iFACT

Iodine Fed Advanced Cusp field Thruster

D2.8 – iFACT System Definition

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Abstract

The iodine fed Advanced Cusp Field Thruster programme develops different building blocks in order to enable efficient and affordable space propulsion. Key technologies are the iodine as highly dense, solid propellant, which enables unique and simple propellant feeding architectures, the advanced Cusp Field thruster that couples good

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efficiency with simplicity, novel neutralizer technologies such as the use of Calcium aluminates and simplified but robust space electronics tailored for high manufacturing rates.

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Acronyms and Terminology

Term	Definition
ACFT	Advanced Cusp Field Thruster
C12A7	12CaO.7Al2O3, [Ca12Al14O33]4+ 4e- calcium aluminate with cage-structure, whereas oxide ions are partially substituted by electrons
EPS	Electrical Power System
EPSS	Electric Propulsion Subsystem
iFACT	iodine Fed Advanced Cusp Field Thruster
Isp	Specific Impulse
LaB6	Lanthanhexaborid
PPU	Power Processing Unit
PTTR	Power To Thruster Ratio
TTPR	Thrust To Power Ratio

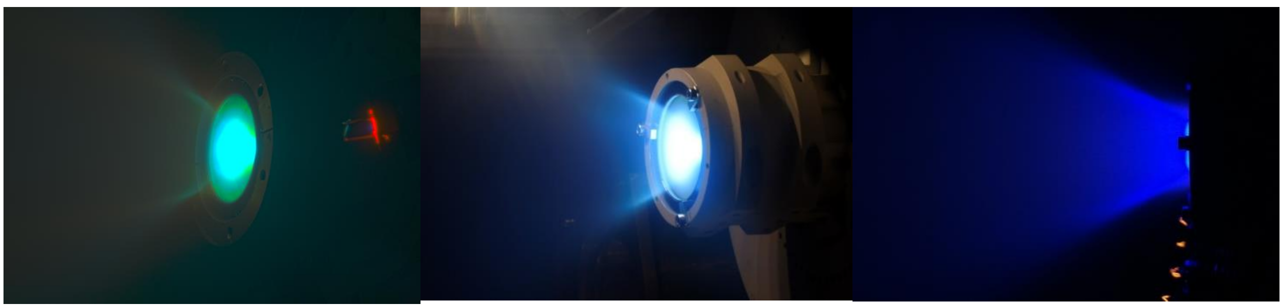
1 Overview

Electric propulsion, with its high mass efficiency, became an enabler to improve the cost efficiency of satellites, especially with respect to launch costs, because it allows the launch of more satellites per launch vehicle instead of one. So far, the savings have been potentially eaten up by the additional costs of the electric propulsion system, which are mainly influenced by the complexity of the required electronics (PPU) and the high cost of the xenon propellant.

The iodine Fed Advanced Cusp field Thruster (iFACT) aims to disrupt the cost of electric propulsion by combing different building blocks to a single subsystem. They are:

- iodine as disruptive propellant for electric thruster,
- the Advanced Cusp Field Thruster (ACFT) as disruptive thruster principle,
- novel cathode concepts featuring,
- calcium aluminate (C12A7) as disruptive, low-work function emitter material for cathodes,
- significant reduction and simplification of the PPU required.

Since many years xenon is the propellant of choice for electric thrusters, because it is inert, non-toxic, has optimal plasma properties and can be used with different thruster technologies and different cathodes. Moreover, heritage has been created since decades with xenon fluidic systems, storage technologies and in-space use. But, the comparable low worldwide production rate of xenon, strongly coupled with the Linde-process and strong competition with other users makes it not affordable and sometimes not available, as well. In addition, as all novel gases, it must be stored as pressurized gases, which makes xenon fluidic and storage subsystem comparably heavy. A potential solid alternative, with good plasma properties, which is widely available is iodine. In general, Iodine is not new to the electric propulsion community, but so far a sufficient testing infrastructure and feeding systems capable for multi kilogram use of iodine during thruster operation and testing is not available. iFACT will change this by demonstration of multiple thousands hours of iodine firing. We aim toprovide an iodine feeding system with the best total impulse to weight ration possible.



a) Iodine b) Xenon c) Krypton

Figure 1-1: Picture of the Advanced Cusp Field Thruster firing with different propellant. The thruster has been tested with iodine, xenon, krypton and other propellants.

