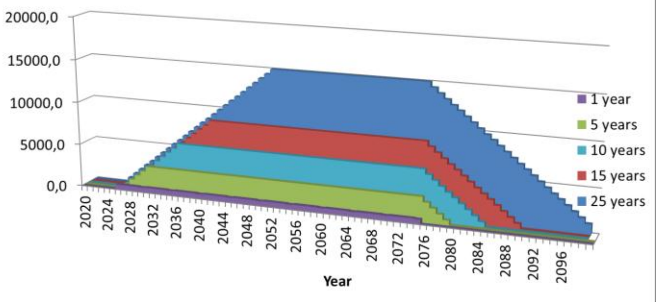
Catastrophic collisions

– They depend on the amount of defunct or decaying satellites → influenced by ADR and time for decay

TAS3200 – amount of defunct satellites on operational orbit



TAS3200 – amount of decaying satellites, comparison of decay strategies

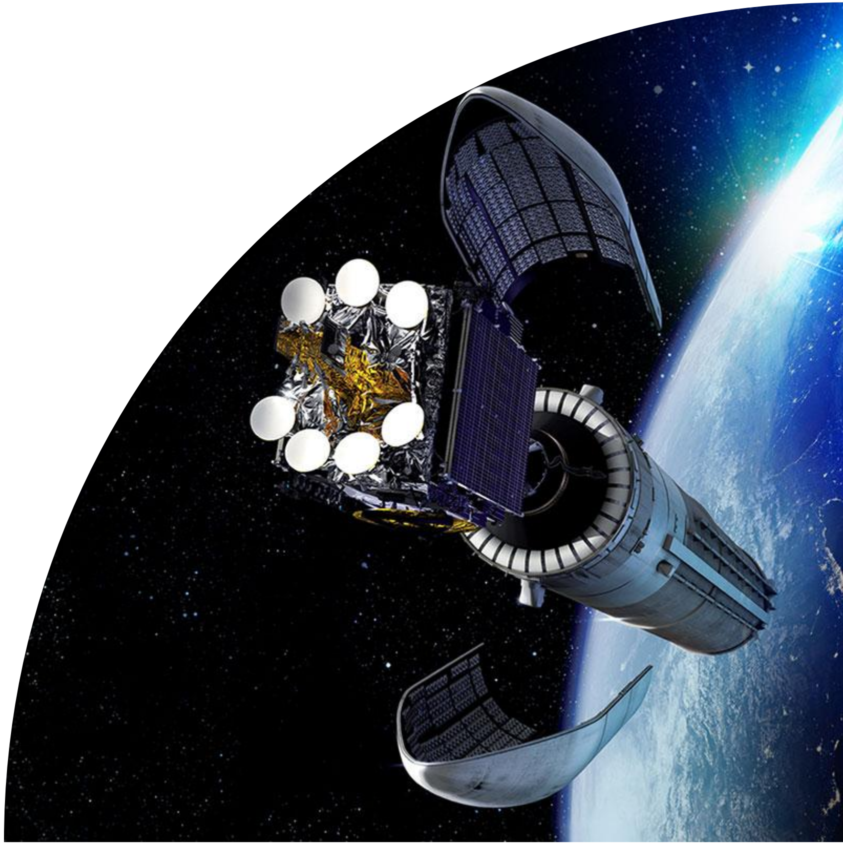


(90% of satellites decaying)

ThalesAlenia Space
a Thales / Leonardo company

Mission Overview

- Mission analysis of the 4 constellation cases
- Launcher selection
- Removers selection



ADR Space and Launch Segment Strategies and Options

- Space Segment configurations & number of services

	Chemical One-shot	Chemical Multi mission	Electrical Multi-mission	Electrical with DOK
Specific Characteristics	Net or simplified capture system	Robotic Arm	Robotic Arm	Robotic Arm DOK installation (higher complexity)

Number of services, Soyuz	EP Deorbit without DOK	EP Deorbit with DOK	EP Graveyard	CP Deorbit
Mega 1000	25	17	15	6
Mega 200	N/A (1)	(Controlled re-entry with DOK) 9	13	(Controlled re-entry) 1
TAS3200	(uncontrolled) 35	22	N/A (11)	(uncontrolled) 14
TAS 100	N/A (1)	(Controlled re-entry with DOK) 9	16	(Controlled re-entry) 1

- Launch strategy options:

