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SMALL SATELLITES AND THE DARPA/AIR FORCE FALCON PROGRAM

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ABSTRACT

The FALCON ((Force Application and Launch from CONUS) program is a technology demonstration effort with three major components: a Small Launch Vehicle (SLV), a Common Aero Vehicle (CAV), and a Hypersonic Cruise Vehicle (HCV). Sponsored by DARPA and executed jointly by the United States Air Force and DARPA with NASA participation, the objectives are to develop and demonstrate technologies that will enable both near-term and far-term capability to execute time-critical, global reach missions. The focus of this paper is on the SLV as it relates to small satellites and the implications of lower cost to orbit for small satellites. The target recurring cost for placing 1000 pounds payloads into a circular reference orbit of 28.5 degrees at 100 nautical miles is $5,000,000 per launch. This includes range costs but not the payload or payload integration costs. In addition to the nominal 1000 pounds to LEO, FALCON is seeking delivery of a range of orbital payloads from 220 pounds to 2200 pounds to the reference orbit. Once placed on 'alert' status, the SLV must be capable of launch within 24 hours.

FULL TEXT

INTRODUCTION

In 2003, the Defense Advanced Research Projects Agency (DARPA) announced a new joint program with the United States Air Force called Force Application and Launch from CONUS (FALCON). The program goal is to develop and validate, in-flight, the technologies that will demonstrate affordable and responsive spacelift as well as enable the capability to promptly execute time-critical global reach missions. The program seeks a common set of technologies that can be evolved to provide circa 2010 responsive global reach capability from the continental United States while enabling future development of a reusable Hypersonic Cruise Vehicle (HCV) circa 2025. These technologies will be advanced in their technology readiness levels to flight readiness and then integrated into a system design and flown in a series of flight tests. [1]

While the global reach capability focuses on the Common Aero Vehicle (CAV) and the HCV, a low-cost responsive Small Launch Vehicle (SLV) is needed to launch and carry the CAV to the proper release conditions as well as to provide responsive spacelift. The CAV will be an unpowered yet maneuverable hypersonic glide vehicle. This paper will focus on the SLV and specifically the spacelift mission for small satellites.

A Phase I solicitation for concept designs was released in May of 2003 for a small launch vehicle that could insert a payload into low earth orbit (LEO), or release a suborbital common aero vehicle (CAV). Twenty-four proposals were submitted by industry in response. In December of that year, nine contracts were initiated for six month studies to Air Launch LLC, Andrews Space, Exquadrum, KT Engineering, Lockheed Martin, Microcosm, Orbital Science, Schafer, and SpaceX.

In May of 2004, DARPA released a solicitation for Phase 2 SLV activities to include detailed vehicle design, development, test, and flight. A full and open competition was conducted with proposals received by the nine Task 1 contractors plus several other aerospace firms. Phase 2 is currently still in source selection with multiple contractor awards likely in September 2004. The Phase 2 period of performance is 36 months, culminating in a demonstration spacelift flight.

SPACELIFT REQUIREMENTS

The SLV must be able to launch a small satellite or other payload weighing approximately 1,000 pounds to a Reference Orbit which is defined as a circular, 100 nautical miles altitude, due east, launched from 28.5 degrees north latitude. A program desire is to demonstrate flexibility in placing payloads ranging from 220 pounds to 2,200 pounds into the same Reference Orbit. An orbital insertion accuracy of plus/minus 13.5 nautical miles must be achieved. Each launch should have a recurring cost of no more than five million dollars (US in CY03$), including range costs but excluding the costs of the payload and payload integration. The cost basis for the recurring cost objective is twenty launches per year for ten years. Ideally, the vehicle used for spacelift could also be used with few modifications for CAV launches.

PHASE 1 RESULTS

The Phase I concepts involved an assortment of air launch and ground launch systems with solid, liquid, and hybrid propulsion systems. Liquid propulsion systems included pressure-fed and pump-fed systems. Air launch enables mission flexibility with respect to the typical launch ranges, but is limited in evolutionary growth potential. Ground launch must deal with weather conditions and azimuth limitations imposed by the launch site location.

