

The DARPA / USAF Falcon Program Small Launch Vehicles

David J. Weeks
National Aeronautics and Space Administration
Mail Code VP32
Marshall Space Flight Center, AL 35812; (256) 544-3309
dave.weeks@nasa.gov

Dr. Steven H. Walker
Defense Advanced Research Projects Agency
3701 North Fairfax Drive, Arlington, VA 22206; (703) 696-2377
steven.walker@darpa.mil

Tim L. Thompson
Booz | Allen | Hamilton
121 South Tejon Street Suite 900, Colorado Springs, CO 80903; (719) 387-3823
Thompson_tim@bah.com

Robert L. Sackheim
Independent Consultant
134 Lansdowne Drive, Madison, AL 35758; (256) 464-3939
babette@knology.net

John R. London III
National Aeronautics and Space Administration
Mail Code DA01
Marshall Space Flight Center, AL 35812; (256) 544-1914
john.r.london@nasa.gov

ABSTRACT: Earlier in this decade, the U.S. Air Force Space Command and the Defense Advanced Research Projects Agency (DARPA), in recognizing the need for low-cost responsive small launch vehicles, decided to partner in addressing this national shortcoming. Later, the National Aeronautics and Space Administration (NASA) joined in supporting this effort, dubbed the Falcon Program. The objectives of the Small Launch Vehicle (SLV) element of the DARPA / USAF Falcon Program include the development of a low-cost small launch vehicle(s) that demonstrates responsive launch and has the potential for achieving a per mission cost of less than \$5M when based on 20 launches per year for 10 years. This vehicle class can lift 1000 to 2000 lbm payloads to a reference low earth orbit. Responsive operations include launching the rocket within 48 hours of call up. A history of the program and the current status will be discussed with an emphasis on the potential impact on small satellites.

INTRODUCTION

The high cost of space access has broad negative impacts on the overall U.S. space program. Current interface processes and delays drive up total satellite costs. Flyaway costs using U.S. launches have resulted in significant loss of the worldwide launch market share over the past twenty years. Space access cost has inhibited the development of new space initiatives in civil, scientific, military, commercial, university and research areas. The high cost of launching has prevented many new innovative

small low-cost satellites from ever being built. Growth in the U.S. aerospace industry has been stifled with a diminishing or at best, a flat low level of annual launches. This has severely reduced opportunities for engineering jobs and hands on flight hardware experience. As aerospace engineers who began work in the 1950s, 1960s and 1970s are rapidly retiring coupled with the shrinking number of U.S. launches, younger aerospace engineers and engineering managers have fewer well-seasoned engineers to draw from in making crucial decisions as they design the launch vehicles of tomorrow.

Because there are fewer aerospace engineering jobs available, universities have witnessed a significant decline in incoming aerospace engineering student classes. A U.S. small launch vehicle (SLV) with a fly away cost (including launch vehicle, range costs, consumables, payload integration and limited mission assurance activities) of \$US 5M to \$US 10M could have profound impact on the current approach to small satellites and small launch vehicles. Such a launcher could invigorate university aerospace engineering programs and provide opportunities for increased hands-on flight hardware experience for aerospace engineers as well as provide new jobs in the aerospace sector of industry. It could also help the U.S. to regain lost share in the small satellite and small launch vehicle markets.

BRIEF HISTORY OF THE FALCON PROGRAM

In May of 2003, DARPA released a Phase 1 solicitation for concept designs of a low-cost, responsive SLV. Twenty-four proposals were received and nine study contracts with a six-month period of performance were awarded. The study contractors were AirLaunch LLC, Andrews Space, Exquadrum, KT Engineering, Lockheed Martin (Michoud), Microcosm, Orbital Science, Schafer and Space Exploration Technologies (SpaceX). Dr. Steven Walker, Deputy Director of DARPA's Tactical Technology Office (TTO), manages the Falcon Program. His deputy program manager is Lt. Col. John Anttonen in TTO.