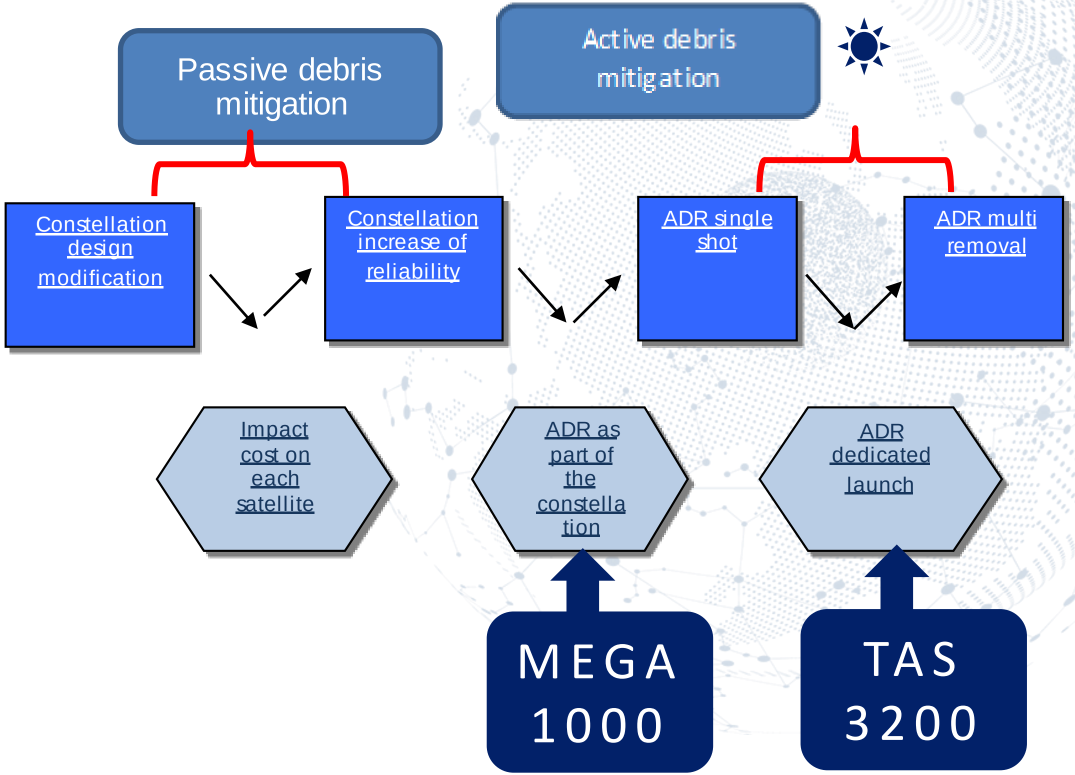
One remover per launcher
Launch when needed

Batch of Removers
Stacked launch of removers, moving in different planes with RAAN drift

Shared Launch with constellation
The remover is sent together with constellation satellites in predisposed planes. Favourable for size of spacecraft comparable with constellation sats

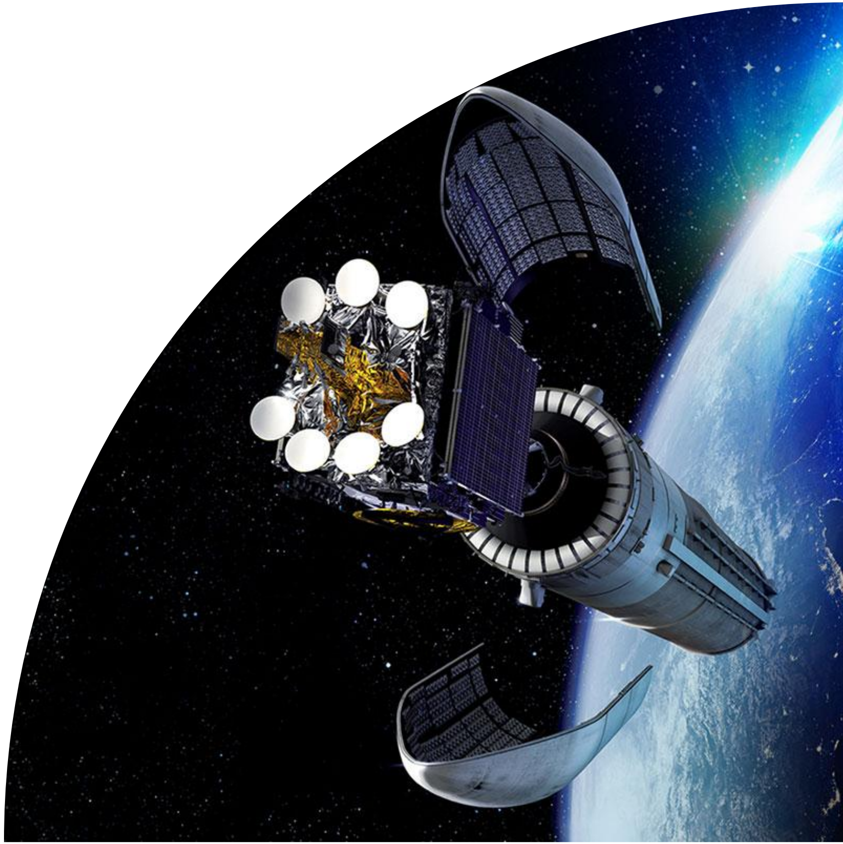
Trade-off Mitigation solution

Parameter
Number of additional launches
Additional mission control functions complexity index
Number of additional Ground Stations & Control
Servicer complexity index
Added cost for Constellation Satellites
Increase of single satellite lifetime because of increase of available propellant (no self-disposal)
Potential Compliance with future regulations
Additional Services
Reduction of constellation size (Reduction of constellation sat. needed)
long term sustainability of the orbit and decrease of CAMs because of failed satellites in the operational orbit which cannot be removed.
Added cost for removers (as % of the constellation cost)



