Introduction to CubeSats and their role in current and future space activities

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Agenda

- Status and trends of Smallsats
- the CubeSat Standard
- Case Study: D-SAT Cubesat mission
- Launch Opportunities for Cubesats
- Conclusion

Status and trends of Smallsats

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Status and trends of Smallsats (1 of 5)

THE FOUR **MASS** CATEGORIES OF SMALLSATS

Pico-Satellite
<10 kg
- Planet, Spire
- SpaceBEEs
- PocketQubes
- Cubesats < 6U

Nano-Satellite
11-50 kg
- Cubesats > 6U
- Satellogic
- PlanetIQ
- HawkEye 360

Micro-Satellite
51-250 kg
- OneWeb
- Starlink
- Skysat
- Microcarb

Mini-Satellite
251-500 kg
- Globalstar
- Grace-FO
- Cassiope
- Ladee

500 kg

Ref. PROSPECTS FOR THE SMALL SATELLITE MARKET // AN EXTRACT © Euroconsult 2019

SMALLSATS KEYWORDS

Verticalization

Reduced Cost

COTS

Reduced Life Cycle

Single Purpose

Standardization

Up-to-date Technology

Status and trends of Smallsats (2 of 5)

SMALLSATS APPLICATION

- **Earth Observation (EO)**: satellites for electro-optical and radar observation of the Earth, as well as for meteorology, both for operational and Earth-science research purposes.
- **Telecommunications (Satcom)**: satellites for commercial and government operators providing broadband communications.
- **Information:** satellites providing narrowband communications services (IOT & M2M) and data collection from ground, aerial and atmospheric sensors (e.g. AIS, ADS-B). It also includes GNSS radio occultation (GPS-RO) and RF monitoring.
- **Security:** satellites for space surveillance and tracking, missile early warning, near-Earth object monitoring, electrical intelligence (ELINT), and space weather.
- **Technology**: technology development satellites (mainly from government and academic players, but also commercial) built to test new technologies or platform/payload components; some technology satellites may serve other applications on a non-operational basis.
- **Science & Exploration**: satellites for astrophysics and astronomy, planetary science (including Earth science), heliophysics, and solar- terrestrial interactions.
- **In-Orbit Servicing:** satellites designed to repair, refurbish, refuel or take-over station-keeping for another satellite fall into this newly-created satellite application, which also includes orbital fuel depots.

SMALLSATS TYPE OF ORBITS

LEO: Low Earth Orbit with altitudes up to 2,000 km

SSO: Sun-Synchronous Orbit, near-polar, synchronous with the Sun

MEO: Medium Earth Orbit, altitudes between 2,000 km to 20,000 km

ESC: Deep space, Lagrange points, anything beyond Earth orbit

GEO: Geostationary Earth Orbit, 35,786 km

HEO: Highly Elliptical Orbit

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Status and trends of Smallsats (3 of 5)

2009 → 2018		2019 → 2028
147	**Average number of Smallsats launched per year**	859
49kg	**Average Smallsats launch mass**	139kg
Single satellite mission 43%	**Mission Type**	83% Constellation mission
EO 35%, TECH 40%, INFO 13%	**Top 3 Applications**	EO 19%, TELECOM 49%, INFO 14%

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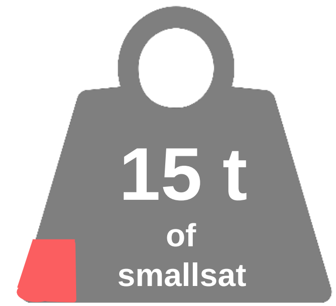
Status and trends of Smallsats (4 of 5)

2018:

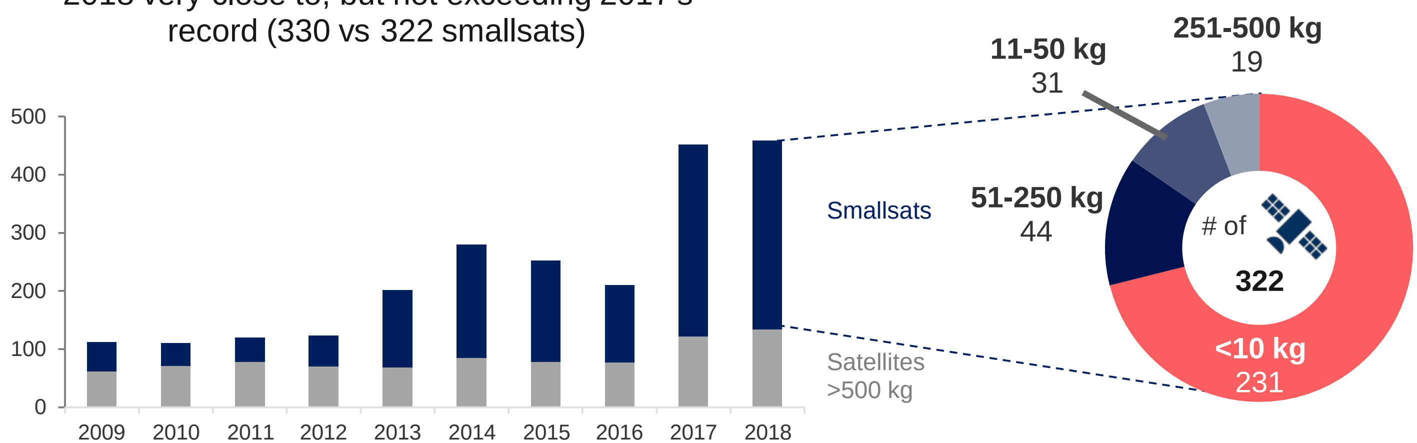
322 smallsats lauched in 2018

of which 40% for constellations



Accounting for 4% of the total mass launched

2018 very close to, but not exceeding 2017's record (330 vs 322 smallsats)



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Status and trends of Smallsats (5 of 5)

2009 - - - - - - → **2018** | **2019** - - - - - - → **2028**

Smallsat manufacturing & launch value

- 2009–2018: **$13B** — $9B (manufacturing), $4B (launch)
- 2019–2028: **$43B** — $30B (manufacturing), $13B (launch)

Top 3 operator regions

2009–2018		2019–2028	
$5B	**North America**	**$18B**	**North America**
$4B	**Asia**	**$14B**	**Asia**
$1B	**Europe**	**$4B**	**Europe**

THE WORLD'S SMALLSAT MARKET OVER TWO DECADES (according to Euroconsult's 2019 forecast)			
	2009–2018	**2019–2028**	**Growth rate**
Satellites launched & to be launched	1,470 satellites	8,588 Satellites	x 5
Total mass launched & to be launched	71 tons	1,195 tons	x 16
Smallsat industry revenue for the decade, of which	**$12.6 billion**	**$42.8 billion**	**x 3.4**
• Manufacturing revenue for the decade	$9.1 billion	$30.1 billion	x 3.3
• Launch revenue for the decade	$3.5 billion	$12.7 billion	x 3.6

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the Cubesat Standard

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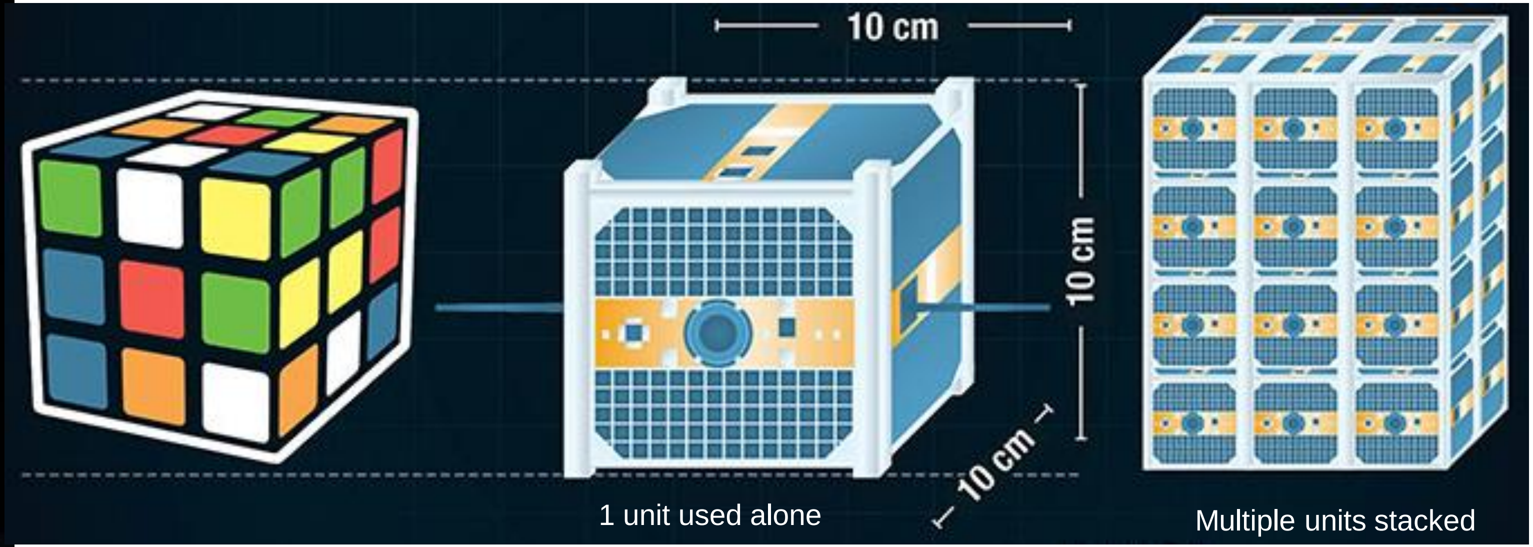
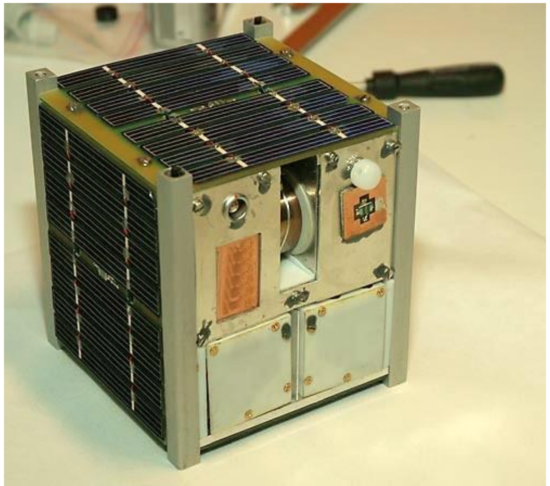
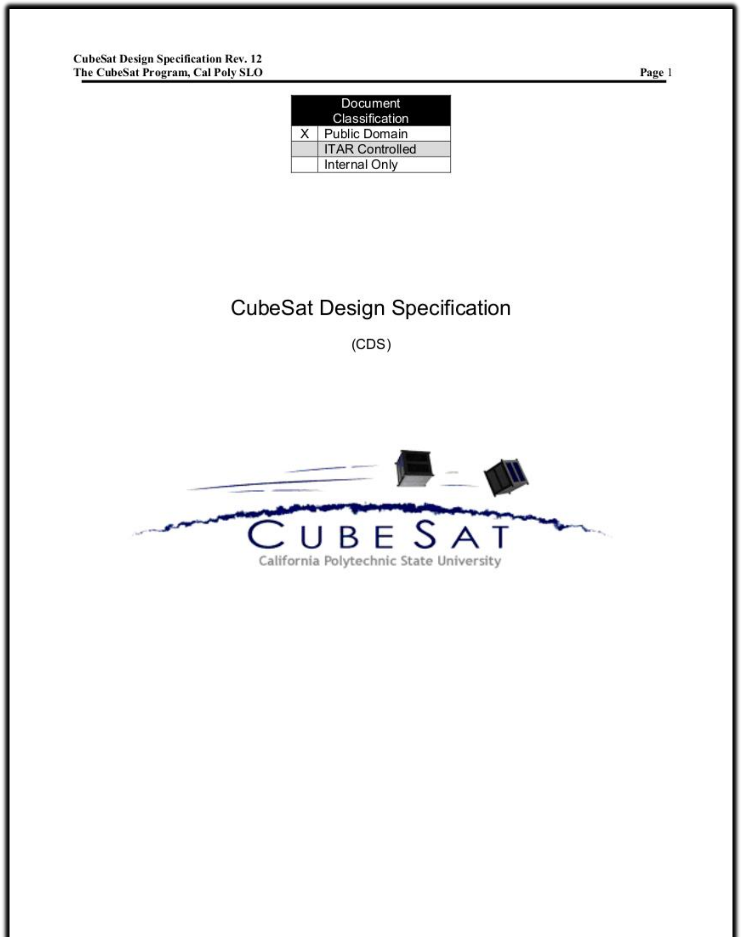
The Cubesat Standard (1 of 5)





Ref. **https://en.wikipedia.org/wiki/CubeSat#** and https://www.asc-csa.gc.ca/eng/satellites/cubesat/what-is-a-cubesat.asp

The Cubesat Standard (2 of 5)



CubeSat Design Specification Rev. 12
The CubeSat Program, Cal Poly SLO
Page 1

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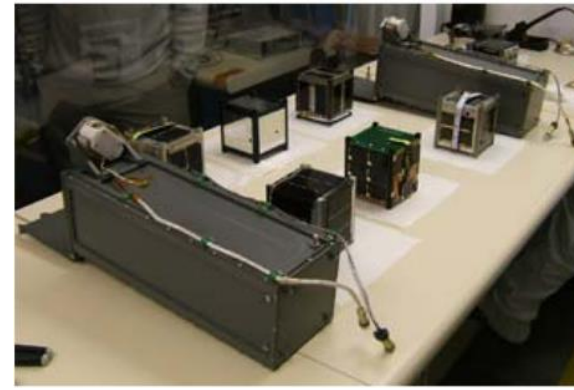
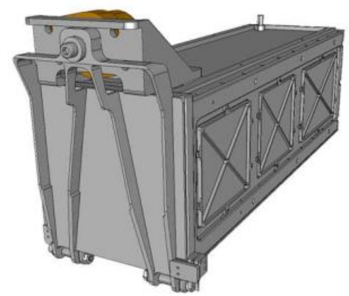
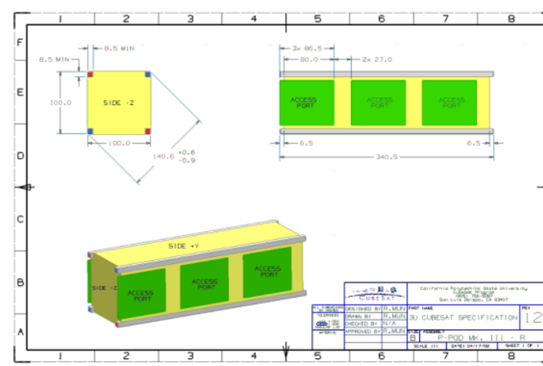
CubeSat Design Specification

(CDS)

CUBESAT
California Polytechnic State University







Ref. CubeSat Design Specification

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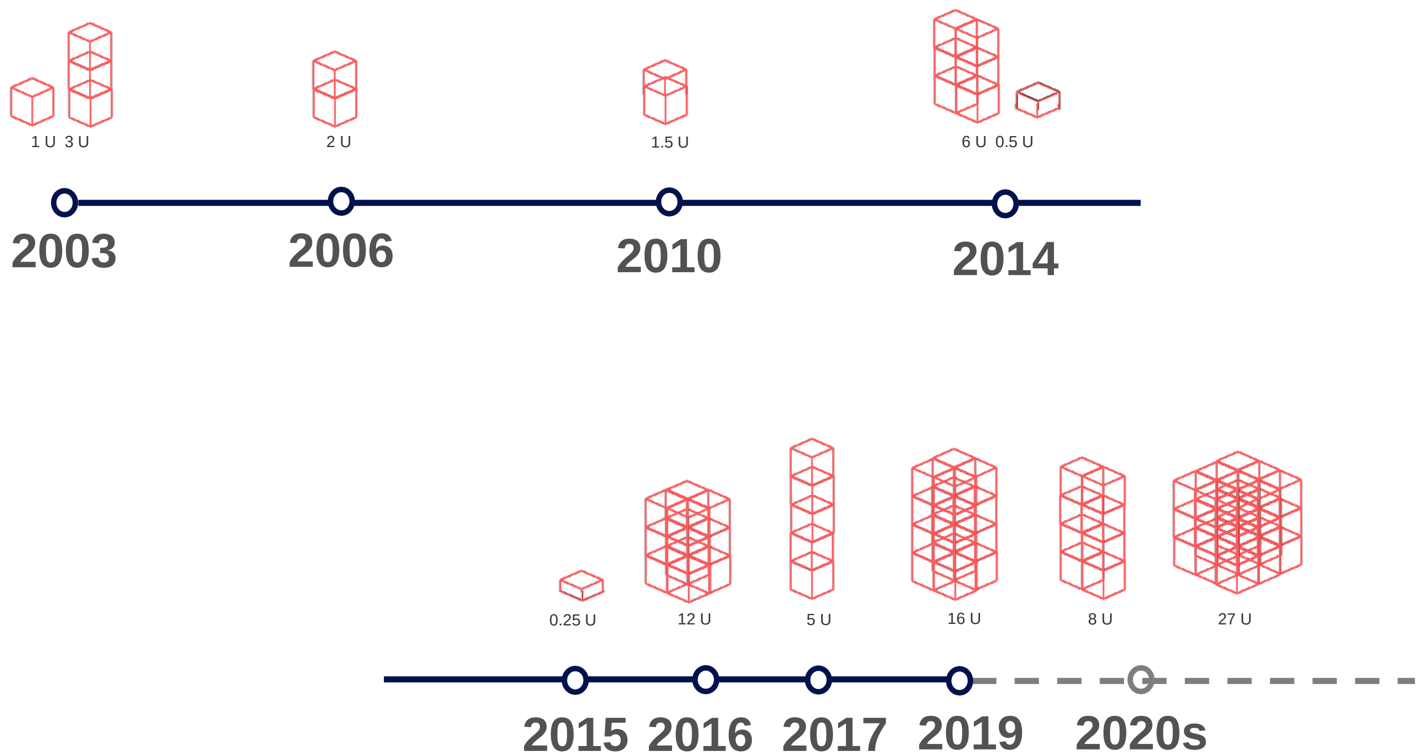
The Cubesat Standard (3 of 5)

