Inter-Laboratory Comparison: Tests of a single thruster in two different facilities, on two different thrust balances

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Franz Georg Hey*, Max Vaupel, Nils Gerrit Kottke, Celia Perez
Airbus, Friedrichshafen, Germany

Leonardo Sestini, Damiano Pagano, Fabrizio Scortecci
Aerospazio Technologie, Rapolano Terme, Iatly

and

Herve Camares, Werner Konrad, Noah Saks
Airbus

In order to experimentally verify the Airbus EP facility upgrade, an inter-laboratory comparison between the Airbus facility and the MVTF1E of Aerospazio has been performed. As device under test to perform the comparison, the Advanced Cusp Field Thruster (ACFT) has been used. The thruster features an optimised cusp field structured magnetic field in order to efficiently generate thrust with reduced complexity of the overall propulsion subsystem. The proceeding presents an overview of the upgraded electric thruster test facility of Airbus in Friedrichshafen. Moreover, a detailed summary of the thruster measurements performed during the inter-laboratory comparison will be shown and discussed, including figures which summaries the points measured. The figures illustrates that the values gained are in good agreement, thus it can be assumed that the thrust and performance measured is correct and reliable.

Nomenclature

ACFT	= Advanced Cusp Field Thruster
COTS	= Commercial-of-the-shelf
HEMPT	= High Efficiency Multistage Plasma Thruster
I_{sp}	= Specific impulse
PTTR	= Power to thrust ratio
PPU	= Power Processing Unit
γ	= Divergence efficiency
η_v	= Acceleration efficiency

*Laboratory for Enabling Technologies, franz.hey@airbus.com.

I. Introduction

In Electric Propulsion (EP) testing the facility effects play an important role for the measurement results, thus an comparison between different facilities is from special importance in order to ensure reliable and standardised measurement result. Aerospazio Technologie in Rapolano Terme / Siena develops and uses EP test facilities since many years, it have been participated in major space programmes and qualification of various thruster types has been performed [1].

Airbus Friedrichshafen developed a thruster test facility since 2010, originally with the successfully achieved goal to characterise mirco-Newton thruster candidates [2,3,4,5]. In the last year, the Airbus facility has been upgraded in size and pumping power to be able to perform thruster testing in the lower milli-Newton range, including of minor adaptions of the highly stable Airbus thrust balance.

In parallel to the facility activities, Airbus develops the Advanced Cusp Field Thruster (ACFT) technology as potential low cost thruster candidate. An Engineering Model (EM) has been built and characterised [6]. In the following proceeding, the results of ACFT EM firing campaigns in two different facilities will be presented, in order illustrate the performance of the thruster, but in particular to compare the measurement result to provide evidence that the measured data obtained is reliable.

II. Device Under Test

The Advanced Cusp Field Thruster (ACFT) Engineering Model (EM) subsystem that has been characterised consists of a thruster, two thermionic LaB6 cathodes and a simplified Power Processing Unit (PPU) Breadboard. For propellant feeding, the laboratory infrastructures available has been used. In both facilities the thruster was fired with xenon.

Figure 1 provides an overview of the subsystem. The EM, equipped with two cathode, was mounted on the thrust balance in the vacuum chamber. The PPU breadboard was connected via a vacuum feed through to the PPU that was placed outside of the vacuum chamber. The PPU is an unregulated DC-DC converter that was connected via an interface block to a laboratory power supply. The laboratory power supply provided the 27 V to 35 V input power required. The thermionic cathodes has been connected to another laboratory power supply via a low voltage vacuum feed through. The two laboratory supplies took over functions of the satellite bus.

The PPU output voltage is 700 V at a nominal input voltage of 30 V. In parallel to PPU breadboard a FUG power supply was used as well, in order to perform measurements at other anode potentials. Due to the fact that the power supply's output is uncontrolled, it varies dependent on the input voltage and the power load of the thruster.

