Total Propulsion Solutions

Man Rated Space Propulsion

Monopropellant Hydrazine Thrusters

Rocket Engine Modules

Bipropellant Control Thrusters

Complete Propulsion Systems

High Performance Apogee Thruster (HIPAT™)

Power Processing Units

“Green” Monopropellant Thrusters

Hall Effect Thrusters

Monopropellant Hydrazine Thrusters

Arcjets

Ion Thrusters

Pulsed Plasma Thrusters
Redmond Operations

- LOCATED IN REDMOND, WA
- 80 ACRE SITE
- FOURTEEN BUILDINGS
- 180,000 SQUARE FEET
Engineering Capability

Mechanical Design
- Liquid/Solid Propulsion Systems and Components
- Structures, Pressure Vessels and Plumbing

Electrical Design
- Analog and Power Conversion Electronics
- Digital-Embedded Processors, Controls and Test Equipment

Manufacturing Engineering-Concurrent with Design

Structural Analysis
- System Dynamics and Static Analysis
- Non-Linear Structural Analysis
- Fracture Mechanics

Thermal Analysis
- Radiation, Conduction, Convection
- Passive and Active Control Systems

Performance Analysis
- Orbital Mechanics and Trajectory Analysis
- Multi-Body Dynamic Simulation
- System Fluid Dynamics for Surge and Water Hammer, Press. Drop Balancing Optimization
- Computational Fluid Dynamics
- Plume Analysis

Magnetic Circuit Analysis
- Magnetic Field Analysis and Design

Circuit Simulation and Timing Analysis

Materials and Processes
- Process Control, Metallurgical Analysis and Mechanical Processing Testing

Component Engineering
- Electrical and Mechanical Components
- Specifications and Performance Analysis
- Supplier/Component Selection, Qualification, Problem Resolution and Risk Mitigation
- Valve Design

Safety and Reliability Analysis

Approved for Public Release and Export
Supported Software

**Mechanical Design**
- Unigraphics NX and I-DEAS, Pro-E
- Electronic Transfer of Model Geometry from Design to Machining

**Electrical Design**
- ORCAD, Unigraphics NX, IDEAS, PADS 2000

**Structural Analysis**
- ANSYS, ABAQUS, Nastran and NISA for Finite Element Analysis
- ANSYS, NISA DISPLAY and IDEAS for Pre / Post Processing
- NASGRO Crack Analysis

**Thermal Analysis**
- SINDA / Thermal Desktop
- IDEAS TMG
- NISA DISPLAY and IDEAS for Pre / Post Processing

**Performance Analysis**
- FORTRAN, C++, MathCAD, Maple, Tecplot, and Custom Codes
- Fluent / Gambit for CFD Analysis
- LETS and AFT / Impulse for Fluid Flow
- Simplorer and Simulink for Systems Analysis

**Magnetic Analysis**
- Magnet

**Circuit Simulation and Timing Analysis**
- P-SPICE, ACTEL Designer

**Manufacturing Engineering**
- Unigraphics NX and IDEAS

**All Engineering, Including Project Office**
- MS Office Suite
- Microsoft Outlook

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Test Capability

Vibration Test Facility
• Sine Sweeps, Random Vibration, Mechanical Shock
• Response Measurements

Hotfire Facilities
• Hydrazine, HAN, MMH/NTO and Other Propellants
• 10 State-of-the-Art Vacuum Firing Chambers
  • Steam Ejector, Mechanical and Cryo-Pumps
  • Acceptance Testing
  • Thermal Model Verification
• Fuel Storage and Testing

Environmental Test Facilities
• Thermal Vacuum, Thermal Shock and Temperature Cycling
• Long Term Hydrazine Compatibility Testing

Electronics
• Automated End Item Test Equipment Utilizing Software Control
• Circuit Card Electrical Test Equipment Design and Fabrication
• High Voltage Corona Testing
• EMI / ESD Testing

Materials and Processing Testing
• Chemical Analysis
• Metallographic Sectioning, Tensile and Shear Tests, Other

Approved for Public Release and Export
Altitude Test Facility

Building 63 - Front View

Approved for Public Release and Export
Altitude Test Facility
Building 63 - Capabilities Summary

Altitude Testing

• Ten vacuum test chambers
• Hydrazine rocket engines 0.02 lbf - 100 lbf (duty cycle dependent)
• Bipropellant and dual mode engines up to 200 lbf
  • 3-Stage steam ejector system
• Arcjets up to 50 kilowatts
• Xenon Hall Effect Thrusters up to 4.5 kilowatts
• Multiple vacuum pump configurations possible
• High vacuum (<1 x 10^-6 torr)
  • Four chambers with cryogenic pumps
• All chambers have a self-contained, fully equipped, closed hydrazine propellant feed system. Modifications can be accommodated to meet new requirements.

Sea Level Testing

• Two protected, fortified test cells
• Multiple and alternative fuel compatible (liquid, solids, bipropellant)
• Two 4’ x4’ x4’ temperature conditioning chambers for conditioned testing
Manufacturing Capability

Machine Shop
- CNC Milling & Turning
- EDM
- Grinding
- Conventional Machining
- Full Service Dimensional Inspection Lab

Mechanical and Electronic Assembly Areas
- Class 1,000, 10,000 and 100,000 Clean Rooms and Assembly Areas
- Automatic Orbital Welding
- Electron Beam Welding
- Manual and Automatic GTA Welding
- Tube Bending
- Precision Part Cleaning
- Water and Gas Flow Testing
- Radiographic and UT Testing
- High Pressure Leak and Test Vault
- Valve Assembly and Encapsulation
- Manual and Wave Soldering
- Wire/Cable Harness Design and Manufacturing

Certification
- AS9100
- ISO 9001: 2000
- ISO 14001

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Manufacturing Capability

Manufacturing Floor Space
• 84,000 of 180,000 total square feet

Integration and Launch Services
• Fueling Carts and Personnel Available to Fuel at Customers’ Locations
Chemistry Capability

Chemical Manufacturing
- Catalyst Fabrication
- Gold and Rhodium Plating
- Chemical Milling and Etching
- Metal Cleaning and Passivation
- Heat Treating
- Teflon Processing

Chemical Analysis
- Full Mil Spec Assay of Hydrazine, MMH and MON-3 Oxidizer
- DI Water According to JSC C-20
- Solvent Purity Analysis
- Trace Metal Content by ICP-OES
- Gas Constituent Analysis by FTIR
- pH and Titration Analysis

Product Development
- Ignition Delay Testing (Pino)
- Propellant Environment Simulation
- High Temperature Catalyst Development
- Material Compatibility Testing
- Thermal Cycling

Environmental Chemistry Support
- Age Sensitive Materials Testing
- Trace Contaminant Testing and Remediation
Products
### Monopropellant

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*Approved for Public Release and Export*
MR-103C 1N (0.2-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics
- Propellant: Hydrazine
- Catalyst: S405
- Thrust/Steady State: 1.02 – 0.22 N (0.230 – 0.05 lbf)
- Feed Pressure: 27.6 – 6.2 bar (400 – 90 psia)
- Chamber Pressure: 23.4 – 5.9 bar (340 – 85 psia)
- Expansion Ratio: 100:1
- Flow Rate: 0.5 – 0.09 g/sec (0.001 – 0.0002 lbm/sec)
- Valve: Dual Seat
- Valve Power: 8.25 Watts Max @ 28 Vdc & 21°C
- Valve Heater Power: 1.54 Watts Max @ 28 Vdc & 21°C
- Cat. Bed Heater Pwr: 3.93 Watts Max @ 28 Vdc & 21°C
- Mass: 0.33 kg (0.73 lbm)
  Engine: 0.13 kg (0.28 lbm)
  Valve: 0.20 kg (0.45 lbm)

Performance
- Specific Impulse: 224 – 209 sec (lbf-sec/lbm)
- Total Impulse: 121,817 N-sec (27,387 lbf-sec)
- Total Pulses: 410,000
- Minimum Impulse Btl: 0.022 N-sec @ 6.9 bar & 15 ms ON
  (0.005 lbf-sec @ 100 psia & 15 ms ON)
- Steady State Firing: 30,000 sec – Single Firing
  60 hrs – Cumulative

Status
- Flight Proven

Reference
- SC00-2000-XI-1

Approved for public release and export
MR-103D 1N (0.2-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics
- Propellant: Hydrazine
- Catalyst: S405
- Thrust/Steady State: 1.02 – 0.22 N (0.230 – 0.05 lbf)
- Feed Pressure: 27.6 – 6.2 bar (400 – 90 psia)
- Chamber Pressure: 23.4 – 5.9 bar (340 – 85 psia)
- Expansion Ratio: 100:1
- Flow Rate: 0.5 – 0.09 g/sec (0.001 – 0.0002 lbm/sec)
- Valve: Dual Seat
- Valve Power: 8.25 Watts Max @ 28 Vdc & 21°C
- Valve Heater Power: 1.54 Watts Max @ 28 Vdc & 21°C
- Cat. Bed Heater Pwr: 3.93 Watts Max @ 28 Vdc & 21°C
- Mass: Engine 0.33 kg (0.73 lbm)
- Engine: 0.13 kg (0.28 lbm)
- Valve: 0.20 kg (0.45 lbm)

Performance
- Specific Impulse: 224 – 209 sec (lbf·sec/lbm)
- Total Impulse: 186,000 N·sec (41,828 lbf·sec)
- Total Pulses: 275,028
- Minimum Impulse Bit: 0.027 N·sec @ 6.9 bar & 15 ms ON
- Steady State Firing: 5,000 sec – Single Firing
- 111.4 hrs – Cumulative

Status
- Flight Proven

Reference
- SC00-2000-XI-1
MR-103G 1N (0.2-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics
- Propellant: Hydrazine
- Catalyst: S405
- Thrust/Steady State: 1.13 – 0.19N (0.253 – 0.043 lbf)
- Specific Impulse: 224 – 202 sec (lbf-sec/lbm)
- Feed Pressure: 28.3 – 4.8 bar (420 – 70 psia)
- Chamber Pressure: 23.8 – 4.5 bar (345 – 65 psia)
- Expansion Ratio: 100:1
- Flow Rate: 0.5 – 0.09 g/sec (0.0011 – 0.0002 lbm/sec)
- Valve: Dual Seat
- Valve Power: 8.25 Watts Max @ 28 Vdc & 21°C
- Cat. Bed Heater Pwr: 6.32 Watts Max @ 28 Vdc & 21°C
- Mass: 0.33 kg (0.73 lbm) Engine, 0.127 kg (0.28 lbm) Valve, 0.204 kg (0.45 lbm)

Performance
- Total Impulse: 97,078 N-sec (21,825 lbf-sec)
- Total Pulses: 835,017
- Minimum Impulse Bit: 0.0133 N-sec@0.015sec ON & 6.9 bar (0.003 lbf-sec@0.015sec) (ON & 100psi)
- Steady State Firing: Single firing: 300 sec, 1,000 sec
  Cumulative: 23.8 hrs – 40.6 hrs

Status
- Flight Proven

Reference
- AIAA-2005-3952
MR-103M 1 N (0.2-lbf) ROCKET ENGINE ASSEMBLY
Minimum Impulse Thruster (MIT)

