Roadrunner, a High-Performance Responsive Space Mission
2004 SmallSat Conference
Terrance Yee, MSI
Roadrunner/TacSat-2 Mission Objectives

• Concept Baseline to Launch Ready in 14 months
• Storage to On-Orbit Functionality in 7 Days
• Autonomous On-Orbit Commissioning in 24 Hours
• In-Field Tactical C3 of Satellite
• Visible Imagery Under 1 Meter GSD
• Geolocate RF Targets and Image in Same Pass
• Demonstrate Additional Advanced Technologies
Design Approach

• MSI believes that small experimental satellites offer an opportunity to greatly shorten the development timeline compared to traditional spacecraft
• Rapid design requires significant buy-in from the customer including coordination on risk approach, required documentation, and most importantly ground rules for generating requirements
Payload Descriptions

- **Imager**: provides sub 1 meter imagery in three color channels plus panchromatic (black & white)
- **TIE**: Target Indicator Experiment, a.k.a. TacSat-2, locates targets based on RF signatures in conjunction with P3 aircraft
- **CDL**: Common Data Link, a space version of the communication system used by UAV’s, running at 274 Mbps
- **ROPE**: an array of reconfigurable processors to demonstrate adaptable, highly capable space processing
- **Hall Effect Thruster (HET)**: next generation ion engine
- **IGOR**: GPS receiver doing doppler-shifted ionospheric reflection and transmission science
- **Atmospheric Density Sounder/Advanced Cross-wind Measurement Experiment (ADS/ACME)** devices to measure atmospheric density and in-situ LEO neutral gas velocity
- **MVIS**: anti-jitter stabilization system designed to provide a smoother imaging platform
- **ISC**: Inertial Stellar Compass, combination star tracker/MEMS Gyro
- **Experimental Solar Array**: foldable thin-film array technology demo
Roadrunner Side and Top Views

Side View

Antennas
ADS
TIE
IGOR

+Z

Imager
CDL
HET

Terma HE-5AS
ISC CGA
ADMS

Top View

- X

ACME
ISC CGA
Roadrunner Deployed View 2

Main Solar Array (Single Junction GaAs)

Payload Electronics

Experimental Solar Array

IGOR

TIE

ADMS

ACME
10:30 am Ascending Node Sun Synch Orbit, View from Sun
### Roadrunner General Capabilities

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Capability</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Vehicle Compatibility</td>
<td>n/a</td>
<td>Falcon I/ Minotaur</td>
<td>Also compatible with some shared slots on larger LV’s</td>
</tr>
<tr>
<td>Spacecraft Control</td>
<td>n/a</td>
<td>3-axis</td>
<td>Nadir, Velocity, or Inertial Std.</td>
</tr>
<tr>
<td>Max P/L Mass</td>
<td>Kg</td>
<td>200</td>
<td>10 Experiments</td>
</tr>
<tr>
<td>Bus Dry Mass</td>
<td>Kg</td>
<td>128</td>
<td>Composite Sandwich Panels</td>
</tr>
<tr>
<td>Stowed Dimensions</td>
<td>cm</td>
<td>135x104x144</td>
<td>Bus + LV Adapter Only</td>
</tr>
<tr>
<td>P/L Power (Orb. Avg., Peak)</td>
<td>Watts</td>
<td>149-191, 468</td>
<td>Add’l peak power available</td>
</tr>
<tr>
<td>Array Power (Avg., Peak)</td>
<td>Watts</td>
<td>351 – 403, 675</td>
<td>Fixed Array, GaAs, depending on pointing</td>
</tr>
<tr>
<td>Battery Capacity</td>
<td>Amp-Hrs</td>
<td>30</td>
<td>Lithium-Ion</td>
</tr>
<tr>
<td>Pointing (Ctrl, Knowledge)</td>
<td>Deg., Deg.</td>
<td>0.10, 0.05</td>
<td>Star Tracker, GPS, IMU</td>
</tr>
<tr>
<td>Slew Rate</td>
<td>Deg. / Sec.</td>
<td>0.34 – 0.64</td>
<td>Depending on Axis</td>
</tr>
<tr>
<td>Comm. (Uplink, Downlink)</td>
<td>Kbps, Mbps</td>
<td>2/128, 2.0/274</td>
<td>S/X-Band, Encrypted</td>
</tr>
<tr>
<td>C&amp;DH (MIPS, RAM, NVRAM)</td>
<td>MIPS, Mbytes, Kbytes</td>
<td>165, 128-1024, 256</td>
<td>Rad 750 Power PC based, hard to 20 krads</td>
</tr>
<tr>
<td>Propulsion Delta-V</td>
<td>m/s</td>
<td>260</td>
<td>HET, 4.5 kg Xenon @ 1300s</td>
</tr>
</tbody>
</table>
### Roadrunner Master Equipment List

