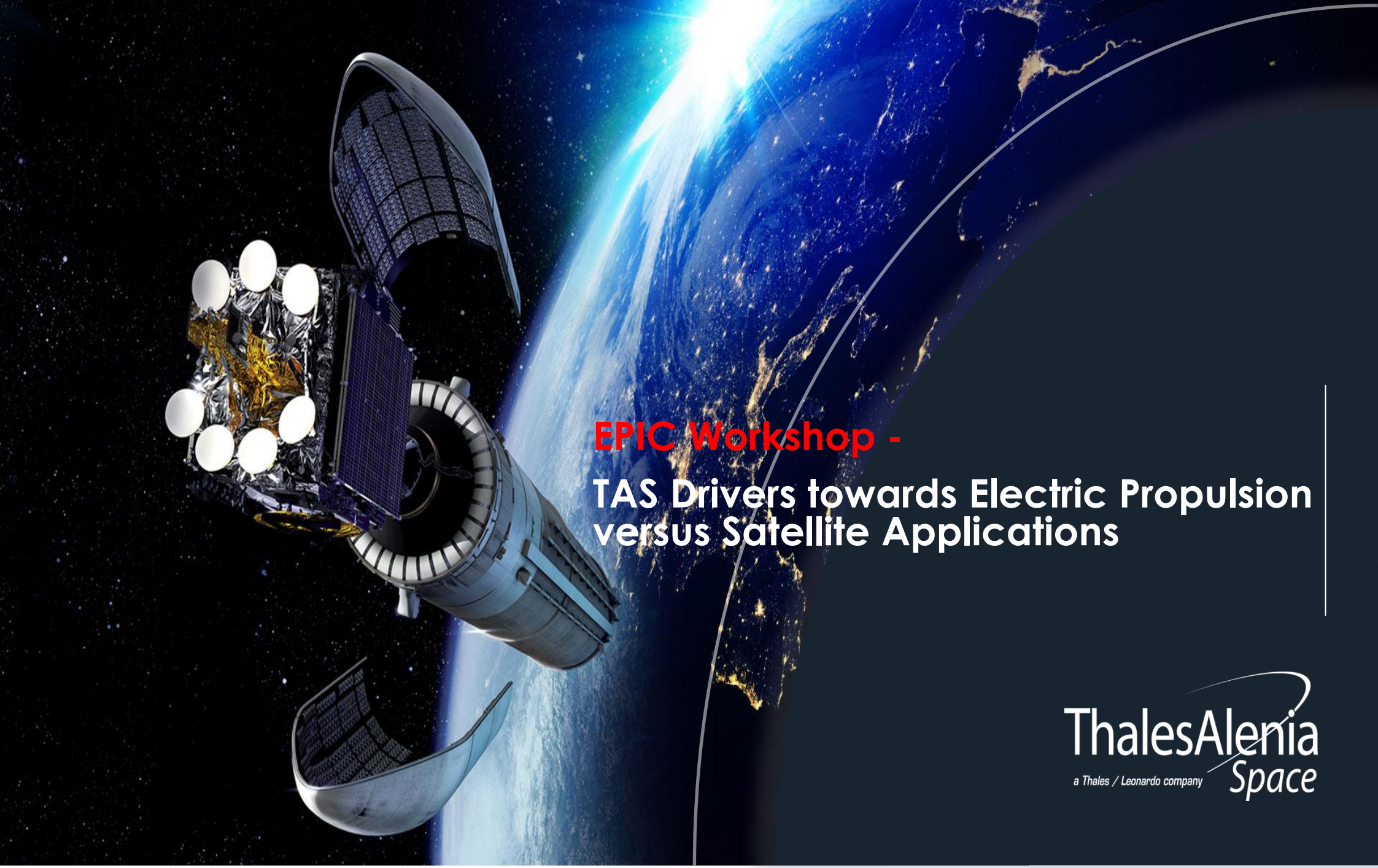


EPIC Workshop -

TAS Drivers towards Electric Propulsion versus Satellite Applications

ThalesAlenia Space
a Thales / Leonardo company

24th of October 2017

Agenda

1- Context - Satellites Missions & Market/Evolutions Trends

2- Drivers towards Electric Propulsion Subsystem

3- Electric Propulsion Performances Needs versus Various Missions

4- Electric Propulsion Way Forward - Technologies & Subsystem Evolutions

Context - Satellites Missions & Market/Evolutions Trends (1/2)

