HORIZON 2020

EPIC

Report

D5.9
Workshop 4 Report 2018

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EPIC

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1 INTRODUCTION

In the frame of the Electric Propulsion Innovation & Competitiveness (EPIC) project, (grant number 640199) and more specifically it's Work Package 5 "Dissemination Education and Outreach", this document has been produced with the aim to report in detail the organization, results and conclusions of the EPIC Workshop 2018 (Workshop 4) as part of the activities performed in by the EPIC PSA regarding Dissemination, (Task T5.1) during the fourth year of execution of the project. These activities are in line with the agreed Dissemination plan [RD1] containing the dissemination objectives, target groups identified, and the structure, means and activities to ensure successful and wide dissemination of project results as well as maximising the project visibility.

The present document is the deliverable D5.9: *Workshop 4 Report 2018*.

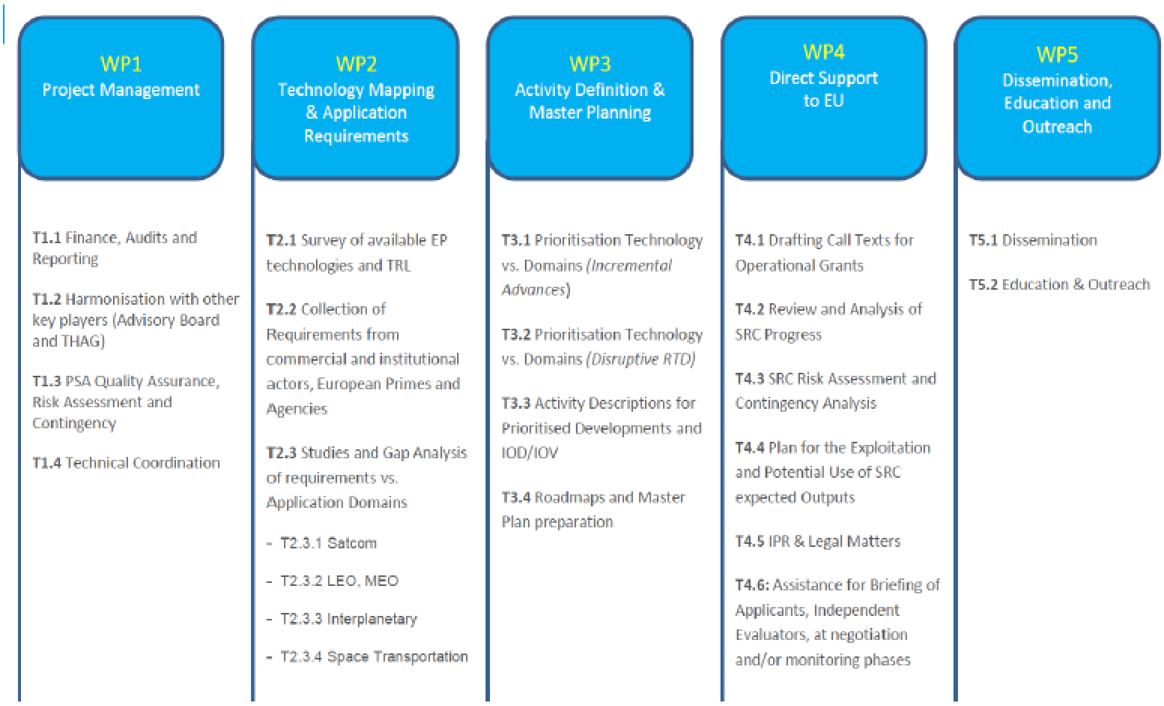

Figure 1.1: EPIC Work Package Structure

2 REFERENCE DOCUMENTS

[RD1] EPIC-CDTI-5.1-RP-D5.1 Dissemination plan
[RD2] D4.3 SRC Collaboration Agreement (CoA)
[RD3] EPIC-DLR-3.4-RP-D3.4 Workshop 2 Report (Stockholm 2015)
[RD4] EPIC-CNES-2.2-RP-D2.3 Workshop 1 Report (Brussels 2014)
[RD5] EPIC-CDTI-5.1-RP-D5.8 Workshop 3 Report (Madrid 2017)

3 ACRONYMS & ABBREVIATIONS

Airbus DS: Airbus Defence & Space
ASI: Agenzia Spaziale Italiana
BELSPO: Belgian Science Policy Office
COSMOS: Continuation of Cooperation Of Space NCPs as a Means to Optimise Services
CDTI: Centro para el Desarrollo Tecnológico Industrial
CNES: Centre National d'Études Spatiales
DLR: Deutsches Zentrum für Luft- und Raumfahrt
EBB: Elegant Bread Board
EC: European Commission
ECRA: Electron Cyclotron Resonance Acceleration thruster
ECSS: European Cooperation for Space Standardization
EO: Earth Observation
EOR: Electric Orbit Raising
EP: Electric Propulsion
EPIC: Electric Propulsion Innovation and Competitiveness
EPPM: Electric Propulsion Pointing Mechanism
ESA: European Space Agency
ESP: European Space Propulsion
EU: European Union
FCU: Flow Control Unit
FEEP: Field Emission Electric Propulsion
FMS: Fluid Management System
GEO: Geostationary Earth Orbit
GIE: Gridded Ion Engine
GTO: Geostationary Transfer Orbit
H2020: Horizon 2020
HEMP-T: High Efficiency Multistage Plasma Thruster
HEO: Heliosynchronous Earth Orbit
HET: Hal Effect Thruster
IEPC: International Electric Propulsion Conference
IPPLM: Institute for Plasma Physics and Laser Microfusion
LEO: Low Earth Orbit
LIF: Laser induced Fluorescence
LSI: Satellite Large System Integrator
MEMS: Micro Electro Mechanical System
MEO: Medium Earth Orbit
MHT: Mini Helicon Thruster
MIB: Minimum Impulse Bit

MPD: Magneto Plasma Dynamic

MSL: Mars Space Limited
NCP: National Contact Points

NEO: Near Earth Object

NGGM: Next Generation Gravity Missions

NSSK: North-South Station Keeping
OG: Operational Grant

PCU: Power Conditioning Unit

PCDU: Power Conditioning and Distribution Unit

PIT: Pulsed Inductive Thruster

PPT: Pulsed Plasma Thruster

PPU: Power Processing Unit

PR: Pressure Regulator
PSA: Project Support Activity

PSCU: Power Supply and Control Unit

QCT: Quad Confinement Thruster

R&D: Research and Development

R&T: Research and Technology

RPA: Retarding Potential Analyzer

RF: Radio Frequency

RPA: Retarding Potential Analyser

SPF: Single Point of Failure

SRC: Strategic Research Cluster

TAS: Thales Alenia Space

TED: Thales Electron Devices

TRL: Technology Readiness Level
UKSA: UK Space Agency

VAT: Vacuum Arc Thruster

VLEO: Very Low Earth Orbit
WP: Work Package

XIPS: Xenon Ion Propulsion System

XFCU: Xenon Flow Control Unit

4 DISSEMINATION OBJECTIVES

In line with [RD1], the EPIC PSA dissemination and exploitation activities are aimed at:

- Promoting the EPIC PSA project, its progress and results.
- Improving access to useful inputs from the SRC Operational Grants.

- Contribute to ensuring that the EPIC and Electric Propulsion SRC achievements are known to the potential users and future potential bidders for SRC Operational Grants.
- Improving the knowledge and acceptance of the SRC and therefore contribute to the subsequent exploitation of the project results by end-users or by a potential next SRC phase beyond 2020.
- Guaranteeing that the EPIC project is exploited to its full potential.

The dissemination activities are the responsibility of and coordinated by CDTI (as leader of Task 5.1 "Dissemination" and of WP 5), but this task includes the participation of all PSA Partners.

EPIC Dissemination activities will be performed as far as possible in coordination with the COSMOS network which is the network of National Contact Points (NCP) for the Space theme under the EU's Horizon 2020 (http://ncp-space.net/); and in collaboration with the PSA Partner organisation NCPs for Space.

The EPIC PSA will also encourage the dissemination of results by the SRC Operational Grants holders, in a united and coordinated way as much as possible, so that all possible channels are exploited, always under the coverage of the SRC Collaboration Agreement (CoA) [RD2].

5 SCOPE OF THE WORKSHOP

The EPIC Workshops one and two were the ones organised by EPIC during the first year of execution of the PSA. The first one was in Brussels: 25-28/11/2014 (http://www.epic2014.eu/) organised by CNES and BELSPO; and the second one was in Stockholm: 11-12/02/2015 (http://epic-src.eu/?page_id=12) organised by DLR with the help of the THAG Swedish Delegation. Information on the EPIC Workshops performed during the first year of EPIC execution are already included in detail in their respective deliverables [RD4] Workshop 1 report and [RD3] Workshop 2 report. The third one, the EPIC Workshop 2017 was organized by CDTI and held on 24-25 October 2017 in Madrid, at: CDTI (Madrid), Spain; with the active involvement of all PSA Partners: 24-25/10/2017 (http://epic-src.eu/workshop-2017/).

The main objective of the EPIC Workshops is to present the Horizon 2020 Electric Propulsion SRC activities to the electric propulsion community and stakeholders and to collect and assess the latest electric propulsion technology developments in Europe. EPIC Workshops are the fundamental element of the SRC dissemination of SRC activities, and the collection of information for the EPIC SRC Roadmap. They have two objectives: an extensive exposure of the EPIC team ideas to the external world (commercial, scientific, programmatic, etc.), and gathering of inputs, and to expand to the maximum the outputs produced during the EPIC project.

The first objective was achieved mainly during the two first EPIC Workshops (Brussels in 2014 and Stockholm in 2015). The second objective (also accomplished during the two EPIC Workshops), is going to be achieved during next EPIC Workshops (Madrid in 2017, London in 2018, The Netherlands (ESTEC) in 2019); where dissemination will be organized to communicate on the roadmap implementation and give a periodic status of the situation to all stakeholders interested. EPIC team will ensure the participation and presentation of all Operational Grants funded at the time, to show a coordinated approach and maximise the dissemination of the SRC progress and achievements.

Figure 5.1: BEIS/ Westminster Conference Centre

The EPIC Workshop 2018 was organized by UKSA and held on 15-17 October 2018, at Westminster Conference Centre, 1 Victoria Street, London SW1H 0ET, United Kingdom; with the active involvement of all PSA Partners (http://epic-src.eu/workshop-2018/).

The EPIC Workshop 2018 program covered the following topics:

- PSA and SRC progress and activities
- H2020 Work Programme EP SRC topics
- Stakeholders interaction with Satellite Operators and Satellite Large System Integrators
- Incremental SRC OGs: objectives, proposed approach, team, progress, and early results
- Disruptive SRC OGs: objectives, proposed approach, team, progress, and early results
- Trends in Power Processing Units
- New developments on EP Incremental and Disruptive Technologies (promising thrusters and transversal technologies)
- Dissemination and education SRC activities

EPIC PSA makes public the presentations in agreement with the authors of the EPIC Workshop 2017 in the EPIC web: http://epic-src.eu/workshop-2018/

6 WORKSHOP SUMMARY

6.1 Welcome (Chair: Nick Cox, UKSA)

- Nick Cox, UKSA: Introduction, and organization logistics
- José GONZÁLEZ DEL AMO, ESA: PSA Welcome, and EPIC Workshop Objectives

6.2 Session 1: PSA Updates and Programmatics (Chair: Nick Cox, UKSA)

- Apostolia KARAMALI, EC: Space in the next MFF Commission proposals
    - EC explained the space policy context and its flagship programmes in the multiannual financial framework (2014-2020). EC presented the Space activities in the next MMF Commission proposal, Horizon Europe with 4 components (EGNOS, GALILEO, GOVSATCOM and SSA) and 3 horizontal activities (Access to space, support to start-up and security).
    - Space activities will be under the second pillar, Global Challenges and Industrial Competitiveness, in the cluster devoted to Digital and Industry together with other areas of intervention. The main identified areas of intervention in space will be: EGNOS and Galileo, Copernicus, SSA, Secure satellite systems, Satellite Communications for citizen and business, non-dependence, space eco-systems (In orbit IOV/IOD, space demonstrators, breakthrough innovations and technology transfer), and space science.
    - EC presenter a new approach to European partnership in Horizon Europe based on objective-driven and more ambitious partnerships oriented to simple architecture and toolbox, coherent life-cycle approach and strategic orientation. Partnership is divided in three categories: Co-programmed, Co-funded, and Institutionalised.
    - Space Horizon Europe timeline decisions were presented together with the consultation process.

