Evaluating the Present and Potential Future Impact of Small Satellites

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Objective

- Answer the question—"Are small satellites a complimentary or a disruptive technology?"
  - Emphasis on the near to medium term
  - Largely qualitative analysis
- This is NOT an assessment of whether small satellites are useful
- Launch history:
Method: Market-Based Analysis

• Three market segments:
  – Military
  – Civil
  – Commercial

• Focus on U.S. market

• Growth can come from one of three means:
  – Displacement of larger satellites
  – Maintenance of existing market share in a growing market (arguably this is not disruptive but is just “riding the wave”)
  – Creation of new markets
Military Space—Displacing Large Satellites

- Major Military Space Programs as of 2001:

<table>
<thead>
<tr>
<th>Program</th>
<th>Sponsor</th>
<th>Purpose</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSP</td>
<td>Air Force</td>
<td>Nuclear and missile warning</td>
<td>2400</td>
</tr>
<tr>
<td>DMSP</td>
<td>Air Force</td>
<td>Weather monitoring and prediction; to be replaced by NPOESS</td>
<td>1500</td>
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<tr>
<td>MilSatCom EHF</td>
<td>Air Force</td>
<td>Communications</td>
<td>~7000</td>
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<tr>
<td>MilSatCom Polar</td>
<td>Air Force</td>
<td>Communications</td>
<td></td>
</tr>
<tr>
<td>T-SAT</td>
<td>Air Force</td>
<td>Communications</td>
<td></td>
</tr>
<tr>
<td>GPS</td>
<td>Air Force</td>
<td>Precise position, velocity, and time transfer</td>
<td>1545</td>
</tr>
<tr>
<td>NPOESS</td>
<td>Air Force</td>
<td>Weather monitoring and prediction; co-sponsored by NOAA and NASA</td>
<td>~2000</td>
</tr>
<tr>
<td>SBIRS-High</td>
<td>Air Force</td>
<td>Nuclear and missile warning; replacement for DSP</td>
<td></td>
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<tr>
<td>Space-Based Radar</td>
<td>Air Force</td>
<td>Moving target tracking; radar mapping</td>
<td></td>
</tr>
<tr>
<td>Wideband Gapfiller</td>
<td>Air Force</td>
<td>Communications; successor to DSCS</td>
<td>6000</td>
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<tr>
<td>DSCS</td>
<td>Army</td>
<td>Communications</td>
<td>1235</td>
</tr>
<tr>
<td>MUOS</td>
<td>Navy</td>
<td>Communications</td>
<td></td>
</tr>
<tr>
<td>Sat Comm Systems</td>
<td>Navy</td>
<td>Communications</td>
<td></td>
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</table>
Displacing Large Satellites

• Many of the systems are in highly elliptical or high altitude (e.g. GEO) orbit
  – Dictates the use of large launch vehicles even if the spacecraft are relatively small
  – Secondary launches are not an option for operational systems

• Power/aperture problem
  – Systems typically require high power (communications) and/or large apertures (communications and reconnaissance)

• Clusters of small spacecraft could theoretically perform the function of some large spacecraft
  – Technology is still too immature
  – Cost-effectiveness not sufficiently demonstrated
Military Space—Market Growth Potential

- Market is very large, but growth is modest (3.5% p.a. 1995-2002)
- Government funding will almost never show a large long-term growth rate

Military Space Budget Authority (constant 2005 dollars)
Military Space—Growth Opportunities

• Military showing increased interest in small satellites
  – Responsive capabilities
  – Space situational awareness
  – Space control

• Numerous efforts undertaken by the military or with military potential
  – Air Force XSS-10 and XSS-11
  – NASA Demonstration of Autonomous Rendezvous Technology
  – Surrey SNAP-1
  – Office of Force Transformation TacSat-1, TacSat-2

• DARPA FALCON program (separate from SpaceX Falcon-1 launch vehicle) aims to provide low-cost, responsive space lift capability for small satellites

• Interest is being shown, but funding is very small compared to the expenditures for large space systems
Civilian Space—Addressable Market

- Much of NASA’s budget devoted to items other than spacecraft
  - $5.8 billion of Science, Aeronautics, and Exploration available
  - $450 million of Space Flight Capabilities available
- The $6.25 billion must cover much more than spacecraft:
  - Science/research
  - Launch vehicles
  - Technology development
  - Mission and science operations
- Exploration Initiative is not likely to help small satellites

<table>
<thead>
<tr>
<th>Budget Line Item</th>
<th>Budget (US$m)</th>
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<tbody>
<tr>
<td><strong>Science, Aeronautics, and Exploration</strong></td>
<td>7,853</td>
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<tr>
<td><em>Space Science</em></td>
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<tr>
<td>Solar System Exploration</td>
<td>1,302</td>
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<tr>
<td>Mars Exploration</td>
<td>596</td>
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<tr>
<td>Astronomical Search for Origins</td>
<td>914</td>
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<tr>
<td>Structure and Evolution of the Universe</td>
<td>456</td>
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<tr>
<td>Sun-Earth Connection</td>
<td>726</td>
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<tr>
<td><strong>Earth Science</strong></td>
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<tr>
<td>Earth System Science</td>
<td>1,513</td>
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<tr>
<td>Earth Science Applications</td>
<td>92</td>
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<tr>
<td>Biological and Physical Research</td>
<td>986</td>
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<tr>
<td>Biological Sciences Research</td>
<td>368</td>
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<tr>
<td>Physical Sciences Research</td>
<td>357</td>
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<tr>
<td>Research Partnerships &amp; Flight Support</td>
<td>260</td>
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<tr>
<td><strong>Aeronautics</strong></td>
<td>1,037</td>
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<tr>
<td><strong>Space Flight Capabilities</strong></td>
<td>7,498</td>
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<tr>
<td><em>Space Flight</em></td>
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<tr>
<td>Space Station</td>
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<tr>
<td>Space Shuttle</td>
<td>3,928</td>
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<tr>
<td>Space and Flight Support</td>
<td>468</td>
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<tr>
<td>Crosscutting Technology</td>
<td>1,608</td>
</tr>
<tr>
<td>Space Launch Initiative</td>
<td>938</td>
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<tr>
<td>Mission and Science Measurement</td>
<td>452</td>
</tr>
<tr>
<td>Innovative Tech. Transfer Partnerships</td>
<td>218</td>
</tr>
<tr>
<td><strong>Inspector General</strong></td>
<td>27</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>15,378</td>
</tr>
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</table>
Civilian Space—Displacing Large Satellites