- **Electric Propulsion (EP)** is intended to be implemented in various missions in coming years based on the confidence gained during last decade through associated background:
  - **Telecom satellites** will continue to lead the market of S/Cs using EP (currently > 80% of the market), it will include both **GEO satellites & LEO constellations**
  - The use of EP will increase for **Observation & Sciences satellites** with wide possible applications
  - **Navigation satellites** can also represent an important number of S/Cs within next 10 years
  - There will be potentially **Exploration/Transportation missions** with powerful EP systems (low expected market << 5%)

Context - Satellites Missions & Market/Evolutions Trends (2/2)

- EP is now accepted for **both orbit transfer & station keeping of Telecom satellites** by a large number of Telecom Operators
- EP is also increasingly considered in **LEO/MEO constellations for medium size satellites (up to 1500kg) & small size satellites (up to 300kg)**, this trend will be pursued at short/medium term
- EP can fulfil **various functions pending applications/mission requirements:** Orbit raising, orbit variation, station keeping, attitude control, de-orbitation…
- There is **a wide range of EP equipment & technologies under development/pre-development** by suppliers, these EP products cover an extended power range from few W to 20kW
- The **market is very dynamic** with changes in business models for customers, introduction of game-changing launchers & wider adoption of EP for emerging markets - EP technologies & industrial capability have to be flexible enough to be able to address this future
- There are **strong requirements for competitiveness** applied to EP subsystem aimed to costs reduction
- There is a need to use **common EP products/equipment to several applications** to reduce development costs & recurring costs (batch effect)

ThalesAlenia Space
a Thales / Leonardo company

Satellites applications - Drivers towards EP Subsystem

Drivers according to Mission	Key Parameters
Functionalities fulfilled by EP	*Orbit raising, station keeping, attitude control, deorbitation…*
Allocated Power level to EP	*Thruster class (power level) & number of thrusters*
Operations Duration & Constraints	*Thrust needs, Total Impulse/ΔV, activation cycles number*
Propellant Mass/Consumption	*Isp, thruster mechanism efficiency*
EP Subsystem Physical Characteristics	*Mass, size/volume & accommodation (plume)*
EP Failure Tolerance/Reliability	*Redundancies, crosstrapping & equipment reliability*
EP Time to Market	*EP development plan/schedule, availability & risks*
EP Competitiveness	*EP costs (*) wrt other solutions*

(*) Covering thrusters, power electronics & fluidic part

ThalesAlenia Space
a Thales / Leonardo company

EP Performances versus Various Missions - Allocated Power

	Satellite Size			Power allocated to EP					
	Small (< 300kg)	**Medium (Up to 1500kg)**	**Large**	**<100W**	**< 300W**	**300W to 700W**	**700W to 3000W**	**3000W to 7000W**	**> 7000W**
Telecom	Constellation (Micro)	Constellation & GEO	GEO		Constellation		Constellation & GEO	GEO	
Navigation & Data Collect (*)	Data Collect (*)	Galileo NG		X (Data Collect)			X (Galileo NG)		
Observation & Sciences	Nano & Micro	X	X	Observation Sat. & Constellation Sciences					
Exploration & Transportation		X	X				X	X	X

Telecom GEO S/C

Telecom Constellation

(*) Data Collect: AIS/VDES,/ARGOS, M2M, ADS-B

ThalesAlenia Space
a Thales / Leonardo company

EP Performances versus Various Missions - Thrust Level

	Satellite Size			EP Thrust Level					
	Small (< 300kg)	**Medium (Up to 1500kg)**	**Large**	**Up to 1mN**	**< 15mN**	**15mN to 50mN**	**50mN to 150mN**	**150mN to 350mN**	**> 350mN**
Telecom	Constellation (Micro)	Constellation & GEO	GEO		Constellation		Constellation & GEO	GEO	
Navigation & Data Collect (*)	Data Collect (*)	Galileo NG		X (Data Collect)			X (Galileo NG)		
Observation & Sciences	Nano & Micro	X	X	Observation Sat. & Constellation Sciences					
Exploration & Transportation		X	X				X	X	X

