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The ESA Policy and Programme for the Development of Electric Propulsion
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ABSTRACT

ESA interest in electric propulsion began about 20 years ago. This interest has progressively increased resulting in the development of different electric propulsion technologies. In order to meet the propulsion requirements of the next decade, the ESA Electric Propulsion Policy has been recently revised and a comprehensive programme was started in 1987. This ESA policy, the consequent programmes, the results achieved and plans for the future activities are described in this paper.

The paper also explains the rationale behind the ESA Electric Propulsion Programme: the constraints and mission priorities by which the programme has been shaped. The benefits offered by electric propulsion are analysed for the four applications of electric propulsion that are of interest to the Agency:

- north-south station-keeping of geostationary satellites;
- orbit manoeuvring and maintenance of large low-orbiting spacecraft (like the Columbus Man-Tended Free Flyer);
- primary propulsion for interplanetary missions;
- fine pointing, attitude and orbit control of scientific satellites.

The paper then presents a detailed description of the development programmes presently under way in Europe under ESA sponsorship and the plans for the future:

- testing of a multipropellant resistojet for a manned space station;
- testing of a 15 Kw arcjet for orbit manoeuvring and maintenance of low orbiting spacecraft;
- final preparation of the RITA ion engine experiment on the EURECA carrier;
- preliminary studies of a pre-operational ion propulsion system to be flown on the Agency's SAT-2 satellite in 1993;
- preparation of a European primary ion propulsion system for interplanetary missions;
- further development of the Field Emission Electric Propulsion (FEEP) system for fine attitude and orbit control of scientific spacecraft.

INTRODUCTION

The Agency's interest in electric propulsion dates back to the early 70's when basic research work on colloid thrusters and subsequently on the Field Emission Electric Propulsion (FEEP) system was started.

The funds available for this work were rather scarce and limited to the annual allocation from the Agency's (at that time ESRO) basic Technology Research Programme (TRP). During this period most of the research and development work on electric propulsion was performed in Europe with national funds and different systems were independently studied in European laboratories, mostly in universities or research institutes. In the second half of the 70's interest in electric propulsion declined. The ESA activities in European electric propulsion programmes then revived in the early 80's with the sponsorship of new electric propulsion system developments in addition to the ongoing work on the FEEP system. Two factors contributed to this change of attitude:

- the introduction of a new generation of launchers (Ariane and STS) which resulted in an increase in the mass, lifetime and electrical power available on spacecraft;
- the work done during the 70's in various universities and research institutes in Europe led to the development of advanced prototypes of electric propulsion systems ready to be taken up by industry for the final phases of development and commercialisation.

A new phase of ESA-sponsored electric propulsion activities then started, with increased funding. During the period 1980-1987 three major lines of development were pursued under ESA sponsorship in Europe:

- the RIT family of ion engines were further developed in Germany. In particular the RIT-IO system was prepared for a flight demonstration on board the ESA EURECA retrievable carrier. The delivery of the flight hardware is scheduled for end 1988;
- MPD propulsion investigated in Italy concentrated on the pulsed ablative solid propellant (teflon) technology.
- The FEEP system was further developed and in particular its operation in pulsed mode was successfully tested in the Agency's ESTEC facility.

By 1987 the development status achieved and emerging new space missions made necessary a review of the ESA Electric Propulsion Policy. A new phase of development was initiated aimed at making available a new generation of operational electric propulsion systems for ESA missions in the 90's.

The missions envisaged for the next decade will impose increasingly demanding requirements on the propulsion systems of future spacecraft:

- the mass and lifetime of geostationary satellites will be increased;
- large masses of propellant will be required for the propulsion functions of space stations and the associated co-orbiting vehicles and polar platforms;
- challenging interplanetary missions, such as the Comet Nucleus Sample Return (CNSR) mission, will be launched or will reach the final stages of preparation;
- scientific satellites will require increasingly demanding pointing and orbit control capabilities difficult to achieve with currently available propulsion systems.

