CIRA Roadmap for the Development of Electric Propulsion Test Facilities

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KEYWORDS: Electric Propulsion, Testing, Hall Effect Thrusters

ABSTRACT

Electric propulsion (EP) represents one of the most promising technologies for the application in the present and future space missions. Nowadays, Electric Propulsion systems are proposed for a large class of primary propulsion applications, such as high altitude orbit raising, orbit transfer and high impulse interplanetary scientific missions. In fact, EP can enable cost saving of commercial and institutional satellites and missions whose requirements may be hardly fulfilled by other propulsion systems. Despite of their promising performances, one of the main criticalities in developing new high power thrusters (in a single or clustered configuration) is represented by the availability of test facilities in order to accomplished extended campaigns of characterization and qualification before the integration in the space applications. Moreover, Electric Propulsion, especially in high power applications, requires a dedicated focus on investigation campaigns linked to the analyses of the complex phenomena that may occur on the fully deployed satellite. It is evident that the industrial development of such high power electric thrusters relies on the availability of suitable test facilities where on-orbit operations may be simulated with reliability. Present European capability tops at about 5 kW thruster power level; however, most future mission scenarios for EP-enhanced space transportation of large payloads foresee the use of thruster power up to 25 kW and beyond. Re-use capability can be achieved only by improving the reliability of key components and technologies, and by a proper thruster design taking into consideration mission requirements (such as long-term in-space storage and similar) which have not traditionally been addressed in past EP designs.

In this scenario CIRA intend to cooperate with the EP community providing world-class testing capabilities for high power thrusters, in order to promote Italy as the European reference point for electric propulsion testing. Thus, CIRA drew up a plan aiming at realizing two facilities, featured by different sizes, and at the same time develop Hall Effect thruster laboratory prototypes The Medium Scale Vacuum Chamber (MSVC), i.e. 2 m of diameter and 5m long, will be ready by the end of 2017 in order to implement first testing capabilities and allow the preliminary studies on laboratory engines, characterized by power up to 1 kW. The Large Scale Vacuum Chamber (LSVC) will be realized by the end of 2018 and it will represent a world-class test facility, i.e. 8 m of diameter and 16m long. The development plan includes also the improvement of advanced diagnostics capabilities. The present paper gives an overview of CIRA development plan on EP with the first achieved goals.

1 INTRODUCTION

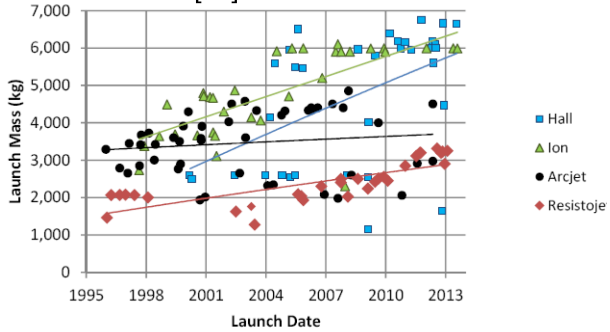
Electric Propulsion is by no means a new concept, having firstly been tested in flight in the 1960s [1]. However, its introduction as a practical alternative to chemical thrusters for S/C propulsion has been slow in developing, owing to a combination of insufficient on-board electrical power on most S/C, and a reluctance by many mission planners to abandon tried and true solutions [1, 2]. The potential performance advantage of primary EP for space missions with large DV requirements was recognized from the beginning, and much of the early research and development work addressed this type of mission. Yet, it has been the gradual application of the simpler forms of EP to secondary propulsion tasks that has led to its acceptance, with the long-envisioned deep-space applications only now beginning to materialize [3, 4]. Today the reasons of a market potential are linked to the possibility to achieve cost reductions of commercial and institutional satellites if a comparison with more "conventional" systems is performed. Moreover, the introduction of EP may bring to enable missions, featured by requirements, which hardly may be fulfilled by other propulsion system solutions [4]. In fact, one of the most important advantage is the high obtainable specific impulse, accompanied by the suitability to missions which require long running times or large radii of action. These characteristics are often exploited in missions like interplanetary transfers or attitude control and positioning. However, the benefits of EP-based systems thrusters are not only linked to the possibility of fuel savings, but also may allow for the reduction in mass, multiple ignitions strategies, thrust modulation and high reusability [5, 6].

Within this framework, Italy intends to play a significant role in the EP technology development, extending and even improving the national system capabilities in terms of design, manufacture and test of electric thrusters. Thus, CIRA, the Italian Aerospace Research Center, endorsed by ASI, will act to support the National and European companies in R&D activities, giving a significant contribution to the present technology maturation (in particular, HET). Another important objective is to integrate the present Italian and European EP testing capabilities by realizing world-class facility, cooperate with the international scientific community and participate to the most important programs, aiming at developing the future EP technologies.

