

A 3.000 Hours Endurance Testing of RIT-22 Thruster in the New Aerospazio Test Facility

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Abstract: The following paper describes the test activities performed at AEROSPAZIO during a 3000 h endurance test carried out on the RIT-22 thruster. In particular, the paper describes the vacuum data and the beam diagnostics test results. The test activities were aimed at performing a continuous firing of the RIT thruster at the selected nominal operating point corresponding to 175 mN of thrust. Characterisation tests (Perveance, Electron Back Stream) were performed at selected operating times. Beam diagnostics was performed approximately each 100 h of thruster operation. The test activities were performed in the new Aerospazio large Vacuum Test Facility. The vacuum conditions were better than 6×10^{-6} mbar during all thruster operations.

I. Introduction

THE grid system is one of the most important components of any ion thruster. Its design has significant impact on the thruster's key data i.e. performance, lifetime and last but not least the engine's reliability. Consequently the grid system is a permanent object of research and development activities, world wide.

In this regard, ESA initiated the project "New Grid Systems for Ion Engines" aiming on analysis, development and improvements of ion optics grid systems for ion engines. The comprehensive activity is conducted by a consortium of 7 European partners under lead of EADS Space Transportation GmbH (D).

In order to demonstrate the achieved improvements in grid technology resulted from the previous study & design phase, representative life test over 3.000 h of thruster operation have been performed in the new large Vacuum Test Facility at AEROSPAZIO.

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II. Experimental apparatus

A. Test Facility

The RIT-22 endurance test was performed in the new large Vacuum Test Facility located at AEROSPAZIO Tecnologie (Fig. 1). The facility consists of a horizontal stainless steel cylinder with two full diameter end caps. The chamber is 11,5 m long and has a diameter of 3,8 m for a total volume of 120 m³. On the side of the chamber there are three 900 mm diameter flanges which allow connecting through gate valves up to three service chambers for parallel tests of several articles.

To date, the following pumping system is installed on the chamber:

- 1) a 1st stage consisting of a roots blower (1.200 m³/h pumping speed) backed by a rotary pump;
- 2) a 2nd stage consisting of a turbomolecular pump (1.000 l/s pumping speed);
- 3) a 3rd stage consisting of two cryopumps (20.000 l/s pumping speed);
- 4) a 4th stage consisting of a special system of panels cryocooled by Cold Heads and Liquid Nitrogen baffles, specifically designed to pump Xenon.

The cryosystem has been tested up to 175.000 l/s at 46 sccm of Xe under thruster firing conditions.¹ However, for the scope of this test campaign, the system has been rearranged and the pumping speed reduced to about 150.000 l/s at 43 sccm of Xe (hot flow with the thruster on).

The thruster is mounted along the axis of the vacuum chamber on a bracket placed close (downstream) the Xe-cryosystem (Fig. 2). The bracket is equipped with a regulation mechanism allowing a precise positioning and orientation of the thruster in the chamber.

During the first 2.500 h testing, a flat water cooled beam target covered with pure graphite plates (Fig. 3) was mounted at the chamber end opposite w.r.t. the cryogenic system in front of the thruster. The interior of the test facility is also fully lined with pure graphite panels. A cylindrical free volume of 80 m³ (7,5 m length x 3,7 m diameter) was available for plume expansion.

Subsequently, in order to minimise the backsputtering to the thruster, a new chevron type beam target (Fig. 4) was installed inside the vacuum chamber and has been used during the last 500h Test Session. The new beam target consists of 16 blades covered by pure graphite sheets, which can be cooled by water or liquid nitrogen.

The blades arrangement and shadowing were calculated taking into account:

- 1) the chamber geometry
- 2) the incident angles of ions on the different blades considering the direct impingement of ions exhausted from the thruster
- 3) the preferred angular distribution of sputtered materials inferred from recent sputtering data.²

Therefore, it was decided to mount converging blades with variable widths (from 32 to 48 cm) and inclinations (from 45 to 60 deg). Considering the new arrangement, the free firing length of the thruster is reduced to 7.1 m.

