Quad Confinement Thruster – Industrialisation & Flight Integration

IEPC-2015-36／ISTS-2015-b-36

Presented at Joint Conference of 30th International Symposium on Space Technology and Science
34th International Electric Propulsion Conference and 6th Nano-satellite Symposium,
Hyogo-Kobe, Japan
July 4 – 10, 2015

Oliver Lane[1]
Surrey Satellite Technology Ltd, Guildford, UK

Aaron Knoll[2]
Surrey Space Centre, Guildford, UKand

Abstract: There is currently a gap in the market for a low cost Electric Propulsion solution for small spacecraft. The 200W Quad Confinement Thruster (QCT-200) has the potential to fill this gap, allowing small satellites to become much more capable in terms of propulsion whilst maintaining a price point which is acceptable to customers. The device fits well with the current SSTL philosophy, and the existing SSTL xenon feed system can be simply adapted to allow the QCT-200 to effectively be a bolt on module. Surrey Satellite Technology Ltd. (SSTL), the Surrey Space Centre (SSC), and Airbus Defense and Space (AD&S) have been working on a flight standard design of the device. This paper discusses the short history of the QCT-200, the operational principle of the device, and the industrialisation of the device from its experimental origins. Finally the application of the QCT-200 into a current spacecraft for in-orbit performance demonstration in 2016 is then related along with the mission scenarios enabled by the device.

Nomenclature

ADS	=	Airbus Defence & Space
COTS	=	Commercial Off The Shelf
dV	=	Delta Velocity
FDV	=	Fill Drain Valve
FM	=	Flight Model
HCN	=	Hollow Cathode Neutraliser
HCT	=	Hollow Cathode Thruster
ISP	=	Specific Impulse
LEO	=	Low Earth Orbit
PPU	=	Power Processing Unit
PT	=	Pressure Transducer
QCT-200	=	Quad Confinement Thruster (200W)
R0	=	Flow Restrictor 0
SLS	=	Selective Laser Sintering
SSC	=	Surrey Space Centre
SSTL	=	Surrey Satellite Technology Ltd
SV	=	Solenoid Valve
TDS-1	=	TechDemo Sat-1

[1] Propulsion Team Leader, SSTL, o.lane@sstl.co.uk
[2] Lecturer in Electric Propulsion. A.knoll@surrey.ac.uk

I. QCT-200 History

The Quad confinement thruster has been developed since it was first proposed in 2009 at the Surrey Space Centre (SSC) in close collaboration with SSTL and with support from Airbus Defence and Space (ADS). The concept has gone through a number of iterations at the experimental level but in 2013, SSTL embarked on an industrialisation of the design with the aim to produce a flight-worthy standard for use on small satellites. Figure 1 is a rendering of the completed thruster.

