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Trade Studies for Air Launching a Small Launch Vehicle from a Cargo Aircraft

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Abstract

This paper describes the concept trade studies that AirLaunch LLC conducted during their Phase I study for air launching an earth-to-orbit launch vehicle for the DARPA/USAF FALCON program. AirLaunch LLC has proposed a rocket carried by and launched from an existing military cargo aircraft for this program. A new method, called Gravity Air Launch (GAL), is proposed that greatly improves simplicity, safety, and reliability of air launching from an unmodified cargo aircraft as compared to existing methods that rely on standard heavy equipment airdrop procedures and equipment. Unlike standard airdrop methods, GAL imparts much of the carrier aircraft's altitude and airspeed onto the rocket, which in turn improves payload mass to orbit.

Introduction

In June 2003, the Defense Advanced Research Projects Agency (DARPA) solicited proposals for a six-month Air Force FALCON program. The FALCON program objectives are to develop and demonstrate technologies that will allow the country to execute time-critical small satellite launch missions. Near-term capability will be accomplished via development of a rocket boosted, expendable launch vehicle for rapid launch of satellites for both civilian and military missions.

In September 2003 DARPA selected 9 companies for six month Phase I studies for a Small Launch Vehicle (SLV) that could place satellites at the required altitude and velocity. In September 2004, DARPA held an open competition and selected 4 companies for

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further Phase II studies and demonstrations leading to a SLV Preliminary Design Review.

The FALCON program hopes to develop a low cost, responsive SLV and demonstrate it in a series of flight tests culminating with the launch of a functional payload. In addition, this SLV would be capable of launching small satellites into a sun synchronous orbit as well as easterly low earth orbits. The SLV must be at least an order of magnitude more responsive than existing launch systems and must have low launch cost.

In response to DARPA's request for proposals, AirLaunch LLC proposed a SLV carried by and launched from an existing military cargo aircraft. AirLaunch LLC was selected to conduct a Phase I study and has also been selected for further Phase II studies and demonstrations.

The purpose of this paper is to describe the Phase I concept trade that AirLaunch LLC conducted to downselect its method of extracting and launching their SLV, the *QuickReach*, from a cargo aircraft.

Air, Ground, and Sea Launch Trade

The air launch method was selected during our pre-Phase I proposal trades because it was, in our opinion, the only method that was guaranteed to meet FALCON's responsiveness goals; see Table 1. As a bonus, air launch could also provide all-azimuth launch capability, and meet mission requirements without any major infrastructure expenditures. Only two C-17 aircraft are needed to meet current FALCON mission launch requirements (16 launches within 24 hours).

Ground launch was ruled out due to its inability to meet FALCON responsiveness goals at all times. Current range policies do not permit a launch if there is maritime traffic within the potential impact zone of a SLV's lower stages, regardless of the fact that official notices were given. Also official notices take several days, which means a ground launch can never be responsive. There are also weather conditions, especially winds aloft conditions, which can prevent a responsive ground launch. Ground launch was also ruled out due to high range costs and the difficulty in meeting surge requirements without major range and launch pad infrastructure investments.

One USAF Operationally Responsive Spacelift (ORS) objective is to support achievement of any earth-centered orbit in 24 hours or less. A ground launch cannot support the achievement of any earth-centered orbit within 24 hours because of the geographic constraints imposed by the launch ranges - only easterly launches are possible from Canaveral and southerly launches from Vandenburg.

In contrast, air launch can occur over the open ocean, sufficiently far from crowded sea-lanes near the shore. There are large offshore areas in which there is no ocean maritime traffic. The launch point can be easily moved so that there is no maritime traffic at either the launch point or at the first stage impact point. An air launch carrier aircraft can fly around or over launch constraining weather, and in any case, the C-17 aircraft can air drop in any weather, day or night. Air launch allows positioning of the launch point to intercept an orbital plane that has the desired over flight conditions on the first orbital pass. Any runway of suitable length can serve as a launch site, missions are recallable, and the carrier aircraft can serve as the SLV transporter if needed. Air launch provides advantages such as eliminating acoustic reflection from the ground and up to a 30% improvement in payload to orbit - these features can reduce costs. Finally, there are no major infrastructure expenditures required for *QuickReach* to meet FALCON surge requirements.