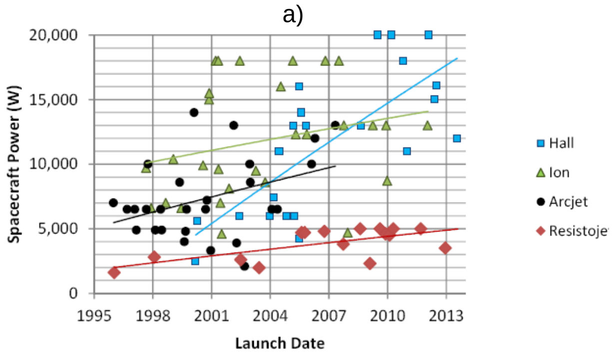
The aim of this paper is to give an overview of CIRA development plans on EP technologies and first achieved goals, with a particular focus on test facilities.

2 TRENDS AND FUTURE PERSPECTIVES

Several modern scientific and technological space programs identify the use of EP systems as a key-factor. The next future scientific observation missions of space and Earth impose more challenging requirements to the propulsion systems and their sub-systems and components, based on advanced technology like micro-thrusters [3, 4]. Moreover, the upcoming space exploratory programs will require more sophisticated EP systems, enabling missions towards Mars or Venus and, for example, bring back specimens from asteroids or comets. All these missions try to exploit the most significant advantages of EP systems, such as the high specific impulse and propellant savings, but electric thrusters are suitable also for orbit raising purposes, enlarging the mission scenarios and allowing to decrease the spacecraft launch costs. The gradual development and maturation of technologies, like HET or other plasma-dynamic engines, will bring to succeed in the commercial space fields: the most important international actors are heading for developing of all-electric satellite platforms and some company foresees the progressive substitution of the chemical thruster on satellites. CNES has recently claimed that the reconversion will concern with about 50% of the telecommunication satellite market; thus, France has allocated significant resources to support the national aerospace industry in in-flight qualification programs [7]. It is worth to underline that the first attempt to develop a full electric platform in Europe is represented by OHB Electra. Its launch has been planned in 2018-2019 [8]. Also Rafael seems to move to a full electric configuration in order to maximize the HET potentiality also for the attitude and control system purposes [9]. In fact, at this moment the Israeli company has already tested the HET-300 (a HE thruster, characterized by a maximum power of 600 W and 13 mN of thrust) in flight. ESA has recently extended the agreement with Thales-Alenia Space for the development and qualification of the new generation satellite platform, named Spacebus Neo (3-6 ton class) [10]. In USA, Boeing will point to the consolidation of the 702HP platform, equipped with the gridded-ion thruster, named XIPS-25 and able to perform station-keeping functions and orbit topping, and to the launch of the full-electric configuration, 702SP [11]. One of the main competitors, Loral Space Systems, has started the qualifications activities of the OKB Fakel SPT-140 thruster (5kW of power) in the view of using it for orbit raising and orbit control purposes. [12]. Thus, from the technological point of view, the short/medium term scenario seems to presume very significant efforts in promoting the maturation of existing EP systems, typically HET, characterized by a power size of about 5-10 kW. For the size of these thrusters adequate testing capabilities are still present also in Italy and Europe. Aerojet has recently published a very interesting overview on the launch mass and total power of operational GEO spacecrafts, equipped with EP and launched in the last 20 years. It is highlighted by Figure 1 that the use of HET is spreading out very rapidly for that kind of mission [13].



a)



b)

Figure 1 - Launch mass (a) and total power (b) of operational GEO spacecrafts, equipped with EP [13].

Other development lines would point to improve the efficiency of low power systems (to be mounted on mini and micro satellites), as indicated by Rafael or Sitael [9, 14]. However, the plans, linked to the next future exploratory missions and full-electric platforms, seem to push towards very high power devices (20-100 kW), as also pointed out by Figure 2.

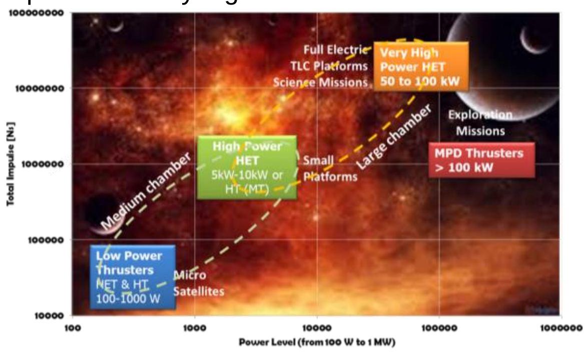


Figure 2 – Power range of application for HET and MPD thrusters.

