HORIZON 2020

EPIC

Report

D5.10
Workshop 5 Report 2019

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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 2019 (ESA-ESTEC) as part of the activities performed in by the EPIC PSA regarding Dissemination, (Task T5.1) during the last year of execution of the original project EPIC. 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 D5.10: *Workshop 5 Report 2019*.

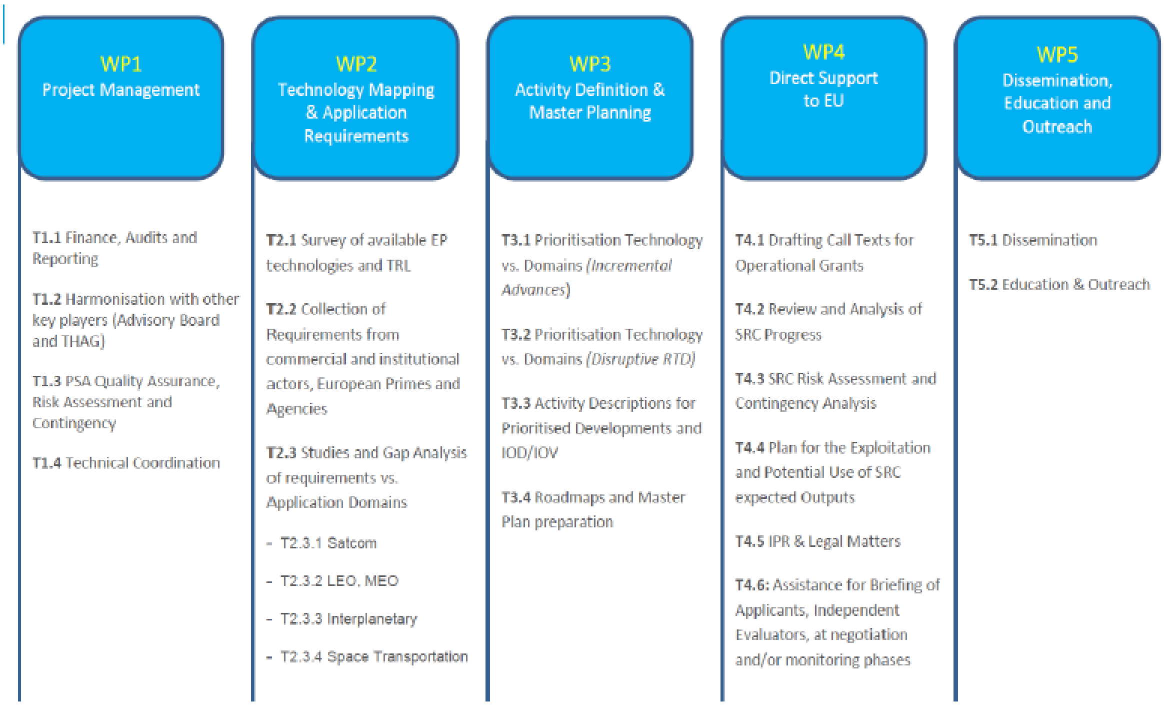

Figure 1.1: EPIC Work Package Structure

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)
[RD6] EPIC-CDTI-5.1-RP-D5.9 Workshop 4 Report (London 2018)

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 WORKSHOPs

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 4th was organised by UKSA in London 15-17 /10/ 2018 (http://epic-src.eu/workshop-2018/). The 5th and last workshop of H2020 was organised by ESA in Noordwijk (ESTEC) 21-23 October 2019 (http://epic-src.eu/workshop-2019/).

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), has been further achieved during next EPIC Workshops (Madrid in 2017, London in 2018, Noordwijk (ESTEC) in 2019); where dissemination has been organized to communicate on the roadmap implementation and give a periodic status of the situation to all stakeholders interested. EPIC team has ensured 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. The two next workshops for the PSA extension EPIC-2 have been announced and will be held by DLR in Cologne in 2021 and ASI in Napoli in 2022.

The EPIC Workshop 2019 was organized by ESA and held on 21-23 October 2019, at ESTEC; with the active organisation of ESA and involvement of all PSA Partners (http://epic-src.eu/workshop-2019/).

The EPIC Workshop 2019 program covered the following topics:

- PSA and SRC progress and activities.
- H2020 Work Programme EP SRC topics, Horizon Europe & IOD/IOV activities.
- Incremental SRC OGs: objectives, proposed approach, team, progress, and early results
- Disruptive SRC OGs: objectives, proposed approach, team, progress, and early results
- Electric propulsion for Cubesats: technologies, actors and round table.
- Electric propulsion general and transversal technologies.
- Constellations: EP technologies, actors and round table.
- Power electronics for EP, analysis & simulation, and new developments.
- Dissemination and education SRC activities

EPIC PSA makes public the presentations in agreement with the authors of the EPIC Workshop 2019 in the EPIC web: http://epic-src.eu/workshop-2019/

6 WORKSHOP SUMMARY

6.1 Welcome EPIC Workshop (Chair: Javier Rodriguez, CDTI)

- José GONZÁLEZ DEL AMO, ESA: Introduction, and organization logistics
- Franco ONGARO, ESA: ESA Welcome, and EPIC Workshop Objectives
- José GONZÁLEZ DEL AMO, ESA: EPIC PSA, Roadmap and activities
    - General introduction to explain what is the EPIC SRC, what is the PSA and the OGs
    - Detailed explanation of the EPIC Roadmap was given, presenting the objectives of the SRC and the differences between Incremental and Disruptive technologies (promising EP thrusters and Transversal EP technologies).
    - The PSA explained the context of the SRCs and the EPIC PSA activities, recalled the SRC EPIC Roadmap, previous Calls (presented the ongoing SRC 2016 Call Operational Grants and the status of the SRC 2019 Call without the result of the Call) and the next SRC Calls to come (SPACE-28-TEC-2020), and outlined the next SRC steps.
    - Detailed presentation of the ongoing OGs in terms of partners and objectives (CHEOPS, GIESEPP, HEMPT-NG, GANOMIC, MINOTOR and HIPERLOC-EP).

6.2 Session A: H2020, EP SRC and IOD/IOV (Chair: Jose González del Amo, ESA) (Raporteur: Cheryl Collingwood, ESA)

- Rémy DENOS, EC: Horizon Europe and EP SRC activities
    - EC presented the preliminary view of the next Frame programme Horizon Europe 2021-2017, with an estimated budget for space of €1.479 Billion; and the Strategic Research & Innovation Agenda (SRIA). Also, EC explained the details of the last year of the work programme 2020.
    - In Horizon Europe, Space activities will be under the second pillar, Global Challenges and Industrial Competitiveness, in the cluster devoted to Digital and Industry together with other 10 areas of intervention. The main identified areas of intervention in space will be: EGNOS and Galileo, Copernicus, SSA, Govsatcom, space eco-systems (In orbit IOV/IOD, space demonstrators, breakthrough innovations and technology transfer), and space science.
    - EC presenter mentioned that the European Space partnership in Horizon Europe will be objective-driven and based on the SRIA high level roadmapping, but without giving any specific detail.

- Florence BEROUD, REA: SRC activities and Operational Grants
    - REA explained the context of the Space Electric Propulsion SRC programme, the evolution 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).
    - REA informed about the results of the SRC 2019 call SPACE-13-TEC-2019, which is actually under negotiation process for the signature of the Grant Agreement. Also, REA presented in detail the content of the next space H2020 EP SRC Call (SPACE-28-TEC-2020) text devoted to Incremental technologies, including its guidelines, this time focused on the applications and market, instead of directly on the technologies.
    - REA concludeded with a slide about lessons learned.

- Rémy DENOS, EC (replacing Jean-Michel Monthiller): IOD/IOV Status of activities in H2020
    - EC gave a general overview introduction about what is the IOD/IOV programme.
    - EC informed about the actual status of the IOV/IOD initiative in the H2020 and the next steps, scheduling and budget associated. 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 38 M€ for 2019).
    - EC concluded with a slide about next steps from now to 2022.