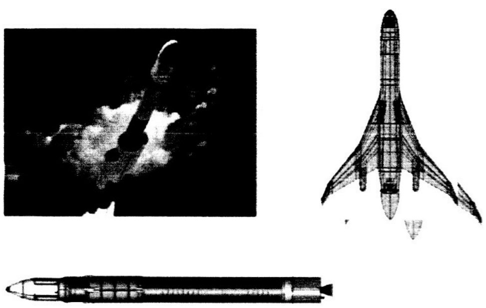

Fig. 1: REPRESENTATIVE PHASE I CONCEPTS

Each conceptual design had associated trade studies in balancing affordable cost objectives with sufficient vehicle performance and operational responsiveness. Contractors were urged to interact directly with various launch ranges in the United States to understand range requirements and to drive down range costs for future launch vehicles. The driver for each design was the low recurring cost per launch goal of five million dollars or less. Vehicle concepts ranged from two staged vehicles with less than 75 feet height to well over 100 feet and 1 million pounds GLOW (gross lift off weight). Design emphases included innovative practices for lowering manufacturing and vehicle assembly costs, incorporating new technology to solve classic vehicle cost and reliability issues, and using existing hardware in new ways. A number of concepts also included streamlined range operations, encapsulated payloads and/or vehicle scalability for larger payloads in the future.

PHASE II BEGINNINGS AND SCHEDULE

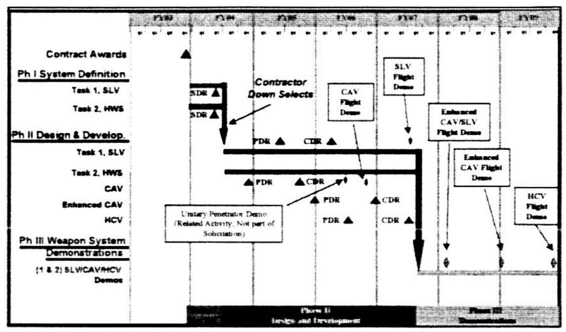

Fig. 2: FALCON PROGRAM SCHEDULE [2]

Figure 2 above shows the program schedule, indicating that the SLV space lift demonstration launch will be conducted no later than FY07. It is conceivable that a SLV will also be used for the CAV demonstration launch around the end of FY06. The SLV task is referred to as Task 1 while the CAV/HCV task is called out as Task 2. Multiple contractor teams will be carried from contract award though Preliminary Design Review (PDR) before down selection occurs to carry one or two teams to flight demonstration.

FALCON PROGRAM APPROACH

The FALCON Program team is led by Dr. Steven Walker as the program manager in the Tactical Technology Office at DARPA. His deputy is Major John Anttonen of the U.S. Air Force Space and Missile Center. The chief engineer is Jess Sponable of the Air Force Research Laboratory in Dayton, Ohio. The SLV technical team is led by David Weeks at the National Aeronautics and Space Administration's Marshall Space Flight Center (NASA/MSFC). NASA is a partner to DARPA and the Air Force on the FALCON program and is supplying personnel, funding, and in-kind contributions.

The approach taken by the FALCON team is to emphasize product (hardware) development over process and paperwork, to work in small government management teams, to employ early communications (no surprises), appropriate division of labor, and remembering that integrity is everything. The SLV Government technical team will have approximately eight core members consisting of personnel from the Air Force Research Laboratory at Kirtland Air Force Base (AFB) and Edwards AFB, NASA (Wallops Flight Facility and MSFC), The Aerospace Corporation, and at Centra Technology (a System Engineering and Technical Assistance - SETA support contractor for DARPA). Personnel on the core team represent specialties in project management, propulsion systems, vehicle integration, range support, avionics, concepts of operations, and user support from the Air Force Space Command headquarters as well as including the contracting officer's technical representative (COTR) for each SLV contract.. An outer ring of specialists will be called upon as needed for turbomachinery, cost analysis and performance, separation systems, structures, specific range issues, etc.

CURRENT PLIGHT OF SPACE TRANSPORTATION AND SATELLITE INDUSTRIES

The global satellite launch rate has remained fairly constant for the last couple of decades with the exception of the late 1990s when the communication satellite constellations were launched. Typically, with the exception of the constellation campaign, the launch rate has averaged about 100 plus/minus 20 launches per year. The U.S. portion over this period has averaged 40 plus/minus 20 launches per year. [3] The situation is not expected to change significantly in the foreseeable future even with new NASA exploration goals.

The United States has lost significant commercial launch share in the global market in recent years. The U.S. launch market has remained even barely viable due to U.S. Government payloads.

