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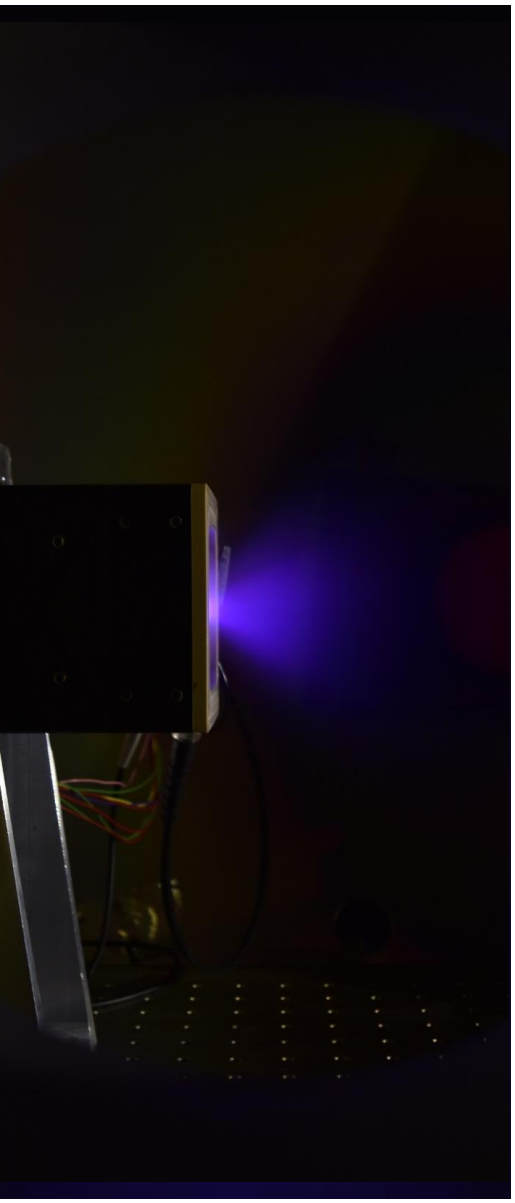

Plasma Jet Pack Technology : Electric Propulsion for Small satellites

07/06/2019

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Our missions :

COMAT designs, manufactures, qualifies and commercializes equipment for space industry **since 1977**.

Our company initially developed its activity in the microgravity field, in particular in designing and building science equipment for manned flight. Some years ago, COMAT enlarged its know how to satellite market and particularly to space equipment such as : mechanism, propulsion, and GSE.

Our integrated offer :

COMAT is an integrated company with the ability to deliver a global offer for **yours space equipment**. The 100 high skills COMAT's employees are dedicated to space activity. This organization allows us reactivity, quality (EN9100/ISO9001) and cost efficiency for equipment development. This organization laid on 3 Business Units:

- BU Space Equipment development
- BU Industrialization: Manufacturing, Integration & Tests
- BU Services

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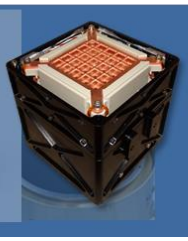
► *Company overview*

Company :

1977 — µGRAVITY EXPERIMENTS

1990 — SPACE MECHANISMS

SPACE PROPULSION



1977 — INTEGRATION/CLEANROOMS AREA

200m² GRAY ROOMS

2006

370m² GRAY ROOMS + 70m² ISO7 CLEANROOM

2016

370m² GRAY ROOMS + 110m² ISO7 CLEANROOM + 20m² ISO5 CLEANROOM

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Summary :

- ✓ Motivations
- ✓ Concept
- ✓ Our proposition
- ✓ Modular products
- ✓ Development review
- ✓ Operations (on-ground, in-orbit)
- ✓ Conclusions

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Assessment : small satellites is a growth market

- ✓ The production cost of the small satellites decreases and their performances increase
  (due to the miniaturization of electronics)
- ✓ So more and more missions can be reached by small satellites :
  - Earth observation : planet (3U), Black Sky…
  - Telecommunication : OneWeb, spaceX,…
- ✓ But the launch cost is still important compared to the cost of nanosatellites & small satellites.
- ✓ The targets of our products is the new space market, characterized by more volume and lower cost. New business (earth observation, or telecommunication) model will appear from low cost space infrastructure.

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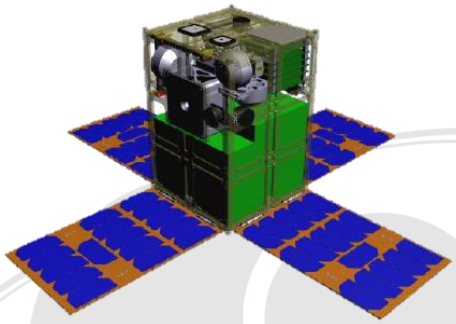
Our proposition : Plasma Jet Pack technology

✓ Plasma Jet Pack® is an electric propulsion module family using solid propellant. The involved technology based on the vacuum arc physics is a smart alternative to gas feed systems for small satellites (<200kg).