Evolution of the Cubesat form factor



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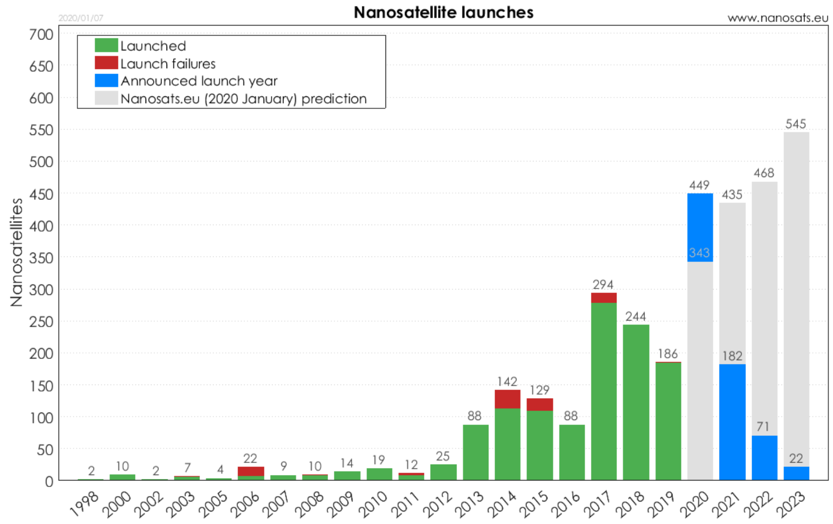
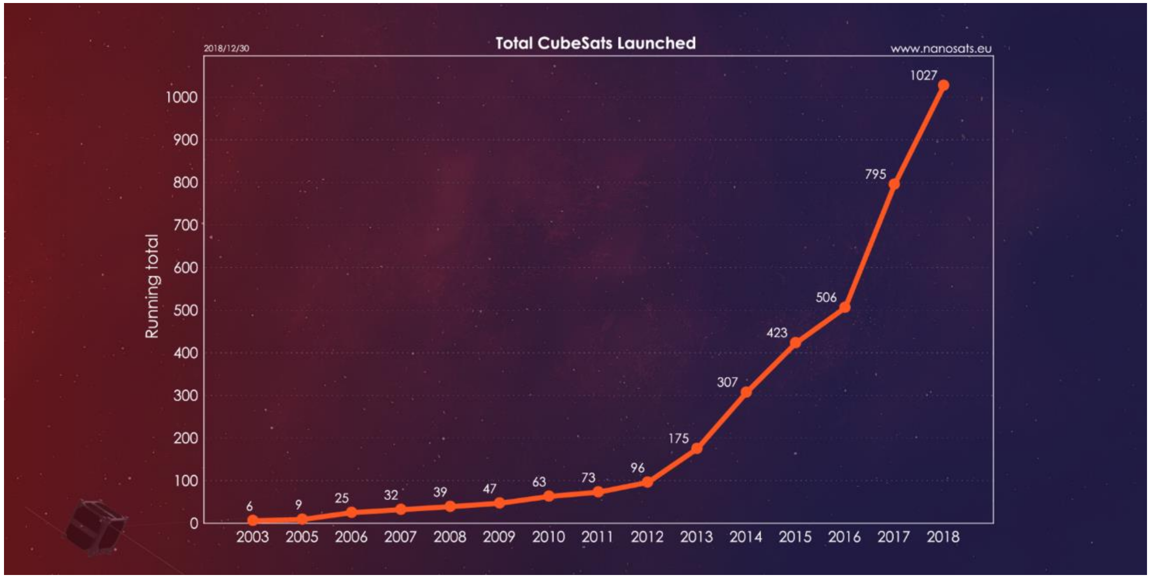
The Cubesat Standard (4 of 5)

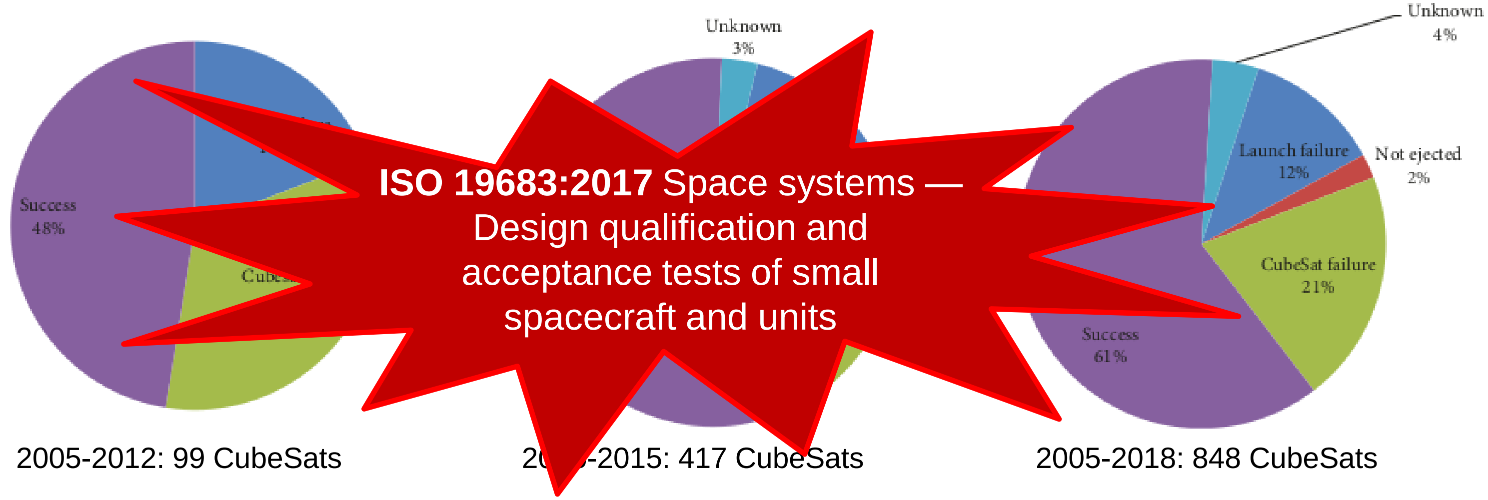




Ref. https://en.wikipedia.org/wiki/CubeSat#

The Cubesat Standard (5 of 5)

CubeSats mission status

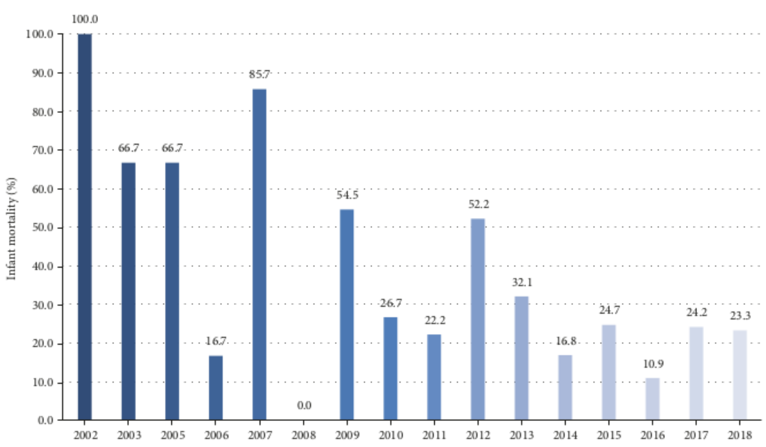


2005-2012: 99 CubeSats

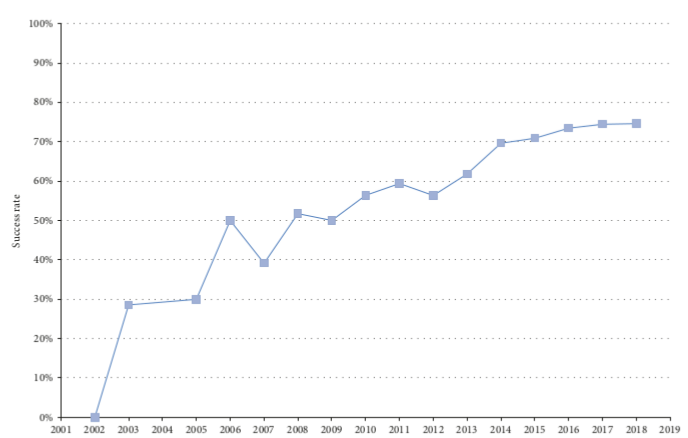
2005-2015: 417 CubeSats

2005-2018: 848 CubeSats

Infant mortality (launch failures excluded)



Success rate over the time



Ref. Towards the Thousandth CubeSat: A Statistical Overview - International Journal of Aerospace Engineering Volume 2019, Article ID 5063145, 13 pages

Case Study: D-SAT CubeSat Mission

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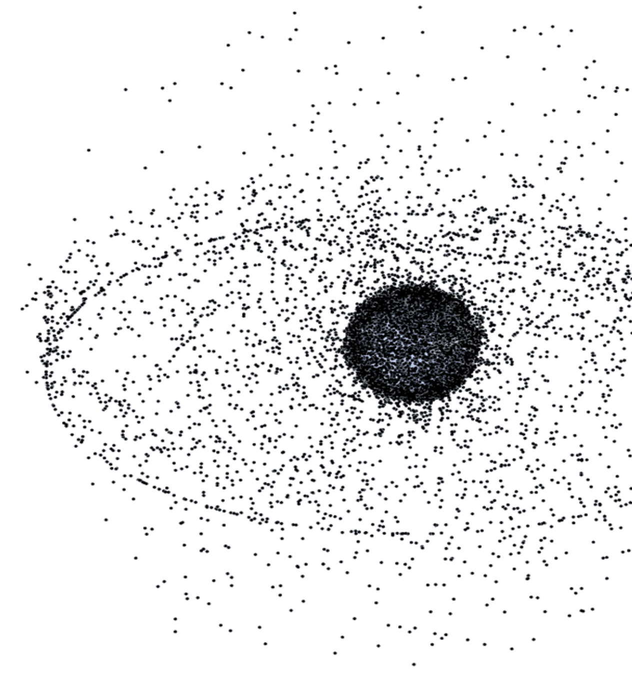
Case Study: D-SAT Mission (1 of 32)

THE CONTEXT

Debris Problem & Mitigation

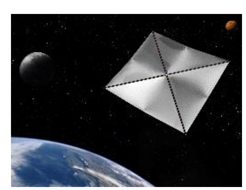


- Orbital satellite **traffic and debris will grow** exponentially
- Potential collisions could result in billions in **revenue losses**
- Planned constellations will have failed satellites and **high collision risk**
- End-of-life satellite and launcher decommissioning is **mandatory – ISO 24113-**

End-of-life disposal technologies:

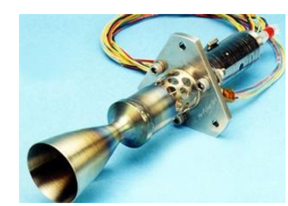
PASSIVE:

- Electromagnetic tethers;
- Drag augmentation
  - Sails
  - Balloons
  - Booms



ACTIVE:

- Electric propulsion
- Liquid propulsion
- Solid propulsion



Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (2 of 32)

D-ORBIT DECOMMISSIONING DEVICE (D3)

AUTONOMOUS

Power and telemetry-independent from the host satellite during the decommissioning maneuver

FLEXIBLE

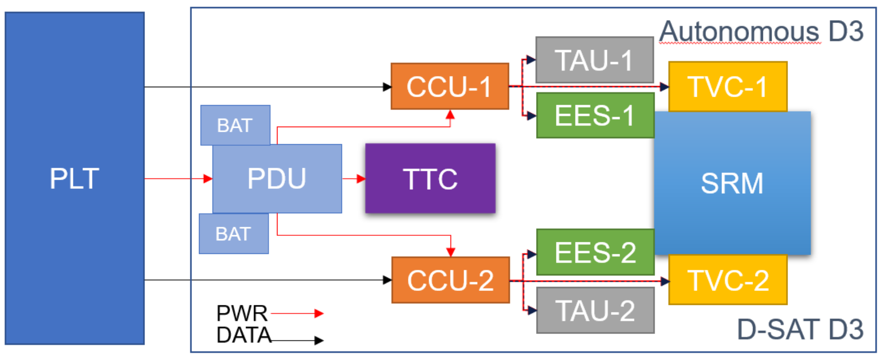
Compact design, easier to be integrated in satellite system and customizable to customer's need

RELIABLE

All the most sensible subsystems have already reached space qualification

SAFE

Complaint with the major safety standard and requirement NASA, ESA and MIL-STD



CDF ESA CleanSat Technology Assessment:

Building Block 14 - Autonomous De-Orbit System

Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (3 of 32)

THE MISSION

D-SAT HAS BEEN DESIGNED TO BE THE FIRST SATELLITE TO BE REMOVED IN A QUICK, SAFE AND CONTROLLED WAY BY AN INDEPENDENT DECOMMISSIONING DEVICE

D-SAT is a miniaturized satellite featuring a zero-single-point-of-failure and full redundant architecture. It hosts two experiments that are tested during the first two months of operations in orbit.

Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

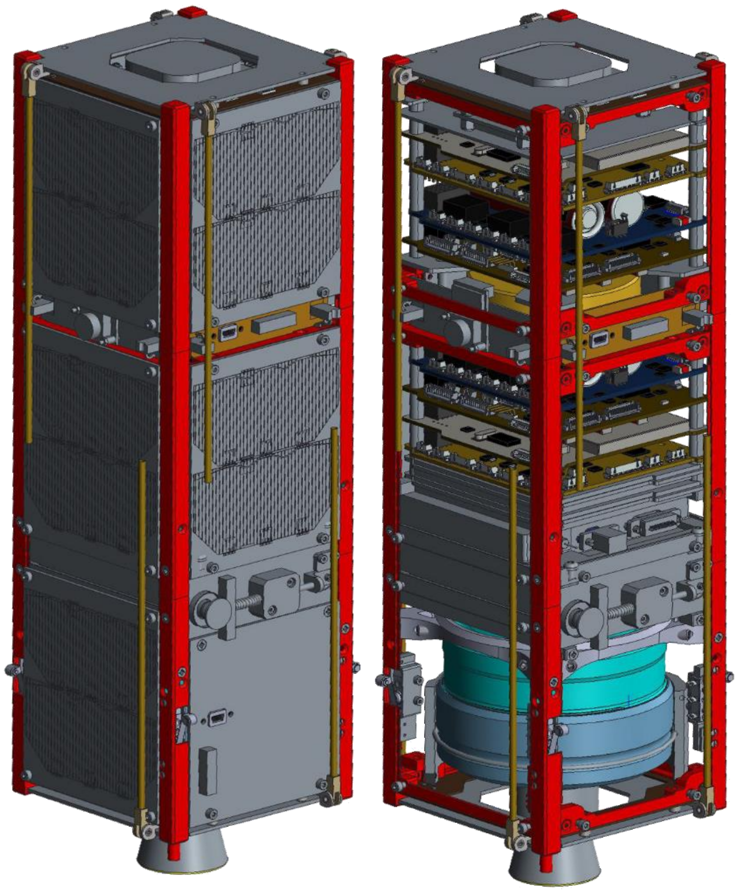
Case Study: D-SAT Mission (4 of 32)

THE SPACECRAFT

- D-SAT is a 4,3 kg nano-satellite (100x100x340 mm) composed by two main elements:

- the **Platform**, a complete, standard CubeSat system;

- the **Decommissioning Device**, with an independent electric power system, on-board computer, communication module and attitude determination and control system. The decommissioning device features a Solid Rocket Motor, to provide the propulsive thrust for the deorbiting maneuver.