Available U.S. small launch vehicles have been limited and expensive. The U.S. Government is by far the primary customer but finds itself only able to afford a limited number of launches per year. Flying as a secondary payload or 'ridesharing' is often unsatisfactory, resulting in many payloads going into storage instead of going to orbit.

Microgravity research has long used sounding rockets to obtain up to 20 minutes of low-g environment. The next logical step is using small launch vehicles for days or weeks of microgravity but the launch vehicle cost has been too high.

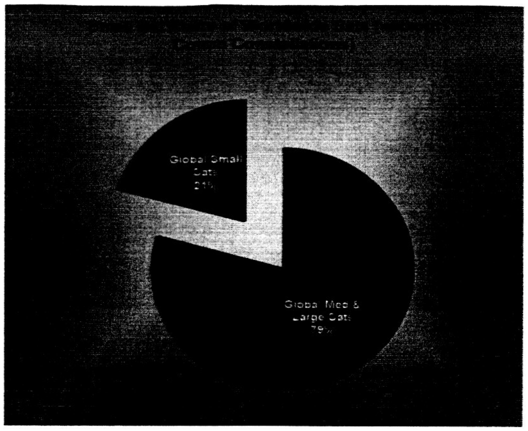

Fig. 3: SMALL SATELLITES SHARE OF ALL SATELLITES GLOBALLY [4]

Figure 3 indicates from 1984-2002 that small satellites internationally comprise 21 percent of the satellite market when the communication satellite constellations of the 1990s (Orbcomm, Iridium, Globalstar) are removed. Figure 4 shows that the U.S. share of the worldwide satellite market is 26 percent. Figure 5 reveals that the U.S. has only a 29 percent share of the worldwide small satellite market. Within the U.S., Figure 6 discloses that within the U.S., small satellites contribute only 7 percent of national satellites.

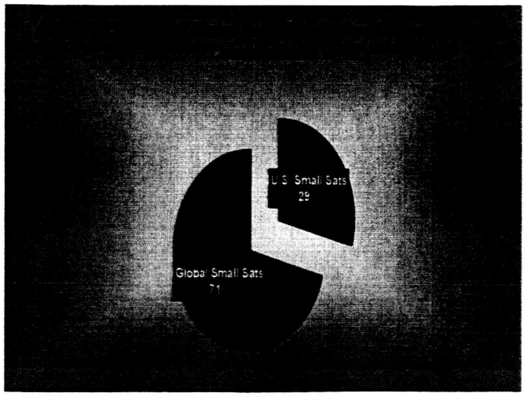

Fig. 4: U.S. SHARE OF GLOBAL SATELLITE MARKET [4]

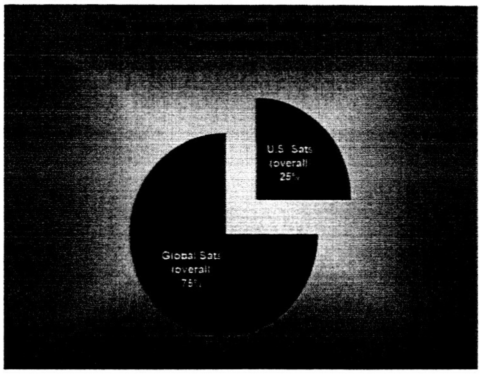

Fig. 5: SMALL SATELLITE SHARE OF ALL SATELLITES GLOBALLY [4]

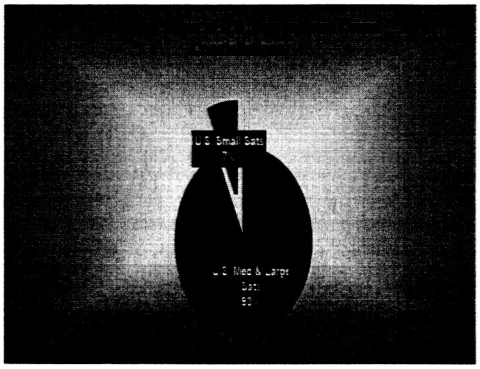

Fig. 6: U.S. SHARE OF GLOBAL SMALL SATELLITE MARKET [4]

While the global satellite market has shrunk over the past decade or two, the U.S. has suffered an even greater decline during this period. Low cost small launch vehicles could greatly propel the number of small satellite launches in the U.S. and abroad.