**Design Characteristics**
- Propellant: Hydrazine
- Catalyst: S405
- Thrust/Steady State: 0.99 – 0.28 N (0.22 – 0.06 lbf)
- Feed Pressure: 27.6 – 6.9 bar (400 – 100 psia)
- Chamber Pressure: 20.7 – 5.9 bar (300 – 85 psia)
- Expansion Ratio: 100:1
- Flow Rate: 0.45 – 0.14 g/sec (0.001 – 0.0003 lbm/sec)
- Valve: Single Seat
- Valve Power: 7.1 Watts @ 28 Vdc & 21°C
- Cat. Bed Heater Pwr: 3.8 Watts @ 28 Vdc & 21°C
- Mass: 160 gm (0.35 lbm)
- Engine: 135 gm (0.30 lbm)
- Valve: 25 gm (0.05 lbm)

**Performance**
- Specific Impulse: 221 – 206 sec (lbf-sec/lbm)
- Total Impulse: 121,817 N·sec (27,387 lbf·sec)
- Total Pulses: 515,344
- Minimum Impulse Bit: ~670E-6 N·sec @ 1.6 ms ON
- Steady State Firing: 30,000 sec – Single Firing
  60 hrs – Cumulative

**Status**
- Qualified

**Reference**
MR-111C 4 N (1.0-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics
- Propellant: Hydrazine
- Catalyst: S405
- Thrust/Steady State: 5.3 – 1.3 N (1.2 – 0.3 lbf)
- Feed Pressure: 27.6 – 5.5 bar (450 – 50 psia)
- Chamber Pressure: 12.1 – 3.4 bar (200 – 35 psia)
- Expansion Ratio: 74:1
- Flow Rate: 2.4 – 0.6 g/sec (0.0053 – 0.0014 lbm/sec)
- Valve: Dual Seat
- Valve Power: 8.25 Watts Max @ 28 Vdc & 21°C
- Valve Heater Power: 1.54 Watts Max @ 28 Vdc & 21°C
- Cat. Bed Heater Pwr: 3.85 Watts Max @ 28 Vdc & 21°C
- Mass: 0.33 kg (0.73 lbm)
  - Engine: 0.13 kg (0.28 lbm)
  - Valve: 0.20 kg (0.45 lbm)

Performance
- Specific Impulse: 229 – 215 sec (lbf-sec/lbm)
- Total Impulse: 260,000 N-sec (58,500 lbf-sec)
- Total Pulses: 420,000
- Minimum Impulse Bit: 0.08 N-sec @ 6.9 bar & 15 ms ON
  - (0.0171 lbf-sec @ 100 psia & 15 ms ON)
- Steady State Firing: 5,000 sec min – Single Firing

Status
- Flight Proven

AIAA-1999-2469
MR-111E 2N (0.5-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics

- Propellant: Hydrazine
- Catalyst: S405
- Thrust/Steady State: 2.2 – 0.5 N (0.5 – 0.11 lbf)
- Feed Pressure: 25.5 – 4.1 bar (370 – 60 psia)
- Chamber Pressure: 14.1 – 3.1 bar (204 – 45 psia)
- Expansion Ratio: 200:1
- Flow Rate: 1.2 – 0.3 g/sec (0.0022 – 0.0005 lbm/sec)
- Valve: Dual Seat
- Valve Power: 8.25 Watts Max @ 28 Vdc & 21°C
- Valve Heater Power: 1.54 Watts Max @ 28 Vdc & 21°C
- Cat. Bed Heater Pwr: 3.85 Watts Max @ 28 Vdc & 21°C
- Mass: 0.33 kg (0.73 lbm)
  - Engine: 0.13 kg (0.28 lbm)
  - Valve: 0.20 kg (0.45 lbm)

Performance

- Specific Impulse: 224 – 213 sec (lbf-sec/lbm)
- Total Impulse: 260,000 N-sec (58,500 lbf-sec)
- Total Pulses: 420,000
- Minimum Impulse Bit: 0.02 N-sec @ 6.9 bar & 15 ms ON
- Steady State Firing: 15.5 hr – Single Firing
- Cumulative: 26.7 hr

Status

- Flight Proven

Approved for public release and export
MR-50S 22N (5.0-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics
- Propellant: Hydrazine
- Catalyst: S405
- Thrust/Steady State: 32.0 – 5.8 N (7.2 – 1.3 lbf)
- Feed Pressure: 27.6 – 3.4 bar (400 – 50 psia)
- Chamber Pressure: 9.3 – 1.9 bar (135 – 28 psia)
- Expansion Ratio: 40:1
- Flow Rate: 14.2 – 3.0 g/sec (0.0313 – 0.0066 lbm/sec)
- Valve: Dual Seat
- Valve Power: 25.3 Watts Max @ 28 Vdc & 21°C
- Valve Heater Pwr: 1.54 Watts Max @ 28 Vdc & 21°C
- Cat. Bed Heater Pwr: 3.95 Watts Max @ 28 Vdc & 21°C
- Mass: 0.68 kg (1.50 lbm)
  - Engine: 0.41 kg (0.90 lbm)
  - Valve: 0.27 kg (0.60 lbm)

Performance
- Specific Impulse: 229-208 sec (lbf-sec/lbm)
- Total Impulse: 459,000 N-sec (103,271 lbf-sec)
- Total Pulses: 609
- Minimum Impulse Bit: 0.32 N-sec @ 3.4 bar & 30 ms ON (0.071 lbf-sec @ 50 psia & 30 ms ON)
- Steady State Firing: 14,400 sec – Single Firing
  - Cumulative: 24,840 sec

Status
- Flight Proven
MR-50T 22N (5.0-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics
- Propellant: Hydrazine
- Catalyst: S405
- Thrust/Steady State: 19.5 – 8.5 N (4.39 – 1.92 lbf)
- Feed Pressure: 24.1 – 6.9 bar (350 – 100 psia)
- Chamber Pressure: 5.8 – 2.6 bar (84 – 37 psia)
- Expansion Ratio: 40:1
- Flow Rate: 8.6 – 3.9 g/sec (0.019 – 0.0087 lbm/sec)
- Valve: Dual Seat
- Valve Power: 25.3 Watts Max @ 28 Vdc & 21°C
- Valve Heater Pwr: 1.96 Watts Max @ 28 Vdc & 21°C
- Cat. Bed Heater Pwr: 3.27 Watts Max @ 28 Vdc & 21°C
- Mass: 0.68 kg (1.50 lbm)
  - Engine: 0.41 kg (0.90 lbm)
  - Valve: 0.27 kg (0.60 lbm)

Performance
- Specific Impulse: 225-215 sec (lbf-sec/lbm)
- Total Impulse: 224,000 N-sec (50,422 lbf-sec)
- Total Pulses: 26,000
- Minimum Impulse Bit: 0.73 N-sec @ 6.9 bar & 80 ms ON
  (0.165 lbf-sec @ 100 psia & 80 ms ON)
- Steady State Firing: 600 sec

Status
- Flight Proven
MR-106E 22N (5.0-lbf) ROCKET ENGINE ASSEMBLY - 28 Vdc

Design Characteristics
- Propellant: Hydrazine
- Catalyst: LCH-227/202
- Thrust/Steady State: 30.7 – 11.6 N (6.9 – 2.6 lbf)
- Feed Pressure: 24.1 – 6.9 bar (350 – 100 psia)
- Chamber Pressure: 12.4 – 4.5 bar (180 – 65 psia)
- Expansion Ratio: 60:1
- Flow Rate: 13.1 – 5.0 g/sec (0.0289 – 0.011 lbm/sec)
- Valve: Dual Seat
- Cat. Bed Heater Pwr: 6.53 Watts Max @ 28 Vdc & 21°C
- Valve Heater Power: 3.27 Watts @ 28 Vdc & 21°C
- Valve Power: 25.3 Watts Max @ 28 Vdc & 21°C
- Mass: 0.635 kg (1.4 lbm) Max

Performance
- Specific Impulse: 235 – 229 sec (lbf-sec/lbm)
- Total Impulse: 36,000 N·sec 125,000 N·sec 90,587 N·sec
  (26,958 lbf·sec) (28,044 lbf·sec) (20,366)
- Total Pulses: 12,405 186 66,631
- Minimum Impulse Bit: 0.46 N·sec @ 12.8 bar & 16 ms ON
  (0.103 lbf·sec @ 185 psia & 16 ms ON)
- Steady State Firing: 2,000 sec – Single Firing
  4,670 sec – Cumulative

Status
- Flight Proven

Reference
- AIAA-2001-3632
- AIAA-1999-2469

*Mars Odyssey Test Program – December, 2000

Approved for public release and export
MR-106E 22 N (5.0-lbf) ROCKET ENGINE ASSEMBLY - 70 Vdc

Design Characteristics
- Propellant: Hydrazine
- Catalyst: LCH-227/202
- Thrust/Steady State: 30.7 – 11.6 N (6.9 – 2.6 lbf)
- Feed Pressure: 24.1 – 6.9 bar (350 – 100 psia)
- Chamber Pressure: 12.4 – 4.5 bar (180 – 65 psia)
- Expansion Ratio: 60:1
- Flow Rate: 13.1 – 5.0 g/sec (0.0289 – 0.011 lbm/sec)
- Valve: Dual Seat
- Valve Power: 39.52 Watts Max @ 70 Vdc & 21°C
- Valve Heater Power: 3.27 Watts @ 70 Vdc & 21°C
- Cat. Bed Heater Pwr: 6.36 Watts Max @ 70 Vdc & 21°C
- Mass: 0.52 kg (1.14 lbm)
- Engine: 0.23 kg (0.50 lbm)
- Valve: 0.29 kg (0.64 lbm)

Performance
- Specific Impulse: 235 – 229 sec (lbf-sec/lbm)
- Total Impulse: 120,000 N-sec REA ‘A’
- Total Impulse: 125,000 N-sec REA ‘B’
- Total Impulse: 90,587 N-sec Mars*
- Total Impulse: (26,958 lbf-sec) (28,044 lbf-sec) (20,366)
- Total Pulses: 12,405
- Minimum Impulse Bit: 0.46 N-sec @ 12.8 bar & 16 ms ON
- Steady State Firing: 4,670 sec – Cumulative

Status
- Flight Proven

Reference
- AIAA-2001-3632
- AIAA-1999-2469

* Mars Odyssey Test Program – December, 2000

Approved for public release and export
MR-106L 22N (5.0-lbf) ENGINE ASSEMBLY - 28 Vdc

Design Characteristics
- Propellant: Hydrazine
- Catalyst: S405/LCH-202
- Thrust/Steady State: 34 – 10 N (7.7 – 2.3 lbf)
- Feed Pressure: 27.6 – 5.9 bar (400 – 85 psia)
- Chamber Pressure: 13.4 – 4.1 bar (195 – 60 psia)
- Expansion Ratio: 60:1
- Flow Rate: 14.7 – 4.5 g/sec (0.032 – 0.010 lbm-sec)
- Valve: Dual Seat
- Cat. Bed Heater Pwr: 13.2 Watts Max @ 28 Vdc & 21°C
- Valve Heater Power: 4.0 Watts @ 28 Vdc & 21°C
- Valve Power: 24.5 Watts Max @ 28 Vdc & 21°C
- Mass: 0.590 kg (1.3 lbm) Nom

Performance
- Specific Impulse: 235 – 229 sec (lbf-sec/lbm)
- Total Impulse: 561,388 N-sec (126,205 lbf-sec)
- Total Pulses: 120,511
- Minimum Impulse Bit: 0.15 N-sec @ 5.9 bar & 16 ms ON (0.034 lbf-sec @ 85 psia & 16 ms ON)
- Steady State Firing: 4,000 sec

Status
- Qualified: Integrated on 3 Spacecraft

Reference
- AIAA-2005-3954
MR-120 90N (20-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics

- Propellant: Hydrazine
- Catalyst: LCH-207/202
- Thrust/Steady State: 111.2 – 40.0 N (25 – 9 lbf)
- Feed Pressure: 24.5 – 7.2 bar (355 – 105 psia)
- Chamber Pressure: 12.4 – 4.5 bar (180 – 65 psia)
- Expansion Ratio: 15:1
- Flow Rate: 49.9 – 19.5 g/sec (0.11 – 0.043 lbm/sec)
- Valve: Single Seat
- Valve Power: 43 Watts Max @ 32 Vdc & 5°C
- Mass: 0.41 kg (0.90 lbm)
  Engine: 0.29 kg (0.63 lbm)
  Valve: 0.12 kg (0.27 lbm)

Performance

- Specific Impulse: 229-222 sec (lbf-sec/lbm)
- Total Impulse: 36,900 N-sec (8,289 lbf-sec)
- Total Pulses: 1,911
- Minimum Impulse Bit: 0.98 N-sec @ 22.4 bar & 11 ms ON
  (0.22 lbf-sec @ 325 psia & 11 ms ON)
- Steady State Firing: 150 sec

Status

- Flight Ready
MR-107B 180N (40-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics
- Propellant: Hydrazine
- Catalyst: S405/LCH-202
- Thrust/Steady State: 178 – 49 N (40 – 11 lbf)
- Feed Pressure: 31.0 – 6.9 bar (450 – 100 psia)
- Chamber Pressure: 15.4 – 4.2 bar (223 – 61 psia)
- Expansion Ratio: 20:1
- Flow Rate: 77.1 – 24.5 g/sec (0.17 – 0.054 lbm/sec)
- Valve: Single Seat
- Valve Power: 50 Watts Max @ 28 Vdc & 24°C
- Mass: Engine 0.88 kg (1.95 lbm), Valve 0.61 kg (1.35 lbm), Valve 0.27 kg (0.60 lbm)

Performance
- Specific Impulse: 235-203 sec (lbf-sec/lbm)
- Total Impulse: 19,000 N-sec (4,278 lbf-sec)
- Total Pulses: 3,890
- Minimum Impulse Bit: 3.2 N-sec @ 31.0 bar & 20 ms ON (0.7 lbf-sec @ 450 psia & 20 ms ON)
- Steady State Firing: 97 sec

Status
- Flight Proven

Approved for public release and export
MR-107J 220N (50-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics
- Propellant: Hydrazine
- Catalyst: LCH-207/LCH-202
- Thrust/Steady State: 258 – 116 N (58.0 – 26.0 lbf)
- Feed Pressure: 34 – 12 bar (500 – 175 psia)
- Chamber Pressure: 9.7 – 4.5 bar (140 – 65 psia)
- Expansion Ratio: 21.5:1
- Flow Rate: 113 – 54 g/sec (0.25 – 0.12 lbm/sec)
- Valve: Dual Seat
- Valve Power: 170 Watts @ 28 Vdc & 21°C
- Mass: Engine 1.46 kg (3.22 lbm), Valve 0.82 kg (1.80 lbm)

Performance
- Specific Impulse: 234 – 224 sec (lbf-sec/lbm)
- Total Impulse: 81,200 N-sec (18,257 lbf-sec)
- Total Pulses: 3,704
- Minimum Impulse Bit: 11 N-sec @ 13.8 bar & 100 ms ON (2.5 lbf-sec @ 200 psia & 100 ms ON)
- Steady State Firing: 450 sec – Cumulative

Status
- Flight Proven

Approved for public release and export
MR-107K 220N (50-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics
- Propellant: Hydrazine
- Catalyst: LCH-207/LCH-202
- Thrust/Steady State: 222–80 N (50–18 lbf)
- Feed Pressure: 31.0 – 6.9 bar (450 – 100 psia)
- Chamber Pressure: 8.27 – 2.6 bar (120 – 38 psia)
- Expansion Ratio: 21.5:1
- Flow Rate: 98.4 – 36.7 g/sec (0.217 – 0.081 lbm/sec)
- Valve: Single Seat
- Valve Power: 37.0 Watts @ 28 Vdc & 21°C
- Valve Heater Pwr: 2.0 Watts @ 28 Vdc & 21°C
- Mass: 0.91 kg (2.00 lbm)
  Engine: 0.63 kg (1.40 lbm)
  Valve: 0.27 kg (0.60 lbm)

Performance
- Specific Impulse: 230 – 222 sec (lbf·sec/lbm)
- Total Impulse: 426,000 N·sec (95,853 lbf·sec)
- Total Pulses: 26,624
- Minimum Impulse Bit: 0.62 N·sec @ 6.9 bar & 6 ms ON
  (0.14 lbf·sec @ 100 psia & 6 ms ON)
- Steady State Firing: 2,137 sec – Single Firing
  2,684 sec – Cumulative

Status
- Flight Proven
MR-107L 130 N (30-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics

- Propellant: Hydrazine
- Catalyst: LCH-207/LCH-202
- Thrust/Steady State: 142–67 N (32.0–15.0 lbf)
- Feed Pressure: 32.8 – 10.3 bar (475 – 150 psia)
- Chamber Pressure: 5.4 – 2.6 bar (78 – 37 psia)
- Expansion Ratio: 21.5:1
- Flow Rate: 64 – 30 g/sec (0.14–0.067 lbm/sec)
- Valve: Single Seat
- Valve Power: 36.3 Watts @ 28 Vdc & 24°C
- Valve Heater Pwr: 8 Watts Nominal @ 28 Vdc & 21°C
- Valve Thermostat Controls Valve Heater
- Mass: 0.91 kg (2.02 lbm)
  - Engine: 0.64 kg (1.42 lbm)
  - Valve: 0.27 kg (0.60 lbm)

Performance

- Specific Impulse: 228 – 224 sec (lbf-sec/lbm)
- Total Impulse: 332,000 N-sec (74,715 lbf-sec)
- Total Pulses: 5,344
- Minimum Impulse Bit: 1.16 N-sec @ 10.3 bar & 20 ms ON
  - (0.26 lbf-sec @ 150 psia & 20 ms ON)
- Steady State Firing: 2,137 sec – Single Firing
  - 2,684 sec – Cumulative

Status

- Flight Proven
MR-107M 220 N (50-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics

- Propellant: Hydrazine
- Catalyst: LCH-207/LCH-202
- Thrust/Steady State: 231.3 – 57.8 N (52 – 13 lbf)
- Feed Pressure: 29.7 – 5.9 bar (430 – 85 psia)
- Chamber Pressure: 8.8 – 2.2 bar (127 – 32 psia)
- Expansion Ratio: 21.5:1
- Flow Rate: 102.5 – 26.5 g/sec (0.226 – 0.0585 lbm/sec)
- Valve: Single Seat w/Internal Diodes
- Valve Power: 37.0 Watts @ 28 Vdc & 21°C
- Mass:
  - Engine: 0.90 kg (2.00 lbm)
  - Valve: 0.64 kg (1.40 lbm)
  - Valve: 0.27 kg (0.60 lbm)

Performance

- Specific Impulse: 230 – 222 sec (lbf-sec/lbm)
- Total Impulse: 426,000 N-sec (95.853 lbf-sec)
- Total Pulses: 26,624
- Minimum Impulse Bit: 0.623 N-sec @ 6.9 bar & 6 ms ON
  (0.14 lbf-sec @ 100 psia & 6 ms ON)
- Steady State Firing: 2,137 sec – Single Firing
  2,684 sec – Cumulative

Status

- Flight Proven

Reference

- AIAA-1994-3378
MR-107N 270N (60-lbf) ROCKET ENGINE ASSEMBLY

**Design Characteristics**
- Propellant: Hydrazine
- Catalyst: LCH-227/LCH-202
- Thrust/Steady State: 296–109 N (66.6–24.6 lbf)
- Feed Pressure: 29.0 – 8.2 bar (420 – 119 psia)
- Chamber Pressure: 11.2 – 4.2 bar (162 – 61 psia)
- Expansion Ratio: 20.7:1
- Flow Rate: 131 – 49 g/sec (0.290–0.108 lbm/sec)
- Valve: Moog Single Seat
- Valve Power: 46 Watts @ 28 Vdc & 24°C
- Valve Heater Power: 3 Watts @ 28 Vdc & 21°C
- Mass: 0.74 kg (1.64 lbm)
- Engine: 0.54 kg (1.20 lbm)
- Valve: 0.20 kg (1.44 lbm)

**Performance**
- Specific Impulse: 232 – 229 sec (lbf-sec/lbm)
- Total Impulse: 68,500 N-sec (15,397 lbf-sec)
- Total Pulses: 1,485
- Minimum Impulse Bit: 1.46 N-sec @ 9.3 bar & 20 ms ON
  - (0.328 lbf-sec @ 135 psia & 20 ms ON)
- Steady State Firing: 40 sec – Single Firing
  - 299 sec – Cumulative

**Status**
- Flight Proven

**Reference**
- AIAA-2001-3261
MR-107P 90N (20-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics

- Propellant ........................................ Hydrazine
- Catalyst .......................................... LCH-207/LCH-202
- Thrust/Steady State ......................... 98 – 34.2 N (22 – 7.7 lbf)
- Feed Pressure ............................... 24.1 – 6.9 bar (350 – 100 psia)
- Chamber Pressure ............................ 8.5 – 3.0 bar (123 – 44 psia)
- Expansion Ratio ........................................ 20:1
- Flow Rate ..................... 44.1 – 15.4 g/sec (0.0973 – 0.034 lbm/sec)
- Valve ............................................. Dual Seat
- Valve Power ................................. 115 Watts @ 34 Vdc & 24°C
- Mass ................................. 1.10 kg (2.43 lbm)
  Engine .............................................. 0.65 kg (1.43 lbm)
  Valve .............................................. 0.45 kg (1.00 lbm)

Performance

- Specific Impulse ................... 226 – 221 sec (lbf-sec/lbm)
- Total Impulse ................... 426,000 N-sec (95,853 lbf-sec)
- Total Pulses .......................... 26.624
- Minimum Impulse Bit ........ 1.78 N-sec @ 6.9 bar & 40 ms ON
  (0.40 lbf-sec @ 100 psia & 40 ms ON)
- Steady State Firing .................. 2,137 sec

Status

- Flight Ready
MR-107S 275N (60-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics

- Propellant: Hydrazine
- Catalyst: S-405 / LCH-202
- Thrust/Steady State: 360–85 N (81–19 lbf)
- Feed Pressure: 35–7 bar (500–100 psia)
- Chamber Pressure: 14–4 bar (197–45 psia)
- Expansion Ratio: 21.5:1
- Flow Rate: 154.7–36.3 g/sec (0.341–0.08 lbm/sec)
- Valve: Single Seat
- Valve Power: <34.8 Watts @ 28 Vdc & 20°C
- Mass: 1.01 kg (2.23 lbm)
  - Engine: 0.67 kg (1.48 lbm)
  - Valve: 0.34 kg (0.75 lbm)


- Specific Impulse: 225–236 sec (lbf-sec/lbm)
- Total Impulse: 337,620 N-sec (75,900 lbf-sec)
- Total Pulses: 30,300
- Steady State Firing: 41 sec @ 360N (81-lbf)
  - 100 sec @ 236N (53-lbf)
  - 30 sec @ 285N (64-lbf)