✓ This technology is declined as building blocks that can be assembled and tailored to the various missions and platform requirements, among others:

- Orbit rising
- Station keeping
- De-orbitation
- Drag compensation
- Attitude control



✓ Today, we have identified 2 initial targets that start our product family:

- **PJP 0-30 & 0-80** for nanosatellites planned in 2019
- **PJP 0-150** for small satellites (150kg class satellites)

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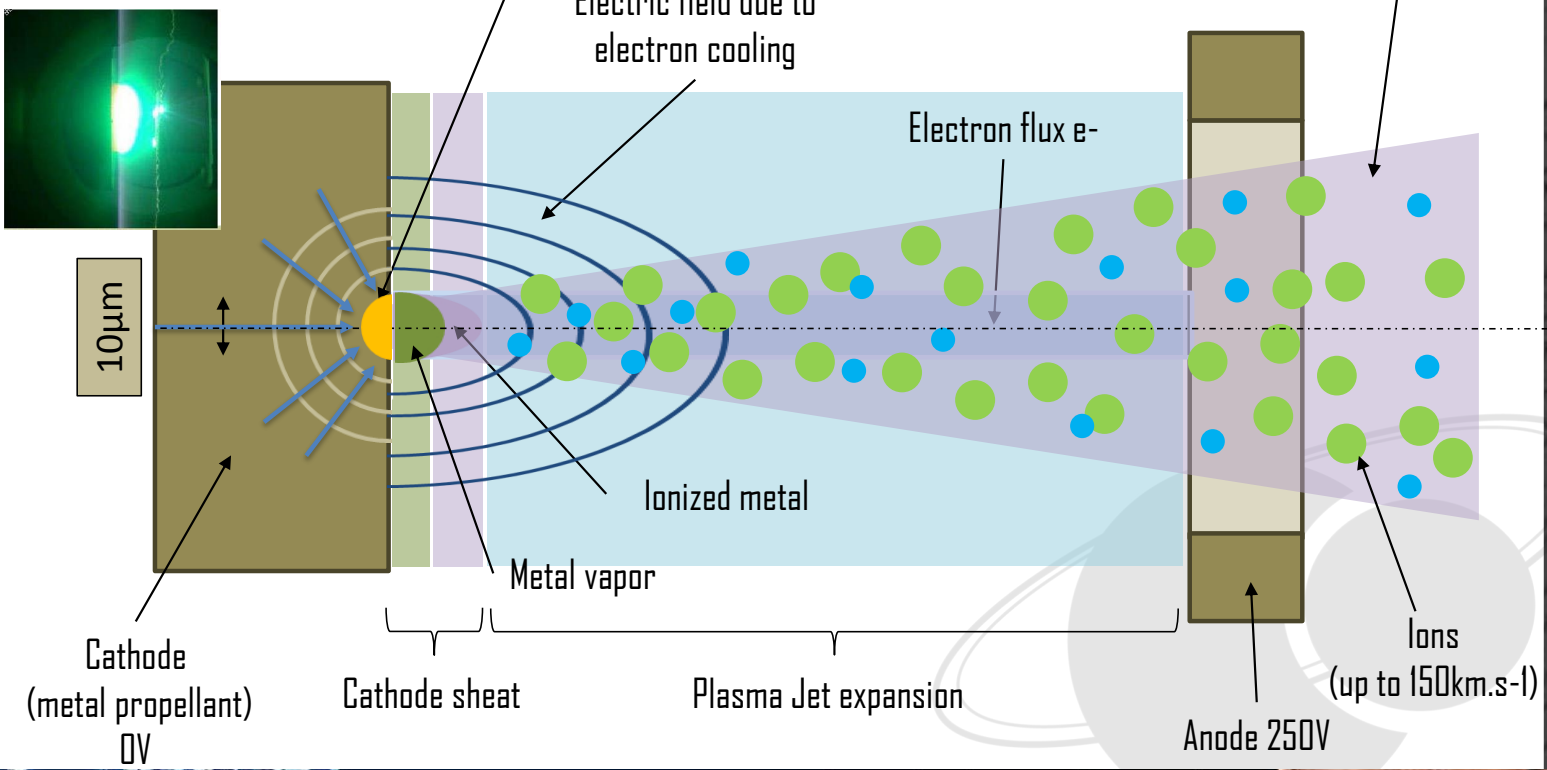
► *Our proposition*

Physics of vacuum arc :



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Our proposition : Plasma Jet Pack technology advantages

✓ **No fluid, solid metal propellant**
- Simpler propulsion module (more reliable), cheaper, no filling operation
- Smaller propulsion module, environment-friendly

✓ **High specific impulse** (e.g. Isp= from 1 000s to 7 000s)
- Lower mass of prop. module @ equal mission, hence e.g. more payload mass

✓ **Ibit flexibility** from nNs to mNs per design concept

✓ **Mean thrust** function of (adjustable) pulse frequency, without efficiency change

✓ **Neutral and focused plasma plume**
- No neutralizer required, easier integration

✓ **Robust power electronics** (fly back converter)

