ESAIL D4.6.3
Cost assessment for industrial production

Work Package: **WP 4.6**

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0. Scope

This document outlines the envisaged thruster development and production roadmap and presents a first estimation of the recurring costs for industrial-scale ionic liquid FEEP production.

1. Introduction

The ionic liquid FEEP thruster represents an advanced in-space propulsion technology that would enable much more effective exploration of our Earth-bounded orbits and of the solar system. This specific technology is particularly suited for small scale missions (e.g. nano-micro-spacecraft) or as a component of a large thruster array (e.g. ESAIL full scale mission). Adopting such a technology on a small spacecraft would permit to plan missions to "fly anytime, anywhere, and complete a host of science objectives at the destinations" [AD-4].

This technology would profitably fit into a portfolio of propulsion technologies to be developed to provide optimum solutions for a diverse set of missions and destinations.

Currently the ionic liquid FEEP thruster is a TRL 5 technology and a further development effort is the first step required to reach at least TRL 7: "System prototype demonstration in an operational environment".

Additional steps would be the thruster qualification and in-space testing (TRL 9) before starting an industrial-space production where the production line, quality procedures and acceptance tests would represent the major cost.

2. Applicable documents

AD-1: "Part B: Description of Work" of final EU E-sail application (final version)

AD-2: D4.6.1 Simplified FEEP design report (project deliverable)

AD-3: D4.6.2 Simplified FEEP test report (project deliverable)

AD-4: In-space Propulsion system roadmap; Technology area 02, NASA report, April 2012

3. Development and qualification

The ionic liquid FEEP thruster unit is at an early stage of its development process.
After the current phase a further development is required to reach TRL 7.
This phase might last some 4 years requiring additional 2 M€.

Afterwards the qualification phase, which may last up to one year, is foreseen. The duration of this phase is heavily dependent of the specific requirements the thruster units must have. Assuming the current thruster requirements [AD-2], i.e. lifetime of 5 years, total impulse of 2040 Ns and no constraints on the thrust noise and on the specific impulse, 1 M€ are considered to be sufficient for the complete thruster qualification.

After this phase the cost of the principal thruster unit components can be more precisely assessed identifying also the recurring cost for a large scale production.

The costs here given are based on the current thruster unit design and the development level reached so far. The major efforts dealt with the thruster unit design and with the test activities to assess the fundamental performance. The following steps would deal with the realization of the engineering model of the electronic unit designed and realized in this project as breadboard and the complete thruster unit critical design review and testing (including also the electronic and control unit). Afterwards the qualification phase can take place.

Starting from the achievement reached under the ESAIL program, the next step for the IL-FEEP thruster development is to freeze the thruster design and the system requirements with a PDR. Starting from this the system can be prepared for a CDR within 18-24 months and for the QR in approximately 3 years.

Figure 1 shows a rough IL-FEEP development timeline.