- Florence BEROUD, REA: SRC activities and Operational Grants
    - REA explained the context of the SRCs and PSA of EPIC within the overall programme and the next steps to be done. The SRC Electric Propulsion implementation and adaptation was explained, with special attention to the role of the actors and its relations (EC, REA, PSA, OGs), the OG implementation (Call 2014, Call 2016, Call 2019, Call 2020) its lessons learned up to now, the impact on the evolution of the market on the SRC, and how the SRC mechanism works and adapts.
    - Other EP activities funded under H2020 but not in the SRC were presented (DISCOVERER, IFM micro thruster, EMBRACE)
    - So far between SRC projects have not led to technical cooperation between projects, but coordination for dissemination is achieved.

- Jorge LOPEZ REIG, CDTI: 2019 Disruptive Call Details and Guidelines
    - PSA presented in detail the content of the next space H2020 EP SRC Call text SPACE-13-TEC-2019 devoted to Disruptive technologies, including its guidelines published by EC.
    - First an introduction to the EPIC Roadmap was given presenting the differences between Incremental and Disruptive technologies (promising EP thrusters and Transversal EP technologies).
    - Particular attention was devoted to explain the need to prove in the proposals the disruptive merits of the technology to be developed, both in terms of performances and in terms of cost reduction for the overall EP subsystem. Also the need to prove adequately the starting TRL level, was pointed out in order to proper address projects funded up to 2 M€ (>=TRL4) or up to 1 M€ (<TRL4) modalities.

- José GONZÁLEZ DEL AMO, ESA: EPIC PSA and activities

- The PSA explained the context of the SRCs and the EPIC PSA activities, recalled the SRC EPIC Roadmap and the next SRC Calls to come (SPACE-13-2019 and SPACE-28-TEC-2020), presented the ongoing SRC 2016 Call Operational Grants, and outlined the next SRC steps.
- All ongoing OGs were presented in terms of partners and objectives (CHEOPS, GIESEPP, HEMPT-NG, GANOMIC, MINOTOR and HIPERLOC-EP).

- Jean-Michel MONTHILLER, EC: IOD/IOV
    - EC recalled the need and the policy context of the IOV/IOD initiative in the H2020. IOD/IOV activities in the Space Work Programme were described (ESA Engineering support with 6 M€ for 2018, Launch services with 39 M€ for 2018 and Mission design integration and implementation with 20 M€ for 2019 and 18 M€ for 2020).
    - The IOD/IOV overall service schedule was presented, including the Call for expression of interest of IOV/IOD experiments. The experiment EOI is always open, but the first cut-off date was 22 May 2018. Experiment activities are not financed in the H2020 activities. The selection of the experiments is ongoing and been performed based on: technical fit, policy relevance, programmatic fit and complementarity.

6.3 Session 2: SRC Project Updates Part I/ Incremental Operational Grants (Chair: José Gonzalez del Amo, ESA)

- Idris HABBASSI, Safran Aircraft Engines: CHEOPS
    - CHEOPS Presentation on the HET Technology and its interest for the space industry. Presentation included the project partners, the objectives and state of development of: the GEO/NAV application (Dual Mode EPS – High Thrust / High Isp), the LEO application (Low Power EPS – Small / Mega Constellation), the Exploration application (High Power EPS – Exploration & Transportation).
    - The main points highlighted in the presentation are: the GEO (7 kW-OR, 3,5 kW-SK) dual mode with a target of 1MN of total impulse and (-30%) of cost reduction; the Low Power EPS for small/mega constellations (200 W-1000W) with a target cost of <200 k€; the High Power EPS (15-20 kW) and direct drive PCU for exploration and space transportation (space tug).

- Cyril DIETZ, ArianeGroup: GIESEPP
    - GIESEPP Presentation of the project, included: objectives and expected impacts; consortium and competencies; GIESEPP concepts using GIE (both from Arianegroup and Qinetiq) and a modular and common PPU for 3 different power ranges (GEO Telecom and Navigation, LEO constellation market and Space transportation and exploration); status of the activities and schedule; design and the main development challenges.
    - The different GIESEPP concepts were described for LEO (1L/2L), for GEO/MEO (1G) and for Exploration (1S) with clustering.
        - LEO 200-700 W (1L/2L): 1 x Thruster, 1 x Power Processing Unit PPU 1L, For 1L: 1 x Electronic Pressure Regulator EPR, For 1L: 1 x Flow Control Unit FCU, For 2L: 1x RADICAL instead of FCU and EPR.
        - GEO/MEO 5kW (1G): 1 x Thrusters, 1 x Power Processing Unit PPU 1G, 1 x Electronic Pressure Regulator EPR, 1 x Flow Control Unit FCU.

  - Exploration 20k€ (1S): Clustering of 4x GIESEPP 1G, 4 x Thrusters, 2-4 x Power Processing Unit PPU 1G, 4 x Electronic Pressure Regulator, 4 x Flow Control Units FCU.
  - The main points highlighted in the presentation: Dual mode is the key issue; Project team thinks in terms of building hardware; Alternative propellants ensuring functionality not performance; AST building block will be a success beyond this project (2L with radical EPR+FCU); EPR electronic not mechanical; 1G no redundancy and this implies low cost, fast design for automation and serial production; Clustering approach for high power: no single failure source; Plug and play design: absolutely targeting one PPU for all.

- Andreas HASCHKA, Thales Deutschland: HEMPT-NG
  - HEMPT-NG Presentation included: the consortium, the project overview and its status, the market target for the HEMPT-NG EPS, the technical achievements and the next steps for the project.
  - The project development logic is presented, with EV0 (100-700 W) for LEO market, and next steps with EV1-EV2 (3-5 kW) for navigation and telecom markets. The presentation confirms the expected advantages of the HEMP-technology (lowest system complexity, simplicity, long lifetime by erosion-free operation, cost-effectiveness and reliability).
  - The EV0 Bread Board Model development and testing is presented with a design oriented for cost effectiveness (single mechanical structure, 70%reduction of parts, 4 attachment points).
  - The main points highlighted in the presentation: Market situation is changing and this requires flexible design to match with everything; Baseline thruster HEMP 3050 not verified in orbit, but has reached TRL 8 with an endurance test of 9.000 hours; High production and testing capacity in Thales Ulm: heritage from existing production line of travelling wave tubes.
  - Next steps will cover the PDR Nav./Telecom and the EV1 development.

6.4 Session 3: Project Updates Part II/ Disruptive SRC Operational Grants (Chair: Vincenzo Pulcino, ASI)

- Louis GRIMAUD, Safran Electronics & Defense: GANOMIC
  - GANOMIC presentation included details on the consortium partners and roles in each work package, main project objectives: improvement of power performances (power level and power by weight) - single 7.5 kW building block power module; high voltage management – up to 600V; modularity and configurability - generic anode discharge power module with software digital robust & adaptive control loops; and shrink cost - recurrent cost divided by 3 at PPU level.
  - The project schedule, progress and the key design drivers of anode module (Efficiency > 98%; Power density > 2kW/kg; High dielectric voltage > 600V; Cost divided by 3 at PPU level) were presented together with the key technology roadmap.
  - Finally the current results were presented: Electrical characterization of embedded power GaN transistors in PCB and mock-up converters parts; 4kW anode module Converter design and electrical & thermal modelling completed; Embedded power boards with power circuit & drive in manufacturing; Processing resources evaluation of robust control algorithm software implementation.

- John STARK, Queen Mary Univ. of London: HIPERLOC-EP

- HIPERLOC-EP presentation included details on the consortium partners and roles in each work package. The project main objective is to develop an Electric Propulsion System based on Electrospray Colloid Electric Propulsion (efficient, performance comparable with current commercial platforms, fully scalable) with cost an order of magnitude below current systems, oriented to the Cubesats market.
- The Electrospray Colloid concepts together with its targets were presented: Isp > 1000 s, Specific Thrust >= 56 mN/kW, Thrust target >= 500 µN, Total Impulse = 2000 Ns.
- The integrated system design composed by Colloid thrust head, PS&FS and PPU is driven by cost requirements. The activities presented as completed were: analysis on market, requirements, performances and components; design a BB model, and the manufacturing of the BB model.
- The system components details and highlight were presented (TU, PPU and PS&FS) with no neutralizer needed (all propellant and power is propulsive, no neutralizer, interface: only a power and data bus, PS&FS thermally integrated with CTH and PPU, propellant isolated from ground).
- BBM Validation setup at laboratory and methodology for verification of performance were presented.

- Denis PACKAN, ONERA: MINOTOR
  - MINOTOR presentation included details on the consortium partners, ECRA technology and its potential advantages, project objectives and achievements, and content of work packages and its relations.
  - The technical hurdles were presented showing no stoppers (PPU efficiency, magnetic torque, EM field, magnet heating and reflected power) together with the ECR thruster developing challenges (plasma physics more complex, no direct experimental knowledge of the total current and of the ion energy, good vacuum levels needed).
  - The main project objectives for thruster and PPU are (starting from TRL 3): understand the physics; demonstrate performances, and extrapolate; determine possible uses: GO/NO GO, and prepare development roadmaps.
  - The project has made good progress: several achievements in the different work packages (modelling, experimental investigations, high efficient MW generator and system impact; journal publications, two in preparation; 8 papers presented at IEPC-2017, including a best student paper award on the joint ONERA-UC3M work. The way forward: Further tests and the availability of modelling codes, in the next few months should help have a better view of the scalability, and performance envelopes of the technology.

6.5 Keynote Speech

- Alan BOND, Mirror Quark Ltd
  - Space electric propulsion could be extended to tens of megawatts electrical power, or beyond, with developments in technology at hand. Vehicles could reach hundreds of tonnes in mass and the Solar System could be reduced to months of transfer time in size.
  - Development of a more efficient and convenient power supply is highly desirable or, indeed, essential. If efficient direct conversion of nuclear energy can be achieved electric propulsion could even be applied to atmospheric flight and the space transportation of science fiction would become reality.

6.6 Session 4-5: Electric Propulsion Technologies for Small Satellites and New Markets (Chair: Giorgio Saccoccia, ESA)

- Sabrina CORPINO, Turin Politecnico: Cubesats

- Turin Polytechnic has developed some 3 CubeSat missions at the University. New generation of Cubesats for challenging applications and unprecedented mission. New missions require to increase CubeSat capabilities such as: high data-rate communications, active thermal control, enhanced attitude and orbit control.
- Electric propulsion is a key technology towards innovative CubeSat applications. EP systems have low maturity and need Low cost fast delivery, new testing approaches (activities on the subject are on-going with ESA within the ESA Propulsion Lab).
- They developed a "CubeSat standard test platform for EP" and are testing it in relevant environment at sea level. A dedicated test plan and procedure will be available in 2019 for testing @ESTEC Electric Propulsion Lab.
- Conclusions: The test platform features high degree of flexibility with respect to the ability to host different EP systems. The platform is fully representative of a 6U CubeSat flight unit, which can be used for qualification of propulsion systems as well as verification of on-board avionics.

- Paolo BIANCO, Airbus DS: Low cost electric propulsion
    - The business case was some years ago: How to compete with chemical propulsion; How to reduce the cost?
    - For thrusters, the main trends at AIRBUS DS are to reduce ancillary elements and complex interfaces, number of parts, the required tolerances. The Hard core baseline is to work on: Materials and testing
    - With the objective to reduce propellant and feed system, increase mass ratio, reduce propellant control, parts, pipes, I/F. For Power conditioning, it is necessary to work on (Number of IF, Complexity or working modes, Harness and connectors, Relax Slice Wave and power SWaPS, hard core/ qualification: hard architecture, power rating, voltage rating, manufacturing and testing).
    - Investigation is ongoing on the use of better and cheaper propellant, which can be packed nicely, easy stored and managed and not aggressive.

- Steven AUSTIN, TAS-UK : LEO Sat Constellation
    - The market is changing rapidly with the growth in telecom driven by new apps (broad band, mobility) and shorter time to market demand.
    - We are not ready in Europe for volume manufacturing, low cost, bring cheaper technologies to market. Need to put European companies at the forefront – to compete with established benchmarks in Russia and US.
    - TAS UK needs: A range of technologies covering the Isp/Thrust map, with power ranges for different satellite sizes; Benefits from constellation prices to be available for all applications; Stable industrialized supply chain able to work in competitive partnership with satellite Prime, fed by new technologies from R&D sources; At least two European sources for key technologies.
    - Conclusions: With such a rapid change in the markets, no-one is fully ready…but many are beginning to move fast; There are some great innovations in Europe….we need to invest wisely, work collaboratively and gear up; This is probably the greatest time of opportunity for Electric Propulsion that we have ever seen.