Chamber pressure was measured by one Penning gauge and three combined full range Ionivac gauges (a Pirani 1st stage and a Bayard Alpert hot cathode 2nd stage) placed at several locations in the chamber.¹ Gauges are factory calibrated for Nitrogen. Therefore, the corrected vacuum conditions during thruster operations were obtained by dividing the gauge outputs (uncorrected measurement) by the Xe gas correction factor 2.87.

A Data Acquisition System (DAS) and a Facility Management System (FMS) have been developed to automate facility operations and control the test behaviour from computer.

All facility pressures and operating parameters are acquired and stored by the DAS. The DAS hardware is based on a PC architecture consisting of a 12 bit National Instruments®¹ DAQ card multiplexed and conditioned by an extensible SCXI™ system. To date a 32 differential channels conditioning module is installed with 200 kS/s max sampling rate, selectable gain and low-pass filter. The DAS software, was developed by AEROSPAZIO in collaboration with the Dept. of Information Eng. of the University of Siena.³ In order to operate the facility continuously for long duration tests (up to several years without interruption for lifetime tests) a number of automatic procedures have been implemented on the FMS for normal and safety operations.

The RIT-22 thruster developed by EADS-ST was the test article and is described in another paper of this conference together with its experimental apparatus and Test Power Supply (TPS). The nominal operating point was set at 175 mN of thrust.

B. Plasma Diagnostics

The diagnostics set mounted on a rotating semicircular arm inside the chamber (Fig. 5) includes:

- 1) 18 Faraday Probe (FP) with guard ring placed at different angular positions on the arm;
- 2) 1 nude Faraday Probe (FPN) without guard ring mounted on a horizontal bar fixed on the arm in perpendicular direction of the thruster firing axis;
- 3) 2 Retarding Potential Analyzer (RPA) mounted on the same bar as FPN.

The probe arm was positioned such that the center of the thruster exit section is at the center of the semicircular arm and the arm rotation axis corresponds to the vertical axis crossing the center of the thruster exit section. Each probe was mounted on the arm so that the collector faces the center of thruster exit section at a distance of 1 m. The position of a probe w.r.t. the center of the thruster is determined by α and β angles, where α is the angular position of the arm w.r.t. thruster axis and β is the angular position of the probe on the arm (Fig. 6). This configuration enable complete 1 m radius hemispherical profiles of the exhaust plume to be obtained. The arm is moved by a stepper motor with a step angle of 0.45 deg controlled by a PC based system.

III. Procedure

A. Test procedure

The test activities were aimed at performing a continuous firing of the RIT thruster at the selected nominal operating point, corresponding to 175 mN of thrust. Additional characterisation tests (Perveance, EBS) were performed by EADS-ST at selected operating times. Beam diagnostics was performed by AEROSPAZIO approximately each 100 h of thruster operation.

After the chamber is closed, the facility pumping procedure is automatically performed by the FMS software. After 24 h of pumpdown an ultimate pressure around 1×10^{-7} mbar is reached. However, in order to allow thruster and in-vacuum equipment well outgasing, test are performed after 48 h from chamber closing.

When the vacuum procedure is terminated, cold flow test are performed so as to characterize dynamic vacuum levels of the facility and the propellant flow pressure at thruster level. At the end of the cold flow test, the RIT thruster is started-up at low power level for some hours (2-3 h) so as to slowly warm-up and additionally outgas the thruster and the test bench.

Then, the thruster and the test facility are operated automatically so as to allow a continuous firing of the thruster. Thruster beam-out are also automatically recovered by the TPS.

B. Beam Diagnostics Procedure

1. Faraday Probes

The following test procedure was in force during the endurance test.

First of all, the test electronics are switched on and the bias voltage on Faraday Probes is selected (-20 V). After 30 min for thermal stabilisation the Rotation Arm Control software (RACsw) is initialised so that the Faraday Probe Acquisition software (FPA sw) starts the scan of the 18 Faraday Probes and stores data on PC each time the arm crosses a given Start Measurement Point (SMP). After the clockwise rotation, the arm moves counter-clockwise and the FPA sw repeats measurements with the same procedure. The SMPs are listed in Table 1.