NASA has already classified the development of EP thrusters, characterized by very high power sizes (ranging from 100 kW to 1 MW), as priority national interest [15]. In fact, NASA is developing the new X3 thruster (a Nested Hall Effect Thruster) of 100 kW power in co-operation with the Plasmadynamics and Electric Propulsion Laboratory (PEPL) and the Air Force Research Laboratory (AFRL). On the European side, in the frame of Horizon 2020 Program, HiPER (High-Power Electric propulsion: Roadmap for the future), has been launched to develop the next European family of electric spacecrafts [16].

Both the visions foresee some future missions in which high power EP thrusters will play a central and indispensable role, such as:

- Cargo mission between LEO (Low Earth Orbit) and HEO (High Earth Orbit) for the on-station

deployment of satellites (for example also in GEO) or for supporting Lunar and Martian exploration;
- Transfers to Near Earth Objects (NEO) or Mars;
- Solar System exploration (moons of Jupiter – for ex. Prometheus Project [17])
- Re-boost of Space Station in LEO;
- Drag make-up in LEO or transfer to high energy.

Also for space transportation some proposals, involving EP for kick stage purposes or servicing for orbital transfer vehicles, have already popped out. For example, an additional electric kick-stage, based on an five-HET-cluster, has been suggested for the evolution of VEGA launcher [18,19] while CNES proposed the implementation of engine clusters, based on SNECMA PPS-5000 thrusters, on the Ariane launcher [20].

For all the aforementioned development and qualification activities on electric thrusters wide are needed by means of appropriate and intensive experimental campaigns, supported by a significant help given by advanced diagnostic methodologies, in order to evaluate life cycle of thrusters. This is particularly mandatory for the development of high power thrusters; however, in Europe there are no appropriate facilities for the class of thrusters beyond 30 kW in order to accomplish the on-ground qualification or long endurance tests but only to perform ignition tests or performance evaluations. In order to promote these development lines, the European Commission has launched the “Electric Propulsion Innovation & Competitiveness” Project (EPIC). The program, led by a consortium coordinated by ESA and composed of six national space agencies (ASI, BELSPO, CDTI, CNES, DLR and UKSA) as well as some European associations, will allow to strengthen the competitiveness of the European Space Sector in the field of in-space electrical propulsion [21]. High power HET has been recognized as one of the most promising technologies and great efforts will be spent in order to improve it. Moreover, activities linked to subsystem components development (for example like valves, flow controllers, power processing units, tanks, etc.) will be supported by the grant. The core of the program is represented by the improvement of the European capabilities in terms of test facilities (including diagnostics) and standardized experimental methodologies [22] in order to support the R&D projects and reduce the impact of acceptance and qualification phases.

Finally, ESA formulated a long term scenario including the possibility to develop un-manned and even manned vehicles, equipped with EP, to reach for the planets near to the Earth in reasonable mission times. Moreover, ESA foresees the future possibility to couple EP with powerful electric generator, even nuclear-energy based, in order to open the road towards the Solar System exploration and beyond [23].

3 TEST FACILITIES

Hall Effect thrusters, relying as they do on low-density plasmas, require large vacuum facilities for ground test operations. The critical plasma acceleration process depends on mechanisms, occurring only in the free molecular flow regime. As such, ground testing is reliant on high quality vacuum systems, capable of high gas through throughput. Pumping speeds of useful vacuum test facilities typically range from 25,000 L/s to several facilities in excess of 1,000,000 L/s.

Available Test Facilities

As mentioned above, all the activities, related to the development of electric thrusters, cannot be performed without appropriate test facilities. Tests are conducted to in-depth the comprehension of the most critical physical aspects, to support the theoretical and numerical modeling and, of course, to help the design and optimization of thrusters by measuring the performances, accomplishing plume characterization activities and long-endurance tests [25]. In particular, it is possible to evaluate one of the most important phenomena, affecting the engine life-cycle, such as the sputtering of the channel walls material, which turns into the progressive erosion of the acceleration channel.

Table *1* briefly reports a list of the most significant facilities, available for the EP thruster tests and in particular for HET: they are generally located in USA and Europe. In USA, important structures have been realized at the Plasmadynamics & Electric Propulsion Laboratory (PEPL) of Michigan University, by NASA at the Glenn Research Centers and also military laboratories have been built by US Airforce. The most significant private facilities belong to Boeing Company and they have been conceived for the tests of ion thrusters [25, 26].

