

Progress Toward First Flight of the QuickReach™ Small Launch Vehicle

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ABSTRACT

AirLaunch LLC has made steady and impressive progress over the past three years in design and development of the QuickReach™ Small Launch Vehicle. QuickReach™ is carried inside of and launched from a C-17A or other large cargo aircraft. It is designed to meet the needs of the DARPA/U.S. Air Force Falcon SLV program to deliver 1,000 pounds to Low Earth Orbit for \$5M per flight with less than 24 hours response time. The vehicle is also intended to fulfill the National Space Transportation Policy priority of demonstrating Operationally Responsive Space (ORS) capability by 2010.

A responsive and flexible launch capability, such as AirLaunch, can deploy specialized small satellites that provide the warfighter with real-time data and communication during time-urgent situations. Responsive space would allow the government to react quickly and launch small satellites equipped with sensors to augment or replace baseline space assets for urgent needs.

AirLaunch has accomplished significant milestones to date in Phase 2B of the Falcon SLV program, including building and testing engine and payload fairing hardware, conducting engine test fires and analyzing the vapor pressurization (VaPak) propulsion system, establishing a comprehensive safety program using Air Force and Mil Std processes, proving its “Gravity Air Launch” methodology through successful drop tests from the C-17 aircraft, and completing the Incremental Critical Design Review (I-CDR).

This paper gives a status on the technical and safety progress of the QuickReach™ to date and the next steps planned toward first flight.

Introduction

AirLaunch has completed Phases 1 through 2B of the joint Defense Advanced Research Projects Agency (DARPA) / Air Force Falcon Small Launch Vehicle (SLV) program. This program originated with a call for proposals in June 2003, resulting in awards to 9 companies in September 2003 to conduct 6-month Phase 1 design studies for an SLV. In September 2004, DARPA held another open competition and selected 4 companies for further Phase 2A studies and demonstrations leading to a SLV Preliminary Design Review. In October 2005, the program selected AirLaunch LLC for contract continuance through Phase 2B, with a \$17.8 million value. AirLaunch completed Phase 2B in April 2007.

The Falcon program is governed by a Memorandum of Agreement (MOA) signed by DARPA and the Air Force in May 2003 with DARPA managing the Falcon SLV program and the Air Force funding the program from its Operational Responsive Space (ORS) budget line. The intent has been to develop operational responsive space launch vehicles as called for in the United States Space Transportation Policy.

Responsive space would allow the government to react quickly and use small satellites equipped with sensors to monitor and provide communication for urgent military needs. Having a quick reaction launch system that can launch specialized small satellites will provide the warfighter with real-time data and communication during time-urgent situations. AirLaunch’s system achieves responsiveness by launching from an unmodified C-17 or other large cargo aircraft.