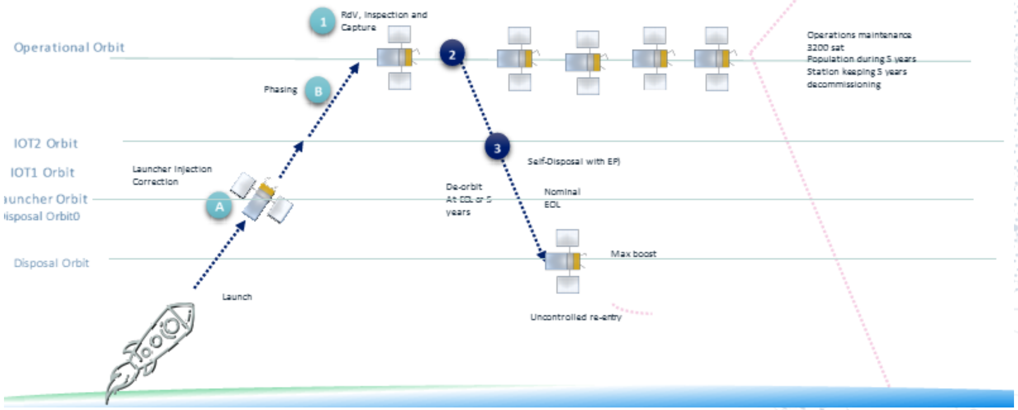
ADR Mega 1000 Operational concept

ADR Trade-off

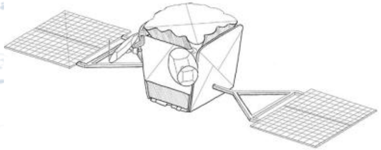


ADR MEGA 1000 Configuration

Operations



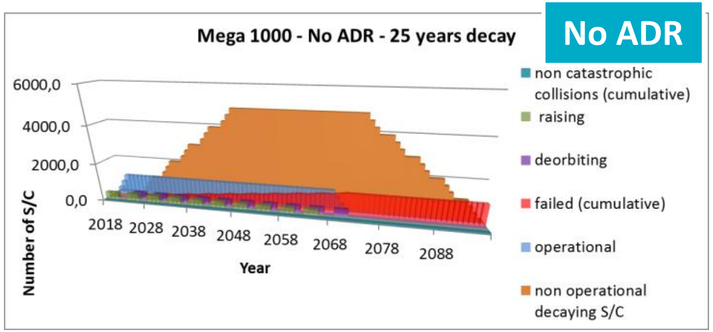
25 satellites per launch



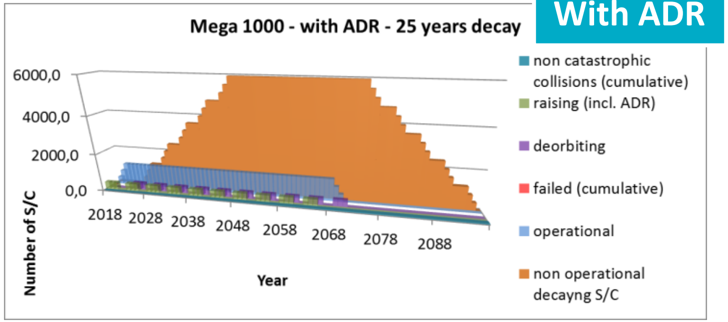
- ADR launch within the population of the constellations
  - Verification IOT
  - Waiting phase on optimal orbit before rescue

MEGA1000: Collision Risk Mitigation Effects

No ADR



With ADR

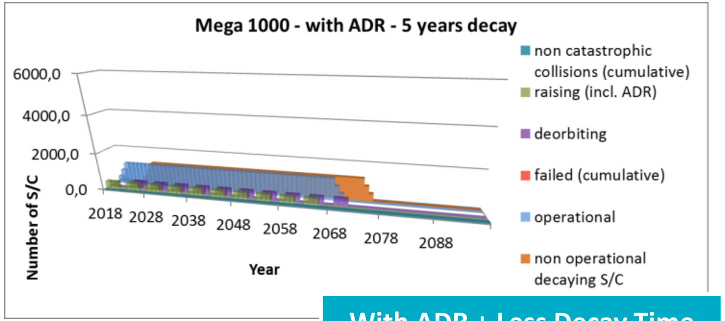


Effects for the space environment:

- 20% more satellites (incl. ADR) decaying at lower orbit
- Drastic reduction of long-term pollution