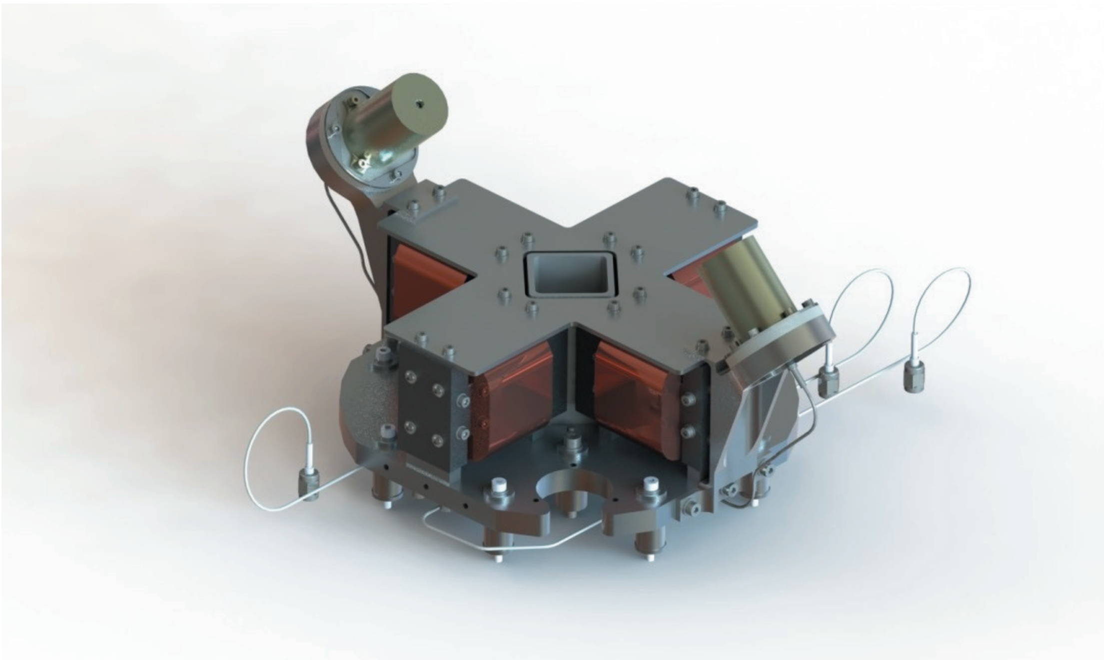

Figure 1. QCT-200 Thruster Assembly

The principal objectives of the industrialisation were to establish a reliable, production-worthy supply chain for the components, modify the design for ease of manufacture & test, validate that the performance was not affected and then conduct life testing on the ground to establish long term performance trends. Sticking with the SSTL approach to qualification, the additional objective was to capitalise on any flight opportunities that might appear.

II. QCT-200 Mode of Operation

The mechanism of ion acceleration for the QCT is similar to a Hall Effect Thruster. A magnetic field barrier is imposed between a positively charged anode and an externally mounted hollow cathode neutralizer (HCN). A gradient in the plasma potential across the magnetic barrier results in a static electric field in the axial direction sustained within the plasma. Ions are accelerated across this potential gradient and exit the thruster with a large component of axial velocity. The thrust force produced by the device is derived from the momentum of the outgoing ions.

The plasma is contained in a ceramic channel at the centre of the device. Propellant enters the channel from the rear face around the periphery of the anode plate. Electromagnets are positioned around the channel to form a magnetic quadrapole arrangement. The power applied to each electromagnet can be adjusted, altering the magnetic field; this provides the QCT with the ability to passively adjust the thrust vector, with laboratory tests suggests a full cone steering angle of 22° can be achieved. A hollow cathode is mounted externally to the channel to neutralize the outgoing ion beam[1].

III. QCT-200 Performance

While not as efficient as the current generation of Hall Effect thrusters, the QCT-200 demonstrated performance[2] of 440s net I_{SP} at 200W with a thrust of 2.5mN is still a step change in capability from a Xenon resistojet. This performance has been further improved significantly during the industrialisation process through the optimisation of the cathode positions. It is now expected that the in-flight performance of the QCT-200 in this configuration will be in the region of 520s net I_{SP} at 200W with a thrust of 5.1mN. Once these results were obtained by the SSC, the design of the QCT-200 was quickly updated with new cathode brackets. These brackets are 3D printed (SLS) in titanium, in common with the cathode bracket flown on TDS-1[3] and can be seen in Figure 2.

