Access to space for technology validation missions: Exploring the possibilities of suborbital flight

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Abstract—Space technology experiments and validation missions share a common dilemma with the aerospace community in general: the high cost of access to space. Whether the experiment is a so-called university cubesat, a technology experiment, or a NASA New Millennium Program (NMP) technology validation mission, the access to space approach must be scaled appropriately: a cubesat might fly as one of a number of cubesats that negotiate a flight on an experimental vehicle; a technology experiment might do the same; a NASA flight validation might partner with another NASA or Air Force experimental mission.

But are there other options, and what are the benefits of one approach over another? What are the limitations of one approach over another? How can one assess the viability for a particular experiment? How does one go about acquiring such a space access? What experiments originally considered for space-flight might be validated instead in a suborbital environment?

New vehicles, most notably unmanned aerial vehicles, are pushing existing capability to higher and higher altitudes and longer duration flights. Reliable suborbital flights and long-used balloon flights can now be applied to new, different payloads as the technology needs change over time.

So what are the similarities and differences between the space and suborbital flights? Where are these programs managed, and with what capabilities both existing (proven) and new?

This guide is written for the space experimenter seeking an understanding of the issues which will drive a large part of the design of a space experiment - the method of access to space.

Since this is, indeed, rocket science, this guide can only serve as a starting point for the reader. The range of suborbital capabilities is so broad - flights cover an altitude range from 3 km to 1400 km, the payload weight from 1 to 3600 kg, the flight time from 5 min to more than 100 days, and the cost from few thousand to tens of millions of dollars - that further research and data will be required. This paper can only point the way to the start of an assessment.

With the range of flight possibilities so broad (a dilemma of too many parameters and too many unknowns), two constraints are established to provide a reference for discussion:

1) earth science measurements are presented as an example of the range of space flight needs as they can apply to the suborbital regime.
2) a sample set of space technologies is considered in the suborbital regime.

With these constraints in place, a framework is established to compare and contrast these different suborbital options.

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1. INTRODUCTION

Sounding rockets and high-altitude balloons have long been used for NASA space and earth science experiments and measurements. In the earth science community, airborne flights have also been used extensively for both sensor prototype development and ground truth measurements for space missions. This paper sets aside the airborne capability for discussion at another time, and focuses on 3 other modes of suborbital flight: balloons, sounding rockets and the relatively new Unmanned Aerial Vehicles (UAVs).

The underlying purpose of this paper is to bring together information about this well-established suborbital community in juxtaposition with the space community's search for low-cost access to space, and to suggest that a re-introduction of the suborbital capabilities can open up options not considered before. This is an attempt to link two communities, Suborbital and Space, at a time when the cost of access to space and dwindling budgets are motivation enough to re-visit alternatives in the suborbital community. Nothing is new here except the paradigm - including suborbital capabilities in the same venue as space mission design.

Recent interest into this Suborbital-Space-interface paradigm has been boosted in part by developments in UAVs and the ever-increasing altitude capabilities of UAVs. The higher altitudes "push the envelope" of what has historically been characterized as suborbital and rather naturally introduces the question of what might be leveraged in this new suborbital regime.

Further, recent research into the so-called "Near Space" (ref to Airforce Article) seeks to understand that area above 100 km and below lower-altitude space missions. By its very nature, this Near Space investigation also compares and contrasts suborbital and orbital capabilities.

To illustrate this Suborbital-Space interface, Figure 1 presents a sampling of earth science measurement regimes. The right-hand side of the figure notes the part of the spectrum measurable at various altitudes, from the lower troposphere up to the thermosphere. In-situ measurements at these different altitudes are made by sensors flown in a variety of vehicles, noted on the left-hand side of the figure. The envelope that is being pushed by suborbital flight is at the 100 km altitude and greater.

Advantages of suborbital flights are very simply the significantly lower cost and simpler working environments. With that theme in mind (lower cost), the reader is presented a broad survey of balloon, sounding rocket and (newly emerging) UAV capability. References are provided, including websites, for each flight capability.

Finally, a set of sample technologies is presented as a test case for possible application in this suborbital environment.

Balloons

Modern scientific ballooning began in the late 1940's. Developments in the past twenty years have brought about significant increases in the reliability of scientific balloon vehicles and operations. Important discoveries in the atmospheric science, space science, and astronomy disciplines have recently been made using balloon-borne instruments.

Table 1 summarizes 3 categories of balloons: Conventional, Long Duration Balloon (LDB), and Ultra Long Duration Balloon (ULDB). The mission duration for each category as well as a first look at the mass, power, and data rate capabilities are presented. As compared to conventional space flight missions which are considered inexpensive at $100M, these suborbital missions if leveraged properly can provide significant flight opportunities (either in cost savings or in the number of experiments to be enabled) to the space experiment community.

