The Large Benefits of Small Satellite Missions

Submitted by:
Daniel N. Baker [1], S. Pete Worden [2], S. Buchman [3], Robert Byer [3], Dan DeBra [3], John Mester [3]

[1]*Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, Colorado*
[2]*NASA Ames Research Center, Moffett Field, California*
[3]*Hansen Experimental Physics Laboratory, Stanford University, Stanford, California*

Abstract

Small spacecraft missions play a key and compelling role in space-based scientific and engineering programs. They have been responsible for greatly reducing the time to obtain science and technology results. Small spacecraft missions tend to be flexible and can thereby be extremely responsive to new opportunities or technological needs. The shorter development times for smaller missions can reduce overall costs and can thus provide welcome budgetary options for highly constrained space programs. In many cases, we would contend that 80% (or more) of program goals can be achieved for 20% of the cost using small spacecraft solutions.

In its 2000 assessment study (Space Studies Board, 2000), the National Academy of Sciences Space Studies Board said:

"What stands out prominently is the professional vitality and community involvement small missions can offer. Researchers who might have waited a lifetime to analyze data are stimulated, freshened, and sharpened when given the opportunity to conduct high-priority, high-quality science in a shorter period. In turn, these programs afford undergraduate and graduate students opportunities to participate in and experience the complex and organic nature of science, from proposal to development, to analysis, to publication."

Based upon the paper:
Baker, D. N., and S. P. Worden, **The Large Benefits of Small-Satellite Missions**,
Eos Trans. AGU, 89(33), doi:10.1029/2008EO330001, (2008).
http://www.agu.org/pubs/crossref/2008/2008EO330001.shtml

The Large Benefits of Small Satellite Missions

Daniel N. Baker and S. Pete Worden

Historical Context

America's extended and intensive exploration of space began with the launch of the first Explorer satellite in 1958. Today, exactly 50 years later, NASA has built and launched over 70 Explorer spacecraft. This represents a continuous and important element of the nation's space program. Traditionally, Explorers were defined as spacecraft with capabilities intermediate between those of sounding rockets and orbiting observatories. They were reasonably inexpensive, could be developed quickly, and provided frequent opportunities for space experiments. Explorers have, for example, provided:

- The primary tool for the detailed study of particular regions of space and of specific physical phenomena
- A cost-effective method for addressing key scientific problems
- A means for the flight demonstration of new spacecraft and instrument design concepts and hardware
- An opportunity to develop scientific research, engineering and project management capabilities
- The capability for a quick response to targets of opportunity
- An opportunity for international cooperative missions.

Explorers and similar space programs cannot play many of these roles when they become ambitious, scientifically or technologically complex projects requiring long development times and large budgets. These roles can be maintained only when scientists have frequent access to new small spaceflight missions [*Space Science Board*, 1984]. The scientific community is beginning to once again realize the value of small spaceflight missions and has recently recommended the restoration of small mission funding [*National Research Council*, 2006].

In reality, the U.S. has a broad spectrum of small, relatively unpublicized scientific space programs. In the course of supporting first-rate scientific research, small-scale space programs support shorter-term projects that are essential to advancing science, technology, and student training. Because the opportunity to participate in the development of space flight instrumentation is usually limited in the large programs, the smaller programs provide important "hands on" experience with scientific hardware for scientists and students. Moreover, the frequency of launches of large NASA and DoD satellites has been relatively low in recent years for a variety of programmatic reasons. Combined with the long development time required for large projects, this fact prevents introduction of the latest scientific technology into space via large-scale missions. In contrast, smaller missions permit specialized, highly focused scientific investigations that often apply the most modern technological innovations.

The NASA Small Explorer Program

To exploit the many advantages of small space projects, NASA in the late 1980s initiated the Small Explorer Program, or SMEX. SMEX was intended to support disciplines traditionally served by NASA's long-standing Explorer Program. This included astrophysics, space physics and upper atmospheric science (see Fig. 1). A central feature of SMEX was that one principal investigator (PI) proposed an entire mission and its experiments. The idea was to have the PI firmly in charge of the entire mission, with the instruments being built by the PI and his or her team of co-investigators. The team usually included scientists at a variety of institutions who had worked together closely. The result was an efficient, highly cohesive research effort [*Baker et al.* 1991]. An important subsidiary goal of the SMEX program was to pass on to a new generation the precious knowledge of spacecraft design accrued by the experienced generation of engineers and scientists at NASA.