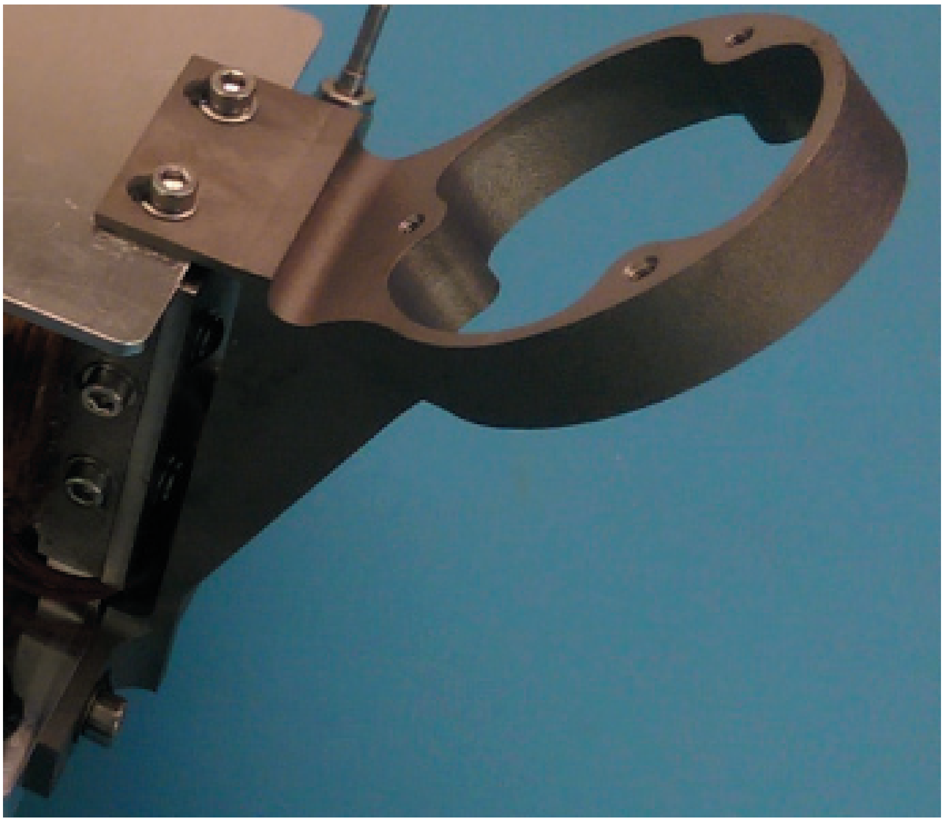

Figure 2: Close up of Hollow Cathode Neutraliser Bracket, Printed in Titanium

IV. QCT-200 Industrialisation

A. QCT-200 Anode

Building on the three previous iterations, the flight standard QCT-200 is comprised of 4 pairs of electromagnets with Aluminium windings and iron cores, mounted between an aluminium base plate and top plate. The central channel is made of ceramic and the central propellant gas feed is made of a high temperature refractory metal. The feed pipes to the cathodes and anode are electrically isolated by the use of ceramic breakers. Figure 3 shows a fully assembled FM anode, which only takes a few days to fully assemble.