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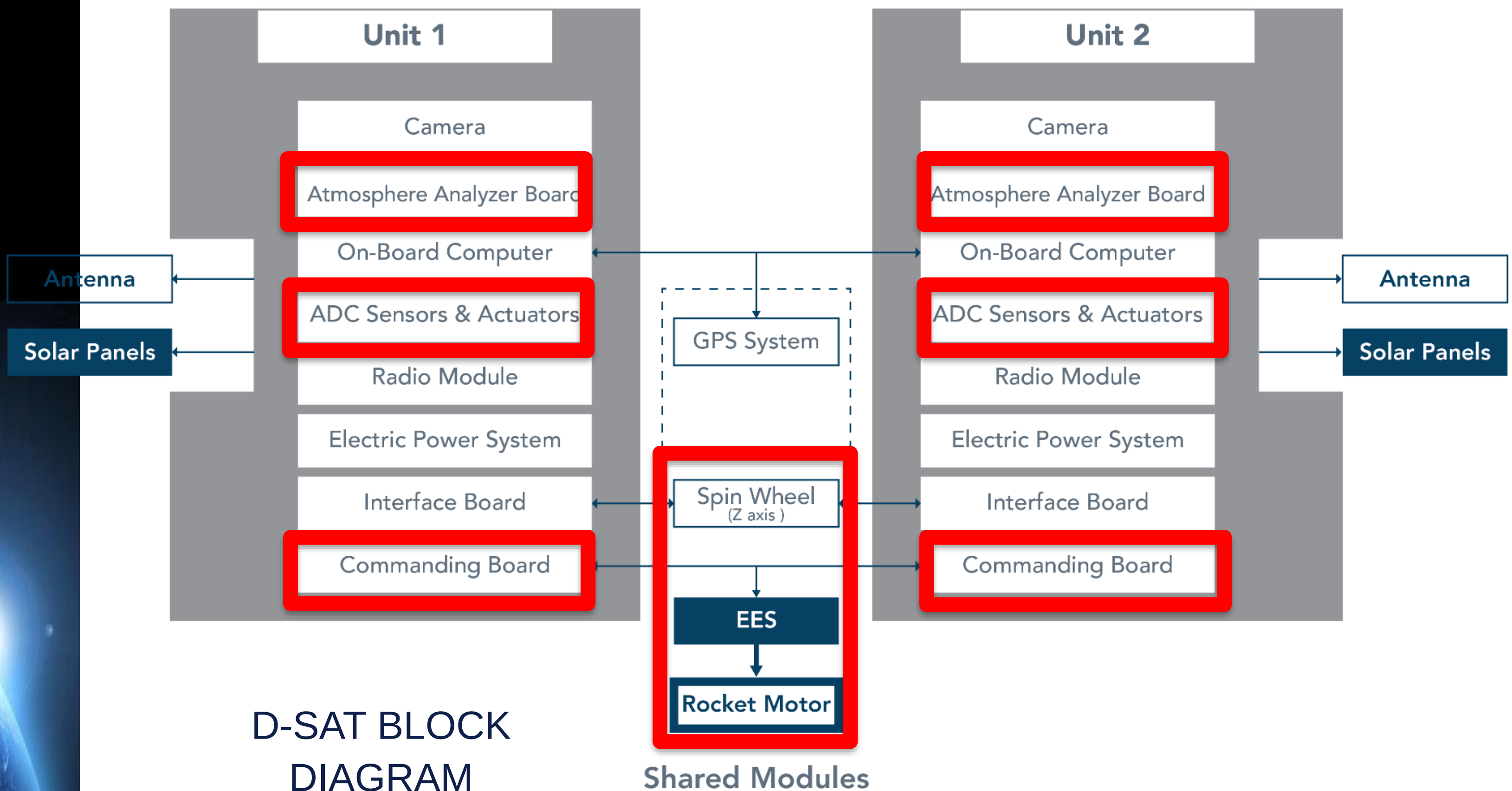
THE SPACECRAFT



D-SAT BLOCK DIAGRAM

Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (6 of 32)

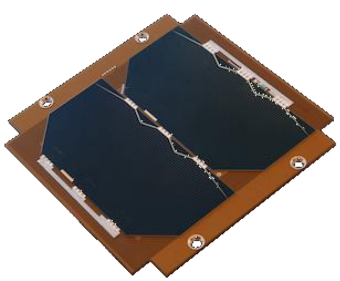
AVIONICS: Electric Power System

Function:

The power source is an COTS electric power system using two rechargeable batteries in series. The batteries are recharged through solar panels placed on the side walls of the satellite.

Specifications:

- Two all lithium ion batteries 3.7V @ 2.7Ah and 18650 form factor
- One unregulated power bus: 7.4 V @3,7A
- Two permanent regulated power buses: 3.3V@5A and 5V@4A
- Three latch-able regulated power buses: 3.3V@2A
- Three latch-able regulated power buses: 5V@2A
- Three independent photovoltaic converter (efficiency 93%) with MTTP controller
- 5 Solar Panels:
  - AzurSpace 3G30A space qualified triple junction solar cell assemblies
  - Power efficiency 30%
  - Assembly compliant to ECSS-Q-ST-70-38C



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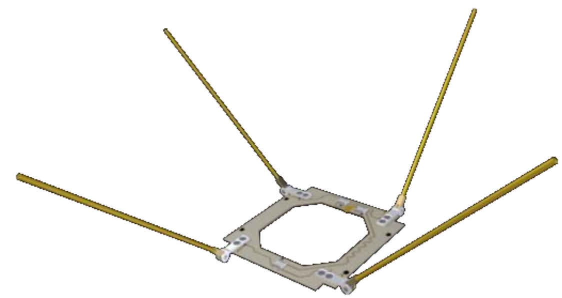
AVIONICS: Communication System

Function:

The communication system provides a reliable and secure Telemetry and Telecommand radio link in all possible satellite attitude condition.



Specifications:

- Omnidirectional turnstile antenna with circular polarization.
- Frequency: 437.505 MHz coordinated by IARU
- Half duplex communication
- Morse Beacon FM Modulated
- Tele-command and Telemetry digital data:
  - Downlink Transmitted Power = 1 W
  - Baud rate 4800 bps
  - GMSK signal
  - TM and TC Channel coding compliant to CCSDS 131.0-B-2 and 231.0-B-2

Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

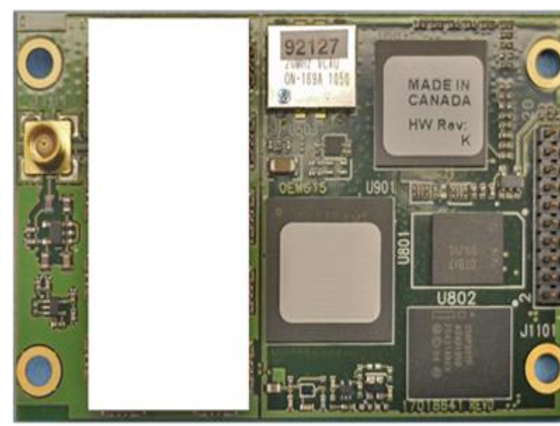
Case Study: D-SAT Mission (8 of 32)

AVIONICS: GPS subsystem

Description:

GPS subsystem include an active Low Noise Gain antenna and a GPS receiver.

- Antenna is a low noise and active L1 GPS antenna. Designed according to military standard as FAA TSO-C144, DO-160D, D0-228, MIL-C-5541, MIL-E-5400, MIL-I-45208A, MIL-STD-810, AND SAE J1455.
- GPS receiver is a Dual-Frequency GNSS Receiver (COCOM limits removed). Main featurese: Low power consumption and space-proven technology.



Case Study: D-SAT Mission (9 of 32)

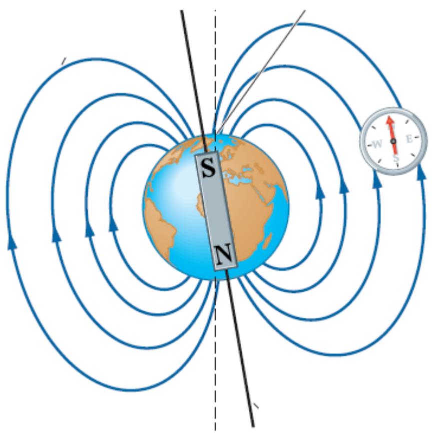
AVIONICS: On-Board Computer

The core of the OBC is an High-performance 32-bit ARM7 CPU, integrated combined with:

- 2MB of Static RAM;
- 4MB Flash Memory for Data Storage;
- 4 MB of Flash Memory Code Storage.

Its main interface to other subsystems are a CAN bus and a I2C bus.

In addition to a fully capable computer system it provides a 3-Axis magnetometer to sense the Earth's magnetic field and coil-drivers that can be used to implement attitude control based on magnetic sensing and actuation.



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Case Study: D-SAT Mission (10 of 32)

AVIONICS: Software

This software controls the D-Sat mission operations:

- Attitude control
- Command and Telemetry Data Handling
- SatAlert Experiment
- Decommissioning Program

Coding in C language for ARM7TDMI processor, using state machine approach

The microcontroller handles the following communications buses I2C bus, CAN bus UART

Same software running in two OBCs → **Fault tolerance**

FreeRTOS real time operative system

- ECSS-E-ST-40C – Software
- ECSS-Q-ST-80C – Software Product Assurance

- MISRA C
- C/C++ Coding Standards BSSC

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Case Study: D-SAT Mission (11 of 32)

Attitude Determination Control Subsystem

Sensors

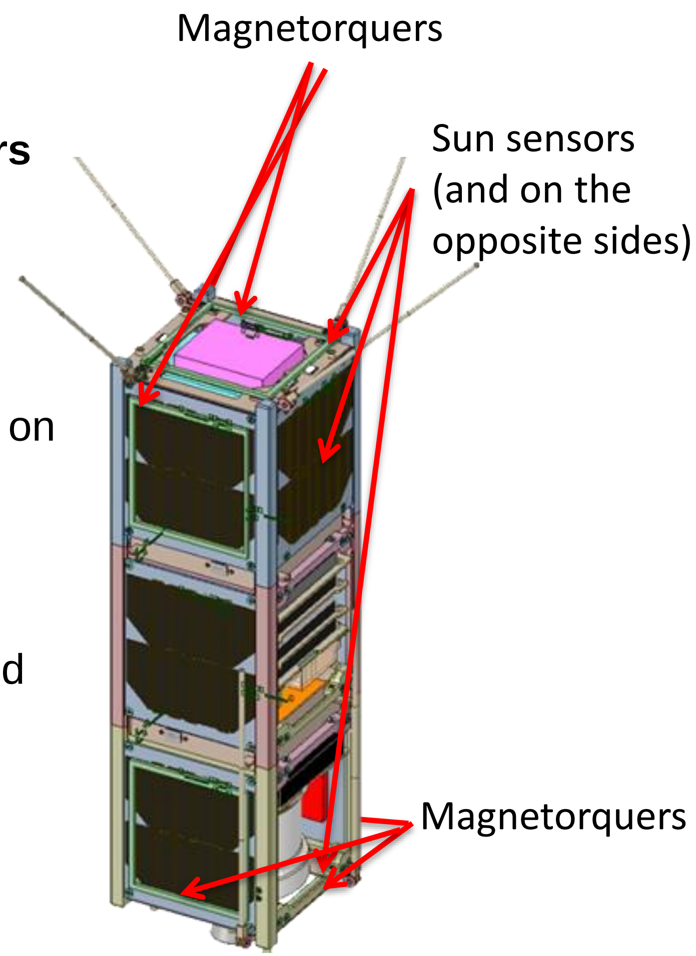
- 6 **sun sensors** (± x, ± y, ± z , integrated on solar panels) – **sensors on ± z are shared** between the two ADCSs
- 1 three-axes **magnetometer** (integrated on On-Board Computer)
- 1 three-axes **gyroscope** (integrated on Interface Board)

Actuators

- 3 **magnetorquers** (x, y, z , integrated on solar panels)

Controller

- On-Board Computer



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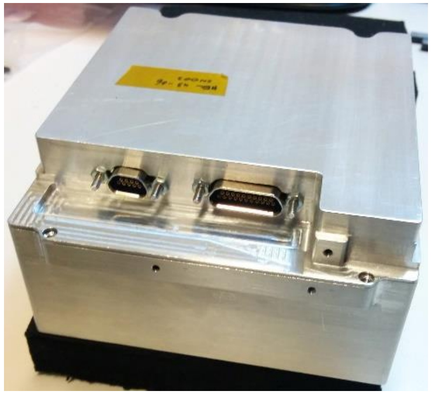
Case Study: D-SAT Mission (12 of 32)

D-SAT - ELECTRO EXPLOSIVE SYSTEM (EES)

EES function is to ignite the rocket motor through an Electro Explosive Device (EED) in a safe and controlled way.



MAIN FEATURES:

- Designed according to MIL-STD-1576 standard
- Mechanical barrier with a double lock architecture
- Four electronic barriers to avoid inadvertent EED ignition
- Hermetically sealed metallic box against EMI, humidity, explosive atmosphere and external fire
- Safing plug connector and additional mechanical provision for a safe ground handling
- Operate temperature range -34 / 71°C
- Cubesat Form Factor

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Case Study: D-SAT Mission (13 of 32)

D-SAT - SOLID ROCKET MOTOR (SRM)

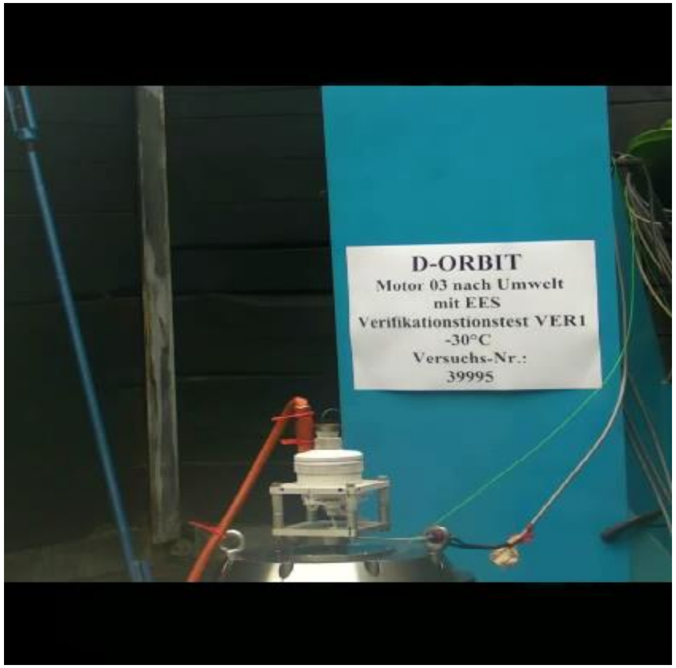
D-SAT propulsion system consists of a small Solid Rocket Motor delivering about 750 Ns total impulse to the satellite. It uses about 300 grams of **non-metalized** composite propellant based on ammonium perchlorate (AP) and binder (HTPB).

MAIN FEATURES:

• Mass	960 g
• Envelope	121 x ø97 mm
• Δv	≈ 180 m/s
• Maximum Thrust	450 N
• Operate temperature range	-30 / 71°C
• Safety temperature range	-34 / 85°C

CONSTRAINT:

- Fixed nozzle: Thrust-vector control systems didn't satisfy programmatic and technical requirements. It imposed D-SAT to be spin-stabilized during firing and strict mounting tolerance.



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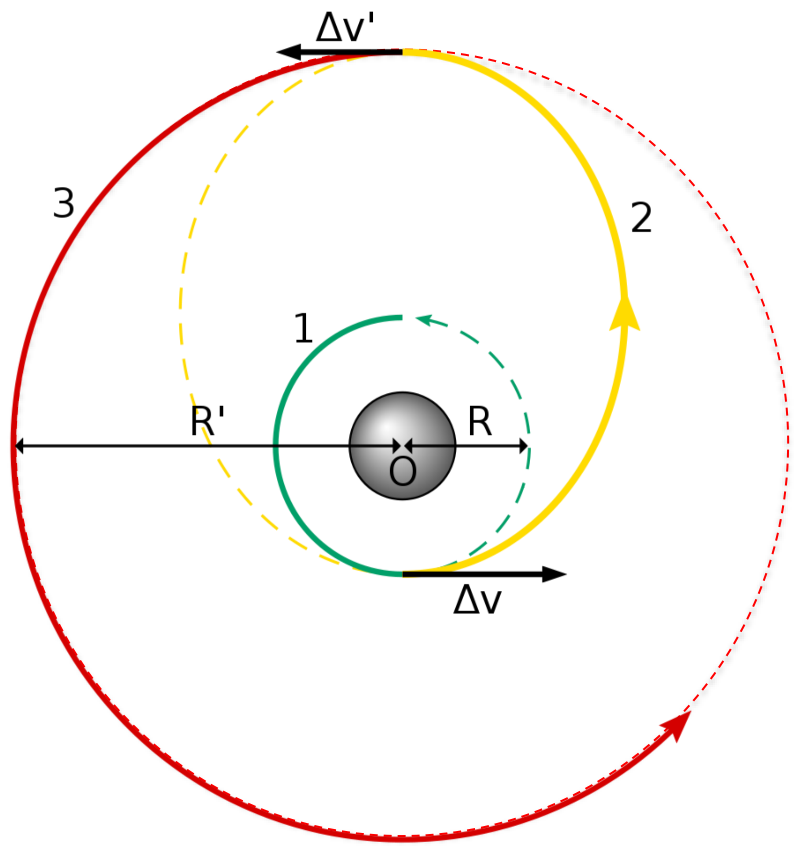
D-SAT - SOLID ROCKET MOTOR (SRM)

Hohmann transfer orbit

In orbital mechanics, the Hohmann transfer orbit is an elliptical orbit used to transfer between two circular orbits of different radii in the same plane.



