July 20, 1969  20:17:40 UTC
Sea of Tranquility  0° 40' 26.69" N,  23° 28' 22.69" E
NASA Programs

Number of Opportunities Decreasing
Budget Pressure Increasing
Research Areas

- Space Biology
  - Radiation Effects On Biology
  - Lunar Dust Interactions
- Space Sciences
  - Near Earth Objects
  - X-Ray Astronomy
- Lunar Sciences
  - Lunar “Weather”
  - Dust and environmental
- Sun Earth System Science
  - Ionosphere/Thermosphere Environments
  - Microphysics Plasma Processes
  - Radiation Hazardous Environments
  - Properties Dynamics Of Solar Wind
  - Lofted Dust/Aerosols
  - Lighting Sprites
Small Spacecraft Trends

Small Satellites On-Orbit By Country (Ex. US)

Source: BAH research and analysis: “Small Satellite Industrial Base Study 9 May 2003”
Small Missions

• Smaller missions excel at
  – Simple focused missions, science, technology or ops demonstrations
  – Unique data obtained in near term (i.e. solar cycle)
  – Short duration missions (<14 days for landers, <2 years for orbiters)
  – Diversity of operating sites, landing sites or orbits
  – Lower cost enables increased number of missions
  – Faster learning cycle, results in lower costs
  – If new technology sooner, lowers cost of flagship missions
  – Smaller teams, fewer interfaces, improved collaboration

• Larger missions excel at
  – Large diameter sensors, optics, antennas, detectors
  – Large scale investigations, several instruments
  – Lower calculated risk per individual mission
  – Lower cost per kilogram
  – Utilize “Proven Launchers”
Small Spacecraft Capability

Advantages
- Narrow capabilities
- Optimized Performance

Disadvantages
- Long initial Development
- Big Infrastructure

Advantages
- Focused capabilities
- Optimized Performance
- Buy down requirements

Disadvantages
- Shorter Development
- Cost Risks Mitigated

Delivery ~ Months
Cost $0.2M-2M

Advantages
- Tailored capabilities
- Adaptable Performance
- PI-led AO process

Disadvantages
- Long Development
- Cost & Schedule Risks
- Many Concepts, Few Missions

Delivery 2-5 Years
Cost $125M - $500M

Advantages
- World-class Science
- Optimized Performance
- Unique, Large Instruments

Disadvantages
- Traditional Development
- Big Cost and Schedule
- Large Development Risks
- Fewer PI & Leadership Opportunities

Delivery 5+ Years
Cost ~$1000M

Targeted Science Missions In An Affordable, Timely Period
<table>
<thead>
<tr>
<th>Country/Entity</th>
<th>Small Satellite Programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>SSTL ~ 40 missions &lt;$100M, 5-500Kg; DERA/QINETIQ (STRV)</td>
</tr>
<tr>
<td>ESA</td>
<td>Smart-1, PROBA-1, PROBA-2………PROBA-N</td>
</tr>
<tr>
<td>France</td>
<td>CNES - Myriade &lt;150kg S/C, &lt;70kg P/L, 6 launched since 2004, 10 in development</td>
</tr>
<tr>
<td>Japan</td>
<td>JAXSA – Index (72 Kg, 2005 launch &lt;$10M)</td>
</tr>
<tr>
<td>Sweden</td>
<td>Swedish Space Corp – 6 Small/Microsats in orbit, 3+ in development (Viking, Freja, Astrid 1,2 Odin, Prisma, Svea etc)</td>
</tr>
<tr>
<td>Germany</td>
<td>DLR, TuB (TUBSAT-A, -B, -N/N1,-DLR, -MAROC,- LAPAN)</td>
</tr>
<tr>
<td>Denmark</td>
<td>DTU, Terma – Oerstad, Romer</td>
</tr>
<tr>
<td>Israel</td>
<td>Rafael, IAI – EROS-A, EROS-B (Imaging Microsatellites)</td>
</tr>
<tr>
<td>Canada</td>
<td>Dynacon/UTIAS – MOST, NESS, Brite, MDA – Rapid Eye</td>
</tr>
<tr>
<td>India</td>
<td>ISRO – HAMSat (45 kg microsatellite)</td>
</tr>
<tr>
<td>Others</td>
<td>China, South Africa, Turkey, Chile, Nigeria, Korea, Taiwan, Australia, Egypt, Indonesia, Russia, Malaysia, Belgium</td>
</tr>
</tbody>
</table>

International Efforts Include >1000 Small Satellites
Leveraging Commercial Products

- **Sensor**: Digital Camera
- **Comm (Wireless)**: IEEE 802.11b and IrDA 1.2
- **Software**: Applications and IDE for OS
- **Power**: Li-Ion Polymer Battery, Power management circuits
- **C&DH**: Ultra-low power, high performance processor XScale 400MHz
- **C&DH**: Digital Data Storage, Operating system, File System
- **Wireline**: PnP USB v1.0