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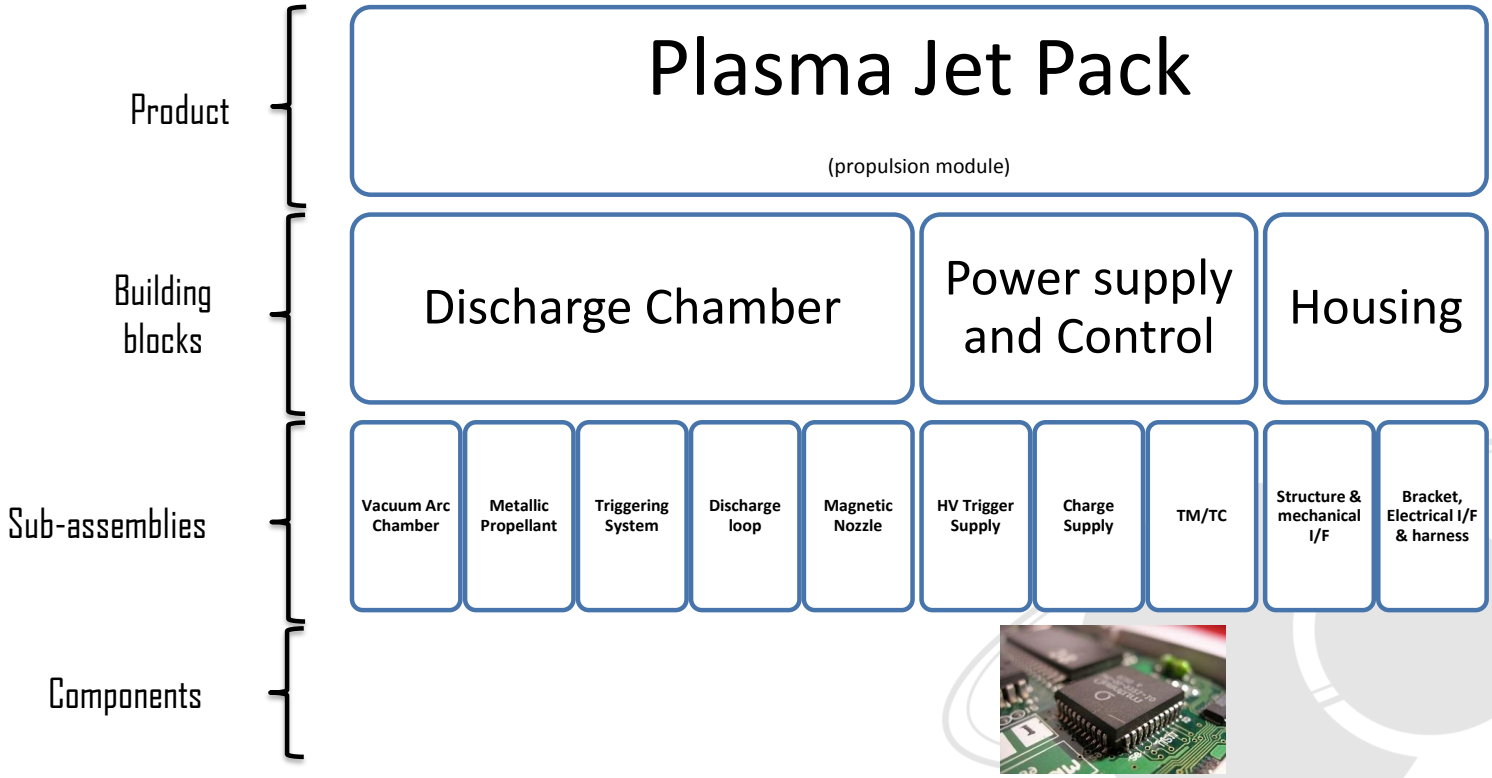
PJP technology

► Modular Products

Technology & Building blocks



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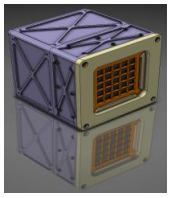
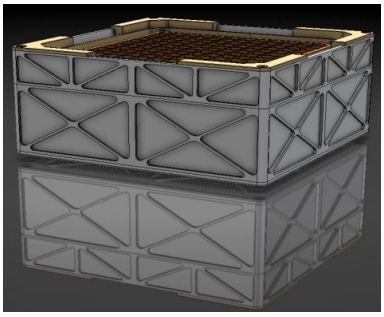
PJP technology

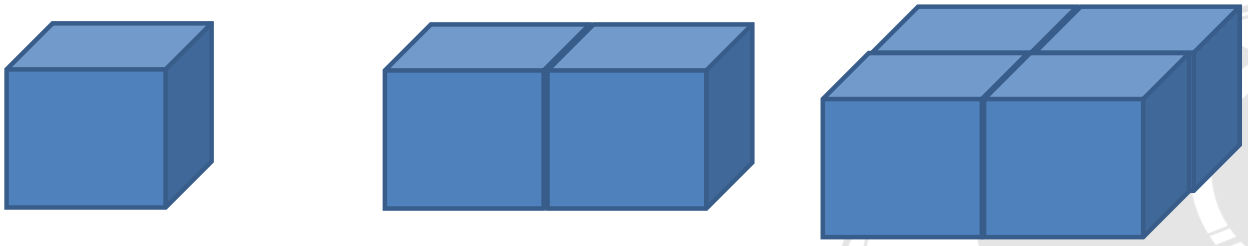
► Modular Products



Building blocks to modular products :

- ✓ Three **PJP Flight Products** targeted :
  - **PJP 0-30** for nanosatellites (<30kg class satellites)
  - **PJP 0-80** for nanosatellites (<50kg class satellites)
  - **PJP 0-150** for small satellites (100-200kg class satellites)