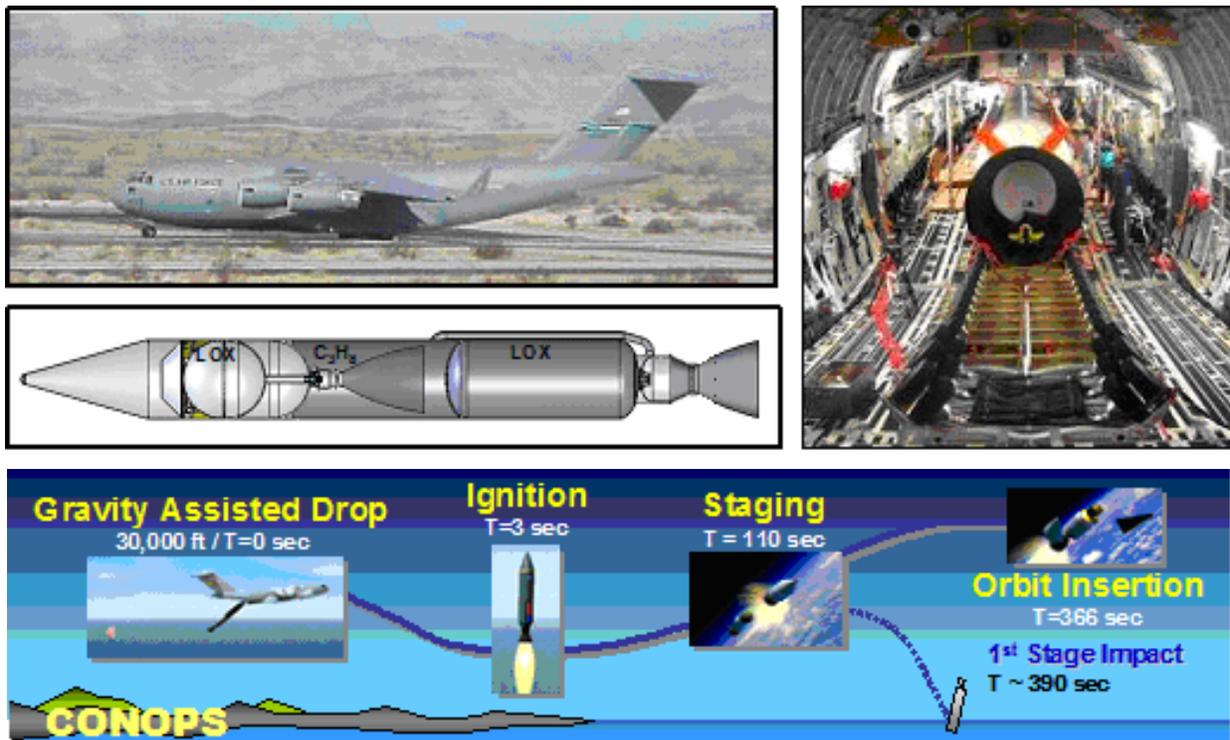
QuickReach™ Small Launch Vehicle Overview

The QuickReach™ SLV is designed to meet the needs of the DARPA/Air Force Falcon SLV program: deliver 1,000 pounds to low earth orbit (LEO), for \$5M per flight, with response time of less than 24 hours. It is an air-launched, two-stage liquid fueled rocket, designed for use with an unmodified C-17A military transport aircraft and compatible with other transports with comparable or greater capacity, such as the An-124 or C-5A. Satellite launch missions will be conducted with a single QuickReach™ vehicle loaded in the aircraft along with range support equipment.

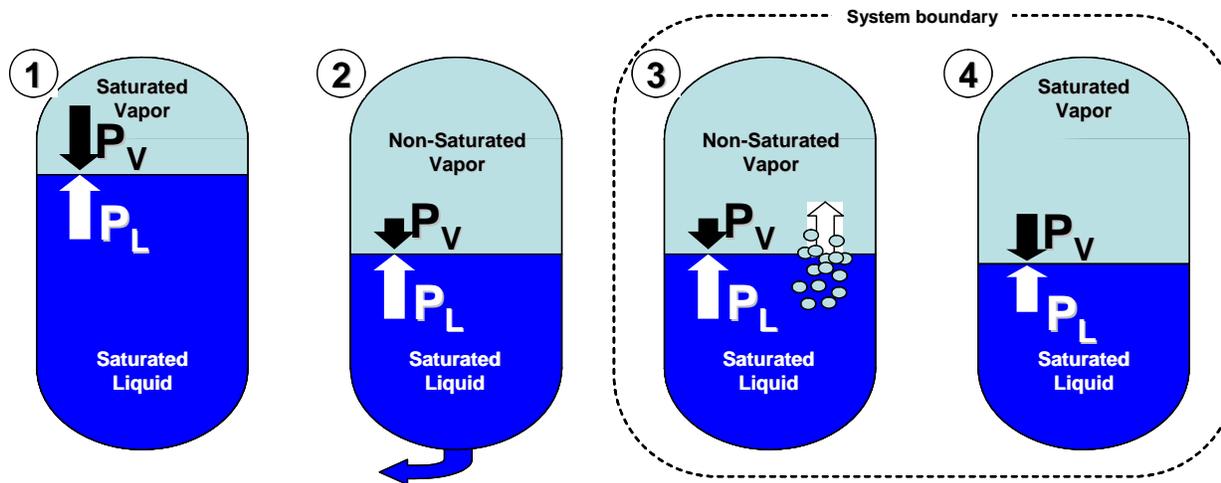
Launching from altitude provides a unique opportunity to operate a simple, low-cost rocket system while maintaining the high performance characteristics of most two stage launch vehicles. AirLaunch opted to launch its vehicle from a cargo aircraft at altitude to provide increased performance to take advantage of the efficiency of the innovative liquid oxygen and propane vapor pressurization (VaPak) propulsion system that QuickReach™ employs.