This fluidic system will be coupled with a novel thruster technology that is developed by Airbus. The so called Advanced Cusp Field Thruster (ACFT) is especially designed in order to achieve the lowest complexity but also high efficiency. The thruster has been already operated with different propellant as presented in Figure 1-1. Image a) shows an iodine discharge, in b) a xenon discharge and in c) a krypton ion beam is shown. With these propellants the thruster shows an excellent performance and operational stability.

The very first Advanced Cusp Field Thruster proof of principle has been built and tested in 2017. Figure 1-2 presents an overview of the test articles that have been developed. The Mk 1.5 thruster, shown on the right side of Figure 1-2, has been developed within the iFACT programme. It includes all lessons learned from the precursor developments.

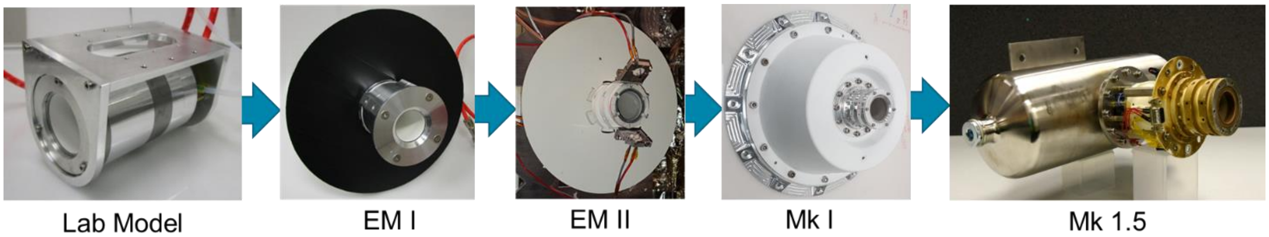


Figure 1-2: Overview of the ACFT models developed by Airbus in Friedrichshafen. Starting with a laboratory model, different test articles have been built and characterised. The latest version developed under European Commission funding is the so called Mk 1.5 thruster, which is shown on the right.

2 Subsystem Description

As other EP devices, the ACFT requires a high voltage input, cathode for neutralisation and a propellant that can gets ionised.

The iFACT subsystem includes all building blocks required to operate an electric thruster in space, namely a thruster, a cathode, propellant feeding and storage and a power processing unit. All of these components are developed and tested within the iFACT programme. Figure 2-1 presents an overview of the general subsystem architecture. In general, the subsystem is designed to be as simple as possible and tailored for the iodine propellant. This means that the number of components is low and in-particular the electrical interfaces are reduced.

The ACFT does not require a precisely regulated high voltage and moreover, the iodine flow rate is controlled via the heater power with the anode power as set point. Hence, neither the high voltage generation nor the iodine flow rate control requires a complex system featuring a FPGA, ASIC or micro-controller with a digital interface. Therefore, dedicated control functions are moved towards the satellite platforms controlling system and the on-board computer, which by design already incorporate the required functionality, i.e. thermal control and power monitoring.