Status

- Qualified
MR-107T 110N (25-lbf) ROCKET ENGINE ASSEMBLY

### Design Characteristics
- Propellant: Hydrazine
- Catalyst: S-405 / LCH-202
- Thrust/Steady State: 125 – 54 N (28 – 12 lbf)
- Feed Pressure: 37 – 7 bar (500 – 100 psia)
- Chamber Pressure: 4.7 – 1.8 bar (69 – 26 psia)
- Expansion Ratio: 21.5:1
- Flow Rate: 55.8 – 22.7 g/sec (0.123 – 0.05 lbm/sec)
- Valve: Single Seat
- Valve Power: <34.8 Watts @ 28 Vdc & 20°C
- Mass: Engine 1.01 kg (2.23 lbm), Valve 0.34 kg (0.75 lbm)

- Specific Impulse: 222 – 228 sec (lbf·sec/lbm)
- Total Impulse: 92,967 N·sec (20,900 lbf·sec)
- Total Pulses: 14,300
- Steady State Firing: 100 sec @ 125N (28-lbf), 100 sec @ 54N (12-lbf)

### Status
- Qualified
**MR-107V 220N (49.5-lbf) ROCKET ENGINE ASSEMBLY**

**Design Characteristics**
- Propellant: Hydrazine
- Catalyst: S-405 / LCH-202
- Thrust/Steady State: 220–67 N (49.5–15 lbf)
- Feed Pressure: 26 – 5.5 bar (377 – 80 psia)
- Chamber Pressure: 8.4 – 2.6 bar (122 – 38 psia)
- Expansion Ratio: 21.5:1
- Flow Rate: 98 – 31 g/sec (0.216 – 0.07 lbm/sec)
- Valve: Single Seat
- Valve Power: <34.8 Watts @ 28 Vdc & 20°C
- Mass: 1.01 kg (2.23 lbm)
  - Engine: 0.67 kg (1.48 lbm)
  - Valve: 0.34 kg (0.75 lbm)

- Specific Impulse: 229 – 223 sec (lbf-sec/lbm)
- Total Impulse: 337,175 N·sec (75,800 lbf·sec)
- Total Pulses: 30,275
- Steady State Firing: 100 sec @ 111 N (25-lbf)

**Status**
- Qualification Testing in 2007
MR-104A/C 440N (100-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics
- Propellant: Hydrazine
- Catalyst: S405 / LCH-202
- Thrust/Steady State: 572.5 – 204.6 N (128.7 – 46 lbf)
- Feed Pressure: 28.9 – 6.9 bar (420 – 100 psia)
- Chamber Pressure: 10.7 – 3.9 bar (155 – 56 psia)
- Expansion Ratio: 53:1
- Flow Rate: 240.4 – 90.72 g/sec (0.53 – 0.20 lbm/sec)
- Valve: Single Seat
- Valve Power: 30 Watts @ 28 Vdc & 21°C
- Cat. Bed Heater Pwr: 13.1 Watts @ 28 Vdc & 21°C
- Mass: 1.86 kg (4.11 lbm)
- Engine: 1.44 kg (3.17 lbm)
- Valve: 0.43 kg (0.94 lbm)

Performance
- Specific Impulse: 239 – 223 sec (lbf-sec/lbm)
- Total Impulse: 693,900 N-sec (156,000 lbf-sec)
- Total Pulses: 1,742
- Minimum Impulse Bit: 8.23 N-sec @ 24.13 bar & 22 ms ON
  (1.85 lbf-sec @ 350 psia & 22 ms ON)
- Steady State Firing: 2,000 sec – Single Firing
  2,654 sec – Cumulative

Status
- Flight Proven

Rev. Date: 5/17/06
11411 139th Place NE • Redmond, WA 98052
(425) 885-5000  FAX (425) 882-5747

Approved for public release and export
MR-104D 100 lbf (440N) ROCKET ENGINE ASSEMBLY

Design Characteristics
- Propellant: Hydrazine
- Catalyst: S405/LCH-202
- Thrust/Steady State: 506.2 – 201.0 N (113.8 – 45.2 lbf)
- Feed Pressure: 24.8 – 6.9 bar (360 – 100 psia)
- Chamber Pressure: 9.4 – 3.8 bar (137 – 55 psia)
- Expansion Ratio: 53:1
- Flow Rate: 217.9 – 90.8 g/sec (0.48 – 0.20 lbm/sec)
- Valve: Dual Seat
- Valve Power: 60 Watts @ 28 Vdc & 21°C
- Cat. Bed Heater Pwr: 14.4 Watts/el @ 28 Vdc & 21°C
- Weight: 2.22 kg (4.9 lbf)
  - Engine: 1.50 kg (3.3 lbf)
  - Valve: 0.72 kg (1.6 lbf)

Performance
- Specific Impulse: 237 – 223 sec (lbf-sec/lbm)
- Total Impulse: 693,900 N-sec (156,000 lbf-sec)
- Total Pulses: 1,742
- Minimum Impulse Bit: 8.23 N-sec @ 24 bar & 22 ms ON
- Steady State Firing: 2,137 sec – Single Firing
  - 2,654 sec – Cumulative

Status
- Flight Ready

Approved for public release and export
**MR-80B 3,100N (700-lbf) THROTTLING ROCKET ENGINE ASSEMBLY**

![Image of MR-80B rocket engine]

### Design Characteristics
- Propellant: Hydrazine
- Catalyst: S405
- Vacuum Thrust/Steady State: 3780 \( \pm 31 \) N (850 \( \pm 7 \) lbf)
- Feed Pressure: 41.7 Bar (605 psia)
- Chamber Pressure: 20.4 \( \pm \) 0.14 Bar (296 \( \pm \) 2 psia)
- Expansion Ratio: 16.7:1
- Cat. Bed Heater Pwr: 6.3 Watts/Element Max @ 30 Vdc
- Valve Heater Power: 9.45 Watts/Element @ 30 Vdc
- Valve: Cavitating Throttle
- Valve Power: 168 Watts Max @ 28 Vdc
- Weight: 8.51 kg (18.76 lbm)
- Engine: 6.92 kg (15.26 lbm)
- Valve: 1.59 kg (3.50 lbm)

### Performance
- Vacuum Specific Impulse: 225-200 sec (lbf-sec/lbm)
- Starts: Dev. #1 8, Dev. #2 8, Dev. #3R 12, Qual. 8
- Total: 292.1 kg (644 lbm), 183.7 kg (405 lbm), 451.3 kg (995 lbm), 308.4 kg (680 lbm)
- Total Firing Time: 334 sec, 418 sec, 806 sec, 560 sec
- Longest Single Firing: 76 sec, 117 sec, 137 sec, 214 sec

### Status
- Flight Qualified

### Reference
- 2007-AIAA-5481

Date: 5/19/08

11411 139th Place NE • REDMOND, WA 98052-9709
(425) 885-5000 fax (425) 882-5747

Approved for public release and export
MRM-103D 1 N (0.2-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics

- Propellant: Hydrazine
- Catalyst: S405
- Thrust/Steady State: 1.02 – 0.22 N (0.230 – 0.050 lbf)
- Feed Pressure: 27.6 – 6.2 bar (400 – 90 psia)
- Chamber Pressure: 23.4 – 5.9 bar (340 – 85 psia)
- Expansion Ratio: 100:1
- Flow Rate: 0.45 – 0.09 g/sec (0.001 – 0.0002 lbm/sec)
- Valve: Dual Seat
- Valve Power (per Valve): 8.25 Watts Max @ 28 Vdc & 20°C
- Mass: 1.27 kg (2.8 lbm)
- Bed Heaters and Temp. Sensors
- REM Plate Hrs (Thermostat Controlled) & Temp. Sensor
- MLI Blanket
- Electrical Interface: 1016 – 1118 mm (40 – 44”) Leadwires

Performance

- Specific Impulse: 224 – 209 sec (lbf-sec/lbm)
- Total Impulse: 125,700 N-sec (28,263 lbf-sec)*
- Total Pulses: 210,238*
- Minimum Impulse Bit: 0.03 N-sec @ 6.9 bar & 15 ms ON
- Steady State Firing: 0.8 hr* – Single Firing
- 176.9 hr* sec – Cumulative

Status

- Flight Proven

*As qualified for the MRM-103D
Basic MR-103D qualified to slightly higher levels.
MRM-106B 27 N (6.0-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics
- Propellant: Hydrazine
- Catalyst: LCH-227/202
- Thrust/Steady State: 27 – 9 N (6.0 – 2.0 lbf)
- Feed Pressure: 31 – 6.2 bar (450 – 90 psia)
- Chamber Pressure: 10.9 – 3.8 bar (158 – 55 psia)
- Expansion Ratio: 61:1
- Flow Rate: 11.8 – 4.1 g/sec (0.026 – 0.009 lbm/sec)
- Valve: Dual Seat
- Valve Power: 27 Watts Max @ 26 Vdc & 21°C
- Mass: Axial: 0.46 kg (1.009 lbm) Lateral: 0.47 kg (1.033 lbm)
  - Engine: 0.19 kg (0.423 lbm)
  - Valve: 0.27 kg (0.586 lbm)
- No Catalyst Bed Heaters or Valve Heaters
- 26 Pin Electrical Connectors on 4 Engine REM
- 18 Pin Electrical Connectors on 2 Engine REM

Performance
- Specific Impulse: 232 – 218 sec (lbf-sec/lbm)
- Total Impulse: 125,000 N-sec (28,044 lbf-sec)
- Total Pulses: 12,405
- Minimum Impulse Bit: 1.16 N-sec @ 31 bar & 15 ms ON
  - (0.26 lbf-sec @ 450 psia & 15 ms ON)
- Steady State Firing: 2,000 sec – Single Firing
  - 4,670 sec – Cumulative

Status
- Flight Proven
MRM-106C 40N (9.0-lbf) ROCKET ENGINE MODULE

Design Characteristics
- Propellant: Monopropellant Hydrazine
- Catalyst: LCH-207/202
- Thrust/Steady State: 40 N (9.0 lbf)
- Feed Pressure: 31 bar (450 psia)
- Chamber Pressure: 16 bar (237 psia)
- Expansion Ratio: 61:1
- Flow Rate: 17.7 g/sec (0.039 lbm/sec)
- Valve: Single Seat
- Valve Power: 15 Watts Max @ 28 Vdc & 20°C
- Mass:
  - Axial: 0.12 kg (0.259 lbm)
  - Lateral: 0.36 kg (0.801 lbm)
  - Engine: 0.15 kg (0.319 lbm)
  - Valve: 0.20 kg (0.440 lbm)
- No Catalyst Bed Heaters or Valve Heaters
- 22 Pin Electrical Connectors

Performance
- Specific Impulse: 231 sec (lbf-sec/lbm)
- Total Impulse: 136,000 N-sec (30,618 lbf-sec)
- Total Pulses: 1,570
- Minimum Impulse Bit: 2.62 N-sec @ 31 bar & 60 ms ON
  (0.59 lbf-sec @ 450 psia & 60 ms ON)
- Steady State Firing: 1,000 sec – Single Firing
  2,991 sec – Cumulative

Status
- Flight Proven

Approved for public release and export
MRM-106D 27/40N (6.0/9.0-lbf) ROCKET ENGINE MODULE