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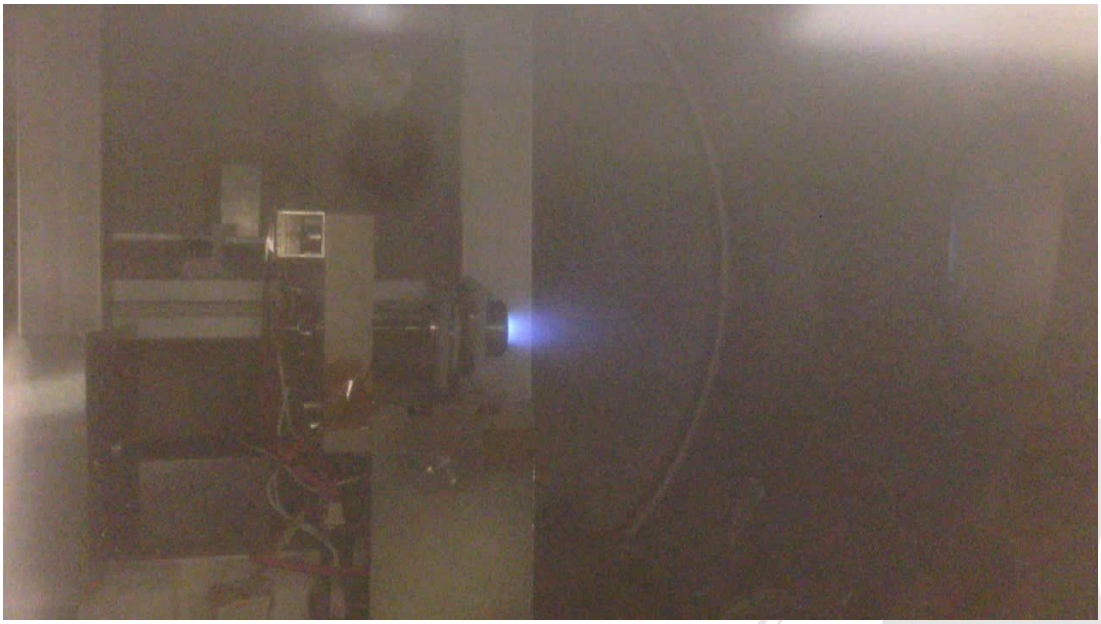
Development review : firing test



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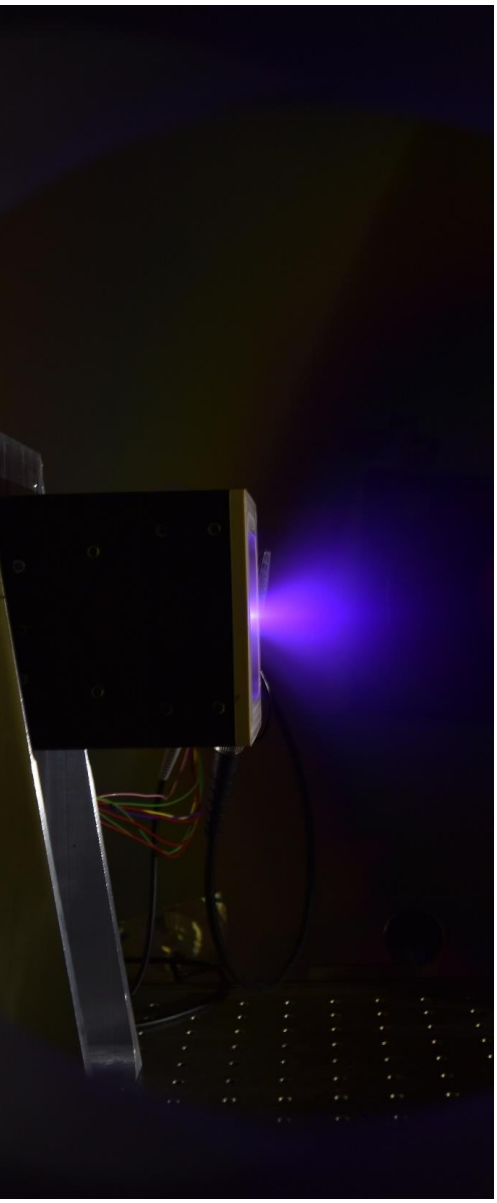

PJP 0-30 Product

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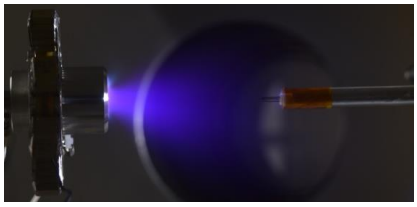
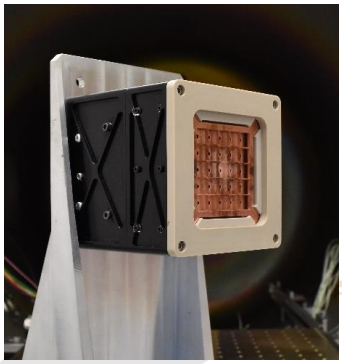


Plasma Jet Pack 0-30W characteristics :

