The development of a family of Resistojet Thruster Propulsion Systems for Small Spacecraft

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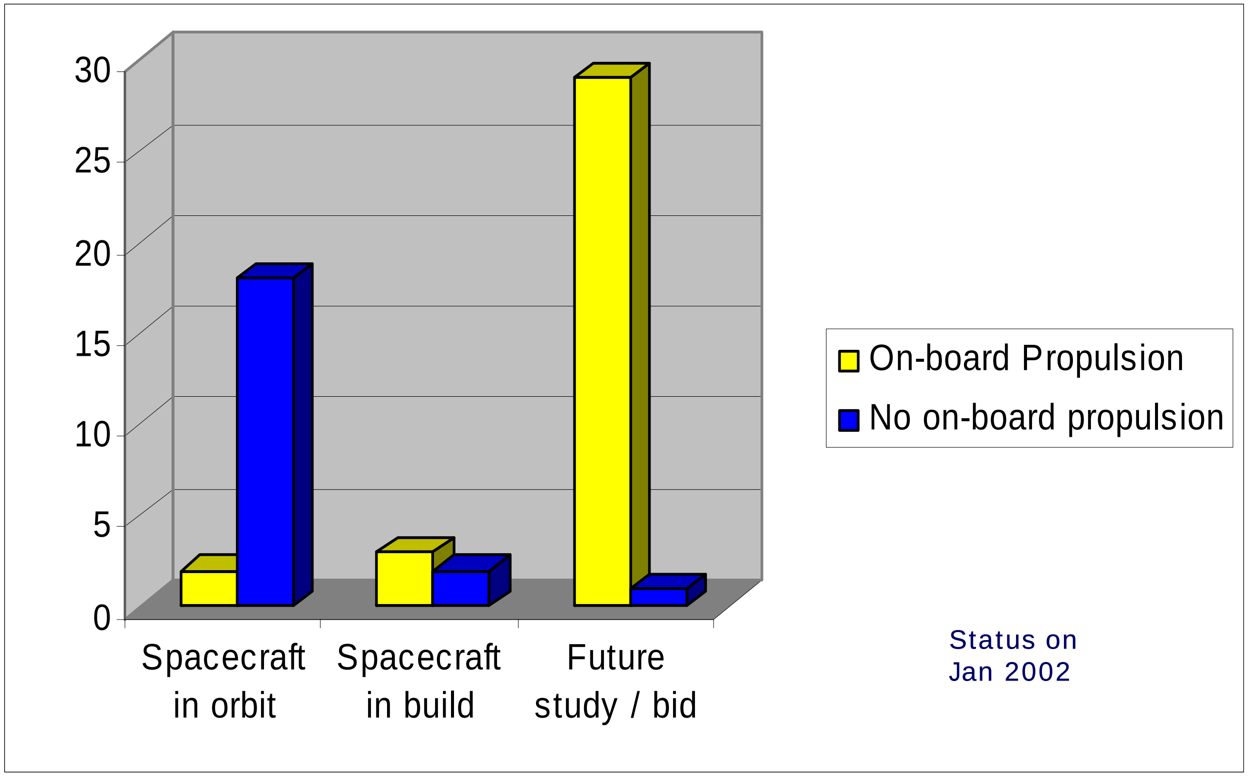
The need for Propulsion



- There is a clear trend at SSTL towards small spacecraft with on-board propulsion