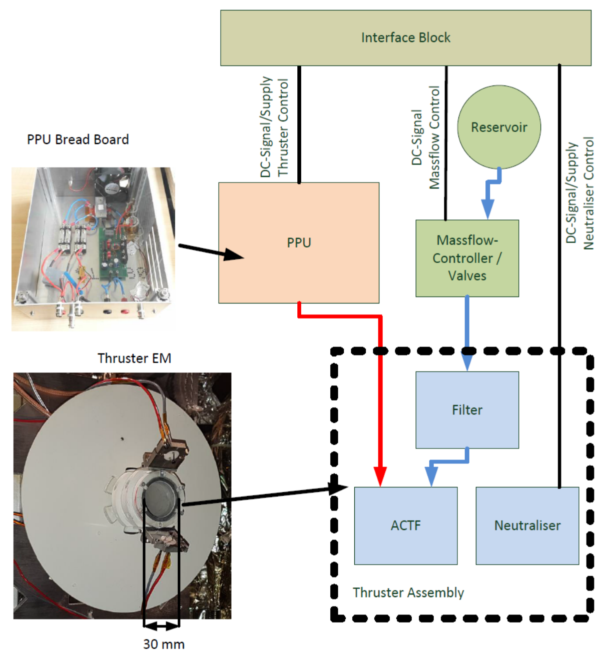
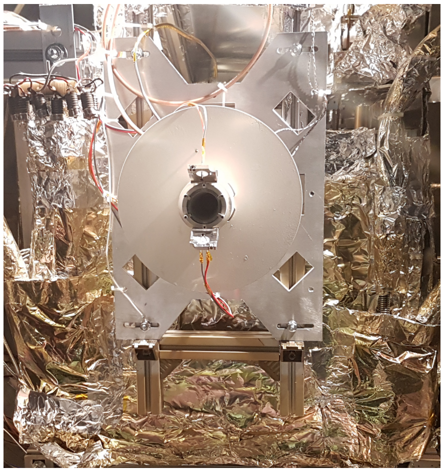


Figure 1: Illustration of the tested thruster subsystem system, it consists of an ACFT EM thruster, two thermionic cathode, an PPU breadboard. The thruster was fed by laboratory xenon propellant feeding.

III. Measurement Setup

The device under test described has been integrated in the two test facility, first the thruster has been tested and characterised in Friedrichshafen. In a second step the thruster subsystem was transferred to Siena and tested in the Aerospazio facility. As last step, the thruster was fired and characterise in Friedrichshafen again.

A. Aerospazio Thrust Balance and Facility



(a)

(b)

Figure 2: Overview of the Airbus thruster test facility. In a the thrust balance assembly is show, it consists of the Airbus double pendulum balance and the ACFT. In b a schematic of the facility is presented.

Testing at AEROSPAZIO were performed in the MVTF-1E test facility. The facility consist of a stainless steel vacuum chamber made of cylinders of different size, the larger being 2 m diameter and 3.5 m length. The total volume of the chamber is about 16 m^3. The main pumping system is made of cryogenic pumps allowing a base pressure in the lower 10^{-7} mbar level and an operational pressure less than 10^{-6} mbar for 1 mg/s xenon flow rate.