- ✓ Average Thrust: 450µN@30Hz T/P ~15µN.W-1 (measured @Onera)
- ✓ Impulse bit: 15µNs (measured @Onera)
- ✓ Specific impulse: >2000-5000s (as function of propellant) (measured)
- ✓ Overall mass with propellant <1000gr
- ✓ Total impulse: 4000N.s (~100 days@30Hz) (on test)
- ✓ Volume: 1U = 10cm*10cm*10cm
- ✓ Efficiency >20%



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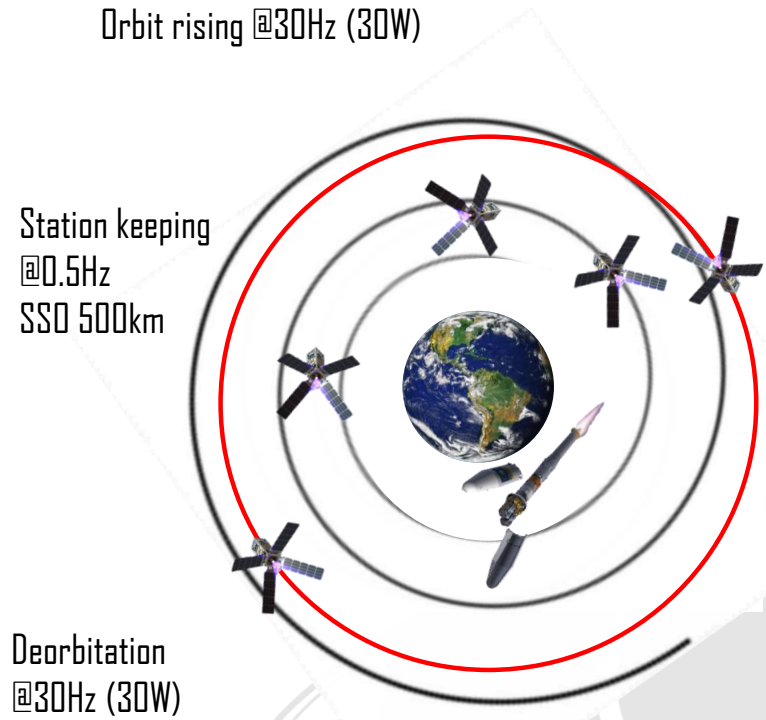
PJP technology

► *Our proposition*

Plasma Jet Pack 0-30 missions :

Example : Nanosatellite 30 kg class orbit SSO 500km mission

- ✓ Speed increment : 130m.s-1
- ✓ 100 days of thrust 450µN@30Hz
- ✓ Extending life duration up to 5 years



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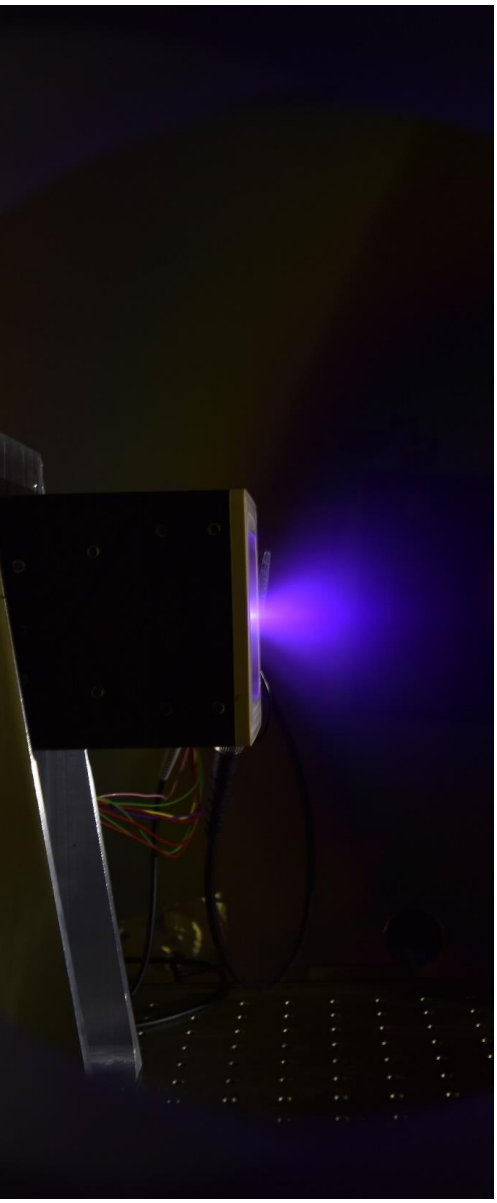

PJP 0-150 Product

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PJP technology

► Plasma Jet Pack 0-150

PJP 0-150 Specifications & Characteristics :

Average Thrust: 2,25mN@30Hz

Impulse Bit: 75µNs

Specific Impulse: >5000s

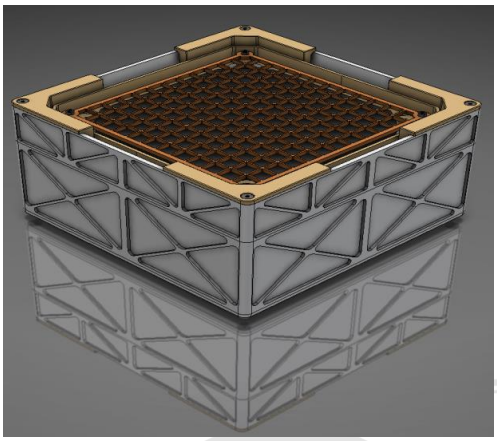
Total Mass with propellant <4 Kg (1kg of W)