The acquired data are stored in text format in the local PC and then transferred to another PC so as to perform the Data Reduction and Analysis.

2. Retarding Potential Analyzer

The test electronics are switched on and the bias voltage on Electron Repelling Grid is selected (-20 V). After 30 min for thermal stabilisation the RACsw is initialised so that just the arm reaches the selected point of measurement, the Oscilloscope begins its acquisition and the Function Generator starts the voltage ramp driving the output of the High Voltage Power Supply which therefore applies the retarding potential to the Ion Retarding Grid (IRG).

The acquired data (current drained by the RPA collector and voltage applied to the IRG) are stored in text format in the local PC and then transferred to another PC so as to perform the Data Reduction and Analysis.

IV. Test Results

A. Vacuum Data

The endurance test was divided in 5 Test Sessions (TSs). At the end of each TS, the status of the thruster and of the grids was checked.

During the overall test time the background pressure in the vacuum chamber remain stable at a level of 5.6-5.9 x 10⁻⁶ mbar (data corrected for Xenon) measured with the Ionivac 1 and 2 (Fig. 2).

The longest period of thruster continuous operations without any beam-out has been 105 h during 1st TS.

The total thruster firing operations during the 5 TSs lasted respectively 660 h 40 min, 850 h 11 min, 562 h 35 min, 490 h 44 min and 485 h 51 min.

During the overall endurance test only few shut-down events occurred mainly due to electric power, computer, water cooling, which were promptly recovered so as to allow a high operational daily test rate (in average about 23,7 h per day). During all the test sessions the vacuum facility did not requested any cryopump regeneration cycle demonstrating the capability to accumulate at least 12 kg of Xe without any deterioration in the vacuum performance (both static and dynamic). Indeed, the static pressure attained at the end of each TS was well below the value obtained at the beginning of test and ranged in the level of 8 x 10⁻⁸ mbar.

As a result of the new chevron type beam target a significant reduction in the daily beam-out rate of the thruster was observed.

B. Ion Current Density Profiles

Figure 7 shows a typical current density data acquired by one Faraday probe on the horizontal plane crossing the thruster axis (FP11). It is possible to note that the data acquired during the forward arm scan (blue 'x' points) are consistent with data from the subsequent backward scan (red '+' points). Figure 8 shows a typical 3D map of the current densities in the plume obtained by interpolating the probe data in α and in β and the related contour map. The homogenous and smooth structure of the thruster beam can be emphasised. Figures 9 and 10 show the contour plot of current density acquired in the first (at about 100 h) and in the last scan (at about 3.000h) with the Faraday probes.

C. Ion Beam Current

In order to perform the beam diagnostic analysis, the current density data have been interpolated every 0.5 deg in α and in β . These values are then numerically integrated on the hemispherical surface having 1 m radius. Assuming that the overall beam current must correspond to the current I_{TPS} measured by the Test Power Supply (TPS) of the thruster, we decided to discard all the measurements outside the θ angle subtending I_{TPS} (θ_{I-TPS}) where θ is the angle between thruster axis and the center of the probe collector (Fig. 12). This procedure would exclude the CEX ion contribution (even if small) to affect the plume analysis.

Figure 11 shows the current I_{TPS} measured by the Test Power Supply (TPS) of the thruster during the endurance test.

D. Thruster Beam Divergence over the Time

Figure 12 shows the relation between the θ and the θ' angles usually employed in describing the thruster beam divergence. For commonalties of analysis of the experimental results, in the forthcoming discussion we consider only θ' angle. In order to calculate the half angle $\theta'_{\%}$ corresponding to a certain percentage % of the beam current, an iterative method is used. At each step the current is calculated only considering the fraction of the spherical surface included in a fixed θ'_0 angle from the thruster axis. Starting from 0 deg and increasing θ'_0 by 0.5 deg step, the calculated current I increases. When I is over the decided percentage of I_{TPS} , the iteration is stopped. The $\theta'_{\%}$ angle is therefore the value θ'_0 when the iteration is stopped.

