QinetiQ Electric Propulsion

Gridded Ion Thrusters

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QinetiQ Introduction

QinetiQ employs over 6,000 experts in the fields of defence, aerospace, maritime, space and various other related markets.

- *5 Major UK Sites:* *Farnborough, Boscombe Down, Malvern, Portsdown Hill & Haslar*
- *International :* *USA, Canada, Australia, Belgium, Sweden*

QinetiQ Space, UK

Farnborough, UK

- Integration Facilities & Cleanrooms
- Test facilities

QinetiQ Space, Belgium

Kruibeke, Belgium

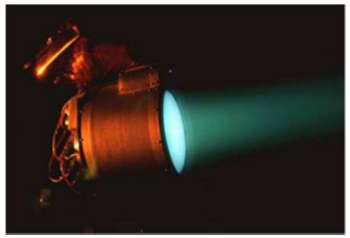
- Integration Facilities & Cleanrooms

QinetiQ Space Ground Station

Redu, Belgium

- ESA satellite ground station
- Jointly operated with SES Astra

QinetiQ Space

Satellites & Platforms	Payloads	Subsystems	Equipment	Downstream services
				
• Small satellite bus • End-to-end mission solutions	• Microgravity research • Planetary exploration • Earth observation	• On-board computers • Data & Power Management Units • Docking / Berthing Mechanisms		• Satellite Operations • Integrated Applications
	• Frequency Monitoring • Metrology	• Electrical Propulsion • Communication Transponders • Penetrator Technology		• GIS applications & services • Secure Navigation

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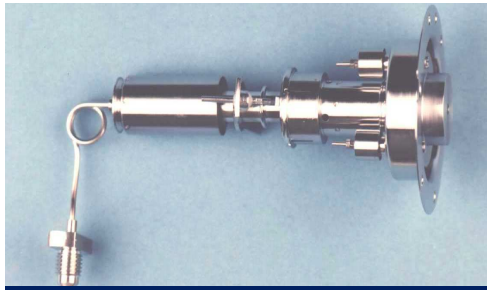
QinetiQ Electric Propulsion

In development at QinetiQ Farnborough since late 1960s.

- One of a few centres around the world



Cathode development

- Hollow cathode technology
- Cathodes for T5, T6, HETs
- Emission currents up to 50A

Artemis

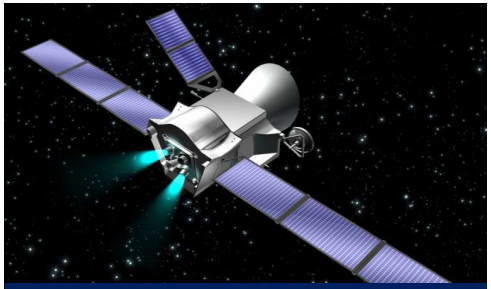
ESA Telecoms Satellite

- T5 Cathodes for UK10 thrusters
- T5 Grid Assembly for UK10 thrusters

GOCE

ESA low orbit mission

- Two T5 thrusters
- >36000 hrs operation (on single thruster)



BepiColombo

ESA mission to Mercury

- QinetiQ EP System
- Four T6 thrusters
- Launch date 20th October 2018

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QinetiQ Gridded Ion Engines (GIEs)

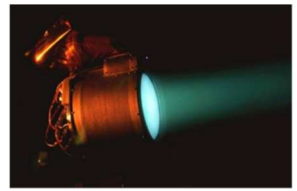
Primary Advantages of GIEs

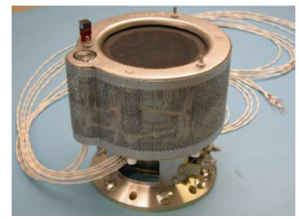
- **High fuel efficiency:** Specific impulse (I_{sp}) ~ 4000s [Typ. 10x efficiency of chemical propulsion]

Lower propellant consumption enables …

Lower Launch Mass / Larger Payload / Longer Life (or combination thereof)

- Wide **operating envelope** (power *versus* specific impulse *versus* thrust)
  - *Specific impulse can be traded to provide higher thrust, for a given power –* ***Dual mode***
- Wide **throttling** range – *optimises use of available power over mission*
- **Narrow beam divergence** (15° half cone) - *Reduces plume impingement / eases accommodation*