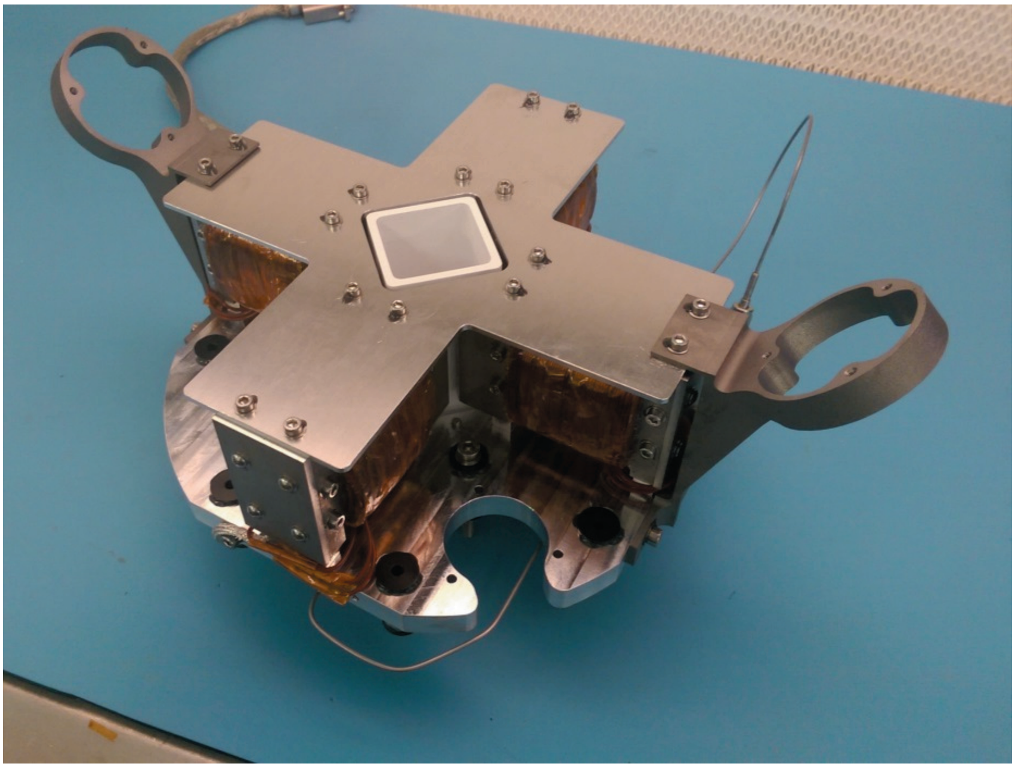

Figure 3. Assembled Flight Model QCT-200 Anode

B. QCT-200 Cathode

The HCN design has also evolved from those developed at the SSC over a number of years. The most recent cathode design was flown on TechDemoSat-1 (TDS-1), launched in 2014, as an experimental thruster (Hollow Cathode Thruster, HCT). The flight standard cathode for the QCT-200 improves on this design further. The primary and redundant heaters are now wound around the same ceramic bobbin & the electrical return is through the heater casing (Figure 4).

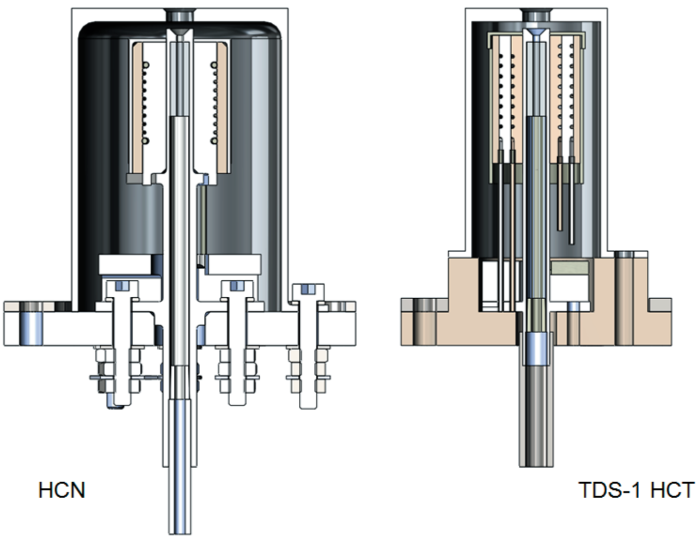

Figure 4. Industrialised HCN (left) compared with HCT as flown on TDS-1 (right)

The original, proof of concept, designs were also made with a large number of “machine to fit” tolerances, which meant that each cathode was slightly different. This was of no consequence when developing the cathodes in the lab, but before embarking on long duration life testing, the design was tightened up to ensure that each cathode would be identical.

C. Power Processing Unit

The detailed design of the Power Processing Unit is described in detail in Ref.4 but in summary, the PPU is designed to supply the QCT-200 and HCNs with a voltage up to 150V and power up to 200W. Because of the stable plasma regime of the QCT-200 there is no need for complex feedback loops in the power unit. This, and the relatively low voltage, means that the completed PPU design is extremely compact. The final housing of the unit is 190x320x30mm and a mass of 1.1kg, which is in family with SSTL heritage propulsion controllers (although with a much more densely populated board). The board layout along with an image of the original engineering model, is shown in Figure 5.