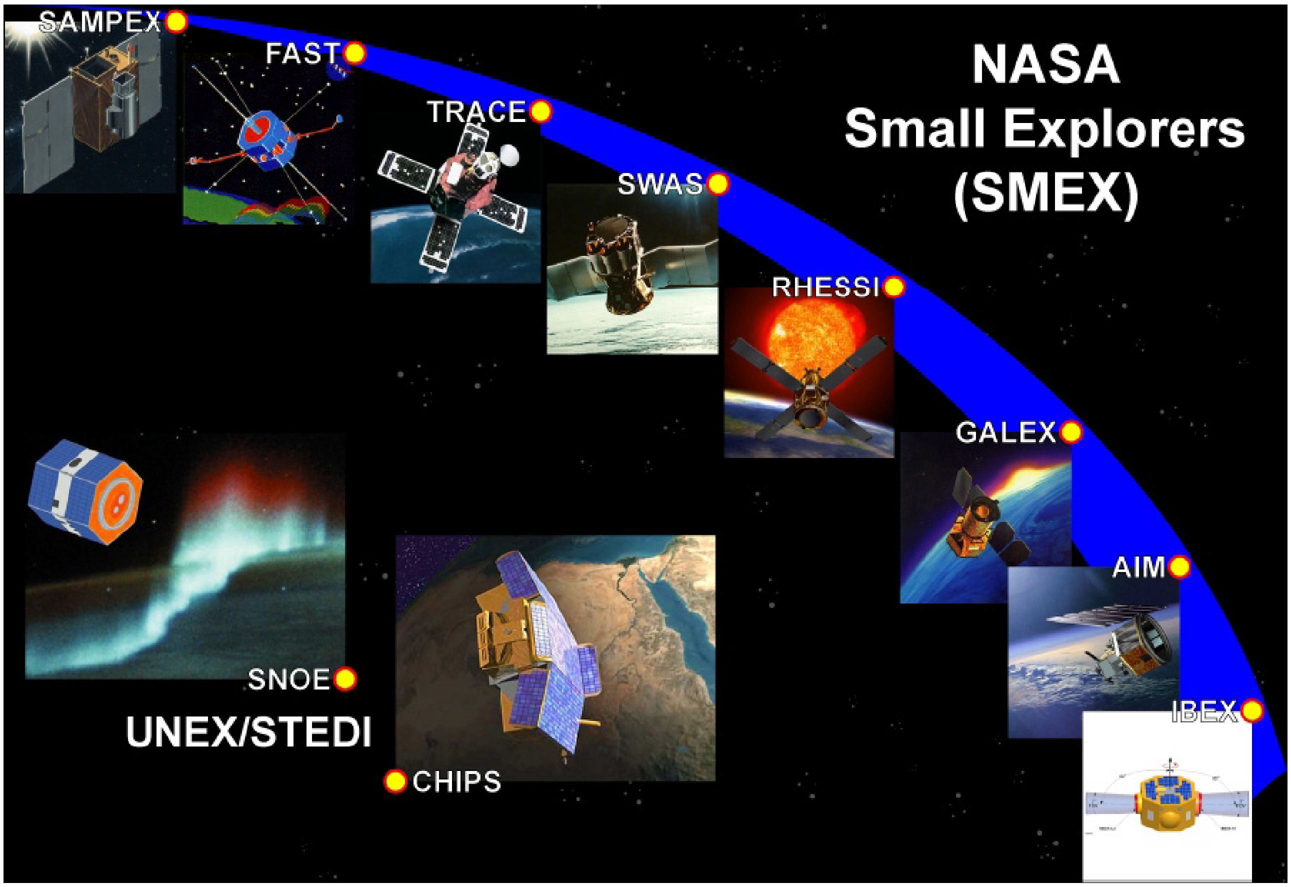

Fig. 1. The NASA Small Explorer and STEDI/UNEX missions that have flown or are under development (IBEX is in the latter category). SAMPEX was launched in July 1992 and AIM launched in April 2007. At an approximate launch frequency of one mission every two years, this is about half the average launch rate that was the original goal for the SMEX program.