6.3 Session B: SRC Project Updates Part I/ Incremental Operational Grants (Chair: Lisa Martin Perez, DLR) (Raporteur: Fabien Castanet, CNES)

- Idris HABBASSI, Safran Aircraft Engines: CHEOPS

- CHEOPS presentation on the HET Technology and its interest for the space industry: The presentation included the project partners (i.e the 3 primes, 5 manufacturers, 4 universities/research centers & 1 SME), the objectives and the state of development for:
    - the Low power (LEO application – Small / Mega Constellation) expected TRL 5-6 end of the project,
    - the Medium power (the) GEO/NAV application with Dual Mode EPS – High Thrust / High Isp) expected TRL 5-6 end of the project and
    - the High Power EPS (Exploration & Transportation) expected TRL 4-5 end of the project.
- The value creation strategy results were presented taking into account different LEO scenarii.
- The Low Power EPS (PPS X00) for small/mega constellations (200 W-1000W->optimized 500-800W, highly modular): First European HET EPS (≤1kW with Total Impulse ≥1MN.s) with a target cost of 200 k€; Propellant optimization for Xenon and compatible with Krypton.Both configurations were tested. Total mass 7kg.
- The main points highlighted in the presentation are: the medium power (PPS DUAL ML) for MEO/GEO (7 kW-OR, Isp ≥1800s, High Thrust 0.5N) 3,5 kW-SK, Isp ≥2100s, High Thrust 0.2N)
- Space Tug: theHigh Power EPS (HT 20K) with magnetic shielding (15-25 kW) and direct drive PCU for exploration and space transportation (Isp 2500s, Thrust 1N @25KW, Total Impulse 50MN.s).
- The modelization and simulations of interaction of the plasma plume were also presented

- 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), the status of the activities and scheduleand the Market assessment.
    - The different GIESEPP concepts were described for LEO (1L/2L), for GEO/MEO (1G) and for Exploration (1S) with clustering.
        - 500+ W Class LEO (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.
        - 5+ kW class GEO/MEO (1G): 1 x Thrusters, 1 x Power Processing Unit PPU 1G, 1 x Electronic Pressure Regulator EPR, 1 x Flow Control Units FCU.
        - Exploration 20kW Class (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.
    - Market assessment to show how GIESEPP is well positioned in the requirement for LEO & GEO. The wet mass reduction of 65% in GEO and 70% in LEO compare with HET and the return on investment.

- Ernst BOSCH, Thales Deutschland: HEMPT-NG

- HEMPT-NG Presentation included: the consortium, the project goals, overview and status, the market target for the HEMPT-NG EPS in the different power fields, the technical achievements and the next steps for the project.
- The project development logic is presented, with EV0 (200-700 W) for LEO market, and next steps with EV1 (1.5-2.8 kW), EV2 (8-14 kW) for navigation and telecom markets and EV3 (>20 kW) . The presentation confirmed the expected advantages of the HEMP-technology (lowest system complexity, simplicity, long lifetime by erosion-free operation, cost-effectiveness and reliability).
- The main points highlighted in the presentation: Market situation is changing and this requires flexible design to match with everything; Baseline thruster HEMP 3050 technology demonstrator will fly in 2021.
- HEMPT EV0: for LEO constellations with cost as the main driver (Low-cost, High-volume manufacturing, Good performance with Krypton, Thrust: 15 -32 mN, ISP: up to 2200s, Total Impulse >1.5MNs, Power: 100W -700W and Operating Voltage 300V -800V, TRL 5).
- The EV0 Bread Board Model, development, evolution and testing is presented with a design oriented for cost effective (single mechanical structure, 70%reduction of parts, 4 attachment points). The technology well suited for LEO applications of the second incremental call.
- HEMPT EV1: LEO/MEO constellations, navigation & GEO,Very flexible,Krypton usage, Thrust: up to 140mN, ISP: up to 3200s, Power: 1,5kW -2,8 kW Operating Voltage 300V –1000 V, Total Impulse >2.5MNs. GEO 5KW market by clustering.

6.4 Session C: Project Updates Part II/ Disruptive SRC Operational Grants (Chair: Nick Cox, UKSA) (Raporteur: Vincenzo Pulcino, ASI)

- Louis GRIMAUD, Safran Electronics & Defense: GANOMIC
  - GANOMIC presentation included details on the consortium partners and roles in each work package and main project objectives: Ganomic is a project aiming at developing a next generation high power voltage converter by the use of GaN transistors achieving 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.
  - Development of European GaNs is a must to have for European non-dependance.

Questions:

- Q1: the cost reduction; which is the initial reference?
  Answer: SAFRAN has looked at flying PPUs and PPU manufacturer. Also, they have taken into account the cost estimated for a PPU developed in house with traditional architecture. The reduced bill of material allowed to reduce the cost

- Q2: The performances depend on GaN technology. So probably also the other systems (not SAFRAN) will increase their performances.
  Answer: the objective of Ganomics is going beyond the state of European State of the Art in terms of GAN technology but also in terms of architecture and embedding.

- Q3: If the component is the main disruptive element which can be used in other part of the world, is there a real advantage of the system developted in Ganomic.
  Answer: these technologies are emerging not only from space but also from aeronautics. The effort of SAFRAN is to merge the different technologies (switching frequency and GaN) to obtain a more advanced and competitive product.

- Q4: Do you have planned to develop higher power converters?
  Answer: the limit is a thermal limit but GaN can handle higher power. SAFRAN is targeting a 20kW PPU

- 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.
  - keypoints: Scalability/Efficiency comparable with current systems/Costs reduced by an order of magnitude
  - 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 detail and highlight were presented (TU, PPU and PS&FS) with no neutralizer needed (all propellant and power are 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. Manufacturing problems were described and the final validation objectives not fully achieved.

<u>Questions:</u>

- Q1: Several transistors in series. If the transistors have different characteristics, then a single transistor my get the entire power on it.
  Answer: We did not have problems with that.

- Q2: No neutralizer is needed. How do you know that each thruster has the same characteristics so to neutralize?
  Answer: The voltages self-adjust in the thrusters

- Q3: How is the propellant?
  Answer: It's a liquid. the important parameter is the viscosity. it does not evaporate in vacuum.

- Q4: Scalability?
  Answer: We did not look at a development plan but they are imagining an order of magnitude of 300 W. The other interesting thing would be to go to extremely small thrusters down to fraction of microN

- Q5: Can the beam divergence be changed and can it be scalable?
  Answer: The beam divergence isn't a specific issue to care about.

- Q6: An advantage is to be different from the others. Do you still think it ?
  Answer: In terms of colloid thruster systems, it is unique. Others are externally wetted systems. This one is driven by capillarity which makes it easier to handle.

- 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.
  - Electron Cyclotron Resonance System with Magnetic nozzle, a self-existing DC field that accelerates the plasma. Microwaves generate plasma through an antenna. The motor tests results are highly sensitive to the vacuum level of the vacuum chamber. The technology is cathodless and needs no neutralizer. It's insensitive to pollutants and compatible with alternative (to Xe) propellants.
  - 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): to understand the physics; demonstrate performances and extrapolate them; to 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, highly 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.

Questions:

- Q1: Two problems. antenna, and erosion. Which parameters do you plan to vary?
  Answer: A clean coating of the antenna is needed but not easy to obtain. To solve the erosion of the antenna, we are making use of the code to better understand the shape of the plasma and perform the right corrective actions.

- Q2: It seems that the system can be easily scalable
  Answer: Indeed the thruster (if all the problems are solved) can be easily scalable. But this has to be investigated with high power tests.

- Q3: Can you tell which actuation you're planning?
  Answer: We plan 5 deg of actuation by moving the flow.

