Research In Outer Space - Facilitating Access to Space Supporting Scientific and Technological Advancement

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One of the biggest challenges in the research and innovation world is to address and push technology maturity by reducing time to market for the benefit of science and industry. Launch and deployment costs of a space mission have pushed the upstream world to design satellites of reduced mass and size using, leveraging launch opportunities both for dedicated and rideshare missions. These new satellites can be carried into orbit from existing launch vehicles, deployed into orbit and then operated from the ground control operation centre. InOrbit NOW is a family of end-to-end solutions leveraging the ION Satellite Carrier, an orbital transfer vehicle able to transport satellites in orbit and accommodate multiple third-party payloads requiring a test in orbit over the course of the same mission. ION can host sensors and scientific instruments integrated within the payload bay: ION Satellite Carrier will provide resources to the technology such as power, telecommunication, pointing, in-orbit storage and so forth. This kind of solution eases the process of reaching a TRL 9 because the technology owner needs to focus only on the development of the sensor, whereas D-Orbit with its ION Satellite Carrier will take care of all the rest such as operations, access to space, data retrieval and so forth.

ION features:

- Faster Time-To-Revenues and positioning in target orbit;
- Launch Cost Reduction: deploy a constellation in multiple orbits on a single mission;
- Faster Time-To-Space: ride on the first available launcher;
- Reduction In Number Of Satellites: ION replenishes constellations faster so there is less need for spare satellites;
- Lower Manufacturing Cost: reduced need for propulsion decreases costs.

ION advanced services:

- Backup Satellite for an existing constellation;
- Integrating Satellite Services via Payloads Hosted on ION;
- Satellite Communication Hub Services.
- In-Orbit Validation and Demonstration (IOD/IOV);

In-Orbit Demonstration/Validation (IOD/IOV) enables the space research community to develop space technologies and test them in real-world conditions, accelerating TRL and technology maturation.

Key Words: Microgravity, Satellite, Space Transportation, IOD/IOV

Nomenclature

EO : Earth Observation
GSAS : Ground Station as a Service
LEOP : Launch and Early Operations
LSP : Launch Service Provider
LTAN : Local Time Of Ascending Node
LTDN : Local Time Of Descending Node
ML : Machine Learning
OTV : Orbital Transfer Vehicle
RAAN : .. Right Ascension of Ascending Node
SSO : Sun-Synchronous Orbit
SME : Small and Medium Enterprise
TAP : .. True Anomaly Phasing
TRL : .. Technology Readiness Level

1. Space as a Service

In the last few years, the space industry experienced an increased demand for access to space. Referring to Kara O'Donnell's "Small Satellite Trending & Reliability 2009-2018", Euroconsult predicted that *about 7,000 SmallSats will be launched over the next decade*[1]*: 580/year in 2022, and growing to 820/year by 2027*.

Looking back at this prediction and comparing it with the current status of launches reported in Figure 1, we can immediately see how much underestimating was that prediction done in 2018.

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[1] The next decade referers to 2018-2028

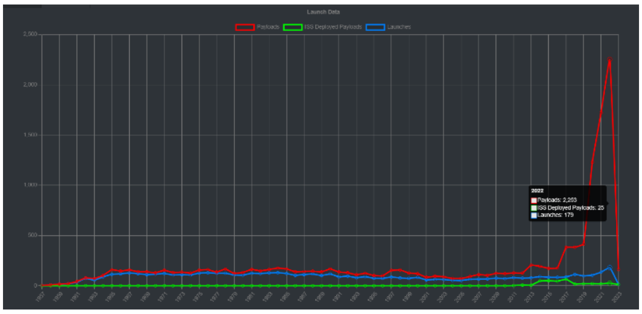


Figure 1. Payload launched per year

The value of 580 satellites in 2022 became in reality 2253, and the threshold year of 820 satellites per year by 2027, has been already reached and overtaken now.