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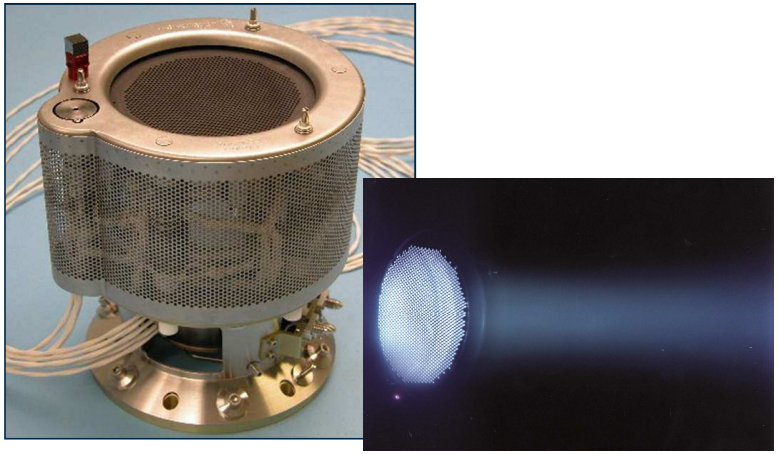
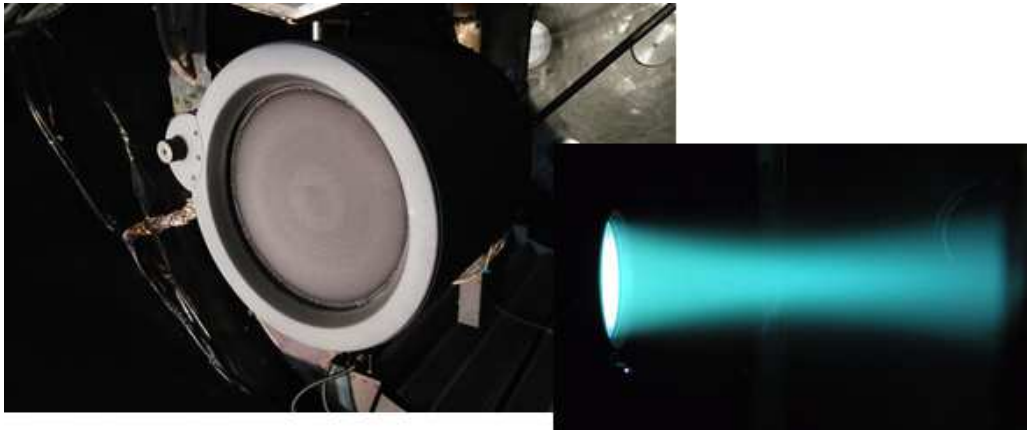
QinetiQ Kaufman Gridded Ion Engines



T5: 700 W class thruster

- 10 cm active grid area
- Thrust capability <1 – 25 mN
  - Grid set can be optimised for different thrust ranges
- High Isp >3000s
- > 3MNs
- Mass 2.5 kg (excl. alignment bracket)

H2020 EPIC (GIESEPP) enabling QinetiQ to industrialise the GOCE T5 thruster to improve competitiveness as a recurring product.



T6: 5 kW class thruster

- 22 cm active grid area
- Thrust capability 30mN to 180 mN
  - Grid set can be optimised for different thrust ranges
- High Isp >4000s
- > 8MNs
- Mass 8.3 kg

H2020 EPIC (GIESEPP) enabling QinetiQ to maximise competitiveness of the BepiColombo T6 through improvements to the QinetiQ supply chain through T5 and T7 developments.

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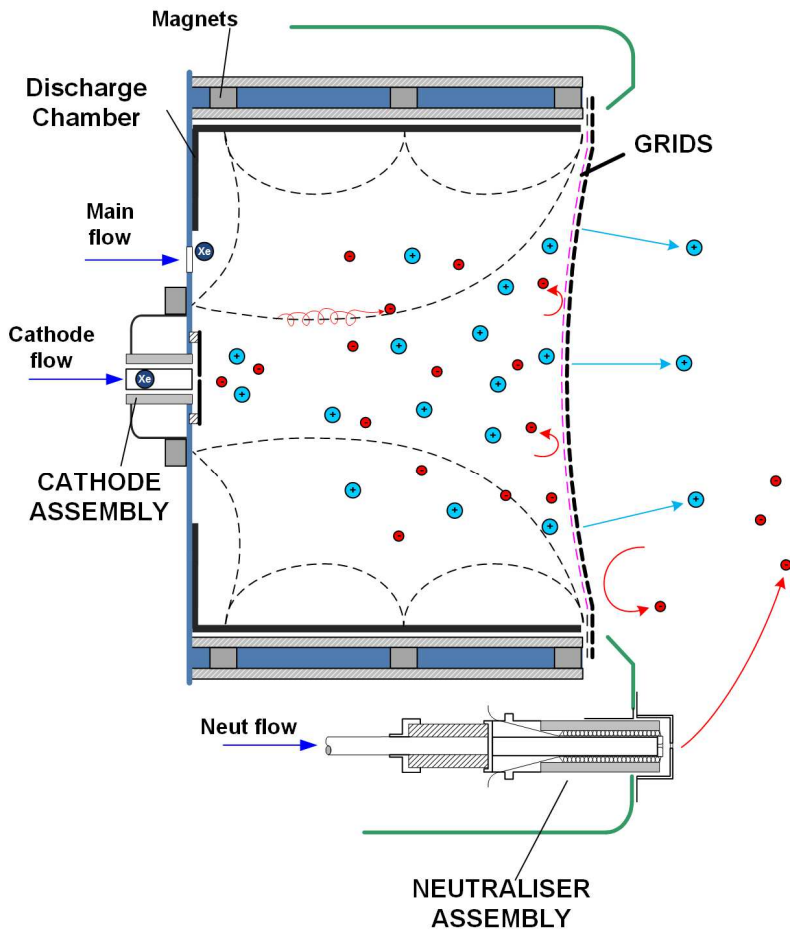
QinetiQ Ring Cusp Gridded Ion Engine – T7