Table 1 – Most significant test facilities for HE thrusters, working all over the world

Facility	Location	Dimens. DxL [m]	Air Pumping Speed [L/s] (x 1000)	Oper. Press. [torr]
USA				
PEPL LVTF	Ann Arbor MI	6.1x9.1	520	2.7E-4
GRC VF5	Cleveland OH	4.6x18.3	3,500	4.0E-5
GRC VF6	Cleveland OH	7.6x21.3	900	1.0E-4
Plum Brook SPF	Sundasky OH	30.5x37.1 (H)	1,300	1.0E-4
Plum Brook B2	Sundasky OH	10.7x16.7 (H)	350	4.0E-4
AEDC V12	Arnold AFB TN	3.7x10.7 (H)	4,200	3.3E-5
AFRL SPEF	Patterson B OH	9.1 (D)	690	2.0E-4
Boeing, XIPS QF	Torrance CA	6.1x12.2	1,800	7.7E-5
ITALY				
ALTA IV10	Ospedaletto PI	5.7x9.4	610	2.0E-4
ALTA IV4	Ospedaletto PI	2.0x4.2	150	2.5E-5
AEROSPAZIO	Rapolano SI	3.8x11.5	220	2.5E-05
GERMANY				
JUMBO	Giessen	3.0x6.1	210	6.6E-4
DLR STG	Goettingen	5.0x12.0	210	1.0E-5
THE NETHERLANDS				
ESA-EPL CORONA	Nordwijk	2.0x5.0	160	<1.0E-4
FRANCE				
Pivoine 2G	Orleans	2.0x4.0	ab.200	2.0E-5

Europe as well as Italy have strongly invested in this field but the largest facility still remains the NASA VF-5 (GRC), characterized by a pumping speed of 3,500,000 L/s (N_2). It is generally adopted for flight/qualification test activities and is equipped also with a solar simulator. On the European side, it is worth to remember, among the most significant space simulators, the facilities working in Germany (DLR-Goettingen and JUMBO-Giessen), in France (ICARE-Orleans), in Holland (CORONA-ESA Nordwijk).

In Italy two active and world-wide recognized private companies have realized relevant vacuum chambers for EP thruster testing: ALTA-Sitael (Ospedaletto - Pisa), which owns IV-4 and IV-10 (the largest and most advanced plant in Italy, having a diameter of 5.7 m, a length of 10 m and a pumping speed of about 600,000 l/s in air) and Aerospazio Tecnologie (Rapolano Terme -Siena) [27, 28]. Besides the servicing activities, both the organizations are also involved in the design and development of electrical engines and components.

Plasma Diagnostics

This section briefly describes the diagnostics methodologies, applied to the analysis of Hall Effect thrusters. The characterization of plasma beam is performed by means of both intrusive and non-intrusive diagnostics. Langmuir probes or Faraday cups belong to the former group, while non-intrusive diagnostics include laser-based systems to perform measurements without perturbations. [29].

Langmuir probes are device placed in the vessels and used to determine the electron temperature, electron density, and electric potential of a plasma. In fact, the device is represented by a conductor, exposed to the plasma, whose current changes if potential changes, giving information on the local characteristics of the plume. Faraday cups are devices similar to Langmuir probes and they are used to directly measure the beam ion flux [30].

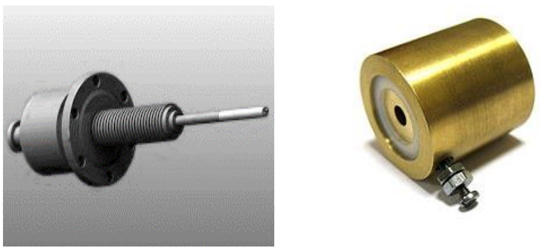


Figure 3 – Intrusive diagnostics: a) Langmuir probe; b) Faraday cup.

Among the non-intrusive methods, OES (Optical Emission Spectroscopy) and D-LIF (Doppler-Laser Induced Fluorescence) can be cited as laser-based techniques. OES allows to analyze the radiation emitted in the UV, VIS and NIR range by chemical species included in the plasma beam. In particular, in the case of HET engines, this technique allows time-resolved monitoring of the plume contamination caused by the erosion of the acceleration channel walls. In fact, since the HET typical architecture includes channel walls made up by dielectric material as boron nitride (BN), the sputtering phenomenon can be investigated by studying the radiation emitted by the sputtered Boron atoms and correlated to channel erosion.

Thus, the design optimization can be accomplished by determining the best operative conditions in order to obtain the minimal wall erosion and the maximum life-cycle, according to all the ranges of ΔV, magnetic field and propellant mass. A typical scheme of an optical set-up for the application of OES to a HET characterization is shown by Figure 4 [31].

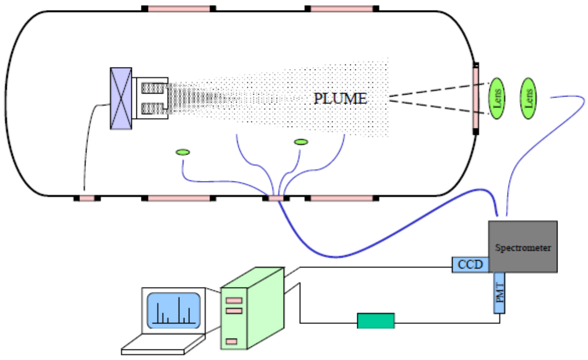


Figure 4 – Example of a scheme for an OES measurement system [31].