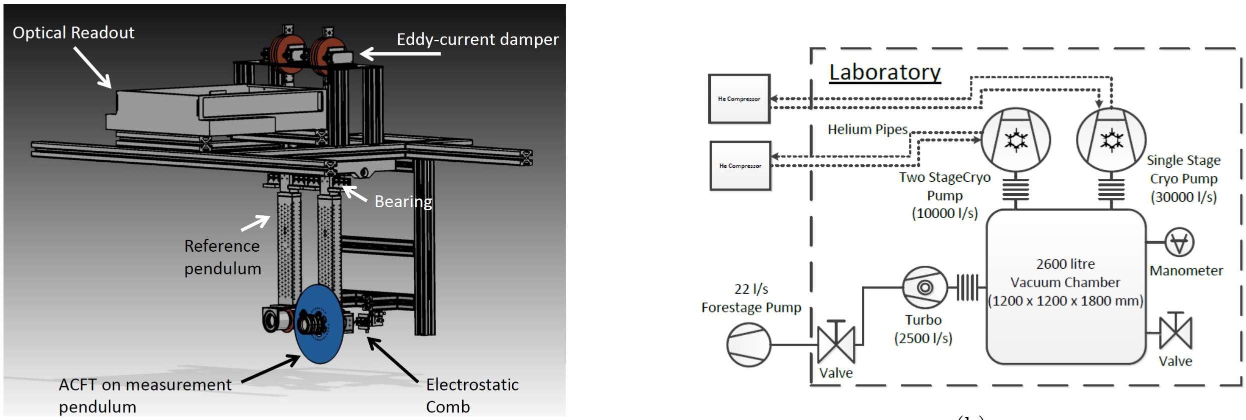
The facility hosts a thrust balance, working as an inverted pendulum on the principle of null reading, i.e. a control loop consisting of an actuator and a displacement sensor regulates continuously the position of the balance so as to maintain fixed during the firing of the thruster at a given zero reference point.

The facility can also host a large variety of plume diagnostics tools (Faraday probes, RPA, Langmuir probes,...). The facility was used in the frame of the ESA TRP programme on “Advanced Electric Propulsion Diagnostics” to qualify the probes and sensors developed in the frame of the programme as standard on-ground diagnostics tools for EP [7].

B. Airbus Thrust Balance and Facility

The thruster test facility of Airbus Friedrichshafen consists of a 2600 l (without volume of the doors) vacuum tank. The tank is beard on isolator feeds in order to shield it from seismic noise. To create and maintain the vacuum required to fire the electric thruster, a three staged pumping system is installed. Figure 3 b provides an overview of the facility. As first stage a 22 l/s forestage pump is used. The pump is a fully iodine compatible screw pump, designed to pump corrosive gases mainly used in the semiconductor industry. Therefore, no absorber or filter is required as part of the forestage vacuum line. The pump itself is placed outside of the laboratory in order reduce acoustic noise coupling with the facility. As a second stage a 2500 l/s turbo pump is installed. The third stage is formed by two cryo pumps, a two stage cryo pump and a single stage cryo pump. Both pumps generate approximately 30000 l/s pumping speed. The cryo pumps are decouple via 50 stage membrane bellows from the vacuum chamber. The cryo heads used are electrically driven, thus the helium expansion frequency can be adapted (best noise characteristic can be achieved at 60 RPM). The helium compressors required are placed outside of the laboratory. The overall cryo pumpp assembly ensures high pumping speed and low seismic noise impact in order to ensure the facility capability to measure highly precise forces in the sub micro-Newton range.

A set of diagnostics is installed in the vacuum chamber. Main instrument is the Airbus micro-Newton thrust balance. The balance has been equipped with counter masses in order to increase the spring rate to be capable of measuring milli-Newton. An illustration with mounted ACFT is shown in Figure 3 a. The calibration of the balance is performed with an Electro Static Comp assembly (ESC), which is designed