**Configuration 4/29/04**

<table>
<thead>
<tr>
<th>Subsystem/Component</th>
<th>Qty</th>
<th>Mass (kg)</th>
<th>Total (CBE)</th>
<th>Growth (%)</th>
<th>Allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADCS</td>
<td></td>
<td>9.09</td>
<td>9.3%</td>
<td>9.93</td>
<td></td>
</tr>
<tr>
<td>Ball Star Camera + Light Shade</td>
<td>1</td>
<td>2.74</td>
<td>2.74</td>
<td>15%</td>
<td>3.15</td>
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<tr>
<td>IMU: LN-200S</td>
<td>1</td>
<td>0.75</td>
<td>0.75</td>
<td>15%</td>
<td>0.86</td>
</tr>
<tr>
<td>Magnetometer (three-axis)</td>
<td>1</td>
<td>0.20</td>
<td>0.20</td>
<td>5%</td>
<td>0.20</td>
</tr>
<tr>
<td>Torque Rod</td>
<td>3</td>
<td>0.33</td>
<td>0.99</td>
<td>5%</td>
<td>1.04</td>
</tr>
<tr>
<td>Sun sensor, Coarse</td>
<td>3</td>
<td>0.02</td>
<td>0.06</td>
<td>5%</td>
<td>0.06</td>
</tr>
<tr>
<td>Sun Sensor Bracket without standoff</td>
<td>1</td>
<td>0.20</td>
<td>0.20</td>
<td>25%</td>
<td>0.24</td>
</tr>
<tr>
<td>Reaction Wheel</td>
<td>3</td>
<td>1.39</td>
<td>4.16</td>
<td>5%</td>
<td>4.37</td>
</tr>
<tr>
<td>Avionics</td>
<td></td>
<td>4.65</td>
<td>11.5%</td>
<td>5.18</td>
<td></td>
</tr>
<tr>
<td>Integrated Avionics Unit (IAU)</td>
<td></td>
<td>4.65</td>
<td>12%</td>
<td>5.18</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td></td>
<td>38.93</td>
<td>10.0%</td>
<td>42.81</td>
<td></td>
</tr>
<tr>
<td>Battery</td>
<td>1</td>
<td>9.25</td>
<td>9.25</td>
<td>10%</td>
<td>10.18</td>
</tr>
<tr>
<td>Solar Array Wing</td>
<td>2</td>
<td>14.84</td>
<td>29.68</td>
<td>10%</td>
<td>32.63</td>
</tr>
<tr>
<td>Harness</td>
<td></td>
<td>9.00</td>
<td>25.0%</td>
<td>11.25</td>
<td></td>
</tr>
<tr>
<td>Propulsion System</td>
<td></td>
<td>12.89</td>
<td>8.6%</td>
<td>13.99</td>
<td></td>
</tr>
<tr>
<td>Thruster and Cathode</td>
<td>1</td>
<td>1.12</td>
<td>1.12</td>
<td>15%</td>
<td>1.29</td>
</tr>
<tr>
<td>PPU</td>
<td>1</td>
<td>3.66</td>
<td>3.66</td>
<td>15%</td>
<td>4.21</td>
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<tr>
<td>Xenon Feed System (XFS) inc. Tank</td>
<td>1</td>
<td>3.10</td>
<td>3.10</td>
<td>10%</td>
<td>3.41</td>
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<tr>
<td>Xenon</td>
<td>1</td>
<td>4.50</td>
<td>4.50</td>
<td>0%</td>
<td>4.50</td>
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<tr>
<td>PPU-to-Thruster Harness</td>
<td>1</td>
<td>0.50</td>
<td>0.50</td>
<td>15%</td>
<td>0.58</td>
</tr>
<tr>
<td>Structures</td>
<td></td>
<td>47.89</td>
<td>15.0%</td>
<td>55.07</td>
<td></td>
</tr>
<tr>
<td>Thermal Control</td>
<td></td>
<td>2.83</td>
<td>73.9%</td>
<td>4.92</td>
<td></td>
</tr>
<tr>
<td>Telecom (Mini-SGLS)</td>
<td></td>
<td>2.29</td>
<td>11.2%</td>
<td>2.54</td>
<td></td>
</tr>
<tr>
<td>Spacecraft Total</td>
<td></td>
<td>127.55</td>
<td>14.2%</td>
<td>145.69</td>
<td></td>
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<tr>
<td>Payload</td>
<td></td>
<td>178.40</td>
<td>12.1%</td>
<td>199.91</td>
<td></td>
</tr>
<tr>
<td>Prop Sensors</td>
<td></td>
<td>2.67</td>
<td>12.3%</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>Experiments</td>
<td></td>
<td>181.07</td>
<td>12.1%</td>
<td>202.91</td>
<td></td>
</tr>
<tr>
<td>Ballast</td>
<td></td>
<td>1.30</td>
<td>1.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Launch Vehicle I/F</td>
<td></td>
<td>4.09</td>
<td>8.1%</td>
<td>4.42</td>
<td></td>
</tr>
<tr>
<td>Launch Vehicle I/F</td>
<td></td>
<td>4.09</td>
<td>8.1%</td>
<td>4.42</td>
<td></td>
</tr>
<tr>
<td>Satellite</td>
<td></td>
<td>309.92</td>
<td>8.1%</td>
<td>349.90</td>
<td></td>
</tr>
<tr>
<td>Launch Mass</td>
<td></td>
<td>314.01</td>
<td>40.30</td>
<td>354.32</td>
<td></td>
</tr>
</tbody>
</table>
Power System Capabilities