Effects for the constellation:

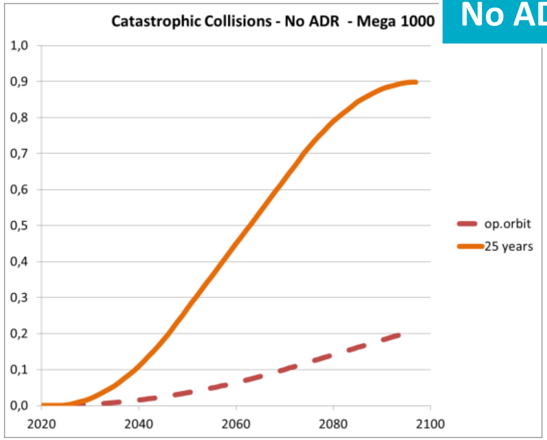
- 10% more operational satellites
- No failed satellites close to operational orbit (reduction of risk of constellation loss and of CAM needs)

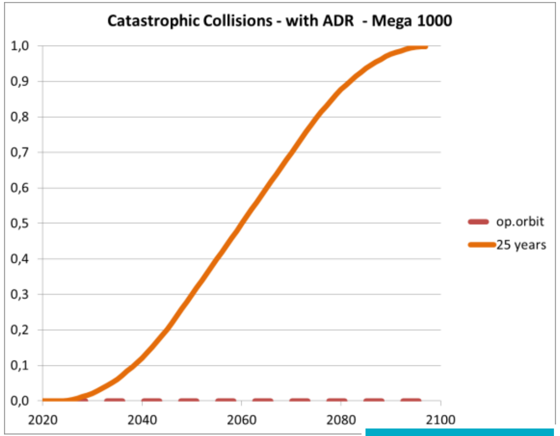


With ADR + Less Decay Time
(25y→5y)

MEGA1000: Evaluation with the 2009 MMOD environment

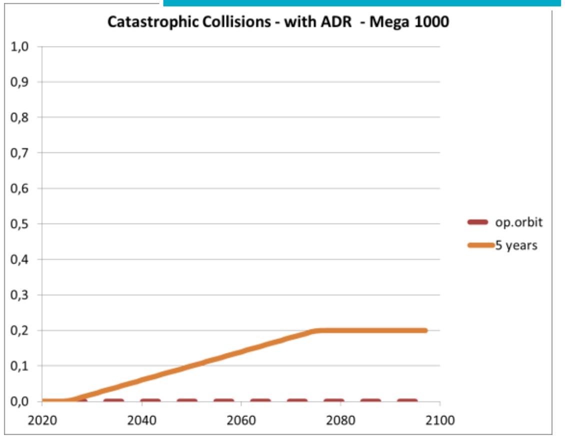
No ADR





With ADR

With ADR + Less Decay Time
(25y→5y)



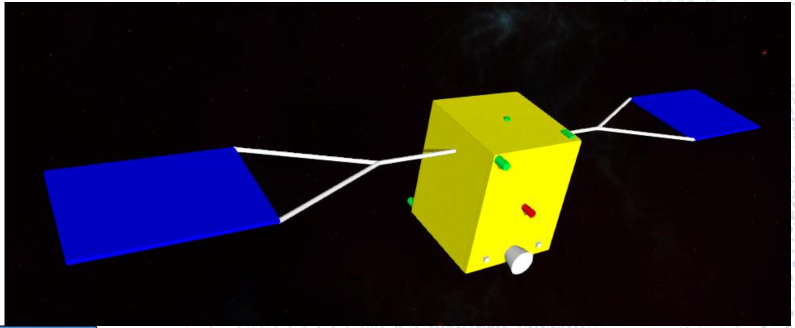
Preliminary calculations show that one catastrophic collision could be prevented (with ESA MASTER 2009 env.)