All these requirements impose a heavy burden on the propulsion systems of future spacecraft and it is foreseeable that, unless more advanced propulsion systems are introduced, the envisaged missions can be performed only at the price of low payload mass ratios.

To cope with these new challenging tasks, the ESA policy on electric propulsion was revised in 1987 and a new development plan defined for each type of electric propulsion system in the Agency's programmes. Considerations were:
1. Possible applications of electric propulsion for European missions envisaged in the next decade. These missions are:
   - north-south station-keeping of geostationary satellites;
   - orbit maintenance and manoeuvring of near Earth space stations, co-orbiting vehicles, polar platforms;
   - orbit manoeuvring for high energy interplanetary missions (e.g. the Comet Nucleus Sample Return mission);
   - fine pointing, attitude and orbital control of scientific satellites.

2. Adoption of a low risk approach: for example arcjets and MPD-arcjets have been preferred to pure MHD thrusters. A pure MHD propulsion system may offer better performance in the long term but at quite a high initial risk. Moreover, while arcjets and MPD-arcjets do not perform as well in terms of system mass savings, they can operate at input power levels of power supplies presently planned in Europe. A pure MHD system would require large power supplies whose requirements are uncertain.

3. Necessity for flight tests, prior to any operational application of a new electric propulsion system: unlike other space powers, Europe has yet not performed flight experiments. The development plans have therefore been devised taking into account the flight opportunities available and in particular those offered by the ESA EURECA retrievable carrier, the ESA SAT-2 satellite and within the ESA Technology Demonstration Programme (TOP).

4. Maximising the use of the know-how available in Europe: this is particularly true for the FEEP system.

5. The limited funds available: this imposes severe constraints to the entire development programme. Although the interest in electric propulsion has substantially increased over the past five years, the funds allocated by Europe to electric propulsion are far less than by the USA and Japan. As a consequence only a limited number of possible options can be pursued and the maximum coordination with European national programmes has been sought.

6. The need for large vacuum test facilities for ground testing and qualification of electric propulsion systems: as a consequence, the thrust (and power level) of the thrusters has been limited by the vacuum plants available.

An overall review of the ESA policy on Electric Propulsion is given in Chapter 1. Chapter 2 contains a more detailed description of the ongoing activities, of the results which have been achieved and of the future plans for each of the development lines pursued in Europe under ESA monitoring or sponsorship.

1. OVERALL REVIEW OF THE ESA POLICY ON ELECTRIC PROPULSION

The four main applications adopted for this policy are reviewed.

1.1 North-South Station-Keeping of Geostationary Satellites

Many studies have been performed (Ref. [1], [2] and [3] are typical examples) to determine the operational scenarios and the mass/cost benefits of electric propulsion for north-south station-keeping.

![Figure 1: North-South Station Keeping of Geostationary Satellites. Mass savings offered by electric propulsion systems. (Sources: Ref. [1],[2],[3])](image-url)
The results of these studies show that:

- arcjets, electrostatic engines and MPD systems are all potential candidates for north-south station-keeping applications;
- each different electric propulsion system offers the best mass saving for a specific range of satellite mass and lifetime. Arcjet thrusters operated at about 1 KW input are competitive with ion engines for medium size satellites (about 1000 Kg beginning of life (BOL) mass) with a lifetime lower than 10 years. Because of the larger input power required and the associated larger dry mass, ion engines find their application on medium/large satellites with a BOL mass larger than 1000 Kg and lifetime longer than 5 years. Ion engines will then provide mass savings between 10 and 15% of the spacecraft BOL mass. Similar mass savings can also be achieved by MPD thrusters operating in pulsed mode.

The application of electric propulsion systems for north-south station-keeping of telecom satellites has the highest priority in the Agency’s electric propulsion programme. Most of the effort so far has been spent on ion engines which over the past years have been subject to a continuous development and have reached an advanced status. Two major milestones are presently planned to ensure the thruster and of its power conditioning systems: reliability.