- Marco VILLA, Tyvak : New EP Applications
    - Note: No presentation on Tyvak
    - Tyvak is specialized for LEO and mini GEO developing 3D sophisticated missions for small satellites.

- Their involvement is pure commercial applications, real market and common request in applications with the goal to do operational and reliable commercial system to compensate the lack or launch opportunities in adding propulsion (from 2 to 6 km/s) on piggy back launches or for maintaining the orbit (150m/s).

- Craig CLARK, Clyde Space : Cubesats
    - Clyde Space is an end to end Microsat provider from 1 to 50 kg, 1U to 12U (M2M, Earth observation (Poicasso, Seahawk, Firesat, GEMS).
    - Different market projections for 1-50 satellites (catapult, slow, fast and worst cases) are made around 100W for EP systems for SK, maneuvering and deorbiting.
    - Propulsion needs for future missions: Station Keeping, Maneuvering, De-orbit, Constellation deployment/development.

- Andrea LUCCAFABRIS, Surrey Space Centre : Emerging Technologies and Applications
    - Surrey space center accounts 10 academics and 50 searchers with a dedicated EPS group. They produced a Development Roadmap for New technologies and search drivers. Their finding is a lack of EP device for CubeSat: high thrust to power and low Isp (for Lunar orbit transfer). They promote the use of unconventional propellant and to work on lifetime, beam steerability and cost reduction.
    - Their developments: The Halo thruster, The QCT (Quad Confinement Thruster) with magnetic cusp topology. They intend to rise TRL with collaboration of an industrial partner, and then to rely on industry for industrialization. R&D activities are also ongoing on Water propelled ECR Microwave EP.

Synthesis of Session 5 Roundtable on Electric propulsion technologies for small satellites and emerging applications: Chair Giorgio Saccoccia.

<u>1-Question to Primes: What could be the relaxed requirements to lower EP costs?</u>

Paolo Bianco –AIRBUS DS:

In the framework of the mission's analyses, certain relaxations could be envisaged. For CubeSat PPUs, it is better not to constrain electronic too much. It is important to have franc discussion with the customer, because savings could be managed at system level.

Steve Austin-TAS UK:

TAS is quite open to do new things. One potential way is linked to the use of redundancy affordable inside constellations. If satellites are designed from scratch, more integrated solutions can be necessary to integrate EP in a more efficient way.

<u>2-How can we optimize integration in satellites?</u>

Marco Villa -Tyvak:

To reduce price is not to develop new things but to mainly to adapt existing ones with optimization of cost as an important parameter. There is no other way to fly cost optimized integrated vehicles.

Andrea Luccafabris Surrey Space Center

Developers want to keep to their standards and may open discussion for other cases where there is more flexibility, depending on mission needs. It's a question of maturity for integration.

3- How can we integrate something if the customers want a second source, because depending on a single source is difficult and leading to long term risk, so there is a need to make compromises.

Marco Villa -Tyvak:

As soon as an engineering model is available Tyvak will take responsibility for the integration.

4-Is there something different that can imply change in mentality (performance, requirements to satisfy)?

Marco Villa -Tyvak:

Anything that has an overall impact on the global system has to be considered.

5-What has been the impact of EP on very small satellites:

Sabrina Corpino-Torino Politecnico

It is the role of the platform testing model developed by the Torino Politecnico with support of ESA to evaluate such consequences.

Steve Austin-TAS UK:

Customers have to be open to newcomers, but need to understand the involved new risks, there is a need for collaboration to discuss properly. New approaches promising to overcome limitations are welcome but have to be discussed together if potentiality is demonstrated.

Andrea Luccafabris Surrey Space Center

Discussion on risk assessment is fundamental.

6-Question to Universities: having propulsion in academic projects, what is changed with regard to students?

Sabrina Corpino-Torino Politecnico

Students are more excited because Electric propulsion is an attractive discipline. They want to expose themselves to real space activities. Propulsion can also be a way to deorbit debris to lower orbits for environmental impact. They are much concerned because they know that half of academic projects satellites have failed mainly because of bad testing. Electric propulsion can allow bigger missions, longer experiments in flight. During development, EP has impact on integration, thermal behavior (students can learn a lot more).

Andrea Luccafabris Surrey Space Center

Mission analysis (1U, 2U) are very limiting. For higher platforms, mission analyses on thermal aspects are considered easier. The students have to take care what EP system they select depending on the mission's needs. But some aspects of introducing EP could also be negative for them. Research and development activities is a very good way to educate students and to train them for industry needs.

7-Is there a commonly agreed approach for CubeSat qualification or do we lose time for qualification approaches which will not be accepted by end users? What standardization to support?

Sabrina Corpino-Torino Politecnico

Qualification approach depends on the stakeholders, and it is not easy to find a balance. CubeSat from Torino Politecnico have been flown on ESA missions using ECSS standards. ECSS have been tailored and adopted but there is no specific ECSS for CubeSat propulsion. Students don't like to write test reports though mostly interested to participate to tests.

Andrea Luccafabris Surrey Space Center

Any approach can be envisaged but finally solutions have to work. They are still to be considered as satellites and have to prove security. A minimum set of qualification requirements could be envisaged for a dedicated standard.

8-Which are the emerging markets opening?

Paolo Bianco –AIRBUS DS:

Earth observation constellations need to be achievable and to be propulsion competitive. Meteorological missions in lower orbit will have specific requirements on deorbiting. Even If more and more satellites become demisable, big satellites will still need bigger deorbiting means.

Marco Villa -Tyvak:

Earth observation flights will increase as much as possible with bigger satellites to be cost efficient.

6.7 Session 6: EP Technologies and Capabilities (Chair: Lisa Martin-Perez, DLR)

- Konstantinos KATSONIS, DEDALOS Ltd: The CO2DGM for CO2-breathing thrusters
    - CO2DGM is a Detailed Global Model of plasma generated from a gas constituted initially by CO2. The effective plasma composition depends on various imposed conditions, e.g. form factor / pressure / absorbed power. CO2DGM is used here to support various types of Electric Thruster (ET) technology, allowing for: Thruster characterization, Functioning description and optimization, and Optical Emission Spectroscopy (OES) diagnostics.
    - Dedalos presents the density of species based on PCC and conjugate diagrams, Ionization percentage based on FD diagrams, OES plasma diagnostics, based on theoretical oxygen I & II spectra.
    - Detailed global model of plasma generated. Energy Harvesting using mars atmosphere components as propellants. Definition of models to include spectral lines intensities of ET in CO2. The approach can even allow the comparison. The approach allows to calculate for every CO2 fed EP system. ISRU is the key impact of the analysis.
    - Conclusions: CO2DGM contributes efficiently to theoretical characterization and diagnostics of ETs fed by CO2 by using PCC and FD diagrams and theoretical spectra, Various absorbed power values have been addressed for 20 sccm of CO2 flow rate and a form factor of R = 2 cm, L = 18 cm.

- Georg HERDRICH, University of Stuttgart: Disruptive Electric Propulsion at IRS
    - IRS gives a programmatic overview of its Disruptive Electric Propulsion activities with an overview of the IRS thrusters, tools for diagnostics and codes; and enters in details on the developments of PPT, AF MPD, IEC and TIHTUS.
    - PPT is studied since 16 years. IRS could extend the capabilities of PPTs to very high levels (more than 30% than the typical).
    - Applied field MPD with SITAEL.
    - IEC Inertial Electrostatic Confinement, very complex system involving many physicists. Using 2 grids with a very high delta voltage the plume is created in different shapes including specific and defined disturbance.

- 100 kW Class Applied-Field MPD SX3 Thruster goes to 100 kW class. Thrust efficiency is breakthrough. Main features: Cost efficient laboratory model, applied field up to 400 mT, arc current up to 1kA, anode + cathode gas injection (Argon).

- Luc HERRERO, COMAT: Plasma Jet Pack (PJP) Technology Overview
    - COMAT is a company experienced in designing, developing, qualifying and selling equipment for space since 1977, and particularly for EP.
    - 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-orbiting, drag compensation, attitude control. Two initial targets: PJP 0-30 & 0-80 for nanosatellites available for IOD in 2018, and PJP 0-150 for small satellites (150kg class satellites).
    - Plasma Jet Pack 0-30W characteristics: Average Thrust: 450µN@30Hz T/P ~15µN.W-1, Impulse bit: 15µNs, Specific impulse: >2000-5000s (as function of propellant), Overall mass with propellant <800gr, Total impulse: 4000N.s (~100 days@30Hz), Volume: 1U = 10cm*10cm*10cm, Efficiency >20%.
    - Plasma Jet Pack technology advantages: No fluid, solid metal propellant, High specific impulse (e.g. Isp= from 1 000s to 7 000s), Ibit flexibility, Mean thrust, Neutral and focused plasma plume.
    - 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%)). PJP technology is simple (power electronic is basic, standard manufacturing process), PJP progress (PJP 0-30 / 0-80 : TRL 4 and 6 bread boards designed and characterized; PJP 0-150 : manufactured and will be test in December 2018). No show stopper is identified today; the next challenge is to perform life duration of 100 days.

- Alberto GARBAYO, AVS: ICE^3
    - AVS is an European SME experimented in ions and plasma sources, radio frequency cavities development and diagnostics associated with test benches who longs to be a new player in electric propulsion around 2020.
    - AVS offer Microwave electro-thermal thruster for CubeSats using plasma in resonant cavity (high thrust, low Isp) as an alternative to Resistojets Microwave platforms, a water cathodeless (no-neutaliser) ECR thruster for small satellites (national UK program) and also Induced non-intrusive fluorescence diagnostic device for EP thrusters (ICECUBE, Mini HET, ElectroSPRAY, SCRamjet, AquaJet, XMET, Scramjet, ICECUBED).
    - ICECUBE is a water thruster with MEMS bipropellant for thruster Chip to be used on more technology approaches.

- Manuel la ROSA BETANCOURT, Pintegral Solution: MPD Technology
    - SUPer conducting Readiness Enhanced Magnetoplasma dynamic Electric propulsion (SUPREME). Project, based on MPD is presented. The thruster is based on 100Kw SX3 (100 kW class AFMPDT demonstrator) from university of Stuttgart, and its target is the Direct Drive 100. Prototype Supreme RV-X1 (20KW).

- Markets SUPREME 20 kW class: Satellite delivery: More payload and faster TTO, On orbit satellite servicing, Active debris removal.
- Markets SUPREME > 20 kW class: Logistics and cargo delivery for human exploration, Lunar transits require 60 –100 kW EP systems, Mars transits require > 200 kW EP systems.
- Partners: Arianespace, THEVA, Airbus, PI Solutions, IRS, University Carlos III of Madrid.
- Key features and targets: Applied Field MPD Thruster, Desired power range: from 20 kW to 500 kW, Specific Impulse Isp: 2000-4000s, Thrust range > 1N.

6.8 Session 7: EP Technologies and Capabilities (Chair: Jorge Lopez Reig, CDTI)

- Mercedes RUIZ, Sener: Helicon O-plasma Thruster experimental platform
  - SENER presented the background of the development of the Helicon Plasma Thruster HPT-05 in collaboration with UC3M-EP2 (models), and presents the evolution to the HPT-05M system experimental setup tested at EP2 Electric Propulsion Laboratory.
  - The test campaign and results (Argon and Xenon) are outlined: parametric analysis based on the optimisation of some propulsive figures, and plasma plume characterisation. The tests allow analysis of density profiles, and allow optimum operating point to be established. Higher performance at lower mass flows.
  - New prototype HPT-05M (1 KW). Helicon thruster is simpler with injector, RF and coils.
  - HPTM-05 M test campaign in June 2018. Problems with thrust balance, but a lot of lessons learn for the future. Next steps are to integrate with new electronics by end 2018, then measure thrust with new balance early 2019, with TRL5 by end of 2019.

- Daniel STAAB, AVS UK: Test campaign results for AQUAJET and XMET
  - AVS gives a overview of its activities in Electric Propulsion; and presents its early results and tests for AQUAJET and XMET.
  - AQUAJET: Electrodeless ECR thrust with magnetic nozzle. Main features: Efficient ionization, outperforming helicon-type; Simple & low-cost design; No grid erosion; flexible propellant choice (Kr, Ar, Ne, Xe, CO2, N2, O2, air); Xe, H2O & NH3 of particular interest. H2O because cost and predicted performance promising. Approach: Simple analytical model & flexible geometry prototype, direct performance measurements, and first tests of H2O propellant, benchmark against Argon.
  - AQUAJET funded by UKSA. Test campaign and thrust balance calibration. Milestones up to date: first demo with water, reliable ignition and stable, up to 200W. Performance scales with power. Not optimized yet. Next steps: Complete Xe, H2O performance tests at lower background pressure; demonstrate ammonia propellant, breadboard model re-design from lessons learnt, antenna erosion study.
  - XMET: Part of University Southampton project based on electro thermal device to outperforms cold gas. US. Cylindrical resonant cavity, expanded through nozzle (various nozzles / pressures investigated with Xe). Cavity modelled and optimized. Predict low input power verified (4W). Sharp resonance demonstrated, and stable operation at 220W and 100W.