Design Characteristics

- Propellant: Monopropellant Hydrazine
- Catalyst: LCH-207/202
- Thrust/Steady State: per Axial Rocket: 27 – 17 N (6.0 – 3.8 lbf) per Lateral Rocket: 40 – 21 N (9.0 – 4.7 lbf)
- Feed Pressure: 31 – 13.8 bar (450 – 200 psia)
- Chamber Pressure: Axial: 11.0 – 6.9 bar (160 – 100 psia) Lateral: 17.2 – 8.6 bar (250 – 125 psia)
- Expansion Ratio: 61:1
- Flow Rate: Axial: 11.8 – 7.51 g/sec (0.026 – 0.017 lbm/sec) Lateral: 17.7 – 9.52 g/sec (0.039 – 0.021 lbm/sec)
- Valve: Single Seat, Non-Sliding Fit
- Valve Power: 20.1 Watts Nominal @ 28 Vdc & 21°C
- Mass: 4-Engine REM: 2.7 kg (5.96 lbm) 2-Engine REM: 1.5 kg (3.34 lbm)

Performance

- Specific Impulse: 234 – 227 sec (lbf·sec/lbm)
- Total Impulse (Axial & Lateral): 91,200 N·sec (20,500 lbf·sec)
- Total Pulses: >7,629 (Lateral) >1,500 (Axial)
- Minimum Impulse Bit: 0.63 N·sec @ 31 bar & 20 ms ON (0.142 lbf·sec @ 450 psia & 20 ms ON)
- Steady State Firing: 1,000 sec – Single Firing

Status

- Flight Proven
MRM-106E 22N (5.0-lbf) ROCKET ENGINE MODULE (REM)

Design Characteristics
- Propellant: Hydrazine
- Catalyst: LCH-227/202
- Thrust/Steady State: 30.7 – 11.6 N (6.9 – 2.6 lbf)
- Feed Pressure: 24.1 – 6.9 bar (350 – 100 psia)
- Chamber Pressure: 12.4 – 4.5 bar (180 – 65 psia)
- Expansion Ratio: 60:1
- Flow Rate: 12.1 – 5.0 g/sec (0.0289 – 0.011 lbm/sec)
- Valvo Power: 25.3 Watto Max @ 28 Vdc & 21°C
- Mass: 4.1 kg (1.86 lbm) Max

Performance
- Specific Impulse: 235 – 229 sec (lbf-sec/lbm)
- Total Impulse: 120,000 N-sec, 125,000 N-sec, 90,587 N-sec (26,958 lbf-sec, 28,044 lbf-sec, 20,366 lbf-sec)
- Total Pulses: 12,405, 186, 66,631
- Minimum Impulse Bit: 0.46 N-sec @ 12.8 bar & 16 ms ON (0.103 lbf-sec @ 185 psia & 16 ms ON)
- Steady State Firing: 2,000 sec – Single Firing, 4,670 sec – Cumulative

Status
- Flight Proven

*Mars Odyssey Test Program
December 2000
MRM-106F 40N (9.0-lbf) ROCKET ENGINE MODULE

Design Characteristics
- Propellant: Monopropellant Hydrazine
- Catalyst: LCH-207/202
- Thrust/Steady State (per Rocket): 40N (9.0 lbf)
- Feed Pressure: 31 bar (450 psia)
- Chamber Pressure: 16 bar (237 psia)
- Expansion Ratio: 61:1
- Flow Rate: 17.7 g/sec (0.039 lbm/sec)
- Valve: Single Seat, Non-Sliding Fit
- Valve Power: 20.1 Watts Nominal @ 28 Vdc & 21°C
- Mass: <2.23 kg (4.9 lbm) per REM
- No Catalyst Bed Heaters or Valve Heaters
- 22 Pin Electrical Connector

Performance
- Specific Impulse: 231 sec (lbf-sec/lbm)
- Total Impulse: 136,000 N-sec (30,618 lbf-sec)
- Total Pulses: 1,570
- Minimum Impulse Bit: 2.62 N-sec @ 31 bar & 20 ms ON (0.59 lbf-sec @ 450 psia & 60 ms ON)
- Steady State Firing: 1,000 sec – Single Firing
- Status: Flight Proven

Approved for public release and export
MRM-122 130N (30-lbf) ROCKET ENGINE MODULE

**Design Characteristics**
- Propellant: Hydrazine
- Catalyst: LCH
- Thrust/Steady State: 142 – 51N (32 – 11.5 lbf)
- Feed Pressure: 29.6 – 6.9 bar (430 – 100 psia)
- Chamber Pressure: 5.4 – 2.0 bar (79 – 29 psia)
- Expansion Ratio: 20.7:1 (Axial), 21.5:1 (Roll)
- Flow Rate: 63.5 – 24.0 g/sec (0.14 – 0.053 lbm/sec)
- Valve: Single Seat
- Valve Power: 43 Watts Max @ 32 Vdc & 4°C
- Mass: Axial: 0.66 kg (1.46 lbm), Lateral: 0.76 kg (1.68 lbm)
  - Engine: 0.54 kg (1.20 lbm)
  - Valve: 0.12 kg (0.26 lbm)
- No Catalyst Bed Heaters or Valve Heaters
- 19 Pin Electrical Connectors on REM

**Performance**
- Specific Impulse: 228 – 217 sec (lbf-sec/lbm)
- Total Impulse: 332,000 N-sec (74,715 lbf-sec)
- Total Pulses: 7,005
- Minimum Impulse Bit: 1.20 N-sec @ 9.3 bar & 20 ms ON (0.27 lbf-sec @ 135 psia & 20 ms ON)
- Steady State Firing: 2,137 sec – Single Firing
  - Cumulative: 2,684 sec

**Status**
- Flight Proven

Approved for public release and export
SPACE SHUTTLE APU GAS GENERATOR

P/N 27745-306  BOOSTER  GAS GENERATOR

P/N 28910-302  ORBITER  GAS GENERATOR

Design Characteristics
- Propellant ........................................ Monopropellant Grade Hydrazine
- Catalyst .................................................. S405/14-18 Mesh
- Thrust – Pulsing Gas Flow ..................... Equivalent to 220 N (50-lbf) Thruster
- Feed Pressure ....................................... 103.4 bar (1500 psia)
- Flow Rate ............................................ 120 – 134 g/sec (0.265 – 0.296 lbm/sec)
- Propellant Valve ..................................... Part of APU
- Mass of Gas Generator ............................ 4.90 kg (10.8 lbm) Max

Performance
- Delivered Power ................................. 11 kW (idle) to 93 kW
- Qualified to ........................................ 99 hrs/6,600 kg (14,500 lbm) N₂H₄, 167 Starts

Status
- Flight Qualified: 3 x 113 Manned Flights (Orbiter), 4 x 113 (Booster)
“Green” Propellants and Systems

- Aerojet Redmond Operations is developing and qualifying “green” propellants for next generation use.
- “Green” Propellants:
  - Hydroxyl Ammonium Nitrate (HAN) Blends
  - CINCH (Competitive Impulse Non-Carcinogenic Hydrocarbons)
  - High Temperature Blends for Improved Performance
- System Planning and Design:
  - System Integration
  - Compatibility and Long Term Storage Evaluations
- Status – In Development
- Reference – AIAA-2003-4643

Hydroxyl Ammonium Nitrate (HAN) Thruster
Catalyst Manufacturing

S-405 Spontaneous Hydrazine Decomposition Catalyst
- Used on Space Shuttle, NASA Exploration Missions, Commercial Launch Vehicles and Satellites
- Industry Standard for Over 40yrs
- Process Technology Licensed from Shell Chemical Co.

LCH Aerojet Family of Catalysts for:
- Hydrazine
- Hydrazine Propellant Blends
- HAN-based Propellants
- MMH Propellant Blends
- H2/O2
- HC/O2
- N2O

Catalyst Testing
- H2 Chemisorption
- Physical Surface Area - BET
- Crush Strength
- Ignition Response (Pino)
- Size Range (Sieve)

Catalyst Development
- Selection and Processing of Catalyst Supports
- Active Phase Identification and Loading
- Hypergolic Coatings for Low Temperature Start

Approved for Public Release and Export
Bipropellant

R-6D 22 N
MTT 22 N
R-1E 110 N
R-4D 490 N
HiPAT™ High Performance 445 N

HiPAT™ High Performance Dual Mode 445 N
R-42 890 N
R-42DM 890 N
AMBR 623 N
R-40 3,870 N
R-40B 4,000 N
R-6D 5-lbf (22N) BIPROPELLANT ROCKEt ENGINE

Design Characteristics
- Propellant: MMH/NTO (MON-3)
- Thrust/Steady State: 22 N (5 lbf)
- Inlet Feed Pressure Range: 27.96 – 6.9 bar (400 – 100 psia)
- Chamber Pressure: 6.7 bar @ 22N (97 psia @ 5 lbf)
- Expansion Ratio: 100:1
- Flow Rate: 7.71 g/sec (0.017 lbm/sec)
- Valve: Single Seat Torque Motor
- Valve Power: 5 Watts @ 28 Vdc (Moog Torque Motor)
- Mass: 0.454 kg (1.0 lbm)

Performance
- Specific Impulse: 294 sec (lbf-sec/lbm)
- Total Impulse: >1,334,400 N-sec (300,000 lbf-sec)
- Total Pulses: 336,331
- Minimum Impulse Bit: 0.0089 N-sec (0.002 lbf-sec)
- Steady State Firing: 0.005 sec to Unlimited

Status
- Flight Qualified

Reference:
- AIAA-1989-2734
MTT 5-lbf (22N) BIPROPellant ROCKET ENGINE

Design Characteristics
- Propellant: MMH/NTO (MON-3)
- Thrust/Steady State: 22 N (5 lbf)
- Inlet Feed Pressure Range: 27.6 – 10.3 bar (400 – 150 psia)
- Chamber Pressure: 6.7 bar @ 22 N (97 psia @ 5 lbf)
- Expansion Ratio: 100:1
- Flow Rate: 7.94 g/sec (0.0175 lbm/sec)
- Valve: Dual Seat Solenoid
- Valve Power: 60 Watts @ 28 Vdc
- Weight: 0.454 kg (1.0 lbm)

Performance
- Specific Impulse: 285 sec (lbf-sec/lbm)
- Total Impulse: >1,334,400 N-sec (300,000 lbf-sec)
- Total Pulses: 300,000
- Minimum Impulse Bit: 0.044 N-sec (0.01 lbf-sec)
- Steady State Firing: Unlimited

Status
- In Development

Approved for public release and export
R-1E 110N (25 lbf) BIPROPELLANT ROCKET ENGINE

Design Characteristics

- Propellant ........................................... MMH/NTO(MON-3)
- Thrust/Steady State ................................. 111 N (25 lbf)
- Inlet Pressure Range ............................... 27.6-6.9 bar (400-100 psia)
- Chamber Pressure* .................................. 7.3 bar (106 psia)
- Expansion Ratio ..................................... 100:1
- Flowrate* ............................................. 40.4 g/sec (0.089 lbm/sec)
- Valve ................................................. Aerojet Solenoid, Single Coil, Single Seat
- Valve Power ......................................... 36 Watts @ 28 Vdc
- Mass ................................................... 2 kg (4.4 lbm)

* At rated thrust

Performance

- Specific Impulse* .................................. 280 sec (lbf-sec/lbm)
- Total Impulse ....................................... 11,120,000 N-sec (2,500,000 lbf-sec)
- Total Pulses ........................................ 330,000
- Minimum Impulse Bit ............................. 0.89 N-sec (0.2 lbf-sec)
- Steady State Firing (sec) .......................... No Limitations