The test flight of the RITA experiment on the ESA EURECA retrievable carrier. The RITA experiment has been developed from the RIT-10 thruster and its delivery for integration on the carrier is planned for the end of this year. The flight is expected to take place in 1991-1992 depending on the final flight manifest of the STS [4].

The Agency is presently actively engaged in studying the opportunity of flying a pre-operational ion propulsion system on the ESA SAT-2 satellite whose launch is planned for 1993. For this application both the RIT-10 thruster developed in Germany and the UK-10 thruster developed in the United Kingdom are candidates [5].

1.2 Near Earth Missions

The next decade will probably see the launch of several near Earth missions. These will include low orbiting satellites for Earth observation and space platforms and stations such as those associated with the ESA Columbus project. The propellant masses associated with the orbit acquisition are rather large and maintenance of this type of spacecraft is extensive and the role electric propulsion can play is therefore significant. Although it may be difficult to identify at this point what will be the first application of an electric propulsion system for near Earth missions (because of the large spectrum of possible missions and the associated propulsive requirements), nevertheless a few points have been recognised:

- Arcjets (and in a more distant future MPD-arcjets) offer substantial benefits for orbit acquisition and maintenance of future near-Earth platforms like the ESA Man-Tended Free Flyer. The mass saving offered by an arcjet system in the orbit maintenance of a space station co-orbiting vehicle (17000 Kg spacecraft mass, 6 year mission) amounts to 1500-2000 Kg [6], [7].

- When compared to ion engines, arcjets are also attractive for the following reasons:
  - Power/thrust ratio is lower than that of ion engines and the input power is compatible with the capabilities of the power supplies presently envisaged (15 Kw). The thrust level is also higher, allowing the use of the arcjet system not only for drag compensation but also for orbit acquisition.
  - Hydrazine can be used as propellant, allowing commonalities with the other propulsion systems.
  - Liquid phase storage of high vapour pressure propellants can be used (e.g. ammonia).
  - The thrust density (thrust/area ratio) of an arcjet is comparable to that of chemical systems (much higher than that of ion engines), thus allowing for compact thruster assemblies and for simpler integration on the spacecraft.
  - The inherent simplicity of the arcjet thruster and of its power conditioning unit results in potentially higher reliability.

The use of MPD propulsion, although attractive in terms of propulsive performance and intrinsic simplicity, is still hampered in Europe by the lack of adequate power supplies in the range of 100 KW and above. Considering the limitations imposed by the power available, the so-called MPD-Arcjet appears presently as a logical step between the arcjet and the high specific impulse devices like ion engines and pure MPD thrusters. The development of MPD-arcjets is still at laboratory level and much work is still required.

Large masses of waste gases will be freely available from the Environment Control and Life Support System of the manned space station making the use of multi-propellant resistojets highly attractive [8].

Based on the points listed above, the ESA policy for the use of electric propulsion for near earth missions can be summarised as follows:

- to develop an arcjet thruster for orbit manoeuvring and maintenance of space station co-orbiting vehicles like the ESA Man-Tended Free Flyer. The thruster so far envisaged is a 15 KW thruster able to operate with Hydrazine as propellant [9];
- to initiate basic research work on MPD-arcjet thrusters which are regarded as a future replacement of arcjets as more powerful power supplies are made available. The development of the arcjet will also benefit from this basic research work on the fundamental mechanisms of thrust generation in electrothermal/electromagnetic thrusters;
- to complete the performance characterisation of the multi-propellant resistojet under investigation in Germany under ESA sponsorship. The future of the ESA resistojet programme is strictly linked to the definition of the European independent manned space
station and therefore future development plans are still uncertain.

1.3 Interplanetary (High Energy) Missions

ESA is presently engaged in planning the next interplanetary missions such as the Comet Nucleus Sample Return (CNSR). All the missions so far investigated are extremely demanding and can be fully accomplished with chemical propulsion only through complex planetary "swing-by" manoeuvres. Electric propulsion systems, such as ion engines and MPD thrusters, with their high specific impulse, represent the only possible alternative to these complex "swing-by" manoeuvres which impose tight constraints to the mission and its launch windows. High thrust ion propulsion systems have been under development in Europe for several years. Their development status is more advanced than that of pure MPD systems and their efficiency higher. On the other hand, MPD systems can claim a higher simplicity and overall compactness. In general it is possible to state that ion engines can perform the primary propulsion function of near term low thrust interplanetary missions, while MPD systems might be more advantageous for interplanetary missions requiring high thrust levels (more than 1-2 Newtons) and consequently high power supply systems, which are presently still under development.