In May of 2004, DARPA released a solicitation for Phase 2 SLV detailed vehicle design, development, test and flight. From the received 14 proposals, four were funded in September of that year: AirLaunch LLC, Lockheed Martin (Michoud), Microcosm, and SpaceX. A decision gate was inserted at the preliminary design review after ten months with program funding allowing AirLaunch LLC and SpaceX to continue. The SpaceX situation was unique in that the company was well past a preliminary design with a fairly mature design and much of the hardware already built. Instead of funding launch vehicle development from SpaceX, DARPA funded a demonstration launch of a Government payload from the Reagan Test Site in the Republic of the Marshall Islands. It is a coincidence that the SpaceX launch vehicle (Falcon 1) shares the name of the DARPA managed Falcon program.

AirLaunch LLC is proceeding toward a critical design decision gate in the fall of 2006. The AirLaunch QuickReach small launch vehicle is to be launched from an unmodified C-17 aircraft. QuickReach will have a payload capacity of 1300 lbm to LEO (100 nmi circular at 28.5 deg eastward

Weeks

inclination). AirLaunch has conducted several second stage propulsion tests and has made three QuickReach mass simulator drops from a C-17. In the upcoming months, they are scheduled to conduct two full second stage vertical full-duration static firings and to complete a second stage CDR by the end of the calendar year. AirLaunch is expected to perform an orbital launch of QuickReach in 2008.

This first generation SpaceX SLV dubbed the Falcon 1 has an advertised payload capability to low earth orbit (LEO) of 570 kg (1254 lbm) at a price of \$6.7 M, which includes range costs and basic payload integration. Though yet to see its first fully successful flight, SpaceX has agreements in place for a total of ten launches from the commercial and government communities.

SMALL SATELLITE STUDY GENESIS

In August 2005, DARPA system engineering and technical assistance (SETA) contractor Booz Allen Hamilton (BAH) negotiated contracts with AeroAstro Corp and Commercial Space Technologies Ltd (CST) to study the impact that the introduction of a responsive low-cost small launch vehicle would have on future small satellite development and on the U.S. share of the worldwide launch market. Mr. Tim Thompson of BAH served as the study manager. AeroAstro was to focus on the domestic market while CST focused primarily on the international market. For purposes of the studies, small satellites were defined as having a mass of no more than 700 kg (1543.2 lbm). This class of satellites was subdivided into three groups: (1) < 100 kg (220.5 lbm); (2) 100 – 300 kg (220.5 – 661.4 lbm); and (3) 300 – 700 kg (661.4 – 1543.2 lbm). A worldwide distribution of small satellites by these mass subdivisions is shown in Figure 1.

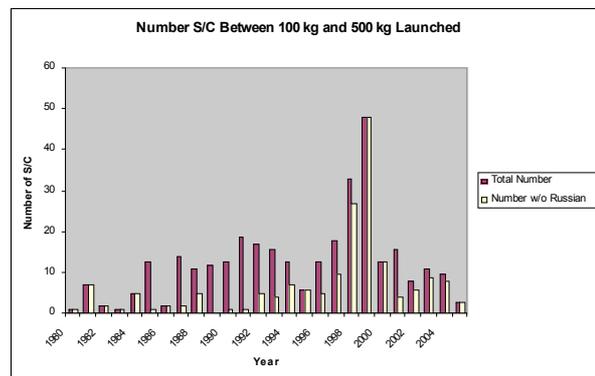


Figure 1. Launched Small Sats Mass Distribution

One observes that with the exception of the communications constellations (Iridium, Orbcomm and Globalstar systems) launched in 1997-99, the launch rate for small satellites has been fairly flat over the past 20 years.

Figure 2 indicates the origin of small satellite launches over the past 20 years, showing again that with the exception of the communication constellations in the late 1990s that the U.S. share is fairly small. In the early years of this period, the Former Soviet Union (FSU) dominated small satellite launches.

As shown in Figure 3, the Government is the primary driver of overall worldwide launches. Though the first commercial launch occurred in 1962, the significance in numbers of commercial launches is growing.