- 149-191 Watts of Payload Power Available Depending upon Flight Attitude Excluding Experimental Arrays
- 468 Watts of Peak Payload Power Available
  - Higher Power Circuits Available as an Option
- Up to 675 W Peak Array Generation Allowable
- 30 Amp-Hr Battery Capacity From 8-cell Li-Ion Battery
- Bus Provides Solar Array Switching/Battery Charging Autonomous
- 16 total 2 Amp switched lines available to Payloads
- 33 Six-Amp switched lines available to Payloads
- Up to 8 Redundant Actuators Can Be Armed/Fired from 4 Separate Circuits
Power System Components

Yardney
Li-Ion Flight Battery
30 A-Hr, 11,000 cycles
@ 20% DoD
28-34V nominal bus

GaAs Solar Array standard, FITS Flexible Array or Triple Junction options available

Custom Harness, No Bake-out Required, Full EMI/EMC Available

Broad Reach IAU w/ integrated EPS

Up to 8 redundant pyros armed/fired from 4 circuits
20 Amp total load standard,
Bus Structures

TS21 Qualified Structure
-DeltaIV/ESPA Loads
-Correlated FEM
-181 Kg at 18.8 g's
-27.7 Hz

RR Baseline Configuration
-270 Kg Max, 8 g's
-25 Hz

Roadrunner
First Mode Frequency: 25.2 Hz
-No Structure Re-Qual Required

Adding New Roadrunner Payloads Required:
- Stiffening Structural Load Path
- Fixing adapter to S/C not LV
- Design to 25 Hz Above Lightband
- Re-Qualify For Stiffness and Strength (August ‘04)
- Proto-Flight Vibration Testing of Structure

New Payloads
-410 kg Max
<- 25 Hz

Re-Qual Structure

August 9, 2004
ADCS Capabilities

- Slew Acceleration Design Capability (For 100 kg P/L)
  - $X = 0.007$ deg/s/s
  - $Y = 0.014$ deg/s/s
  - $Z = 0.008$ deg/s/s

- Slew Rate Design Capability (Based on 100 kg P/L)
  - $X = 0.5$ deg/s
  - $Y = 0.9$ deg/s
  - $Z = 0.6$ deg/s

- Pointing Control: 0.10 deg (each axis)
- Attitude Knowledge: 0.05 deg (payload, after cal)
- Jitter (5 second, TS-21 design): 0.001 deg (each axis)
- High precision pointing is extended to Star Tracker outage attitudes by an LN-200S IMU
ADCS Block Diagram

1 Billingsley TFM100S Magnetometer

1 Northrop Grumman LN-200S Inertial Measurement Unit

3 Goodrich Sun Sensor Modules

3 Microcosm MT-15-1 Torque Rods (15 A-m²)

3 Dynacon Reaction Wheels (1.0 Nms)

August 9, 2004
Thermal Control System

- **TCS Capabilities**
  - Can support an orbit average of 224W of internal load dissipation
  - Maintains Bulk Spacecraft Temperature below 25°C in hot case and above 10°C in Cold Case
  - TCS supports:
    - 48 AD590 Temperature Sensors
    - 8 Platinum Resistance Thermistors
    - 6 Software-Controlled Heater Zones (3 for bus, 3 for payloads) with mode-dependent set points
  - Passive design, no active components except heaters
S-Band Communications