Large ion engines (with a thrust of about 200 mN) are under development both in Germany (RIT 35) and in the United Kingdom (UK 25). The Agency intends to intensify its efforts towards the development of a Common European Primary Propulsion System and therefore a coordinated programme is being set out in order to harmonise the capabilities existing in Germany, the United Kingdom and Italy [10], [11].

The first milestone of this European programme should be the testing, by 1991, of an engineering model of the thruster coupled to a functional demonstration model of the positive high voltage power supply.

1.4 Ultra-Fine Pointing, Attitude and Orbit Control of Scientific Satellites

The application of the field emission principle to electric propulsion has resulted in the development under ESA sponsorship of a high specific impulse ion thruster called FEEP (Field Emission Electric Propulsion). This activity was started in 1972. In 1987 the operation of a FEEP thruster in pulsed mode was successfully demonstrated, opening up a new field of application for this type of electric propulsion: the fine pointing and attitude control of scientific satellites [12], [13].

The test results from the ESTEC electric propulsion laboratory and from the main ESA Contractor over the last 2 years have confirmed the original expectations and a flight demonstration is now regarded as the next milestone towards the qualification of an operational system. To this end a new phase of development was started in March 1988 with the objective of performing a FEEP System Validation Test in 1991. This test will represent the first attempt to evaluate the performance of the entire FEEP system by assembling the hardware items developed and tested separately during the preceding phases.

2. Review of the ESA-Sponsored Electric Propulsion Activities in Europe

2.1 Resistojet

A preliminary investigation of a multipropellant resistojet thruster was undertaken by MBB-ERNO Bremen under ESA contract in 1987.

The performance of the thruster with different propellants as well as the thruster lifetime will be assessed.

The technical specification for the thruster has been devised considering the drag compensation of a manned spacecraft orbiting between 485 and 525 km altitude with a 350 square metre solar array. The main thruster characteristics are summarised as follows:

- Propellant: carbon dioxide
- Thrust: 0.3 N
- Power/thrust ratio: lower than 1.15 KW/N
- Specific impulse: higher than 137 s
- Total operating time: 3000 hours

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Figure 2: MBB-ERNO/ESA Multipropellant Resistojet, Thrust Unit
The running contract will be completed by the end of 1988 and includes:

- design and manufacturing of a multipropellant thruster;
- definition of the interface between the thruster and the other propulsion system elements;
- set-up of a laboratory power-conditioning and control unit;
- performance mapping tests of the thrust unit (thruster and propellant control valve) using different propellants (carbon dioxide, ammonia, nitrogen, hydrogen and methane);
- lifetime evaluation test for at least 300 hours using carbon dioxide as propellant.

The thruster design features a heat exchanger made of platinum alloy and a separate heater made of rhenium alloy. In order to gain preliminary information on the thruster performance, to gain confidence in the thruster design and to set up the test facilities, a stainless steel heat exchanger has been initially used and cold and hot tests were performed early in 1988 using nitrogen as propellant. The test results confirm the original expectations and important lessons on the detailed design of the thruster have been learnt. These lessons will be incorporated in the updated version of the thruster with the platinum alloy heat exchanger. This thruster will undergo a performance mapping and lifetime evaluation test programme between September and December 1988.

The future of the ESA resistojet programme is linked to the definition of the independent European Space Station and in particular to the configuration of its Environment Control and Life Support System. Further development work will therefore be suspended until the Agency's policy for a permanently manned space station is determined.