The technique of Doppler-Laser Induced Fluorescence (D-LIF) can provide non-intrusive measurements of velocity for atomic species and ions, even in the engine channel region and not only in the plume. The specie to be examined is excited by a laser beam with a wavelength selected to be the one at which the specie has its largest cross section. The excited species will, after a time delay, usually in the order of few nanoseconds to microseconds, de-excite and emit photons of lower energy and longer wavelength than the excitation wavelength. An example of a possible optical set-up is shown in Figure 5 [32].

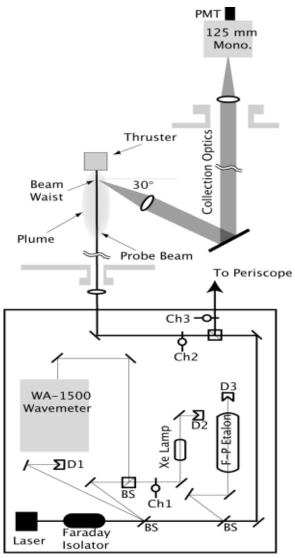


Figure 5 – Example of a scheme for a D-LIF set-up [32]

Other non-intrusive diagnostics are represented by High-speed Imaging (HSI) and thermography techniques. HSI allows to globally visualize the HET flow field, without perturbing its operation, and identify the spoke regions characterized by low and high frequency oscillations, affecting the engine. The spoke structures are denser areas of the flow, observed by means of HSI systems, as regions characterized by higher average emissions that propagate in azimuth direction. The responsible for the light emission are the ions and neutral atoms of Xenon propellant, generally used in these thrusters. An example for the set-up of HSI technique, applied to an HET, is given in Figure 6, while in Figure 7 "spoke" instability regions are shown [33].

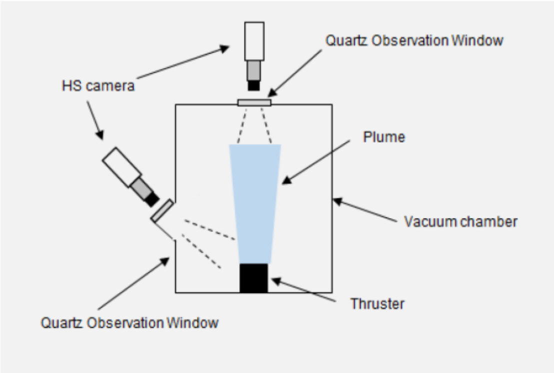


Figure 6 - Typical scheme of a High-speed Imaging acquisition system [33].

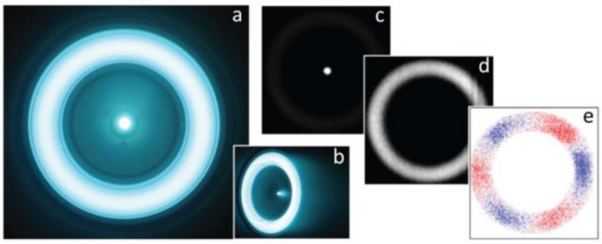


Figure 7 – Spoke instability regions in HET: (a) and (b) front and side view of the thruster exit area; (c) raw front image acquired by HIS; (d) and (e) post-processed HSI images to visualize spoke regions [33].

Also thermography has been successfully applied to the study of HET engines by some research groups, both in the United States and France [34, 35]. This technique includes the use of commercial cameras, working in the MIR (Medium Infra-Red) and FIR (Far Infra-Red) ranges in order to evaluate the temperature maps of hardware, subjected to thermal loads. Temperature measurements are not intrusive and consist into crucial information since the spacecraft integration requires the estimations of the heat load from the thruster body to the thruster gimbal/mount. Furthermore, the magnetic circuit of a Hall Effect thruster is subject to collapse if the magnetic circuit exceeds the Curie temperature of the ferromagnetic materials. Other issues concern with the overheating of electromagnetic coils and coil insulation. Temperature data of some parts of the thruster may also provide information about the thruster functionality and suggest potential methods to improve the efficiency. Finally, it has been proved the correlation between the sputtering increase of Borosil (BN-SiO_2 used in Russian Hall Effect thrusters as the dielectric insulator), influencing the engine lifetime, with the temperature variation [36].