- Q4: Potential upscale to large powers; will it also affect the scaling of the nozzle? Is it a higher magnetic field needed?
  Answer: no

- Q5: Typical divergence? and planning a different shape of the nozzle?
  Answer: 30-40 deg; no, we have tested few magnetic configurations.

- Q6: The order of magnitude of ION acceleration?
  Answer: Ion acceleration order of magnitude 300 eV

- Q7: Alternative propellantsthe system is simpler?
  Answer: Xe is actually the best. Low ionization power and heavy ions. The lighter the gas probably the lower the erosion but this has to be studied and tested. Not planned at the moment.

- Q8: Why is the vacuum so important for tests?

Answer: It has not yet been investigated too much. It may be due to the magnetic fields and the trapped electrons. But this is a hypothesis to be investigated also by the codes.

6.5 Session 1: Electric Propulsion Technologies for Cubesats (Chair: Fabien Castanet, CNES) (Raporteur: Rosario Pavone, SME4SPACE)

- David HENRI, Exotrail (Agile Space): Low power Hall thrusters and mission design and operation software for small-sats
    - Objective giving agility to smallsat services, reducing launch cost, increasing the performances and facilitating services to improve future space ecosystem.
    - ExoMG-nano: Power 50W, Thrust 1.5mN, Isp 800 s (nano S 1U+Volume 1KNs, nano L 2U+volume 5kNs)
    - ExoMG-Micro: 100W, Thrust 5 mN, Isp 1000s, 4U 20kNs. Clustering up to 35mN @800W and 400kNs.
    - Modular, Flexible and easy to accommodate in the spacecraft. Easy mission integrationFor in space future services.
- Nicolas BELLOMO, T4i: REGULUS electric propulsion unit
    - The presentation is structured into: Introduction, the REGULUS EPS, subsystems, applications and conclusions.
    - REGULUS is a “Plug & Play” electric propulsion system fed with iodine propellant, that integrates: Magnetically Enhanced Plasma Thruster, Electronics, Fluidic line, Thermo-structural subsystem.
    - Spec: Thrust 0.55 mN@50W (0.25-0.7) mN; Isp 550 s @ 50 W (up to 650 s); Total Impulse 3000-11000 Ns; Power 20-60W; Propellant Solid Iodine (I2); Volume 93.8 x 95.0 x 150.0 mm @ 3000 Ns; weight 2.5 kg @ 3000 Ns.
    - Ready to fly Q3 2020.
- Luc HERRERO, COMAT: Plasma Jet Pack (PJP) Technology Overview
    - COMAT 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).
    - 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 <800g, 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), QM expected for 2022.
    - PJP has been selected to fly on IOD/IOV.
- David KREJCI, Enpulsion: Commercial Success of FEEP thrusters
    - Enpulsion as an example of success. The presentation begins with a graph that shows that already 25 thrusters have been launched and more than 80 have been delivered.

- The FEEP technology was developed at AIT (now FOTEC) for > 25 years for scientific missions, support through ESA The IFM Thruster technology was developed by FOTEC based on this heritage.
- IFM Nano Thruster: Dimension <1U, 40W, Thrust range 10-400µN, Isp 2000-6000s, Total Impulse >5kNs (Status 25 in space).
- IFM Micro Thruster: 100W, Thrust range 75-1500µN, Isp 1500-6000s, Total Impulse >50kNs (Status first FM delivery early 2020).
- Optimise production line, reduce cost, time and increase reliability. Key for success.

6.6 Round Table 1: Cubesats (Chair: Davina di Cara, ESA) (Raporteur: Fabien Castanet, CNES)

- A-Roger WALKER, ESA :
  - CubeSats are enabling new missions because of advanced state of the Art on technical aspects and IOD.
  - The global development logic is: Study mission concepts, develop enabling technologies, fly (IOD), use operational systems
  - Use of Tailored standards from ECSS and constantly mitigating risks

    The panorama of satellites:
  - 2012 first cubesat 1U with limited capabilities, 2015 GOMX 3 6W 3 axis, 2018 GOMX 4B
  - Expand the flight envelop of cubesats: GOMX 5 with GomSpace (DK) as prime for a 12U with IPOD mission large orbit transfer manoeuvres using EP systems developed by Exotrail and Thrustme for launch in 2021;
  - Phase 1 of 2 (12U) LUMIO (Lunar meteoroid impact observer), and VMMO (volatile and mineralogy mapping orbit) for moon mission study.
  - Propulsion trade-off between chemical and EP are necessary.
  - Phase A of M-ARGO (12U) Miniaturized asteroid remote geophysical observer launch in 2023-2024 not possible with EP
  - GSTP contract KO 11/2019 for High specific EP with integrated cold gaz reaction control system, involving Sweden and Germany. Expected TRL 5 at the end of 18months contract.
  - Rapid evolution of Cubesats has been allowed in the last period, thanks to miniaturisation of technologies including EP.
  - Challenge of volume constraints will more allow to take advantage of EP opportunities given by innovations.

- B-Tor-Arne GRONDLAND, GOMSpace:
  - Evolution of cubesats:
    - 2003 1st decade was dedicated to education, technical demonstration and entrepreneurship
    - 2013 2nd decade allowed to reach 100 cubesats satellites and useful application (tracking, EO, narrow band communication)
    - The 3rd decade is coming: there is a lot to prove and to consolidate the business model.
  - More useful applications (wide band com, radar, data delay and advanced mission's proximity operation and beyond LEO) are expected.

- How does propulsion fit with CubeSats?
- Market trends: Telecommunication market is growing rapidly, dominated by constellations to drive the number. Most of them will need propulsion. Platform size is growing from 3U toward 6U and bigger. More likely to have propulsion on board.
- Legislation: de orbit capability will favour propulsion
- Gross market on 5-50 kg range.
- To the question: What is the ultimate propulsion System for cubesat? The answer is: "It does not exit". Different missions have different needs. An example: For Self-propelled transfer from NEO (Near Earth Orbit), a 5000m/s delta V is needed. Constraints: Maximum usable power 100W. Transfer time shall be minimized. High level of autonomy during transfer and 6DOF manoeuvrability around the NEO will be needed.
- Other examples of use cases: Deployment, phasing, collision avoidance, wheel unloading, drag compensation, removal lower than 100m/s, pPointing while thrusting. This will need multiple thrusters Time to manoeuverthrust level, Payload ON while thrusting will induce power consumption,
- Each mission deserves a "decent" propulsion trade-off

* C-Fabio NICHELE, Tyvak:
  - Their business is End to End small satellites with new facilities available in Torino. 2019 5 satellites, 10 contracts for 2020 EO, IOT
  - Variety of mission's EP for larger spacecraft are considered for very high delta V. No large total impulse is required for small constellations. Most of the platform integrators prefer their payloads and not to incorporate part of cubesats.
  - Tuna cans volume is very useful for deployment but not yet suitable/available for 6U.
  - For 12U no needs for Tuna cans.
  - Power budget is tight for cubesats. Usually, simple panels and no SADA mechanisms are available. Power to thrust ratio is considered the most important parameter.
  - Duty cycle is a very effective mitigation for the power concern. Pulsed ignition is considered.
  - Thermal aspects: energy dissipated as thermal powers. A definition of a baseline thermal Interface would be useful; Thermal straps are used for passive radiators panels. Preliminary thermal budget can help to mitigate risks.
  - Parasitic torque: How to determine misalignments of the CubeSat, and of the EP itself. Some EP proposes gimballing or thrust vectoring considered very interesting.
  - Interfaces: Power busses 9 to 12V would be appreciated.
  - PLUME: divergence is important for the mission
  - EMC estimation for RF thrusters.
  - Integrator provides flight opportunities Would like to have access to engineering models and test or space data.
* D-Alexander REISSNER, Enpulsion:
  - Propulsion needs for future missions: Station Keeping, Manoeuvering, De-orbit, Constellation deployment/development. Cubsats are disrupting the space industry
  - He presents 3 types of operator's behaviour
    - 1-Self build operator
      - Full control on the risk rather than risk and heritage (low entrance barriers)

            - Focus on cost and contractual flow down
            - Strong interaction between business case and satellite/ Subsystem
            - Risk on company level rather than on satellite level
            - Projects are usually not fully financed
        - 2-New platform manufacturers to resell them to customers
            - The frozen system requirements are reasonably static, risk acceptance but good control required
            - Flow down of operator requirement can be unclear
            - Non direct communication between subsystem and operator.
            - Low visibility on project schedule and financing giving high risk
        - 3- Heritage platform manufacturer
            - Requirements clearly defined
            - Customer has a good understanding
            - Low flexibility of requirements.
            - Lean manufacturing in Space industry (allowing high reliability at low cost)
- E-Fabrizio STESINA, Politecnico di Torino:
    - Push maturity by fostering collaboration between propulsion EP systems, system developers and primes
    - In the frame of ESA Micro propulsion actions: Offer a one stop test facility (CTP) for Cubesats with EP up to 2020
    - CTP designed for a 6U EP system.

