Electrothermal Monopropellant Thrusters

- With hydrazine, can achieve T_o~1200-1400K
- To achieve higher I_{sp}, need even higher T_o
- How?
  - nuclear thermal
    - nuclear heat source (direct or indirect)
    - studied
  - electric heating
    - any electrical source (solar, nuclear, fuel cell, …)
    - deployed!!
    - known as **electrothermal thrusters**
    - I_{sp} ~ 300-800(1500) s
    - thrust-to-weight <10^{-3}

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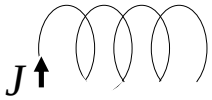
Electrical Heating

- Current passing through conductor heats it by amount proportional to its resistance

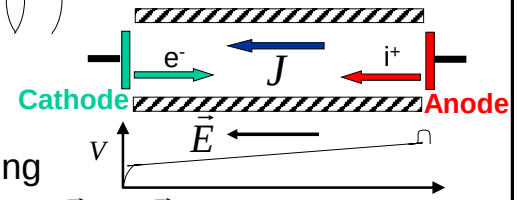
Current (A=C/s) Resistance (Ohms)

$$\dot{Q} = J^2 R$$

- Wire



- Gas (Plasma) Discharge
  - resistance heating due to collisions



$$\vec{E} = -\vec{\nabla} V$$

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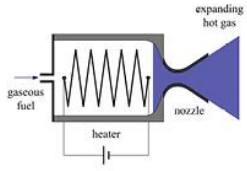
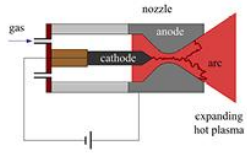
Types of Electrothermal Thrusters

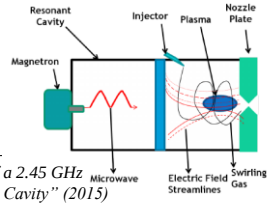
- **Resistojets**
  - current passing through solid resistive heating element, heat transfer to propellant



- **Arcjets**
  - current flows through flowing propellant gas as arc discharge across electrodes



- **Microwave Heated Thrusters**
  - microwave transmitter produces and energizes plasma in propellant flow



From Yildiz et al., "Geometry Optimization of a 2.45 GHz Microwave Electrothermal Thruster Resonant Cavity" (2015)

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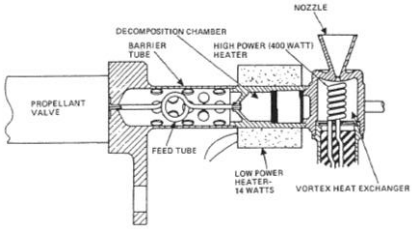
Resistojets

- More common electrothermal thruster in space (to date)
- Early deployment on Intelsat V (by TRW Space & Commun.)
  - I_{sp}=295 s, τ=0.45 N (0.1 lb_f), I_{tot}=80 kN s, τ/w=0.13, ε=200, P_{elec}~0.4kW
- More recent Aerojet MR-501 series
  - I_{sp}=294-303 s, τ=0.2-0.4 N, I_{tot}=327 kN s, τ/w~0.03, ε=200, P_{elec}~0.5kW

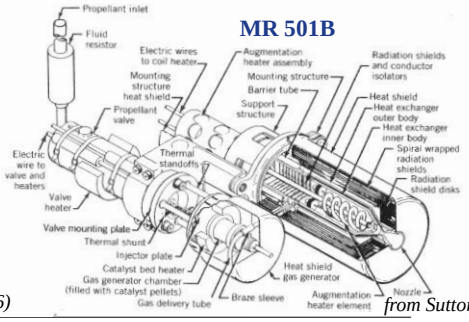
later Northrup Grumman

EHT Intelsat V



*from C. Brown, **Spacecraft Propulsion** (1996)*

MR 501B



from Sutton

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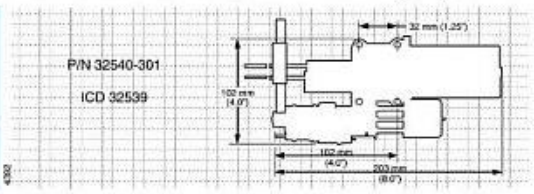
Hydrazine Resistojet

MR-501B–ELECTROTHERMAL HYDRAZINE THRUSTER (EHT)