ADR MEGA 1000

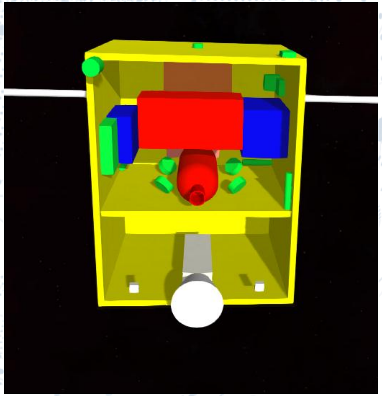
Overall Architecture

Wet Mass under 200 kg

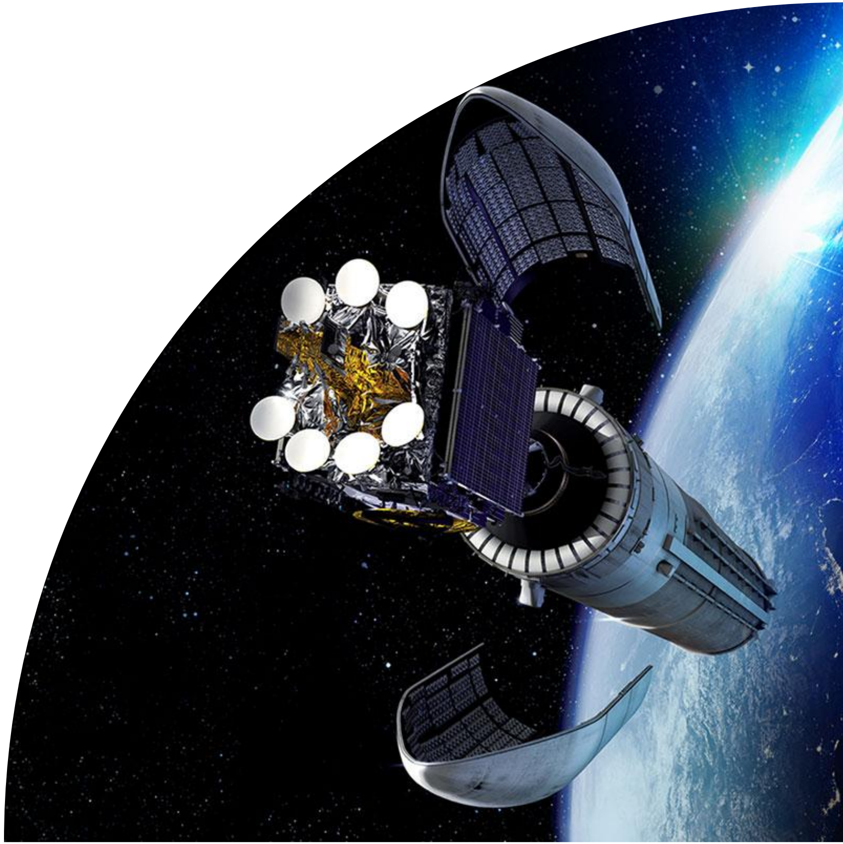
- Compatible with rest of constellation



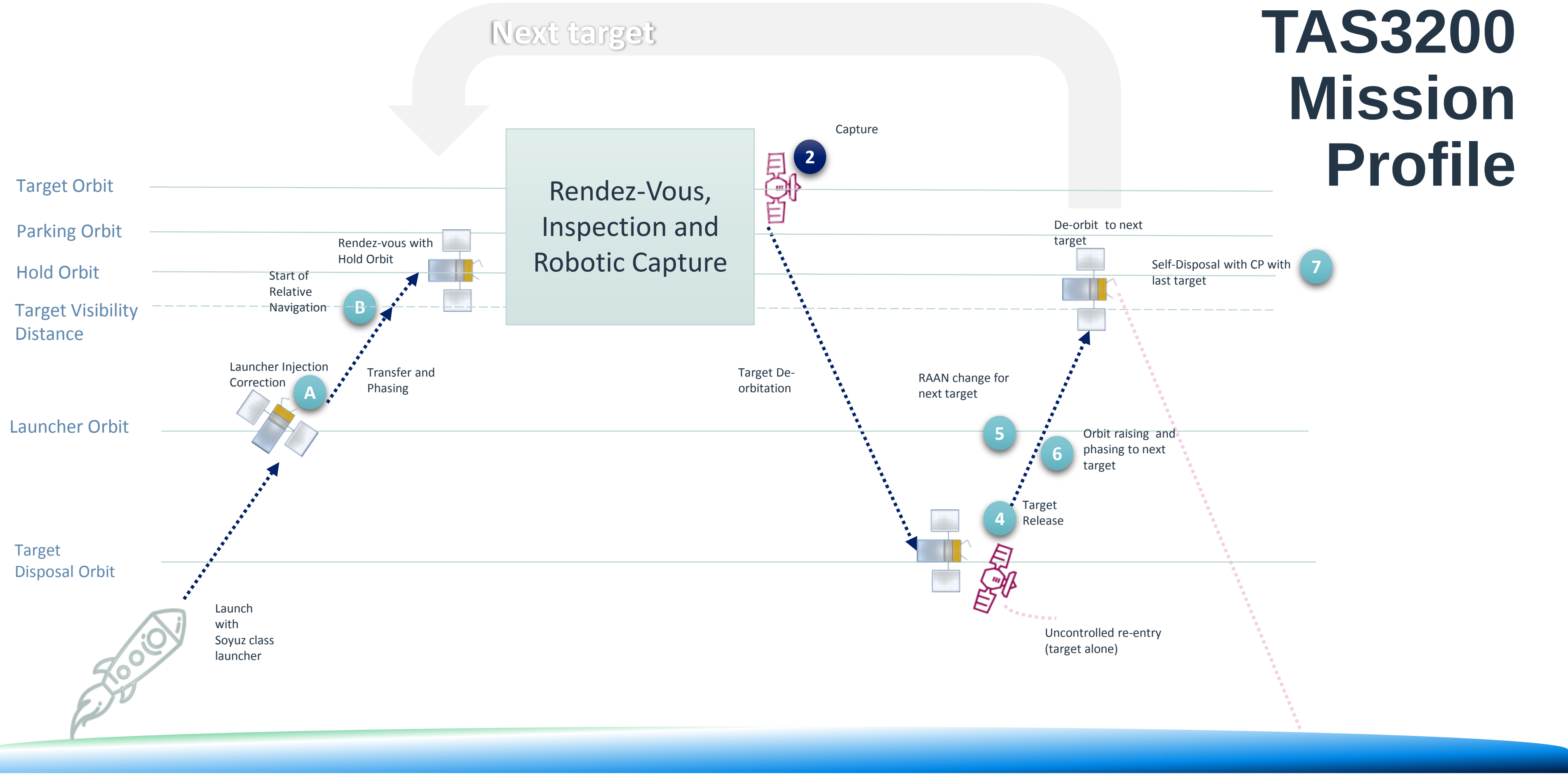
SVM	
Propulsion	Electric - ARDÉ 8.2l – 2 * 13mN – 39mN
Architecture	Derived from OneWeb
Power	2 * SA wing
Avionics	SMU with LEON2/3 FT Processor
TTC	Ka-Band
Payload	
Capture	2 Net Capture Systems
RDV sensors	2 * 2D camera