Perhaps the most important promise of the Small Explorer Program – to provide frequent access to space for outstanding science missions – could be fulfilled only by maintaining a steady schedule of follow-on SMEX missions [*NASA Advisory Council*, 1986]. Launching one mission a year was an important goal that the SMEX project could meet given adequate funding and personnel. Unfortunately, this launch frequency has not happened, much to the detriment of science [*Baker*, 2006].

The STEDI and UNEX Programs

A small satellite program was managed for NASA by the Universities Space Research Association (USRA) under the Student Explorers Demonstration Initiative (STEDI). The goal of STEDI was to show that small relevant research satellite missions could be developed at very low cost and with high educational benefit by giving students a large involvement. Three missions (TERRIERS, CATSAT, and SNOE) were selected, but only one mission (SNOE) was a full success. CATSAT and TERRIERS achieved several education and training goals despite technical problems.

SNOE was developed and operated through its primary mission for under $5 million (excluding only launch vehicle costs). The development team consisted primarily of students working closely with a small number of experienced professionals at the University of Colorado's Laboratory for Atmospheric and Space Physics (LASP). Students had significant responsibilities in all areas of the mission. In carrying out the STEDI program [*Barth et al.*, 2002], USRA set an important tone for how to manage small missions: Appropriate levels and numbers of reviews were employed and key types of help were provided to the STEDI teams, only as needed.

The NASA University Explorer (UNEX) program has generally been regarded as the successor to STEDI. The pressures of funding requirements for large missions and the lack of suitable access to space for small missions have resulted in ending the UNEX effort. It is regrettable that this program and the opportunities afforded by the legacy of the Student Explorers concept are not available to university scientists for research and educational opportunities. At least as troublesome is the fact that the stresses that are continuing to occur in the sounding rocket and balloon programs suggest the suborbital program also is very limited as an access to space and as a "hands-on" training ground for young scientists and engineers.

Other Small Satellite Programs in the United States

Despite the demise of formalized small and student-oriented space opportunities, considerable progress is still being made – often in partnership with private sector space endeavors. NASA Ames Research Center “GENESAT” weighs about 20kg and costs about $6M to develop. It flew as an auxiliary payload on an Air Force mission in 2006 [*NASA Press Release*, 2006]. The payload, “GENEBOX” weighs about 9kg and is designed to conduct in-flight genomic analysis of living organisms and tissues. It was first flown in July 2006 as a payload on the privately funded Bigelow Aerospace Genesis-1 spacecraft. Subsequent GENESAT missions could revolutionize our ability to conduct needed biological scientific and exploration-related experiments.

The CubeSat program has been a successful effort to involve students in spacecraft development and operations. The program's mission description is found at CubeSat's homepage http://cubesat.atl.calpoly.edu. With over 60 universities and high schools participating in the CubeSat program, the educational benefits are tremendous. Students, through hands-on work, develop the skills and experience needed to succeed in the aerospace industry. The CubeSat program also benefits private firms and the government by providing a low-cost way of flying payloads in space. All of this occurs while creating important educational opportunities for future leaders of industry.

Small Spacecraft Requirement: Access to Space

A key to a successful, viable small satellite program is low-cost, frequent access to space. Such access – or rather the lack of such access – is the single biggest impediment to reestablishing a vigorous small scientific satellite program [*Space Studies Board*, 2000]. However, some new capabilities are presenting themselves that offer hope for much improved launch options.