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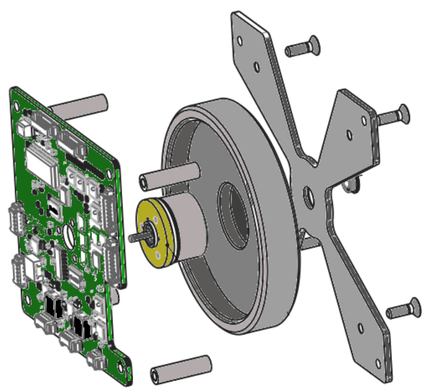
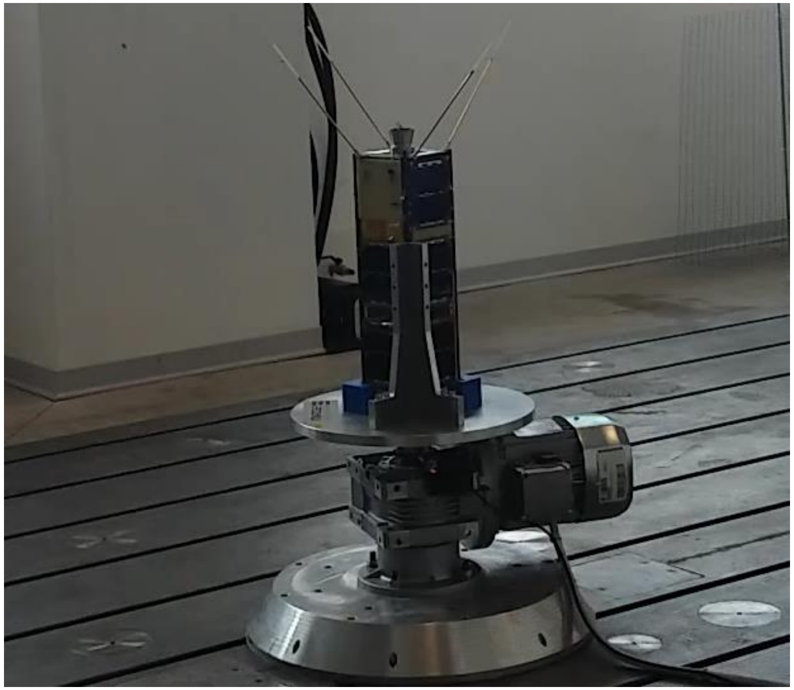
Case Study: D-SAT Mission (14 of 32)

D-SAT - SPIN WHEEL

The D-SAT spin wheel system provides an angular momentum for spinning the satellite up to 400 rpm (6.6 Hz).





MAIN FEATURES:

- Mass = 200 g
- Momentum of inertia, Ir = 1.8 [kg cm^2]
- Angular Velocity, ω = 16000 rpm

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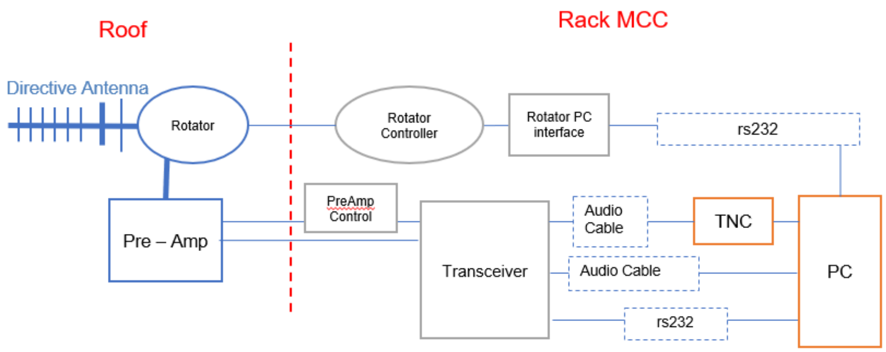
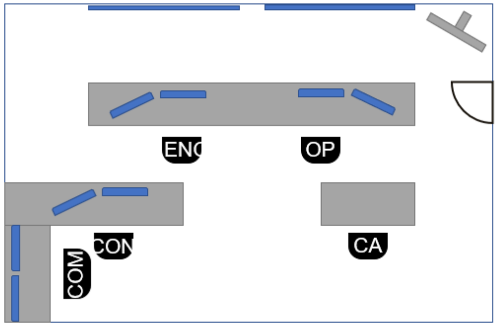
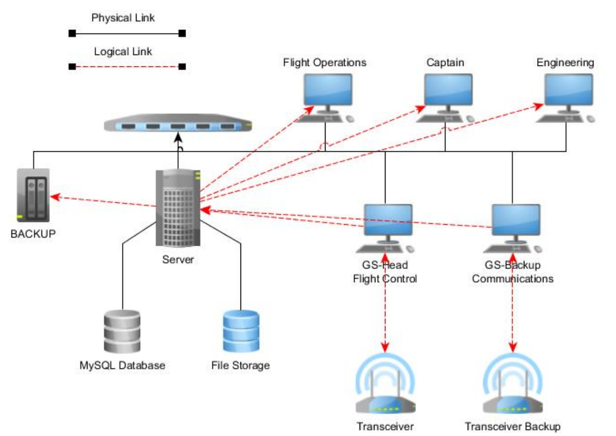
Case Study: D-SAT Mission (15 of 32)

D-SAT - GROUND SEGMENT



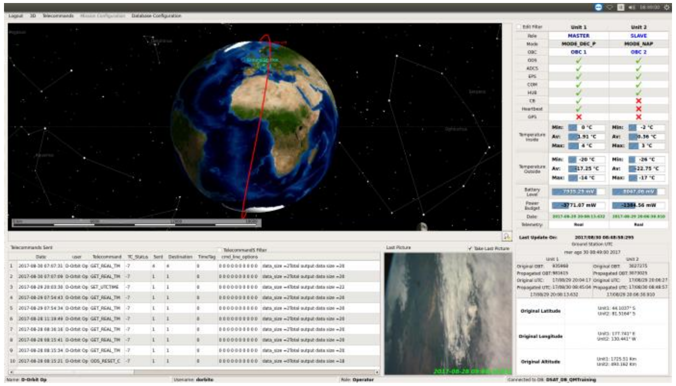


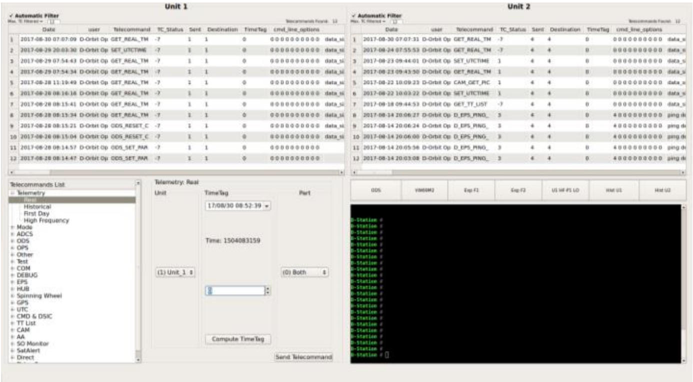


Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (16 of 32)

D-SAT - GROUND SEGMENT





- Completely developed in-house
- With point-and-click user interface
- Interfaces directly with TNC, ground station hardware and remote database
- Real-time update of telemetry and plotting utility
- Implementing reconfigurable color-code and format for all windows
- Allows multiple telemetry frames and units (i.e. satellites) information merge and filtering
- Database suitable for MATLAB export and post-processing

Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

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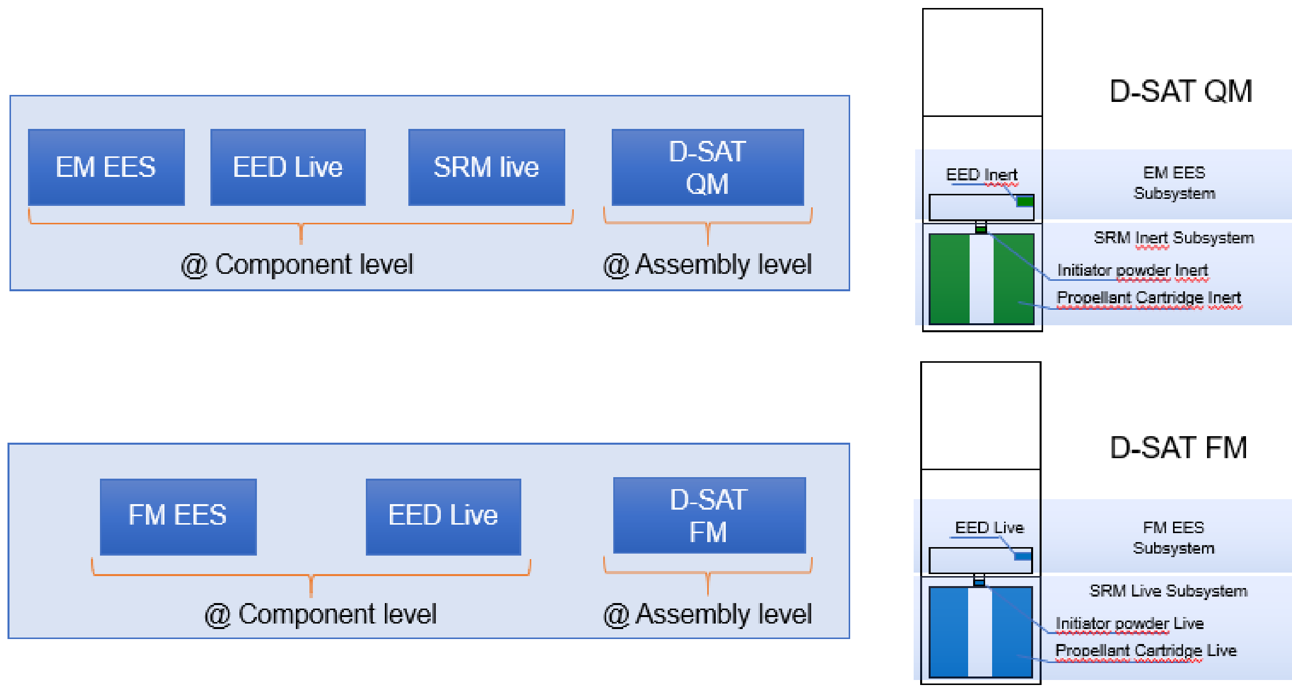
Case Study: D-SAT Mission (17 of 32)

D-SAT VERIFICATION PLAN

Who perfomed Qualification tests?

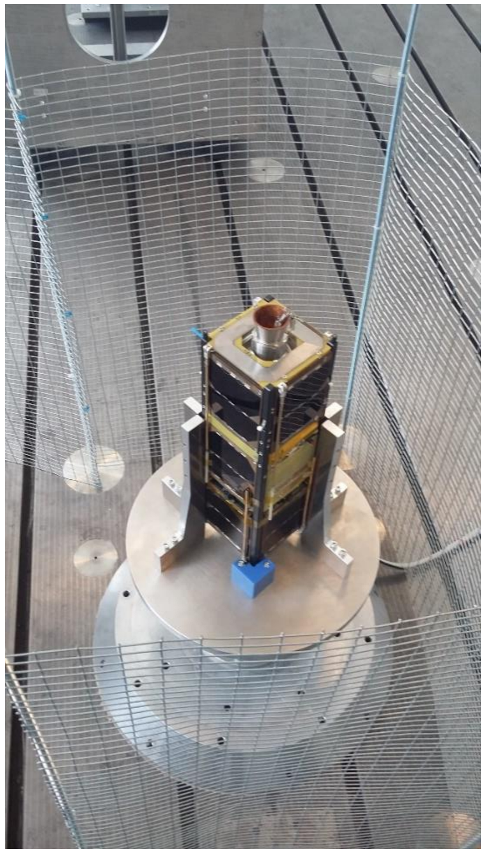
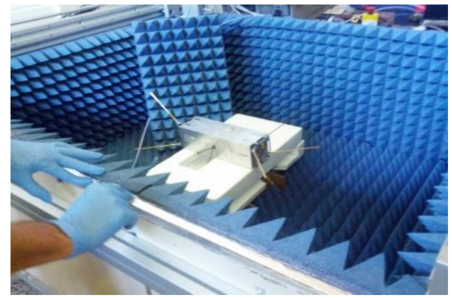
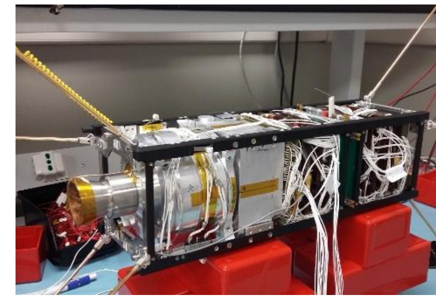
Who perfomed Acceptance tests?



Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (18 of 32)

INTEGRATION PROGRESS


!!! PFM Acceptance - Q4 2016 !!!

Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

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Case Study: D-SAT Mission (19 of 32)

!!! Launch PSLV C-38 23rd June, 2017 !!!

Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (20 of 32)

D-SAT - Mission Schedule

Phase	Start	End	Description
LEOP and Commissioning	23 Jun	01 Jul	During LEOP, the telecommunication link has been acquired, frequency characterized and health status confirmed. Systems testing and characterization has been carried out.
ADCS Calibration	01 Jul	15 Jul	In this phase, sensors and actuators was deeply tested, calibrated and characterized, and ADCS performance have been verified by means of testing pointing manoeuvres.
Experiments Campaign	15 Jul	08 Aug	During these weeks, the partner's experiments have been conducted
Earth-Imaging Campaign	08 Aug	25 Aug	In these weeks of Earth-imaging campaign, a number of Earth pictures have been taken and downloaded, mainly for outreach purposes.
Testing for Decom. Manoeuvre	25 Aug	Sep. 2017	In this phase, multiple testing to prepare the system for the decommissioning manoeuvre and to allow precise mission analysis for the deorbiting have been conducted.
Decommissioning Maneuver	2nd of Oct 2017		In this final (and very short) phase, the spacecraft will be removed (see Section 4.2.8) by activating the D-Orbit Decommissioning Device

Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

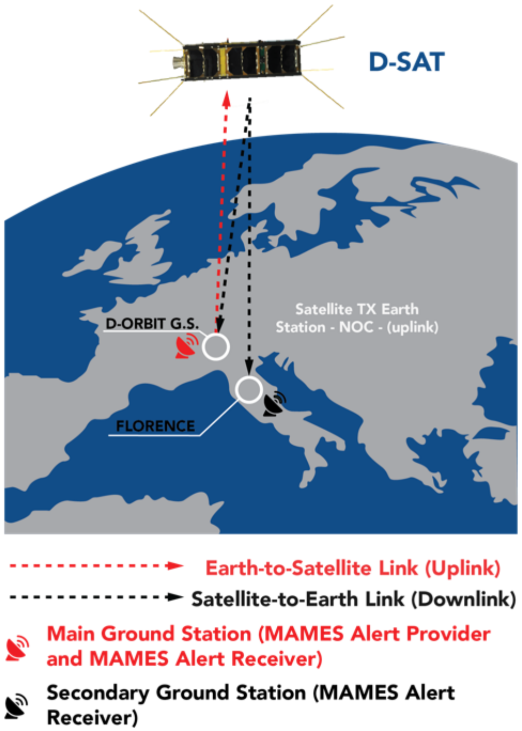
D-SAT Experiments

SAT-ALERT EXPERIMENT

The experiment consists of the generation and transmission of a MAMES ALERT message, from an Earth station to satellite, which will process and broadcast the received message back to Earth.

Multiple Alert Message Encapsulation Protocol Objectives:

- Powerful encapsulation scheme for embed other alerting alert messages (e. g. Common Alert Protocol (CAP), unstructured text, image, paging protocols);
- Provide a multi-semantic representation of the alert, allowing the interpretation by automated devices with low capabilities;
- Designed to support transmission over satellite also over limit ed channels;
- Fit in the main SatCom and SatNav systems.



Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (22 of 32)

D-SAT Experiments

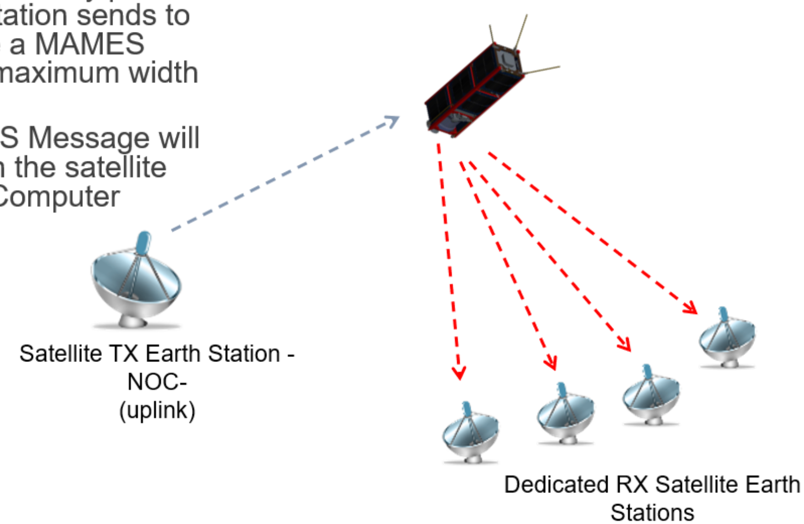
SAT-ALERT EXPERIMENT

UNIVERSITÀ DEGLI STUDI FIRENZE
DINFO DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

cnit

Earth-to-Satellite path

- During the visibility period the Earth station sends to the satellite a MAMES message (maximum width of 4KB).
- The MAMES Message will be stored in the satellite On-Board Computer memory.



Satellite-to-Earth path

- As a trigger command is sent by the Earth Station (NOC), the MAMES message stored on satellite will be broadcasted (on-demand transmission).
- MAMES broadcast transmission will be activated in all the available visibility windows.

Two dedicated Earth Stations will be implemented for the reception and de-encapsulation of the MAMES messages.

Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (23 of 32)

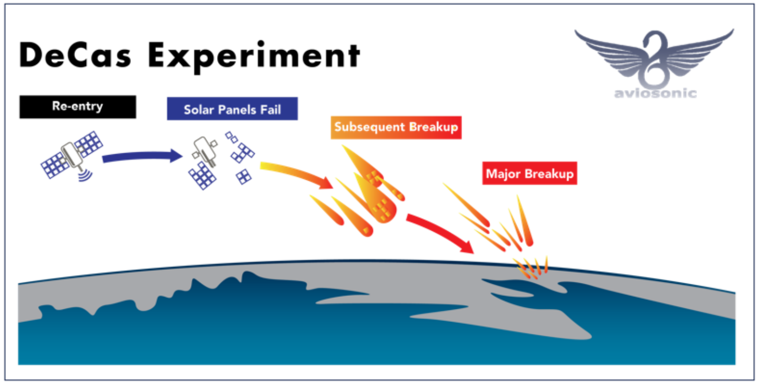
D-SAT Experiments

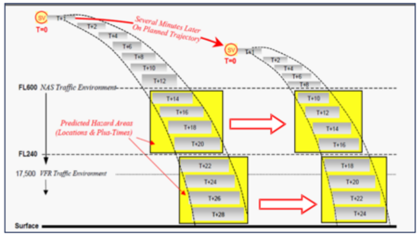
DeCas – DEBRIS COLLISION AVOIDING SYSTEM

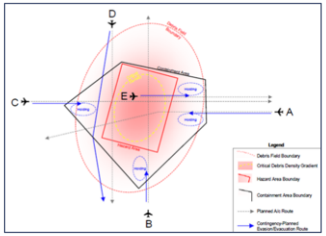
The space debris generated by a not controlled re-entry of a satellite can be very dangerous to the population, high-risk industrial plants and aviation (e.g. a fragment more than 300gr causes loss of air craft).

DeCAS, Debris Collision Alerting System determines the dynamics of the Danger Area associated to the fragmentation of a Space Vehicle, transmits a warning to all interested users and provides the elements to "suggest" to pilots an initial escape heading to a void danger area.

DeCAS is integrated on D-SAT and various simulations will be performed during D-SAT mission to inorbit to validate the DeCAS operation.



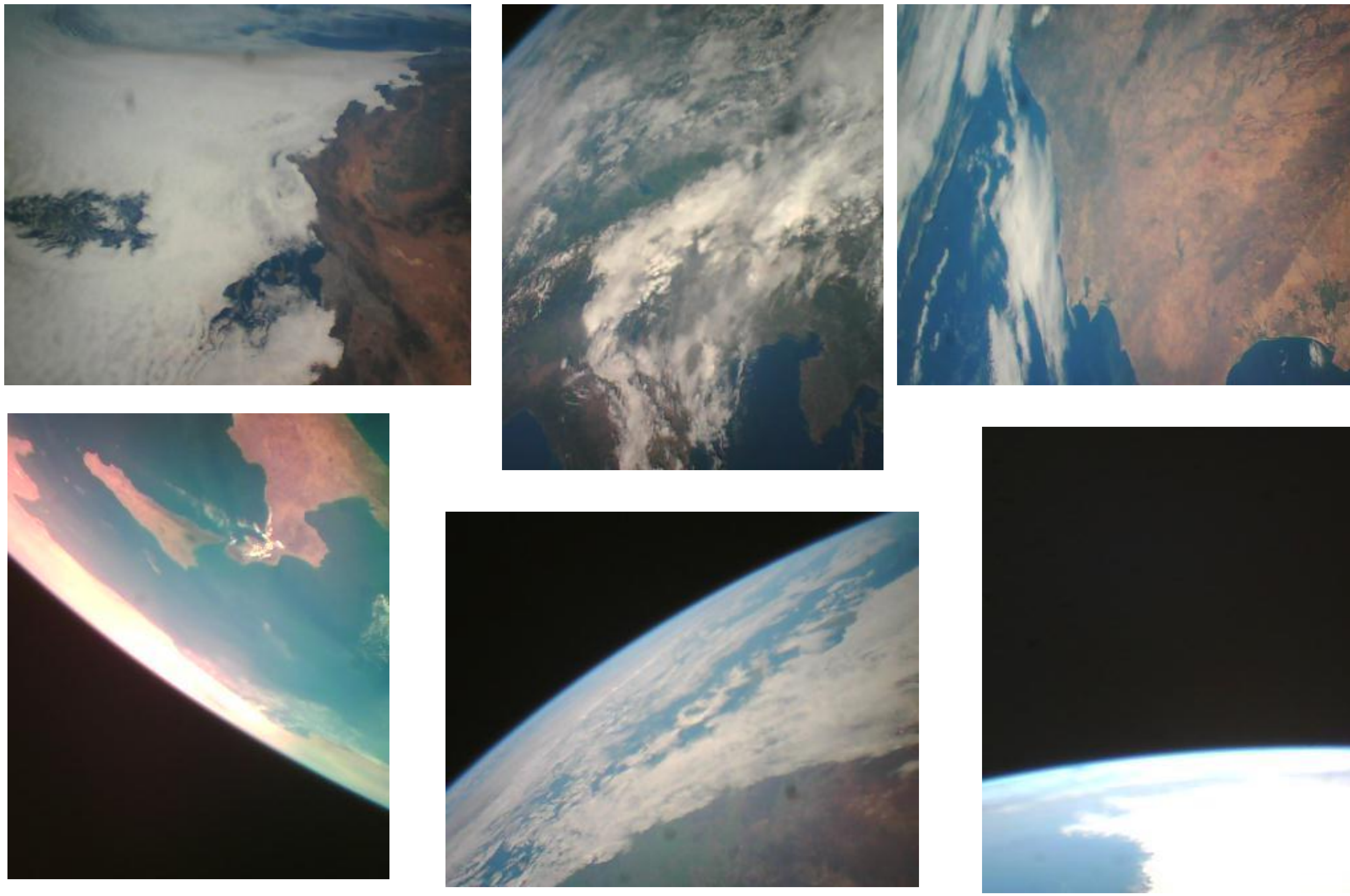




Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (24 of 32)

D-SAT - EARTH IMAGING CAMPAIGN

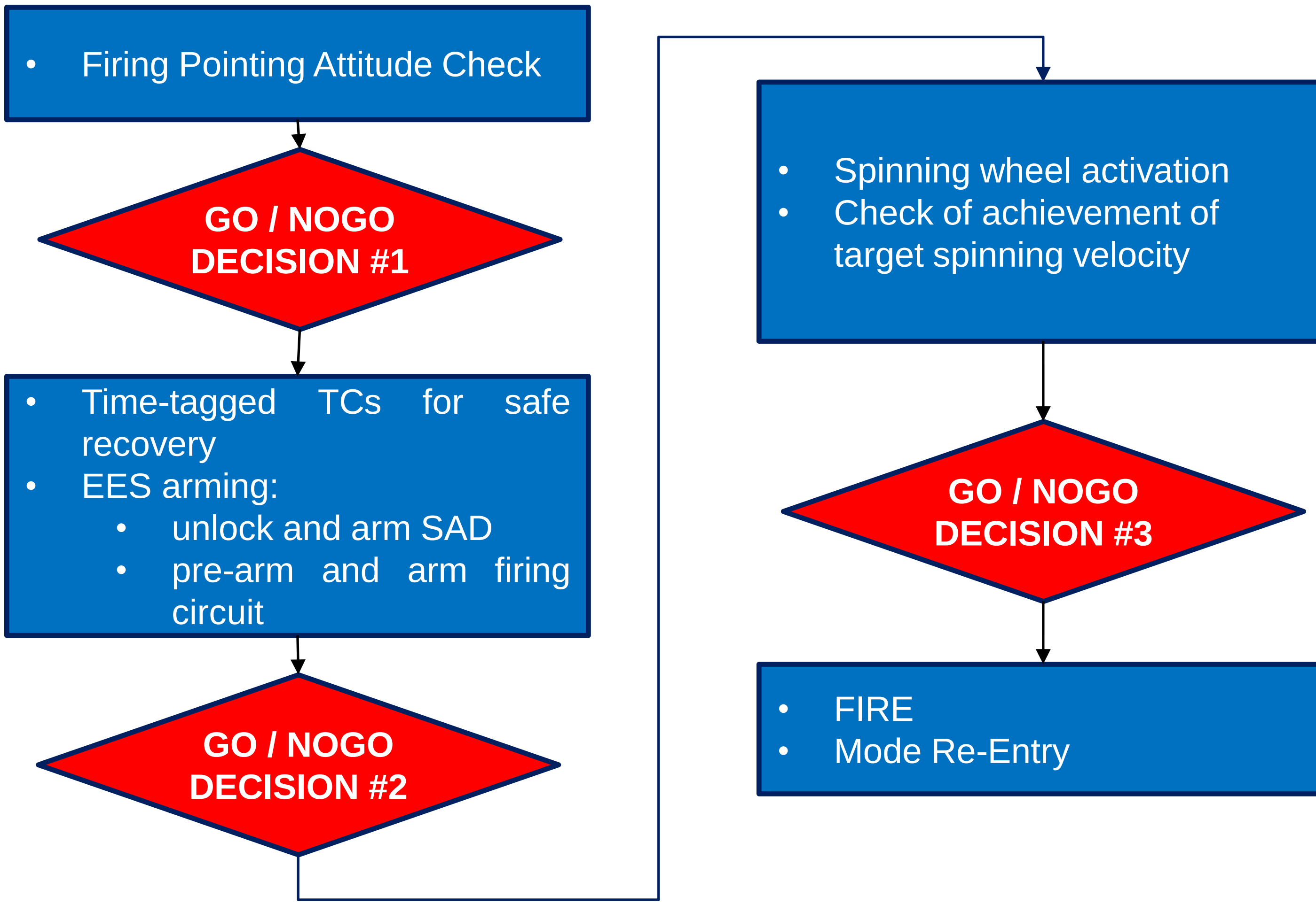


Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (25 of 32)

D-SAT - Disposal Manoeuvre Analysis

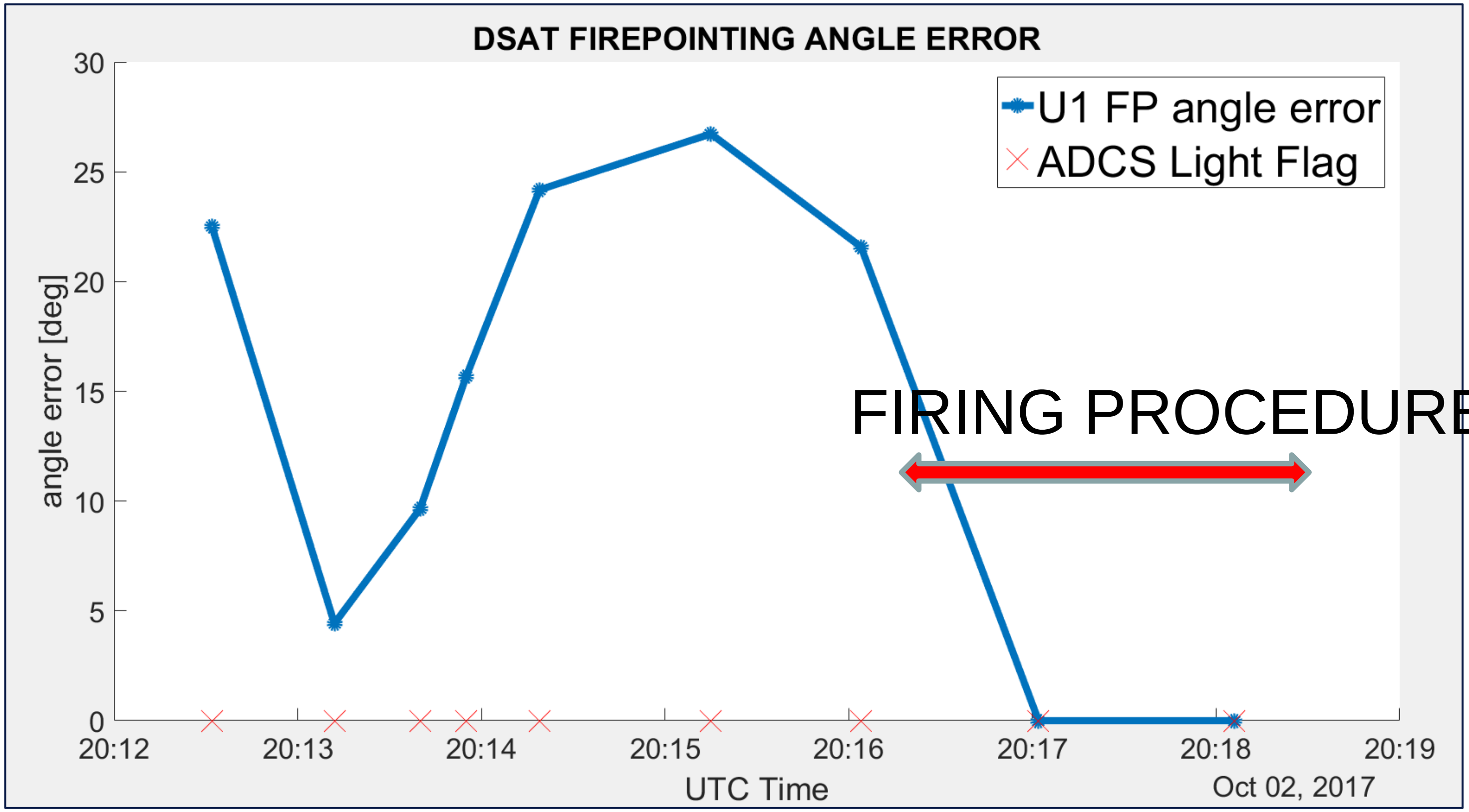
Steps of the Firing Procedure in chronological order:



Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (26 of 32)