Table 1 HERE

Sound rocketing...
For 40 years, the NASA Sounding Rocket Program has been one of the primary vehicles for space and earth science research. The program has provided data to support the scientific community, NASA’s orbital space programs, the Department of Defense, other Government agencies, and the international space community. See Table 2.

### UNMANNED AERIAL VEHICLES

NASA has sought to use UAVs in scientific and commercial applications, particularly to study the Earth’s environment with high-altitude long-endurance UAVs. These vehicles are relatively new and do not have the maturity of use as do the balloons and sounding rockets. The full potential of UAVs cannot be realized until an ability is demonstrated to operate safely and routinely within the existing air-traffic FAA management system.

NASA’s Dryden Flight Research Center, Edwards, California, has been conducting flight demonstrations of collision-avoidance systems necessary to achieve the “equivalent level of safety” of a piloted aircraft. The ability to sense and avoid conflict is a key step toward allowing UAVs to fly routinely and reliably in the national civil airspace.

Table 3 presents a representative list of current UAV capabilities. Note that the current altitudes are well under the 100 km altitude noted earlier in this paper - pushing upwards in altitude is the area of current development with these vehicles.

Table 3 is adapted from Herb Schlickenmaier’s presentation at the 2nd workshop of Utilization of Unmanned Aerospace Vehicles for Global Climate Change Research at Boulder, Colorado, 7 - 8 December, 2004 (http://uav.noaa.gov/uav_workshop/uav_workshop2/summary/index.htm). For smaller UAVs with total lifting weight less than 50 kg, flight height lower than 3 km and endurance shorter than 4 hr, information can be found at the website at http://www.aeroconcepts.com/UAVHome.html.

### TECHNOLOGY EXPERIMENTS FOR SPACE OR SUBORBITAL REGIME

Table 4 identifies a sample set of technologies that are currently of interest and in development in the space community, both at NASA and in the Air Force communities. Only a few parameters are presented which give form to the technology: mass, power, volume.

To be sure, many other parameters define the experiment, but this list is kept short to keep the comparison simple and to provide a first-order look at possible matches to suborbital launch capabilities. Table 5 compares these first-order experiment requirements to the general capabilities of each of the 3 suborbital vehicle types and finds many “YES” matches. Several configuration and operational constraints (deployment, volume, power) preclude suborbital flight for a few of the experiments, but the survey is not overwhelmingly “NO”.

### CONCLUSION

Using earth science measurement regimes as an example of “space” measurements which cross between suborbital and orbital space, the stage was set to consider what existing launch capabilities, suborbital in particular, might provide a platform for technology experiments. Technology experiments are cited in particular because of the high cost of access to space and the significant limiting factor that cost presents to the experimental development of space.
technology. Funding for science space flight missions accounts for the high cost of launch to space, but limited budgets for technology development can make the space access cost an extreme impediment.

Further, developments in UAV capability and Near Space naturally introduces the question of what might be leveraged in this suborbital regime.

Three suborbital options were considered: balloons, sounding rockets and UAVs. Flight capabilities for each option provided a comparison of one approach over another, which in turn were compared to a sample set of technology experiments. The comparison was simplistic (only mass, power and volume were compared) by design, with a complete analysis requiring a detailed set of parameters and operational scenarios to actually verify the experiment feasibility.

The reader is encouraged to consider the next level of assessment, and guided to consider options (sometimes called “descopes”) for the experiment. Suborbital altitudes and mission duration, for instance, are shorter than typical space mission experiments, but modifications to experiment goals could be the enabling alternative rather than the need for access to space – it can be easier to modify experiment goals to a more modest end than to keep a test requirement which continues to demand an overwhelmingly costly access to space.

REFERENCES

References and websites are provided below for balloon, sounding rocket and UAV capabilities.