Synthesis of the Roundtable on Cubesats

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

As CubeSats are proving their ability to capture images and gather scientific data, developers are eager to send these miniature satellites on increasingly complex missions, many of which require propulsion to enable efficient deployment, orbit change, formation flying, proximity operations, attitude control, drag makeup, interplanetary transfer and decommissioning at end of mission. Among these,

<u>a. Which applications will benefit the most of implementing electric propulsion?</u>

A- The applications that exist today: Orbit change requirement constellation where great power is available on board, HP telecom. Occurring after the launch and to de orbit.

B-A satellite is a system. If payload is “power hungry”, the power left for EP will be low.

C-Orbital phasing to enable precise EO, application needing time management

D-Low orbit (300km): optical missions, and a lot of activities with high reliability

E-Commissioning and de orbiting of satellites

<u>b. Which application will be enabled by the use of electric propulsion?</u>

A-Lunar CubeSat missions, interplanetary missions 3.5km/s challenging in small scale

B- If delta-V is more than 200N/s and if such capabilities are available, it will allow more flexibility on launch constraints

2. What are the main challenges of integrating an electric propulsion system on CubeSats?

B- 1Integration into a complete system.

2-Good match with power generation.

3-Different kind of interferences

Which are sensitive?

4-Great value of on earth testing (need to have large facilities)

5-To many CubeSat failing at the time being

C-Thermal aspects in initial design phases, coatings, EMC and EMI aspects Integration into a small container

D-Interfaces things are not fully defined when you integrate depending of the integrators

Trust between supplier and integrator: interface definition

A- System autonomy is a major point because EP will have to be "On and Off" a lot of times failure detection.

3. What are the most challenging aspects or the limitations to consider when designing/developing/qualifying/integrating an electric propulsion system for CubeSat (e.g. performance, reactivity to allow collision avoidance, reliability, neutralization, miniaturization of the electronics, miniaturization of the propellant storage & feeding system, manufacturing processes control, standardization of interfaces, validation of performance and lifetime modelling, testing, ...)? Why?

D-One of the challenges is reliability. In large satellites, it is clearer.

Different conceptions of reliability are used in the CubeSat area. It will impact the business cases if you fail all mission; What kind of reliability is necessary is depending on the mission.

Lot of customers are struggling for safety concerns. Much more advantage than initially thought.

4. What are the typical development time and cost associated to the development of a mission-ready electric propulsion system product for CubeSAT? Is it the same or faster/cheaper than what we have experienced when developing electric propulsion system for conventional size satellites or constellation of small satellites?

D-A lot of things to do. Reduce costs but you cannot parallelize a lot of things, needs to understand the physics.

3,5 million investments for 2 years for industrialization, for high-rate production.

5. Could the implementation of electric propulsion on CubeSATs disrupt the overall satellite propulsion market? How?

C-Constellations are disrupting world of CubeSat's, coming to high production numbers.

B-It will accelerate; New space is a transient phase. When you are New Space and will fly successfully you will be considered as old (or traditional) space. Both will not have to be discriminated anymore. He likes the 3 classes of operator's behavior from Alexander REISSNER-ENPULSION

D-convergence is coming. Large volume production and rapid access to space; If you fly a lot of things are opportunities to get data from space in LEO

6. We live in the years of what has been named the 2nd generation space race. There are a lot of new, relatively small companies/start-ups coming along in the space market with bright new and disruptive propulsion concepts. What are the technical challenges these companies face moving from R&D or even in orbit demonstrations to a commercial profitable and qualified product? How can these companies ensure sufficient revenue to emerge as leader supplier in the CubeSAT propulsion market?

D-Fortunate position in Europe with well-developed funding supported in the early days.

High tech companies have enough time to show confidence to the financers; Have to maximize revenues for customers. Support of ESA as a partner is extremely valuable, more than the money is the link and access to experts? Access to test facilities? Tests measurements methods.

7. Which lessons learned from accomplished IOD missions can be incorporated in future EP development activities?

A-The lessons learned:

- Flying with GOMSPACE,
- EP to provide DV,
- to be integrated with RCS;
- to compensate misalignments;
- To have gimbaled mechanisms.
- valuable for deep space missions;

Lessons learned also on leaks in the FMS.

8. Could standardization (ECSS) help to capitalize these lessons learned and help developing electric propulsion systems for CubeSats in a more efficient way? In which disciplines or areas? What are the CubeSats specificities to be taken into account which are not developed today in standards?

B-ECSS can be useful. Have made a job with ESA considered useful; Example of useless requirements: “shall be resistant to fungus”: recommendation to get these requirements out of the way by tailoring at least,

D-Cubesat customers do not use ECSS may be because they are not tailored to them. What exist is COTS requirements, to know kill you if you have a lot of customers. Not penetrating the world of integrators. Would be very happy to have a standard for CubeSat’s

A-try to retain engineering best practices and try to tailor out the unusable ones.

9-How do you compare EP for CubeSat with USA?

D-Different aspects are usually considered by USA customers.

- Main Issue is the safety issue (launch is preeminent in USA)
- Need for de orbiting is similar
- No difference in operational use

A-Europe is in good place but has to fly more

10-Constellation are coming. Space debris, in orbit collision: Comment on launching in very low orbit having propulsion.

D-will spend a lot of time with EP in radiation belts

B-Cubesat were aimed to be launched in a container can and as such are orbit agnostic. For orbits lower than 600 km, they have no redundant systems. They go down automatically. Not a major problem for CubeSats.

A-For some mission application you will need more satellites, needs of mission analysis is growing

6.7 Session 2 : Electric Propulsion Technologies (Chair: Nick Cox, UKSA) (Raporteur: Javier Rodriguez, CDTI)

- Hans LEITER, Ariane GROUP: Smart RF-Ion Thruster Systems for Small Satellites
  - Presented the Radio-Frequency Ion Thruster Family, based in the heritage of RIT-µX, miniaturized RF Ion Engine for science & small satellites.
  - The advantages of RIT Technology: Easily scalable, multiple propellants, flight proven, perfect trust control, high efficiency and inherent High-Voltage insulation.
  - Flexible, versatile and easy to adapt.
- Daniela PEDRINI, Sitael: Qualification of a Low Power Propulsion System Based on HT100 Hall Thruster
  - Target mission, µHETSat : requirements and constraints. HT100 Thruster and HC1 Cathode.
  - Supported by ESA and ASI, the mission aims at validating in orbit a low power electric propulsion system
    - Target: 1000 hours of HT100 operation in LEO (orbit change + drag compensation phase + de orbit
    - Platform: SITAEL S 75 (75 kg mini satellite mainly intended for IOD/IOV missions)
    - Available power: up to 140 W at the Thruster Unit
    - Thruster Unit PFM delivery expected in 2020 Q1