- 5 to 7 kW class Gridded Ion Thruster
- Thrust capability up to 250 mN
  - Grid set can be optimised for different thrust ranges
- High Isp: ~3000s to ~4000s
- Dual Mode operation:
  - Variable power/thrust ratio: 31 W/mN to 24 W/mN

H2020 EPIC (GIESEPP) enabling QinetiQ to

- Improve competitiveness
  - Adoption of a Ring Cusp discharge chamber configuration
    - Improves electrical efficiency over the T6's Kaufman configuration
    - Cost reduction
- Incremental Development
  - Shares many design features with T6 thruster



Market Applications (1/2)

Market/Application	EP Function	T5	T6	T7	Comment
LEO Small Satellites	Primary propulsion *(New – emerging)*	✓			QinetiQ existing heritage… • T5 thruster is able to meet near term mission requirements and provide competitive edge QinetiQ is developing … • T5 industrialisation is reducing the recurring cost of the thruster to improve competitiveness and enable new missions based on smaller lower cost platforms • T5 performance enhancement will not only extend the capability of the thruster but improve the performance of the existing thrust range
Constellations	Primary propulsion *(New – emerging)*	✓	✓	✓	QinetiQ existing heritage… • T5 and T6 thrusters are able to meet near term mission requirements QinetiQ is developing … • Dual Mode (Isp) T7 provides a higher thrust mode to reduce the time to orbit which is likely to provide a better compromise between time to orbit and the propellant mass saving. • T7 Ring Cusp thruster offering a lower cost product & increased performance capability (lifetime / power / thrust) • T5 industrialisation is reducing the recurring cost to improve the competitiveness, for low cost small platforms
Geo Telecoms Satellites	North-South Station-Keeping ***(established)***		✓	✓	QinetiQ existing heritage… • T6 thruster is able to meet near term mission requirements QinetiQ is developing … • Dual Mode (Isp) T7 to provide a higher thrust mode to reduce the time to orbit , whilst retaining the high fuel efficiency for station keeping over the operation mission • T7 Ring Cusp thruster offering a lower cost product, & increased performance capability (lifetime / power / thrust)

Market Applications (2/2)

Market/Application	EP Function	T5	T6	T7	Comment
In-Orbit Servicing of Geo Telecoms Satellites *(i.e. mission extension; end-of-life deorbiting; potentially in – orbit refuelling also)*	North-South Station-Keeping PLUS Orbit transfer *(New – emerging)*	✓	✓	✓	QinetiQ existing heritage… • T5 and T6 thrusters are able to meet near term mission requirements and provide competitive edge QinetiQ is developing … • T7 Ring Cusp thruster offering a lower cost product and increased performance capability (lifetime / power / thrust) to enable the customer to get the most operational life out of the vehicle. • Dual Mode (Isp) means the full capability of the T7 is available to the mission designers, providing greater operational flexibility in planning, but also in-flight to optimise mission as it progresses. • T5 industrialisation , means that it is also available for in-orbit servicing vehicles based on smaller platforms
Space Transportation *Servicing exploration infrastructures (e.g. on/around Mars or Moon)*	Primary propulsion *(New – emerging)*		✓	✓	QinetiQ existing heritage… • T6 thruster is able to meet near term mission requirements and provide competitive edge QinetiQ is developing … • T7 Ring Cusp thruster offering a lower cost product and increased performance capability (lifetime / power / thrust) to enable the customer to maximise efficiency of its transportation solution. • Dual Mode (Isp) means the full capability of the T7 is available to the mission designers, providing greater operational flexibility in planning, but also in-flight to optimise mission as it progresses.
Deep Space Missions	Primary propulsion ***(established)***	✓	✓	✓	QinetiQ existing heritage… • T5 thruster performance to enable smaller missions • T6 thruster launching on BepiColombo in October 2018 QinetiQ is developing … • Dual Mode (Isp) means the full capability of the T7 is available to the mission designers, providing greater operational flexibility in planning, but also in-flight to optimise mission as it progresses. • T5 industrialisation , means that it is also available for such missions exploiting smaller spacecraft and/or lower levels of power available further out in the solar system. • T7 Ring Cusp thruster offering increased performance capability (lifetime / power / thrust) • Common product for commercial & institutional customers, all benefiting from volume cost benefits and common heritage .