- Igor GOLOSNOY, University of Southampton: Novel cathodes and alternative propellants for EP

- University of Southampton presents three ongoing projects: Current Heaterless Hollow Cathode (HHC), Low current, dry cathodes based on MEMS, and Alternative propellants for GIE.
- Heaterless Hollow Cathode: conventional cathodes need 2000K to emit – but heat losses from heater. Now propose to heat with ion bombardment – only need heater to start. Removes problems of reliability due to cycling / mass and power reduced. Model uses Lanthanum hexaboride – instrumented prototype. Ignition within 50 sec – then stable operation with no heater current. No erosion seen. Next step is long term tests. Potential high impact.
- Dry Cathodes – based on MEMS technologies - for small thrusters – cost reduction from simplification.
- Alternative propellants – as part of GIESEPP – most efficient, but also compatibility with existing systems. Qualitative analysis – noble gases best, but I and Hg attractive but impractical. Used QinetiQ T5 to test – Kr enquires 30% higher power and bigger tanks. Hollow cathode tried with Krypton – needs 50% more flow than Xe (but lower flow relative to thruster – 6:1). Tank bigger, but may not be a problem.

- Jens HADERSPECK, TAS Deutschland: Microfluidic flow control for next NG HEMP thrusters
  - Fluidic Management System (FMS) is a subsystem of the Highly Efficient Multistage Plasma Thruster - Next Generation (HEMPT-NG) electric propulsion system, and its top level objective is to develop, assemble and test the next generation Fluidic Management System for HEMP-T. Its major objectives are: usage of miniature fluidic components, design having reduced complexity, mass production capability with reduced manual production, define generic products for several HEMP types, develop components with European origin.
  - Radical low cost approach: cold gas is a requirement therefore different redundancy concept is needed. For redundancy separation of FCU and PSA. Key design features: designed for Xenon or Krypton, supports cold gas thruster, supports cross strapping of multiple PSAs with multiple FCUs.
  - PSA Key features: two stage pressure regulator (Bang-Bang regulation), triple barrier against propellant loss.
  - FCU design and architecture: Includes modified µFCU with miniaturised components, controlled by three valves of one type, includes 5 µm particle filters at inlet & outlet, mazes integrated into the Flow Path Board, gas flow to neutralizer is routed through a gas purifier.
  - Part of HEMPT-NG project – Fluid management system – aiming at TRL 6. Gas feed for Xe or Kr system supports cold gas, too. Propellant supply system designed and developed. CAD model produced, and resulting system designed for two stage regulation and triple barrier against propellant loss.

- Eric BOURGIGNON, TAS-Belgium: GEO Dual Mode PPU and LEO HEMPT PPU
  - Thales Alenia Space Belgium presented the background (PPU Mk1 & PPU Mk2 PPU Mk3), the GEO Dual Mode PPU and the LEO HEMPT PPU.
  - TAS-B has designed, developed and qualified the competitive PPU Mk3 product dedicated to 5kW HET and 100V satellite platforms with short time to market.
  - Thanks to the H2020 EPIC, TAS-B is designing and developing two PPU competitive products: In the frame of CHEOPS to drive HET up to 7KW, Dual Mode HET PPU for GEO/NAV applications; in the frame of HEMPT-NG, HEMPT PPU for LEO applications.
    - CHEOPS: Now developing 7KW dual mode PPU as part of CHEOPS – specified, now designing – breadboard coupling test with HET in 2020. Has anode and cathode modules – planar transformer, digital space micro-controller, GaN transistors.

  - LEO HEMPT PPU – for HEMPT-NG. Definition and design completed, breadboard tests in 2019. Anode and neutralizer modules, with same new technologies as dual mode PPU.

- Conclusions: Strong heritage from PPU Mk1 and from PPU Mk2, TAS-B has designed, developed and qualified the competitive PPU Mk3 product dedicated to 5kW HET and 100V satellite platforms. Thanks to the EPIC H2020, TAS-B is designing and developing two PPU competitive products: CHEOPS - Dual Mode HET PPU for GEO/NAV applications, HEMPT-NG & HEMPT PPU - LEO applications.

- Angelo GRUBISIC, University of Southampton: IMPULSE
  - Integrated Microwave Architecture for Telecommunication Satellites (IMPULSE) is a fast track project aiming at Develop an enabling next generation telecommunication spacecraft electric propulsion system employing a novel integrated architecture.
  - IMPULSE objectives are: Demonstrate at TRL-2 an Integrated Microwave Propulsion Architecture for Telecommunication Satellites (IMPULSE) in coupling test compatible with existing SSTL GMP-T busses, Complete development and manufacturing trials of 20cm Xenon ECR Electric Propulsion Thruster (XEPT-20) with neutralizer, Design and manufacture Xenon Microwave Electrothermal Thruster (XMET-500), and Establish performance requirements and functional modes of an IMPULSE system for current platforms.
  - IMPULSE currently TRL 2 with AVS designing XSEPT and XMET thrusters (with SSTL and RAL) – project proved concept – 90% AM. Plasma and RF modelling. AM allows complex geometries. AM grids too. First European triple gridded engine. Neutralizer challenging. Resonant thruster with AVS.
  - Future projects: Aim to develop an enabling next generation telecommunication spacecraft electric propulsion system employing a novel integrated architecture with the objectives to demonstrate at TRL-5 an Integrated Microwave Propulsion Architecture for Telecommunication Satellites (IMPULSE) compatible with existing GEO busses in systems coupling test with XSEPT, XMET, PPU, and FCU.
  - Aiming at H2020 project to develop both and demonstrate at TRL 5- challenges existing thrusters based on previous heritage. Looking for partners.

- Luis CONDE, UPM Spain: ALPHIE
  - UPM presents the ALPHIE design based in a new technology of a plasma accelerator for satellite propulsion in space (small 10 X 15 cm), (Power 450 W), application for small and medium sized satellites (100-200 Kg) and commercial target for the growing LEO/MEO satellite market.
  - New technology for plasma acceleration: only 3 DC power supplies; only one cathode; variable throttle; and Grids are not used for ion acceleration. ALPHIE performances: Variable specific impulse: Up to the order of ISP ≃3000 s with (estimated), thrust of up to 1-0,5 mN and trust-to-power ratios of about T/p ≃0.05 mN/W. DC power below 900 volts. Simplify PPU design and reduces power to 200-300 W.
  - ALPHIE main advantages: Throttleable operation, Variable specific impulse, Clustering, Low DC electric power consumption, No high voltages for ion acceleration, Adaptable, Low gas flow rates.
  - ALPHIE development status: TRL 4 (laboratory). Relevant issues not yet fully addressed: PPU design and Measurements of the delivered thrust in a microbalance.

- Angel POST, AT Devices: Novel electrode material C12A7
  - The ATD space technology group, founded in 2013, make research in different fields. Once the research field is identified, ATD looks for partners with higher knowledge in that field. Advanced Thermionic Emission Devices with C12A7 material are one of the projects and research conducted by ATD. The

project aims to generate energy from heat and also to be a way to support ionic thrusters (by the production of Plasma).

- ATD has first synthetized the new material C12A7, then developed a configuration for producing electricity and started to improve the technology with the goal to achieve 15% efficiency in energy conversion; finally they are also working to prevent the electride degradation due to highly aggressive environment.
- Advanced Thermal Devices – a perfect cathode material candidate. Company devoted to high temp material research – started looking at C12A7 in 2013. The material is formed of 12 cage structure of a light metal oxide 7eV band gap, but processed into a semiconductor by replacing O ions with electrons. Synthesis developed – not easy given the complex phase diagram – have now demonstrated three phase process to produce 98% purity. A couple of months away from ideal electride recipe.
- Conclusions: C12A7:e- (electride) is a serious candidate as an electron emitting cathode for the ionization of multiple ion thruster models. The synthesis processes of the C12A7 base ceramic are key in obtaining high purity material and its subsequent transformation into electride. Operational conditions of long operation time have been fixed: - Temperature: up to 1050 ºC (recommended operation up to 1000 ºC) Maximum bombardment energy: 600 eV. There are clear advantages compared with traditional materials in terms of energy and operating temperature (ionization energy) and in terms of low degradation rate by passivation, oxidation or ion bombardment.
- So looks very good material for cathodes – keen for partners.

- Eduardo AHEDO, Universidad Carlos III de Madrid: HYPHEN
  - Universidad Carlos III Madrid presented their EP2 team as a well-recognized expert group in plasmas and space propulsion, simulation capabilities and developments (NOMADS 2D hybrid code, PIC code, electron fluid model), preliminary simulation results and EP2 vacuum facility.
  - HYPHEN is a multi-thruster simulation of EMT thrusters (Hall Effect and HEMPT, HPT, Vasimr etc.). It improves thruster physics understanding, optimize code development, and incorporates the experience of EP2 in: Axisymmetric (2D), hybrid (PIC-MC/fluid), modular, OMP-parallelized. HYPHEN will share structure and algorithms with EP2PLUS (3D hybrid code, focused on plumes), and will include our Magnetic Nozzle Physics models.
  - The code modular structure includes: Ion-module, Electron module, Wave module, Sheath module, Circuit module and Auxiliary full-PIC code for anisotropy and wall effects.
  - CHEOPS results are presented (20 hr for full simulation): Electron code heavily used – aiming to improve. HPT results too. Benchmarking against other 2D and 3D codes – good matches presented.

6.9 Session 8-9: New Strategies for EP Qualification and Entry Into Service (Chair: Neil Wallace, ESA)

- Cosmo CASAREGOLA, EuTelSat: EuTelSat Qualification Strategies
  - Eutelsat presented the company as satellite operator and its strategy, track and achievements regarding electric propulsion. They used and they will continue to use EP. EP has been a real added value.
  - Qualification activities are conducted to prove hardware (and software) meet specification requirements with adequate margin (ECSS-S-ST-00-01C). An adequate life test margin – a 1.5 factor has been historically used and accepted in the space industry for margins against wear.

- In Eutelsat, each equipment susceptible to noticeable wear, degradation, fatigue or creep during its projected lifetime shall be subjected to life test under conditions representative of their intended usage. Some reasons to maintain the 1.5 margin factor for EP: To cover the discrepancy between ground and flight performance/behaviour.
- Ideas for new qualification: Opportunity for satellite manufacturers and operators based on a substantial return of experience and on EP flight data; Faster bringing into use of new developments, e.g. accelerated life tests at higher power levels to reduce the life test duration could be envisaged instead of modifying the margin factor.

- Morten PAHLE, Vivet: Insurance of EP Systems
  - Insurances take whatever risk you do not want, desire or can't take. Insurances are familiar with failure, thus we understand the best we can support.
  - Insurance Underwriters and Brokers often have engineering background and/or employ engineers, but they cannot remain current on new technology. For them, understanding the technical risk is KEY.
  - EP as a friend: Improved lifetime margins possible without exorbitant mass penalties, reduced complexity propulsion system and possibility to implement redundancy relatively easily.
  - EP on the other hand: Increased reliance on the power subsystem which historically has been a source of failures, low thrust may be insufficient for fallback/emergency maneuvers, new technology may have less heritage and lower demonstrated reliability, mass savings on propulsion redeployed to complex payloads and increasingly complex missions with reduced flight heritage, and potentially poorly understood effects, e.g. plume impingement, surface charging, etc.
  - Insurer's concerns are related with global financial situation diversification, and product development is key for insurers to increase income.
  - Insurers would like to understand technologies better, impact of technologies on the systems in which they are installed, and propose to transfer risks not only to launch and sat operators, but even to manufacturers, integrators and investors.
  - Conclusions: Important to maintain an understanding of new and emerging technologies; Insurers want to provide the right product at the right price; Insurers want to support new technology, also because they hope to create income by doing this.

- Richard BLOTT, Space Enterprise Partnerships: Qualification of EP Systems
  - Mr. Blott presented its views on qualification of EP systems.
  - EP qualification also requires: Qualification to high (quantified) levels of confidence; and increasingly efficient, competitive (mass) production.
  - Qualification requirements are a successful demonstration of: performance, compatibility, robustness, endurance and reliability.
  - The great choice is to observe or predict (qualification based on observed (mainly test) results, or qualification using proven engineering performance prediction methods validated by test results).