Citing Parrella, "*Current pieces of evidence, then, show unprecedented investments from angel and VC funds in space start-ups and recently established firms, although the amounts still pale compared with public funding.*", we can understand what happened: large corporations, private equity, are redirecting their funds towards the space sector.

Figure 2 depicts more in detail how these funds are structured, and more in particular to whom are redirected.

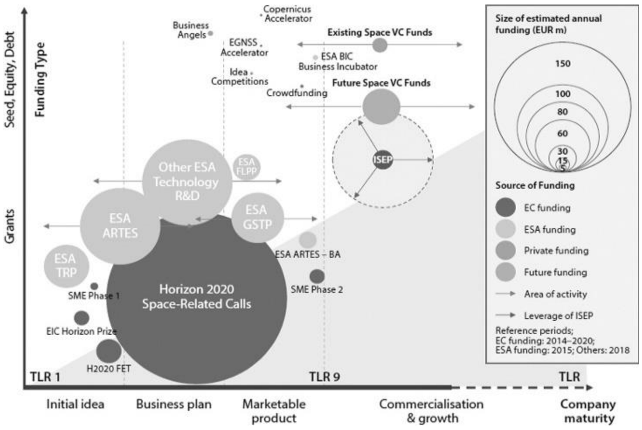


Figure 2. Overview of space-focused financial instruments in Europe and estimated annual funding volume and TRL

It is interesting to notice that their target companies and technologies are those companies with a TRL of 4-5. These TRLs values are linked to the component and/or breadboard validation in a relevant environment.

After though reaching this value, the ladder to reach TRL 9 is still long, and in this latter part, funds are small, and the possibility to test in space is even more reduced. Regarding this point, it is always interesting to quote the quarterly innovation of Boeing to depict how giant this leap is to achieve higher TRLs: "*After TRL 6, there is a significant cost to mature the abilities of products and systems so that those seeking to use them can be confident that they will work as advertised. This cost and risk is the first part of the Valley of Death that makes it hard to transition a new technology or approach to real life. Even if the risk is low that a new invention will work as intended, there is still an enormous amount of cost and risk before successful implementation on or as a product.*"

At this point, it is important to cite again O'Donnell's study on smallsat trend. Technology and/or Test demonstration mission defined as "*missions whose purpose is to demonstrate new payloads, components, or subsystems*" account for 27% of the overall mission, as per Figure 3.

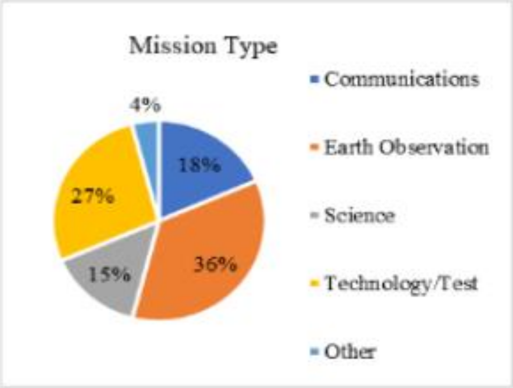


Figure 3. Mission Type Distribution

Besides, as per Figure 4, an additional categorization is reported, showing what is the most selected form factor per mission type. As expected, the smallest form factor is the most selected for the Technology demonstration.

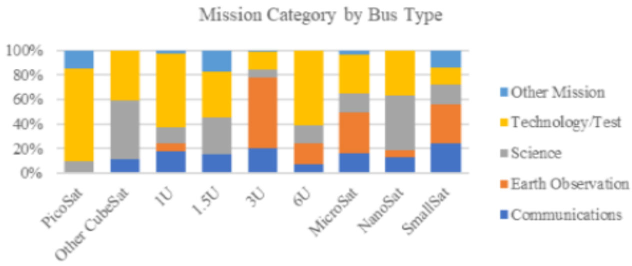


Figure 4. Mission Category by Bus Type

This is of course easy to explain: the technology demonstration is just a step towards the commercialization of the technology, not the final goal of the company.