IMPLICATIONS OF LOW COST SMALL LAUNCH VEHICLES

Small satellite missions have several major components that drive mission cost including the following:

- satellite design, development and test
- launch vehicle
- launch range and telemetry

• mission assurance

• satellite integration with launch vehicle

• on-orbit checkout of satellite

• on-orbit operations of satellite

• satellite disposal

For small satellites, the cost of the launch vehicle is a primary driver. Cost of access to space has been a major barrier for many potential space applications, historically at approximately $10,000 per pound of payload. For small satellite missions, a more appropriate metric is perhaps cost per mission rather than cost per pound. Though small satellites (for purposes of this paper, small satellites are considered to be less than 500 kilograms) often cost less than $5,000,000 to design, develop, and test – a ride to orbit for $5,000,000 has been non-existent.

There are several major issues involving small satellite launches today, including:

• Though small satellites are often in the $500,000 - $10,000,000 cost range, the launch vehicle flyaway costs are usually above the $20,000,000-$30,000,000 range. This makes insuring the satellite difficult as well as justifying the satellite launch. Thus many small satellites are never launched and many more are never carried beyond the conceptual level because the designers realize that the economics are not justifiable.

• 'Ridesharing' or 'piggybacking' as a secondary payload is less expensive but the small satellite is relegated to steerage class, flying when the primary payload wants to fly, where the primary payload wants to fly, and often putting up with being barely tolerated by the primary payload entities.

If the flyaway launch cost can be reduced to the $5,000,000 to $10,000,000 range including range, payload integration and mission assurance costs, new possibilities arise. Instead of designing the small satellite for a five to ten year life on-orbit, it may be affordable to design the satellite for a three-year life. This in turn drives lower radiation hardening requirements, allows more frequent technology updating, and encourages greater automated on-orbit operations (including on-orbit checkout) to further drive down mission cost.

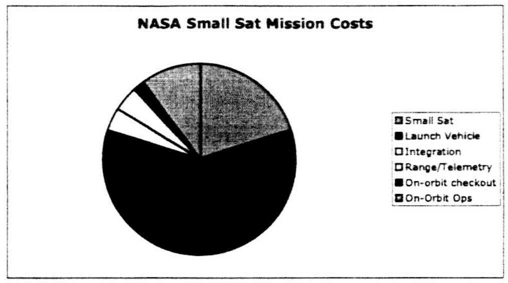

Fig. 7: NASA SMALL SATELLITE MISSION BREAKDOWN [4]

Figure 7 assumes a $10,000,000 small satellite of 500 kilograms (1100 pounds) on a NASA Pegasus with a vehicle flyaway cost of $30,000,000, a cost of $2,000,000 for payload integration, $2,000,000 for range and telemetry/tracking, a maximum of $1,000,000 for on-orbit checkout over 30 to 90 days, and up to $5,000,000 for on-orbit operations for up to five years including satellite disposal. Launch vehicle costs include mission assurance activities as well as other reporting required by the Government. The launch vehicle cost of $30,000,000 represents 60% of the mission cost and is the primary cost driver.

The Delta II is a larger launch vehicle carrying larger payloads even to geosynchronous transfer orbit (GTO) and beyond. The cost breakdown for a Delta 7925 is comparable to that for a small satellite mission as shown in Figure 8 below:

Delta 7925 – Recurring Cost

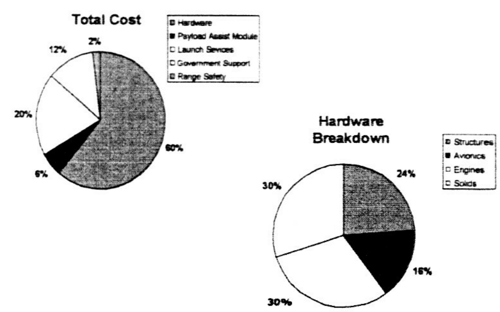

Fig. 8: Recurring Cost of Delta 7925 Launch Vehicle [4]

The Atlas-Centaur recurring cost as shown below in Figure 9 also indicates hardware cost of greater than 60 percent (66 percent).