- Hans LEITER, Ariane Group: Qualification of EP Systems
  - Ariane Group presents its capabilities and facilities at Lampoldshausen in EP.
  - Product qualification is required on 3 levels (component, subsystem and system); by comparison of key requirements (interfaces, functional & performance, environment, lifetime, EMC) reveals challenges and cost drivers for EP.

- Mastering the life time qualification is key for entrance into space and market: EP lifetime verification is a major driver for cost and schedule; EP lifetime test gives "felt" confidence, but no statistic confidence; Primes and operators considers full life time testing mandatory; Analytical life prediction is essential for risk mitigation. Key question: Can analytical life prediction replace life time tests?

- Mariano ANDRENUCCI, Sitael: Qualification of EP Systems
  - Note: No presentation on Qualification of EP Systems.

- Fabrizzio SCORTECCI, Aerospazio: Qualification of EP Systems
  - Aerospazio presents its capabilities and facilities for Qualification of EP Systems.
  - Electric Propulsion test services; Vacuum Test Facilities (LVTF-1, LVTF-2, MVTF-1, MVTF-2, MVTF-3&4); In-vacuum EMI/EMC Test Facility; Diagnostics are presented and an examples for HEMP-TIS Life test and Safran (PSS1350E, PSS5000) qualification are outlined.

Synthesis of Session 8 Roundtable on New Strategies for EP Qualification and Entry Into Service. Chairman: Neil Wallace (ESA).

1.- What is needed now?

Cosmo Casaregola, Eutelsat:

A mix of testing with simulation, but before, we need to know that the model and the test really fit the flight real performances. We need to understand the gap between flight measurements and test with the ground test and ground modelling. We need involvement in the stage of qualification; we need to see and to interact. Early involvement from the very beginning, if not we are losing an opportunity. Share results and take the opportunity to validate results. Invite primes to be involved. If we combine experience from all manufacturers we will gain.

Richard Blott, Space Enterprise Partnerships:

There is lack of standardization and methodology on testing. Proper measurement practice and to understand much better differences on test results in different test facilities and in addition with the results we have in space.

Mariano Andrenucci, Sitael:

The situation is very difficult, it is very dependent on the test chamber, and completely different than in space operation. Methodology: define a hypothetical reference case of test, defined as a reference for all test facilities, and second a correlation with the flight space operational conditions. We need to know how to correlate with reality and to understand the differences.

2. - Do you could support a collective collections of lessons learns?

Fabrizio Scortecci, Aerospazio:

Very difficult because we are in a competitive environment and systems from customers are very different, they want different ways. They are cautious of their own methodology and setups.

Hans Leiter, Ariane Group:

Customer can make very specific questions. Is EP hard to predict? This is not the case; all aspects need to be taken into account. We need tools to take all aspects into consideration, a common standard and a simulation tools to be developed to be used. We have to work to merge the test comparable with light.

Richard Blott, Space Enterprise Partnerships:

The problem is that there are problems or effects we do not know.

Audience, OHB:

About sharing methodologies and results: it is difficult and when we have a failure or an incident, that element is the most interesting to understand. We would need a simulation SW, Ecosim, from ESA, could be something similar: it collects the results of all the failures. Could it be?

Neil Wallace, ESA-PSA:

Let's establish a set of reference data to compare with and validate.

Cosmo Casaregola, Eutelsat:

Need to be validating the reality, and not validate the ground test and ground models. Sometimes we are ignoring the boundary conditions in the chamber with huge effect on the results.

Jose Gonzalez, ESA-PSA:

We started to collect data but the data is not available, sometimes not even from ESA participated missions. We just can use some of them. Try to standardize this is very difficult, the LSIs will not share data, perhaps this is too much but I ask to the LSIs here, too. Problem of sharing data for the qualification and between the private companies. Standardization of testing methods, and measurement of Thrust, Isp and mass flow are needed. Other measures are different measures methods.

Jorge Lopez, CDTI-PSA:

We have to measure and look to the future: the future is a proper simulation method. Instead of everyone going to the chamber, we'll have to move to simulators, slightly, continuously, now we have standard simulators. These simulators need to be compared and adapted with the ground simulators.

Fabien Castanet, CNES-PSA (also Technical authority chairman of ECSS):

If we have a good justification of the need for these standards, we will do them, but this shall be done with the agreement of industries and member states. Why not IOD/IOV experiment to correlate flight data with test data? Can we use IOD/IOV to create a dedicated experiment?

Mariano Andrenucci, Sitael:

Mr. Andrenucci says IOD/IOV experiment is not so useful.

He proposes to create a benchmarking facility not to be used for qualification to host EP thrusters in order to compare their behavior with that of the others and their behaviors with that of other facilities. We need simulation and modelling, but not for designing but to extrapolate long term behaviors. The confidence will grow in the future.

Nick Cox, UKSA-PSA:

Digital twins, delta qualifications based on simulations validated with test data, simulations, many are the potential techniques. Are the Insurer or the Operator interested in supporting such qualification approaches? .

6.10 Session 10: EP Technologies and Capabilities (Chair: Fabien Castanet, CNES)

- Ane AANESLAND, ThrustMe: Low-end Disruption & Delta-V Capability
    - ThrustMe is a spin out from the Ecole Polytecnique in France. The approach of the company is a vertical integration strategy focusing on multiple laboratories. They already include services: Thermal Management, Customized Electronic sys, Plasma and Beam diagnostics and Operational optimization.

- Products portfolio (3 products) from 0,1 to 12 mN: cold gas product I2T5 0,5U (ready); NPT30 1,5U ready; NPT300-AC 4U for mega constellations (targeting 2021 delivery).
- Products based on 3 main Innovations: use of iodine propellant, cathode for low power GIT, and AC acceleration for medium/high power GIT.
- Iodine propellant: solid, corrosion mitigation, surface passivation. The company continues to study and analyze the behaviour of iodine. The flow control is under patenting and control of flow rates is via controlled sublimation of iodine.
- NPT30-CD with Xenon with simple and robust cathode (first mission 2019). Discussion of DC (classic) and AC (ThustMe Technology) acceleration approach for the next step NPT30-AC at TRL 5.

- Mariano ANDRENUCCI, Sitael: Electric Propulsion: The Way Forward For A Spacefaring Future
  - SITAEL presented the high power electric propulsion case and its applications, the company activities and heritage on electric propulsion (HETs, development lines, high power HETs, and test facilities).
  - Space exploration is presented as the market for the High power Electric Propulsion. High power level needed for large trust levels; if we get closer to the sun probably solar array shall be flanked or substituted by nuclear power systems. Clustering is the solution for units from 0,1 to 1 MW power single thruster capability. The process is complex but we cannot do it with chemical propulsion. Ion Thrusters, Plasma (HET, HEMP, MPD), Arcjects, others (VASIMIR, Helicon) are proposed as potential solutions presenting performance maps.
  - High power HET development in NASA/USA (Arojet Rocketdyne) is a 12,5 KW HET thruster, the largest.
  - The high power HET thrusters development (20 kw Class) activities were explained in detail (TRP, design, test campaigns), and the planned activities based on a development model HT5K with its test campaigns and HT20K DM2 characterization. The activities are performed in a GSTP project and in the CHEOPS activity. The 20KW adding CHEOPS and GSTP programmes are well supported.
  - Conclusions: Provided that the necessary financial conditions are secured, SITAEL is ready to commit to make a 20 kW-class Hall thruster available for flight within the mid-2020s

- Mario MERINO, Universidad Carlos III de Madrid: Magnetic Nozzles
  - Magnetic Nozzles operate contactless, avoiding touching the hot plasma. Many plasma thrusters have a final acceleration based on a kind of magnetic nozzle.
  - A magnetic nozzle (MN) is a convergent-divergent magnetic field created by coils or permanent magnets to guide the expansion of a hot plasma, accelerating it supersonically and generating thrust. The MN works in a similar way to a traditional “de Laval” nozzle with a neutral gas.
  - The MN has the following advantages: It operates contact-less: we avoid touching the hot plasma; MN shape can be modified in-flight, by changing the coil currents; with more than one coil, we can create 3D magnetic configurations to deflect the plasma jet laterally.
  - DIMAGNO is a code for Magnetic Nozzles. FUMAGNO is another simulator that operates far from the detachment area of the plasma flux in the nozzle; it is 3D and can be used to modify the orientation. Both are open source. Other codes are: AKILES, VLASMAN (Non Stationary Boltzmann-Poisson solver).
  - Magnetic nozzles are a transversal technology used in many next-gen plasma thrusters as acceleration stage (Contactless operation, In-flight geometry modification (including 3d vectoring).

   - EP2 has modelled and studied magnetic nozzles for 10 years (Thrust generation mechanisms and energy conversion, Plasma detachment far downstream, Advanced phenomena: induced magnetic field effects, collisional and electron-inertial effects, collision-less cooling and anisotropization of electrons)
   - Codes are available to study magnetic nozzle flows: (quasi-1D, 2D and 3D; two-fluid, kinetic).

- Tommaso MISURI, Sitael: Low Power Hall Effect Propulsion Systems for Small Satellites
   - Description of EP SITAEL EP systems and small satellite platforms. Considering Low Power EPT, Sitael offers: HET, ElectroThermal Propulsion (resistojets), FEEP.
   - HET classes presented (HT100, HT400, HT5K, HT20K): 100W (IOD muHETsat, today 3500hrs, test with iodine, preparing for high production rates, magnetically shielded version in preparation), 400W (300-800W, PPU EM development, 600hrs today, extended endurance test), 5KW, 20KW.
   - Micro HET sat mission, single thruster, very complex and simplified, task to change orbit and then to deorbit itself. HC1 cathode status description.
   - Low Power Electrothermal Propulsion: SITAEL XR-150 Resistojet can work at power levels up to 150 W and can be operated with any non oxidizing propellant.
   - COMFIT: Field Emission Propulsion: COMFIT, Cesium. Nonhazardous propellant, key components made by additive manufacturing.
   - Conclusions: Importance of Low Power Electric Propulsion as: (Necessary technology to enable new missions by providing a high delta-V capability even to very small platforms, Mandatory element for all small satellites operating in LEO at least to carry out collision avoidance maneuvers and end-of-life disposal, Main propulsion system for smallsats operating in large constellations).
   - SITAEL Target: to have an adequate electric propulsion system for every small platform below 500 kg

- Angela ROSSODIVITA, Sitael: Hall Effect Thruster RAM-EP Concept
   - Air breathing EPS. The spacecraft engine ingests the atmospheric gasses, ionizes a fraction of them and accelerates the ions to higher velocity. The system does not require storing the propellant as with conventional electric propulsion. A collecting unit receives gas, compresses it and tan accelerates it through a HET.
   - The air-breathing EPS will allow to perform long duration LEO missions with less or no propellant. It can be used for very low Earth orbit missions such as earth observation, telecommunications, science missions.
   - The project has been supported by the ESA TRP. The present status has been simulated to test an orbit of 200Km altitude. Initially the company thought it could have been opportune to join with air a percentage of classic HET propellants (Xenon, Krypton etc.) but now they have enough experience to confirm they can operate only with air (probably apart from the ignition phase). Today the RAM is a spacecraft not exactly a subsystem, the TRL is 4 due to the testing in a relevant environment.
   - The roadmap for the RAM-EP concept is presented: (Design, MAI and test of the passive intake; Experimental validation of the Particle Flow Generator; Design, MAI and test of the air-breathing Hall effect thruster.

- Igal KRONHAUS, Israel Institute of Technology: Narrow Channel Hall Thruster for Nanosatellite Propulsion
   - Advantages and limitations of HET. Historically these thrusters were developed for hundred watts. Under 50W is traditionally a no-operating-region. Typically this is an aspect been linked to the

geometries of the thruster structures. Increasing the neutral gas density and reducing the voltage we reduce the ISP but we keep other parameters.

- The Narrow Channel Hall Thruster Concept (NCHT) is presented: Instead of following the dimensional scaling of a conventional HT h/dm = 1/6 the NCHT uses a ratio of 1/30; To reduce power a discharge voltage < 100 V is considered, taking into account that the electron-ion pair cost is about 40 eV; To reduce channel length and hence volume metal walls are preferred, i.e. TAL configuration; Assuming full ionization and a Hall thruster level ion current density a NCHT with 3 cm diameter channel can produce about 1 mN.
- The NCHT experimental model is presented together with the prototype testing and the performances figures. Next steps are outlined.
- Conclusions: A narrow channel Hall thruster in the 1 mN range was operated successfully between 15 and 30 W; during the measurement campaign a total operational time of about 100 h was accumulated. No significant pole erosion or performance degradation was observed.