2.2 Arcjet Thrusters

Most of the efforts are presently focussed on the development of an arcjet system optimised for the orbit manoeuvring and maintenance of low Earth orbit spacecraft. This work would lead by 1992 to the testing of advanced models of a radiatively/regeneratively cooled thruster.
whose technical specification has been defined by the Agency as follows:

Thrust: up to 1 N
Input power: lower than 15 kW
Specific impulse: in the range 800-1200 s
Propellant: decomposed hydrazine, ammonia

In order to achieve the final target, the following activities have been planned with SNIA-BPD as the main contractor and the Universities of Stuttgart and Pisa as sub-contractors:

- design, manufacturing and testing of two water-cooled thrusters for the optimisation of the thruster geometry and operating parameters. The first of the two thrusters is presently being tested at the University of Stuttgart while the second thruster, based on the results from the first one, will be designed, manufactured and tested at SNIA-BPD in Italy. Besides the two propellants specified above, the thrusters will be also tested with hydrogen, nitrogen and hydrogen/nitrogen mixtures;
- design, manufacturing and testing of a flight oriented radiatively/regeneratively cooled arcjet thruster based on the data gathered from the water-cooled models. Besides the performance mapping tests this thruster will eventually be tested for an evaluation of its lifetime;
- upgrading of the vacuum test facilities at the SNIA-BPD plant in Colleferro (Italy) to test up to 1 Newton arcjet thrusters with a background pressure lower than about 1.5x10^-2 torr [14];
- set up of non-intrusive optical plume diagnostic instrumentation.

These activities were started in 1987 and the design and manufacturing of the first water-cooled thruster was completed at the University of Stuttgart. A first phase of tests on the first model was started in August 1988 and it is expected to be completed early in 1989. The design of the vacuum test facilities and the plasma diagnostic system has also been completed [15].

In parallel to the experimental activities outlined above, the development of mathematical models is presently being carried out at the University of Stuttgart under ESA contract. Two mathematical models have so far been set up, the "dual channel mode" and the "mixing model". In this first phase of development only hydrogen has been studied as propellant. It is intended to extend the two models for other propellants such as nitrogen, argon and hydrogen/nitrogen mixtures [16].

The objective of the programme outlined above is to make available by 1991-1992 an advanced model of the arcjet thruster. A flight demonstration of the arcjet system will be the next step and in this context flight opportunities are already being investigated within the Agency's in-orbit Technology Demonstration Programme (TDP).

2.3 MPD-Arcjet and MPD Thrusters

Since 1980 ESA has been engaged in the development of solid propellant (Teflon) pulsed thrusters, laboratory models of which have been extensively tested by SNIA-BPD in Italy [17]. In order to complete this characterisation phase of the thruster performance a very limited programme has been planned. This will include:

- performance testing of an axially fed thruster in a quasi-steady mode (pulse width shorter than 1 ms with direct coupling to the condenser tank);
- design and testing (again in the quasi-steady mode) of a radially fed thruster.

After completion of the tests described above the two thrusters (the axially fed and the radially fed) will undergo a life evaluation test for not less than 10,000 pulses.

Both MPD-arcjet and MPD gas fed thrusters will also be designed and tested. This part of the programme is mainly intended as basic research work aimed at a better understanding of the physical mechanisms governing the thrust process in electrothermal/electromagnetic thrusters. The funds allocated are much lower than those used for the arcjet thruster and maximum commonality has been sought between the two lines of development in terms of testing equipment. Two different types of thruster will be investigated: the first thruster will be a flared anode MPD-arcjet thruster and will be designed and tested at SNIA-BPD; the second thruster will be of the ring anode type and will be a pure MPD thruster. This second thruster has been designed and will be tested at the University of Pisa under sub-contract from SNIA-BPD.

2.4 Ion Engines for North-South Station-Keeping

The major ESA milestone in this application for electric propulsion is represented by the final preparation of the RITA experiment on the ESA EURECA retrievable carrier.

Delivery of the flight hardware is planned to take place by the end of 1988. The launch of the EURECA spacecraft by the NASA STS is planned in 1991-1992.