Balloon References and Links

Kerzhanovich, V.V., et al., Breakthrough in Mars balloon technology, COSPAR, 2002.


http://heawww.gsfc.nasa.gov/docs/balloon/balloon_top.html (NASA Scientific Ballooning homepage)
http://www.nsfb.nasa.gov/index.html (NSBF homepage)
http://www.ccss.washington.edu/Space/SpaceExp/Balloon/
http://www.isas.ac.jp/e/enterp/ball/index.shtml
http://www.centennialofflight.gov/essay/Lighter_than_air/early_scientific_balloons/LTA7.htm
http://www.gaerospace.com/projects/StratoCon/strato_con_presentations.html (Trajectory control)
http://www.gaerospace.com/projects/ULDBStratoSail/ULDB_balloon_trajectory.html (Trajectory control)

Other balloon URLs:

Naval Academy Balloons Test flight of Amateur Radio Operators
Air Force Academy The Small Satellite team builds and integrates instruments for characterizing the behavior of upper atmosphere plasma and near-earth plasmas. Various platforms are possible for these instruments, the primary of which is the USAFA family of FalconSat spacecraft. Other possible platforms used to conduct investigations include high-altitude balloons, rocket launches, Space Shuttle, and Space Station deployed missions.
Danish Space Research Institute The High Energy Focussing Telescope (HEFT) mission is a balloon experiment, aimed at performing imaging
and focusing at X-ray energies between 20 and 100 KeV. The HEFT project is a co-operation between the California Institute of Technology, Columbia University and DSRI.

NSBF - National Scientific Balloon Facility

Index of /docs/balloon - NASA Long Duration Balloons
http://heawww.gsfc.nasa.gov/docs/balloon/

OTHER BALLOON LINKS - NASA Long Duration Balloons
http://heawww.gsfc.nasa.gov/docs/balloon/other_links.html

PROSPECTS FOR 100 DAY BALLOON FLIGHTS - NASA/Goddard
http://heawww.gsfc.nasa.gov/docs/balloon/works hop96/

Planetary Aerovehicles (Balloons and Ballutes) - JPL/NASA
http://www.jpl.nasa.gov/adv_tech/balloons/summ ary.htm

Swedish Space Corporation
http://www.ssc.se/default.asp?groupid=20046161 43041665

Missions:
http://cmb.phys.cwru.edu/boomerang/
http://www.wff.nasa.gov/~code820/missions/booomerang.htm
http://atic.phys.lsu.edu/aticweb/
http://www.wff.nasa.gov/~code820/pdf/ATIC.pdf
http://tiger.gsfc.nasa.gov/
http://www.wff.nasa.gov/~code820/missions/tiger.htm
http://cosray2.wustl.edu/tiger/
http://tracer.uchicago.edu/
http://www.wff.nasa.gov/~code820/pdf/TRACER.pdf
http://nightglow.gsfc.nasa.gov/ng.html
http://cosmicray.umd.edu/cream/cream.html
http://www.wff.nasa.gov/~code820/missions/cream.htm
http://www.wff.nasa.gov/~code820/pdf/CREAM.pdf
http://heawww.gsfc.nasa.gov/docs/gamcosray/hec er/BESS/BESS.html
http://www.wff.nasa.gov/~code820/missions/bess.htm
http://tower.nsf.na.gov/
http://www.wff.nasa.gov/~code820/pdf/BLAST.pdf
http://www.wff.nasa.gov/~code820/pdf/DSTB.pdf
http://www.wff.nasa.gov/~code820/pdf/NSBF_S WEDEN_OPS_ESRANGE.pdf
http://heawww.gsfc.nasa.gov/docs/balloon/New GRIS_hom epage/gris.html
http://cosmology.berkeley.edu/group/cmb/index.htm
http://hurlbut.jhuapl.edu/FlareGenesis/
http://topweb.gsfc.nasa.gov/
http://www.gaerospace.com/index.html

Sounding Rocket References and Links
http://rsience.gsfc.nasa.gov/
http://www.univ-perp.fr/fuseurop/a/nasa.htm
(NASA Sounding Rockets Launch Log)
http://www.univ-perp.fr/fuseurop/a/nasa.htm
http://www.wff.nasa.gov/~code810/srpo.php
http://www.ssc.navy.mil/mission/soundingrockets.htm#rocketsa
http://www.ssc.se/default.asp?groupid=20046161 43029656
http://www.astro.psu.edu/xray/rockets/
http://www.nsroc.com/front/mainmenu/mmframe.htm
http://www.nsroc.com/front/what/whframe.html
(p.31 Fig 3.2.1.1)
http://tycphysics.org/IPC4%20group_projects/Group%201/srocks.htm
http://www.pfrr.alaska.edu/ Poker Flat Research Range
http://www.ericweisstein.com/encyclopedias/rocket s/ Rocketry history, Univ of Verigina sounding rocket
DRAFT
http://esapub.esrin.esa.it/microgra/micrv10n2/seiv10n2.htm ESA sounding rocket page
http://www.isro.org/rs.htm Indian sounding rocket
http://www.gsoc.dlr.de/moraba/sounding_rockets.htm (Air Force Sounding Rocket Program)
http://www.bristol.ca/BlackBrant.html
http://www.ssg.sr.unh.edu/index.html?tof/Rockets/ UNH missions for aurora and ionosphere
http://www.scsc.navy.mil/mission/soundingrockets.htm (for each rocket, Fig 3.3)
http://rscience.gsfc.nasa.gov/index.html
http://www.pha.jhu.edu/groups/rocket/ (JHU Sounding Rocket Home Page)
http://www.hao.ucar.edu/public/research/svosa/rocket/rocket_home.html (NCAR/CU Rocket Home Page)
http://www.astro.psu.edu/xray/rockets/ (Sounding Rockets at Penn State)
http://sprg.ssl.berkeley.edu/rockets/ (UCB Sounding Rocket Programs)
http://serts.gsfc.nasa.gov/ (SERTS Solar Sounding Rocket Program)
http://eunis.gsfc.nasa.gov/ (EUNIS, A rocket experiment to study solar corona)