4 CIRA OUTLOOK

CIRA, the Italian Aerospace Research Center, has been established to create technology know-how in order to support the Italian aerospace companies and contribute to the European aerospace development activities in cooperation with international institutions, universities, research centers and companies. One of the missions is represented by to develop strategic competences and know-how in the field of aerospace propulsion. At this moment, CIRA is involved in several national and international projects concerning solid, liquid and electric propulsion [37,38] and intends to improve the testing capabilities, besides the theoretical and simulation ones, recognized all over the world. On the side of EP, in fact, CIRA has planned to build facilities, featured by adequate sizes and equipment to enable the tests of the brand new electric thruster and start R&D activities in this strategic field. Given this background, the idea consist into realizing new plants, such to improve the National testing capabilities in Italy: on one side the goal is to integrate the present vacuum chambers, already working but oriented towards commercial applications, and in the other one to offer a world-class space simulator, suitable for the challenges imposed by the future EP systems.

The development plan of CIRA EP Program, called IMP-EP, is organized in three principal lines (OR) and will develop according to:

I. design and realization of the facilities including the improvement of test definition and competences;
II. development and improvement of basic and advanced diagnostics methodologies;
III. development of design methodologies and technologies for electrical thrusters, including the set-up of a preliminary design tool, improvement of numerical modeling and post-test analyses and laboratory models manufacturing.

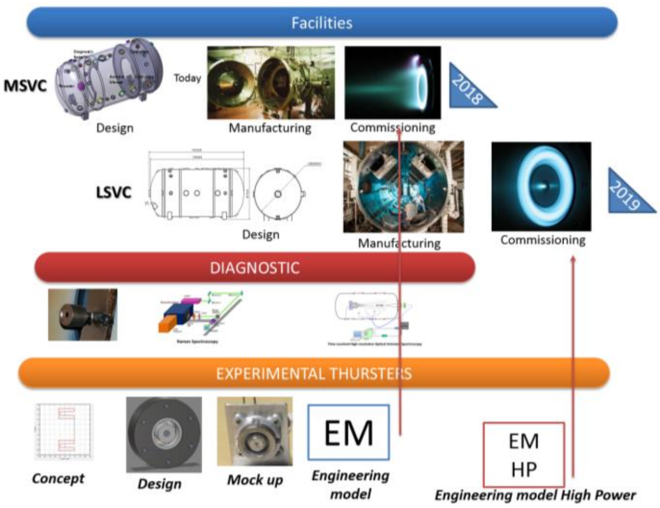


Figure 8 - CIRA EP roadmap

In particular, the facility development plan includes the realization of two facilities at Capua:

1) Medium Scale Vacuum Chamber (MSVC), conceived for R&D-oriented activities and the tests of EP thrusters to be mounted on micro/mini spacecrafts;
2) Large Scale Vacuum Chamber (LSVC), designed to test high power thrusters and even complete high power electric propulsion systems.

Besides these plants, other support facilities will be built in order to allow the test and development of critical sub-systems, like cathodes.

Facility design and realization (line 1)

The MSVC, conceived for R&D purposes, will have a diameter of 2.0 m and a length of about 5 m and it will be the first facility to be realized at CIRA by the end of 2017. Some information is reported by Table 2.

Table 2 - Some details about CIRA MSVC

Medium Scale Vacuum Chamber (MSVC)	
Dimensions	(ab.) 2 m diam. x 5 m length
Vacuum	Up to 5e^{-7} Pa (ultimate pressure) Lower than 2.5e^{-3} Pa (working)
Applications	R&D purposes, equipped with advanced diagnostics
Reference test article	HET (up to 5 kW) fed up by Xenon (up to 15 mg/s)

As aforementioned, MSVC will represent the first implementation of the EP testing capabilities at CIRA. It will allow to enable the planned R&D activities and eventually perform characterization and long-endurance tests. The reference engine is a HE thruster, characterized by a power up to 5 kW and fed up by 15 mg/s of propellant (Xe). Performance, plasma characterization and long-endurance tests on low power EP thrusters will be possible, with the installation of a ultra-vacuum generation system, capable of a pumping speed of about 120,000 l/s (N_2) at least, and even assisted by a cooled internal liner.

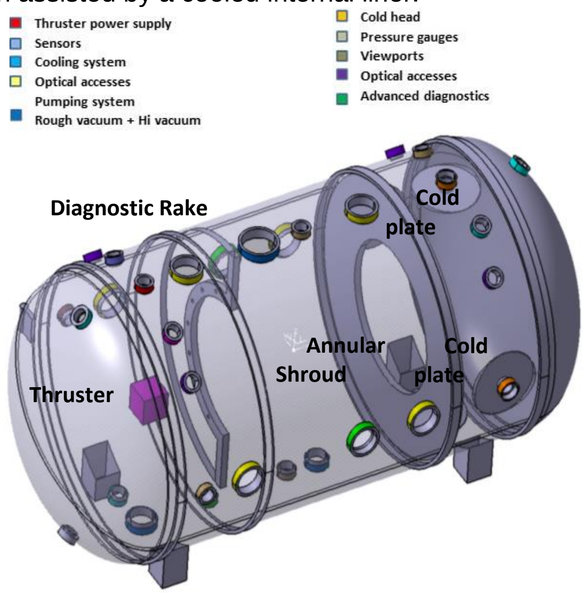


Figure 9 – Preliminary sketch of the MSVC vessel, including some utilities.