• A review of NASA’s 2004 budget shows that most satellite expenditures are directed towards large spacecraft such as MER, JWST, EOS
  – Power/aperture problem makes it difficult to use small satellites
  – Interplanetary spacecraft require high-energy trajectories that discourage the use of small satellites
  – Need to precisely co-locate/co-align multiple instruments
• UNEX cancelled after approving two missions (one flown)
• MIDEX competition delayed by at least one year, overall Explorer program expected to see lower flight rates
Civilian Space—Market Growth Potential

- NASA budget has been trending downwards for more than a decade
- Budget increase sought for FY 2005, but Congress is resisting due to a tight budget environment
  - Additional money slated for Exploration Initiative

![NASA Budget History (constant 2005 dollars)]
Civilian Space—Growth Opportunities

• Some small satellite activity under way
  – ST-5
  – THEMIS (5 satellite MIDEX program)
  – Magnetosphere constellation (~100 micro-/nano-satellites)
  – Ongoing SMEX competition

• Overall, little near-term opportunity seen
Commercial Space

• Disruptive technologies typically gain acceptance and growth by enabling new capabilities and applications rather than by simply displacing existing technology
  – PC initially took hold because of word processing and spreadsheet applications; partial displacement of mainframes was a by-product

• This type of innovation is more likely to occur in the commercial marketplace than in government space programs
  – Especially true in the current risk-averse environment

• Therefore, commercial space is the most likely route for the emergence of disruptive small satellite technology
Commercial Space—Displacing Large Satellites

- Commercial space expenditures dominated by geosynchronous communications satellites
  - High orbit forces the use of large launch vehicles, which makes larger spacecraft far more cost-efficient
- New and growing market for high-resolution imaging
  - Aperture problem for small spacecraft
Commercial Space—Growth Potential

• LEO communications systems were technical successes but financial disasters
  – Iridium, Globalstar used mid-size spacecraft (690kg, 450kg, respectively)
  – ORBCOMM used micro-spacecraft (42 kg)
  – All three went bankrupt and were bought for a few pennies on the dollar; all now appear to be financially viable
  – ORBCOMM is pursuing next-generation spacecraft

• Surrey-led Disaster Monitoring Constellation suggests the presence of a modest market for medium-resolution imagery

• However, truly disruptive applications capable of generating billions in revenue have yet to be identified
Launch Cost Impact on Commercial Small Space

- Getting there is NOT half the battle
- ORBCOMM example:
  - $800 million invested
  - Launch costs represent 9% of total investment

- IRIDIUM example:
  - 93 spacecraft launched prior to bankruptcy
  - Assuming $10,000/kg, $690 million in launch costs
    - Delta 2 (5 spacecraft) $34.5 million
    - Long March (2 spacecraft) $16 million
  - ~$5.5 billion invested prior to bankruptcy
  - Launch costs represent 13% of total investment

- Venture capitalists typically look for >30% annual return on investment, so **even if launch costs were zero, they would only make a marginal system look viable**

- The problem is on the revenue, not the cost side of the balance sheet

### ORBCOMM Estimated Launch Costs

<table>
<thead>
<tr>
<th>S/C</th>
<th>Launch Vehicle</th>
<th>Year</th>
<th>Est. Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM1-2</td>
<td>Pegasus (w/ MicroLab-1)</td>
<td>1995</td>
<td>$10m</td>
</tr>
<tr>
<td>FM5-12</td>
<td>Pegasus</td>
<td>1997</td>
<td>$14m</td>
</tr>
<tr>
<td>FM3-4</td>
<td>Taurus (secondary)</td>
<td>1998</td>
<td>$5m</td>
</tr>
<tr>
<td>FM13-20</td>
<td>Pegasus</td>
<td>1998</td>
<td>$14m</td>
</tr>
<tr>
<td>FM21-28</td>
<td>Pegasus</td>
<td>1998</td>
<td>$14m</td>
</tr>
<tr>
<td>FM30-36</td>
<td>Pegasus</td>
<td>1999</td>
<td>$15m</td>
</tr>
<tr>
<td>35 spacecraft, 6 launches</td>
<td>1999</td>
<td>$72m</td>
<td></td>
</tr>
</tbody>
</table>
Educational Institutions—Another “Market”

- Small satellites have been a disruptive impact to space education
- CubeSat program lists 66 universities and four high schools participating
  - 16 countries on 6 continents
- Other government-sponsored efforts aimed at educational institutions
  - UNEX
  - University Nanosatellite-2
  - University Nanosatellite-3
Conclusions

• At present small satellites are a complementary technology in the military, civilian, and commercial space marketplace
  – Small satellites are making very valuable contributions
  – Total expenditure dwarfed by that spent on large satellites
• Although small satellites have some growth potential, explosive growth consistent with a disruptive technology is unlikely
  – Military space spending shows only a modest growth rate
  – NASA spending has been declining
  – Within at least the commercial market, launch vehicle costs are not a primary roadblock

• Small satellites will remain a complementary technology for the foreseeable future