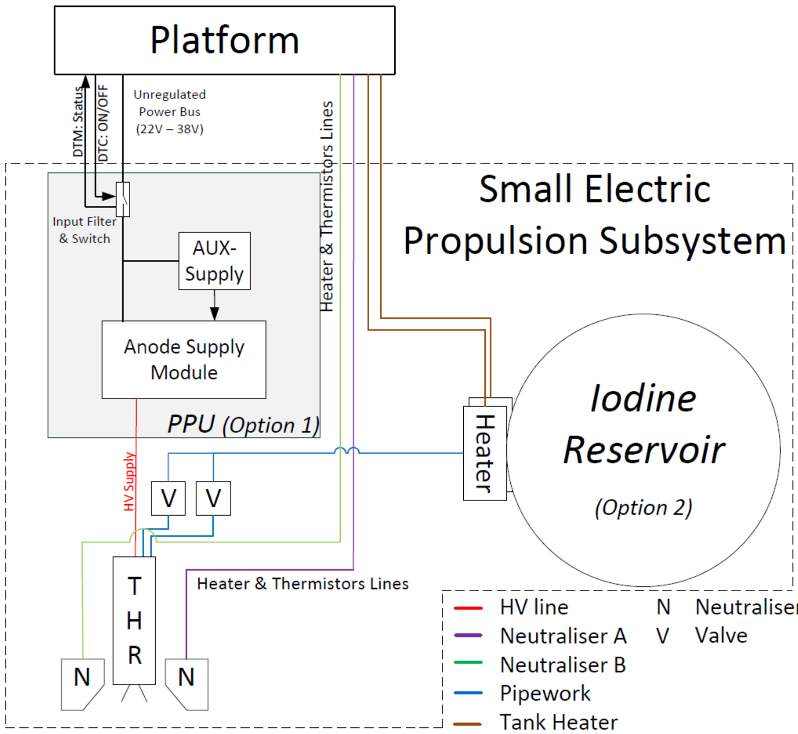
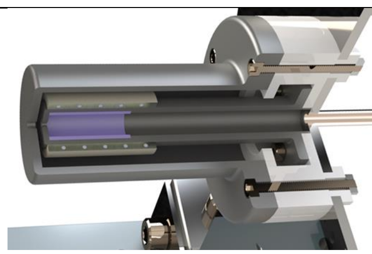
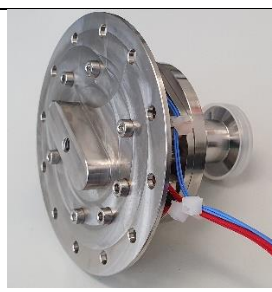
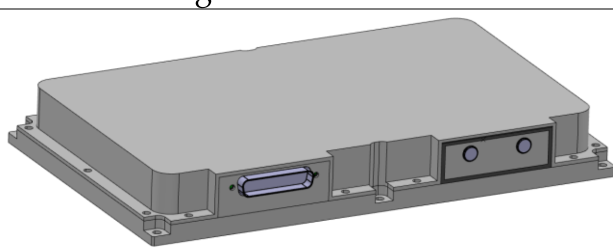


Figure 2-1: Functional block diagram of the simplified electric propulsion system based on the Advanced Cusped Field Thruster. The system includes the thruster, two cathodes, for redundancy, a simplified PPU and an iodine propellant feeding system.

Table 2-1 provides an overview of the different building blocks developed within the iFACT development programme and their specific features.

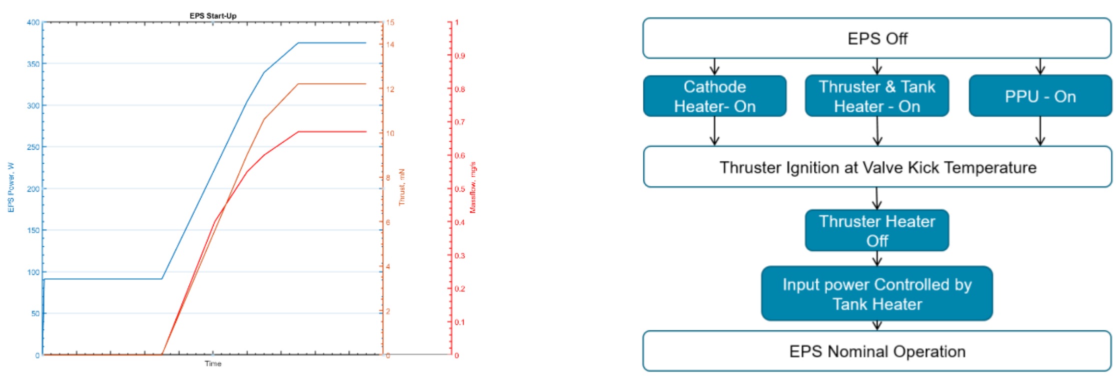
Table 2-1: Overview of the developed iFACT building blocks, which forms the iodine Fed Advanced Cusp Field Thruster electric propulsion subsystem.