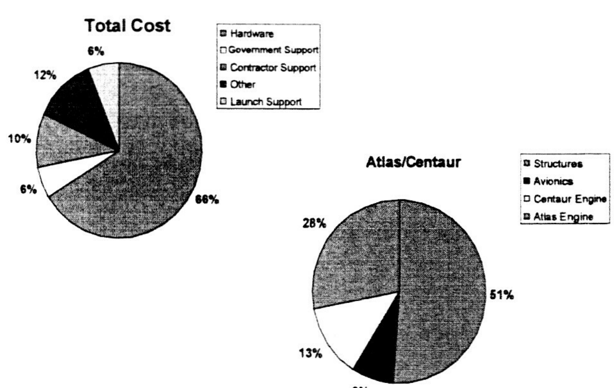

Fig. 9: Recurring Cost of Atlas-Centaur Launch Vehicle [4]

The Titan III recurring cost of launch vehicle hardware as shown in Figure 10 is well above 60 percent (82 percent) and the Titan IV recurring cost breakdown in Figure 11 indicates the hardware costing 59 percent for each flight.

Titan III – Recurring Cost

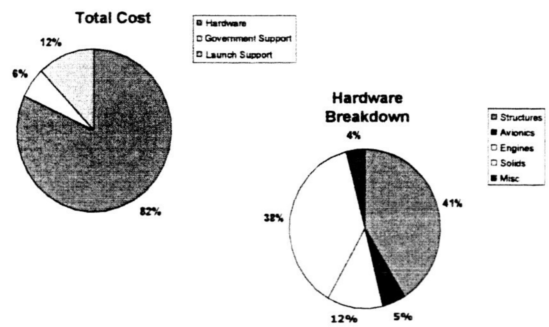

Fig. 10: Titan III Recurring Cost Breakdown [4]

Titan IV – Recurring Cost

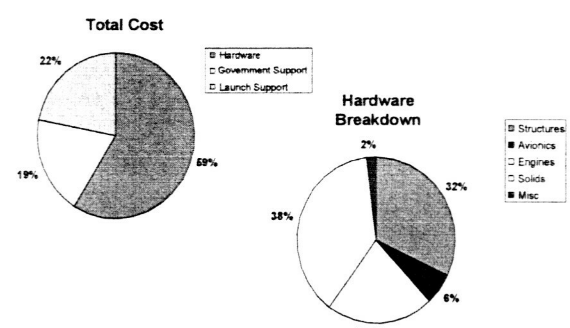

Fig. 11: Titan IV Recurring Cost Breakdown [4]

Overall, one observes that roughly 60 to 80 percent of the launch vehicle cost is in the vehicle hardware for an expendable launch vehicle (ELV). If the launch is commercial, the hardware portion is closer to 60 percent while government launches move the hardware closer to 80 percent of the total cost. Hardware cost remains the top candidate for significant overall cost reduction.

DRIVING DOWN LAUNCH VEHICLE COSTS

Launch costs have several elements: launch vehicle, launch vehicle processing including payload integration, launch operations including range, tracking, and telemetry,

Launch vehicles in their early design often appear headed toward low cost but eventually the flyaway cost may rise to as much as $30,000,000 or more. One lesson learned from the United States Air Force EELV program was that having launch vehicle competition could drive down cost by 25 percent. The Pegasus began as an $8,000,000 DARPA launch vehicle but today routinely costs approximately $30,000,000 to launch. There are several reasons for this but until now, lack of competition has been a significant reason in the free market for launching small satellites.

There is also credence to the argument that neither the government nor industry has been strongly motivated to develop a low-cost small launch vehicle. Industry realizes far greater profits on larger launch vehicles and the government by and large has been more comfortable dealing with larger launch vehicles.

Affordable small launch vehicles constitute a great target opportunity for demonstrating lower recurring costs for launch vehicles. They are less expensive than larger vehicles, have potentially more users allowing far greater numbers of small satellites to be flown, provide affordable technology demonstrations for universities, have the potential to change the small satellite mission life cycle cost by changing the paradigm, have the potential to influence lower recurring costs for larger launch vehicles and provide a mechanism for hands on training for engineers and engineering students.