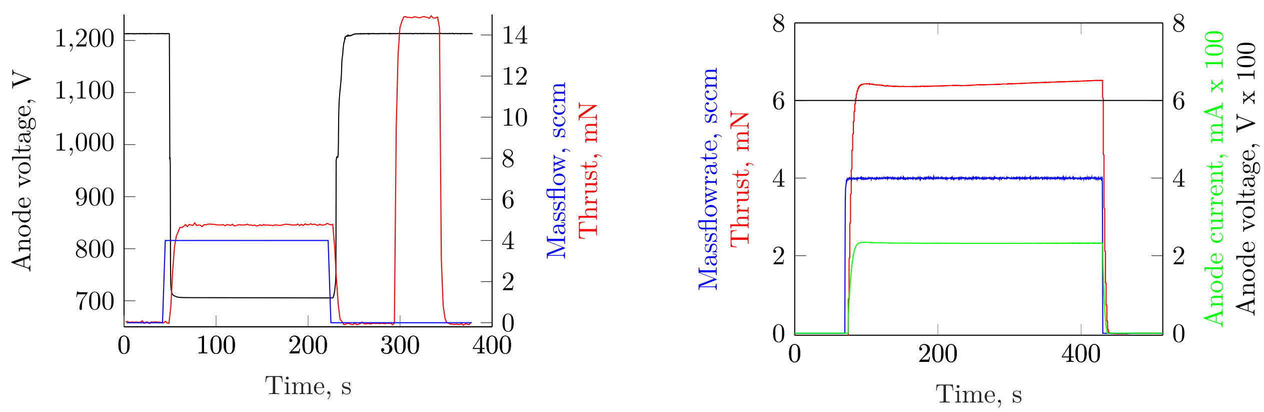
(a) (b)

Figure 3: Overview of the Airbus thruster test facility. In a the thrust balance assembly is shown, it consists of the Airbus double pendulum balance and the ACFT. In b a schematic of the facility is presented.

to perform the micro-Newton calibration [5]. The calibration assembly is capable to apply up to 1 mN off thrust to the balance, thus the calibration results have to be extrapolated into the targeted thrust range. It is assumed, that due to the linear behaviour of the calibration, the extrapolation can be performed without an adaption of the error budget (5 % relatvie error) of the balance.

Beside the thrust balance, the facility features a grid less Retarding Potential Analyser (RPA) array, an ExB probe and a mass spectrometer. Therefore, a detailed characterisation of the engine tested can be performed, including direct and indirect thrust measurements.

IV. Measurement Results



(a) (b)

Figure 4: Illustration of characteritic thrust measurements. On the left side a direct thrust measurement of the Aerospazio thrust balance is shown. The second larger thrust step is a result of a calibration step. On the right side a thrust measurement of the Airbus thrust balance is shown.

The characterisation performed and the results presented rely on direct thrust measurements. Exemplary measurements of both thrust stands used are shown in 4. The anode voltage (V, in black), massflow (sccm, in blue) and measured thrust (mN, in red) versus time (s) is plotted. In (a) a thrust measurement from Aerospazio is shown, in (b) a measurement from Airbus is presented. The Aerospazio, measurement has been performed with the unregulated PPU breadboard, thus without load (i.e. thruster off) the output voltage rises up to more than 1200 V, as shown in the first 30 s of (a). After switching on the massflow (blue curves in both plots) the thruster ignites, a corresponding thrust was measured.

In (a) a calibration run has been performed after the thruster was switched off, this can been see as second thrust signal, after 290 s. In (b), a fixed anode potential of 600 V has been used. The ignition procedure was equivalent, with simple activation of the propellant mass. In addition to thrust, potential and massflow, the anode current (in green) is plotted in (b). The plots illustrates the different calibration schemes in the facilities as well, direct calibration with calibration weights in (a) and ESC calibration before and after a complete measurement cycle in (b).

At Aerospazio the balance was calibrated with calibration weights. The calibration weight used produces an higher thrust than the thrust measured itself. In Friedrichshafen ESCs has been used, the maximum ESC force of the specific ESC assembly is an order of magnitude lower than the thrust measured, therefore an extrapolation of the balance spring rate must be performed. An detailed description of the errors involved is available in [5].

In figure 5, 6 and 7 the results of the measurement campaign are summarised. Measurements at different anode potentials (500 V, 700 V, 900 V) and at different mass flows are presented. Data points at 500 V are marked with a point, 700 V points are marked with a cross and 900 V data is illustrated with a square. Measurement data that has been gained in Siena is shown in red, whereas measurements from Friedrichshafen are shown in blue.