Building Block	Features
 Thruster	• 300 W anode input power • 12 mN nominal thrust • 5 % to 135 % throttle range
 Cathode	• Iodine compatible design • Operable with different low function emitters • > 1 A discharge current possible
 Iodine Feeding	• Iodine compatible • Clogging free design • designed for 1 MNs total throughput • Passive valves do not required electrical actuations
 Power Processing Unit	• Full planar design • Minimum number of electrical components used • Input Voltage 28 V to 35 V • 92 % efficiency • > 300 W output power

The overall subsystem design is tailored for simple operation. It makes further use of the thermal losses, which taking place at the thruster during operation in order minimise the heating power required in order to evaporate and feed the iodine into the subsystem.

Figure 2-2 and Figure 2-3 illustrating the operation sequences of the EPS. As mentioned earlier, the overall control relies on thermal management, i.e. that the platform can switch on or switch off the thruster by activating or de-activating the heaters attached to the thruster, cathode and tank.

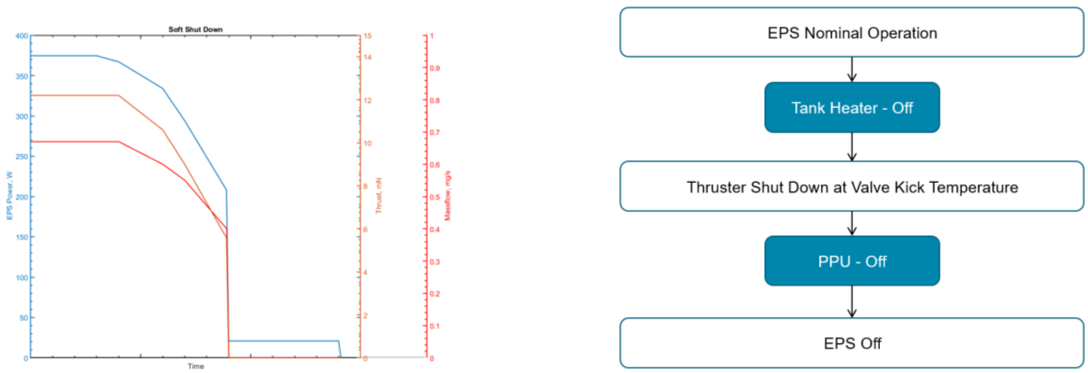
For thruster ignition all nominal heaters and the PPU must be switch on, thus high voltage is provide to the thruster anode, cathode emitter starts to become as hot as required in order to emit electrons and the thruster and feeding temperature rise until the valve kick temperature is reached and the iodine flow starts, as shown in Figure 2-2. At this kick temperature the iodine flow starts, that leads depending on the cathode technology used, to cathode ignition followed directly by the thruster ignition. The EPSS can be throttled to its nominal operation point by adapting i.e. increasing the tank temperature, in case of Figure 2-2, 300 W and 12 mN. Auxiliary heaters, such as the thruster heater, can be switched off at this point.



a) b)

Figure 2-2: Illustration of the iFACT ignition procedure: The thruster controlling is performed by simple thermal control provided by the satellite platform.

In order to turn off the EPSS, the tank heater must be switched-off. This leads to a negative feedback loop that ultimately forces the iodine feeding valve to be closed, and without any propellant flow the discharge will stop i.e. no thrust is created. As last step the PPU is deactivated. As shown in Figure 2-3, a certain dead time between tank heater deactivation and shut down is expected. This dead time is a design parameter based on the agility and throttle range required for the final application.



a) b)

Figure 2-3: Shut down sequence of the iFACT subsystem. It is thermally designed in order to be automatically soft switching off when the external heater power is de-activated.

3 Preliminary Performance

Currently, two out of four iFACT building blocks have been developed and first tests have been performed. As a first step the thruster itself has been characterised with Xenon and Krypton as reference for the operation with iodine. The characterisation was performed in the EP-facilities of Airbus in Friedrichshafen. During testing, the anode potential, anode current, mass flow, thrust and many other parameters were measured continuously. Hence, providing detailed performance figures of the thruster in a wide operation range.