The hypothesis is that as low-cost responsive U.S. SLVs are developed and become increasingly available, the small satellite launch rate will increase which will give impetus to increased SLV production rates which in turn will increase further SLV production and further drive down SLV costs. As this cycle continues, at some point the 'flat launch market' will experience a fairly significant increase, aided in large part by a 'rack and stack' launch vehicle approach likely to influence all classes of launch vehicles with resulting lower costs. This cycle is illustrated in Figure 4.

- Launch vehicle
- Launch range and tracking/telemetry
- Mission assurance
- Satellite integration with launch vehicle
- On-orbit checkout of satellite
- On-orbit satellite operations
- Satellite disposal

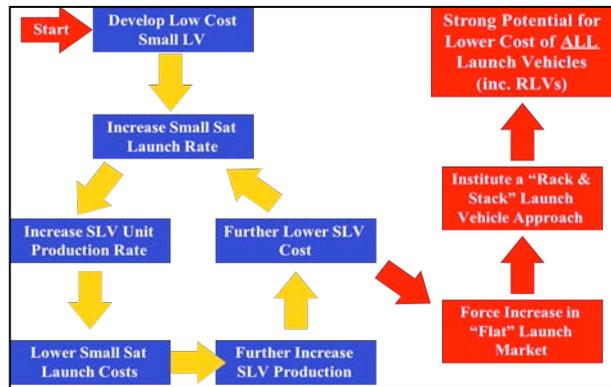


Figure 4. Compound Benefits of Stimulating the Small Satellite / Small Launch Vehicle Market

As SLVs become less expensive (\$5M to \$10M fly away cost) and waits for rides become shorter, the pervading approach to small satellite development will change. Currently, many small satellites in storage or on the drawing board are unlikely to fly due to cost imbalances between spacecraft and ride to orbit. Low-cost rides will allow for less expensive satellites designed for shorter life on-orbit (< three years), which should require less radiation hardening, and protection from other space environmental effects. In many cases, this will allow for the satellite technology to be updated and flown more frequently. Two to five million dollar satellites destined for a \$25M or greater ride to space are difficult to insure as well as pass upper management's reasonableness test. Flying as a secondary payload carries a set of challenges and baggage driven by the primary payload and the launch vehicle. While some are willing to accommodate the compromises often associated with secondary payloads, for many such a route means delays (or rush ups) in schedule, adjusting to changing interfaces or volume/mass allocation, compromise of science objectives, and sometimes loss of ride completely.

Figure 5 illustrates the mission cost driver of the small launch vehicle. It shows a government \$50M mission using the fly away cost of the lowest cost operational SLV today, which is about 60 percent of the mission cost. Thus the best thing that can happen for the small satellite mission is to significantly reduce the cost of the small launch vehicle. The illustration assumes a \$10M Spacecraft, \$30M launch vehicle with mission assurance, \$2M integration, \$2M range/telemetry, \$1M on-orbit checkout and \$5M on-orbit operations.