Design Characteristics

- Propellant ..... Hydrazine
- Catalyst ..... S 405
- Thrust/Steady State ..... 0.369 – 0.182 N (0.083 – 0.041 lbf)
- Feed Pressure ..... 24.1 – 6.9 bar (350 – 100 psia)
- Flow Rate ..... 0.1225 – 0.045 g/sec (0.00027 – 0.0001 lbm/sec)
- Valve ..... Dual Seat
- Valve Power ..... 8.25 Watts max at 28 Vdc & 21°C
- Valve Heater Power ..... 8.00 Watts max at 28 Vdc & 21°C
- Cat. Bed Heater Pwr ..... 4.00 Watts max at 28 Vdc & 21°C
- Augmentation Heater Power ..... 493 – 467 Watts
- Augmentation Heater Voltage ..... 24.4 Vdc
- Mass ..... 0.889 kg (1.96 lbm)

Performance

- Mission Specific Impulse at 24.4 Vdc ..... 303 – 294 sec (lbf-sec/lbm)
- Total Impulse ..... 326,928 N-sec (73,500 lbf-sec)
- Demonstrated Total Off-Pulses* 500,000
- Minimum Off-Pulse Bit at Max Feed Pressure ..... 0.0022 N-sec (0.0005 lbf-sec)
- Steady State Firing ..... 1.7 hrs — Single firing ..... 389 hrs — Cumulative

*Off-Pulse = Short duration shutdown during otherwise steady operation, for attitude control

*Designed primarily for steady state operation but has demonstrated off-pulse capability

Rev Date 4/2/03

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Approved for public release and export

AEROJET

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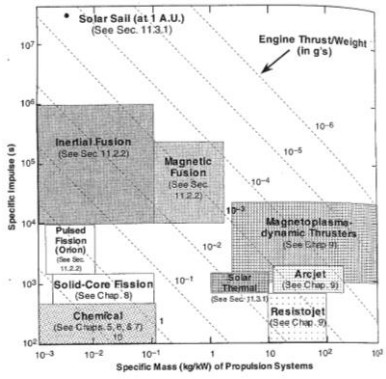
Resistojets Propellants

- Hydrazine most common propellant
  - 300 s specific impulse is ~30% increase over purely chemical (decomposition) versions
- Could use H_2 and achieve ~840 s
  - not easily stored for long times
  - requires high electrical power and thus low thrust to weight (electrical power systems have high specific mass=mass system/power)
- Ammonia (NH_3) has also been used
- ISS (space station) includes multipropellant low-thrust resistojets that utilize waste fluids



from Humble, Henry and Larson (1995)

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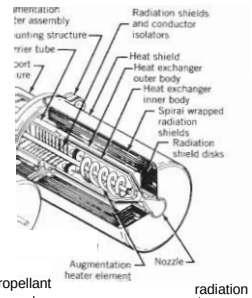
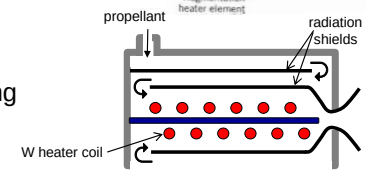
Resistojet I_{sp} Limitations

- Maximum specific impulse typically limited by maximum electrical heater temperature
  - materials limits of heating element
- High temperature materials available
  - rhenium, platinum, refractory metals and alloys their (tungsten, tantalum, molybdenum), cermets (ceramic and sintered metal mixtures)
  - e.g., tungsten (W) T_{max}~3000K, gives $I_{sp}N_2H_4$ = 300s
- Also need to minimize heat losses from heating chamber
  - insulation
  - internal radiation shields
  - flow patterns, entrant flow cooling
- Maximum pressures typically < 200-300 psia





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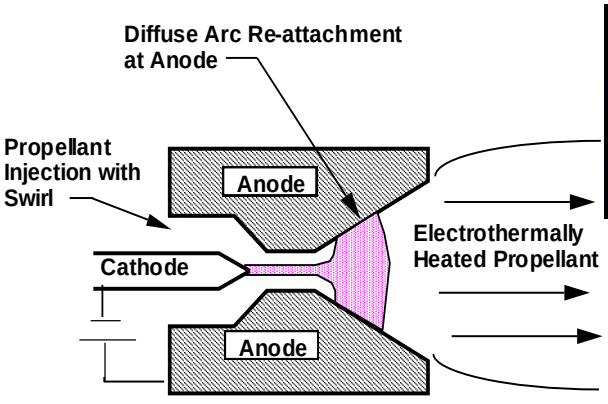
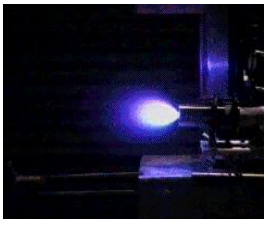
Arcjets