ADR TAS 3200
Operational concept



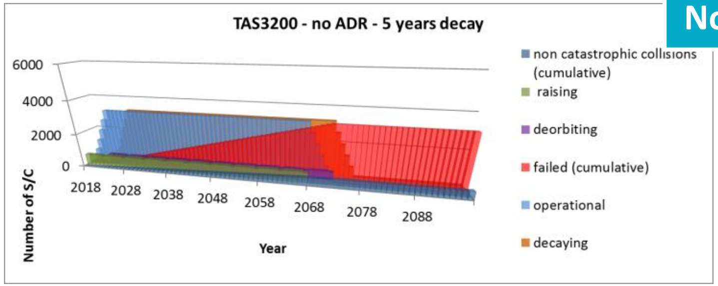
TAS3200 Mission Profile



ThalesAlenia Space
a Thales / Leonardo company

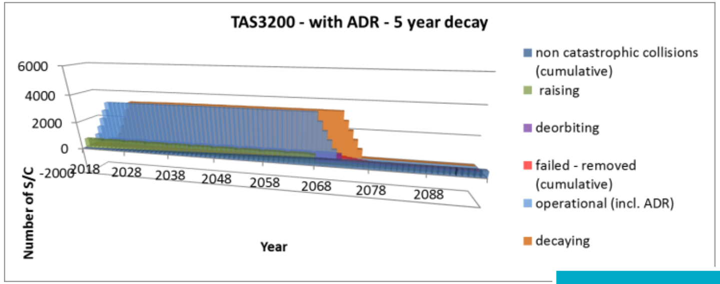
Collision Risk Mitigation Effects for TAS3200

No ADR

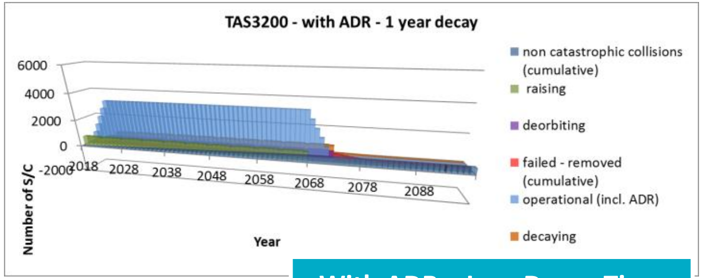


Effects for the space environment:
- ~10% more satellites decaying at lower orbit
- Drastic reduction of long-term pollution

Effects for the constellation:
- Additional ADR system
- Limited number of failed satellites close to operational orbit (reduction of risk of constellation loss and of CAM needs)