Figures 13-14 summarise the half angles corresponding to 90% and 95%, respectively, of the beam current calculated during the overall endurance test.

Additional test data, including RPA results and Beam vector behaviour are under evaluation at the present time.

V. Conclusion

A 3.000 h endurance test on the RIT-22 thruster operated at 175 mN of thrust level was successfully performed in the new large Vacuum Test Facility at AEROSPAZIO. The facility show high operational readiness (in average about 23,7 h of thruster firing per day during the overall endurance test). During all the test sessions the vacuum facility did not requested any cryopump regeneration cycle demonstrating the capability to accumulate at least 12 kg of Xe without any deterioration in the vacuum performance (both static and dynamic). The static pressure attained at the end of each TS was in the level of 8×10^{-8} mbar.

The thruster beam diagnostics (Faraday Cups) was performed with reliability about each 100 h of the endurance test. The gathered results were not affected by noise and allow a reliable determination of the thruster plume divergence during the overall test. Additional test data, including RPA results and Beam vector behavior are under evaluation at the present time.

Acknowledgments

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References

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²Williams, J., Gardner, M., Johnson, M., and Wilbur, P., “Xenon Sputter Yield Measurements for Ion Thruster Materials,” *Proceedings of the 28th International Electric Propulsion Conference*, IRPS, Toulouse, FR, 2003.

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Table 1. Start Measurement Points (α) at which the FPA software starts the scan of the 18 Faraday Probes.

SMP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
deg	-81.45	-71.55	-61.65	-51.75	-41.85	-31.95	-22.05	-12.15	-2.25	7.65	17.55	27.45	37.35	47.25	57.15	67.05	76.95

Figure 1. The Large Vacuum Test Facility.



Figure 2. Schematic of the Inside of the Vacuum Test Facility.

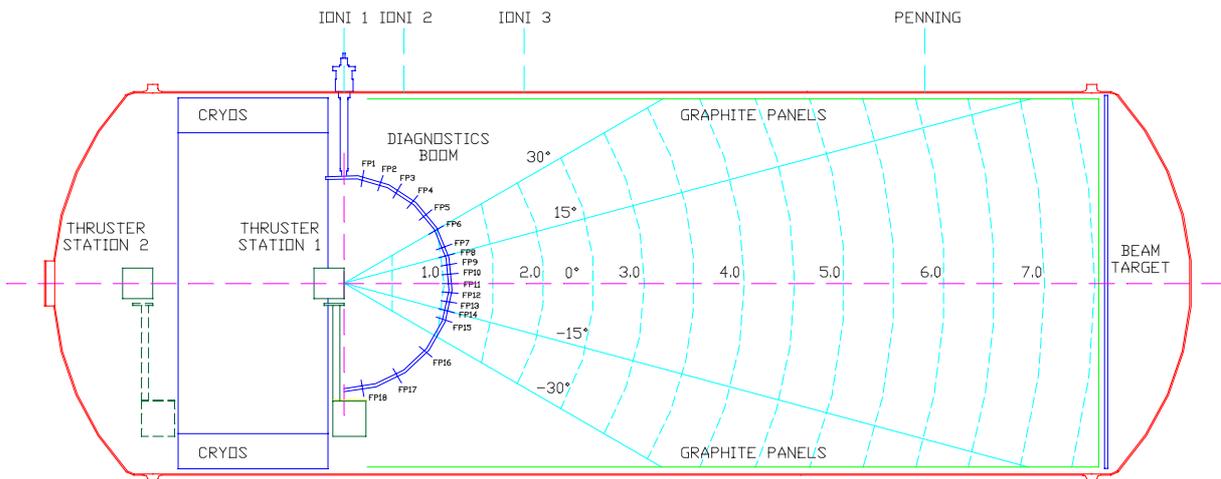


Figure 3. Flat Beam Target (first 2,500h testing)