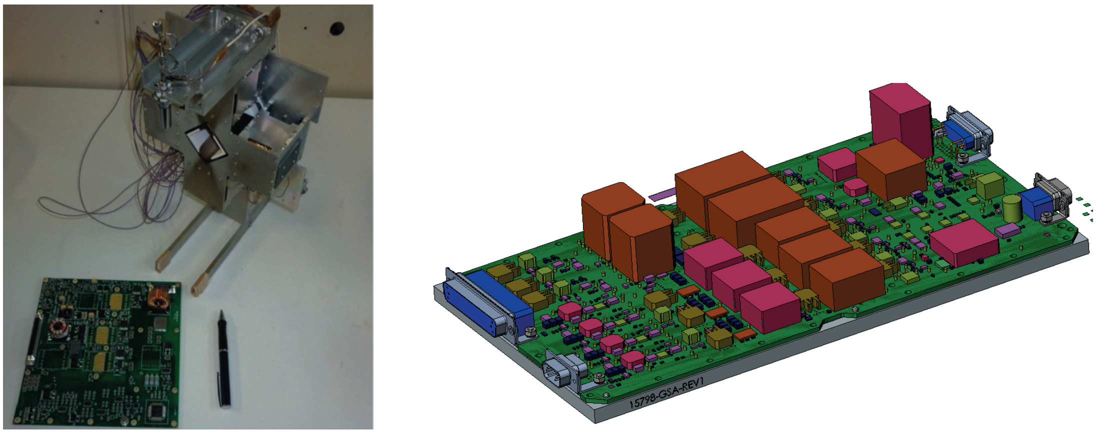

Figure 5. Early Prototype PPU with QCT (left) and Illustration of final PPU design (right)

The industrialisation of the PPU from prototype shown in Figure 5 to the final flight model involved switching individual components over to their flight-heritage counterparts & introducing appropriate levels of redundancy & a new layout to fit within a standard half-microtray planform. As with most SSTL flight electronics, most of the components are not sourced from traditional space-qualified suppliers, but they do all have in-flight heritage from previous SSTL missions. This COTS, low-complexity PPU is a key differentiator of the QCT-200 compared to a traditional electric propulsion system.

D. Integration of the QCT-200 onto NovaSAR

NovaSAR is novel Synthetic Aperture Radar (SAR) spacecraft built by SSTL with Airbus Defence & Space providing the Radar payload. It is scheduled for launch in 2016. To achieve its mission objectives, the platform is fitted with an SSTL heritage Xenon resistojet propulsion system. This includes 3 interconnected tanks of Xenon at 70bar. The Xenon is regulated in bang-bang mode down to 1 bar via a pair of solenoid valves into a plenum, which is connected directly to the resistojet.
The relatively high power of the spacecraft means that it is an ideal host for the QCT-200 as an experimental thruster. Figure 6 is a rendering showing the main propulsion system panel with the QCT-200 and PPU installed.