Preparation of the flight hardware, based on the RIT-10 thruster, was initiated by MBB-ERNO in Ottobrunn under ESA contract in 1985. During the last three years the engineering model of the entire experiment has been developed and tested. In particular, a dedicated Power Conditioning Unit and a Digital Automatic Control Unit have been tested together with the flight software. Over the past year the engineering model of the experiment has undergone a series of tests to assess the
During operation in space, the experiment will be operated for 1500-2000 hours (depending on the EURECA mission duration) at different input power levels ranging between 230 and 440 watt.

The RITA experiment represents the first step towards an operational ion propulsion system for north-south station-keeping of commercial geostationary satellites. As a next step in this direction the Agency is pursuing flight opportunities for a pre-operational system. The Agency is presently examining the flight of an operational system on the ESA SAT-2 satellite. The SAT-2 technology mission comprises a spacecraft to be launched into geostationary orbit in 1993 to demonstrate the feasibility of:

- inter-orbit and inter-satellite links at optical frequencies;
- L-band land mobile voice communication;
- S-band inter-orbit links for single access (SSA) experimental data relay service;
- on-board processing of communication traffic;
- inter-satellite and inter-orbit links, as well as fixed services and propagation experiments at extremely high frequencies.

The SAT-2 satellite will have a mass at launch of about 2000 Kg and is planned to be launched by an Ariane-4 launcher. The mission duration will be 5 years.

System studies for the application of an ion propulsion system to north-south station-keeping were started in 1988. In order to achieve the necessary redundancy and the maximum industrial return from this mission, the ion propulsion system presently envisaged for this application is based on the parallel use of the German RIT-10 thruster and the British UK-10 thruster [18], [19].

In the meantime the RIT-10 neutraliser has been subjected to an extended lifetime test of 2000 hours and so far a total of about 1500 hours has been clocked. The flight hardware is presently undergoing the final preparation. Before delivery the entire experiment will undergo a final qualification test programme which will include vibration and electromagnetic compatibility tests and a functional test of the entire experiment under vacuum conditions.

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Figure 7 - RITA Experiment on EURECA. Development Plan

Figure 8: UK 10 Ion Engine
2.5 Ion Engines for Primary Propulsion

Two development programmes are underway in Europe in the area of large ion engines for primary propulsion, one in Germany and the other in England [20]. The German programme is led by MBB-ERNO in Ottobrunn with the University of Giessen providing scientific support [21]. This programme is centred on a 35 cm diameter version of the RIT family thrusters, the so called RIT-35.

The vacuum test chamber at Culham has also been improved with a cryogenic system to allow testing of large ion propulsion systems.

In order to unify the two development programmes conducted in Europe and make available a European ion propulsion system for interplanetary missions [22], ESA has started a coordinated development work in 1988 which will harmonise the work done in the Member States on the thruster and other elements of the propulsion system (propellant storage and management system, power conditioning and control unit).

A major milestone has been identified for 1993/94 with the performance of a lifetime test of the engineering model of the entire ion propulsion system. A new series of activities has begun in 1988 for completion in 1991/92. This will include:

- set-up of comprehensive evaluation criteria for thruster selection;
- thruster selection (RITA-35 or UK-25);
- design and manufacturing of the engineering model of the selected thruster;
- characterisation of the thruster performance with xenon propellant and with a new set of dished grids;
- similar development work has been performed in the United Kingdom on the UK-25 thruster by the Culham Laboratories, leading to a full performance characterisation of the thruster with xenon and to the development of a new grid perforation technique.

Figure 9: RIT 35 Ion Engine

Figure 10: UK 25 Ion Engine
German national activities

RIT 25
AGORA + EPM ESA

RIT 25 Hz + 2× DISHEG GRIDS

Life Time Test (6000 hrs) Proplant Maneg. Sys. PCU - EM
Thruster choce System definition EM of Thruster BB of HV- PCU Functional tests

UK 25
British national activities

82 83 84 85 86 87 88 89 90 91 92 93

Figure 11 - European Coordinated Primary Propulsion System

- study and selection between the digital and analogic propellant flow controllers and design of the selected concept;
- design and manufacture of a positive high voltage converter breadboard;
- parametric mapping and extended performance verification tests.