Total impulse: 50 kNs (~260 days @30Hz)

Volume: 4U

Power Consumption: adjustable from 5 to 150 W

Efficiency >20%



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PJP technology

► Plasma Jet Pack 0-150

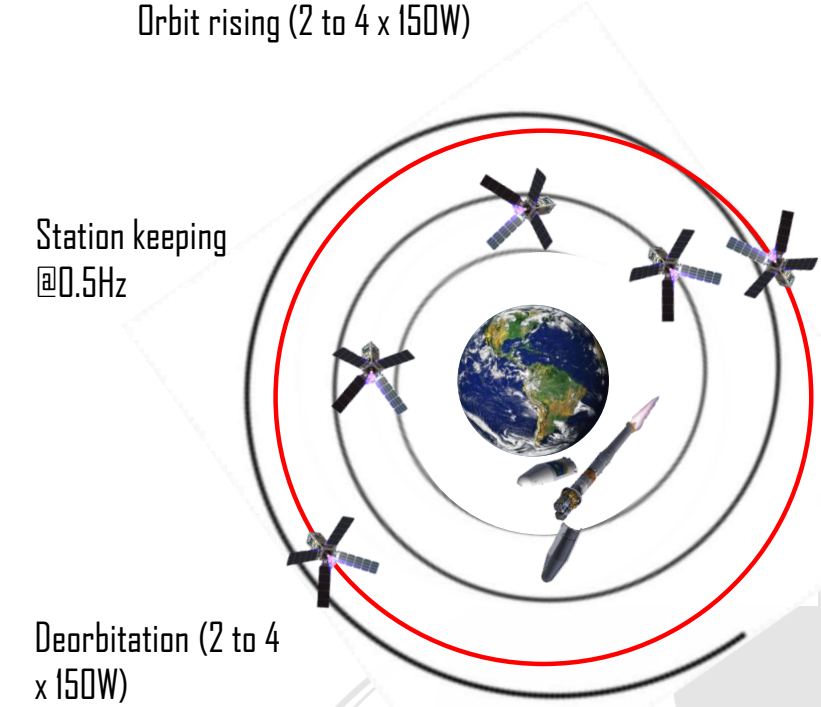
Mission Requirements:

Add value to microsatellites missions :

Example : Microsatellite 150 kg LEO 500km mission

- Speed increment : 330 $m.s^{-1}$
- 260 days of thrust 2,25mN@30Hz
- Constellation Management

- Typical use of 2 to 4 PJP 0-150 products per satellite



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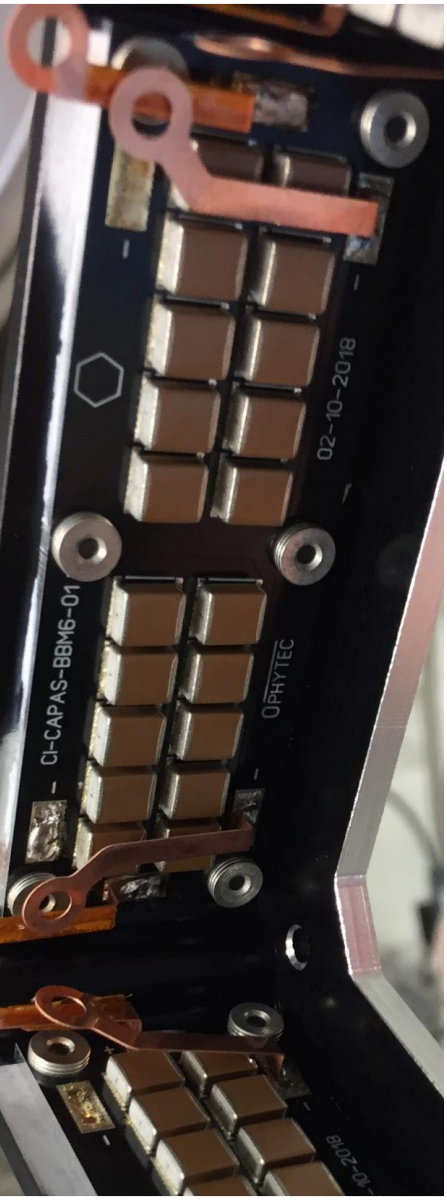

Development review

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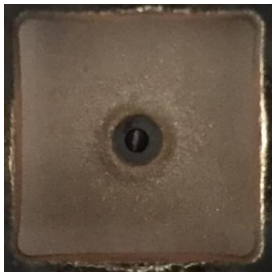
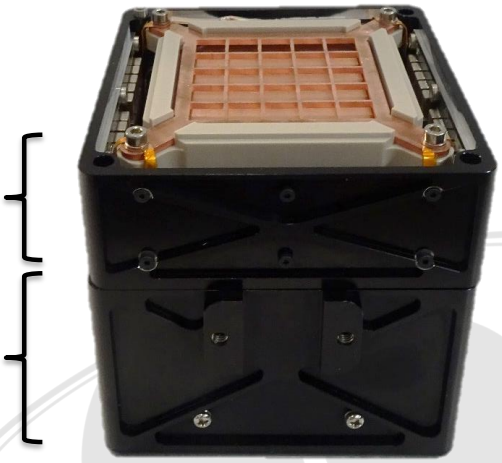
Development review :BBM6 description