**Pros**
- Much less expensive – savings can be passed on to design and test
- State-of-the-art performance
- Widespread availability
- More choices of suppliers
- Greater product variety

**Cons**
- May require significant redesign
- Greater sensitivity to radiation dosages requiring extensive testing and protection schemes
- Performance data may not be available or considered proprietary by manufacturer
- May require more careful assembly

$Billions of R&D

How can we leverage technology development

**Design**

- Designed for small, low cost, low-power, long-life, high connectivity, PnP, etc
Highly Integrated Approach

**Current Approach to Small Satellites**

- Space-Rated Boxes / Components (smallest mass, power, and size)

**Collection of Subsystems**

- Integration of boxes and systems

**Needed Approach to Get To Ultra Low Power & Size**

- Highly Integrated System (Integration of lower level components)

- Commercial Components (smallest mass, power, and size)

**Mini/Micro-satellite**

- Aerospace MEPSI

**Pico/Nano-satellite**

- CubeSat

- Requires a low level of integration for very small/dense packaging and reducing supporting overhead hardware

- Allows component multi-use (e.g., CMOS imagers used for star-tracking, RPO, and inspection)
### GeneSat-1

**Total Mass (Satellite + PPOD)**  
7.1 kg (4.1+ 3 kg)

**Satellite Power (on-orbit average)**  
4 - 5 W

**Satellite Volume**  
3 “Cubes” (14” x 4” x 4”) incl beacon

**Science Data/Command Up/Downlink**  
~200 kB/day, ISM band (2.4 GHz)  
Amateur band (~437 MHz)

**Flight hardware Delivery**  
11/13/2006

**Mission Duration (spacecraft design life);**  
> 21 days (Experiment Duration ~ 100 hours)

**Orbit Altitude**  
390 km

**Orbit Inclination**  
45°

**Launch Vehicle**  
Minotaur I (TacSat-2 Primary)

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**Genesat Continues to Perform Flawlessly: Biology Experiment Complete**
Angels Conceptual Design

36cm Optics, 25Watt Payload, 50 M/s
25 Kg, $ 3 M, Launch in 2010

Basketball as Reference
Transiting Exoplanet Survey Satellite (TESS)

- Single focus, ‘small’ spacecraft
- Quick development of spacecraft allows for follow-on ground observations of candidates
- High value planets to be observed by JSWT for characterization
- Excellent example of innovative partnership (academia, industry, and government) and maximization of space science assets (ground-based, small spacecraft, and flagship missions)

Comparison of Alternatives

- Ground-based observation campaign
  - All sky survey for transiting exoplanets with a period of less than 60 days would be expensive and time consuming
- Navigator Program Strategic Missions
  - Small Spacecraft = <$1B
Kestrel Eye

Very small optical imaging satellite concept developed by DARPA

- ITT (Kodak) 10” telescope with flight heritage
- 10 Kgs launch mass
- 1.5 meter ground resolution
- Goal of $1M unit recurring cost
- Imagery downlinked near real-time to ground

ITT SSD Relevant Experience

9 in. Gimbaled Telescope

Engineering Model of MRW System (Contains 3 RW, 3 Motor Drivers and µP)
Lunar Explorer Missions

- Orbiter or lander missions
- Utilize small launcher class for lift
- Carry ~50 kg of instruments to lunar orbit, ~25 kg to lunar surface
- Perform Exploration tasks/surveys or conduct science investigations
- Low cost enables multiple sorties, landing sites
- Architecture uses available technologies and subsystems
Launchers

**Minotaur I through IV**
- Composite clamshell fairing
  - 92” Taurus design
**Stage 5 Assembly**
- Star 37GV solid rocket motor
**Stage 4**
- Cold Gas ACS
- Stage 4 Star 48V SRM
**Stages 1,2,3 Peacekeeper**
- Performance: 496 kg to TLI
- Total launch cost (ROM):
  - Minotaur IV
    - $36M (first mission)
    - $26M (recurring)
  - Minotaur I
    - $20M
- Secondary Cost $100K

**ESPA**
- Designed to carry up to 6 microsatellites
- Limit of 180 kg (400 lbs) each
- CG limited to 20 inches from port
- Limited to a 24” x 24” x 38”
- Total launch cost $1,000K to $2,000K
- Orbit limited to primaries orbit constraint

**Falcon**
- New Booster Design
- Two Stage Liquid
- Performance (Approx):
  - Falcon I: 500 Kg to LEO
  - Falcon V: 1,000 Kg to GEO
- Total Launch Cost (ROM):
  - Falcon I: $10M
  - Falcon V: $20M
- Secondary cost ~$200K
Significant Lift Performance

- Launch Vehicles provide hundreds of kilograms of excess performance yearly.
- Effective space exploration requires continued development and demonstration.
- This requires routine, low cost access to space.
- Opportunities for 6 to 12 secondary payloads per year.
- More than 30,000 pounds!
The Apollo 11 crew Neil Armstrong, Mike Collins, and Buzz Aldrin Liftoff occurred 38 years ago at 9:32 a.m. EDT, July 16, 1969.