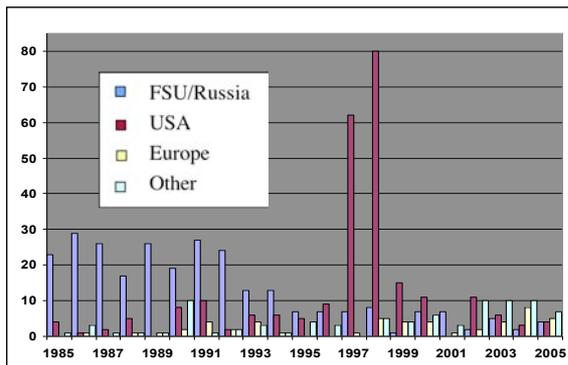


Figure 2. Distribution of Launched Satellites by Origin

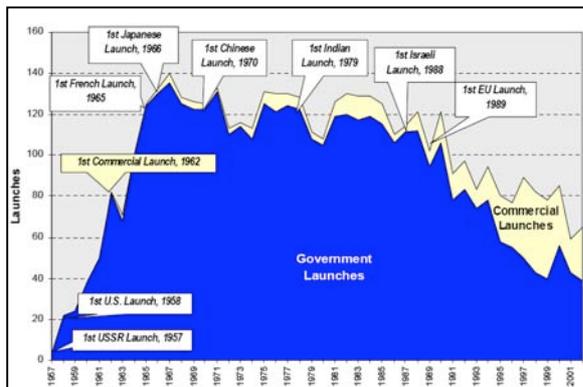


Figure 3. Government Portion of All Launches
Small satellite missions have several major components which drive mission cost including:

- Satellite design, development and test

Weeks

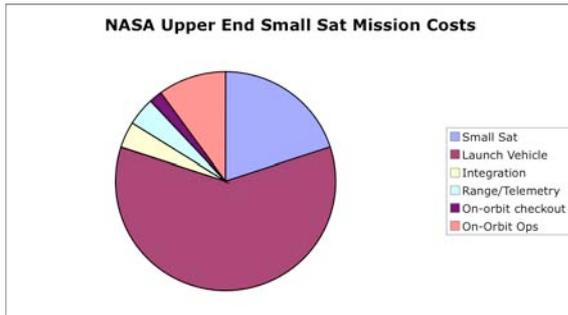


Figure 5. Launch Vehicle is the Primary Cost Driver

Range tracking and telemetry are not inexpensive. In order to help drive down mission costs, space-based range services will be needed. Today, NASA/Wallops Flight Facility has prototype telemetry downlink and autonomous range safety systems flying. The low-cost TDRSS transmitter (LCT2) and the Autonomous Flight Safety System (AFSS) are scheduled to fly on an orbital launch flight later this year. The LCT2 should be upgraded to a transceiver next year and there are hopes of adding Ku band as well in order to increase downlink bandwidth. These systems can greatly reduce the cost of Government suborbital missions as well as continuous flight termination system (FTS) coverage can run into several million dollars with deployed land, sea and air assets.

The Commercial Space Technologies Study

In August 2005, BAH issued a study contract to Commercial Space Technologies, Ltd. (CST) based in London England. CST was asked to focus on the international small launch vehicle and satellite markets. CST is perhaps best known as a broker for Russian launch vehicles to launch small satellites but has performed numerous satellite and launch vehicle studies.

CST investigated the international launch vehicle market and history since 1985 with an eye on how the current launch demand for small satellites is being met. Concurrently, CST analyzed the impact that a U.S. built low-cost small launch vehicle would have on the current market and what the impact of such a launcher would have on future small satellite development. CST employed a team of Russian specialists in London and in Moscow who are advised by experts employed by prime Russian aerospace companies. In addition to low-cost, the small launch vehicles are assumed to have responsive launch capability (i.e. able to be launched within 48 hours of vehicle call up) per the DARPA Falcon program's objectives. A total flyaway cost for this new U.S. small launch vehicle was assumed to be no Weeks

more than US \$10M including range, consumables, SLV, and mission assurance activities.

The distribution of small satellites into these three categories allows one to estimate the most likely launch approach. Category 3 satellites with their heavier mass would most often be launched by dedicated launch vehicles and in rare instances, be accompanied by piggyback satellites from Category 1. Category 2 satellites would usually be launched as rideshare payloads or with several piggyback payloads from Category 1. In some rare instances, heavier Category 1 satellites might employ cluster launches when intended for relatively low orbits (less than about 400 km). Category 1 satellites would be launched as piggyback payloads or in cluster launches.

CST investigated the current small satellite market forecasts after evaluating current trends and historical data over the past twenty years. Concurrently, CST examined how current small satellite launch demands are being met by dedicated small launch vehicles (with single and rideshare payloads) and by heavier launch vehicles and small launch (with clusters – of at least 4 - and piggyback payloads). The CST study did not include small satellites launched into any orbit with an apogee higher than 3000 km (1860 mi) or payloads that remained attached to their upper stage.