From GT HPEP Lab

- An electrical arc (stream of energetic electrons) heats propellant that is then expanded through a nozzle

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Arcjets for In-Space Applications

- **Application Range**
  - station keeping of moderate-sized spacecraft (few kW, hydrazine)
    - 1st application Dec 1994: LM Astro Series 7000, Telstar 401 satellite
  - piloted Mars mission (100 kW, hydrogen)
- **Advantages**
  - high I_{sp}: 600s (N_2H_4), 800s (NH_3,TRW/AFRL) to 2000 s (H_2)
    - vs. hydrazine decomp. thrusters (~240 s) and resistojets (~300 s)
  - improves propellant efficiency $\Rightarrow$ larger satellite payloads
  - similarity between hydrazine arcjets and space-qualified thrusters already integrated into spacecraft for station keeping
- **Drawbacks**
  - excessive heating $\Rightarrow$ limited life and/or advanced materials
  - higher frozen flow losses in nozzle (high T_e) $\Rightarrow$ low thrust efficiencies (~35% of input power converted to useful thrust)
  - possible plume contamination

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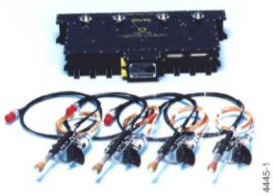
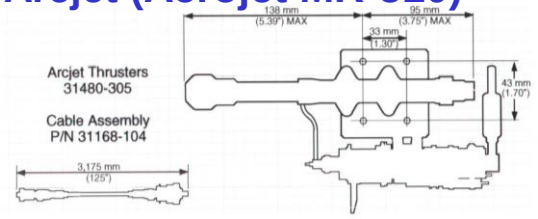
Hydrazine Arcjet (Aerojet MR-510)





Design Characteristics

- Propellant ..... Hydrazine
- Feed Pressure ..... 17.9 –12.7 bar (260-185 psia)
- Thrust/Steady State ..... 258-222 mN (58-50 mlbf)
- Mass
  - Arcjet Thruster
  - + 3175 mm (125") cable ..... 1.58 kg (3.49 lbm)
- Envelopes
  - Arcjet ..... 237 x 125 x 91 mm (9.3 x 4.9 x 3.6 in.)
- Valve ..... Wright Components Dual Seat
- Valve Power ..... 8.2 Watts @ 28 Vdc & 21°C

Rev. Date: 2-8-00

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Demonstrated Performance

Beginning Of Life

- Thrust ..... 258-222 mN (58-50 mlbf)
- Specific Impulse ..... > 570-600 sec (BOL)
- Total Impulse ..... 1,450,000 N-sec (326,000 lbf-sec)
- Firing Time
  - Total (1 hr on, 1/2 hr off) ..... >1730 Cycles
  - Longest Single Burn During Qualification ..... 3 hr
- Starts ..... > 1950
- Telemetry Signals Available
  - Gas Generator Temperature
  - Valve Temperature

vs. MR-501

I_{sp}=2×, P_{elec}=4×
(T_o=4×)

I_{sp}=600 s, τ=0.25 N,
I_{tot}=1500 kN s,
τ/w<0.02, P_{elec}~2 kW

AEROJET

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Hydrazine Arcjet

1999 Test Firing of a Primex (now Aerojet) MR-510 Hydrazine Arcjet

- **Thrust** 222-258 mN
- **Input Power** 4340 W (into Power Supply [PCU] for 2 arcjets); 2000 W input to each arcjet from PCU)
- **Isp** > 570-600 s

A shipset of Aerojet MR-510 Hydrazine Arcjets and a Power Conditioning Unit

- 16 Lockheed Martin A2100™ spacecraft (satellites) with MR-510 systems have been launched
- Each spacecraft has 4 thrusters and 1 PCU; 2 at a time used for N-S station keeping orbit maneuvers

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