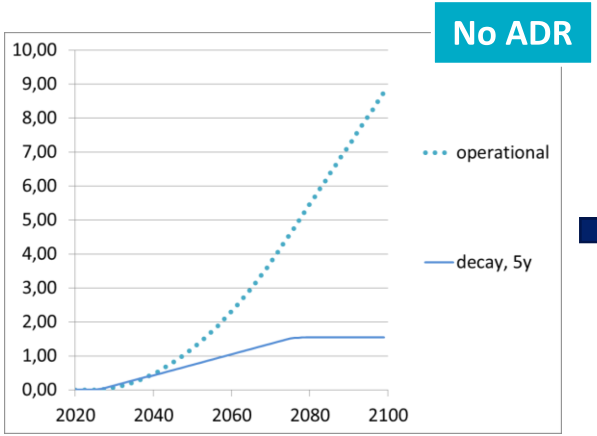


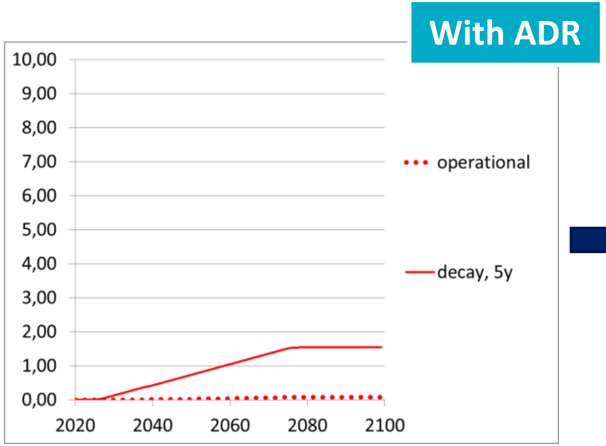
With ADR

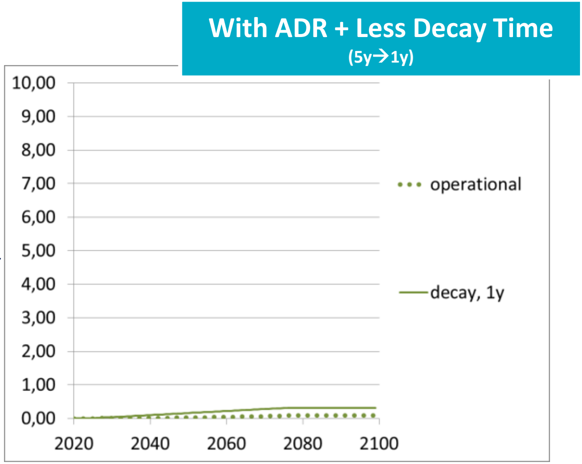


With ADR + Less Decay Time
(5y→1y)

Effect on catastrophic collisions (with 2009 MMOD environment)







From > 10 collisions to ~0,3 collisions in 50 years (with ESA MASTER 2009 env.)

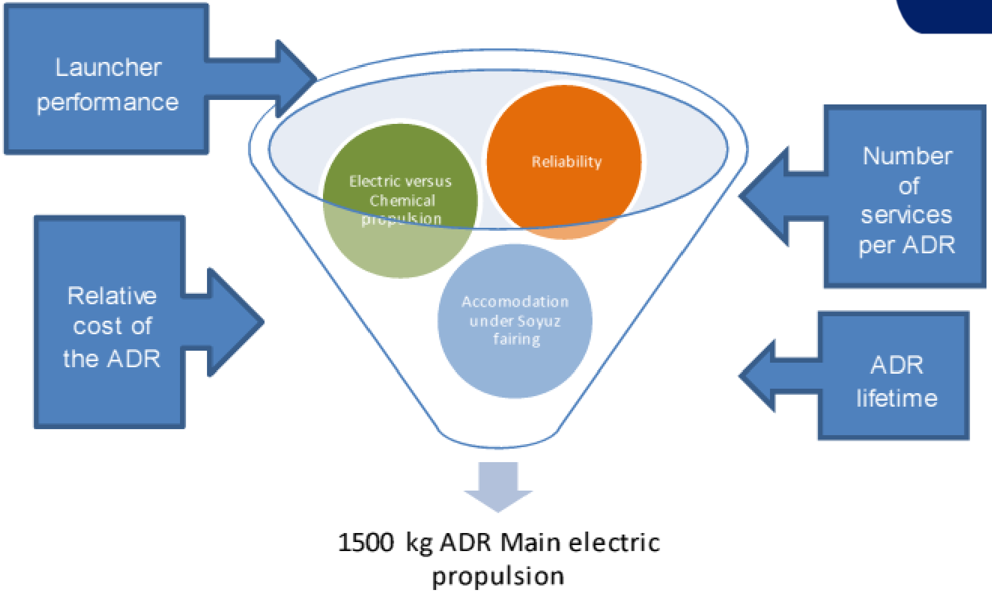
ThalesAlenia Space
a Thales / Leonardo company

ADR TAS 3200 Trade-off

Soyuz Launch

- Evaluation of number of services per launch

Sensitivity analysis supports selection of:
-thrusters -> QT6
- Reliability -> 0.95
- re-entry -> non-controlled
- Accomodation -> stack

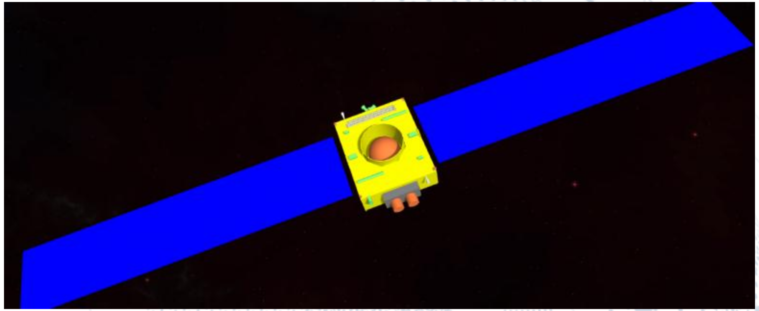


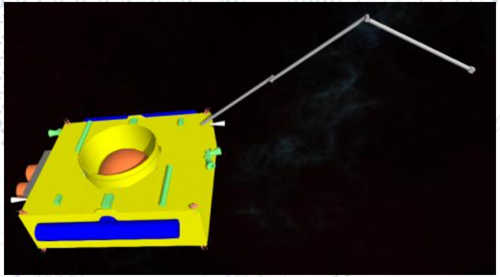
ThalesAlenia Space
a Thales / Leonardo company