- Francesco GUARDUCCI, Mars Space Ltd.: Electric Propulsion Technologies Development at Mars Space Ltd
  - Test & Qualification: Cathodes 4-45A for neutralizers & discharge chambers. Support for qualification & test.
  - Design & Modelling: Hollow Cathode modelling, Ion optics code for GIE, 2D ring cups discharge, and Optics lifetime prediction.
  - Three vacuum chambers with independent E-GSE, F-GSE and pumping systems.
  - LaB6 Cathodes: No susceptibility to oxygen poisoning, Lower gas-fed impurity level, Advanced heater element design, and Simple, modular & highly scalable design

Alex SCHWERTHEIM, Imperial College of London: Electric Propulsion Research at Imperial College London

  - Water as a Propellant: Very cheap, Storable at high densities, and low pressures, doesn't condense (will evaporate), Non-reactive, Simplifies spacecraft fueling and integration, Safe for rideshare, Some space qualified hardware already exists, Common throughout the solar system, Found on asteroids useful for mining.
  - Water for Dual Mode Chemical-Electrical Propulsion:
    - Electrical burns near 3000s at 30 mN
    - Chemical burns near 300s at 1 10N (pulse) or 150mN/kW (continuous)
  - Hybridization with Energy Storage:
    - Batteries can be replaced by fuel cells and electrolysers working as a Regenerative Fuel Cell System (RFCS)
    - Fuel cells long flight heritage (e.g Gemini and Apollo)

- Up to four times the energy density (in optimal scenarios).

6.8 Session 3: Electric Propulsion Technologies for Constellations (Chair: Lisa Martin Perez, DLR) (Raporteur: Vicenzo Pulcino, ASI)

- Stephan WEIS, Thales Deutschland GmbH: Development of the low power HEMP Thruster EV0
  - Basic principle explained.
  - Test facility performances shown
  - Working points shown to explain how the optimal working point has been obtained (in terms of thrust and Isp)
  - The difference of efficiency between Xe and Kr is almost negligible
  - Predicted lifetime of the model is 10000 hours

Questions:

- Q1: Different plasma plumes. You hardly see the plasma plume at 200 V.
  Answer: Visibility is due to exposure time
- Q2: Do you have any plan for optimizing the thruster for krypton?
  Answer: the model does not change for using with krypton.
- Q3: The current range for the cathode?
  Answer: Designed for low current but up to 5 A

- Yoann FENDLER, Air Liquide: Innovative Xenon/Krypton FMS (Feed Management System) for Electric Propulsion. (Air Liquid)
  - The system is compatible with cubesat size satellites
  - The development overview is show. TRL 6 planned in 2020. Currently EM is ready.
  - The FMS has to be compatible with Xe and Kr
  - Low recurring cost; redundancy at FMS level. mass 500 g. flowrate 0.5-10 mg/s
  - The valve is based on thermal expansion and also works as pressure regulator.
  - It has been tested to 20000 cycles (opening and closing of the valve)
  - The electrical power increases with the increasing need of flowrate.
  - The test at CNRS has been performed to demonstrate the possibility to feed a thruster up to 1kW power.

Questions:

- Q1: Is the flowrate tunable separately at the two outputs?
  Answer: The flowrate cannot be regulated inflight
- Q2: The power/flowrate graph looks strange in the 0.7-1 W
  Answer: There is no hysteresis phenomenon.
- Q3: How many have been manufactured?

Answer: Some 30 valves have been produced and tested; there are some differences of behavior between the batches of production. Operated in open loop they exhibit a slightly different behavior which is compensated by the closed loop control.

- Massimo PANAROTTO, Chalmers University Of Technology: Functionality-based value assessment of alternative architectures for satellite electric propulsion
  - Different EPS scenarios are presented: modular, Hybrid, modular and integrated design. Different power, same voltage (300V)
  - Modular is less complex to develop but more complex to integrate.
  - Integrated is more complex to develop but way less complex to integrate. there are different needs from Operators, Sat suppliers, etc.
  - The challenge is to merge engineering view and business view when developing and producing an EPS system.
  - Functionality-Based Value Assessment:
    - Functional modelling
    - Design structure matrix
    - AIT cost estimation
    - Surplus value model
  - The model was introduced in CHEOPS accounting for revenues and cost behavior along lifecycle.
  - This allows to select the architecture taking into account the cost impact on customer and market.
  - Also the model can be used to evaluate the cost impact due to architecture changes.

Questions:

- Q1: Is it derived from Automotive (did it fly?)? When does it play a role (at which stage of the project) ? How to practically inject the method into real engineering?
  Answer: 10year experience also in aerospace. Volvo is interested. Not fully validated. It is an iterative project. There is a SW implemented at Safran and the idea is to develop it.

- Q2: How were the coefficients derived?
  Answer: They were estimated by experts, from guesses or educated guesses, or data coming from the existing products.

- Q3: How long does it take to make an assessment?
  Answer: The code object oriented; everything is interchangeable.

6.9 Round Table for constellations & EP (Chair: Alain Demaire, OHB) (Raporteur: Javier Rodriguez, CDTI)

- Philipp LAMOTE, Thales Alenia Space:
  - Introduce the actual situation of constellations, with a sharp increase in the number of constellations in the last 5years, but not only Mega-constellations also smaller.

  - Management of the constellations, simplified industrial process, maintenance & recovery are key factors.
  - Totally different approach between LEO & GEO constellations.
  - Why to use EP in Constellations & SmallSats?
    - More compact & gains in terms of mass
    - Adaptations of satellite design & missions to EP performances/constraints (e.g. requested power: few W to 500-700W - longer operations duration)
    - More mature EP solutions on the market (to be pursued in next 2 years)
    - Gains in terms of competitiveness obtained in past 5 years
    - Less operations during AIT & on the launch site

- Philippe TEMPORELLI, OneWeb:
  - OneWeb F6 phase successfully deployed Q1 2019.
  - OneWeb GEN1 deployment started Q4 2019 with 34 satellites, and a total of 648 sats are foreseen for 2021.
  - Initial orbit 500Km-> final orbit 1200Km. Ascent phase 22 weeks.
  - Electric propulsion is the natural solution for constellations because it allows minimizing mass & volume and simplifying fluidics & operations.
  - Constellations target a cost reduction with a simplify design and new production approaches but maintaining the reliability without shortcuts in the qualification.
  - Production rate and automation of integration & testing is one of the keys for the recurrent cost reduction.
  - Perspectives for constellations & Electric Propulsion:
    - Satellites constellations management is complex with several aspects to consider
    - A large growth of satellites constellation number is expected by market analysis, nevertheless increase level needs to be confirmed versus effective set-up, maintenance impacts & market profitability for customers
    - There are good perspectives wrt the use of EP on Constellations/SmallSats in the future
    - EP products/technologies have gained in maturity in past 3-4 years: Several EP products become mature; But several other EP products are still in development with important milestones in coming months/year; Choices on EP technologies/products will have to be done versus market/missions needs
- Alexander REISSNER, Enpulsion:
  - The promise of constellations
    - High volumes, boosting revenues
    - Willingness of integrators to revisit heavy heritage requirements
  - A word on caution
    - When does the supplier break-even? And how does that relate to the risk of the overall project to be continued?
    - Serial production has its own break-even point
    - Reliability of statistical PA