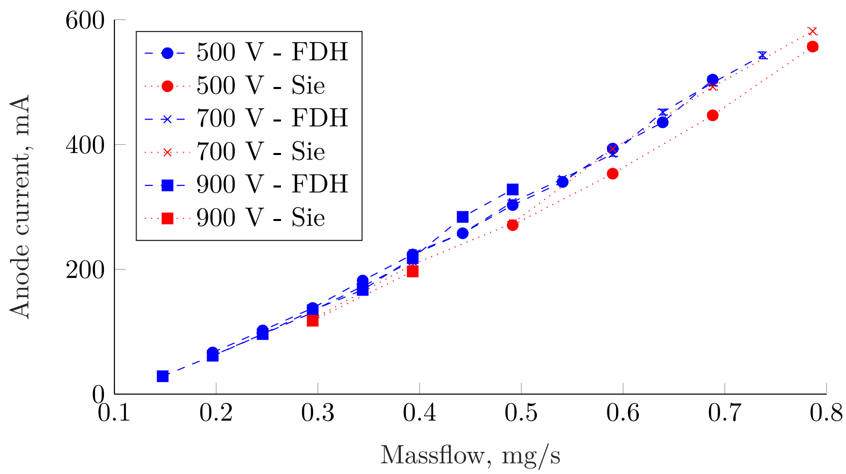


Figure 5: Summary of the tested operation points in Aerospazio (Sie) and Airbus (FDH). The Anode current is plotted versus the massflow. Measurements has been performed at different massflow rates which created a corresponding anode current.

In Figure 5 the anode current measured (in mA) at the power supply is sketched versus the massflow (in sccm). For each point shown more than one thrust measurement has been performed. The steps size used was 0.5 sccm at a fixed anode potential. In can been seen that in the range characterised, the massflow change responded almost linear to the anode current. The difference of the measurement current, in between the facilities is small, especially for anode potential at 700 V and 900 V, the difference was marginal. At 500 V anode potential a difference of the current to massflow ratio has been measured. A clear reason, for the observed difference has not been identified yet. It can be assumed that difference because of the back ground pressure differences between the facilities would have an effect of all measured points. However, the figures illustrates that due to the similar anode currents per massflow, similar thrust can be expected.

The thrust (in mN) is plotted versus the anode current (mA) in figure 6. It can been seen that the data obtained with the two different thrust balances fit very well. An increase of the the anode current leads to a larger thrust measured. Similar anode currents at similar anode potentials lead to equal thrust measurements within the error bars of the balances.

In figure 7 the thrust is plotted against the anode power. The thruster used has been scaled for a nominal operation of 300 W. However, due to the ACFT principle it is throttleable by changing the massflow

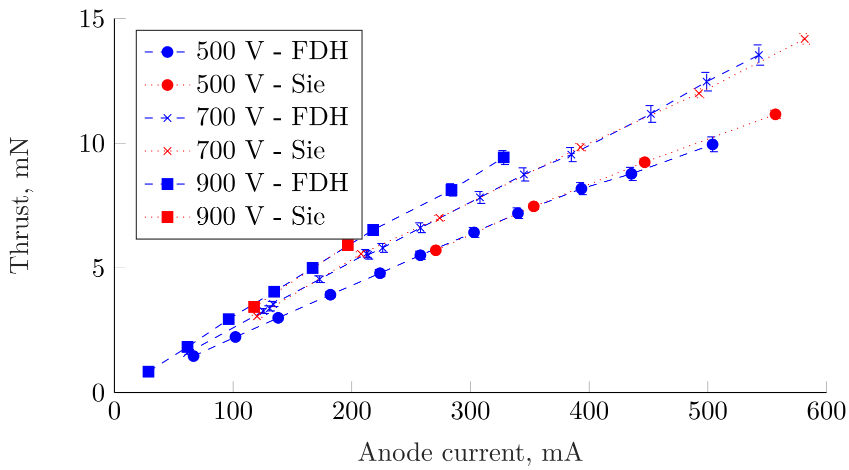


Figure 6: The figures presents the thrust measured (in mN) versus the anode current (mA) for different operation points measured in the two facilities, for 500 V, 700 V, 900 V anode potential. It can be seen that the difference between the two facilities are marginal and therefore in good agreement.

exclusively. It can been seen, that in accordance with the anode current versus massflow measurement, the thrust measured in both facilities is equivalent. Also the anode current reduction at 500 V leads to an equivalent lower thrust.