Status

- Flight Proven

Reference

- AIAA - 1990 - 1837

Dimensions are in inches
R-4D 490N (110-lbf) BIPROPELLANT ROCKET ENGINE

Design Characteristics

- Propellant: MMH/NTO(MON-3)
- Thrust/Steady State: 490 N (110-lbf)
- Inlet Pressure Range: 29.3–4.1 Bar (425–60 psi)
- Chamber Pressure*: 7.45 Bar (108 psi)
- Expansion Ratio: 44:1, 164:1, 300:1
- Flow Rate*: 158 g/sec (0.348 lbm/sec) (300:1)
- Valve: Aerojet Solenoid, Single Coil, Single Seat
- Valve Power: Various (46 Watts @ 28 Vdc Typical)
- Mass: 44:1, 3.40 kg (7.5 lbm)
- 164:1, 3.76 kg (8.3 lbm)
- 300:1, 4.31 kg (9.5 lbm)
- Engine: 44:1, 2.49 kg (5.5 lbm)
- 164:1, 2.86 kg (6.3 lbm)
- 300:1, 3.40 kg (7.5 lbm)
- Valve: 0.9 kg (2.0 lbm)

*at Rated Thrust

Performance

- Specific Impulse*: 44:1 = 300 sec (lbf-sec/lbm)
  164:1 = 311 sec (lbf-sec/lbm)
  300:1 = 315.5 sec (lbf-sec/lbm)
- Total Impulse Demonstrated: 20,016,000 N·sec (4,500,000 lbf·sec)
- Total Pulses: 20,781
- Minimum Impulse Bit: 15.6 N·sec (3.5 lbf·sec)
- Demonstrated Steady State Firing: 12,000 sec

Status

- Flight Proven

References

- AIAA - 2004 - 3694
- AIAA - 1980 - 1294
- AIAA - 1979 - 1331
HiPAT™ 445N (100-lbf) HIGH PERFORMANCE LIQUID APOGEE THRUSTER

**Design Characteristics**
- Propellant: MMH/NTO (MON-3)
- Thrust/Steady State: 445 N (100-lbf)
- Inlet Pressure Range: 27.6 – 6.9 bar (400 – 100 psia)
- Chamber Pressure*: 9.4 bar (137 psia)
- Expansion Ratio: 300:1, 375:1
- Flow Rate*: 141 g/sec (0.31 lbm/sec)
- Valve: Aerojet Solenoid, Dual Coil, Single Seat
- Valve Power: Various (46 Watts @ 28 Vdc Typical)
- Mass: 300:1, 5.2 kg (11.5 lbm); 375:1, 5.44 kg (12 lbm)

*At rated thrust

**Performance**
- Specific Impulse*: 300:1 = 320 sec (lbf-sec/lbm); 375:1 = 323 sec (lbf-sec/lbm)
- Total Impulse Demonstrated: 20,016,500 N-sec (4,635,000 lbf-sec)
- Total Pulses: 500
- Minimum Impulse Bit: 35.6 N-sec (8 lbf-sec)
- Demonstrated Steady State Firing: 3600 sec

**Status**
- Flight Proven

**References**
- AIAA - 2001 - 3253
- AIAA - 2000 - 3161
HiPAT™ 445N (100-lbf) DUAL MODE HIGH PERFORMANCE LIQUID APOGEE THRuster

Design Characteristics

- Propellant: Hydrazine/NTO(MON-3)
- Thrust/Steady State: 445 N (100-lbf)
- Inlet Pressure Range: 21.4 – 15.2 bar (310–220 psia)
- Chamber Pressure*: 9.4 bar (137 psia)
- Expansion Ratio: 300:1, 375:1
- Oxidizer/Fuel Ratio: 0.85
- Flow Rate*: 141 g/sec (0.31 lbm/sec)
- Valve: Aerojet Solenoid, Dual Coil, Single Seat
- Valve Power: Various (46 Watts @ 28 Vdc Typical)
- Mass: 300:1, 5.2 kg (11.5 lbm); 375:1, 5.44 kg (12 lbm)

*At rated thrust

Performance

- Specific Impulse*: 300:1 = 326 sec (lbf-sec/lbm); 375:1 = 329 sec (lbf-sec/lbm)
- Total Impulse Demonstrated: In Excess of 9.55 x 10^6 N-sec (2.15 x 10^6 N-sec)
- Total Pulses: 672
- Total Thermal Cycles: 345
- Minimum Impulse Bit: 35.6 N-sec (8 lbf-sec)
- Demonstrated Steady State Firing: 1800 sec

Status

- Qualified

Reference

- AIAA - 2003 - 4775

Approved for public release and export
**Design Characteristics**

- Propellant: MMH/NTO(MON-3)
- Thrust/Steady State: 890N (200 lbf)
- Inlet Pressure Range: 29.3-6.9 bar (425-100 psia)
- Chamber Pressure*: 7.1 bar (103 psia)
- Expansion Ratio: 160:1
- Flowrate*: 300 g/sec (0.66 lbm/sec)
- Valve: Aerojet Solenoid, Single Coil, Single Seat
- Valve Power: 46 Watts @ 28 Vdc
- Mass: 4.53 kg (10.0 lbm)

*At rated thrust

**Performance**

- Specific Impulse*: 303 sec (lbf·sec/lbm)
- Total Impulse: 24,271,000 N·sec (5,456,700 lbf·sec)
- Total Pulses: 134
- Minimum Impulse Bit: 44.48 N·sec (10.0 lbf·sec)
- Steady State Firing Cumulative: 27,000 sec
- Steady State Firing (Single Firing): 3,940 sec

**Reference**

- AIAA - 1990 - 2055
R-42DM 890 N (200 lbf) DUAL MODE HIGH PERFORMANCE ROCKET ENGINE

Design Characteristics
- Propellant: Hydrazine / NTO (MON-3)
- Thrust/Steady State: 890 N (200 lbf)
- Inlet Pressure Range: 25.5 – 13.8 bar (370 – 200 psia)
- Chamber Pressure*: 9.6 bar (140 psia)
- Expansion Ratio: 200:1
- Oxidizer / Fuel Ratio: 0.8 – 1.2 (1.0 nominal)
- Flow Rate*: 277 g/sec (0.61 lbm/sec)
- Valve: Aerojet Single or Dual Seat
- Valve Power: Various (45 Watts @ 28 Vdc Typical)
- Mass: with single seat valves 7.3 kg (16 lbm)

*at rated thrust

Performance
- Specific Impulse: 327 sec (lbf-sec/lbm)
- Total Impulse: >20.0 x 10^6 N-sec (4.5 x 10^6 lbf-sec)
- Total Pulses: >100
- Total Thermal Cycles: >50
- Steady State Firing: 1000 sec

Status
- FY2008 IR&D, TRL 6
- Ready for final flight design and analysis, and formal qualification (program specific)
AMBR 623 N (140 lbf) DUAL MODE HIGH PERFORMANCE ROCKET ENGINE

Design Characteristics

- Propellant: Hydrazine / NTO (MON-3)
- Thrust/Steady State: 623 N (140 lbf)
- Inlet Pressure Range: 22.4 – 12.1 bar (325 – 125 psia)
- Chamber Pressure*: 13.8 bar (200 psia)
- Expansion Ratio: 400:1
- Oxidizer / Fuel Ratio: 1.0 – 1.3 (1.1 nominal)
- Flow Rate*: 204 g/sec (0.45 lbm/sec)
- Valve: Aerojet Single or Dual Seat
- Valve Power: Various (45 Watts @ 28 Vdc Typical)
- Mass: with single seat valves 5.4 kg (12 lbm)

*at rated thrust

Performance

- Specific Impulse: 333 sec (lbf·sec/lbm)
- Total Impulse: 5,586,000 N·sec (1,255,800 lbf·sec)
- Total Pulses: >100
- Total Thermal Cycles: >50
- Steady State Firing: 2700 sec

Status

- FY2008-9 NASA funded, TRL 6
- Ready for final flight design and analysis, and formal qualification (program specific)

Reference:

- AIAA-2009-5125
R-40 3,870N (870-lbf) BIPROPELLANT ROCKET ENGINE
(Space Shuttle)

Design Characteristics
- Propellant: MMH/NTO (MON-3)
- Thrust/Steady State: 3870 N (870 lbf)
- Inlet Pressure Range: 27.6 – 10.3 bar (400 – 150 psia)
- Chamber Pressure*: 9.9 bar (145 psia)
- Expansion Ratio**: 22:1
- Flow Rate*: 1.40 kg/sec (3.07 lbm/sec)
- Valve: Aerojet
- Valve Power: 70 Watts @ 28 Vdc
- Mass**: 6.8 kg (15.0 lbm)

*At rated thrust
**Design, but varies by configuration

Performance
- Specific Impulse*: 281 sec (lbf·sec/lbm)
- Total Impulse: 92,073,600 N·sec (20,700,000 lbf·sec)
- Total Pulses: 50,000
- Minimum Impulse Bit: 111 N·sec (25.0 lbf·sec)
- Steady State Firing: 23,000 sec

Status
- Flight Proven

Reference
- AIAA-1985-1222
- AIAA-1980-1131
- AIAA-1979-1144
- AIAA-1978-1006
- AIAA-1975-1300
- AIAA-1974-1109
- AIAA-1970-0618
R-40B 4,000 N (900-lbf) BIPROPELLANT ROCKET ENGINE

Design Characteristics
- Propellant: MMH/NTO (MON-3)
- Thrust/Steady State: 4,000 N (900 lbf)
- Inlet Pressure Range: 27.6 – 10.3 bar (400 – 150 psia)
- Chamber Pressure*: 10.34 bar (150 psia)
- Expansion Ratio: 60:1
- Flow Rate*: 1.40 kg/sec (3.07 lbm/sec)
- Valve: Aerojet
- Valve Power: 70 Watts @ 28 Vdc
- Mass: 6.8 kg (15.0 lbm)

*At rated thrust

Performance
- Specific Impulse*: 293 sec (lbf-sec/lbm)
- Total Impulse: 92,073,600 N-sec (20,700,000 lbf-sec)
- Total Pulses: 50,000
- Minimum Impulse Bit: 111 N-sec (25.0 lbf-sec)
- Steady State Firing: 23,000 sec

Reference
- IAF-1987-0283

Approved for public release and export
Electric Propulsion

<table>
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<tr>
<th>Electric Proulsion System</th>
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<tbody>
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<td>MR-509</td>
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<tr>
<td>Dual Mode BPT-4000</td>
<td>MR-512</td>
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<td>MR-501B</td>
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<td>MR-502A</td>
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<td>MR-502 &amp; MR-502A PCU</td>
<td>6.9 kW Ion Propulsion System</td>
</tr>
<tr>
<td>MR-510</td>
<td></td>
</tr>
</tbody>
</table>
BPT-2000 Hall Effect Thruster

Design Characteristics

- Propellant ................................................................. Xenon
- Mass (Thruster & Cathode) ................................. <5.2 kg
- Envelope Dimensions ............................. 15 x 17 x 22 cm
- Nominal Input Power ............................... 2200 Watt
- Operational Power Range .......... 1200 – 2700 Watt
- Nominal Voltage ..................................... 350 Volt
- Operational Voltage Range .......... 250 – 400 Volt

Performance at 2.2 kW

- Thrust ................................................................. 123 mN
- Specific Impulse* ............................................. 1765 sec
- Efficiency* ......................................................... 48%
- Life (Continuous)** ...................................... >6000 hr
- Total Impulse .............................................. >2.6 x 10^6 N-sec
- Nominal Flowrate ...................................... 7.1 mg/sec
- On/Off Cycles ................................................. 6000 cycles

* Corrected for facility pressure effects
** Based on accel life tests and analysis