- Francesco GUARDUCCI, Mars Space Ltd: Hollow cathodes, resistojets, GIE and pulsed plasma thrusters
  - Mars Space presented their developments and MSL laboratory: Ring cusp discharge chamber, Ion Optics Code Development, GIESEPP, LaB6 Cathodes, Hollow Cathodes, Alternative Cathode Designs, Micropropulsion: PPTCUP, Micropropulsion: NanoPPT and Minion, VHTR: Introduction and Performances.
  - Ring cusp discharge chamber; 23 different configurations tested. Simulated Ion Beam and cost, Langmuir Probe measurement. New study for the impact of HC design parameters on discharge chamber performance. Evaluations: Neutrals, primary electrons, plasma density, plasma potential, electron temperature. Ion optic code development with special features like multiple electrodes.
  - Role of MSL in GIESEPP OG participation mainly in simulation. New class of LaB6 cathodes.
  - Hollow Cathodes modelling activities, and 3D thermo mechanical model. Hollow cathode based on alternative insert material (C12A7:e- electride) for development of a dry neutraliser for Low Power Ion Engines in collaboration with ATD and on development of a diamond-based cold cathode in collaboration with Evince Ltd.
  - PPTCUP, a Pulsed Plasma Thruster for CubeSat Propulsion compliant with the CubeSat standard and with flight qualification completed. Nano PPT, designed to provide attitude and translation control on a 20 kg nano-satellite. Minilon NSTP-2 Project to develop Mini Ion Engine for high delta-V CubeSat missions.
  - Very High Temperature Resistojet with an innovative heater design and technology in order to maximize the overall thruster efficiency.

- Francesco TACCOGNA, CNR-Nanotec: Numerical modeling and diamond technology for electric propulsion at PLASMI Lab
  - EP activities in PLasmiLab
  - Database for gas/plasma elementary processes in bulk and on surfaces: freely available cross-sections; provides formulas and behaviors.
  - Electric propulsion virtual lab based on particle numerical simulations. Multiple numerical models (State-to-state neutral kinetics, Collisional-Radiative model, Particle-based models: PIC-DSMC, Fluid codes).

- Diamond base high efficiency cathode: CVD Diamond films ideal for electron emission. Micro nano particles of different sizes. The team was capable of increasing sensibly the quantum efficiency bringing them to patent the process.

- Bernhart SEIFERT, FOTEC Forschungs: Testing & Qualification of EP Thrusters
  - Company overview. Connection with University of Applied Sciences Wiener Neustadt and FOTEC Forschungs- und Technologietransfer GmbH.
  - The IFM nano thruster module is presented (key characteristics and PPU features): dynamic from 1 to 350 microN, 870 gr (wet), 2000-7000 s Isp, propellant mass up to 250 gr Indium, Total Impulse more than 5000 Ns. PPU features: emitter up to 10kV, up to 4 mA.
  - In orbit demonstration: continuous operation for 30 minutes at 2 mA emitter current, and good accordance between reference and measured current.
  - List of Testing facilities in house: vibration/shock table, thrust balance (verified with ESTEC/EPL), Plume characterization (Faraday Cups and RPAs, real time monitoring of beam divergence and deflection). Update rate up to 7Hz. Thermal Vacuum Tests.
  - The most important lessons learnt from the IOD was the fragility of our system. The thermal environment to be verified in IOD was fundamental. .

6.11 Session 11: EP Technologies and Capabilities (Chair: Peter Van Geloven, BELSPO)

- David HENRI, Exotrail: Exotrail HET thrusters for nano/microsats
  - EXOTRAIL is a spin off company founded in 2016 proposing ITAR free Hall Effect Thruster for small satellites and mission services for space industry, with the objective to develop a fully integrated miniaturized Hall Effect thruster prototype for 5 – 100 kg satellites.
  - Presentation of the company Exotrail: development in Paris region and mission design in Toulouse. Products: HET systems for orbit raising and very low earth orbit station keeping (300 km), cathodes and ExoOps, propulsion mission and operation software.
  - After prototyping, manufacturing, AIT and testing at subsystem level, the complete thruster characterization is planned for 2019 (with interest for IOD demonstration of the complete system), with R&D optimizations started in parallel for a scale up version in 2020 to be time to market.
  - ExoMG – nano 1mN, 40W, 900s and micro 5mN, 100W, 1000s (performance simulated, not tested), first deliveries 2020. Cathodes MID, MINI and SMALL work with nano and micro.
  - Philosophy: reduce costs by using non-space components in-house qualified. Modular, integrated approach for the thruster systems.
  - ExoOps: Propulsion Mission & Operation software.

- Kevin HALL, QinetiQ: GIESEPP 2 and QinetiQ updates (T5, 6, 7)
  - QinetiQ presented the company heritage in electric propulsion, its GIEs (T5 – 700 W, T6 – 5 kW, T7 - up to 7 kW) and the advantages of GIEs (high fuel efficiency: Isp ~ 4000s, wide operating envelope, wide throttling range, narrow beam divergence).

- QinetiQ participation in GIESEPP is enabling QinetiQ to develop a T7 Ring Cusp variant of its Gridded Ion Engine technology - improving performance and reducing cost to meet market needs.
- Products: cathodes up to 50A, GIE thrusters T5 (700W, Kaufman) to be industrialised in GIESEPP, T6 (5kW, Kaufman) and T7 (5-7kW, Ring-cusp-thruster) designed in GIESEPP.
- Market applications: constellations in LEO, MEO and GEO to be addressed by all products; in orbit servicing, space tugs.
- Qualification and acceptance: lessons learned to improve current approach, importance of sharing data, attempt to reduce scope of testing, etc. Same problem for delta qualification and acceptance test campaign. QinetiQ welcomes the opportunity to work with peer group to streamline qualification: thruster suppliers, modelling experts and space agencies.
- Conclusion 1: Market for Electric Propulsion technology is increasing (Increasing uptake in the traditional GEO telecom satellite market, as well as for orbit raising function, Adoption for satellite constellations, Continued use for interplanetary missions, Enabling new applications such as space transportation, in-orbit servicing and new/novel LEO application).
- Conclusion 2: GIEs, such as QinetiQ's T-series, offer the greatest fuel efficiency options to customers (Industrialisation is driving costs down, from its science applications heritage). H2020 project GIESEPP is helping Qinetiq to improve competitiveness in global market. Further work required on developing a lower cost approach to Qualification and Acceptance (QinetiQ welcomes the opportunity to discuss optimisation of the approach taken).

- Aaron KNOLL, Imperial College London: New Research Capability
    - Description of the capabilities, team and facilities of Imperial College London laboratory.
    - The presenter worked previously for Surrey.
    - Presentation in detail of the Research activities: VeX Vectorable Cross-Field Thruster, Quad Confinement Thruster, RF initiated hollow cathode and power electronics, Hybrid Chemical Electric Thruster, ICE Cube thruster.
    - Detailed description of the ICE Cube thrusters (An experimental concept realization of a high specific impulse, low thrust chemical bipropellant micro-thruster system featuring electrolysis propellant capture and catalytic combustion) and the Quad Confinement Thruster (QCT) (in orbit demonstration on NovaSAR).

- W. van Meerbeck, Bradford Engineering: Development of Electric Propulsion Solutions for LEO & GEO Platforms
    - Bradford Engineering BV presented: its heritage and standard designs in PR Systems and FCUs; the next-generation FMSs goals for GEO/NAV: high-reliability, 30% cost reduction / 4-8 thruster architecture; and goals for MEGA/LEO: low-cost, tailored-reliability, <100-200 kEuro, 1-2 thruster architecture.
    - The Bradford Engineering BV subsystems developments are focused on: functions combination and components similar & affordable. At component level their activities are focused on: development of next generation pressure transducers and design/qualification of alternative valves.
    - Development in the frame of CHEOPS: combined pressure regulation and flow control units for size and cost reduction. Pressure transducer evolution: miniaturization and use of proportional valves. Significant mass reduction.

   - LEO Flow Management System (FMS) design description and performance test data: confirmed feasibility of the LEO FMS single stage pressure reduction and flow control concept. The initial performance test data are presented. Next steps: Final integration and Testing (Q1 2019)
   - GEO FMS baseline design and main characteristics are presented to enable dual operation mode.

- Chloe BERENGER, Dedalos: Characterization and Optical Diagnostics of Air Breathing Electric Thrusters by 4CDGM
   - 4CDGM, a four initial components (O, O_2 , N, N_2) is a volume averaged detailed global model meant to analyze the functioning of Electric Thrusters (ET) of Air-Breathing Electric Thrusters (ABET) type, to foresee the plasma constitution and to diagnose it by Optical Emission Spectroscopy (OES). Towards this aim, 4CDGM provides Plasma Component Composition (PCC), Functioning Diagrams (FD) and theoretical atomic line intensities with the adequate model allowing for Optical Emission Spectroscopy (OES) diagnostics.
   - Results of 4CDGM are presented consisting of: Density of species, containing PCC and concomitant diagrams; A pressure depending FD; Typical oxygen & nitrogen theoretical emission spectra, leading to Optical Emission Spectroscopy (OES) diagnostics.
   - Conclusions: 4CDGM allows for ET feeding by an adequate O_2 / N_2 mixture on ground, to replace the cumbersome AtR one. It leads to experimental results equivalent to those obtainable by AtR feeding; Plasma containing neutral and ionized species created in case of ETs fed by AtR allow for OES; After including in 4CDGM extended sets of nitrogen and of oxygen data, encompassing the main N I – III and O I – III levels, better description of the atomic and molecular structure effects and of the chemical reactions was obtained.

- Filippo CICHOKI, Universidad de Carlos III: EP2PLUS
   - Universidad Carlos III Madrid presented their EP2 team as a well-recognized expert group in plasmas and space propulsion, their participation in different projects.
   - EP2PLUS description of the code: it permits computing electric currents and electric potential correction due to both collisions and magnetization. Main characteristics: Hybrid PIC/fluid code; 3D code - asymmetric physics simulation; Industry-level standards. Most distinguishing features: Electron model enables the computation of both electric currents and magnetic field effects; Non-neutral code; Deformed structured meshes; Easily adaptable to full-PIC.
   - The magnetized electron fluid model is explained and the benchmark simulations for the electron model are presented (Gridded ion thruster plume neutralization and Plasma plume expansion with a uniform background magnetic field).
   - Deformed mesh algorithms and applications are presented to enable new types of simulations.
   - Conclusions: EP2PLUS electron fluid model permits computing (Electric currents and Electric potential correction due to both collisions and magnetization); Benchmark simulations for the electron model (Neutralization of the current in an unmagnetized GIT plume, Effects of a uniform background magnetic field on plume expansion); Newly developed deformed meshes extend the applications of the code
   - Future work: Study of the near plume of HETs, HEMPTs and asymmetric magnetic nozzles; Study of the grid optics of an ion thruster; and Full-PIC simulations of the plume expansion.

- Peter KLAR, University of Gießen: Optimising Molecular Propellants for Ion Thrusters
   - Description of the capabilities and activities in University Gießen and DLR Göttingen.

- Limitations of atomic propellants. Selection criteria: high mass, easy handling, efficient ionization, no energy loss channels, availability and costs.
- Conclusions: There is no perfect atomic propellant. Choice depends on mission requirements; There are only about 100 chemical elements, but an infinitely large number of molecules.
- Criteria for classifying molecules as propellant. Challenges: Fragmentation of molecules inside the plasma, many species inside the plasma, high degree of complexity.
- Evaluation process requires special testing facilities and main challenges are described.
- Iodine propellant is presented with properties and performances (diatomic molecule): performance at low mass flow better than Xenon.
- Diamondoids: ionization energy very low, so electrons can be extracted easily, but fragmentation energy is only slightly higher: performance worse than Xenon.
- Fast screening of molecular propellants to check suitability.
- Future strategy: increase the gap between ionization energy and fragmentation energy, towards larger molecules optimized by modification and screening.