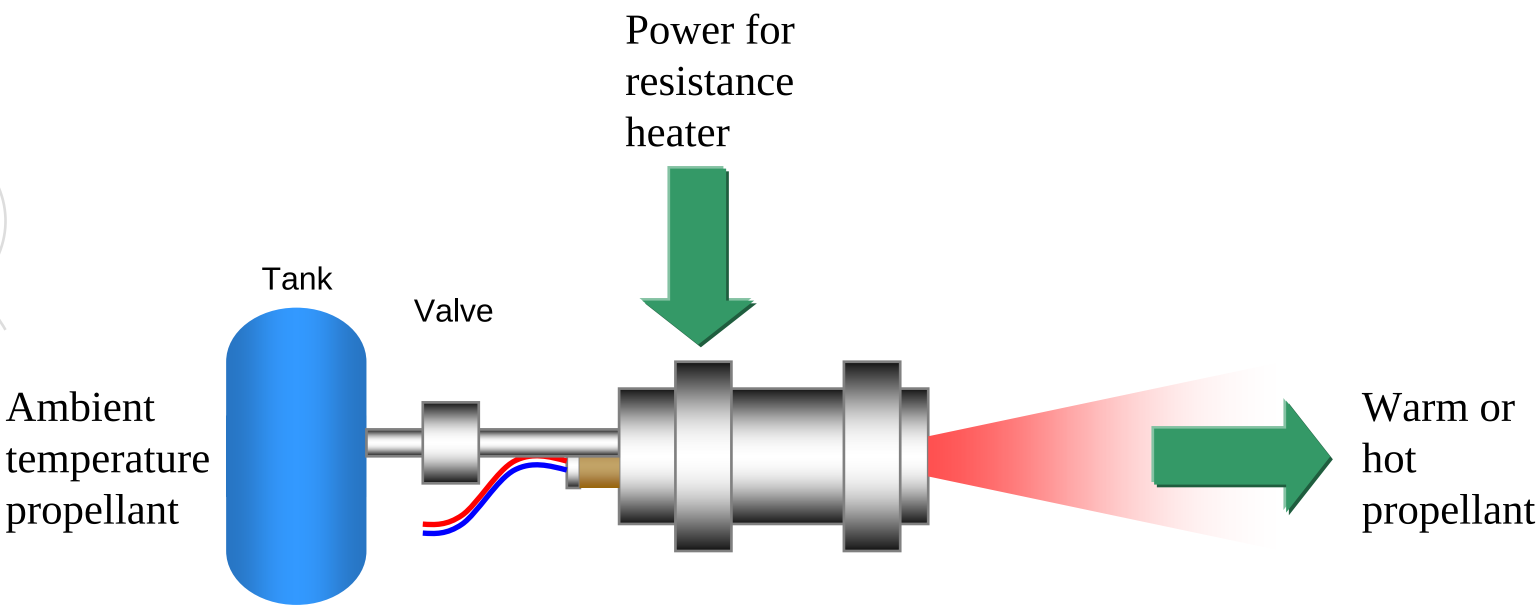
Theory

- From classic thermodynamics the sonic velocity at the throat of a rocket nozzle is given by :-

$$V_{throat} = \sqrt{\gamma R T_{throat}}$$

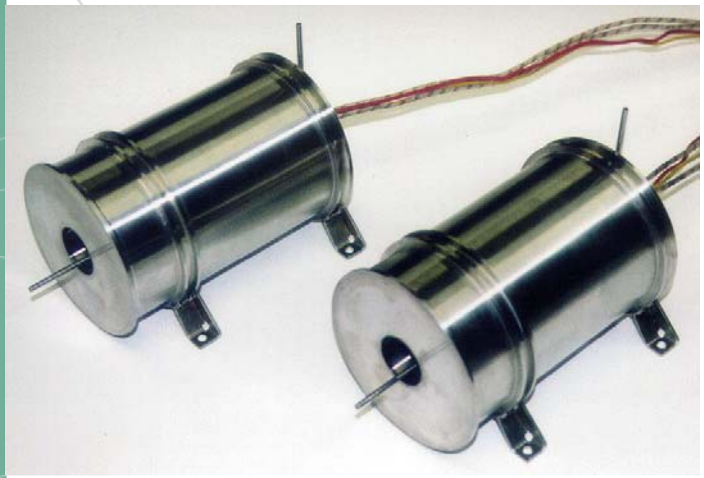
- Where
  - γ = ratio of specific heat (approx constant)
  - R = Gas constant
  - T_{throat} = gas temperature at throat
- Therefore the hotter the gas the higher its velocity, hence higher the specific impulse
- Hence if you double the gas temperature from 300K to 600K a specific impulse of √2 (i.e. 41%) is gained

Resistojet Thruster



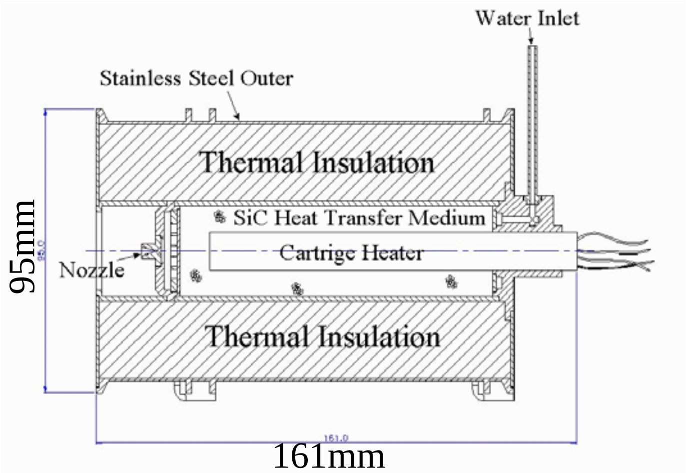
- A resistojet thruster increases the propellant temperature through resistance heating
- Also can act as a vaporiser, hence it can be fed liquid phase propellant and it will expel vapour phase.