Status

- Flight Prototype Unit Fabricated and Tested

Rev. Date: 4/02/03
11411 139th Place NE • Redmond, WA 98052
(425) 885-5000  FAX (425) 882-5747

Approved for public release and export
DUAL MODE BPT-4000 HALL THRUSTER

**Design Characteristics**
- Propellant: Xenon
- Mass (Thruster & Cathode): <12.3 kg
- Envelope: 14 x 25 x 28 cm
- Input Power: 1000 to 4500 Watt
- Input Voltage: 200 or 400 Volt

**Status (as of Feb. 2006)**
- Qualification Complete
- >6,700 hours Demonstrated, Additional Life Testing Planned
- >6,300 Cycles Demonstrated, Additional Life Testing Planned

**Performance**

<table>
<thead>
<tr>
<th>Power</th>
<th>2.0 kW</th>
<th>3.0 kW</th>
<th>4.5 kW</th>
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</thead>
<tbody>
<tr>
<td>Thrust (300 Volts)</td>
<td>132 mN</td>
<td>195 mN</td>
<td>290 mN</td>
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<tr>
<td>Thrust (400 Volts)</td>
<td>117 mN</td>
<td>170 mN</td>
<td>254 mN</td>
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<tr>
<td>Specific Impulse (300 V)</td>
<td>1676 sec</td>
<td>1700 sec</td>
<td>1790 sec</td>
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<tr>
<td>Specific Impulse (400 V)</td>
<td>1858 sec</td>
<td>1920 sec</td>
<td>2020 sec</td>
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<tr>
<td>Life Capability</td>
<td>&gt;10,000 hr</td>
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<tr>
<td>Total Impulse</td>
<td>&gt;5.5 x 10^6 N-sec</td>
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<td></td>
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<tr>
<td>On/Off Cycles</td>
<td>6,700 Cycles</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Reference**
- AIAA-2005-3682
MR-501B ELECTROTHERMAL HYDRAZINE THRUSTER (EHT)

Design Characteristics
- Propellant: Hydrazine
- Catalyst: S405
- 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 @ 28 Vdc & 21°C
- Valve Heater Power: 8.00 Watts Max @ 28 Vdc & 21°C
- Cat. Bed Heater Pwr: 4.00 Watts Max @ 28 Vdc & 21°C
- Augmentation Heater Pwr: 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

Status
- Flight Proven

Reference
- AIAA-1983-1255

* Performance dependent on feed pressure blowdown
** Designed primarily for steady state operation but has demonstrated off-pulse capability

Approved for public release and export
MR-502A IMPROVED ELECTROTHERMAL HYDRAZINE THRUSTER (IMPEHT)

Design Characteristics
- Propellant: Hydrazine
- Catalyst: S405
- Thrust/Steady State: 0.80 – 0.36 N (0.18 – 0.08 lbf)
- Feed Pressure: 26.5 – 6.2 bar (385 – 90 psia)
- Flow Rate: 0.28 – 0.12 g/sec (0.0061 – 0.00026 lbm/sec)
- Valve: Dual Seat
- Valve Power: 8.25 Watts Max @ 28 Vdc & 21°C
- Valve Heater Power: 1.54 Watts Max @ 28 Vdc & 21°C
- Cat. Bed Heater Pwr: 3.93 Watts Max @ 28 Vdc & 21°C
- Augmentation Heater Pwr: 885 – 610 Watts
- Augmentation Htr Voltage: 29.5 – 24.5 Vdc Letdown
- Mass: 0.87 kg (1.92 lbm)

Performance
- Mission Specific Impulse*: 303 – 294 sec (lbf-sec/lbm)
- Total Impulse: 524,864 N-sec (118,000 lbf-sec)
- Total Pulses: MR-502A not designed for pulsing
- Steady State Firing: 2.0 hrs – Single Firing
- 370 hrs – Cumulative

Status
- Flight Proven

Reference
- AIAA-1987-0996

*Performance dependent on feed pressure blowdown

Approved for public release and export
**MR-502 & MR-502A IMPEHT POWER CONDITIONING UNIT**

**Design Characteristics**
- Mass: 2 kg
- Envelope: 27.94 x 9.42 x 14.61 cm
- Input Voltage: 15-29.9 vdc
- Inrush Current: 32 Amp Max
- Efficiency: >97%

**Demonstrated Performance**
- Limits inrush current to the 30 Amps during augmentation heater warm-up
- Two identical independent channels that can be operated either redundantly or simultaneously
- When used simultaneously, the IMPEHT pair should be started one after the other

**Interface**
- Enable/Disable Command: Latch Relay Drive
- On/Off Command: 0V – Off, 14V – On

**Status**
- Flight Proven

Date: 2/22/05

11411 139th Place NE • Redmond, WA 98052
(425) 885-5000 fax (425) 882-5747

Approved for Public Release and Export
MR-510 ARCJET THRUSTER & CABLE ASSEMBLY

**Design Characteristics**
- Propellant: Hydrazine
- Feed Pressure (Nominal): 18.6–13.8 bar (270–200 psia)
- Thrust/Steady State: 258–222 mN (58–50 lbf)
- 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: Dual Seat
  - Valve Power: 8.2 Watts Max @ 28 Vdc & 21°C
  - Power Cable - PCU Arcjet: <4650 mm/183"

For Power Conditioning Unit Information, see separate Data Sheet

**Demonstrated Performance**
- at 2000 Watts input power to the arcjet:
  - Thrust: 258 – 222 mN (58 – 50 lbf)
  - Specific Impulse: >585 – 615 sec
  - 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 Qualifications: >20 hrs
- Starts: >1960
- Telemetry Signals Available:
  - Gas Generator Temperature
  - Valve Temperature
  - Arc Voltage and Current through Power Conditioning Unit Telemetry

**Status**
- Flight Proven

**Reference**
- AIAA-2001-3901
- AIAA-1999-2272
- IEPC-1997-082

Approved for public release and export
MR-509 LOW POWER ARCJET SYSTEM

Design Characteristics
- Propellant: Hydrazine
- Feed Pressure (Nominal): 17.6–14.1 bar (255–205 psia)
- Thrust/Steady State: 254–213 mN (57–47 lbf)
- Mass
  - Arcjet Thruster: 2000 mm/79” cable = 1.38 kg (3.04 lbm)
  - Power Conditioning Unit (PCU): 4.13 kg (9.1 lbm)
- Envelopes
  - Arcjet: 237 x 125 x 91 mm (9.3 x 4.9 x 3.6 in.)
  - PCU: 236 x 185 x 83 mm (9.3 x 7.3 x 3.3 in.)
- Valve: Dual Seat
- Valve Power: 8.25 Watts Max @ 28 Vdc & 21°C
- PCU Input Power (per Arcjet): 1800 Watts
- Input Voltage: 65 – 96 Vdc
- PCU Efficiency, Avg: >91%
- Power Cable - PCU Arcjet: <2000 mm/79”

Demonstrated Performance
- at 1670 Watts input power to the arcjet
  - Thrust: 254 – 213 mN (57 – 47 lbf)
  - Specific Impulse (Blowdown Mission Avg.): >502 sec
  - Total Impulse: 866,500 N-sec. (194,500 lbf-sec)
- Demonstrated Firing Time
  - Total (1 hr On, 1/2 hr Off): >1050 Cycles
  - Longest Single Burn During Qualifications: 65 hrs
- Starts: >1170
- Telemetry Signals Available
  - Arcjet Current
  - Arcjet Voltage
  - PCU Status Flags
  - Gas Generator Temperature
  - Valve Temperature
  - PCU Temperature

Status
- Flight Proven

Reference
- IEPC-1997-081
MR-512 LOW POWER BUS ARCJET SYSTEM

Design Characteristics

- Propellant: Hydrazine
- Feed Pressure (Nominal): 17.6–13.8 bar (255–200 psia)
- Thrust/Steady State: 254–213 mN (57-47 lbf)
- Mass
  - Arcjet Thruster: +2000 mm/79” cable = 1.38 kg (3.04 lbm)
  - Power Processing Unit (PPU): 6.2 kg (13.7 lbm)
- Envelopes
  - Arcjet: 237 x 125 x 91 mm (9.3 x 4.9 x 3.6 in.)
  - PPU: 310 x 220 x 95 mm (12.2 x 8.7 x 3.7 in.)
- Valve: Dual Seat
- Valve Power: 8.25 Watts Max @ 28 Vdc & 20°C
- PCU Input Power (per Arcjet): 1780 Watts
- Input Voltage: 33–51.5 Vdc
- PPU Efficiency, Avg: >91%
- Power Cable - PCU Arcjet: <2000 mm/79”

Demonstrated Performance

- Power Conditioning Unit: ICD ED 1086
- Arcjet Thrusters: ICD 33312
- Cable: ICD 33311
- 138 mm (5.45”) MAX:
  - 33 mm (1.30”)
  - 43 mm (1.70”) MAX
- 95 mm (3.75”) MAX

- at 1670 Watts input power to the arcjet
  - Thrust: 254 – 213 mN (57 - 47 lbf)
  - Specific Impulse (Blowdown Mission Avg.): >502 sec
  - Total Impulse: 866,500 N-sec (194,500 lbf-sec)
  - Firing Time
    - Total (1 hr On, 1/2 hr Off): >1050 Cycles
    - Single Burn: 65 hrs
  - Starts: >1170
- Telemetry Signals Available
  - Arcjet Current
  - Arcjet Voltage
  - PCU Status Flags
  - Gas Generator Temperature
  - Valve Temperature
  - PCU Temperature

Status

- Flight Proven

Reference

- AIAA-1998-3631

Approved for public release and export
PRS-101 Pulsed Plasma Thruster System

Design Characteristics
- Propellant: Teflon® (Solid Bar)
- Max Thrust Level: 1.24 mN @ 100 Watts
- Power Level: Up to 100 Watts @ 28 vdc Unregulated
- Compact Solid State Propulsion System
- Ultra Low Minimum Impulse Bit for Precision Control
- Enables All-thruster ACS (No Momentum Wheels)
- Mass (w/o propellant): 4.74 kg
- Includes Integral Power Processing Electronics
- Power Efficiency: >80%

Performance
- Specific Impulse: Up to 1350 sec
- Thrust to Power Ratio: 12.4 μN/Watt
- Demonstrated Capability: 3,000 N-sec/thruster
- Predicted Capability (backed by selective testing): 15,600 N-sec/system (thruster pair)

Status
- Flight Proven

Reference
- AIAA-2003-5016
- AIAA-2001-3637
- AIAA-2002-3973
- AIAA-1999-3376

Approved for public release and export
Gridded Ion Engine Technology

NEXT 6.9 kWe Ion Thruster and Propellant Management System (with NASA GRC)

NEXIS 20 kWe Ion Thruster (with JPL)

HiPEP 25 kWe Ion Thruster (with NASA GRC)

Low Power Ion Thruster 0.5 kWe Ion Propulsion System (with NASA GRC)

NSTAR-class 2.5 kWe Ion Thruster

Power Processing

Digital Controllers

Xenon Propellant Management Systems
NEXT 6.9 kW Ion Propulsion System
Thruster, Propellant Management System, Digital Control Interface Unit

**Design Characteristics**
- Propellant ........................................... Xenon
- Thruster Mass................................. <13.3 kg
- Thruster Envelope Dimensions ....... 58 dia. x 44 cm
  Active optics area............................ 36 cm dia.
- Thruster Input Power ...............600 to 6900 Watt
- Propellant Management System Mass
  High Pressure Assembly ................. < 2.2 kg
  Low Pressure Assembly....................< 4.1 kg
- PMS Volume ..................................< 11,775 c.c.
  PMS does not require plenum tanks
- DCIU interface with Power Processing........RS-485