The purpose of this model is to test :

- Thermal stabilization
- Life duration up to 7,2kNs (Propellant mass 239gr)





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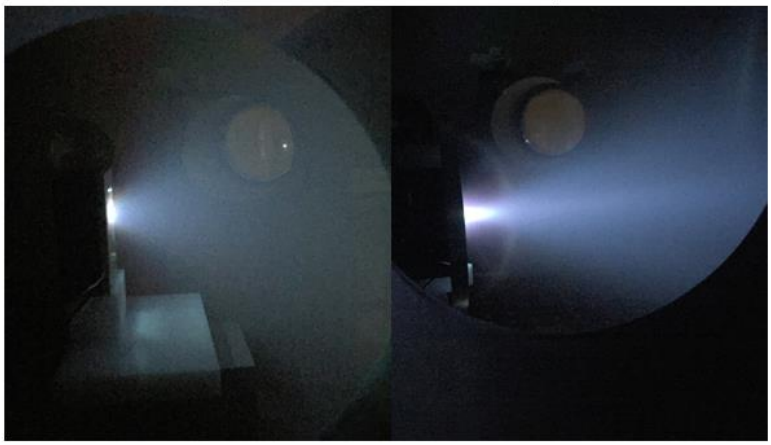
Development review :improve performances

- ✓ Improve thrust to power & specific impulse with magnetic field : efficiency *2 with low intensity magnetic field

BBBM6 Cuivre – 2.5J



B=0 mT B=22 mT

- ✓ Next step improve thrust to power up to 20µN.W-1 with higher magnetic field to extract more than 0,1% ions of electric current to 1%.

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PJP on-ground and in-orbit

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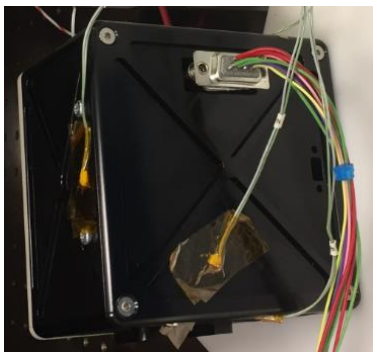
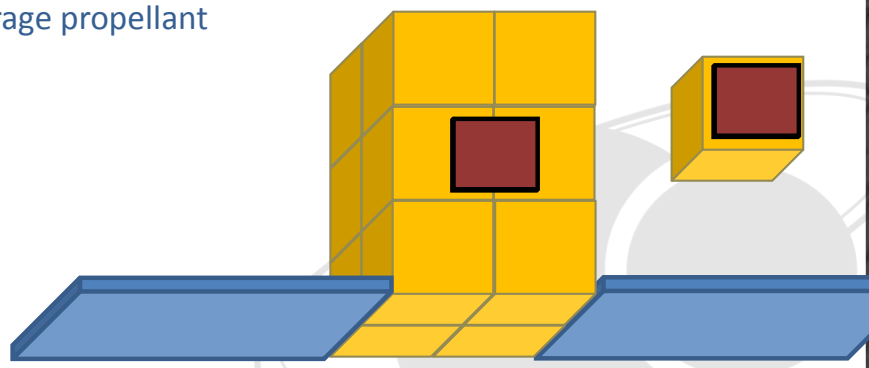
PJP technology

► *PJP on ground*

On ground integration :

- ✓ No filling operation
- ✓ No safety issue with propellant
- ✓ No transport issue
- ✓ No environmental issue with metal storage propellant
- ✓ Thermally decoupled from satellite
- ✓ Easy to accommodate due to :
  - ✓ Integrated system
  - ✓ Small volume





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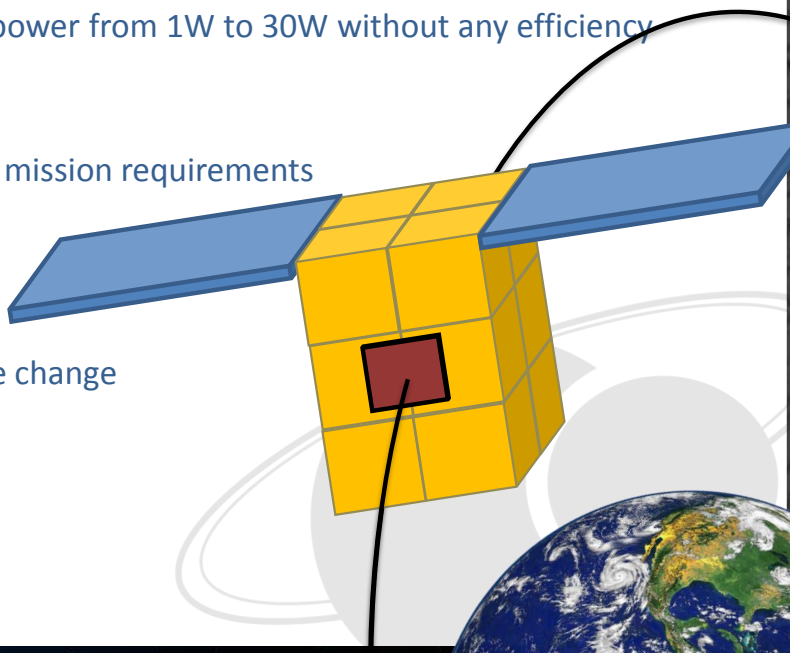
In orbit capabilities : Orbit rising, station keeping