For the U.S. Air Force's Orbital/Suborbital Program (OSP), Orbital Sciences Corp. has developed the low-cost, four-stage Space Launch Vehicle (SLV) Minotaur rocket using a combination of U.S. government-supplied Minuteman II motors and proven Orbital space launch technologies. Another small launch vehicle under development is the DARPA “QuickReach” booster concept. This vehicle is being designed to launch from an unmodified C-17A or other large cargo airplane. The goal is to deliver 450 kg to low-Earth orbit for less than $5 million. QuickReach is being developed by AirLaunch LLC for DARPA and U.S. Air Force and a new agreement has just been signed as well with NASA Ames Research Center [*Space News*, 2006].

Other low-cost access to space opportunities may be offered by the Space Exploration Technology (SpaceX) Falcon launch vehicle family (information can be found at http://www.spacex.com). This new rocket would deliver 570 kg to LEO (on the Falcon 1 vehicle) for an estimated price of $6.7M. Much larger launch capabilities would be achieved by bigger vehicles in the Falcon/SpaceX family, but for very affordable prices. Alternate approaches for low-cost space access are flight as a secondary payload. Long used by European and Russian launch providers, a secondary payload of up to 200kg can be launched for as little as a few million dollars.

Scientific Payoffs

Space experts and scientists have often belittled the contribution of small, low-cost space missions. Furthermore, most small missions to date have been launched into low Earth orbit having limited relevance for space exploration and planetary science interests. New technology and capabilities are changing this. Low cost, lightweight optical systems will enable both Earth observation and significant astronomy to be done from small satellites. Optical systems greater than 1 meter in diameter can weigh as little as 10 kilograms manufactured from new, lightweight materials such as silicon carbide with nano-laminate coatings. Entire medium-class space telescope systems for Earth or space science can be hosted on satellite systems with a total mass less than 200 kg.

A substantial portion of NASA's efforts in the coming years will be devoted to the Vision for Space Exploration. While the focus of initial work will be on human exploration many opportunities exist for scientific return from this initiative. Traditionally, robotic deep space missions to the moon or elsewhere have cost a good part of $1B. Small missions can change this paradigm. Lightweight propulsion technology – developed under U.S. DoD auspices for mission defense and other purposes – can provide a small satellite with significant ability to maneuver and even land on solar system bodies. Similarly, solar-electric propulsion can make the entire inner solar system accessible to small, low-cost missions. Advances in micro- and nano-electronics and sensors now make possible significant scientific instruments weighing a few kilograms or less.

NASA Ames Research Center and NASA Goddard Space Flight Center recently proposed a series of small lunar landers. Each lander would weigh about 60 kilograms including landing fuel and 10 kg or more of useful payload. The landers are small enough so that they could be launched on the Space-X Falcon I booster. Total mission cost would be less than $100M for the first mission. However, if a series of missions were planned – a key requirement for truly affordable space missions – unit mission costs could be $50M or less. Significant scientific and exploration related possibilities emerge from such an approach.

References

Baker, D.N., G. Chin, and R.F. Pfaff, Jr., NASA's Small Explorer Program, *Physics Today*, 44, 44, 1991.

Baker, D.N., Exploration without Explorers?, *Space News*, p. 19, 24 April 2006.

Barth, C.A., D.N. Baker, K.D. Mankoff, and S.M. Bailey, Magnetospheric control of the energy input into the thermosphere, *Geophys. Res. Lett*., 29, 13, doi:10.1029/2001 GLO14362, 2002.

NASA Ames Research Center, Press Release, Jul 17, 2006.

National Research Council, An Assessment of Balance in NASA's Science Programs, National Academies Press, 2006.

Space and Earth Science Advisory Committee, NASA Advisory Council, The Crisis in Space and Earth Science: A Time for a New Commitment, NASA, Washington, DC, November 1986.

Space News, p. 7, 7 August 2006.

Space Science Board, A Strategy for the Explorer Program for Solar and Space Physics, National Academy Press, Washington, DC, 1984.

Space Studies Board, Assessment of Mission size trade-offs for NASA's Earth and Space Science Missions, National Academy Press, Washington, DC, 2000.

Author Information

Daniel.N. Baker, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder; email: daniel.baker@lasp.colorado.edu; S.Pete Worden, NASA Ames Research Center and Astronomy, Optical Sciences, and Planetary Sciences, University of Arizona, Tucson, AZ.