UoSAT-12 thruster



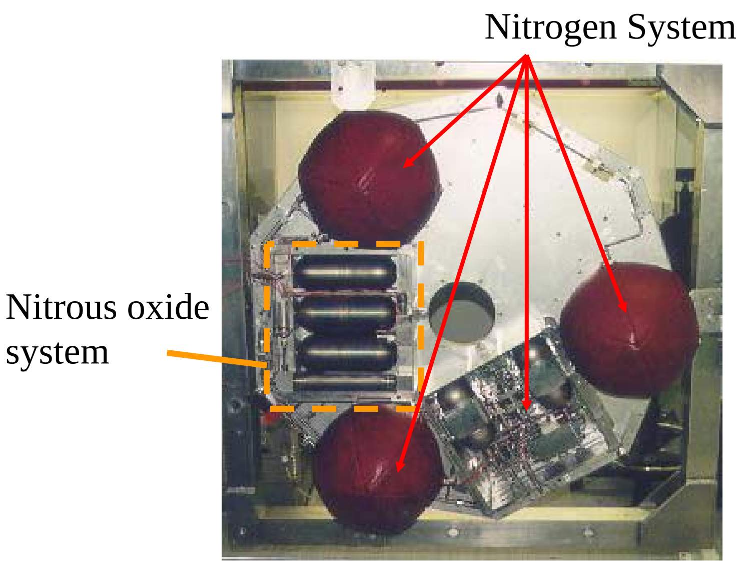
- Result of 3 years of PhD study
- 100 Watt cartridge heater
- 50 – 100 mN thrust
- Qualified with water and nitrous oxide
- Heats propellant to ~ 800°C

- Flown on UoSAT-12 in April 1999 with nitrous oxide as propellant
- Nitrous oxide as cold gas Isp ~ 60 sec. In this thruster Isp ~ 127 sec



UoSAT-12 Propulsion Systems

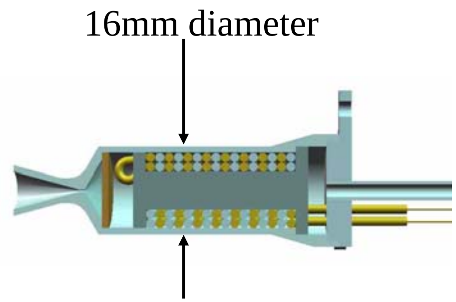
Propulsion system	Type	Propellant mass	DeltaV
Nitrogen	Cold gas	6.4 kg	14 m/sec
Nitrous oxide	Resistojet	2.1 kg	9.7 m/sec



UoSAT-12 propulsion panel

- Using the resistojet gives 2/3 of the delta V for 1/3 of the propellant mass
- The nitrous oxide system also occupies far less volume as it is stored as a liquid at higher density

Low power resistojet design



- Designed to SSTL's 80 / 20 philosophy (80% of the performance at 20% of the cost)
- Redundant 15 Watt heaters wound on a central bobbin
- No direct flow path for propellant, it is forced to spiral through the heater
- Filter disc downstream of heater protects the throat
- Heater power rating can be changed without changing any interface parameters (dual 50 Watt version tested)
- Runs directly off 28 Vdc spacecraft bus