- Alexander REISSNER, ENPULSION: A Brief History of FEEPs - From Research to In-Orbit Results, Series Production and the Future of Space Mobility
    - ENPULSION is a start-up founded in 2016 stemming from FOTEC, a research subsidiary of University of Applied Science in Wiener Neustadt. It makes research and builds FEEP (single spiked or multi spiked). The thruster is named IFM and has different sizes and performances.
    - Additionally, taking example from airplane and automotive industries, and thrusting an increasing trend in the market of CubeSat's, ENPULSION is developing a system which is able, with a ramp, to manufacture in house up to 500 FEEP units per year. They are establishing a production line for more than 100 thrusters per years. Since 2018 two IFM nano thrusters per week.
    - Main points are the definition of methods and procedures to test this high amount of engines and make it match the strict PA rules for space. Integrated design, thrust vectoring, no overheating and inert safe launch. Disruption of the system is not the technology but the architecture of the satellite, because there is no tank.
    - Future: ENSPACE new company – Brand for unlimited mobility. VEXEL concept is presented as a a set of several EPS systems for orbit raising attached to the satellite only during the orbit raising phase with a service mode (high power and high thrust) and a cruise mode (low power and high Isp). Also for orbit lowering and de-orbiting. Usable several times, as a space tug.

6.12 Workshop Conclusions

- José GONZÁLEZ DEL AMO, ESA: EPIC Workshop conclusions

These were the main conclusions presented at the end of the Workshop:

- In order to improve the trust of the customer and reduce the qualification time (1.5 times the operation time), it is important to have more flight experiences and work on the design, modelling and specific testing.

- There is a gap between the flight data and the ground data that has to be understood better as a consequence of the use of vacuum facilities on ground; to understand this issue it is important to share information, but this is difficult due to the current competitive environment.
- The differences in the results of ground testing between different vacuum facilities reduce the trust of the customers. A test bench accepted at European level and the standardisation of the test methods would help to resolve this issue.
- The different OGs have shown a good progress that has to be maintained to finalise the work of phase 1 successfully.
- Insurers and operators have stated that workshops like EPIC help to build trust between investors, operators, primes and Electric propulsion developers.
- During the insurers' presentation, it was shown that Electric propulsion spacecraft had only few amount of failures.
- A great interest from the community was shown during the EPIC workshop and many proposals for the disruptive call are expected.
- Electric Propulsion saved missions such as Artemis or AHLF.
- Constellations is the NEW IMPORTANT market and the time to market is short, thus we need to accelerate the developments of these engines and, at the same time, provide flight opportunities for the electric propulsion systems required by these constellations.
- Milli-Newton thrusters, High power thrusters, air-breathing propulsion systems, FEEPs, new propellants, cathode-less thrusters, GaN materials for power electronics, etc. are some of the main subjects presented during the workshop.

7 WORKSHOP FACTS AND FIGURES

The EPIC Workshop 2018 was performed in two and half days of intensive work and interactions, with 56 presentations and 47 speakers. The Workshop had 164 participants from more than 10 countries, all from the European electric propulsion community, including the main space stakeholders in Europe. European participants came from: EC, REA, ESA, Space National Agencies, main Satellite Large System Integrators, main Satellite Operators, main Propulsion Subsystem Integrators, equipment industry, research institutions, universities, and industry associations.

Figure 7.1: EPIC Workshop 2018 participation

Figure 7.2: EPIC Workshop 2018 sessions and presentations

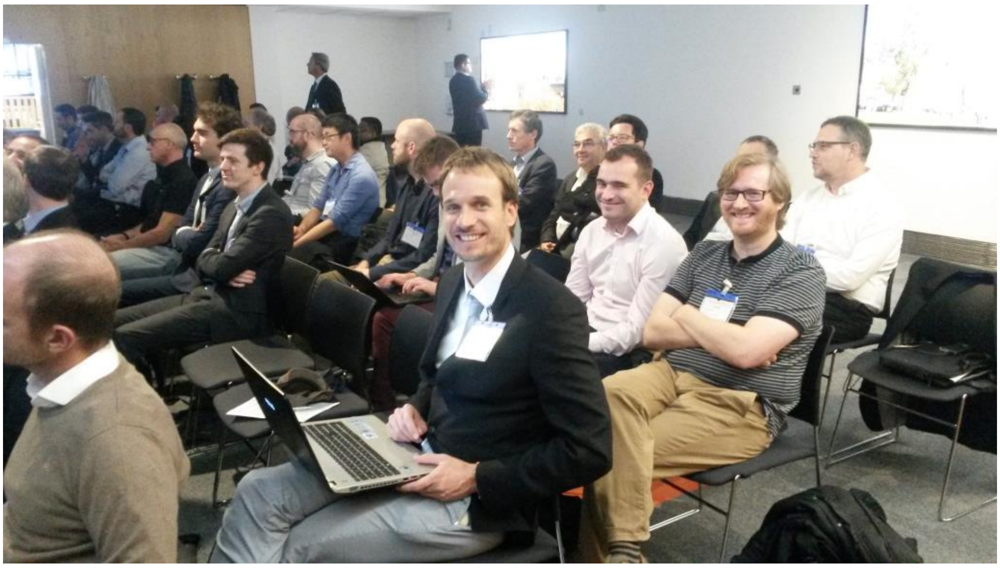

Figure 7.3: Experts and attendees during the EPIC Workshop 2018

Figure 7.4: EC, REA and EPIC PSA Teams at the EPIC Workshop 2018

Figure 7.5: EPIC Workshop 2018 Poster

The future EPIC Workshop will be organized in 2019 in ESTEC. The preparation had already started for the one to be held in The Netherlands in October 2019 in full coordination with REA, EC, and all SRC OGs under the SRC Collaboration Agreement [RD2]. Further details on the EPIC Workshop 2019 will be published soon at: http://epic-src.eu/workshop-2019/

8 CONCLUSIONS

One of the main objectives of the EPIC PSA is to disseminate its progress and results, and to contribute to the dissemination of the SRC results'. The dissemination activities are been implemented following the EPIC PSA Dissemination plan [RD1] in close coordination with all Operational Grants under the SRC Collaboration Agreement (CoA) [RD2], and the most important dissemination activity during the fourth year was the EPIC Workshop 2018.

This document aims at reporting in detail the organization, results and conclusions of the EPIC Workshop 2018 (Workshop 4) organized by UKSA and held on 15-17 October 2018 in London, United Kingdom; with the active involvement of all PSA Partners (http://epic-src.eu/workshop-2018/).

The main objective of the EPIC Workshops is to present the Horizon 2020 Electric Propulsion SRC activities to the electric propulsion community and stakeholders and to collect and assess the latest electric propulsion technology developments in Europe. EPIC Workshops are the fundamental element of the SRC dissemination of SRC activities, and the collection of information for the EPIC SRC Roadmap.

The EPIC Workshop 2018 was performed in two and half days of intensive work and interactions, with 56 presentations and 47 speakers. The Workshop had 164 participants from more than 10 countries, all from the European electric propulsion community, including the main space stakeholders in Europe. European participants came from: EC, REA, ESA, Space National Agencies, main Satellite Large System Integrators, main Satellite Operators, main Propulsion Subsystem Integrators, equipment industry, research institutions, universities, industry associations, and insurance companies.

9 ANNEX 1: WORKSHOP'S PROGRAMME

EPIC WORKSHOP 2018

Westminster Conference Centre, 1 Victoria Street, London SW1H 0ET

AGENDA / FINAL PROGRAMME: MONDAY 15TH OCTOBER 2018

12:00	**Registration & Coffee**	
13:15	Introduction, and organization logistics	Nick Cox, UK Space Agency
13:30	PSA Welcome, and EPIC Workshop Objectives	Jose Gonzalez Del Amo, ESA
SESSION 1: PSA Updates and Programmatics **Chair: Nick Cox, UK Space Agency & Co-Chair: Lisa Martin-Perez, DLR**		
13:50	H2020 and EP SRC, Next Work Programmes	Tanja Zegers, European Commission
14:10	SRC activities and Operational Grants	Florence Beroud, REA
14:30	2019 Disruptive Call Details and Guidelines	Jorge Lopez Reig, CDTI
14:50	EPIC PSA and activities	Jose Gonzalez Del Amo, ESA
15:10	IOD / IOV	Jean-Michel Monthiller, European Commission
15:30	**Coffee Break**	
Session 2: SRC Project Updates Part I **Chair: Jose Gonzalez Del Amo, ESA & Co-Chair: Vincenzo Pulcino, ASI**		
15:45	CHEOPS	Idris Habbassi, Safran Aircraft Engines
16:20	GIESEPP	Cyril Dietz, Ariane Group
16:55	HEMPT-NG	Ernst Bosch, Thales Deutschland
17:30	**DAY 1 CLOSE**	

HORIZON 2020

EPIC

EPIC WORKSHOP 2018

Westminster Conference Centre, 1 Victoria Street, London SW1H 0ET

AGENDA / FINAL PROGRAMME: TUESDAY 16TH OCTOBER 2018

08:30	**Registration & Coffee**	

09:00	Welcome Remarks	Nick Cox, UK Space Agency

Session 3: SRC Project Updates Part II Chairs: Vincenzo Pulcino, ASI & Co-Chair: Fabien Castanet, CNES		
09:10	GANOMIC	Louis Grimaud, Safran
09:45	Hiperloc-EP	John Stark, Queen Mary University London
10:20	MINOTOR	Denis Packan, ONERA
10:55	EPIC PSA and activities (TBC)	Jose Gonzalez Del Amo, ESA

11:15	**Coffee Break**	

11:30	**Keynote Speech**	**Alan Bond, Reaction Engines**

Session 4: Electric Propulsion Technologies for Small Satellites and New Markets Chair: Giorgio Saccoccia, Propulsion & Aerothermodynamics Head, ESA & Co-Chair: Fabien Castanet, CNES		
12:00	Cubesats	Sabrina Corpino, Turin Politecnico
12:10	OneWeb Constellation	Paolo Bianco, Airbus DS
12:20	LEO Sat Constellation	Steven Austin, TAS-UK
12:30	New EP Applications	Marco Villa, Tyvak
12:40	CubeSats	Craig Clark, Clyde Space
12:50	Emerging Technologies and Applications	Andrea Luccafabris, Surrey Space Centre

13:00	**LUNCH BREAK**	

Session 5: Electric Propulsion Technologies for Small Satellites and Emerging Applications Panel Discussion Chair: Giorgio Saccoccia, Propulsion & Aerothermodynamics Head, ESA & Co-Chair: Fabien Castanet, CNES		
14:00	Cubesats	Sabrina Corpino, Turin Politecnico
	OneWeb Constellation	Paolo Bianco, Airbus DS
	LEO Sat Constellation	Steven Austin, TAS-UK
	New EP Applications	Marco Villa, Tyvak
	CubeSats	Craig Clark, Clyde Space
	Emerging Technologies and Applications	Andrea Luccafabris, Surrey Space Centre

Session 6: EP Technologies and Capabilities Chair: Lisa Martin-Perez, DLR & Co-Chair: Vincenzo Pulcino, ASI		
14:45	The CO2DGM for CO2-breathing thrusters	Konstantinos Katsonis, DEDALOS Ltd
15:00	Disruptive Electric Propulsion at IRS	Georg Herdrich, University of Stuttgart
15:15	Plasma Jet Pack (PJP) Technology Overview	Luc Herrero, COMAT
15:30	ICE^3	Alberto Garbayo, AVS
15:45	MPD Technology	Manuel la Rosa Betancourt, Pintegral Solution

16:00	**COFFEE BREAK**

Session 7: EP Technologies and Capabilities (Continued) Chairs: Jorge Lopez Reig, CDTI & Co-Chair: Nick Cox, UK Space Agency		
16:15	Helicon O-plasma Thruster experimental platform	Mercedes Ruiz, Sener
16:30	Test campaign results for AQUAJET and XMET	Daniel Staab, AVS UK
16:45	Novel cathodes and alternative propellants for EP	Steven Gabriel, University of Southampton
17:00	Microfluidic flow control for next NG HEMP thrusters	Jens Haderspeck, TAS Deutschland
17:15	GEO Dual Mode PPU and LEO HEMPT PPU	Eric Bourgignon, TAS-Belgium
17:30	IMPULSE	Angelo Grubisic, University of Southampton
17:45	ALPHIE	Luis Conde, UPM Spain
18:00	Novel electrode material C12A7	Angel Post, AT Devices
18:15	HYPHEN	Eduardo Ahedo, Universidad Carlos III de Madrid

18:30	**COCKTAIL NETWORKING EVENT** **SPONSORED BY THALES ALENIA SPACE UK**

HORIZON 2020

EPIC

EPIC WORKSHOP 2018

Westminster Conference Centre, 1 Victoria Street, London SW1H 0ET

AGENDA / FINAL PROGRAMME: WEDNESDAY 17TH OCTOBER 2018

09:30	**Registration & Coffee**	

10:00	Welcome Remarks	Nick Cox, UK Space Agency

Session 8: New Strategies for EP Qualification and Entry Into Service: **Chair: Neil Wallace, ESA & Co-Chair: Jorge Lopez Reig, CDTI**		
10:10	EuTelSat Qualification Strategies	Cosmo Casaregola, EuTelSat
10:25	Insurance of EP Systems	Morten Pahle, Vivet
10:40	Qualification of EP Systems	Richard Blott, Space Enterprise Partnerships
10:55	Qualification of EP Systems	Hans Leiter, Ariane Group
11:10	Qualification of EP Systems	Mariano Andrenucci, Sitael
11:25	Qualification of EP Systems	Fabrizzio Scortecci, Aerospazio