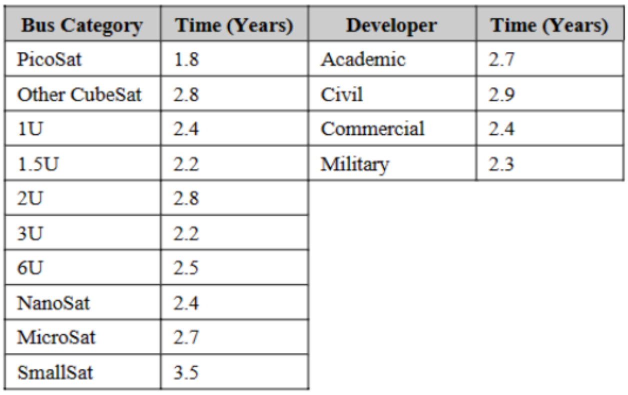
So the test in space, if possible, needs to have a reduced cost, which can be easily achieved with small satellites, CubeSats or even picosats, which are cheaper to manufacture and cheaper to launch.

Figure 5 depicts finally the success rate by year: the average is slightly above 87%. Per se, the value is high, but not enough to guarantee continuity of the operations, but also to guarantee a reliable workbench for testing to companies, that sooner want to put the technology developed with the TRL 9 in the market.

Finding paying customers for those technologies which didn't achieve a TRL 9 is difficult, and coping with a mission failure of a satellite that was supposed to allow the company to reach this TRL, means delaying the revenue stream of potential years, that for SMEs and start-up could potentially be a death sentence.

Figure 5. Success Rates by year

Despite the data generated by O'Donnell might be a bit outdated since 2018, as an order of magnitude it is important to keep in mind the table of Figure 6 that depicts the time needed to develop the bust to be launched.



Bus Category	Time (Years)	Developer	Time (Years)
PicoSat	1.8	Academic	2.7
Other CubeSat	2.8	Civil	2.9
1U	2.4	Commercial	2.4
1.5U	2.2	Military	2.3
2U	2.8		
3U	2.2		
6U	2.5		
NanoSat	2.4		
MicroSat	2.7		
SmallSat	3.5		

Figure 6. Development timeline by bus and developer

So, a company that wants to test its technology in space, needs to account am additional time between 1.8 and 2.2 years for the bus development.

The data gathered so far from O'Donnell's research serves as a clear stepping stone to introduce the concept of hosted payload.

The scenario depicted so far, starts from the assumption, that the company that wants to test the technology in space, will build operate and launch the satellite that needs to host the technology to be tested.

This is happening, because at this stage it was the only way to reach the TRL 9, achievement that can both trigger reliability towards the end customer, and also towards additional investors.

The concept of hosted payload depicted in the following chapter can be a game changer for this kind of scenario.

2. ION Satellite Carrier OTV

Figure 7 depicts an ION satellite Carrier OTV. ION Satellite Carrier is designed, manufactured, tested and operated by D-Orbit and it is composed of two modules:

- The Platform which includes all the spacecraft subsystems and avionics
- The Payload Bay is a fully configurable payload bay that can host separation rings for satellites, and CubeSat deployers and can provide mechanical, data and power interfaces for hosted payload.

Payloads are integrated into the Payload Bay at the D-Orbit facility or the launch site by D-Orbit personnel and, if requested, connected to the platform via an umbilical.

Such umbilical connection gives the ability to monitor the status of the payload during the in-orbit transportation manoeuvres. The Platform is based on a fully redundant architecture comprising the following subsystems:

- On-Board Data Handling subsystem.
- Telemetry and Telecommand subsystem.
- Power Generation and Distribution, and Energy Storage subsystem.
- Attitude Determination and Control subsystem.
- Propulsion subsystem.
- Thermal Control subsystem.
- Structural subsystem.
- Payloads Management subsystem.