Conceived in 1960 by Aerojet, VaPak combines the simplicity and reliability of a solid rocket with some of the performance advantageous of a liquid propellant design. VaPak is based on using the internal energy of a liquid stored in a closed container to provide the pressure and to perform the work required to expel the liquid from the container. The principle of VaPak propellant pressurization is similar to the process that pressurizes a simple can of hair-spray. In a VaPak propulsion system, the propellants are pressurized by the vapor pressure in the ullage volume, generated by the liquid propellant phase being maintained at a saturated state.

VaPak systems hold the promise of low complexity propulsion systems for highly reliable and cost-effective vehicle designs. VaPak eliminates costly components such as turbopumps, gas generators, high pressure bottles, or complex valving used in a typical pump-fed launch vehicle. In conjunction with appropriate engine design, the resulting systems are equally useable for trans-atmospheric or in space operations.



**QuickReach™ Small Launch Vehicle
Providing Extraordinary Capability with Ordinary Technology**



The VaPak model is based on an enthalpy balance, assuming an isentropic process, with both liquid and vapor phases at uniform temperature at a fully saturated state

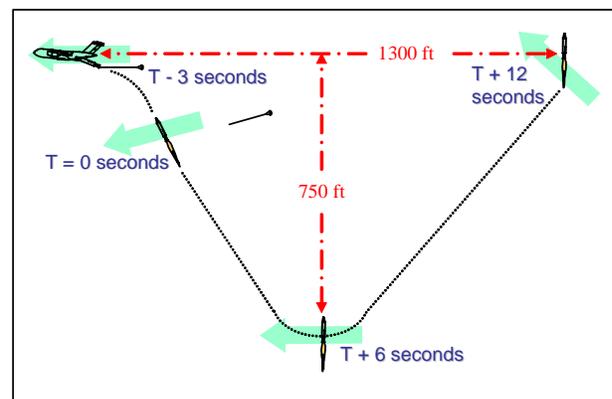
Air launching takes advantage of the low outside atmospheric pressure at altitude (30,000 feet or greater) which allows a pressure-fed launch vehicle to use high area ratio nozzles while operating at relatively low engine chamber pressures. AirLaunch's approach provides weight and specific impulse (Isp) performance that is competitive with high-pressure turbopump-fed systems without the associated safety, cost, or complexity issues.

AirLaunch's approach simplifies operations and minimizes reliance on fixed launch ranges. For example, required coordination is minimized with other users of the range, weather constraints can be avoided by flying to open sky, and there will be fewer delays waiting for specific launch windows (to match desired orbits) because the launch vehicle can be flown to an alternate launch point that is better aligned with the desired orbit. In addition, ground launches are often postponed when ships enter the ocean zones near the coastal launch sites or where rocket stages are expected to drop. The QuickReach™ carrier aircraft can avoid such delays by flying to a different release point. Public safety is greatly enhanced since the launch takes place over the open ocean, far away from any populated areas. Air launching minimizes range costs and maximizes operational flexibility by allowing deployment from any 4,000 foot runway without need for fixed installations.

For an actual launch mission, the design goal is to be able to load QuickReach™ onto the aircraft in 20 minutes, and then fly to a nominal launch point ~200 or more miles off the coast. The aircraft will climb to ~30K–35K feet altitude where it cruises to the desired drop point. The aircraft can loiter before launching for several hours. If a dangerous situation arises on-board,

emergency extraction may be triggered by the loadmaster anytime during flight. During an emergency extraction all rocket components and propellants would be extracted in less than 30 seconds.

The carrier aircraft will be flown to a "drop box," an approximately 1 x 1 mile area over the open ocean for an operational mission. Several minutes prior to launch the aircraft deck angle is established at approximately 6 degrees nose up, cabin pressure is equalized with local atmospheric pressure, and the aft cargo door is opened. Fifteen seconds before launch, a small drogue parachute attached to the first stage nozzle is deployed. Upon launch command, the rocket is released and gravity pulls the launch vehicle out of the aircraft, assisted by the small stabilizing drogue chute. The launch vehicle pitches up after leaving the cargo bay due to cresting the end of the cargo ramp. The drogue chute damps this pitch rate and after about 3 seconds the launch vehicle's pitch attitude is 70 to 80 degrees above the horizon.