11:40	**COFFEE BREAK**	

Session 9: New Strategies for EP Qualification and Entry Into Service: **Panel Discussion** **Chair: Neil Wallace, ESA & Co-Chair: Jorge Lopez Reig, CDTI**		
12:00	EuTelSat Qualification Strategies	Cosmo Caselagari, EuTelSat
	Insurance of EP Systems	Morten Pahle, Vivet
	Qualifiction of EP Systems	Richard Blott, Space Enterprise Partnerships
	Qualifiction of EP Systems	Hans Leiter, Ariane Group
	Qualifiction of EP Systems	Mariano Andrenucci, Sitael
	Qualifiction of EP Systems	Fabrizzio Scortecci, Aerospazio

12:45	**LUNCH BREAK**	

Session 10: EP Technologies and Capabilities Chair: Fabien Castanet, CNES & Co-Chair: Vincenzo Pulcino, ASI		
13:30	Low-end Disruption & Delta-V Capability	Ane Aanesland, ThrustMe
13:45	Electric Propulsion: The Way Forward For A Spacefaring Future	Mariano Andrenucci, Sitael
14:00	Magnetic Nozzles	Mario Merino, Universidad Carlos II de Madrid
14:15	Iodine Propellant for future space missions	Franz Georg Hey, Airbus-DS Deutchland
14:30	Low Power Hall Effect Propulsion Systems for Small Satellites	Tommaso Misuri, Sitael
14:45	Hall Effect Thruster RAM-EP Concept	Giovanni Cesaretti, Sitael
15:00	Narrow Channel Hall Thruster for Nanosatellite Propulsion	Igal Kronhaus, Israel Institute of Technology
15:15	Hollow cathodes, resistojets, GIE and pulsed plasma thrusters	Francesco Guarducci, Mars Space Ltd
15:30	PLASMI Lab	Grazia Cicala, CNR-Nanotec
15:45	Testing & Qualification of EP Thrusters	Bernhart Seifert, FOTEC Forschungs

16:00	**COFFEE BREAK**

Session 11: EP Technologies and Capabilities Chair: Peter Van Geloven, BelSpo & Co-Chair: Lisa Martin-Perez, DLR		
16:15	Exotrail HET thrusters for nano/microsats	David Henri, Exotrail
16:30	GIESEPP 2 and QinetiQ updates (T5, 6, 7)	Kevin Hall, QinetiQ
16:45	New Research Capability	Aaron Knoll, Imperial College London
17:00	ARTES Developments	Michel Poucet, Bradford Space
17:15	4CDGM	Chloe Berenger, Dedalos
17:30	EP2PLUS	Filippo Cichoki, Universidad de Carlos III
17:45	Optimising Molecular Propellants for Ion Thrusters	Peter Klar, University of Gießen
18:00	A Brief History of FEEPs - From Research to In-Orbit Results, Series Production and the Future of Space Mobility	Alexander Reissner, ENPULSION
18:15	**WORKSHOP CONCLUSIONS**	**Jose Gonzalez Del Amo**

18:15	**WORKSHOP CLOSE**

10 ANNEX 2: LIST OF ATTENDEES

Surname	First Name	Qty	Ticket Type
Aanesland	Ane	1	Speaker
AHEDO	EDUARDO	1	Delegate Ticket
Ahmad	Muhammad	1	Delegate Ticket
Andrenucci	Mariano	1	Speaker
APPEL	LEONID	1	Delegate Ticket
Austin	Steven	1	Speaker
Balika	Lahib	1	Delegate Ticket
Becker	Ralf	1	Delegate Ticket
Berenguer	Chloe	1	Speaker
Beroud	Florence	1	Speaker
Bianco	Paolo	1	Speaker
Blanchet	Antoine	1	Delegate Ticket
Blanco-Maceiras	Ramón	1	Delegate Ticket
Blott	Richard	1	Speaker
Bond	Alan	1	Speaker
BONIFACE	Claude	1	Delegate Ticket
Bosch	Ernst	1	Speaker
Bourguignon	Eric	1	Speaker
Bridot	Eric	1	Speaker
CAMARES	HERVE	1	Delegate Ticket
camonita	giuseppe	1	Delegate Ticket
camonita	giuseppe	1	Delegate Ticket
Cesaretti	Giovanni	5	Delegate Ticket
Cicala	Grazia	1	Speaker
Cichoki	Filippo	1	Speaker
Clark	Stephen	1	Delegate Ticket

Surname	First Name	Qty	Ticket Type
Clark	Craig	1	Speaker
Coletti	Michele	1	Delegate Ticket
Conde	Luis	1	Speaker
Conde López	Luis	1	Delegate Ticket
Corpino	Sabrina	1	Delegate Ticket
Cortado	Sabrina	1	Speaker
Cox	Nick	1	Speaker
Curtis-Rouse	Mike	1	Delegate Ticket
Daudois	Ludovic	1	Delegate Ticket
de Boissieu	Jean-Baptiste	1	Delegate Ticket
Degremont	Julien	1	Delegate Ticket
Deleuze	Ignacio	1	Delegate Ticket
Derntl	Andreas	1	Delegate Ticket
Devereaux	Andy	1	Delegate Ticket
Dietz	Cyril	1	Speaker
Fabien	CASTANET	1	Delegate Ticket
Feili	Davar	1	Delegate Ticket
Franke	A	1	Delegate Ticket
Fraselle	Stephane	1	Delegate Ticket
Gabriel	Steve	1	Speaker
Garbayo	Alberto	1	Speaker
Garcia	Vincent	1	Delegate Ticket
Garrigos	Ausias	1	Delegate Ticket
GAUTHIER	LAURENT	1	Delegate Ticket
Gibbon	Dave	1	Delegate Ticket
Girardin	Maxime	1	Delegate Ticket
Girault	Philippe	1	Delegate Ticket
Gollor	Matthias	1	Delegate Ticket
Golosnoy	Igor	1	Delegate Ticket

	Surname	First Name	Qty	Ticket Type
☐	Gomez	Victor	1	Delegate Ticket
☐	GONZALEZ DEL AMO	JOSE ANTONIO	1	Delegate Ticket
☐	Grabulosa Lesniowski	Jaume	1	Delegate Ticket
☐	Grey	Andy	1	Delegate Ticket
☐	Grimaud	Louis	1	Speaker
☐	Grubisic	Angelo	1	Speaker
☐	Guarducci	Francesco	1	Speaker
☐	Gurciullo	Antonio	1	Delegate Ticket
☐	Habbassi	Idris	1	Speaker
☐	Haderspeck	Jens	1	Speaker
☐	Hall	Kevin	1	Speaker
☐	Hayder	Syed Jafir	1	Delegate Ticket
☐	Henri	David	1	Delegate Ticket
☐	Herdrich	Georg	1	Speaker
☐	Herrero	Luc	1	Delegate Ticket
☐	Herrero	Luc	1	Speaker
☐	HERSCOVITZ	JACOB	1	Delegate Ticket
☐	Hey	Franz	1	Speaker
☐	Hoffman	David	1	Delegate Ticket
☐	Holtmann	Peter	1	Delegate Ticket
☐	Horgan	Ryan	1	Delegate Ticket
☐	Iles	Mick	1	Delegate Ticket
☐	Ingram	Daniel	1	Delegate Ticket
☐	Janhunen	Pekka	1	Delegate Ticket
☐	Jarvis	Rhys	1	Delegate Ticket
☐	Jennings	Oscar	1	Delegate Ticket
☐	Jethani	Vivek	1	Delegate Ticket
☐	Katsonis	Konstantinos	1	Speaker
☐	Kazeminejad	Shahin	1	Delegate Ticket

	Surname	First Name	Qty	Ticket Type
☐	King	Charlotte	1	Delegate Ticket
☐	Klar	Peter	1	Delegate Ticket
☐	Knoll	Aaron	1	Speaker
☐	Koppel	Christophe	1	Delegate Ticket
☐	Kronhaus	Igal	1	Speaker
☐	Kyle-Henney	Stephen	1	Delegate Ticket
☐	La Rosa Betancourt	Manuel	1	Delegate Ticket
☐	Lamotte	Philippe	1	Delegate Ticket
☐	Leiter	Hans	1	Speaker
☐	LEV	DAN	1	Delegate Ticket
☐	Liénart	Thomas	1	Delegate Ticket
☐	Liu	Junjie	1	Delegate Ticket
☐	Lopez	Jorge	1	Speaker
☐	lopez	Eric	1	Delegate Ticket
☐	Maldonado	Pablo	1	Delegate Ticket
☐	Malik	Mobin	1	Delegate Ticket
☐	MANESSE	Noelle	1	Delegate Ticket
☐	Marcozzi	Massimiliano	1	Delegate Ticket
☐	Maria	Jean-Luc	1	Delegate Ticket
☐	Marshall-Bailey	Charlotte	1	Delegate Ticket
☐	Martin Perez	Lisa	1	Delegate Ticket
☐	Massotti	Luca	1	Delegate Ticket
☐	Merino	Mario	1	Speaker
☐	Mine	Pierre-Olivier	1	Delegate Ticket
☐	Misuri	Tommaso	1	Speaker
☐	Muir	Charles	1	Delegate Ticket
☐	Neumann	Andreas	1	Delegate Ticket
☐	Obrusnik	Adam	1	Delegate Ticket
☐	Packan	Denis	1	Speaker

	Surname	First Name	Qty	Ticket Type
☐	Pahle	Morten	1	Speaker
☐	Panarotto	Massimo	1	Delegate Ticket
☐	Pavone	Rosario	1	Delegate Ticket
☐	Pei	Xiaoze	1	Delegate Ticket
☐	Perez Luna	Jaime	1	Delegate Ticket
☐	Pessana	Mario	1	Delegate Ticket
☐	Petkow	Dejan	1	Delegate Ticket
☐	Peukert	Markus	1	Delegate Ticket
☐	Pinto	Fernando	1	Delegate Ticket
☐	Post	Angel	1	Speaker
☐	Potterton	thomas	1	Delegate Ticket
☐	Poucet	Michel	1	Speaker
☐	Prin	Coralie	1	Delegate Ticket
☐	Pulcino	Vincenzo	1	Delegate Ticket
☐	RAMETTE	PHILIPPE	1	Delegate Ticket
☐	Reid	Bryan	1	Delegate Ticket
☐	Reissner	Alexander	1	Delegate Ticket
☐	Richardson	Barbara	1	Speaker
☐	Robinson	Matthew	1	Delegate Ticket
☐	RODRIGUEZ	Javier	1	Delegate Ticket
☐	Ruiz	Mercedes	1	Delegate Ticket
☐	Ryanryan	charlie	1	Delegate Ticket
☐	Saccoccia	Giorgio	1	Delegate Ticket
☐	SCHILDER	SHLOMO	1	Delegate Ticket
☐	Schwertheim	Alexander	1	Delegate Ticket
☐	Scortecci	Fabrizio	1	Speaker
☐	Seifert	Bernhard	1	Speaker
☐	Sharbash	Omar	1	Delegate Ticket
☐	Shaw	Peter	1	Delegate Ticket
☐	SIVIS WUTA	DODO	1	Delegate Ticket
☐	Smith	Kate	1	Delegate Ticket
☐	Staab	Daniel	1	Speaker
☐	Stark	John	1	Speaker
☐	Stefan	Dr. Weis	1	Delegate Ticket
☐	Taccogna	Francesco	1	Delegate Ticket
☐	Tahiri	Armaan	1	Delegate Ticket
☐	Thibaut	François-Xavier	1	Delegate Ticket
☐	Toor	Mohammad Ahmad	1	Delegate Ticket
☐	van Put	Patrick	1	Delegate Ticket
☐	Varastet	Frederic	1	Delegate Ticket
☐	Vial	Vanessa	1	Delegate Ticket
☐	Wallace	Neil	1	Speaker
☐	Wollenhaupt	Birk	1	Delegate Ticket
☐	Zafar	Kamran	1	Delegate Ticket
☐	Zain	Muhammad	1	Delegate Ticket
☐	Zegers	Tanja	1	Speaker
☐	Zikan	Petr	1	Delegate Ticket

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