ADR TAS 3200

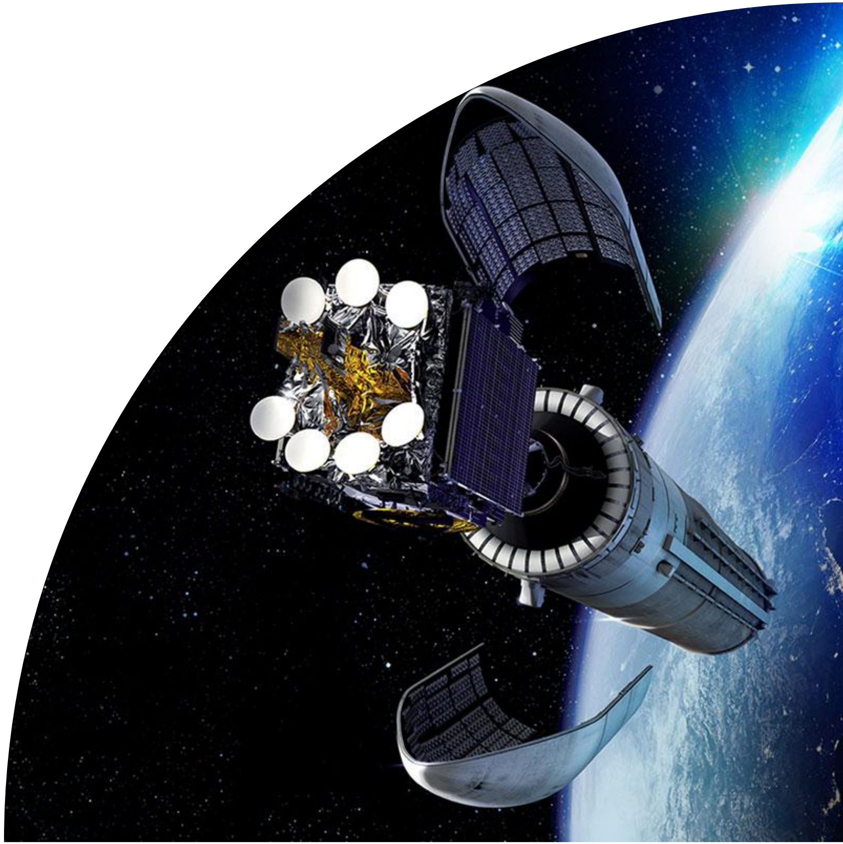
Overall Architecture

SVM	
Propulsion	Hybrid Electric – MT-Aerospace L-XTA 300l - 2 * QT6 thruster Chemical – MT Aerospace PTD-222l – 16 * 1N
Architecture	Derived from SpaceTug
Power	2 * SA wing
Avionics	SMU with LEON2/3 FT Processor – ICU - PCDU
TTC	X-Band
Payload	
Capture	6 degree of freedom Robotic Arm
RDV sensors	2 * NAC – 2 * WAC – Illuminator





Conclusion



Conclusion

For the 4 cases of mega-constellations considered in this study, the ADR solutions which give the best positive impact vs the initial baseline are :

- ADR one shot based on constellation platform for MEGA 1000
- ADR EP multi-mission with Soyuz for TAS 3200

- ADR impacts the operators business plan up to 30%
  - For very large constellation, it is mandatory
    - At one step, the revenu will stop because of catastrophic collision

- Constellation reliability increase is a favorable trend

- Analogies can be found with on-ground situation for Electrical and Electronic Equipment
  - Subjected to individual handling and management
  - Regulatory requirements exist for Waste EEE
  - For those requiring individual operations, end-of-life logistic cost is in the range from 20 to 30%.

Recommendations

Current regulations are not relevant with the emergence of mega-constellations

- Sustainable low earth orbit cannot be maintained with the 25 years decay orbit rule
- Recommendation to change Standards and Policies to prevent orbits becoming overpopulated with debris and to drive the constellation operators to use space responsibly and sustainably
- Solutions have to be considered at constellation level

Use of ADR for EOL constellation management

- Is necessary when the number of failed satellites in the operational orbit becomes unmanageable
- Is necessary to keep long-term business without endangering space activities
- Needs Operators/Industry to anticipate and « prepare » satellite
- Needs ADR technology ready with sufficient TRL

Thanks