QuickReach™ Launch Sequence

The Stage One engine ignites when the launch vehicle is over 200 feet from the aircraft, with the launch vehicle descending at 100 feet per second (fps) down and traveling 50 fps aft relative to the aircraft. At the point of ignition, the parachute is released by the simple mechanism of having its risers burned off. Following ignition, the vehicle aligns itself into the desired ascent trajectory and performs a gravity turn through the region of maximum dynamic pressure. Because of the relatively low thrust to weight (T/W) of the Stage One engine, the launch vehicle needs another 500 feet of altitude to arrest its descent. The rocket flies to a vertical heading and continues in this attitude until it re-crosses the launch altitude more than 1,000 ft behind the launch aircraft 15 seconds after extraction.

In this segment the first stage engine operates on liquid combustion and tanks are pressurized using the VaPak mode. Once the liquid in the tanks has been depleted, the vehicle transitions to vapor burn mode, and both tank and engine chamber pressure drop rapidly. The stage is shut down and separated when the T/W is less than one.

Following separation, the second stage ignites under VaPak operation. The payload fairing is released when the environment outside of the vehicle is no longer harmful to the payload. The second stage burn is designed to transition to vapor operation prior to completion of the initial burn. This allows the second stage to restart following the coast to apogee, with only vapor in the propellant tanks, which eliminates propellant settling concerns. Lastly the second stage engine performs the final injection burn into a circular low earth orbit.

Development Progress to Date

AirLaunch LLC completed Phase 2B of the Falcon Small Launch Vehicle (SLV) program in April 2007. During this phase, AirLaunch completed an Incremental Critical Design Review (I-CDR) of the QuickReach™ system; conducted 30 test fires of its second stage engine on the Horizontal Test Stand

(HTS) and 5 test fires of the QuickReach™ Integrated Stage 2 (IS2) on the Vertical Test Stand (VTS); completed the payload fairing and executed a payload fairing separation test; performed a full-scale stage separation test; conducted numerous analyses of VaPak, engine and vehicle performance; and completed two record-setting drop tests of full-scale inert test articles from the C-17.

In 2005, Team AirLaunch completed Phase 2A on time and within budget with significant hardware development and testing. This included 4 engine test firings, a stage separation test, a ground drop test, and a C-17 drop test. Phase 2A ground tests and the first air drop generated early data on propulsion, airframe, avionics and operations.

Design Status

In November 2006, AirLaunch successfully completed the Incremental Critical Design Review (I-CDR) of the QuickReach™ SLV. In addition to the DARPA and Air Force program management team, government personnel from a variety of agencies participated in the review.

All Mil-Std-882 safety tasks assigned to Phase 2B were completed to the satisfaction of the program system safety review board, which included representatives from the C-17 Airworthiness Review Board at Wright Patterson AFB and the Safety Review Board at Edwards AFB. Both review boards approved the successful drop tests of inert test articles from the C-17 in Phase 2B.

Drop Tests from C-17 Aircraft

A total of three drop tests from three separate unmodified C-17 aircraft have been performed by AirLaunch as part of the Falcon SLV program, each setting a record for the longest and heaviest single objects dropped from the aircraft. Each one dropped a simulated QuickReach™ rocket at 65.8 feet long, of increasing weight up to full-scale.



AirLaunch Preparing for Drop Tests

- Drop # 1 was conducted during Phase 2A on September 29, 2005, with a 50,000 lb Drop Test Article (DTA) dropped from 6,400 feet above ground level. This drop set the record for the longest single object, at 65.8 feet, ever dropped from a C-17 aircraft. The flight test crew was nominated by Air Force Materiel Command (AFMC) for the 2005 Mackay Award, for the most Meritorious Air Force flight of the year.
- Drop # 2 was conducted during Phase 2B on June 14, 2006, with a 65,000 lb DTA from an altitude of 29,500 feet and a true airspeed of 330 knots. This drop set the record for the heaviest single object ever dropped from the C-17 aircraft.
- Drop # 3 was conducted during Phase 2B on July 26, 2006, with a full-weight 72,000 lb DTA from an altitude of 32,000 feet and a true airspeed of 330 knots. This drop broke its own record and set a new one for the heaviest single object ever dropped from the C-17 aircraft.