Qualification and Acceptance

- Testing a GIE thruster is a significant portion of the cost and schedule
  - Both in terms of qualification and acceptance
    - Effort required to reduce the cost and timescales for both activities
  - New approaches required to meet demand from emerging markets
    - Constellations driving the cost and timescales
    - Current approaches not suited to meet emerging market requirements
      - Difference in the risk appetite of customers
      - Major challenges still exist to address these new market drivers
  - Work required to address these issues across the complete EP system
    - Thruster, FCU and PPU
- Different challenges for each activity
  - Qualification of a new development
  - Delta qualification of a previously qualified thruster
  - Acceptance testing for a recurring build

Current Approach - Qualification of a new development

- Standard qualification campaign for space hardware
  - Performance testing, thermal vacuum testing, mechanical testing, **LIFETEST….**
- Lifetime qualification is the most expensive part of the test campaign
  - Relies on long duration tests that match or exceed the expected lifetime
  - Margins applied to lifetime of 1.3x for lifetime and 1.5x for operational cycles
    - May also include additional worst case assumptions to account for
      - Failures
      - Uncertainty in the use cases of the thruster
  - Production of thruster models for lifetime prediction
    - Current models not validated
    - Requires significant test data to allow for approximations of the life time predictions to be made
- Main challenges are
  - The expense and long timescales to complete qualification
    - No reliable approach to accelerated life testing has yet been identified
  - Work funded on a project by project basis with data ownership retained by commercial customer
    - Sharing of data between life tests required to avoid repeating similar test campaigns for each customer

Current Approach - Delta qualification of a previously qualified thruster

- Limited testing tailored to cover the areas under development
- Some or all of the full qualification test campaign required
  - Aim for all tests to be ‘value adding’
- Lifetime delta qualification
  - Inclusion dependent on the impact on the main life limiting elements of the thruster
  - Short duration tests that feed into the modelling from the qualification test
  - Limits the cost and timescales with minimal increase in the risk from a full life test
  - Requires an accurate model generated during the original development programme
- Main challenges are
  - Similar challenges to qualification
  - Approach requires data to be readily available from qualification campaign
    - Commercial restrictions may limit access to data requiring full life test
  - Modelling tools need to be mature enough to enable this approach

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Current Approach - Acceptance of a qualified thruster

- Acceptance test campaign required for each thruster
  - Similar suite of tests as per qualification but with reduced levels and durations
  - Performance testing, thermal vacuum testing, and mechanical testing
  - Currently accounts for a significant proportion of the total cost of the thruster
- Main challenges are
  - Reducing the costs and timescales to complete acceptance
    - Need to maintain levels of reliability and traceability
  - Generating statistical evidence to reduce scope and / or remove acceptance tests
  - Approach to testing of multiple thrusters

Future approach to Qualification and Acceptance

- Divergence of approach to Qualification and Acceptance
  - Qualification will still be based on long duration tests
    - Significant improvements required in modelling to allow for alternative approaches
  - Acceptance will be driven by better understanding of limitations in variability in the recurring build standard as production rates increase
    - Targeted testing based on experience with step away from all encompassing test campaigns
    - Reduction of the scope of testing is Work in progress and key objective for QinetiQ
- QinetiQ welcomes the opportunity to work with peer group to streamline qualification
  - Interest in gridded ion community working together on common approach to qualification of lifetime
    - Thruster suppliers and modelling houses with Agency support

Conclusions

Market for Electric Propulsion technology is increasing …

- Increasing uptake in the traditional GEO telecom satellite market, as well as for orbit raising function.
- Adoption for satellite constellations
- Continued use for interplanetary missions
- Enabling new applications such as space transportation, in-orbit servicing and new/novel LEO application.

GIEs, such as QinetiQ's T-series, offer the greatest fuel efficiency options to customers

- Industrialisation is driving costs down, from its science applications heritage (bespoke, one-off, high-performance)

H2020 EPIC is realising ….

…. incremental changes to QinetiQ's proven technology to improve competitiveness in global market

Further work required on developing a lower cost approach to Qualification and Acceptance…

…QinetiQ welcomes the opportunity to discuss optimisation of the approach taken

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