From 1985 – 2005 (with the exception of 1997 – 1999) about 25-35 small satellites were launched per year. 1998 witnessed a peak of 105 small satellites launch and this period benefited from the Iridium, Orbcomm and Globalstar systems. The low earth orbit communication constellations lost out to cable/cellular communications and geostationary satellite systems.

However, the role of low-orbital small satellites has remained significant for military communications. Such communications satellite systems could also service the polar regions of Canada and Russia. Without the development of new fields of applications, the current trend is for 25-30 satellites per year. The current applications are primarily composed of Earth's remote sensing (ERS) and scientific / experimental spacecraft. Having heavier masses traditionally, the ERS satellites have shown an average decrease in mass over the past five to ten years. CST believes that modern miniaturization will enable future ERS spacecraft masses of less than 100 kg (220.5 lbm).

Russia, the U.S., Europe and China have all gone to higher orbits for their navigation satellite systems. For future projections, this leaves the ERS and scientific/experimental spacecraft for dominance among the small satellites. ERS spacecraft are

expected to continue their trend of average decreased mass as miniaturization continues. In fact, it is expected that in the future, ERS satellite masses will not exceed 100 kg. CST also forecasts a majority of scientific/experimental small satellites will not exceed 100 kg and would be launched primarily in clusters by SLVs.

It is expected that category 1 (heavier) small satellites will comprise 15-20 percent of the small sat market with category 2 (mid-weight) small satellites comprising 30-35 percent. The low-cost SLV would also accommodate the category 3 (light weight) satellites by launching in clusters and as piggybacks in combination with mid-weight satellites.

With an over supply of mid-sized launch vehicles, many of them have been used to launch small satellites due to the mid-size launch vehicle operators being content with minimum profit versus the possibility of no profit at all.

Competition to the low-cost SLVs will come from the current Russian launches and from heavier launch vehicles offering piggyback launches. One U.S. developer is designing a low-cost heavier lift vehicle with a 9300 kg payload capability to low earth orbit (LEO) and 3400 kg to geosynchronous transfer orbit (GTO) for an advertised price of \$27M per flight. They are also advertising another version with a 5.2 m fairing capable of placing 16,500 kg (~36,300 lbm) in LEO or 6,400 kg (~14,100 lbm) to GTO. Their largest advertised model would accommodate 24,750 kg (~54,500 lbm) for LEO applications and 9,650 kg (~21,250 lbm) for GTO applications.

Factors for Success

CST indicates that there are three key factors for a SLV's success: (1) optimum payload capability; (2) a specific launch price which is competitive against all methods of launch by other launch vehicles; and (3) availability for launching payloads in the world and regional/domestic markets. A low-cost U.S. SLV should be able to satisfy the optimum factor with up to a 700 kg (1543.2 lbm) payload capability. It should partially meet the second factor for price competition as it should see domestic success and perhaps partial success against the less expensive Russian launchers. The US low-cost responsive SLV will likely have limited success in ready availability for payloads from anywhere in the world due to International Traffic in Arms Regulations (ITAR) restrictions.

CST Forecast Trends

Forecast trends for small satellites are: (1) stable level of 25-35 satellites launched per year; (2) stable distribution by mass with 50 percent light weight, 30 Weeks

percent mid weight and 20 percent heavy weight; (3) domination by ERS and scientific/experimental applications while communication and navigation applications shrink; (4) share of commercial launches is increasing; and (5) worldwide market leaders today are the U.S. and Russia but the market shares of Europe, Japan, China and others are growing and will eventually equally share the market with the U.S. and with Russia. Overlaid with these trends is the expected decrease in mass/dimensions of small satellites for both ERS and scientific/experimental applications with observable results showing no earlier than five to ten years but with negligible impact on the yearly SLV launch rate.