The test series was designed to assure that AirLaunch could safely extract the QuickReach™ rocket from a C-17. In each test, the simulated QuickReach™ booster rested inside the aircraft cargo bay on a Storage and Launch Carrier, consisting of 84 tire/wheel assemblies. As the aircraft turned nose up by six degrees, gravity pulled the test article across the upturned tires and out the aft cargo door.

The tests demonstrated the QuickReach™ release technology and the feasibility of Gravity Air Launch (GAL). Unlike the standard heavy equipment airdrop method, GAL imparts much of the launch carrier aircraft's altitude and airspeed onto the rocket, which in turn improves payload mass to orbit. Each test used a separate C-17 aircraft, demonstrating that any C-17 can be used for AirLaunch drops and ultimately for QuickReach™ launches.



AirLaunch has completed 34 test fires of the second stage engine on the Horizontal Test Stand (HTS)



AirLaunch's Record Setting Drop Tests from C-17 Expanded Aircraft Envelope

The tests were conducted at Edwards Air Force Base by the Air Force Flight Test Center 412th Flight Test Wing and 418th Flight Test Squadron, in conjunction with the Air Force Space Command Space and Missile Systems Center / Detachment 12, and the C-17 Systems Group and Air Mobility Command which supplied the aircraft.

Engine / Stage Testing

AirLaunch has conducted a total of 39 test fires in Phases 2A and 2B of the Falcon SLV program. All tests have used AirLaunch's innovative VaPak propulsion system and gathered data to validate its use with liquid oxygen and propane. Thirty-four (34) tests have been performed on the HTS with the QuickReach™ second stage engine, totaling 282.5 seconds of burn time, in addition to several cold flow tests.



QuickReach™ Integrated Stage 2 Readied for Test



QuickReach™ Test Fires of IS2 in VTS, including longest VaPak burn in history (191 seconds)

Five (5) tests have been performed to date on the VTS with the QuickReach™ IS2, totaling 315.5 seconds of test fire time, as well as several loading and conditioning tests. The IS2 firings signal the beginning of the process to validate the QuickReach™ propulsion system, the ground propellant loading operations, and flight-type avionics, software and systems. Transition of liquid oxygen to gaseous oxygen has been demonstrated in test fires on both the HTS and VTS.

AirLaunch LLC and its teammates conducted its longest test fire to date on April 6, 2007, as the culmination of the Phase 2B activity. The stage contained over 6 tons of vapor-pressurized (VaPak) propellant and burned for 191 seconds, representing a liquid-liquid burn and a transition of the liquid oxygen (LOX) from liquid to vapor phase. The LOX-Propane engine performed as expected, testing the design of the injector with integral main propellant valve and demonstrating much lower than expected erosion rates on the ablative chamber. All test operation was initiated and controlled by the flight-type avionics wafer attached to the stage.

This test was the longest VaPak burn in history. Aerojet conducted a 60 sec burn using VaPak on a Titan motor in 1963, and Scaled Composites performed a 77 sec burn using VaPak (oxidizer only) on the hybrid engine for SpaceShip One in 2004.

System & Component Testing

As the first major milestone of Phase 2B of the DARPA/Air Force Falcon program, Air Launch completed a full scale stage separation test of its QuickReach™ SLV. This test convincingly demonstrated that the innovative gas pneumatic stage separation technique, pioneered by AirLaunch's founder Gary C. Hudson, is practical and safe. Prior to this test, AirLaunch performed detailed modeling and conducted a number of component and subscale tests.

During Phase 2B, AirLaunch and its teammate Delta Velocity completed assembly of the payload fairing and payload adapter cone. A payload fairing separation test was conducted at NASA Wallops Flight Facility. All pyrotechnic sequences and mechanical actions operated properly.