- Luc PIGUET, Clearspace:
    - Objectives: ClearSpace aims at providing an affordable Failed Satellite Removal service for satellite operators and space agencies: Space Tow-Truck service. One-Web selected for Sunrise PPP.
    - Roadmap & evolution/achievements of the company are presented.
    - Number of satellites launched grows fast, debris population grows faster. Large constellations consolidate the business model.
    - We address the challenge of autonomously capturing and removing non-cooperative satellites in space
    - Enablers for a future ADR market:
        - The recognition that Launching States* remain liable for a satellite as long as it is in space
        - An affordable removal services
        - An in-orbit technical demonstration to set-up a precedent
    - ClearSpace provides a European Solution addressing the main cause of space debris at a global scale.
- Morten PAHLE, Volante Global: Insurance of EP Systems
    - Insurance enables innovation and development by taking those risks which commercial enterprise cannot take themselves
    - Constellation specifics:
        - Low value, high numbers
        - Value creation by the constellation and associated ground systems, not by each individual satellite
        - Mass production of identical satellites
        - Quick launches with little experience return before next launch, sometimes relatively unknown launchers
        - Challenging in-orbit phasing and manoeuvres throughout life
        - End of life 'requirements'.
    - Orbital redundancy or insurance?
        - Large constellations will use several different orbits and planes, with 'spare' satellites kept in reserve above the operational satellites
        - Satellite in-orbit failures are catered through the use of plane spares
        - Small launchers like Launcher One can cheaply and quickly replenish planes where required
        - Satellite failure rates are expected to be relatively high
        - Role of insurance shifts towards catastrophe cover: higher than expected attrition rates, generic failures. System level performance, including ground stations?
    - Electric propulsion challenges:
        - Increased reliance on the power subsystem which historically has been a source of failures
        - Low thrust may be insufficient for fallback/emergency manoeuvres
        - 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
        - Potentially poorly understood effects, e.g. plume impingement, surface charging etc.

- Insurers would have: better understand technologies, impact of technologies on the systems in which they are installed, propose to transfer risks not only to launch and satellite 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 hope to create income from this.

Synthesis of the Roundtable on Constellations & EP

Question 1: What should be done to anticipate possible problems in orbit?

- PT: The best help to avoid problems in orbit is to aid to grab the satellite and help the rendezvous operation.
- LP: other additional possibility is to help to stabilize the client satellite.
- MP: Also it is necessary to define who is the responsible in each possible situation and what need to be covered by the insurance.
- LP: Evolving process. Profit needs to be done, regulation need to be implemented and insurance need to enter.

Question 2: Do you see feasible to implement the full ECSS or a different approach will be necessary?

- PL: Simple reduction of ECSS is not possible, but a rational tailoring could be done.
- PT: It is possible to pick up some valuable part of ECSS, but full ECSS can be only applied to science missions, but not to constellations. New Space implies a new way to do things and maybe a new standard is needed.
- AR: All depends of the life of the satellite, ECSS is too heavy for commercial use. The requirements need to be tailored & accepted by the prime. A new guide of best practices is needed for new type of missions.

Question 3: Until what way is part of the business model of one web take measures for these problems?

- PT: No, economically is difficult. If you have many extra measures into account, the business equuation is not possible.

Question 4: What type of EP technologies are you checking for constellations for next year?

- PT: More power is needed. Satellite will be more complex and power consumption is key.

Question 5: The perceived risk for LEO is high. How was the insurance in the first 6 satellites of One-Web?

- PT: First 6 satellites are not insured. Insurance is not the best solution for constellations.
- MP: Operator need to have a spare & replacement plan to maintain service in case of failure. Insurance needs to be driven by the market & heritage.

Question 6: How innovation goes with heritage?

- MP: For the insurance companies, go for an insurance with one or two risks (Innovation) is viable but as many risks as constellations is madness.
- AR: Heritage shows that things are possible and developments will work, and it is also necessary to build a solid business case.

Question 7: Radiation is still a problem for constellations, what about electronics?

- PT: All the tests are done in all the components to verify that electronics will work despite been COST.
- AR: Space components are more expensive because the supplier has tested them. But components can also be tested in house in order to reduce cost.
- PT: we have found a new way to do the things.

Question 8: If we speak of numbers, the huge number of satellites of the constellations help to reduce risk & cost?

- AR: When you raise the number you enter a totally new value chain, and constellations are able to exploit these benefits.
- PT: In constellation the risk needs to be analyzed in global, because all the process goes really fast and a different approach is needed.
- AR: A team to analyze the ramping-up is necessary if you want to be competitive.

6.10 Session 4: Power Electronics for Electric Propulsion Technologies (Chair: Peter Van Geloven, BELSPO) (Raporteur: Nick Cox, UKSA)

- Eric BOURGUIGNON, TAS-Belgium: Power Processing Unit Activities at Thales Alenia Space in Belgium
    - ETCA heritage – power supplies since 1963. Three sites. Complete manufacturing and test facilities. First product was PPU Mk 1 – 35 off since 2003 – 1.5KW.
    - PPU Mk2 – 2.5KW – 16 orders since 2014
    - PPU MK3 – 4.7KW – 40 orders since 2016 (21 delivered, 9 flying)
    - CHEOPS project – developing dual mode 7KW PPU – 2 modules – Anode and Cathode/FMS modules. Uses HV planar transformer, digital programme controller and GaN components. SRR in 2018. Coupling test planned for Q2 2020.
    - HEMPT-NG PPU as well – 700W up to 900V – includes neutralizer supply and FMS. Includes digital control. Aug 2019 coupling test successful. Demonstrated automatic start sequence. Resistant to power disruptions.
    - So – strong heritage, EPIC has allowed development of two new products

- Angel CARRETERO, CRISA: Generic Gridded Ion PPU activities and future challenges for multiple applications
    - Many products for Hall and GIE thrusters – Goce, Bepi, Elektro, T6 development and small thrusters
    - Topaz PPU for HET – cots based, EQM 2018
    - Elektro – can drive six thrusters – qualified – 30 orders.
    - RIT2X PPU – 5KW - qualification 2019
    - Roadmap of development since 2002 with Goce.
    - GIESEPP – PPU for GIE thrusters – 5KW for GEO, 700W for LEO. Cost reduction and modularity. RIT and T6/T7 applications. 5KW, dual operating point, wide voltage range, high efficiency
    - 7—W for LEO GIE and RIT – mainly common modules GaN

- Future – needs low cost, flexibility for small PPUS – further use of GaN, digital control, cots. Medium size needs hybrid and full EP – high power similar. High voltage a driver too – demonstrated on Bepi.

- Pierre THEBAULT, DACTEM: Electrical propulsion thruster simulator: presentation of a solution to simulate the behavior of an electrical thruster in terms of impedance characteristics (operating points, transients, noise), beam events, ignition and failure cases.
  - PPU dynamic load simulators. DACTEM French – south of France with Chinese office. 12Meuro turnover. Test and measurement across various industries – automotive, aerospace, energy. 20years involvement over 20 years. Load simulation, thrust balances, EGSE. Simulate all interfaces, cathode voltage, failure cases. Use host PC, real time system, measurement conditioning interfaces and connection to PPU. Reproduces all electrical behavior of an HET thruster. PC user interface allows full control. Can simulate thruster and EGSE – interface with satellites. 40W to 20KW for HET, 500W to 7KW for GIE.

6.11 Session 5 : Electric Propulsion Analysis (Chair: Vincenzo Pulcino, ASI) (Raporteur: Peter Van Geloven, BELSPO)

- Adam ORUSNIK, Plasmasolve: Leveraging open-source and cloud infrastructure for efficient 3D simulation of plasma.
  - Developing predictive models for plasma coating companies and plasma's themselves.
  - Non-equilibrium plasma dynamics, plasma-surface interactions, plasma-thermal phenomena. 3D modelling
  - The simulators rely on open-source simulator libraries.

- Eduardo AHEDO, Universidad Carlos III: Simulation of hall thruster performance, HYPHEN
  - Main goal: solid know-how on physics of most relevant EP technologies.
  - The Hyphen tool will be coupled with the EP2PLUS code for neutralization and far plume expansion in 2020-2021.
  - There is a lack of a turbulence model for anomalous transport.

- Filippo CICHOCKI, Universidad Carlos III: Simulation of Hall thruster 3D plumes with EP2PLUS
  - Including simulation of the impact of the position of the cathode with respect to the thruster.