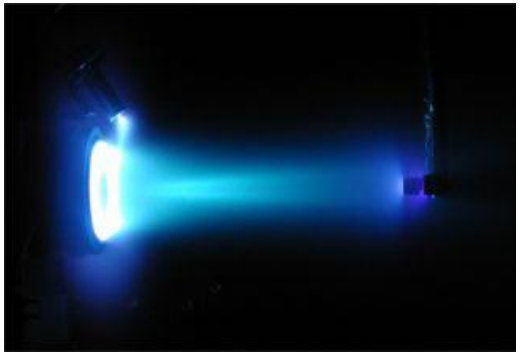
Space Tug (Transportation) - High Thrust requested

(*) Data Collect: AIS/VDES,/ARGOS, M2M, ADS-B (nanosats & microsats)

ThalesAlenia Space
a Thales / Leonardo company

EP Way Forward - Technologies & Subsystem Evolutions (1/3)

- **3 main thrusters technologies will be largely used in the overall EP market within next 5 years:**
  - **Hall Effect Thrusters** will continue to lead Telecom applications for both GEO or LEO constellations (above 200W), HETs will be implemented also in lots of other satellites applications
  - **Ion Grid Thrusters** will be implemented in Observation, Navigation & Sciences satellites particularly in case of strong mass & volume constraints (high Isp required)
  - **HEMPT technology** is a possible alternative for constellations (200W to 1500W per thruster) with the capability to modulate thrust level in a wide range



- TAS expect in the short term future to have a broader choice of competitive solutions, offering the best Power/Thrust ratio & Isp and cost combinations to respond to different mission needs of EOR/SK in GEO Telecom satellites, to LEO/MEO constellations of Observation, Navigation & Science satellites

- All 3 main technologies need to improve their map of Power/Thrust ratio & Isp coverage (Isp has to be optimized considering other required performances levels to fulfil) as well their recurring costs

- **Alternative propellant** (e.g. iodine, krypton) to xenon are to be further assessed/considered for competitiveness improvement

EP Way Forward - Technologies & Subsystem Evolutions (2/3)

- **Several new EP technologies are under (pre-)development for increasing SmallSats market** (from few W to 200-300W), their implementation will depend on obtained development/performances outcomes & costs:
  - Electrospray/Colloid & FEEP Thrusters (Field-Emission Electric Propulsion)
  - VAT (Vacuum Arc Thruster) & PPT (Pulsed Plasma Thruster)
  - Next Generation Ion Thruster with imbedded neutralization & propellant
  - ECRA (Electron Cyclotron Resonance Accelerator)
  - Helicon…

Nanosat
There are micropropulsion needs for Data Collect & Observation missions

Increase of EP market expected for SmallSats

EP Way Forward - Technologies & Subsystem Evolutions (3/3)

EP Power Electronics/PPUs:

- New PPU technologies (high Voltage switches/connectors, SIC & GaN components, high voltage PCB)
- Innovative PPU topologies versus various applications (modularity/flexibility of PPU, dual mode & discharge voltages, cross-trapping, high power levels up to 20kW…)
- Alternative system architectures (integration of PPU boards within satellite power distribution module, unregulated bus for small satellites, direct drive…)

EP Fluidic Chain:

- Simplification & flexibility of architecture (pressure regulation & valves) versus failure tolerance requirements
- Next generation of EP pressure regulator design, new solution of thruster regulation valve

EP Verification & AIT at subsystem & satellite levels:

- Simplification of EP testing needs/logic considering subsystem/equipment ground testing & flight background + new equipment design
- Optimization of acceptance tests to be done at different levels (equipment, subsystem & satellite levels)
- Design of a compact EP module fully integrated by a supplier (case of SmallSats) to reduce costs
- Integration of power electronics within satellite power module in some applications allowing to reduce overall acceptance tests costs at system level