Subscale and Full Scale Stage Separation Tests Completed

Next Steps

DARPA and the Air Force have agreed for AirLaunch to move into Phase 2C and to jointly fund the activity. It is anticipated that Phase 2C will emphasize propulsion characterization of the liquid oxygen/propane VaPak system. Discussions are underway to define the Phase 2C technical content and associated milestones.

Future phases would include a full CDR, additional safety mitigation, design and development of the onboard propellant conditioning system, first stage engine testing, and additional drop tests. Approvals by the appropriate safety review and flight readiness review boards would be required prior to a first test flight.

Payload Accommodations

QuickReach™ is designed to meet the DARPA/Air Force Falcon SLV program requirement of delivering 1,000 pounds to a reference Low Earth Orbit of 28.5°, 100 nmi, due east. Air launching has the added ability to launch at any azimuth, thus enabling similar performance to a variety of orbits. The aircraft can fly to the optimum drop point that satisfies overflight concerns, orbit inclination, and apsis location requirements. Specific cases can be run for individual customer missions.

AirLaunch intends to offer customers a set of standard and optional services that can be tailored to satisfy payload needs. QuickReach™ will provide low cost, rapid call-up launch of payloads designed for responsive missions, so the basic launch service may appear to impose more restrictions on the payload than conventional launch vehicles. Conventional payloads that require support beyond that of the basic service can select from a variety of extra cost options.

The Falcon SLV program requirement is to carry a 40 inch x 60 inch satellite, and the QuickReach™ payload fairing was selected to provide the largest payload volume of any launch vehicle in the sub-2000 pound class. This provides the customer with considerable flexibility in payload design. As an example, satellites can be made more responsive if deployable appendages can be reduced or eliminated. AirLaunch's fairing is known as the "encapsulated cargo element (ECE)" – the design allows off-line payload processing independent of the launch vehicle. It also provides security and environmental control during ground processing, integration operations, and ascent.

QuickReach™ vehicle performance and payload accommodations were described in detail in the paper entitled, *AirLaunch's QuickReach™ Small Launch*



QuickReach™ Payload Fairing Elements and Payload Fairing Separation Test

Vehicle: Operationally Responsive Access to Space, SSC06-IX-4, presented at the 2005 Utah State Small Satellite conference. These details remain the same, and are reprinted for convenience in the attachment.

Missions

The Falcon SLV program goal is to develop a vehicle that can launch a 1,000 pound satellite to Low Earth Orbit (LEO) for less than \$5 million, within 24 hours of notice. Currently it costs about \$20 million to launch a satellite of this size into space and the lead time can be months to years. Having a quick reaction launch system that can launch specialized small satellites will provide a new capability for both military and civil applications as well as stimulate commercial opportunities.

QuickReach™ provides real value for changing the way the nation operates in the launch business. Integrating Air Force air (C-17) and space capabilities, with AirLaunch's responsive, low-cost and operable QuickReach™ rocket, ultimately gives the warfighter faster access to space, enabling a variety of ORS missions.

AirLaunch's capability will enable customers to respond quickly when a time-urgent need arises or in response to a natural disaster by launching small remote sensing satellites on short notice. These small satellites can be equipped with communication, camera and sensor payloads that allow special purpose support for military activities, hurricanes, and forest fires, as well as enable time-urgent communications in remote areas. A small launch vehicle may be a very attractive approach for providing affordable, responsive launch capabilities for bio-tech, lunar and other small spacecraft payloads of interest to civil, commercial, and university commercial users.

In August 2006, AirLaunch signed a Memorandum of Understanding with NASA Ames Research Center to explore collaborations in space launch systems and payloads launched from aircraft. NASA Ames Research Center is seeking partnerships to promote the development of a robust commercial space industry to benefit and support NASA's exploration mission goals, in particular to help provide sustainable exploration. Under terms of the agreement, AirLaunch and NASA Ames will explore areas of collaboration to include mission, vehicle, and payload concept analyses; systems engineering; and payload integration, as well as use of NASA Ames facilities, such wind tunnels, arc-jet facility, flight simulators, hangars, and runways.