D-SAT - Disposal Manoeuvre Analysis

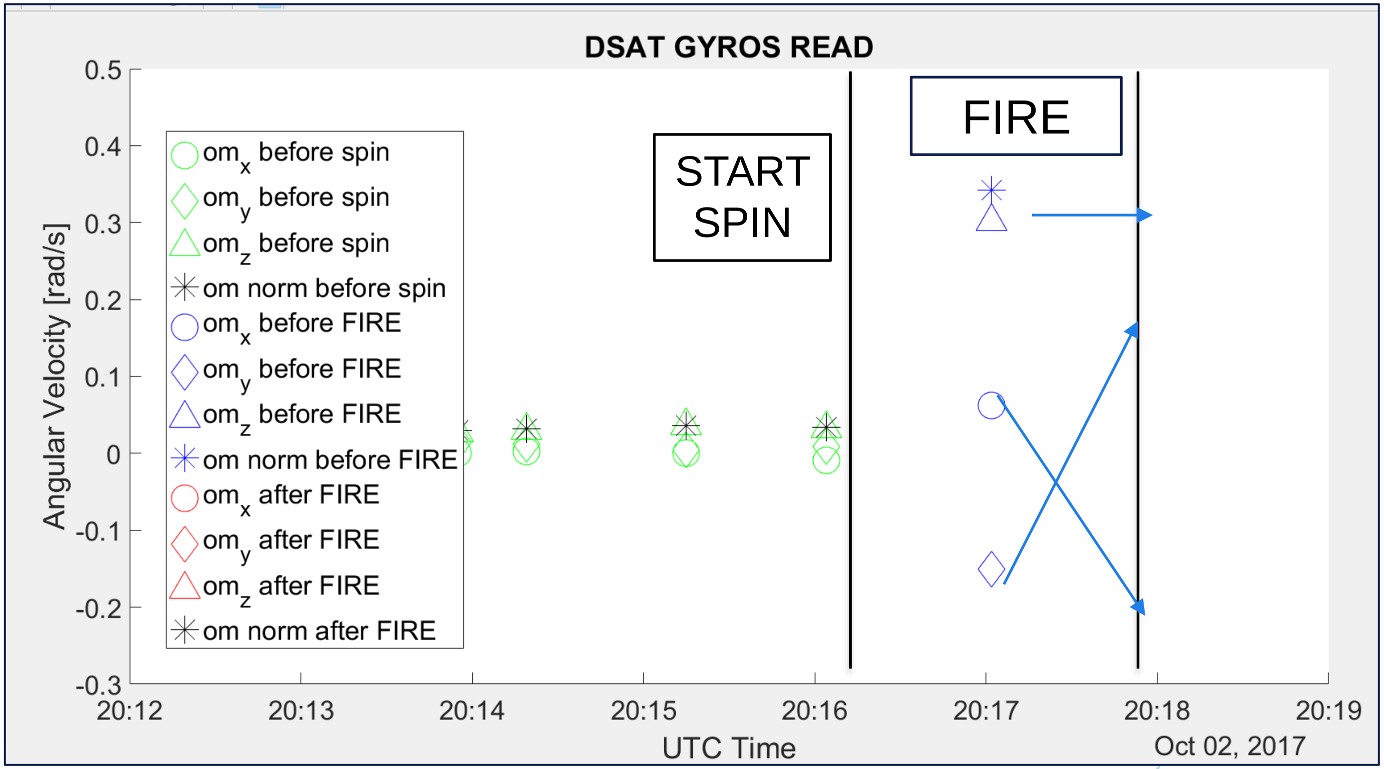


Pointing Error: Nominal within tolerances (i.e. **< 25 deg**)

Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (27 of 32)

D-SAT - Disposal Manoeuvre Analysis



Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (28 of 32)

D-SAT - Disposal Manoeuvre Analysis

Tot delta-V provided ≈ 70 m/s

against ideal 180 m/s

Red = original orbit

Perigee = 503 km

Apogee = 514 km

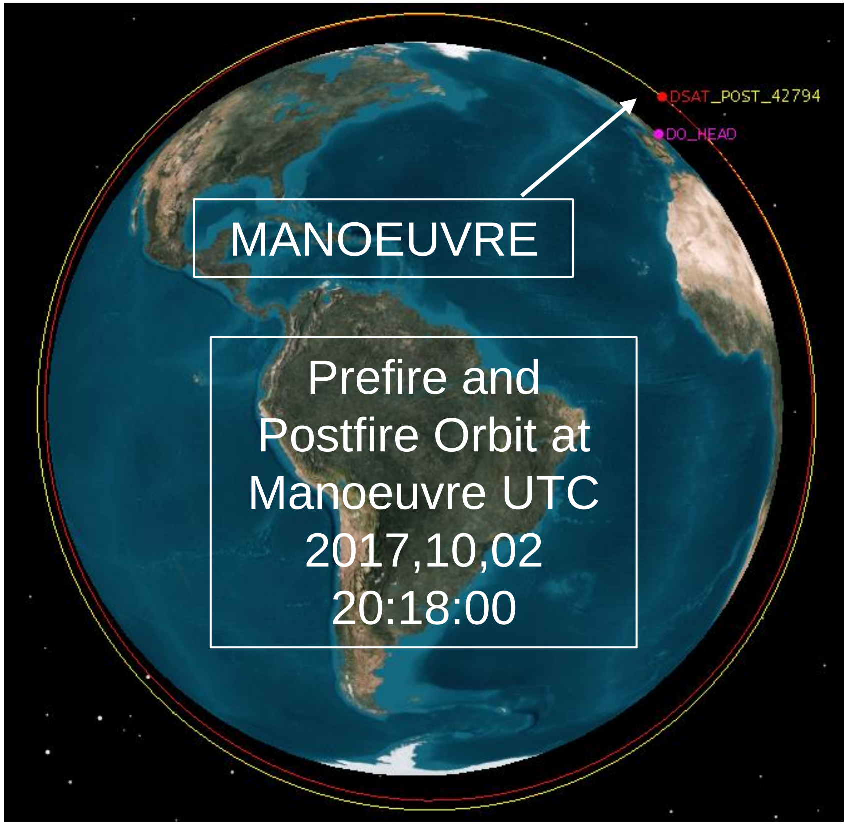
Inclination = 97.4388 deg

Yellow = post-fire orbit

Perigee = 513 km

Apogee = 692 km

Inclination = 97.6306 deg



Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

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Case Study: D-SAT Mission (29 of 32)

D-SAT - Disposal Manoeuvre Analysis

Conclusions

1. The D-SAT disposal manoeuvre was not nominal because:
   Mounting misalignments of SRM within satellite structure (tolerances in this regards were critically < 1.5 mm);
   Possibly combustion instabilities, which may deviate the thrust vector during the fire.

2. Possible mitigations: Thrust misalignments could be assessed both during SRM verification and during D-SAT qualification campaign via dedicated firing test on thrust vectoring bench.

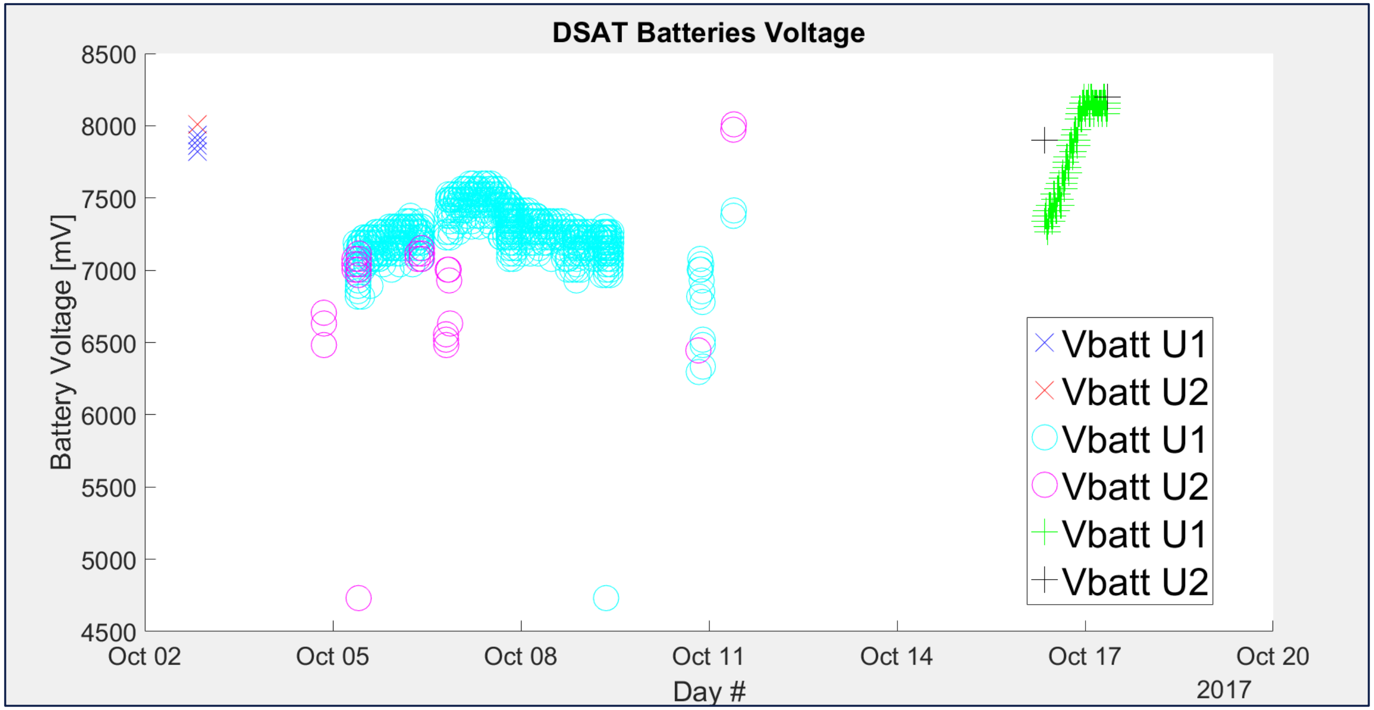
3. The D-SAT post-fire orbit is about 100km higher than the original one and with 0.2deg delta-inclination (still compliant with the 25-year rule)

Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (30 of 32)

D-SAT - Disposal Manoeuvre Analysis

D-SAT Survived: EPS and Batteries Status



Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Case Study: D-SAT Mission (31 of 32)

D-SAT - RESULTS

D-SAT has been the first CubeSat:

1. With a completely redundant avionic's architecture;
2. With a pyrotechnic device compliant with the MIL-STD-1576 standard;
3. To maintain a stable communication link during the spin-stabilizing pre-firing phase when it was rotating on its axis at 400 rpm;
4. To survive after firing of a solid rocket motor with a total impulse of 750 Ns (a very high trust for such a small satellite);
5. To perform an orbital maneuver with a delta-velocity of 70 m/s.

Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

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Case Study: D-SAT Mission (32 of 32)

D-SAT - RESULTS

#	Major/Minor	Mission Objectives	Expected Time	Feedback
~~1~~	~~Major~~	~~Get to space!~~	~~23-June~~	~~Feedback from the laucher and photo~~
~~2~~	~~Major~~	~~Reception of Beacon Signal~~	~~23-June~~	~~Decode signal from Beacon U1 or U2~~
~~3~~	~~Major~~	~~Acquisition of Link~~	~~25-June~~	~~Correctly sent a telecommand and receive the ACK~~
~~4~~	~~Major~~	~~Antenna Deployment~~	~~25-June~~	~~Antenna deployment telemetry~~
~~5~~	~~Major~~	~~ADCS Detumbling Achieved~~	~~25-June~~	~~ADCS Telemetry~~
~~6~~	~~Major~~	~~ADCS Sun Pointing Achieved~~	~~28-June~~	~~ADCS Telemetry~~
~~7~~	~~Major~~	~~EPS Batteries Charging~~	~~30-June~~	~~EPS Housekeeping~~
~~8~~	~~Minor~~	~~Picture from space~~	~~30-June~~	~~Picture download~~
~~9~~	~~Minor~~	~~OPS Functioning~~	~~30-June~~	~~OPS telemetry~~
~~10~~	~~Major~~	~~GPS Functioning~~	~~11-July~~	~~GPS Test~~
~~11~~	~~Major~~	~~CBs Functioning~~	~~11-July~~	~~Commanding Board Test~~
~~12~~	~~Minor~~	~~DECASS~~	~~14-July~~	~~DECASS Output~~
~~13~~	~~Minor~~	~~Atmosphere Analyzer~~	~~14-July~~	~~Atmosphere Analyzer~~
~~14~~	~~Minor~~	~~SATALERT Functioning~~	~~14-July~~	~~SATALERT Telemetry~~
~~15~~	~~Major~~	~~ADCS Inertial Pointing Achieved~~	~~29-September~~	~~ADCS Telemetry (state_flag = 6)~~
~~16~~	~~Major~~	~~Spin Wheel Functioning~~	~~02-October~~	~~word1~~
~~17~~	~~Major~~	~~D3 EES SAD Armed~~	~~02-October~~	~~word0~~
~~18~~	~~Major~~	~~D3 EES - FC Armed~~	~~02-October~~	~~word0~~
~~19~~	~~Major~~	~~D3 SRM Fire~~	~~02-October~~	~~orbital parameters change~~
20	Major	Direct re-entry	02-October	post-fire orbit intersecating Earth. Entry confirmation from TM & NORAD
21	Major	Uncontrolled re-entry	02-October	post-fire orbit intersecating Earth. Entry confirmation from TM & NORAD
~~22~~	~~Major~~	~~Survive after Firing~~	~~02-October~~	~~Receive Telemetry after the motor firing~~

Ref. D-SAT MISSION: an In-Orbit Demonstration of Satellite Controlled Re-entry Clean Space Industrial Days October 26th 2017 – ESA-ESTEC – Credit: D-ORBIT Spa

Launch Opportunities for CubeSats

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Launch Opportunities for CubeSats (1 of 20)

How are CubeSats launched into space?

Feb. 14, 2017 - An ISRO Polar Satellite Launch Vehicle lifts off carrying 104 satellites on a single rocket. The rocket's primary payload was an Indian remote sensing satellite, Cartosat-2D

Credit: ISRO

Launch Opportunities for CubeSats (2 of 20)

How are CubeSats launched into space?

May 26, 2017 - Successful launch of Ex-Alta 1, University of Alberta's CubeSat, from the International Space Station

Credits: Canadian Space Agency, NASA

Launch Opportunities for CubeSats (3 of 20)

FIVE TYPES OF LAUNCHERS:

Defined by payload capability to LEO:

> **Micro:** <500 Kg

> **Small:** 500 Kg to 2 Tons

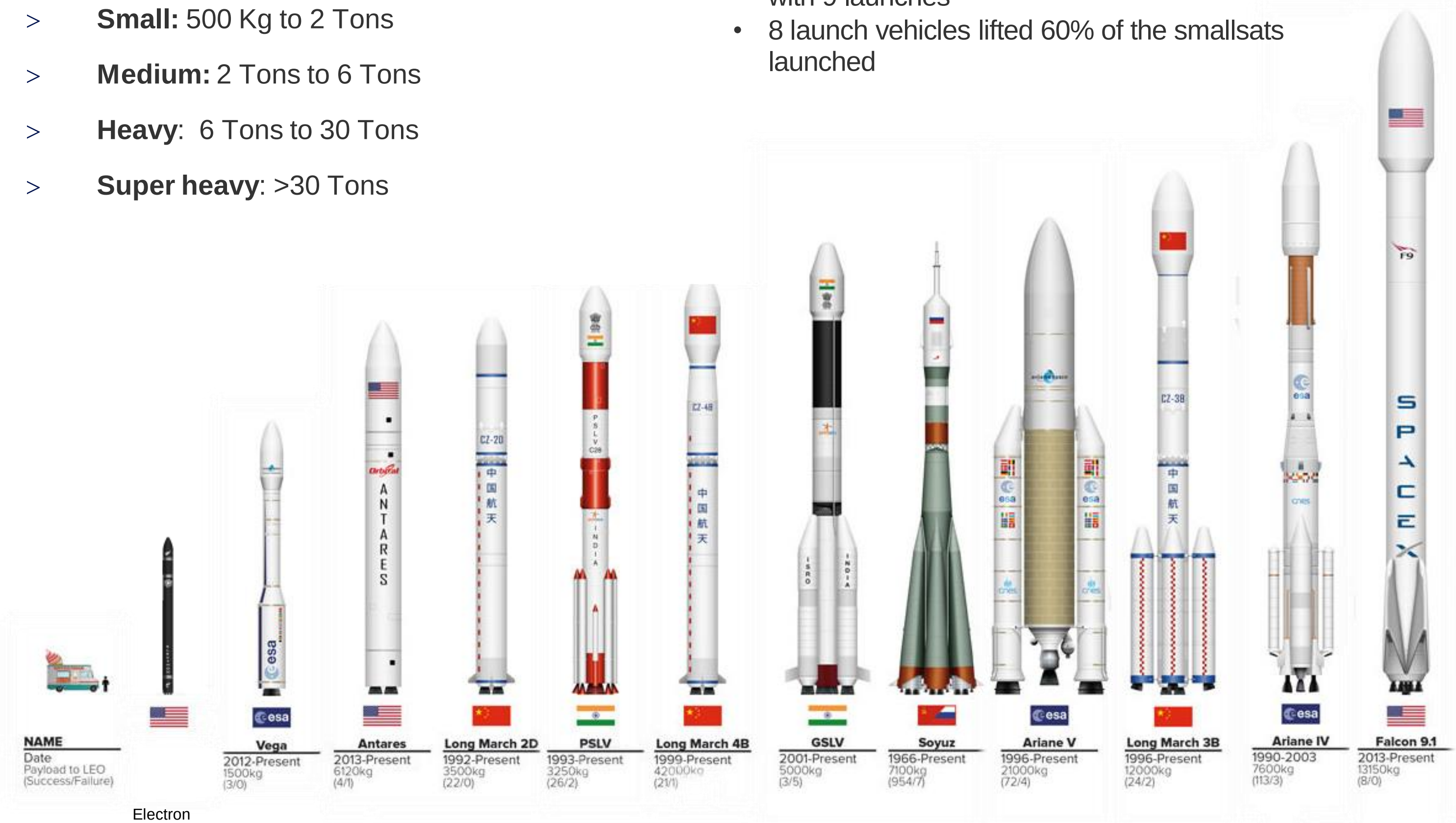
> **Medium:** 2 Tons to 6 Tons

> **Heavy**: 6 Tons to 30 Tons

> **Super heavy**: >30 Tons

In 2018:

- Falcon 9 was the most used launcher (87 smallsats of which 64 during SSO A mission)
- Long March 2C/D was the most available launcher with 9 launches
- 8 launch vehicles lifted 60% of the smallsats launched