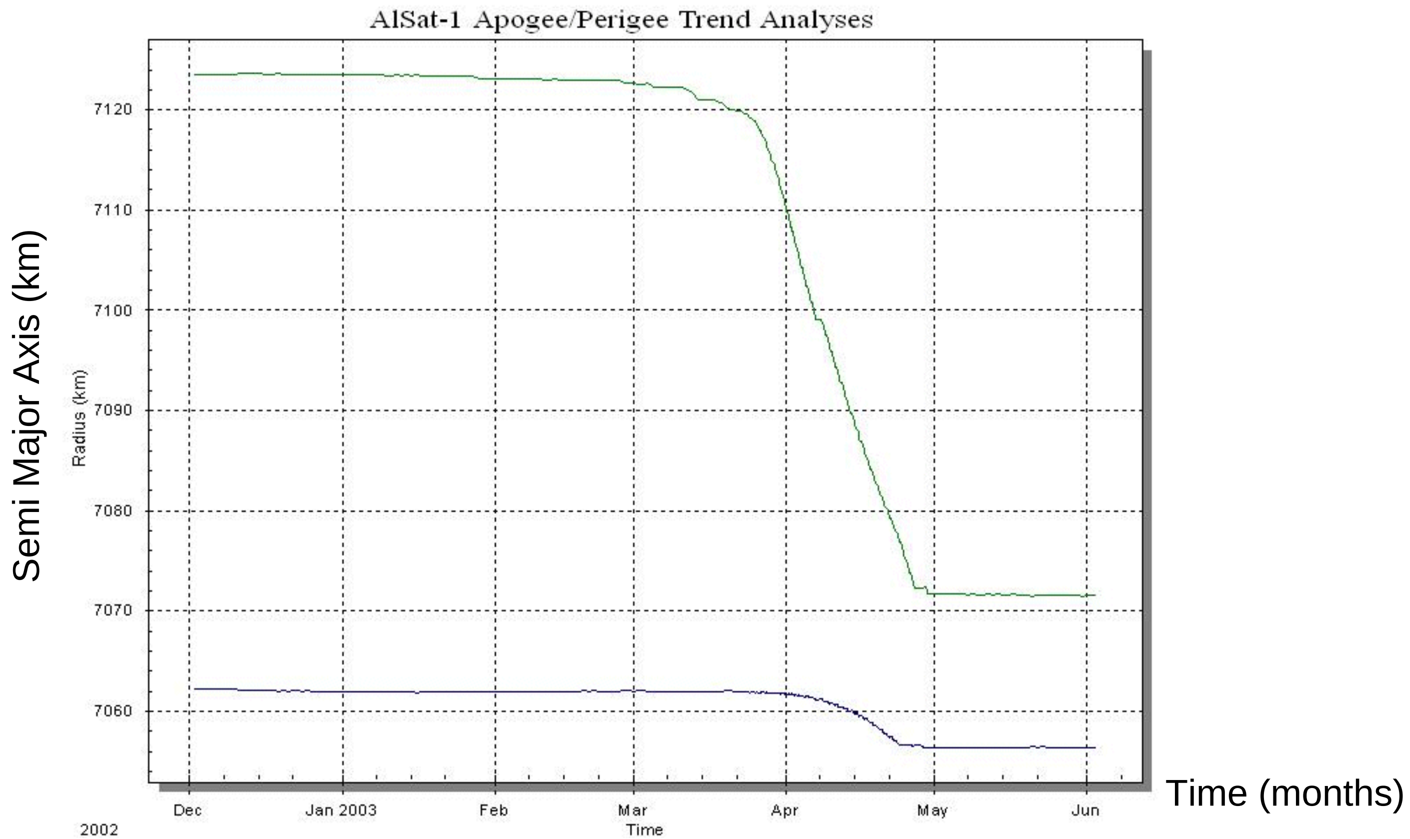
Benefits on DMC spacecraft

- Typically 20 – 25 m/sec of delta V from 2.35 kg of butane
- Traditional approach is to use nitrogen gas ~ 2.0 kg needed with the resistojet
- But nitrogen at 200 bar has less than half the storage density than butane. Hence 4 high pressure propellant tanks would be needed. This gives a massive increase in mass and volume used.
- Butane is stored as a liquid and vaporised by the resistojet
- Hence the use of the resistojet allows liquefied gases to be used, saving volume and mass over compressed gases

UK-DMC spacecraft
without solar panels fitted

2 propellant tanks.
(4 would be required with traditional nitrogen solution)