Summary

AirLaunch's innovative process leads to growth opportunities and new markets for operationally responsive space. Its QuickReach™ vehicle is specifically designed to meet the needs of the DARPA / US Air Force Falcon Small Launch Vehicle program, capable of delivering 1,000 pounds to low earth orbit for \$5 million per launch, with a 24-hour response time. AirLaunch's approach achieves responsiveness by flying the two-stage, pressurized QuickReach™ system inside an unmodified C-17A or other large cargo aircraft and deploying from the aircraft using Gravity Air Launch. AirLaunch provides a responsive, flexible Concept of Operations for multiple payloads, with short call-up to launch and multiple azimuth capability which avoids operational issues associated with current ranges.

AirLaunch has successfully completed Phases 1, 2A, and 2B of the Falcon SLV program. In total, AirLaunch has completed 2 stage separation tests; assembly of the integrated LOX/propane tankset for stage two and the vertical test stand; 34 engine test firings on the Horizontal Test Stand and 5 test fires of its Integrated Stage 2 on the Vertical Test Stand; assembly of the payload fairing and payload fairing separation test; series of ground drop tests and 3 record setting C-17 drop tests with a simulated full-scale, full-weight QuickReach™ rocket; and an Incremental Critical Design Review.

AirLaunch's significant hardware and testing to date can be attributed to the rapid prototyping process and milestone-based approach used in the Falcon SLV program. Technical and safety issues are addressed systematically, including use of Mil-Std safety processes.

AirLaunch welcomes payloads interested in flying on the test and early launches of the QuickReach™ system. The first test flight, with a live launch to LEO, is anticipated at the end of Phase 2D. Small payloads may fly together or in a ride-share arrangement, subject to coordination with the primary DARPA/Air Force Falcon SLV program customer. The first launch is expected to be conducted out of Wallops. Future launches of the Operational System may be conducted out of Wallops or any other site with a runway suitable for a large cargo aircraft.

Acknowledgements

AirLaunch LLC acknowledges the contributions of all members of Team AirLaunch shown in the map below, as well as employees and independent contractors.

AIRLAUNCH

NASA AMES RESEARCH CENTER
Small Payload Collaboration
Moffett Field, CA

WESTERN MAILLER
Ground Transporters
Boise, ID

Mojave Airport
Test Facilities
Mojave, CA

PROTECH
Instrumentation, Testing & Integration
Mojave, CA

SPACE VECTOR
C-17 Drop Tests
Edwards AFB, CA

SCALED COMPOSITES
Storage & Launch Carrier, Vehicle Components & Integration Support
Chatsworth, CA

BOEING
C-17 Performance Group
Long Beach, CA

USL
Avionics
Newport Beach, CA

SPACE MICRO INC.
Flight Computer
San Diego, CA

freeflight
Parachute Risers
Lake Elsinore, CA

UC DAVIS
Extraction Dynamics & Computational Fluid Analysis
Davis, CA

Program Management Systems Engineering Design & Integration
Kirkland, WA

HMX
Engine Design & Development
Reno, NV

Compositex
Thrust Chambers
Sandy, UT

Space Command
Colorado Springs, CO

Contract Management & C-17 Analysis
Wright Patterson AFB, OH

DARPA

U.S. AIR FORCE
Joint Falcon Program Management
Arlington, VA

Spincraft
Aluminum Tanks
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DELTA VELOCITY
Drogue Parachutes
South Windsor, CT

Payload Operations & Safety Support
Purcellville, VA

NASA WALLOPS FLIGHT FACILITY
Range Coordination
Wallops Island, VA

Orion
Propulsion GSE Test Support
Huntsville, AL

C-17 HQ
Scott AFB, IL

BMT
Drop Test Article
Albuquerque, NM

THE UNIVERSITY OF ARIZONA
Wind Tunnel & Model Testing
Tucson, AZ

SMC/Deputy Program
El Segundo, CA

ITS
Systems Engineering
Gardena, CA

IRVING AEROSPACE
Drogue Parachutes
Santa Ana, CA

NEAR
Computational Fluid Dynamics Analysis
Mountain View, CA

Drop Test Article
Los Angeles, CA

Nose Cone
Mojave, CA

Thrust Chamber Assemblies
Costa Mesa, CA

SMC/Space Dev & Test Wing
Drop Test T & E Support
Kirkland AFB, NM

Experienced Team Working Together