Figure 7. ION Satellite Carrier

The mass and dimension of ION Satellite Carrier, allow the OTV to be hosted literally on all the launch vehicles currently in the market offering launch possibilities.

Additionally, ION Satellite Carrier has been designed to withstand the environmental loads of the launch vehicles currently flying and of those still under development.

This allows the OTV to have the possibility of flying on different launch vehicles, offering its customers a variety of launch windows.

2.1. In-Orbit Transportation Performance

ION Satellite Carrier is capable to perform any type of manoeuvres for on-orbit transportation services to payloads: altitude raising/lowering (e.g. deorbit), inclination change, true anomaly phasing, and LTAN/LTDN shift.

2.2 Hosted Payload Capabilities

ION Satellite Carrier offers as well the possibility to have the technology to be tested in space to be directly installed in the payload bay.

It will be the responsibility of the ION Satellite Carrier to provide the main resources to the customer's tech to carry out the functionality tests in space. These resources are for instance:

- **Power:** ION Satellite Carrier provides peak and orbital average power to the customer-hosted payload, through several interfaces
- **Data:** along with the power interface, also data interface is provided to the hosted payload, allowing a bi-directional exchange of data and commands with the ION Satellite Carrier hosting platform to and from the hosted payload
- **Telecommunication:** the data generated from the hosted technology is collected from the ION Satellite Carrier and then downloaded to ground through one of the ground stations provided by Ground Station As a Service (GSAS) providers
- **Cloud Computing:** ION Satellite Carrier is equipped with a dedicated flight computer specifically designed to run Machine Learning algorithms. This feature is designed for those customers willing to post-process the data directly in orbit, without the need of downloading a large amount of data, to be analysed on the ground. This feature was successfully tested over a 10 months experiment on board the ION SCV-004 launched on the 13th of January 2022. This was the first of a kind experiment, that involved close collaboration between D-Orbit, Unibap and Amazon Web Services (AWS) (Figure 8). The team started running AWS AI and ML in order to reduce the size of EO images: it lead to a reduction of image size by up to 40%, increasing processing speeds and enabling real-time inferences on-orbit. Specifically, this solution is a secure in-orbit cloud computing service which provides a familiar environment and adequate computing power, enabling near-edge intelligent data analytics. It provides access to raw data on-demand through space networks. This cloud computing solution uses the same space networks to deliver intelligence for impact.

  D-Orbit's proposal is to deploy a scalable constellation of interconnected nodes that provide on-demand access to high-performance CPU and GPU resources directly in space. Optical/RF inter-spacecraft data connections allow spacecraft and constellations to offload computation-intensive tasks, reducing the reliance on ground resources, allowing real-time response to observations, and enabling more efficient use of space data. Practical applications include:
  - **Civil security and public protection:** Object detection (illegal shipping, piracy, smuggling, etc.); crowd location and detection; atmosphere and pollution alert.
  - **Disaster monitoring and response**: Real-time detection (wildfires, floods, landslides, avalanches, traffic accidents, tsunamis); real-time alerts (directly to ground and via network to authorities); real-time response support; cross-task other satellites (e.g. targeted observation for a passing commercial SAR)
  - **Climate and weather monitoring**: Detection of dangerous weather events; prioritization of data inputs into model ensembles to obtain earlier and better forecasts.
- **On-Board Data Storage:** the data generated from the customer's technology can be as well stored on board in order to be post-processed or reused for comparison for the following test,
- **Pointing:** ION Satellite carrier can provide specific pointing accuracy if this is requested from the customer to test the technology properly
- **Orbital Parameters Change:** thanks to its propulsion system, the ION Satellite carrier can change the orbital parameters, allowing the technology to be tested in

Figure 8. Unibap's iX5-100 processor unit flown aboard D-Orbit's ION SCV-4 satellite

different conditions, with one very single launch.