- Filippo CICHOCKI, Universidad Carlos III: Modelling and simulation tools for ionic thrusters.
  - combination of HYPHEN and EP2PLUS simulators, including the implementation of boundary conditions.
  - There is little comparison between the simulated results and actual measurements in real thrusters. The conclusions are drawn from the simulations themselves, without real-life verification. They plan to do more comparisons, e.g. divergence of the plumes, effects of different apertures. Some parameters are hard to verify due to the lack of proper real-life measurement techniques for such parameters.

- Jaume NAVARRO, Universidad Carlos III: Experimental activities at the Electric propulsion and plasmas team on the Helicon Plasma Thruster.
  - Impressive test facilities with different types of probes to analyze the plumes in a vacuum chamber.

- Joern KRENZER, Universitat der Bundeswehr Muenchen: Influencing grid erosion and better model.
    - Nitrogen extends the lifetime by decreasing the surface erosion.
    - A combination of existing simulation code and own code is used.
    - High performance analysis tools of the plumes (spectrometers, X-ray analysis, ...)
    - Iteration of the simulations until agreement with experiments.
    - The work will lead to obtain better fuel mixtures, increasing the lifetime of thrusters.

6.12 Session 6: Electric Propulsion Technologies (Chair: Rosario Pavone, SME4Space) (Raporteur: Lisa Martin Perez, DLR)

- Stephen GABRIEL, University of Southampton: Novel Cathodes and alternative propellants for EP.
    - Development of cathodes working with iodine. This development will be pursued as partner at project iFACT, one of the winners of SPACE-13-TEC disruptive line.
    - Heaterless hollow cathodes (HHC): Ignition using the keeper during less the 50 seconds. The total ignition energy is far less important → disruptive potential of this approach for LEO systems (lower costs and higher reliability)
    - Comsol Modelling of Hollow Cathodes: Prediction of erosion at discharge cathodes validated with data of own measurements, JPL and Surrey.
    - Dry cathodes: Low current cathodes based on MEMS technology.
    - Alternative propellants: Participant in GIESEPP, currently focussing on Krypton vs. Xenon.

- Angel POST, ATD Advanced Thermal Devices: NACES Cathode, High performance cathode for EP devices based on C12A7:e- electride novel material
    - ATD is a company devoted to thermal materials for industrial needs. ATD is the coordinator of the NEMESIS project, one of the winners of SPACE-13-TEC disruptive line.
    - Current work on C12A7: e- Electride: the synthesis on the material is very sensible to the production procedure (sintering and melting). Analysis of the material is performed before use and purity below 99% is rejected.
    - The NACES cathode is a narrow and controlled thermionic emission cathode that will be developed to TRL4 in the NEMESIS project.
    - The NEMESIS project will develop cathodes (NACES and micro cathodes) for a variety of thrusters and propellants: ultra-low power thrusters, alternative propellants and other thruster architectures.

- Charlie RYAN, University of Southampton Development of small Hall Effect Thrusters operating on alternative propellants.
    - Cylindrical HET thruster has been optimized for the use with the metallic propellant. Problems occur as the Zinc did not sublimate as expected.
    - Annular HET thruster with 100 W will be developed to test further propellants.

- Marcus COLLIER-WRIGHT, Neutron Star Systems: Neutron Star Systems closing the gap from laboratory to market for Superconducting-based Readiness Enhanced Magnetoplasmadynamic EP technology (SUPREME).
    - MPD-based EP-concept with a 5kW proof of concept model (phase 1), a 20 kW thruster (phase 2) and a future 100 kW.
    - Current TRL is 4 for most components being adapted from other thruster technologies (PPU and Cathode), AF module at TRL 3.

- Biggest challenge for the 1st phase is the integration of the HTS coils with cryogenics (thermal issues). Further thermal challenge is the cooling of the anode, as current anodes are water cooled and not compatible for space.
- Phase 3 includes production and standardization for commercialization.
- Start beginning of 2020, 5kW demonstrator completed by mid-2021, market entry of 20 kW system by mid-2026.

- Manuel DE LA ROSA, PI Integral Solutions:
    - 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.

- Luis CONDE LÓPEZ, Universidad Politécnica de Madrid: Thrust and supersonic ion beams of the alternative low power hybrid ion engine (Alphie) -
    - Presentation of the patented Alphie technology. Tested with Argon and showing performance

6.13 Workshop Conclusions

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

- José GONZÁLEZ DEL AMO, ESA: EPIC Workshop conclusions
    - Standardization of Electric Propulsion testing procedures for different tests such as lifetime test, acceptance test, etc… are very important. A specific round table in the next EPIC workshop at Cologne in Germany will be organized on this important subject.
    - Thousands of cubesats will be manufactured in the next 10 years of which 40% may have electric propulsion. Therefore, it is important to put attention to the development of small electric propulsion systems for cubesats.
    - New challenges for the integration of electric propulsion systems in cubesats are miniaturization of the power, thermal, structural systems, thus the propulsion designers should take these elements into account in the early development phase.
    - Due to the great amount of satellites using electric propulsion in telecommunication and earth observation constellations, the use of Xenon as an expensive propellant is highlighted. Different propellants such as Krypton (Star link constellation make use of mini–Hall Effect thrusters using Krypton), Iodine (a salt that does not need pressurized tanks), Argon and other propellants is being assessed by the community.
    - Constellations is the biggest market for electric propulsion in the next 5 years and the developments of the electric propulsion need to be accelerated to arrive at the market on time.
    - In constellations the mass savings provided by electric propulsion are very appreciated but another important issue is the volume savings providing by electric propulsion.

- Constellations aim for electric propulsion with low cost but keeping a high reliability and quality. The car industry is the main example of what it is required by the different systems in constellations.
- The big numbers of satellites for constellations highlighted the need to assess the de-orbiting manoeuvres and the possible debris removal activities in the future. Electric Propulsion is a main actor in these domains.
- Insurance of satellites requires from the Electric Propulsion systems the following points: heritage, electronics reliability and assessments of electric propulsion spacecraft interactions.
- The new market will require a high level of autonomy in the electric propulsion systems (failure detection, on-off procedures, etc.)

7 ANNEX 1: WORKSHOP'S PROGRAMME

Day	Session	Time	Invited speaker			Presentation
			Last name	First name	Company	
Monday 21st/October 2019	Registration	13:00-14:10				
	Welcome (Chair: Javier Rodriguez)	14:10-14:20	Torben	HENRIKSEN	ESA	ESTEC Welcome, Inauguration Workshop
		14:20-14:40	José	GONZÁLEZ DEL AMO	ESA	PSA Welcome, EPIC Workshop Objectives & logistics, EPIC PSA
	H2020, EP SRC and PSA (Chair: José González del Amo, Raporteur: Cheryl Collingwood)	14:40-14:55	Rémy	DENOS	European Commision	Horizon Europe and EP SRC activities
		14:55-15:10	Florence	BEROUD	REA	Status of Incremental and Disruptive activities
		15:10-15:30	Rémy	DENOS	European Commision	IOD/IOV Status of activities in H2020
	Coffee break	15:30-16:00				
	Incremental SRC Operational Grants (Chair: Lisa Martin Perez, Raporteur: Fabien Castanet)	16:00-16:40	Idris	HABBASSI	Safran Aircraft Engines	CHEOPS
		16:40-17:20	Cyril	DIETZ	ArianeGroup	GIESEPP
		17:20-18:00	Ernst	BOSCH	Thales Deutschland GmbH	HEMPT-NG
	EOM (EO Day)	18:00				