MSVC is part of the CIRA EP development plan, including the improvement of analysis, theoretical and numerical modeling, design and fabrication competences in the field of EP thrusters with a particular interest in HETs, which represent the core of the CIRA efforts. Moreover, investigations on alternative propellants with respect to Xenon (such as Argon, Krypton, etc.), innovative materials and research activities on other promising but not sufficiently mature technologies, like Helicon and MPD thrusters will be activated in the next future. The purpose is to bring CIRA to co-operate with the most important Italian and European companies and research centers in the EP field. For a R&D-oriented space simulator, it is essential to foresee the implementation of the most advanced diagnostics methodologies. For these reasons, MSVC will be provided with state-of-the-art systems like *Hi-Res Optical Emission Spectroscopy* and *Doppler LIF*, in order to exploit the CIRA heritage. Moreover, intrusive diagnostics will be used and allocated in a dedicated rack in order to perform detailed plasma characterizations. In fact, the in-depth comprehension of all the phenomena connected with the performance of the thrusters and their life cycle is essential to successfully accomplish the design and optimization phases.

The LSVC will be realized by the end of 2018 and it will represent a world-class test facility, i.e. 8 m of diameter and 16m long., as reported by Table 3 and pointed out by Figure 10. The baseline concept would foresee the installation of an auxiliary chamber, connected to the main chamber, in order to ease the eventual operations on the engines without influencing the vacuum conditions. The internal liner will be completely cooled and all the most advanced diagnostics devices have been foreseen. The chamber has been conceived to be the largest and most advanced facility in Europe, having a pumping speed of 2,500,000 L/s at least. Having these features, LSVC will allow to significantly improve the present Italian and European testing capabilities. In fact, the largest plant in Europe is represented by IV-10, owned by ALTA-Sitael and built in Ospedaletto (Pisa), and able to reach a pumping speed of about 610,000 L/s. A facility as large and advanced as LSVC will allow to respond to the challenging requirements, demanded by the next future development lines of high power EP thruster. In fact, the facility has been designed by considering engines with power higher than 50 kW and propellant mass of 100 mg/s (Xe) at most as reference thrusters.

Table 3 - Some details about CIRA LSVC

Large Scale Vacuum Chamber (LSVC)	
Dimensions	(ab.) 8 m diam. x 16 m length
Vacuum	Up to 5e^{-7} Pa (ultimate pressure) Lower than 2.5e^{-3} Pa (working)
Applications	Tests on complete high power EPT, solar simulation, thermal simulation, plasma interaction effects on spacecraft, integration of space systems. Equipped with state-of-the-art diagnostics
Reference test article	HET (50 kW class) fed up by Xenon (100 mg/s)

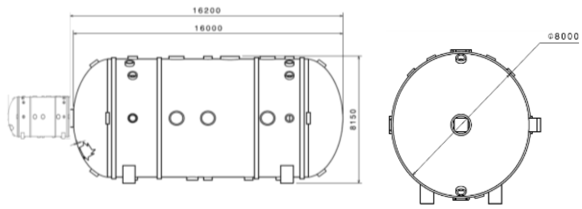


Figure 10 – Preliminary sketch of the LSVC

The LSVC Facility will enable also other important activities, like the following ones:

- Performance characterization, plasma diagnostics and qualification of HET with a power higher than 25 kW;
- R&D activities on high power HET, based on alternative propellants, or other technologies like Helicon and MPD;

- Development of space-qualified hardware in large scale;
- Investigations on the interaction effects of plasma, generated by high power EP thrusters, with space systems and sub-systems (for example, a complete satellite platform, including all the sub-systems);
- Integration of all the power generation sub-systems and relative space qualification (for ex, deployed solar panels);
- Experimental analyses on fundamental physics, interaction of magnetized plasmas (for example, the interaction with solar wind).

All these experimental activities require the investigation on plasma beam, produced by thrusters, in the "very far field" zones [39], as indicated by NASA: the interaction between the thruster plasma beam with high power solar arrays has been studied and the P5 thruster, a 5 kW engine, developed by PEPL and USAF, has been adopted. The investigation is on-going in the VF-5 facility since the plasma characterization for this kind of experimental tests require large vessels, with a length greater than 9 m at least. These activities have been planned in the frame of the programs involving the development of SEP vehicles (Solar Electric Propulsion), having power ranging from 30 kW and 300 kW and destined to Earth-Moon missions and even NEO exploratory manned missions [40].