The ION Satellite Carrier has been designed to offer a variety of data, software, power and mechanical interface, oriented to ease up the process of integrating and operating the technology to be hosted on board. So far, more than 25 different technologies have been tested on the eight ION Satellite Carriers that flew since 2020.

3. TRL 9: What's Next?

As proposed by Straub in 2015, and remarked by Lord in 2019, maybe it is time to establish "a TRL 10 level that indicates proven technology demonstrated through extended operations". Lord analyses this sensible difference between TRL 9 and a hypothetical TRL 10, investigating the outcome of Psyche Mission's commercial SEP Chassis.

This point becomes more and more actual in the time we are living now, where satellites are launched more often, at a higher rate than what was predicted. Satellites are very often just a commodity, a tool, necessary to be deployed only to distribute the service they were originally designed for.

Nevertheless, we have as well underline, that very often are deployed into very busy orbits such as the 500-600km SSO orbit with morning LTDN: such busy orbits require satellites to be reliable, fault-tolerant, and always able to manoeuvre in case of collision, to not jeopardise one of the busiest orbits.

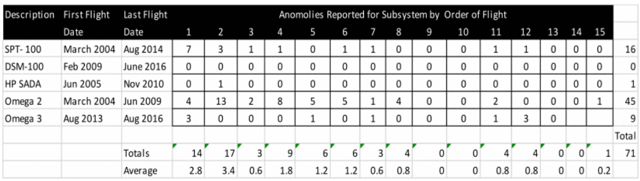
It is interesting to note how Lord, analysing the failures reported by the 1300 SSL product line, came up with a definition of two additional TRLs levels.

Lord can quantify the number of flights without failures that might be associated with those higher TRLs: in particular, for TRL 10, defined as reliable Flight Proven Technology, it *can be quantified by having at least 5 flights of the same production technology* without anomalies.

For TRL 11, defined as Mature Flight Proven Technology, the technology should have demonstrated only a single or no anomaly at all over 15 flights.

ION Satellite Carrier could be considered in this scenario too as an essential key element to gain heritage to reach these higher TRL.

The ION Satellite Carrier could be seen as an extension of a test facility in space, that customers rely on gain heritage and to reach the minimum flight heritage to mark TRL 10 or 11 as their products.



Description	First Flight Date	Last Flight Date	Anomolies Reported for Subsystem by Order of Flight 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
SPT- 100	March 2004	Aug 2014	7	3	1	1	0	1	1	0	0	0	1	1	0	0	0	16
DSM-100	Feb 2009	June 2016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HP SADA	Jun 2005	Nov 2010	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Omega 2	March 2004	Jun 2009	4	13	2	8	5	5	1	4	0	0	2	0	0	0	1	45
Omega 3	Aug 2013	Aug 2016	3	0	0	0	1	0	1	0	0	0	1	3	0			9
																		Total
		Totals	14	17	3	9	6	6	3	4	0	0	4	4	0	0	1	71
		Average	2.8	3.4	0.6	1.8	1.2	1.2	0.6	0.8	0	0	0.8	0.8	0	0	0.2	

Figure 9. Anomalies reported by a subsystem of 1300 series per order of flight

4. Conclusion

In this final section, we would like to wrap up the possibilities explored with the ION Satellite Carrier, and how those can be leveraged by companies to use an alternate approach to a standard satellite launch to test and gain heritage for their technology in space.

One of the key advantages that we would like to stress is regarding the development timeline: what is in the order of years as depicted by Figure 7, can be shrunk to months with the hosted payload solution. In the end, the time necessary to space can be in the order of 10 months, from having the technology tested in a laboratory to having the technology installed on an ION Carrier and launched into space. This reduction in time can benefit as well the revenue stream of the company, allowing them to enter the market earlier, and with a more solid background.

An additional point is related to the reliability of the mission per se: in the case of the hosted payload solution, the technology installed on the ION Satellite Carrier that is a platform with no single point of failure: this means that any potential failure of a subsystem, can be by-passed to allow the mission running.

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