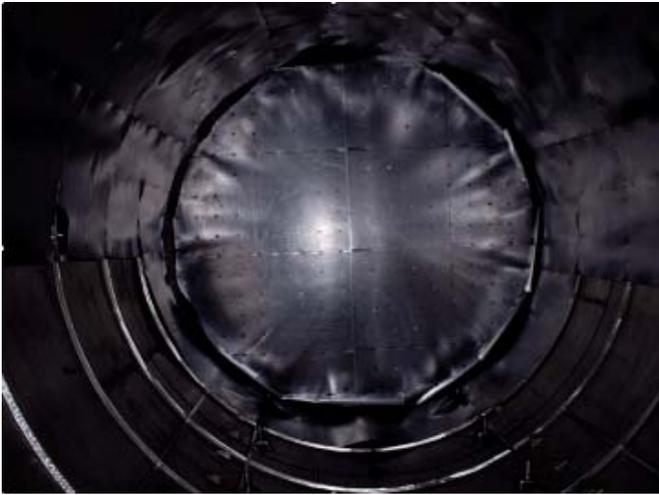


Figure 4. Chevron Beam Target (last 500h testing)



Figure 5. The Beam Diagnostic Arm.



Figure 6. Definition of Probes Characteristic Angles.

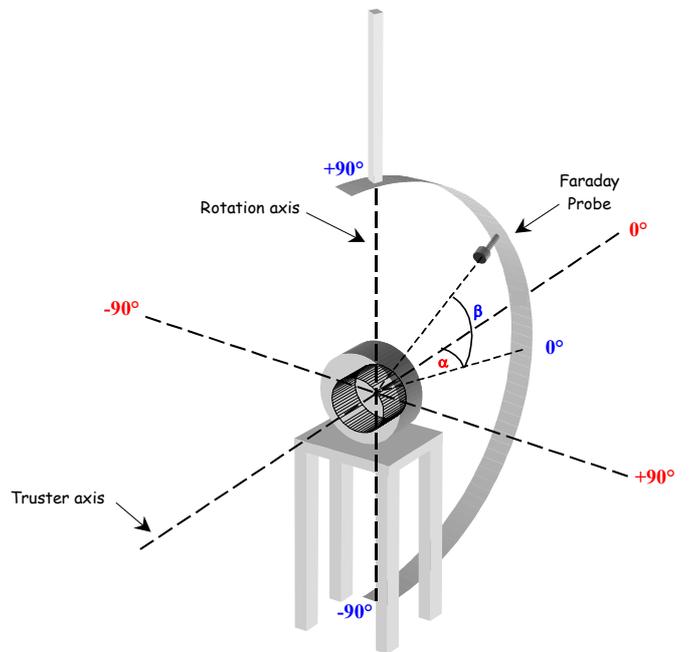


Figure 7. Current density data acquired by the probe crossing the thruster axis at different α angles.