**Performance**
- Thrust ................................................. 235 mN
- Specific Impulse........................................ >4100 sec
- Efficiency @ full power ................................ >70%
- Propellant Throughput ............................ >270 kg
- On/Off Cycles ..................................... >3650 cycles
- End of Life Xenon Residuals ................. < 1% BOL

**Status**
- Thruster at Prototype Model Design
- Propellant Mgmt System at Engineering Model Design
- Digital Control Interface at laboratory design level

**Reference**
- AIAA-2005-3885
- AIAA-2004-4111
Space Electronics

Heritage Chart
MR-510 PCU
4.5 kWatt Hall Thruster PCU
MR-510 ARCJET POWER CONDITIONING UNIT (PCU)

**Design Characteristics**
- PCU – has three internal power converters, any two of which can operate simultaneously.
- Output can be switched between four different Arcjets
- Includes “Bubble Protection Mode” to mitigate gas induced shutdowns
- Mass ................................................. 15.8 kg (34.8 lbm)
- Envelope ...... 632 x 361 x 109 mm (24.9 x 14.2 x 4.3 in.)
- Input Voltage ........................................ 69 ±1 Vdc
- Efficiency, Avg ...................................... >90.7%
- Heat Rejection (two Arcjets operating @ 2000 Watts) ................................................. <410 Watts @ 23°C
- Output per Channel (up to two Channels) ................................................. 1500, 1670, 1830 or 2000 Watts
- Input Power, when operating two Arcjets @ 2000 Watts ................................................. 4340 Watts

**Demonstrated Performance**
- Telemetry Signals Available
  - Arcjet Current
  - Arcjet Voltage
  - PCU Status Flags
  - PCU Temperature

**Status**
- Flight Proven

**Reference**
- AIAA-1998-3630
4.5 kW HALL THRUSTER POWER PROCESSOR UNIT

Design Characteristics
- Mass . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 12.5 kg
- Envelope . . . . . . . . . . . . . . . . . . 43 x 40 x 11 cm
- Input Voltage . . . . . . . . . . . . . . 70 +/- 2 VDC
- Efficiency (Avg) . . . . . . . . . . . . . . . >92%
- MIL-STD-1553 Command & Telemetry Interface:
  - 30 Telemetry Channels
- Commandable Power Settings:
  - Discharge Power . . . . . . . . . . . . . . . . 2.0 - 4.5 kW
  - Discharge Voltage . . . . . . . . . . . . . . . 150 - 400 V

Demonstrated Performance
- Closed Loop Control of Xenon Flow Controller and Discharge Current
- Holding Valve Drivers
- S-Level, Radiation Hardened Components
- Optimized for Manufacturability
- Only Four Circuit Cards

Status
- Qualified

Reference
- AIAA-2005-3682

Rev. Date: 5/23/06

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Propulsion Systems

**Geosynchronous Satellites**
- B-Sat 2
- INDOSTAR (Cakrawarta-1)

**MEO Satellites**
- GPS IIF

**LEO Satellites**
- EO-1
- IKONOS
- MSTI

**Interplanetary and Scientific Satellites**
- CONTOUR
- Coriolis
- ACE
- STEREO
- Pluto/New Horizons
- THEMIS

**Launch Vehicles**
- Athena
- Pegasus HAPS
- Atlas Roll Control Module

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THEMIS (Time History of Events and Macroscale Interactions During Substorms)

• NASA MIDEX Mission, Scheduled for Launch in October of 2006
• Number of Systems: 5
• Propellant Load: 109 lbm (49.5 kg) Hydrazine
• 400-50 psia (27.6-3.5 bar) Blowdown Operation with Single Repressurization Event from 1700 psia (117 Bar) Pressurant Subsystem
• 4 MR-111C 1-lbf (4.5 N) Thrusters
• Used for Delta-V and Orbit Maintenance
• Aerojet Designed and Integrated System on Customer-Supplied Structure

Reference: AIAA-2006-5217
Solar-TErrestrial RELations Observatory (STEREO)

- NASA Earth-Sun Science Mission
- Planned Launch: July 2006
- Systems Delivered to JHU/APL: 2
- Propellant Load: 135 lbm (61 kg) Hydrazine Each
- 320-110 psia (22.1-7.6 bar) Blowdown Operation
- 12 MR-111C 1.0-lbf (4 N) Thrusters
- Designed for Attitude Control and Course Correction
- Aerojet Designed and Integrated System on Customer-Supplied Structure
Pluto/New Horizons

- NASA New Horizons Mission
- Launched: January 19, 2006
- Systems Delivered to JHU/APL: 1
- Propellant Load: 143 lbm (65 kg) Hydrazine
- 420-75 psia (28.9-5.2 bar) Blowdown Operation
- 12 MR-103H 0.2-lbf (1N) Thrusters
- 4 MR-111C 1-lbf (5N) Thrusters
- Designed for Attitude Control and Course Correction
- Aerojet Designed and Integrated System on Customer-Supplied Structure

Reference: IAC-2004-S.1.09

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- Systems Delivered: 3
- Propellant Load: 464 lbm (210 kg) Hydrazine Total in 2 Tanks
- 400-100 psia (27.5-6.9 bar) Blowdown Operation
- 12 MR-103G 0.2-lbf (1 N) Thrusters
  - 4 MR-501B Electrothermal Hydrazine Thrusters (EHTs)
- Used for Orbit Raising and Attitude Control (GEO Spacecraft)
- Aerojet Integrated System on Customer-Supplied Structure
INDOSTAR PROPULSION SYSTEM
Design Summary

**Performance Parameters**
- Propellant Mass ..................... 227 kg (500 lbm)
- Total Impulse .................. 632,000 N·sec (141,923 lbf·sec)
- Pressurant Mass ................... 0.5 kg (1.2 lbm)
- Pressure BOL/EOL ............ 21 / 8 bar (305 / 118 psia)–est.
- Blowdown Ratio ................... 2.6/1

**Status**
- Flight Proven – Launched 11/12/97

**Component Description**

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First system delivered to CTA in June 1996
GPS IIF MODERNIZATION PROGRAM
Propulsion System Design Summary

Performance Parameters

- Propellant Mass: 118 – 145 kg (260 – 320 lbm)
- Total Impulse: 249,000 N-s (56,000 lbf-sec)
- Pressurant Mass: 1.8 kg (4 lbm)
- Pressure BOL/EOL: 27.5 / 6.5 – 11.4 bar (400 / 95 – 165 psia)
- Blowdown Ratio: 4:1

Reference
- AIAA-1999-2469

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**EO-1 PROPULSION SYSTEM**

**Performance Parameters**
- Propellant Mass: 22.3 kg (49 lbm)
- Total Impulse (per REA): 46,000 N·sec (10,428 lbf·sec) @ 21°C
- Pressure BOL/EOL: 18.8 / 5.2 bar (273 / 76 psia) @ 21°C
- Blowdown Ratio: 36:1

**Component Description**

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**Status**
- Flight Proven

**Reference**
- AIAA-2001-3637
**IKONOS (CRSS) PROPULSION MODULE**

**Design Summary**

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**Performance Parameters**
- Propellant Mass: 37.6 kg (83 lbm)
- Total Impulse: 73,000 N·sec (16,500 lbf·sec)
- Pressure BOL/EOL: 21 / 5 bar (307 / 72 psia)
- Blowdown Ratio: 4.3 / 1

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**Component Description**

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Performance Parameters

- Propellant Mass: 22 kg (49 lbm)
- Total Impulse: 42,000 N·sec (9,500 lbf·sec)
- Pressurant Mass: 0.22 kg (0.49 lbm)
- Pressure BOL/EOL: 22.7 / 6.2 bar (329 / 90 psia)
- Blowdown Ratio: 3.7 / 1
- System Mass BOL/EOL: 39.5 / 17.2 kg (87 / 38 lbm)

Status

- MSTI-2, Launched 5/16/96

Component Description

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Comet Nucleus Tour (CONTOUR)

- Systems Delivered: 1
- Propellant Load: 165 lbm (90 kg) Hydrazine
- 350-125 psia (24.1-8.6 bar) Blowdown Operation
- 14 MR-103G 0.2-lbf (1 N) Thrusters
  2 MR-106E 5-lbf (22 N) Thrusters
- Used for Attitude Control (Interplanetary Spacecraft)
- Aerojet Integrated System on Customer-Supplied Structure

Approved for public release and export
Coriolis

- Systems Delivered: 1
- Propellant Load: 200 lbm (91 kg) Hydrazine
- 400-75 psia (27.5-5.2 bar) Blowdown Operation
- 4 MR-111C 1-lbf (4 N) Thrusters
- Used for Orbit Raising (LEO Spacecraft)
- Aerojet Integrated System and Secondary Structure on Customer-Supplied Primary Structure

Coriolis HPS Schematic

Approved for public release and export
ACE PROPULSION SYSTEM
Design Summary

Primary Performance Parameters
- Propellant Mass: 90 kg (42 lbm)
- Total Impulse: 409,900 N·sec (92,158 lbf·sec) (@21°C)
- Pressurant Mass: 0.59 kg (1.3 lbm)
- Pressure BOL/EOL: 21.1 / 5.5 bar (307 / 80 psia) (@21°C)
- Blowdown Ratio: 3.8:1
- System Mass BOL/EOL: 229 – 40 kg (505 / 89 lbm)

Component Description

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<td>Filter</td>
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</table>
Athena Attitude Control System

- ACS CONSISTS OF TEN (10) 220 N (50-lbf) THRUSTERS, VALVING, TANKS AND INSTRUMENTATION OPERATING IN A BLOWDOWN MODE
- ACS CAN CARRY 2, 4 OR 6 TANKS WITH A MAXIMUM OF 354 kg (780-lbs) OF N2H4

Approved for public release and export
Pegasus Hydrazine Auxiliary Propulsion System (HAPS)

- Systems Delivered: 9
- Propellant Load: 130 lbm (60 kg) Hydrazine
- 450-90 psia (30.9-6.2 bar) Blowdown Operation with Aerojet-Designed Low Cost AF-E-332 Bladder Tank
- 3 MR-107K 50-lbf (220 N) Thrusters
- Used for Final Orbit Trim (4th Stage) for Pegasus XL
- Aerojet Integrated System on Customer-Supplied Structure
Atlas II Roll Control Module (ARCM)

- Systems Delivered: 64
- Propellant Load: 35 lbm (16 kg) Hydrazine
- 498-175 psia (34.3-12.1 bar) Blowdown Operation
- 4 MR-107J 50-lbf (220 N) Thrusters
- Used for Vehicle Roll Control
- Fully Modular System Built by Aerojet, Integrated onto Launch Vehicle

Propulsion Schematic
Contact Information

Space and Launch Systems
Aerojet, Redmond, Washington

Physical and Mailing Address:
11411 139th Place NE
Redmond, WA 98052

Shipping Address:
11650 137th Place NE
Redmond, WA 98052

Operator No: 425 – 885-5000

O. M. Morgan (Olwen)
425 936-5285
425 882-5747 (Fax)
425 985-7853 (Mobile)
olwen@rocket.com

A. C. Wilson (Fred)
425 702-6823
425 882-5747 (Fax)
206 321-5414 (Mobile)
acw@rocket.com

W. Andrew Hoskins (Andy)
703 650-0277
703 650-0271 (Fax)
425 945-6362 (Mobile)
wah@rocket.com

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