Together with MSVC, LSVC will enable CIRA to participate to the most important European projects, linked to EPIC Program or next future program and research activities (partnering with ESA, ASI and other Space Agencies). Moreover, together with the MSVC plant, the new test capabilities will be the starting point to co-operate with the most important Italian partners (like ALTA-Sitael, Aerospazio Tecnologie, SELEX-Galileo), international ones (Thales Alenia, EADS-Astrium Space Transportation) research centers and universities (IMIP-CNR, INFN, University of Siena, University of Pisa), involved in EP development.

It is important to underline that the first facility will be ready by October 2017 (MSVC) and the first CIRA-designed EP thruster is foreseen for that time. All the activities linked to the implementation of diagnostics capabilities are moved some months up. Finally, LSVC realization is planned for the end of 2018.

Diagnostics (line 2)

From the point of view of diagnostics, it appears necessary to use both conventional diagnostics and advanced ones for all the proposed types of facilities, also taking advantage of the know-how acquired by CIRA in related fields. The collected experimental data will support the physical modeling and numerical and testing capabilities. Furthermore, both the MSVC and LSVC plants, having a research and development connotation, will offer the possibility of developing new diagnostic than currently available on the world stage. Besides conventional diagnostics (Faraday cups, Langmuir probes, etc.), according to the previous paragraphs, CIRA will acquire and apply advanced methods such as:

a. High speed imaging
b. Doppler Laser Induced Fluorescence
c. Optical Emission Spectroscopy.

Experimental test articles (line 3)

In order to develop CIRA EP capabilities in terms of comprehension of physical phenomena, facility and diagnostics operations, some experimental test articles will be developed. They will be tailored on MSVC and LSVC testing performances. In this context, CIRA has the objective of developing a low power class thruster (hundreds of watt class) and a high power class thruster (tens of kilowatt). The thruster architecture, selected for the development activities, are the Hall Effect thrusters, due to their scalability and the scientific community interest [41]. Both thrusters will follow a technology development phase where different mock-up models will be produced and tested at different level.

Currently the low power class thruster (a 250 W nominal power has been selected) is in a Preliminary Design Review Phase and have been designed according to the criteria reported in [42]. The preliminary version of the thruster is reported in the following picture (thruster external diameter 80 mm). The high power thruster is currently in the conceptual design phase.

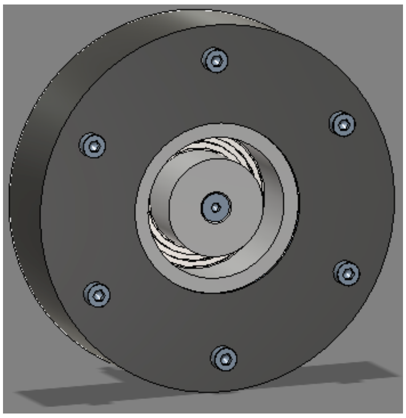


Figure 11 - Preliminary design of CIRHET-250

The roadmap for the development of the thrusters is coherent with the development plan of the facilities and phased with it, as reported in Figure 8.

5 CONCLUSIONS

Electric propulsion is already well established for the use in the aerospace industry to the point that the electrical thrusters have become over time a viable alternative to chemical thrusters. The benefits are mainly related to the obtainable high specific impulse (and consequent fuel savings and reduction in mass), multiple ignitions, thrust modulation, re-usability and capability to be adopted in long-running-time missions or large radii of action (like interplanetary transfers or attitude control and positioning).

Among the technologies used in the field of electric propulsion Hall Effect Thrusters (HET) are the currently most promising class as regards the applicability to satellite systems, due to their reliability and stability of operation. Moreover, at this moment this technology seems to be the most established and, therefore, the most promising for the development of high power solutions (> 50kW). In this perspective, it becomes necessary an intensive testing activities, which requires suitable facilities, aided by the use of advanced diagnostic, able to perform high fidelity performance and long duration tests. Given the gradual increase in power, it should be put in facility, able to test future engines above the class reference current (≈5kW), and currently absent in the European scene. On the other hand, we must not leave out the activities of research and development to guide the maturation of the engines HET and the purely scientific, necessary to investigate new possible technologies.

CIRA, thanks to the ASI significant commitment, will realize two facilities in order to cover the R&D activities for the present class of EP thrusters (up to 5 kW power) by means of MSVC and contribute to develop the next future engines (> 25 kW power) by building LSVC, the most advanced and largest facility in Europe. In this way, a medium scale facility could operate R&D activities and support the other Italian space simulators, commercially oriented. CIRA will also improve know how on Electric Propulsion by developing advanced methodologies of analysis. Moreover, a deeper comprehension of main physical phenomena and consequently thruster optimization criteria will be achieved by means of the coupled use of the advanced diagnostic with physical models.

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