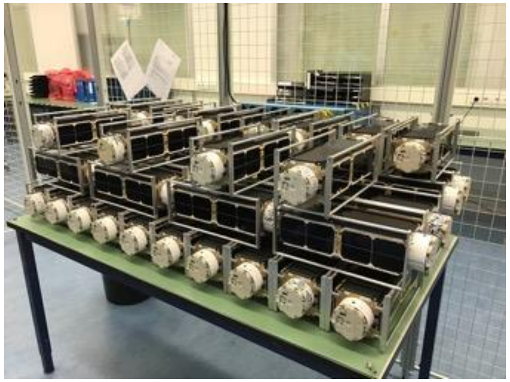
Ref. https://www.universetoday.com/118922/all-the-worlds-rockets-past-present-and-future/

Launch Opportunities for CubeSats (4 of 20)

ALL IN LINE TO GET LAUNCHED…

Get into business in a reasonable time

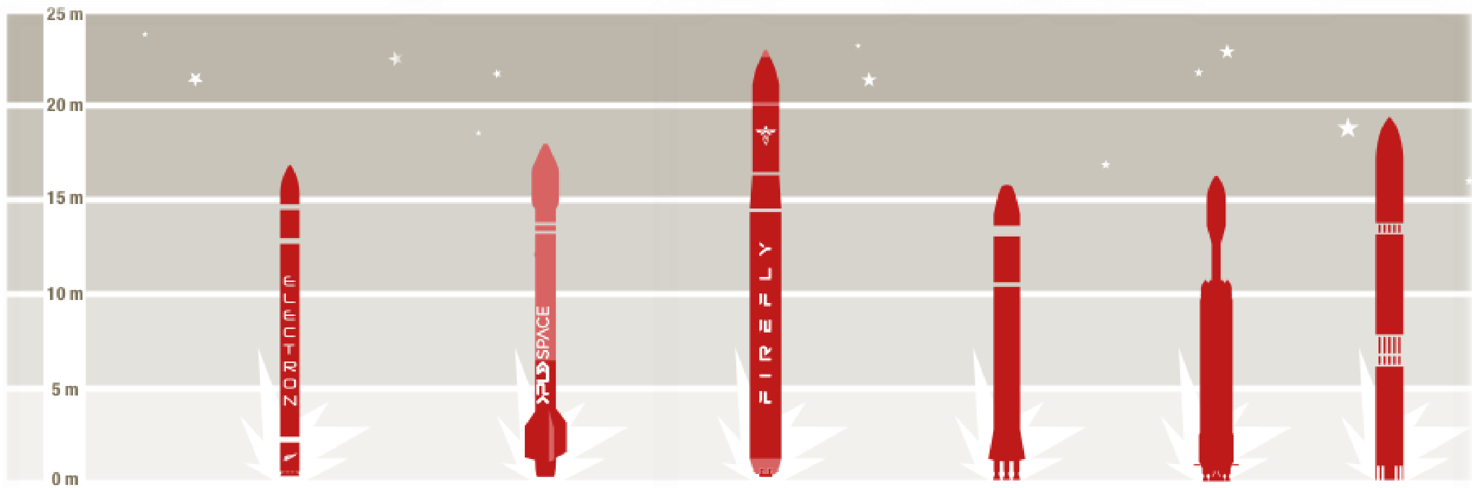
- Small satellites cannot decide «when» or «where»;
- Once in orbit, 6 to 10 months to get «phased»;
- Average Launch delay: 1 to 2 years;
- New launchers? Up to 10 years and 120 million investment.



Ref. https://www.universetoday.com/118922/all-the-worlds-rockets-past-present-and-future/

Launch Opportunities for CubeSats (5 of 20)

LAND MICRO-LAUNCHERS:

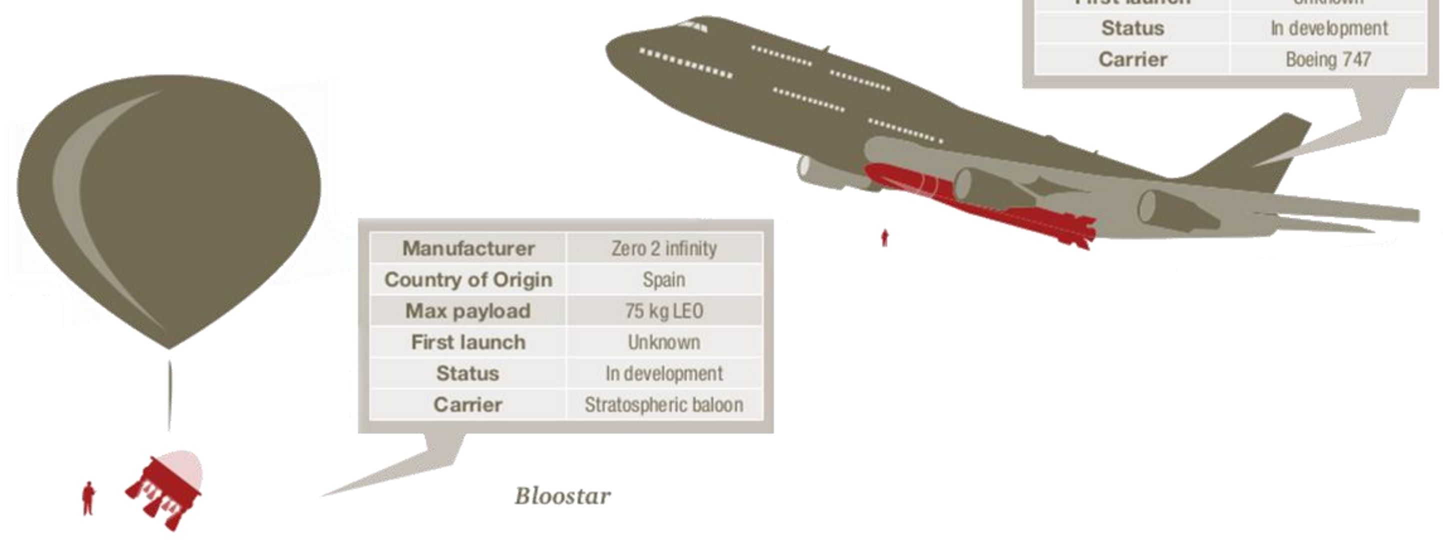


System	Electron	Arion 2	Alpha	Vector H	Taymyr 7	VLM 1
Manufacturer	Rocket Lab	PLD Space	Firefly Space Systems	Vector Space Systems	Lin Industrial	CTA
Country of Origin	USA / New Zealand	Spain	USA	USA	Russia	Brazil
Max payload	225 kg LEO	150 kg LEO	200 kg LEO	120 kg LEO	180 kg LEO	200 kg LEO
First launch	2017	2021 (expected)	Unknown	Unknown	Unknown	2018

Ref: micro-launchers: what is the market? – Feb. 2017

Launch Opportunities for CubeSats (6 of 20)

AIR MICRO-LAUNCHERS:

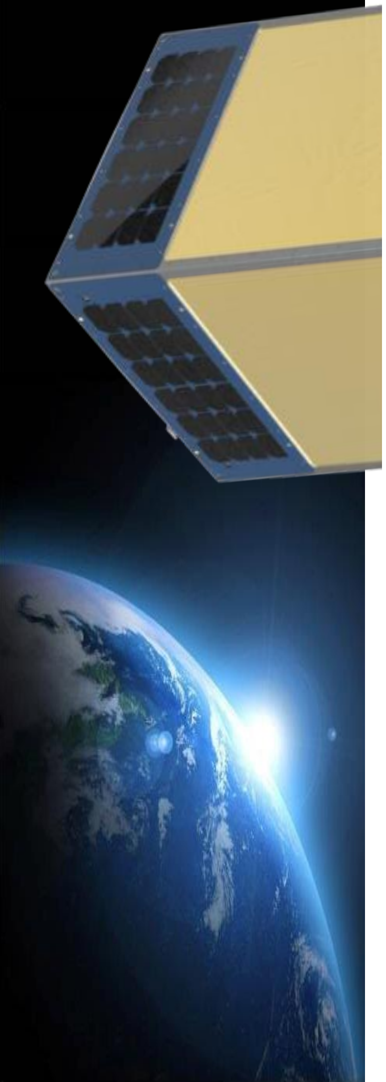


Manufacturer	Virgin Galactic
Country of Origin	USA
Max payload	Unknown
First launch	Unknown
Status	In development
Carrier	Boeing 747

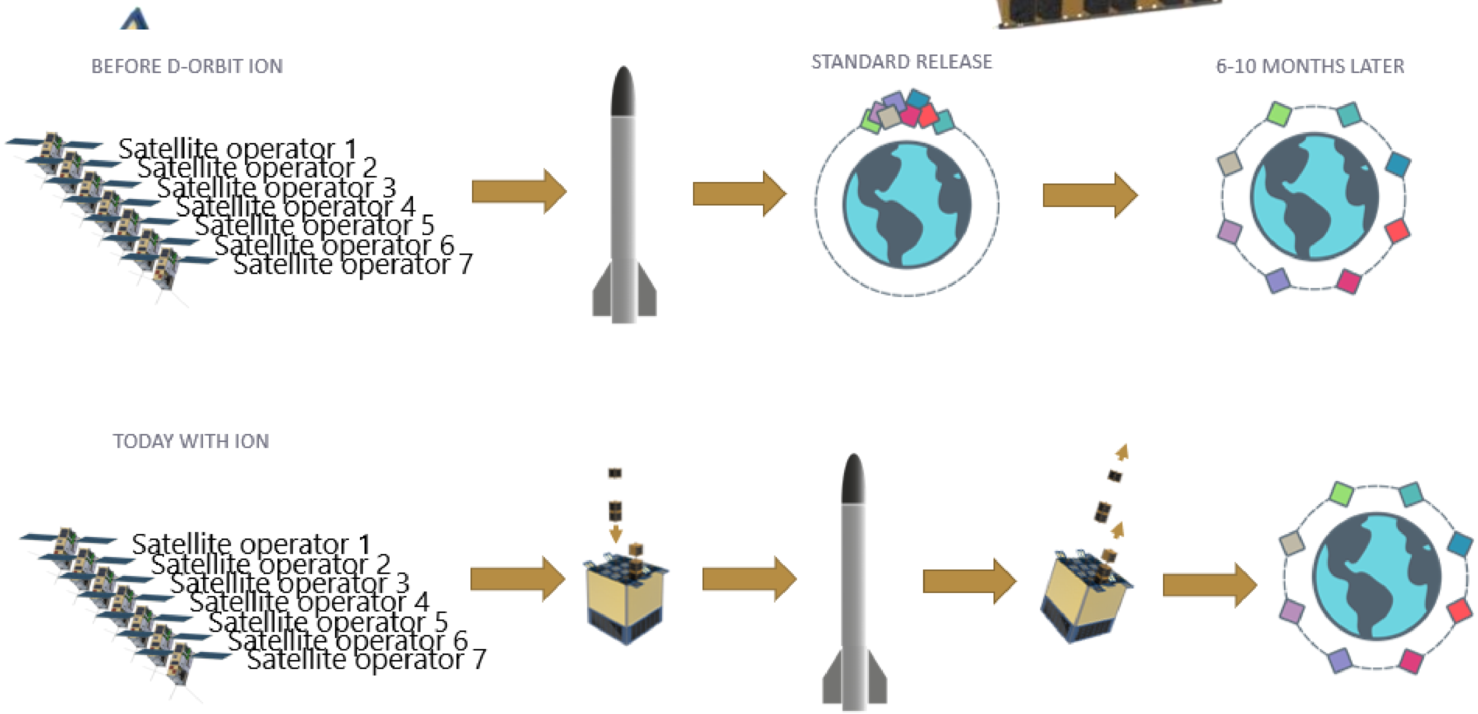
Manufacturer	Zero 2 infinity
Country of Origin	Spain
Max payload	75 kg LEO
First launch	Unknown
Status	In development
Carrier	Stratospheric baloon

Ref: micro-launchers: what is the market? – Feb. 2017

Launch Opportunities for CubeSats (7 of 20)



FREE-FLY DEPLOYER: ION CubeSats Carrier

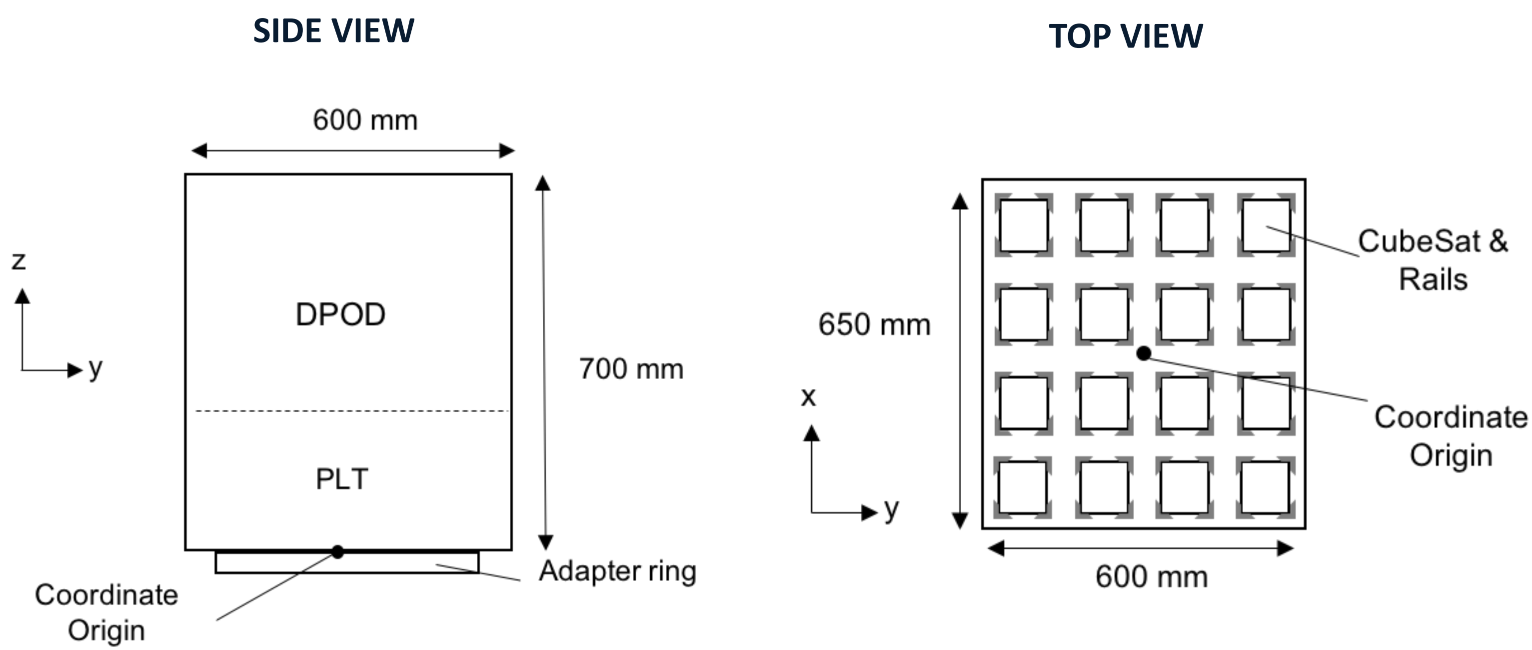


ION CubeSat Carrier

Ref. Worshop: «Servizi Ground per macrocostellazioni» - Telespazio – Roma 25-26 giugno 2018 – Credit: D-Orbit Spa

Launch Opportunities for CubeSats (8 of 20)

FREE-FLY DEPLOYER: ION CubeSats Carrier - Physical Description



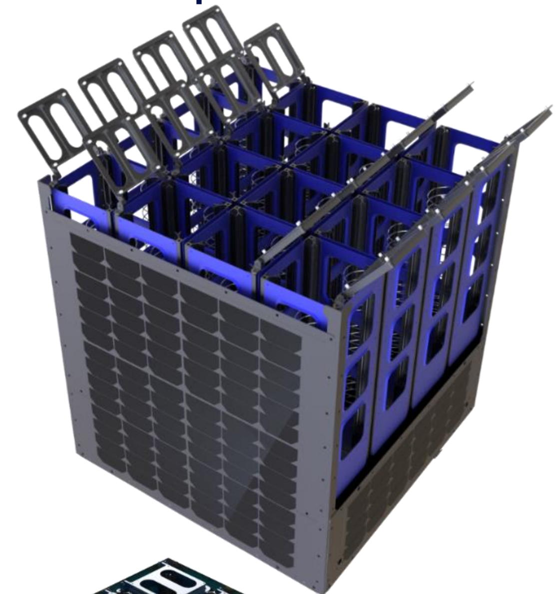
REFERENCE DIMENSIONS AND DRAWINGS

Empty mass: approx. 75 kg
Max fully-loaded mass: approx. 175 kg

Launch Opportunities for CubeSats (9 of 20)

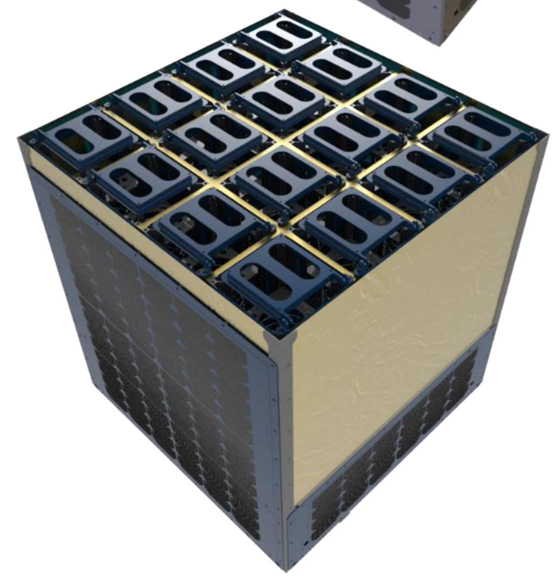
FREE-FLY DEPLOYER: ION CubeSats Carrier - Physical Description

- PLATFORM (PLT)



The architectural design consists of commercial off-the-shelf components, placed to form two identical Units each implementing the following functions:

- *On-Board Data Handling;*
- *Telemetry and Telecommand;*
- *Thermal Control;*
- *Power Generation and Distribution, and Energy Storage;*
- *Attitude Determination and Control;*



+ Propulsion shared by the units.