2.6 Field Emission Electric Propulsion

Since the early 1970's ESA has developed high specific impulse electrostatic thrusters based on the principle of field emission. After an initial phase of basic laboratory investigation which led to the present configuration of the linear slit emitter, further activities were undertaken for the industrialisation of a FEEP system with in-house activities performed in the ESTEC Electric Propulsion Laboratory, and with SEP in France as the main contractor [23]. The work up to 1987 was dedicated to a system operated in continuous mode with different emitter lengths.

![FEEP Emitter](image)

Figure 12: FEEP Emitter

The main performance of the thruster is summarised as follows:

- Emitter length (cm) 8.0
- Emitter depth (cm) 2.4
- Emitter thickness 0.8
- Slit width (micron) 1.1
- Thrust per unit length (mN/cm) 0.3
- Power-to-thrust ratio (W/mN) 55

Specific impulse (Ns/Kg) 60000
Mass efficiency 60%
Transmission efficiency 99%
Power efficiency 98%

In 1987 tests performed at ESTEC have proved that the FEEP system can easily be operated in pulsed mode with a very high pulse repeatability [24]. This has opened a new range of applications for FEEP: the fine attitude and orbit control of scientific spacecraft for:

- astronomy missions (e.g. FIRST, Space Telescope);
- geopotential research missions;
- optical interferometry.

All these missions require a very fine attitude (milli arc seconds) and orbit control (relative positioning of several satellites to millimeter accuracy); a domain of application on which the FEEP system can claim several advantages compared with chemical and other electric propulsion systems:

- continuous thrust throttling from zero to maximum value;
- small impulse bit;
- instantaneous switch-on/switch-off capability;
- mechanical and electrical simplicity;
- thruster clustering capability (to any desired thrust level).

Besides the activities performed in house at ESTEC, the FEEP programme is being conducted under ESA contract at SEP in France, FIAR in Italy, Fulmer Laboratories in the United Kingdom and at the Universities of Pisa and Vienna [25], [26]. The development status of the system is summarised as follows:

- the emitter geometry has been optimised and its operation in pulsed mode has been tested;
- a plasma bridge neutraliser has been successfully tested at SEP for 600 hours;
- a demonstration model of the propellant system has been manufactured and tested by SEP under ESA contract;
- a high voltage breadboard of the power supply has been completed by FIAR in Italy.

The test results so far achieved have confirmed the theoretical performance of the FEEP system. A flight demonstration of the entire system is now regarded as the next milestone towards the qualification of an operational system. To this end a fifth phase of development has been started with the main objective of performing by 1991 a FEEP system validation test.

This test (to be performed in the new vacuum chamber of the ESTEC Electric Propulsion Laboratory) will represent the first attempt to evaluate the performance of the entire system at breadboard level, by assembling the hardware items developed and tested separately during the preceding four phases.

For this fifth phase, four major tasks have been identified:
Figure 13 - FEEP Propulsion System. Development plan

- system studies for fine attitude and orbit control and a configuration study for a FEEP flight demonstration;
- development of new emitter technologies;
- investigation of new types of neutralisers;
- performance of the FEEP system validation test.

3. CONCLUSIONS

After 30 years of research and development work, electric propulsion is slowly approaching full operational status. As far as the European scenario is concerned, it is possible to formulate some predictions on future applications of electric propulsion: ion engines will be operational both for NSSK and, as primary propulsion systems, for planetary missions; while small ion engines for north-south station-keeping might achieve this operational status by the mid 90's, larger ion engines for primary propulsion might be available in the second half of the 90's; arcjet thrusters offer many advantages for orbit acquisition and maintenance of near earth orbiting spacecraft and might also become operational in the second half of the next decade. They might be replaced in the more distant future by MHD-arcjets and MHD engines whose development in Europe is hampered for the Space Station. Inert Gas Performance of the RIT 35 Main Arcjet System. Development plan

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