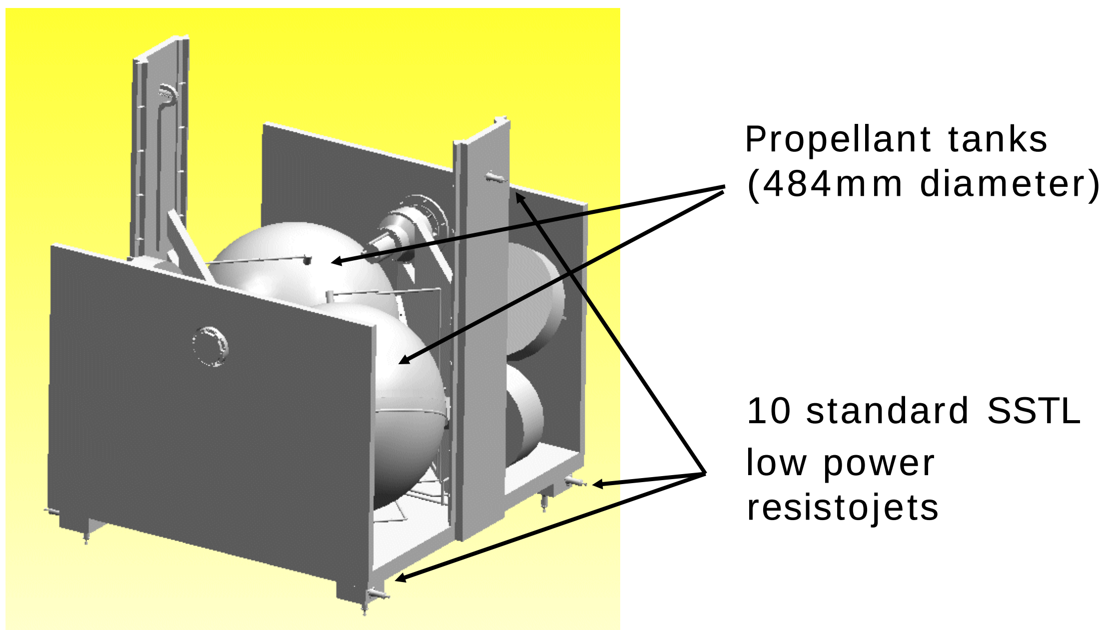
Alsat –1 in-orbit performance



- Orbit apogee reduced from 745.5 km to 693.6 km
- 14.5 m/sec delta V to spacecraft
- 168 operations
- 8.08 hours firing time

GSTB-V2

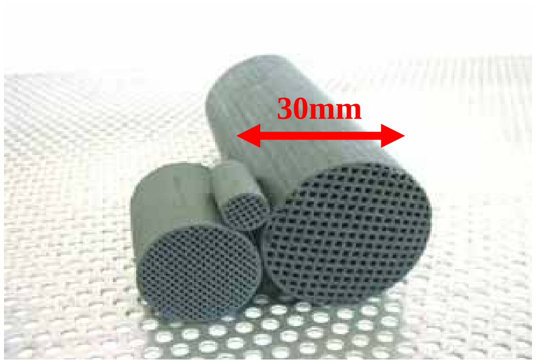
- Based on SSTL's GEMINI platform, which has 2 x 60 litre tanks.
- The full platform capability is > 500 m/sec using hydrazine as the propellant. GSTBV-2 only requires 90 m/sec.
- Nitrogen cannot be substituted as a low cost alternative as its storage density is too low
- Butane is used to give 117 m/sec using the same tank volume. The only way butane can be used is with a resistojet as a vaporiser. This gives a significantly lower cost system, without significant structural changes



Micro Resistojet

- Micropropulsion experiment to fly on UK-DMC in Sept 2003
- Propellant is 2.06 g of water
- Microresistojet operates from 3 Watts of power
- Aimed at CUBESAT type missions

Next generation resistojet



- Carbon heat exchanger
- Using extruded carbon ‘Monolith’
- Electrical conductivity ~1Ω/m, tailorable
- Temperature coefficient of resistance, tailorable
- Direct electrical heating of monolith, high heat transfer to propellant

Conclusions

- Resistojet thrusters can be used as a simple form of extending the spacecraft delta V capability, hence mission lifetime
- Used in the vaporiser mode they allow the use of liquefied gases, e.g. butane and nitrous oxide.
  - This gives higher density Isp than traditional compressed gas systems, e.g. nitrogen
  - Lower costs than hydrazine systems
- First resistojet flown on UoSAT-12 with nitrous oxide
- Low power resistojet flown on ALSAT-1 in Nov 2002 and achieved 14.5 m/sec ΔV for orbit injection correction
- 6 further spacecraft with 15 thrusters will use this thruster