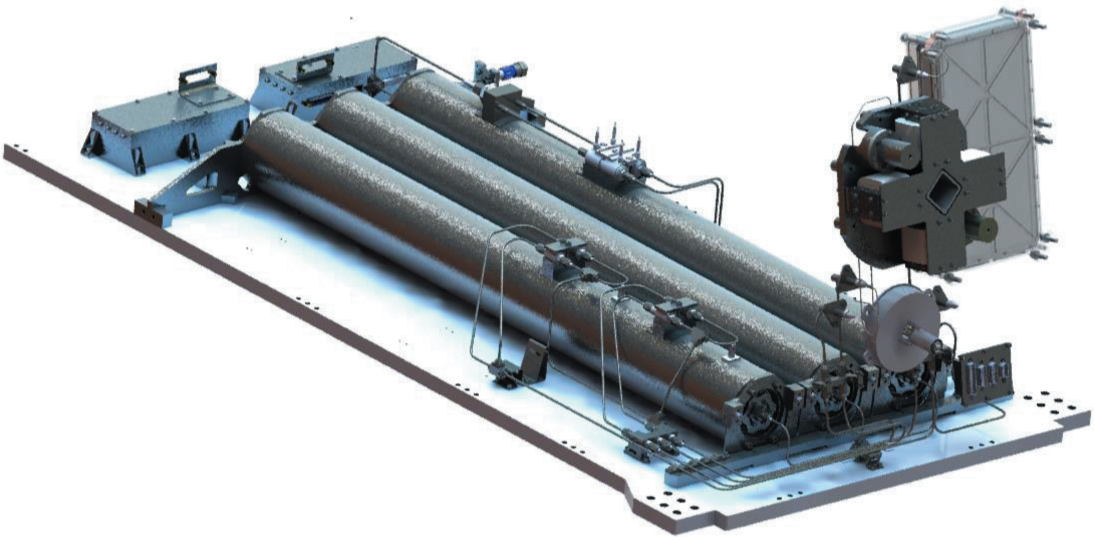

Figure 6. QCT-200 and PPU integrated into the NovaSAR propulsion system

Because of the experimental nature of the QCT-200, the system modification strategy has been to minimise the risk to the primary propulsion system. This means that the QCT-200 can be added, or removed, very late in the build schedule. It also means that some compromises to the gas feed system have been made due to limitations in the number of valve driver channels available in the baseline system.

Figure 7 is a schematic of the propulsion system showing the integrated QCT-200; everything upstream of the plenum is unchanged from the heritage configuration. Where as in the baseline system the resistojet would be connected directly to the plenum, in this design there is an additional pair of solenoid valves installed to isolate the resistojet when the QCT-200 is in operation.

The SSTL heritage Xenon propulsion controllers are only designed to control two solenoid valves, therefore the QCT-200 does not have independent control of the flow to the cathode and the anode. Flow restrictors are in place in the flow lines to fix the ratio of flow between the anode and cathode. This is a very cost-effective arrangement given the experimental nature of the mission opportunity, but it means that during the cathode startup sequence, Xenon will also be flowing out of the Anode. When the QCT-200 is used as the primary thruster, this arrangement may be changed if required. The flow rate through the QCT-200 can be modified by setting the plenum pressure set point.

There is also only one PPU fitted in this configuration, however the unit has been designed to be one of two cross-strapped PPUs & will be flown in that way on the first critical mission for the QCT.