- ✓ Pulse thrust on demand (no heating required before thrust)
- ✓ Thrust level can be adapted to the platform power from 1W to 30W without any efficiency change
- ✓ Very precise thrust is available as function of mission requirements
- ✓ The total impulse is 100days @ 30W (4kNs)
- ✓ Station keeping can be done without attitude change



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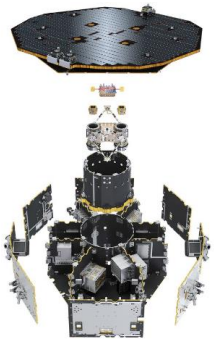
In orbit capabilities : attitude control & orbit control

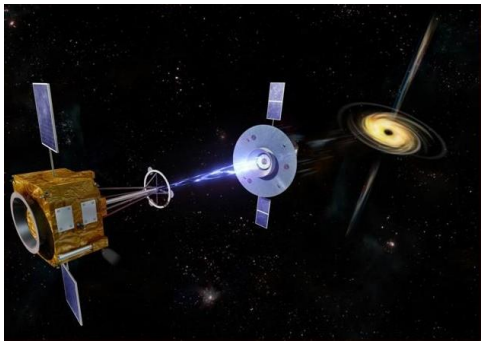


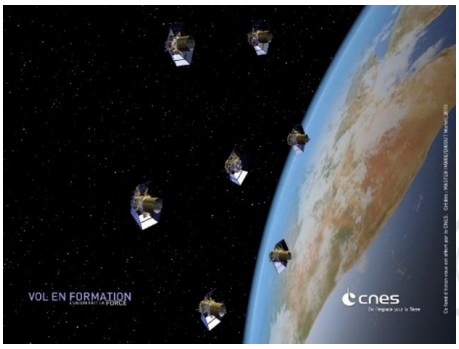
- ✓ Accurate control of thrust by step from mNs to 10nNs.
  - ✓ The ibit is largely scalable as function of materials and bank energy.

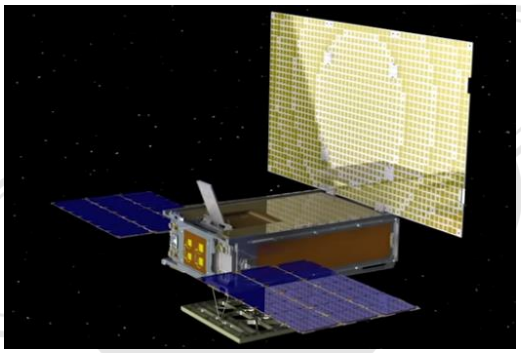
Applications :

- ✓ Attitude control for science
- ✓ In-flight formation

✓ Source : Nasa Marco A,B,C







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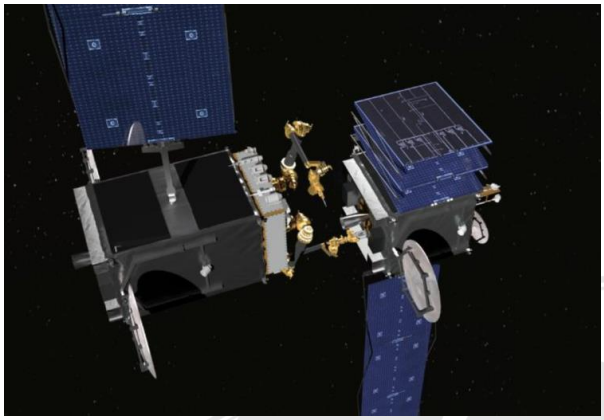
In orbit capabilities : attitude control & orbit control

Applications :

✓ Maneuvers “rendez-vous” & docking

✓ Inspection of one satellite by other one



Source : SSTL

Source : Esa

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Conclusions :

- ✓ Plasma Jet Pack is based on Vacuum arc physics
  - Solid metal propellant
  - High power and current density (100kW, impulse thrust up to 4N)
  - Efficiency conversion
    - Measured ~20%
    - Thrust to power ratio > 15µN.W^{-1} (as function of propellant)

- ✓ PJP technology is simple
  - Power electronic is basic (all components are cots)
  - Standard manufacturing process

- ✓ Progress :
  - PJP 0-30 / 0-80 : TRL 5 and 6 bread boards designed and characterized
  - PJP 0-150 : under characterisation

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Conclusions :

- ✓ No show stopper is identified today
- ✓ The next challenges are to perform life duration of 100 days and to increase efficiency
- ✓ New Space Products Guidelines are developed in order to improve quality of products and to reduce cost (KO 01/2018)

Perspectives :

- ✓ Plasma Jet Pack is designed to open the missions field to small satellites.
  - Performances are function of cathode material : T/P, ISP, efficiency
  - Ibit is function of energy storage from nNs to mNs
- ✓ Commercial phase is ongoing…

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PJP technology

► *Questions*