http://bbsnews.net/bw2003-03-24a.html

BIографИES

Linda Herrell has a BA in math/computer science/languages (1972, University of Texas) and a MSME in fluids and heat transfer (1983, City College of New York). In addition to analytical work in computer science and thermal and structural analysis, she has worked as both a payload (instrument) and spacecraft systems engineer on Earth-orbiting (Hubble Space Telescope, Earth Observing System (EOS)) and deep space (Cassini) NASA missions, and as Proposal Manager for several NASA science missions. She currently serves as the Program Architect for NASA’s New Millennium Program.

Xioayan Zhou ........

ACKNOWLEDGEMENT

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<table>
<thead>
<tr>
<th>Mission Class</th>
<th>Altitude (km)</th>
<th>Speed Mission Name</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helios RPV*</td>
<td>15 – 30 km</td>
<td>30 KIAS** 5 crew</td>
<td></td>
</tr>
<tr>
<td></td>
<td>14 days to 6 months</td>
<td></td>
<td>HALE</td>
</tr>
<tr>
<td></td>
<td>100 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global Hawk Autonomous</td>
<td>12 – 18 km</td>
<td>250 KIAS (large crew)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>36 hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1000 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proteus Piloted Surrogate</td>
<td>12 – 18 km</td>
<td>200 KIAS 2+ crew</td>
<td></td>
</tr>
<tr>
<td></td>
<td>24 hours</td>
<td></td>
<td>HALE</td>
</tr>
<tr>
<td></td>
<td>1000 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predator B/Altair RPV</td>
<td>12 – 16 km</td>
<td>170 KIAS 2+ crew</td>
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<tr>
<td></td>
<td>32 hours</td>
<td></td>
<td>MALE</td>
</tr>
<tr>
<td></td>
<td>400 kg</td>
<td></td>
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</tr>
<tr>
<td>Aerosonde-Class Autonomous RPV</td>
<td>0.06 – 6 km</td>
<td>35 KIAS 2-3 crew</td>
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<td></td>
<td>20 – 30 hours</td>
<td></td>
<td>LALE</td>
</tr>
<tr>
<td></td>
<td>2 – 5 kg</td>
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</table>

* Remotely Piloted Vehicle; **Knots Indicated AirSpeed
NASA Sounding Rocket Performance

The diagram shows the performance characteristics of various sounding rockets, with axes for altitude (in kilometers) on the y-axis and payload weight (in pounds) on the x-axis. Curves are labeled for different rocket models.
<table>
<thead>
<tr>
<th>Capability</th>
<th>Conventional</th>
<th>LDB</th>
<th>ULDB</th>
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</thead>
<tbody>
<tr>
<td>Instrument Volume</td>
<td>55 m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>55 m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>55 m&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Instrument Weight</td>
<td>2500 kg</td>
<td>1000-1600 kg</td>
<td>1000 kg</td>
</tr>
<tr>
<td>Instrument Power</td>
<td>PI provided</td>
<td>PI provided</td>
<td>PI provided</td>
</tr>
<tr>
<td>Up Link/Down Link</td>
<td>300 bps/1 mbps</td>
<td>300 bps/1 mbps</td>
<td>300 bps/1 mbps</td>
</tr>
<tr>
<td>Payload Recovery</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Mission Duration</td>
<td>1 to 2 days</td>
<td>8 to 21 days</td>
<td>60 to 100 days</td>
</tr>
<tr>
<td>Mission Cost</td>
<td>&lt;$500K</td>
<td>$1M-2M</td>
<td>$2-3M</td>
</tr>
</tbody>
</table>