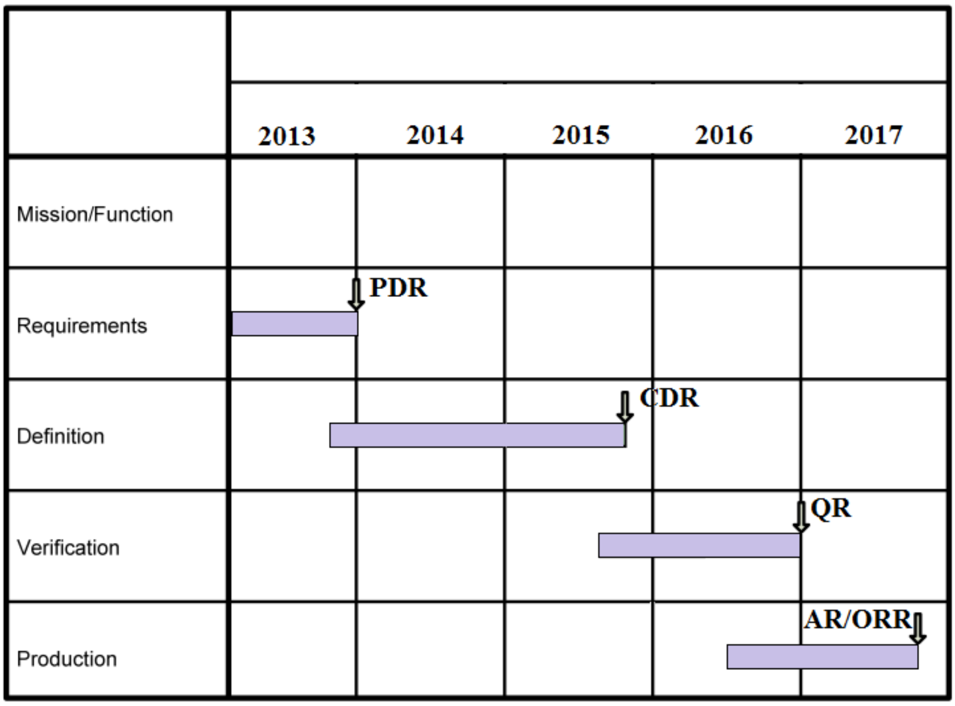

Figure 1: Rough IL-FEEP project life cycle

4. Industrial-scale cost assessment

For this phase the main costs will be divided between thruster unit raw components and production line design and set up.

In the early production phase, and for a limited number of units (eg. <10), the preparation and development of a suitable production line would represent the largest cost.

Ad-hoc facilities design and procurement and specific procedures identification and application are the first steps to assure a space qualified production line.

The already qualified devices obtained from this industrial-scale line would eventually undergo acceptance tests. These might aim at assessing the unit functionality and for some random samples, also the thrust characteristics (functional tests in vacuum chamber). These are additional costs to be considered and assumed to be divided among the number of units delivered. As a consequence the larger the number of thruster units required, the lower their recurrent cost.

The raw material required for each unit would represent only a marginal cost for a massive production (>50 units). The material procurement can be divided between electronic equipment cost and mechanical cost.

The electronic and control unit would cost only some k€ of raw material mainly devoted to the LV/HV switch that can be, as used for the current test campaigns, a commercial unit or can rely on a space qualified devices developed on purpose (where also a dedicated radiation shielding system might be included).

For the raw material of the thruster unit, instead, only machined parts are required and once the complete thruster has been designed and qualified only some a few k€ of material might be sufficient. In this case the largest cost would be the one of the thruster emitter. This is the most critical elements and special attention (thus additional costs related to post inspection and unit acceptance) is required for the surface planarity, the slit linearity and the surface finishing. As a result a single unit cost will be only marginally composed by the raw materials, but also the costs of the production line and of the procedures definition and implementation must be considered.

Assuming to deliver 100 thrusters, the number required for a full scale ESAIL mission, the single unit might cost between 30 and 50 k€. The cost is of course much higher, 200-400 k€, if only a few units would be required.

Since also the timing might become fundamental, in case of multiple lines are required a single unit would cost some 20-30% more, but starting from a qualified device all units would be ready in less than 3 years for the beginning of the production.

5. Conclusions

The ionic liquid FEEP and the ESAIL concepts are both advanced propulsion technologies enabling completely new missions. The ionic liquid FEEP might be the key technology to face the ESAIL technical challenges [RD-4]:

- Quantification of thrust magnitudes with on-orbit data.
- Demonstration of non interfering centrifugal deployment of multiple wires from a single spacecraft.
- Validation of current collection and electrostatic propulsion from the solar wind.
- Validation of electrostatic attitude control in the solar wind.

Moreover the ionic liquid FEEP thruster would help to develop control laws for the ESAIL full scale mission attitude control and wire spinning tuning.

The ionic liquid FEEP technology, however, represents an advantage also by its own. It might enable maneuvering capabilities in nano- micro-spacecraft were just ballistic trajectories are allowed so far. In addition the same technology might also fill the gap for more advanced propulsion technologies (e.g. the ESAIL full scale mission) allowing for a subscale space validation. For instance a small ESAL mission flying outside the Earth magnetosphere might be powered by a set of ionic liquid FEEP thrusters and the ESAIL conductive wires considered as the scientific payload.

All in all the current cost assessing for an industrial scale production leads to assume that for a full scale ESAIL mission, where approximately 100 thruster units would be required, a 5 M€ project would be sufficient to develop the industrial scale production line and the appropriate procedures to delivers all the units required in 3 years.