So how can the small launch vehicles be made more affordable? In addition to introducing serious competition in the field, commonality and simplicity of systems is being emphasized. Commonality leads to common building block (modular) approaches as well as to increased production rates. Greater non-aerospace commercial products and processes are being utilized. Sometimes these parts are heavier but cost one to two orders of magnitude less. Cost is prized above performance (design margins are traded against greater performance and low weight). This may translate to heavier but more robust vehicles that have much lower recurring costs. Design margins traded against redundant systems reduce complexity and cost and potentially increase reliability. In some designs expensive pump-fed propulsion systems and/or high performance upper stages can be avoided. The Former Soviet Union countries have long demonstrated lower cost, less redundant launch vehicles that are produced via assembly line and designed to ship and launch with automated launch pad operations. The first stage of a smaller launch vehicle might be the second stage of the next larger sized vehicle. Recoverable first stages that are reusable might be more economical than expendable first stages. Air launches can have low recurring costs if the launch vehicles fit into ejectable canisters inside the aircraft without requiring any aircraft modifications.

APPLICABILITY TO LARGER LAUNCH VEHICLES

Figure 12 below portrays what can occur as a result of lowering the cost of small launch vehicles. If the recurring cost of a small launch vehicle capable of carrying 1,000 pounds payload to low earth orbit (LEO), more small satellites may be developed and launched. Universities might go together to launch four or more payloads to LEO on a SLV costing $5,000,000 to $7,000,000 per launch. An affordable ride exists for various segments of the Government, academia, the amateur radio community (OSCAR), and other civil space, which may drive the SLV launch and production rate. Now the lower cost for access to space encourages even greater small satellite development. Small satellites can then be made as "throwaways" for a two to three year life on orbit allowing for more frequent technology updating and pushing automated on-orbit checkout and operations even further. Ranges begin to compete for the higher volume of SLV launches and certify the use of space-based assets (GPS, next generation communication satellites) for range safety (GPS/INS with autonomous flight termination system) and telemetry/tracking. The greater volume allows for steeper discounting of SLV costs. As more small satellites are launched, the SLV cost decreases somewhat further. Using the approaches and lessons learned from the small satellite space lift vehicles, a new spiral is developed for the 10,000-pound payload space lift vehicle. Some of these approaches are conducive to heavy lift launch vehicles in the 40-50 metric ton payload class, which could support exploration missions to the lunar and Martian surfaces. Eventually, one can even lower the cost of all launch vehicles, including reusable launch vehicles (RLVs), by applying the modular building block approaches used in expendable launch vehicles (ELVs). All the while, the aerospace economy is stimulated, resulting in new jobs and greatly desirable hands-on experience for its workforce.

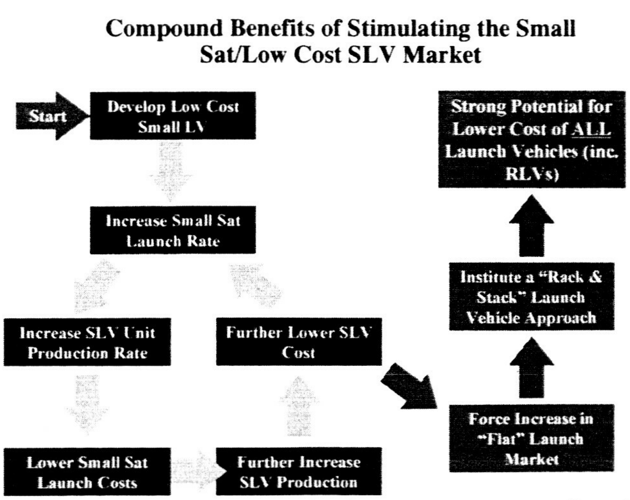

Fig. 12: Benefit Cycle from Lowering Small Launch Vehicle Cost [4]

SUMMARY

With the exception of the constellation communications satellites in the late 1990s, the worldwide annual launch rate has been stagnant. Unless one is flexible enough to deal with rideshare issues, launch vehicles are currently too expensive for small satellites. As the launch market increases, the mission costs will decrease.

A new paradigm is needed to stimulate the production of small satellites, which can have a significant impact on the overall global satellite market. The high cost of space access drives total satellite mission cost, inhibits development of aerospace initiatives, prevents many innovative small low-cost satellites from being developed, stifles growth in the aerospace industry, and reduces opportunities for engineering jobs and hands on experience.

The proposed solution is a new low-cost small launch vehicle that utilizes a higher modular rack and stack approach and can be scaled to mid- and even heavy-lift vehicle development. A new small satellite launcher can serve as a technology test bed to retire technology risks for larger launchers and can stimulate development and qualification of new technologies for space.

The FALCON program offers an excellent opportunity to develop such a paradigm-changing small satellite launch vehicle. NASA has opted to partner with DARPA and the U.S. Air Force to help make space access more affordable.

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