Table 1 Ballooning Mission Capabilities
## Flight Experiments
- Attitude control sensor
- Solar array
- Optical comm
- Telescope
- Low-power avionics
- Thermal cooler
- Serial bus electronics
- Autonomous operations

<table>
<thead>
<tr>
<th></th>
<th>Balloon</th>
<th>Sounding</th>
<th>Rocket</th>
<th>UAV</th>
</tr>
</thead>
<tbody>
<tr>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>YES</td>
<td>MAYBE</td>
<td>MAYBE</td>
<td>deployment</td>
<td></td>
</tr>
<tr>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>volume</td>
<td></td>
</tr>
<tr>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>volume, power</td>
<td></td>
</tr>
<tr>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
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</tr>
<tr>
<td>YES</td>
<td>MAYBE</td>
<td>NO</td>
<td>volume</td>
<td></td>
</tr>
<tr>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Experiment Type</td>
<td>Mass (kg)</td>
<td>Power (W, peak)</td>
<td>Volume (cm)</td>
<td></td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-----------</td>
<td>-----------------</td>
<td>---------------------</td>
<td></td>
</tr>
<tr>
<td>Attitude control sensor</td>
<td>4</td>
<td>40</td>
<td>16 cm sphere</td>
<td></td>
</tr>
<tr>
<td>Solar array</td>
<td>60</td>
<td>40 (electronics)</td>
<td>0.75x10^6 (stowed)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4x10^6 (deployed)</td>
<td></td>
</tr>
<tr>
<td>Optical comm</td>
<td>30</td>
<td>50</td>
<td>0.5x10^6</td>
<td></td>
</tr>
<tr>
<td>Telescope</td>
<td>560</td>
<td>400</td>
<td>3.1 X 3.5 X 2.7 m</td>
<td></td>
</tr>
<tr>
<td>Low-power avionics</td>
<td>2</td>
<td>1.5</td>
<td>18 X 18 X 8</td>
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</tr>
<tr>
<td>Thermal cooler</td>
<td>430</td>
<td>85</td>
<td>115 x 115 x 225;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>plus electronics</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>70 x 50 x 30</td>
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</tr>
<tr>
<td>Serial bus electronics</td>
<td>3</td>
<td>3</td>
<td>10 x 10 x 15</td>
<td></td>
</tr>
<tr>
<td>Autonomous operations</td>
<td></td>
<td></td>
<td><strong>NA - software resides on a host computer</strong></td>
<td></td>
</tr>
<tr>
<td>NASA Vehicle Numbers</td>
<td>Type of Sponsoring Organization</td>
<td></td>
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<tr>
<td>----------------------</td>
<td>-------------------------------------------------</td>
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<tr>
<td>(12) Special/Development Test Vehicles</td>
<td>A Government Agency other than D or N</td>
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<tr>
<td>(15) Super Arcas</td>
<td>C Industrial Corporation</td>
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</tr>
<tr>
<td>(21) Black Brant V</td>
<td>D Department of Defense</td>
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<td></td>
</tr>
<tr>
<td>(27) Nike Black Brant</td>
<td>G Goddard Space Flight Center</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(29) Terrier-Malemute</td>
<td>I International</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(30) Orion</td>
<td>N Other NASA Centers</td>
<td></td>
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<tr>
<td>(31) Nike-Orion</td>
<td>U College or University</td>
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<td></td>
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<tr>
<td>(33) Taurus Orion</td>
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<tr>
<td>(35) Black Brant X</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>(36) Black Brant LX (Terrier Black Brant VC)</td>
<td>E Geospace Sciences</td>
<td></td>
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<tr>
<td>(37) Viper Dart</td>
<td></td>
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<td></td>
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<tr>
<td>(40) Black Brant XI</td>
<td></td>
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<tr>
<td>(41) Black Brant XII</td>
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<tr>
<td>(42) Terrier Orion</td>
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<td></td>
<td><strong>Type of Experiment</strong></td>
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<td></td>
<td>E Geospace Sciences</td>
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<td></td>
<td>G UV/Optical Astrophysics</td>
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Figure 1 Earth Science Measurements in Both the Suborbital and Space Regimes

Figure 2 NASA Balloon Flights Per Fiscal Year 1990-2003 (Adopted from Report of the Scientific Roadmap Team, 2004)

Table 1 Ballooning Mission Capabilities

Figure 3 Balloon Load and Volume Capabilities with Altitude

Table 2 Sounding Rocket Vehicle, Agency and Experiment Identification

Figure 4 Sounding Rocket Performance

Table 3 A Sample of Current Science UAV Capabilities

Table 4 Sample Space Technology Experiments

Table 5 Possible Suborbital Flights for Space Technology Experiments
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