Launch Opportunities for CubeSats (10of20)

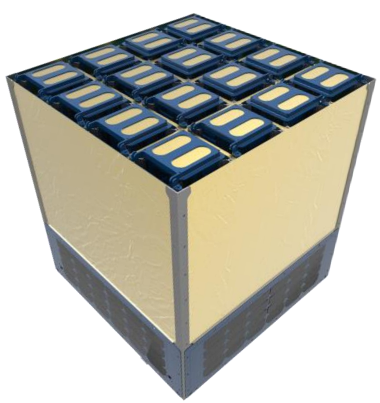
FREE-FLY DEPLOYER: ION CubeSats Carrier - Physical Description

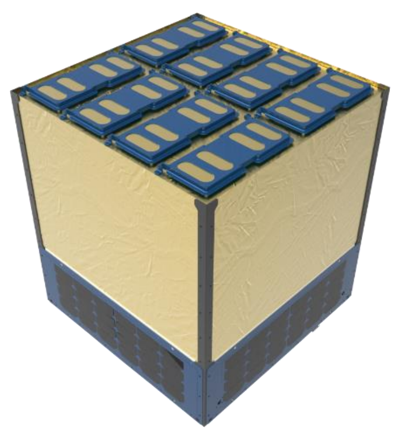
- D-ORBIT PICOSALLITE ORBITAL DEPLOYER (DPOD)

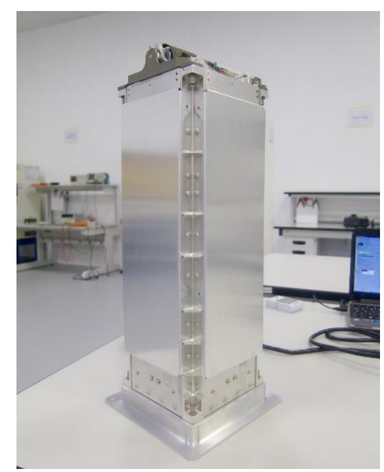
The DPOD is composed by “**DPOD-Tubes**” assembled together to allow easy reconfigurable configurations.

- **DPOD-Tube-3**: designed for 3U+ CubeSats. It can also host a combination of 1Us and 2Us;
- **DPOD-Tube-6:** designed for one CubeSat of form factor 6U+.
- **DPOD-Tube-12:** designed one CubeSat of form factor 12U+.

Each DPOD-Tube features a redundant release mechanism. All CubeSats contained in a single DPOD-Tube are deployed together.







Ref. Worshop: «Servizi Ground per macrocostellazioni» - Telespazio – Roma 25-26 giugno 2018 – Credit: D-Orbit Spa

Launch Opportunities for CubeSats (11of20)

SPACE4U EU law, policies, actions & technology JEAN MONNET CHAIR
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FREE-FLY DEPLOYER: ION CubeSats Carrier - Physical Description

- EXTRA VOLUME

Example for a 3U+ CubeSat

- ***Protrusion Volume***

  148% more volume than CDS v13 (P-POD)

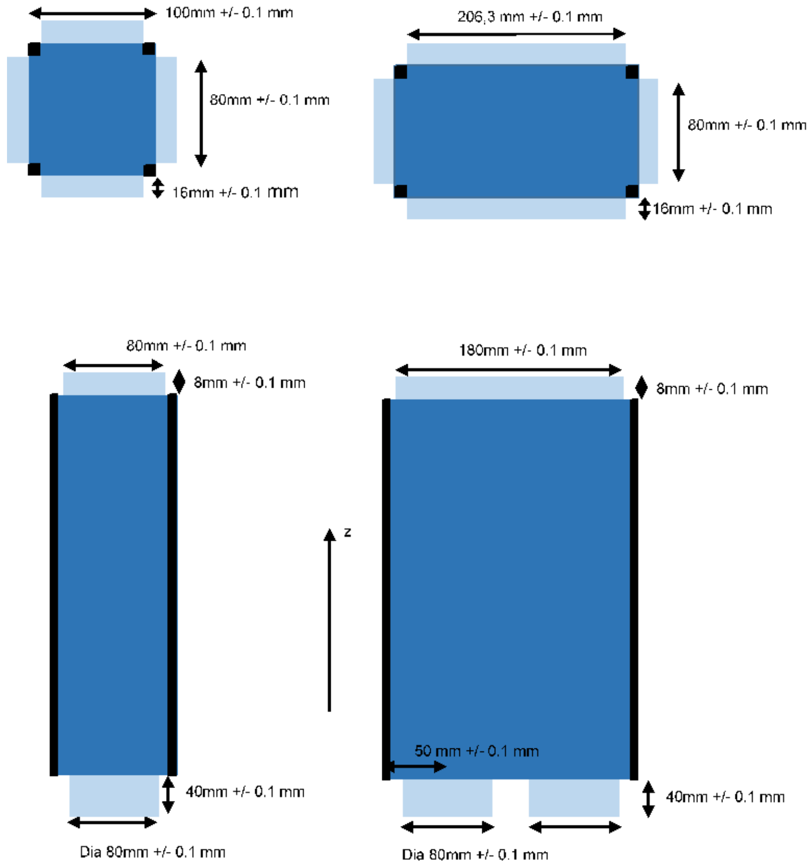
  25% more volume than best found on market

- ***Total Volume***

  25% more volume than CDS v13 (P-POD)

  8% more volume than best found on market

ION CubeSat Carrier is the only dispenser offering >5L of volume for a 3U



Ref. Worshop: «Servizi Ground per macrocostellazioni» - Telespazio – Roma 25-26 giugno 2018 – Credit: D-Orbit Spa

Launch Opportunities for CubeSats (12of20)

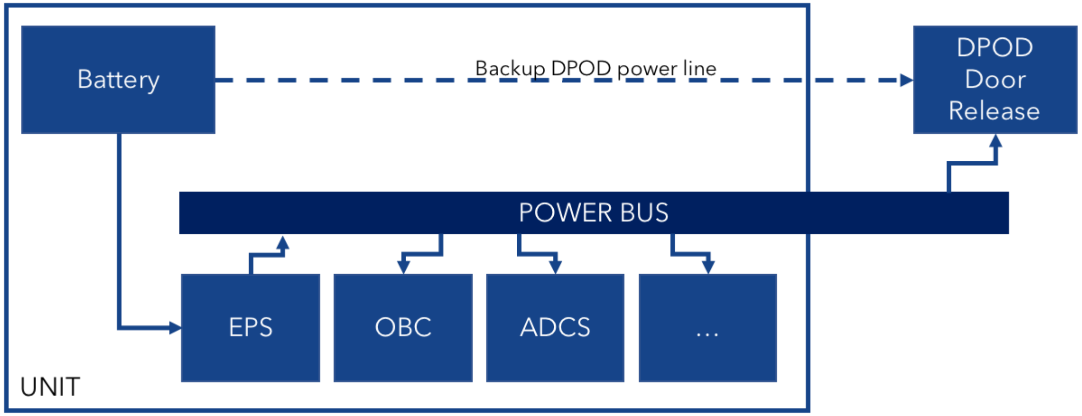
FREE-FLY DEPLOYER: ION CubeSats Carrier - FAILURE TOLERANCE:

GUARANTEED DEPLOYMENT

The system is capable of performing the Minimum Mission even with failure of both the units. The deployment command and actuation chain is* ***triple-fault-tolerant****.*

*Minimum Mission is the simple CubeSat deployment mission, without Precise Deployment and Fast Dispersion features.

This Minimum Mission is, in fact, the current state-of-the-art of all CubeSat dispensers available on the market, except ION-mk01.



Ref. Worshop: «Servizi Ground per macrocostellazioni» - Telespazio – Roma 25-26 giugno 2018 – Credit: D-Orbit Spa

Launch Opportunities for CubeSats (13of20)

FREE-FLY DEPLOYER: ION CubeSats Carrier - Launchers Compatibility

The structural design of the ***ION CubeSat Carrier*** *allows the spacecraft to be integrated either on-axis or cantilevered to have maximum cross-launchers compatibility*

ION CubeSat Carrier has been designed to be hosted (at least) on the following launchers:

- VEGA and VEGA-C
- PSLV
- Falcon 9
- Electron
- Launcher One
- Long March 4B
- Long March 11
- Soyuz
- Pegasus

Launch Opportunities for CubeSats (14of20)

FREE-FLY DEPLOYER: ION CubeSats Carrier – Precise Deployment

The **ION CubeSat Carrier** is capable of releasing CubeSats on a **precise orbital position**, with **controlled ejection conditions:**

- The ADC subsystem allows CubeSat **release along any inertial direction specified by the Customer**, within an **error of ±10 degrees**.
- **Angular rates** induced by the release dynamics, **do not exceed 6 deg/s**, for the laterally stored CubeSat. Inner stored CubeSats present significantly lower rates.
- CubeSats **separation mechanism** is constituted by a **spring** capable of imparting a typical **relative speed of 0.5 to 1.5 m/s** (for a 3U CubeSat), with respect to **ION**. **Customized separation velocities can be obtained** during the springs manufacturing process, to exploit a precise ejection impulse.

Ref. Worshop: «Servizi Ground per macrocostellazioni» - Telespazio – Roma 25-26 giugno 2018 – Credit: D-Orbit Spa

Launch Opportunities for CubeSats (15of20)

FREE-FLY DEPLOYER: ION CubeSats Carrier – Fast Dispersion

The deployment capabilities of the **ION CubeSat Carrier** can be exploited to optimize a CubeSat **constellation dispersion with a single launch**, significantly reducing commissioning time.

By releasing each CubeSat into a precise orbital slot and following a precise release strategy, **ION CubeSat Carrier** guarantees:

- a **wide separation** between spacecraft,
- a **faster** signal acquisition,
- a **stable collision-free** formation that is essential for spacecraft with no independent propulsion.

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Launch Opportunities for CubeSats (16of20)

FREE-FLY DEPLOYER: ION CubeSats Carrier – Fast Dispersion

Assumptions:

Launching orbit:
- Altitude: 750 km
- Eccentricity: 0.0

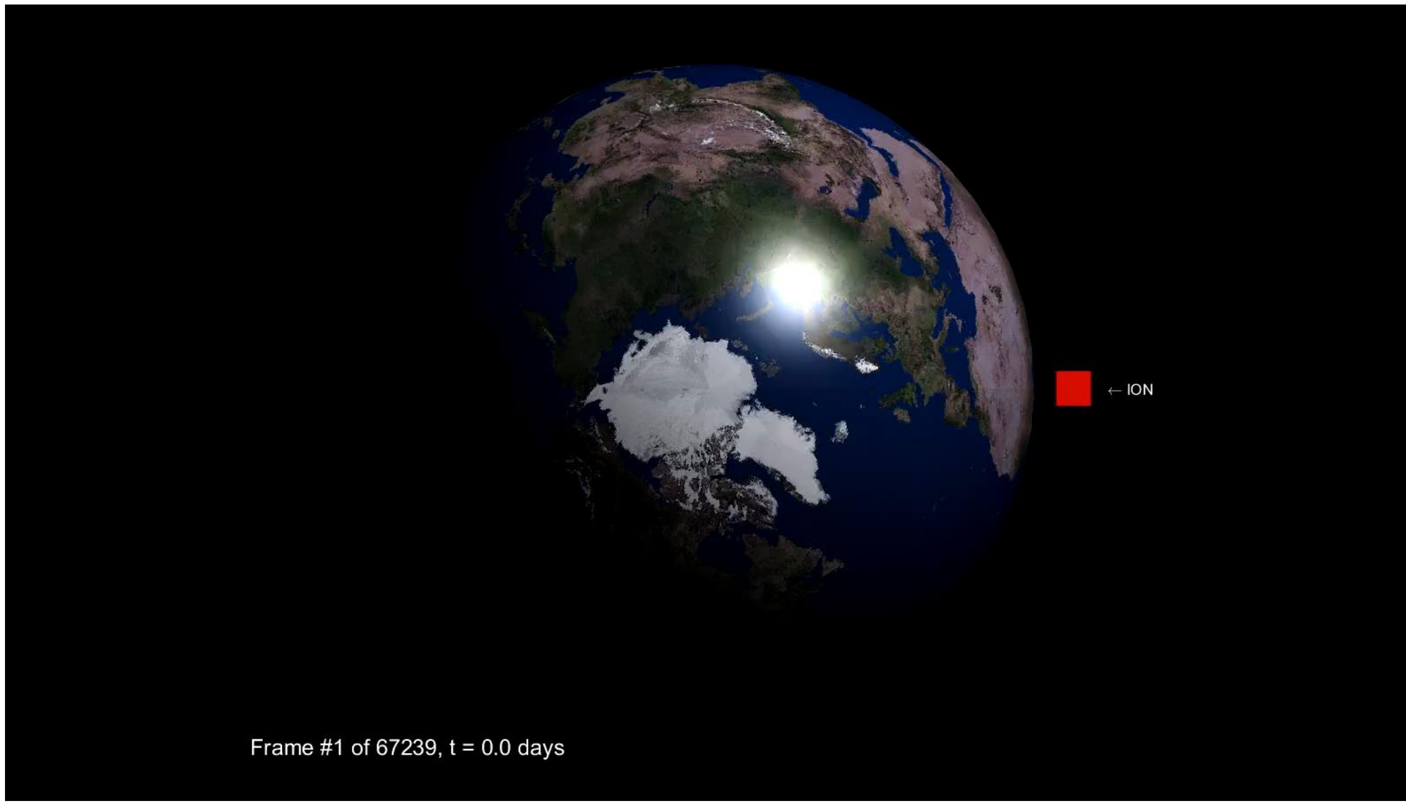
Satellite characteristics:
- 6U+ form factor
- No drag management

Deployment conditions:
- Separation Velocity up to 1,5 m/s
- Tumbling rate < 6 deg/s

Ref. Worshop: «Servizi Ground per macrocostellazioni» - Telespazio – Roma 25-26 giugno 2018 – Credit: D-Orbit Spa

Launch Opportunities for CubeSats (17of20)

FREE-FLY DEPLOYER: ION CubeSats Carrier - Physical Description



Launch Opportunities for CubeSats (18of20)

FREE-FLY DEPLOYER: ION CubeSats Carrier

Ref. https://inorbitnow.space/ion/

Launch Opportunities for CubeSats (19of20)

FREE-FLY DEPLOYER: ION CubeSats Carrier – Status

1. Subsystems Verification (Q1-Q3 2018)
   - Functional verification
   - Environmental validation (TVAC, Vibration, Shock)
   - Structural Model validation
   - Engineering Model validation
2. PFM (Q3 2019)
   - Functional verification
   - AIV and model verification (e.g. thermal balance)
   - Environmental qualification (TVAC, Vibration, Shock)
   - Acceptance testing with STM CubeSats (also for recurring flights)

FIRST FLIGHT on VEGA SSMS
PoC MISSION in Q3 2020

Ref. Worshop: «Servizi Ground per macrocostellazioni» - Telespazio – Roma 25-26 giugno 2018 – Credit: D-Orbit Spa

Launch Opportunities for CubeSats (20of20)

Vega VV-16 Mission - Small Spacecraft Mission Service - Proof of Concept

Ref. https://www.youtube.com/watch?v=E9WyG4VdaW0&ab_channel=AsiTV

Conclusion

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Conclusion

(R)EVOLUTION OF SMALLSATS

- Platforms for testing new technologies
- Reduced Life Cycle
- Standardization
- Single Purpose
- Up-to-date Technology
- New Applications
- Competitiveness with ground-based technologies
- Competitiveness with conventional satellites
- International Cooperation

Ref. Status and Trends of Smallsats and their Launch Vehicles — An up-to-date Review doi: 10.5028/jatm.v9i3.853