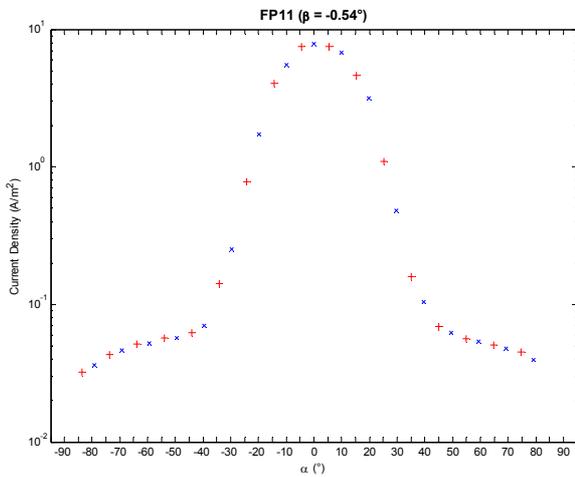


Figure 8. 3D Map of Current Density

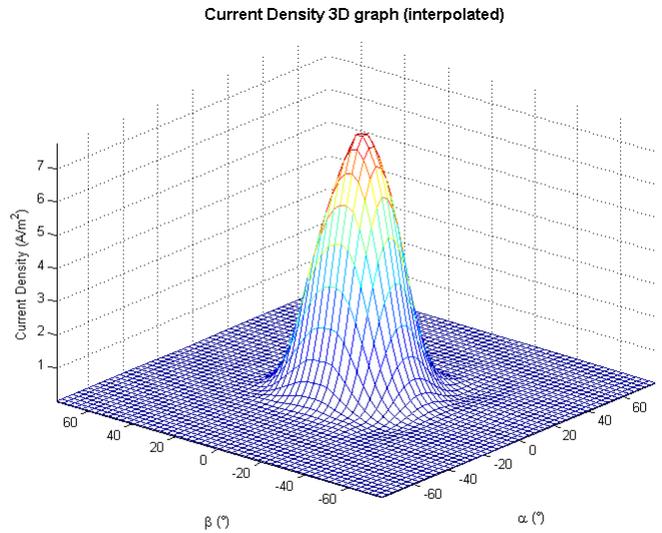


Figure 9. Contour Map of Current Density. (first 100h Scan)

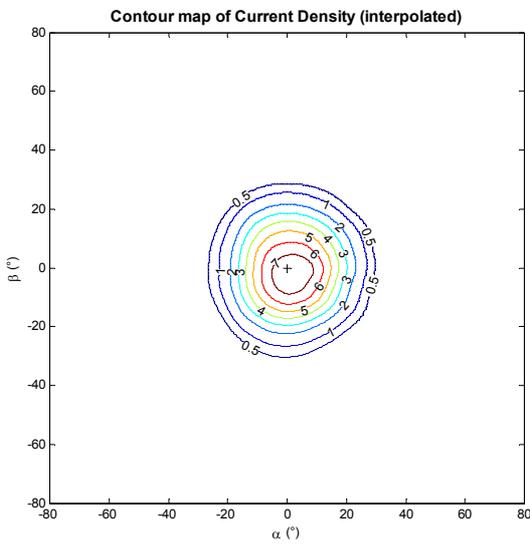


Figure 10. Contour Map of Current Density. (last 3.000h Scan)

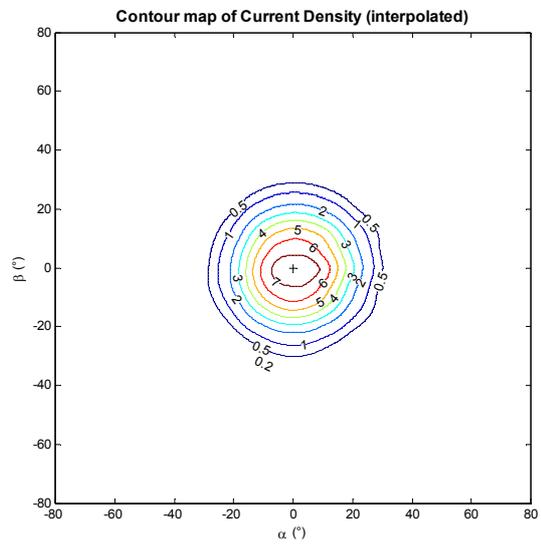


Figure 11. Ion Beam Current measured at TPS over the Time.