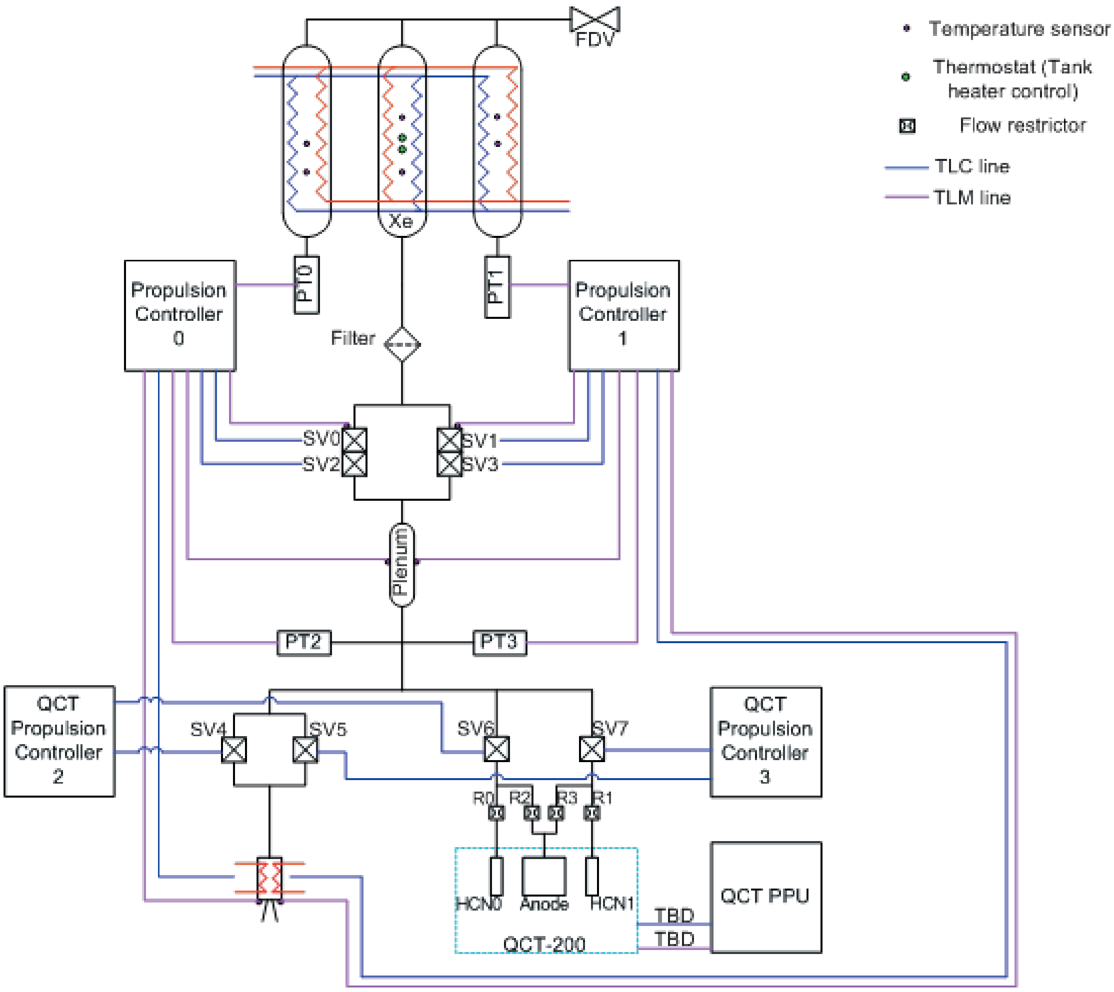

Figure 7. QCT-200 NovaSAR Propulsion System Schematic

V. Mission Scenarios Enabled by the QCT-200

The QCT-200 is expected to give a ten-fold increase in I_{SP} compared to SSTL's heritage Xenon Resistojet. The thrust level of 5mN is a quarter of that from the heritage systems, which is not a huge penalty considering the performance boost. For constellations of spacecraft the QCT-200 is an appealing choice as it will allow for smaller Xenon tanks & a more compact propulsion system. On typical trade studies the system is close to paying for itself through Xenon propellant saved. Additionally, the extra dV available improves the range of acceptable ride-share launches for small satellites.

The other early use case for the thruster will be in earth observation missions. Because the QCT-200 can be dropped into an existing SSTL Xenon platform with relatively little modifications, a platform like the 300-S1 can increase its dV capability from 25m/s to 250m/s. This allows the platform to operate at a significantly lower orbit (circa 450km) and so increase its imaging resolution from 1m to around 0.75m without any changes to the imager.

Finally, the QCT-200 could also be useful to fulfil the deorbit requirement of platforms that operate in LEO that will not naturally decay within 25 years. Above 700km or so this can become the dominant driver for the dV budget. Care needs to be taken when relying on electric propulsion for this role however, since the degradation of the power system is often the reason to declare the end of life.

VI. Conclusions

From first proposal in 2009 through to on-orbit demonstration in 2016 the QCT-200 has gone from laboratory prototype to a flight-worthy, production-ready product in an extremely short period of time. SSTL in partnership with the SSC and ADS. The QCT-200, HCNs and the PPU are now fully developed into flight standard equipment and are scheduled to be integrated into the NovaSAR platform with an anticipated launch in 2016. The performance of this system represents a 10-fold increase in performance from the SSTL heritage Xenon resistojet and yet can be simply integrated into existing platforms at a price point that is extremely competitive.

Acknowledgments

The project has been funded by Airbus Defence & Space and SSTL. The Authors would like to thank the many people who have contributed to this project, especially Mark Pollard, Hasan Ozakya and Thomas Potterton.

References

[1]Quad Confinement Thruster – A Low Cost, EP Solution for Small Spacecraft. M. Pollard et al. *Space Propulsion Conference 2014*

[2]Experimental Performance Characterization of a Two-Hundred-Watt Quad Confinement Thruster. Knoll, A., Harle, T., Lappas, V., & Pollard, M. (2014). *Journal of Propulsion and Power*, *30*(6), 1445-1449.

[3]Hollow cathode thruster design and development for small satellites. D.Lamprou et al. *International Electric Propulsion Conference, Wiesbaden, Germany*.

[4]Power Processing Unit of 200w Quad Confinement Thruster. Hasan Özkaya et al. *ESPC 2014, Noordwijkerhout, The Netherlands*