CST Conclusions

Final conclusions reached by CST include: (1) the launch rate for small satellites is low and flat, remaining so unless external factors are brought to bear. (2) A U.S. low-cost SLV with optimum payload capability, low set price with responsive launch would expand the market by enhancing demand for launch services. (3) This market expansion will be realized by lightweight small satellite growth with current small satellite development approaches and by leveraging of the responsive access concept with significant changes in satellite development including large-scale small satellite development carrying over to larger satellites and reusable small satellites. (4) CST also developed an approximate mathematical model for forecasting annual SLV launch rates. They have also developed preliminary quantitative timing estimations for satellite developments and their influence on the small satellite market. These theoretical models indicate a good chance of success for a new U.S. low-cost responsive SLV in the worldwide small satellite market and especially in the U.S. domestic market.

The AeroAstro Inc Study

AeroAstro, Inc. is known for micro satellite and nanosatellite system design and fabrication, spacecraft technologies and components, and satellite-based data communications. AeroAstro attempted a survey of 129 different individuals and organizations within Government, commercial industry and academia. The survey involved eleven questions on future launch plans, payload types, orbit types, reasonable LV costs, important LV attributes, etc. Contact was made with 58 of the 129 and of the 58 contacted, 41 interviews were conducted.

The interviews revealed a ground swell of interest in reliable low-cost access to space. Interviewees indicated that opportunities to fly small payloads to orbit are not that plentiful. The problems associated with being a secondary payload were mentioned in

the interviews. These included being tied to the launch schedule and orbit set by the primary payload and coordination with the launch company. Additionally, the primary payload providers do not appreciate having secondary payloads that add risk to their mission.

The study report author believes that strong competition for such a low-cost small launch vehicle resides in the Unmanned Aerial Systems (UAS) community. Additionally, Russian launch vehicles offer less expensive access to space. U.S. companies are willing to deal with export laws due to the lower cost and the interviewees' position that dealing with the Russians on payload integration to their launch vehicle is easier than in the U.S. This is coupled with the statement that the Russians are more likely to keep to the scheduled launch date.

In order to drive a rapid demand for such a low-cost SLV, the author is convinced that a partnership must be cultivated that will stimulate the commercial markets involving companies which sell products or services benefiting from the space environment.

Assuming the presence of a responsive, low-cost SLV, the following pure commercial concepts were identified:

- Orbital tourism, likely to include orbiting lodging facilities
- Consumer imaging with resolution of one meter; customer would pay \$100 per image through internet connection
- Entertainment involving integration of real space hardware with on line gaming
- Manufacturing and production including specialty pharmaceuticals
- Space burial
- Advertising
- Novelties
- Hazardous waste disposal

Government and Department of Defense concepts identified were:

- Fractionated space involving the use of several small satellites performing individually with the capability of coordination such they can work together for a synergistic result and more cost effectively than the large satellites of today

- Space control and space situational awareness missions
- Responsive denied area surveillance
- Orbital transportation services for the International Space Station re-supply/mass download
- Technology validation and qualification in space prior to base lining for major acquisitions
- Universities involving programs such as AFRL's University Nanosatellite Program
- Low cost dedicated science experiments

Past Satellite Trends

The majority of satellites launched to date have had a mass greater than 1000 kg. However, over the past 25 years the small satellite market for less than 500 kg has been growing. During this 25-year period, of the 320 small satellites between 100 kg and 500 kg mass, the largest contributor was Russia/FSU with 142 spacecraft.

Of the 323 spacecraft launched having a mass of 10 kg to 100 kg, 146 were Russian/FSU small communication satellites deployed in groups of eight.

Interviewee Preferences

Mass

Academics have the largest share in the less than 100 lbm (45 kg) spacecraft with many below 10 lbm (4.5 kg) while commercial and military/Government organizations dominate in the larger small satellites. This is illustrated by the growing number of small cubesats built by U.S. universities but launched on rockets from Russia and Ukraine.

Desired Orbits

Interviewees generally preferred high inclination orbits for LEO missions and low inclination orbits for GTO and Geosynchronous Earth Orbit (GEO) missions.