IAU CAPI Card

- Temp Sensors (3- AD590)
- LPT Reset (RS-422)
- Downlink RS-422 Clk & Data
- T&C RS-422 Data @ 230.4Kbaud

LPT Electronics Box

- RF Switch Transfer Switch
- Downlink Xntr (2247.50 MHz SGLS or 2287.5 MHz TDRSS)
- Un-switched Essential Bus + 28 VDC

IAU PAPI Card

- MCU Reset (RS-422)
- Uplink Clk & Data

- Un-switched Essential Bus + 28 VDC

Mini- COMSEC Unit (MCU-100)

- MCU-100 Tlm, Data, Gate & Clk (RS-422)
- Uplink Clk & Data RS-422 @ 50KHz

August 9, 2004

New LPT Components in Tan

PSL Helix Antenna 5.7” High 4” Dia.
## C&DH (Broad Reach IAU) Capabilities

<table>
<thead>
<tr>
<th>Resource/Feature</th>
<th>Capabilities Available to P/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor</td>
<td>BAE Rad750 (Power PC Based)</td>
</tr>
<tr>
<td>S/C Commanding</td>
<td>HW &amp; SW commands, CCSDS Format</td>
</tr>
<tr>
<td>Non-Volatile Memory</td>
<td>16MBytes</td>
</tr>
<tr>
<td>Volatile Memory</td>
<td>640MBytes (128M CPU + 512M CASI)</td>
</tr>
<tr>
<td>LVDS interfaces</td>
<td>2 Mux’ed Inputs</td>
</tr>
<tr>
<td>RS422 interfaces</td>
<td>26 RX, 2632 TX</td>
</tr>
<tr>
<td>TTL Discrete In</td>
<td>10</td>
</tr>
<tr>
<td>TTL Discrete Out</td>
<td>16</td>
</tr>
<tr>
<td>Analog Voltage/Current Sensors</td>
<td>22</td>
</tr>
<tr>
<td>28V Timed Switches</td>
<td>9</td>
</tr>
<tr>
<td>28V Low Power SW Outputs</td>
<td>7 (3 Arm-Fire, 4 Fire-Only)</td>
</tr>
<tr>
<td>28V High Power SW Outputs</td>
<td>33 (4 Arm-Fire, 29 Fire-Only)</td>
</tr>
</tbody>
</table>
Propulsion

• Busek Tandem Hall Thruster (BHT-200-X3)

• 4.5 kg of Propellant Nominal Load
  – Propellant mass may be increased by either adding a second tank or modifying regulator and loading Xenon at the launch site to avoid DOT tank safety factor limits

• Typical operation is at 1300 sec, 11 mN, 330 W
• Isp selectable from 1200-1600 sec
• Wattage selectable from 50-330 W
• Thrust is up to 12.5 mN
Payload Integration & Test Flow

Inputs
- ICD/Specs/User Guide
- Command & Tlm. Data Set
- Power-Up Sequence
- Operational Sequence Of Events
- RVM

Inputs
- User Provided EGSE
- Tested SCL Scripts

Inputs
- Avionics Emulator
- Payload
- Contamination Covers
- Purge System?

Inputs
- Cubes Installed & Aligned to Focal Plane

Develop Test Flows and SCL Scripts

Test Scripts And Commands On Flatsat With Emulator

Component Level Environmental Testing

Deliver P/L To AFRL

Integrate P/L Onto SC

Alignments

Spacecraft Level System Tests

P/L Bench Tests

SC Level Thermal Vac/Balance

SC Level Vibration Test

Prep for Ship 3/28/05

August 9, 2004
Lessons Learned

• Fewer Organizations Lead to Streamlined Communications
• Simplified Requirements Allow Limited Manpower to Focus on the Most Important Aspects
• Adequately Funding Programs and Allowing the Major Players to All Get Under Contract Before Starting Detailed Design is Much More Efficient Than the Alternative
• Optimize Work Time by Minimizing Meetings and Keeping Most of Those as Working Meetings
• Capabilities Driven Approach Greatly Reduces the Necessity of Redesign to Accommodate Changes
Conclusions

- Roadrunner is setting a new standard for small, high-performance spacecraft
- As part of the TacSat program, Roadrunner is pioneering order of magnitude increases in utility to military end-users
- The lessons learned on Roadrunner are paving the way for huge increases in the capabilities of both experimental and operational small satellites in responsive military applications