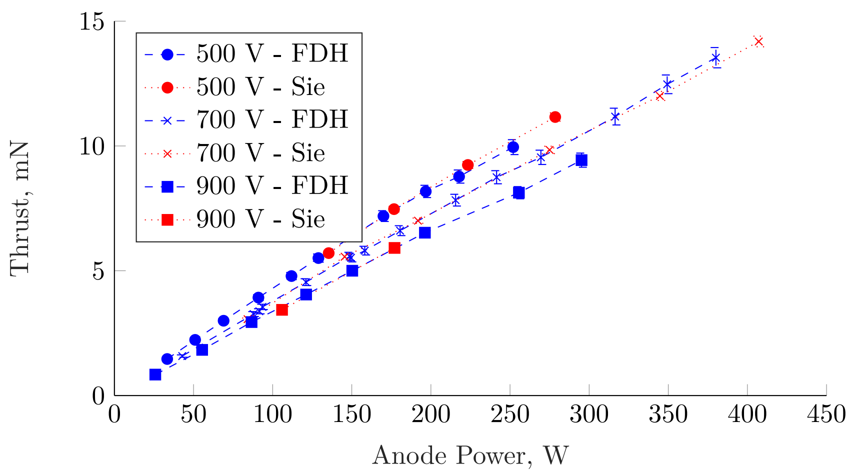


Figure 7: Summary of the tested operation points, where the thrust is plotted versus the Anode power. The thruster has been operated over a wide range. With the range no major deviation in between the different thrust measurements has been found.

V. Conclusion

The thrust of a single thruster was measured in two different facilities with two different thrust balances. It has been found that the thruster performance, in particular the anode current per massflow, is comparable in both facilities at anode potential of 700 V and 900 V. At 500 V a different current per massflow ratio has been measured in the different facility, the difference was in the order of a few percent.

The thrust measured corresponded to the anode current. the thrust per anode current obtained with the thrust balances has not shown major differences. Therefore, it can be assumed that both thrust balances are measuring correct thrust values within their predicted error bars. Thus the facility modification in Friedrichshafen has successfully enabled milli-Newton thruster characterisation in this facility, which has been validated during this inter-laboratory comparison. It has been shown that an ESC calibration can be extrapolated to higher forces without additional measurement errors.

Due to the gained results, the Advanced Cusp Field thruster tested could be used as reference for other inter laboratory comparisons as well.

Acknowledgments

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References

[1] Giovanni Coduti, et al., Commissioning of the Aerospazio's vacuum facilities with Safran's Hall Effect Thruster, IEPC-2017-414 (2017).
[2] Franz Georg Hey, et al., Development of a Highly Precise Micro-Newton Thrust Balance, IEPC-2013-275(2013).
[3] Franz Georg Hey, et al., Development of a Highly Sensitive Micro-Newton Thrust Balance: current status and latest results, IEPC-2015-260 (2015).
[4] Franz Georg Hey, et. al. Development of a Highly Precise Micronewton Thrust Balance, Plasma Science, IEEE Transactions on 43.1 (Jan. 2015).
[5] Franz Georg Hey, Micro Newton Thruster Development, Springer (2018).
[6] Max Vaupel, et. al. Advanced Cusp Field Thruster with a 3D-printed discharge channel - Performance with Iodine and Xenon, IEPC-2019-A-621.
[7] C.Bundesmann, et. al. An advanced electric propulsion diagnostic (AEPD) platform for in-situ characterization of electric propulsion thrusters and ion beam sources, The European Physical Journal D 70(10), October 2016.