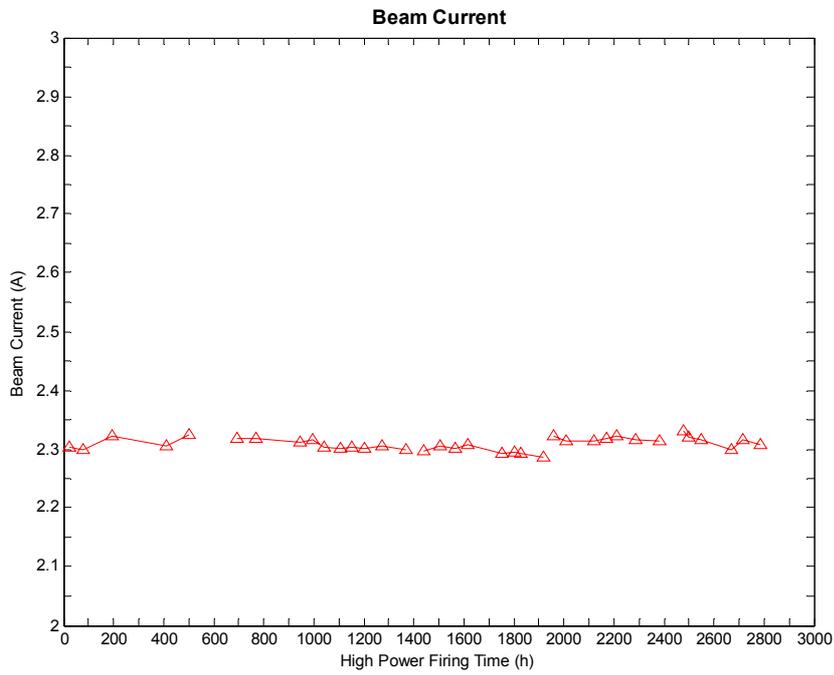
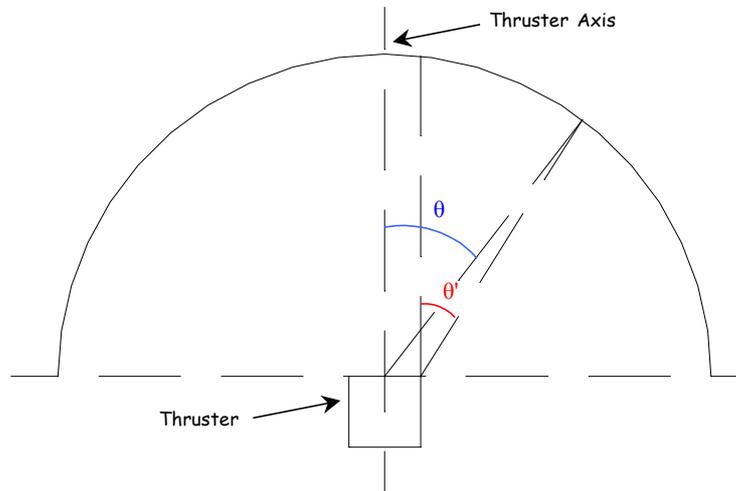
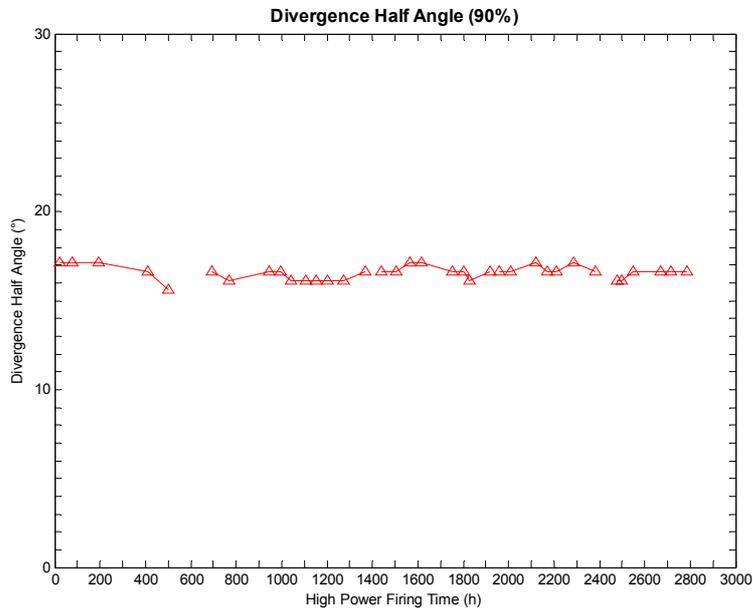


Figure 12. Divergence Half Angle definitions (top view).



**Figure 13. Beam Divergence over the endurance test time
(half angle subtending 90% of TPS beam current)**



**Figure 14. Beam Divergence over the endurance test time
(half angle subtending 95% of TPS beam current)**