A summary of this xenon and krypton characterisation is presented in Figure 3-1, where the Thrust To Power Ration (TTPR) is plotted versus the specific impulse. Total efficiency envelops are illustrated by four coloured lines. With both propellants the thruster achieved total efficiencies above 35 % and Isps of more than 2000 s has been measured at some operation points. With xenon the total efficiency was generally higher than with krypton. Figure 3-1 illustrates that the thrust to power ratio or PTTR scales with the anode potential, almost independently from the propellant mass flow whereas the specific impulse scales with the propellant mass flow. This behaviour is well understood and was observed with the precursor ACFTs as well.

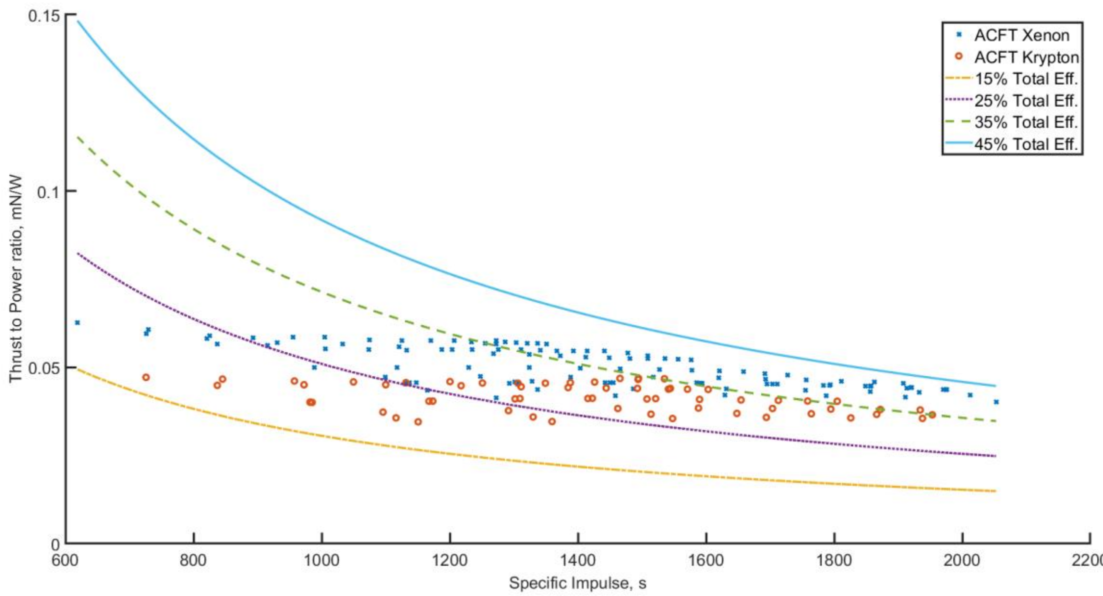


Figure 3-1: Summary of the xenon and krypton characterisation where the Thrust to Power Ratio is plotted versus the specific impulse. With both propellants the thruster shows total efficiencies above 35 % over a wide operation range.

A selection of different operation points with different propellants is presented in Table 3-1, cathode or electronic loses is not considered. The best efficiency and performance was measured with xenon with a total efficiency of 44 %. With Iodine, the total efficiency and therefore other performance parameters are less good than with Xenon, but the obtained data is still excellent and within the expected range.

Table 3-1: Selection of different operation points characterised to illustrate the ACFT performance.

Propellant	Anode Potential, V	Massflow, mg/s	Anode Power, W	Thrust, mN	ISP, s	PTTR, W/mN	Tot. Eff., %
Xenon	300	1.21	297	16.8	1420	17.7	39
Xenon	650	0.64	303	13.16	2013	23	44
Xenon	650	0.3	91	4.18	1445	21.8	32
Iodine	650	0.67	300	12.2	1835	25	36
Iodine	650	0.48	209	8.12	1736	25.8	33
Iodine	400	0.47	108	6.76	1456	15.98	44
Krypton	350	0.91	284	13.26	1494	21.5	34
Krypton	650	0.3	91	3.24	1116	28	20
Krypton	650	0.59	310	11.32	1953	27	35