Secondary Payload Opportunities

All academic interviewees expressed a willingness to fly as a secondary payload with several stating that going this route was their only opportunity to get to orbit. The majority of the commercial and Government organizations indicated a willingness to fly as secondary payloads, especially for their smaller satellites.

Reaction to Proposed Dedicated Low-Cost Launch Vehicle

Commercial organizations stated that they might plan more missions but that would be driven by market demands. The impression was that a low-cost U.S. SLV would drive this demand up but several wanted to “wait and see” remembering the low cost promises of the Pegasus launch vehicle. Some military/Government organizations indicated that their planned future missions are already assuming the presence of a U.S. low-cost SLV.

Satellite Projections

Figure 6 shows the AeroAstro projection for satellites over the next 20 years organized by mass and by customer sector. U.S. Air Force Space Command projections are omitted due to the large number of tactical satellites indicated. The chart emphasizes the dominance of the smallest small satellites by academia.

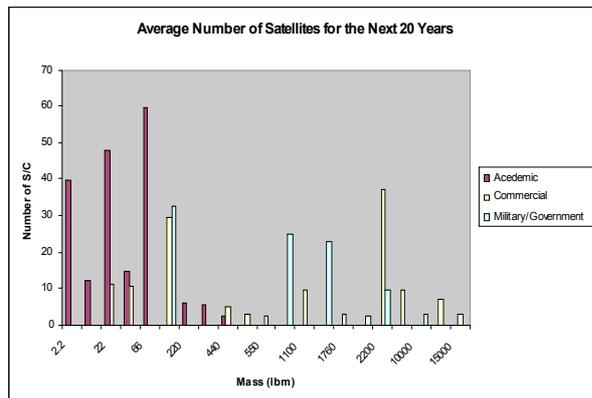


Figure 6. Satellites Project for Next 20 Years

AeroAstro Study Conclusions

The overall enthusiasm for a proposed U.S. low-cost responsive SLV was less than anticipated. As expressed by interviewees in the study, this was due in part to the SpaceX Falcon I being advertised at a price consistent with the study reference cost. However, the community wants to see such a launch vehicle become operational before they get too excited.

The study author believes that the greatest challenge is in engaging the principal commercial space economic engine of our country, the companies providing the goods and services to our population. The challenge is get these companies involved to create the demand for low cost access to space.

Acknowledgements

The authors wish to acknowledge DARPA/ Tactical Technology Office for funding these studies and to DARPA, the U.S. Air Force Space Command and NASA for the Falcon Program and its potential impact on small launch vehicles and small satellites.

The authors also wish to acknowledge the research efforts of the CST and AeroAstro teams. Specifically Gerry Webb, General Director of CST (<http://www.commercialspace.co.uk/>) and his team members in London and Moscow provided valuable insights, data, and forecasts. Richard Glover and his team at AeroAstro (<http://www.aeroastro.com/>) provided insight into the thoughts of aerospace leaders as they consider future plans.

Bibliographical References

1. Sackheim, R.L., D.J. Weeks, J.R. London III, “The Future for Small Launch Vehicles,” Presentation at 2004 Small Payload Rideshare Conference. May 12, 2004.
2. Weeks, D.J., S.H. Walker, R.L. Sackheim, “Small satellites and the DARPA/Air Force FALCON program,” *Acta Astronautica* 57 (2005), pages 469-477.
3. Webb, G., “The Impact on the Small Satellite Market from the Introduction of a Low-cost U.S. Small Launch Vehicle,” Commercial Space Technologies Inc. study report in support of DARPA Falcon Program to Study Manager Tim Thompson, Booz Allen Hamilton, December 2005.
4. Glover, R. “Small Satellite Launch Vehicle Study,” AeroAstro study report in support of DARPA Falcon Program to Study Manager Tim Thompson, Booz Allen Hamilton, March 2006.
5. DARPA Falcon Technology Demonstration Program Fact Sheet. November 2003.
6. Falcon, Phase II, Task 1 Program Solicitation 04-05, DARPA TTO, <http://www.darpa.mil/baa/#tto>. May 7, 2004.