Tuesday 22nd/October 2019	Registration	8:00-9:00				
	Welcome of the day	9:00- 9:15	José	GONZÁLEZ DEL AMO	ESA/ EPIC PSA	PSA Wellcome of the day & logistics
	Disruptive SRC Operational Grants (Chair: Nick Cox, Raporteur: Vincenzo Pulcino)	9:15-10:00	Louis	GRIMAUD	Safran Electronics & Defense	GANOMIC
		10:00-10:45	John	STARK	Queen Mary Univ. of London	HIPERLOC-EP
		10:45-11:30	Denis	PACKAN	ONERA	MINOTOR
	Coffee break	11:30-12:00				
	Session 1: Electric Propulsion Technologies for Cubesats (Chair: Fabien Castanet; Raporteur: Rosario Pavone)	12:00-12:15	David	HENRI	Exotrail	Low power Hall thrusters and mission design and operation software for smallsats
		12:15-12:30	Nicolas	BELLOMO	T4i	REGULUS electric propulsion unit: current and future developments
		12:30-12:45	Luc	HERRERO	COMAT	Plasma Jet Pack (PJP) Technology Overview
		12:45-13:00	David	KREJCI	Enpulsion	Commercial Success of FEEP thrusters
	Lunch break	13:00-14:15				
	Invited Speakers to round table **"Cubesats"** (Chair: Davina di Cara, Fabio Nichele, Fabrizio Stesina, Roger Walker, Alexander Reissner, Tor-Arne Grondland, Raporteur: Fabien Castanet)	14:15-14:30	Roger	WALKER	ESA	
		14:30-14:45	Tor-Arne	GRONDLAND	GOMSpace	
		14:45-15:00	Fabio	NICHELE	Tyvak	
		15:00-15:15	Alexander	REISSNER	Enpulsion	
		15:15-15:30	Fabrizio	STESINA	Politecnico di Torino	
	Round table **"Cubesats"** (Chair: ESA, Raporteur: Fabien Castanet)	15:30-16:15				Round table "**Cubesats & EP**": Questions and Answers prepared by the Chair & PSA
	Coffee break	16:15-16:30				
	Session 2: Electric Propulsion Technologies (Chair: Nick Cox, Raporteur: Javier Rodriguez)	16:30-16:45	Hans	LEITER	Ariane Group	Smart RF-Ion Thruster Systems for Small Satellites
		16:45-17:00	Tommaso	MISURI	Sitael	Qualification of a Low Power Propulsion System Based on HT100 Hall Thruster
		17:00-17:15	Francesco	GUARDUCCI	Mars Space Ltd.	Electric Propulsion Technologies Development at Mars Space Ltd
		17:15-17:30	Maria	SMIRNOVA	Transmit GmbH	RIT3.5 EM - classic technology for earth observation and science missions
		17:30-17:45	Alex	SCHWERTHEIM	Imperial College London	Electric Propulsion Research at Imperial College London
		17:45-18:00	Georg	HERDRICH	IRS Stuttgart	Assessment of Gaps for Dedicated Electric Propulsion Systems: The View of IRS
	EOM (EO Day)	18:00				
	Workshop cocktail	18:00-19:30	Networking light cocktail			

Wednesday 23rd/October 2019	Registration	8:30-9:15				
	Welcome of the day	9:15- 9:30	José	GONZÁLEZ DEL AMO	ESA/ EPIC PSA	PSA Wellcome of the day & logistics
	Session 3: Electric Propulsion Technologies for Constellations (Chair: Lisa Martin Perez, Raporteur: Vincenzo Pulcino)	9:30-9:45	Ralf	HEIDEMANN	Thales Deutschland GmbH	Development of the low power HEMP Thruster EV0
		9:45-10:00	Pascal	BARBIER	Air Liquide Advanced Technologies	Innovative Xenon/Krypton FMS (Feed Management System) for Electric Propulsion
		10:00-10:15	Massimo	PANAROTTO	Chalmers University Of Technology	Functionality-based value assessment of alternative architectures for satellite electric propulsion
	Coffee break	10:15-10:45				
	Invited Speakers to round table "**Constellations & EP**" (Chair: Alain Demaire, Philippe Temporelli, Philippe Lamot, Muriel Richard, Alexander Reissner, Morten Pahle, Raporteur: Javier Rodriguez)	10:45-11:00	Philippe	TEMPORELLI	OneWeb	
		11:00-11:15	Philippe	LAMOTE	Thales Alenia Space	
		11:15-11:30	Muriel	RICHARD	Clearspace	
		11:30-11:45	Alexander	REISSNER	Enpulsion	
		11:45-12:00	Morten	PAHLE	Volante Global	
	Round table "**Constelations & EP**" (Chair: Alain Demaire, Raporteur: Javier Rodriguez)	12:00-12:45				Round table "**Constellations & EP**": Questions and Answers prepared by the Chair & PSA
	Lunch break	12:45-14:00				
	Session 4: Power Electronics for Electric Propulsion Technologies (Chair: Peter Van Geloven, Raporteur: Nick Cox)	14:00-14:15	Eric	BOURGUIGNON	Thales Alenia Space Belgium	Power Processing Unit Activities at Thales Alenia Space in Belgium
		14:15-14:30	Fernando	PINTO MARIN	CRISA, Airbus Defence & Space	Generic Gridded Ion PPU activities and future challenges for multiple applications
		14:30-14:45	Pierre	THEBAULT	DACTEM	Electrical propulsion thruster simulator: presentation of a solution to simulate the behavior of an electrical thruster in term of impedance characteristics (operating points, transients, noise), beam events, ignition and failure cases.
	Session 5: Electric Propulsion Analysis (Chair: Vincenzo Pulcino, Raporteur: Peter Van Geloven)	14:45-15:00	Adam	OBRUSNIK	Plasmasolve s.r.o.	Leveraging open-source and cloud infrastructures for efficient 3D simulation of plasma and thermal balance.
		15:00-15:15	Eduardo	AHEDO	Universidad Carlos Iii De Madrid	Simulation of Hall thruster performances with HYPHEN
		15:15-15:30	Filippo	CICHOCKI	Universidad Carlos Iii De Madrid	Simulation of Hall thruster 3D plumes with EP2PLUS
		15:30-15:45	Filippo	CICHOCKI	Universidad Carlos Iii De Madrid	Modeling and simulation tools for Ion Thrusters
		15:45-16:00	Jaume	NAVARRO CAVALLE	Universidad Carlos Iii De Madrid	Experimental activities at the Electric Propulsion and Plasmas Team (EP2-UC3M): an example of an intense testing campaign on the Helicon Plasma Thruster (HPT05M)
		16:00-16:15	Joern	KRENZER	Universitaet der Bundeswehr Muenchen	Influencing grid erosion in RITs by fuel additives and desgining a better model for the underlying abrasive processes
	Coffee break	16:15-16:30				
	Session 6: Electric Propulsion Technologies (Chair: Rosario Pavone, Raporteur: Lisa Martin Perez)	16:30-16:45	Stephan	GABRIEL	University of Southampton	Novel cathodes and alternative propellants for Electric Propulsion
		16:45-17:00	Angel	POST	Advanced Thermal Devices S.L.	NACES cathode: High performance cathode for electric propulsion devices based on C12A7:e- electride novel material
		17:00-17:15	Charlie	RYAN	University of Southampton	The development of small Hall Effect Thrusters operating on alternative magnetic propellants
		17:15-17:30	Manuel	LA ROSA BETANCOURT	PI Integral Solutions Ltd.	Superconductor-based Readiness Enhanced Magnetoplasmadynamic Electric Propulsion. SUPREME Consortium for High Power EP Space Missions).
		17:30-17:45	Manuel	LA ROSA BETANCOURT	PI Integral Solutions Ltd.	Neutron Star Systems – closing the gap from laboratory to market for Superconducting-based Readiness Enhanced Magnetoplasmadynamic Electric propulsion technology (SUPREME).
		17:45-18:00	Luis	CONDE LÓPEZ	Universidad Politecnica de Madrid	Thrust and supersonic ion beams of the Alternative Low Power Hybrid Ion Engine (ALPHIE)
	Workshop Conclusions	18:00-18:15	José	GONZÁLEZ DEL AMO	ESA	EPIC Workshop conclusions
	EOM (EO Workshop)	18:15				