Sea launching was ruled out due to very high capital cost of deploying SLV's at sea.

Candidate Aircraft Trade

The Boeing C-17A GlobeMaster III is the preferred carrier aircraft for *QuickReach* operations; see Table 2. At least four modern transport aircraft are capable of carrying one or more *QuickReach* SLVs. Three of these are in active USAF inventory (C-141, C-17, and C-5) while the fourth is available commercially from two sources (An-124). The An-124, C-5, and C-17 can each lift two *QuickReach* vehicles at a time, but only the C-17 can launch two in one mission. The C-5 and An-124 would have to have their cargo compartment petal doors either removed or modified to launch two *QuickReach* vehicles in one mission. Although the C-141 is currently in service, in three years the inventory of C-141 aircraft will be zero.

The C-17 is preferred because C-17 production is ongoing, all training and depot services are in place and being maintained, the C-17 offers considerable growth margin, and the C-17 is currently in use for SRALT (Short Range Air Launch Target) and LRALT (Long Range Air Launch Target) air launches.

Air Launch Method Trade

Air launch from an existing cargo aircraft was selected during our pre-Phase I proposal trades because this method allows the launch of the largest possible SLV (up to 87,320 lbs already demonstrated) from an <u>unmodified</u> aircraft; see Table 3. The next best method, which involves dropping a rocket from an aircraft's pylon, has demonstrated only a 51,000 lb capability, but only when launched from a highly modified and one-of-a-kind Lockheed L-1011 aircraft. From an unmodified B-52 bomber, 25,000 lbs is possible, and from a F-15 fighter only 10,000 lbs. A rocket released from either the B-52 or F-15 is too small to meet FALCON payload goals with current technology solid rocket motors. Other air launch methods, which include carriage of a rocket on top of a launch aircraft, towing a rocket, and aerial refueling, require modifying the carrier aircraft and require a multi-stage SLV with wings and either a pilot or sophisticated flight control system in the 1st stage. Since these air launch methods required custom launch aircraft, they could not meet FALCON development cost goals.

Launch from an existing cargo aircraft was also selected because there are no external indications that a standard cargo aircraft is carrying a SLV.

Propellant boil-off concerns are minimized since the SLV is not subject to either radiation heating from the sun or convective heating from the air stream. The benign environment inside the carrier aircraft allows maintenance and safety problems to be detected prior to launch.

Launch Direction Trade

We choose a forward facing launch because of its numerous advantages; see Table 4. Payload can be up to 30% larger with a forward facing launch as compared to a ground launch. An aft facing launch from a cargo aircraft only improves payload by less than 10%. A forward facing launch means the payload can be saved in the event that the rocket needs to be jettisoned during an emergency. This method also eliminates dropping an expendable launch sled that weighs several thousand pounds and costs several $100,000. An aft facing launch requires such a sled to protect the rocket nozzle during extraction. Reliability and safety are improved since <u>all</u> parachute disreefings, explosive cut-a-ways, and explosive line cutters are eliminated with a forward launch. Finally, forward facing launch subjects the rocket to only 0.1 g loads. Parachute disreefings can cause over 3 g loads for an aft facing launch.

Orientation Method Trade

Orientation refers to positioning the launch vehicle to the correct attitude after it exits the aircraft. We studied 6 different methods to orient QuickReach including fins, reaction control system thrusters installed in the rocket, and a static line that would involve connecting the aircraft and SLV together with a line; see Table 5. We even examined a method called Somersault that would involve waiting until the rocket revolved to the proper attitude before starting the engine. We picked a stabilizing parachute because it was a simple, passive, lightweight, and an inexpensive method to orient the rocket to the correct attitude relative to the local horizon.

In our selected method a small drogue chute is deployed and its proper inflation is checked prior to releasing the SLV. The orientation chute is currently base lined as a standard 15-ft diameter drogue chute that is used for USAF and Army airdrop missions. The chute is reefed to provide the correct amount of force to stop the rockets pitch-up as it exits the aircraft. The chute will be stored and released from the C-17 recessed Parachute Deployment Mechanism (PDM). The C-17 has two PDM's located on either side of its cargo ramp. The chute is deployed hydraulically by an electrical signal from the loadmaster or the pilot, although a manual backup is provided. Once deployed, the chute remains attached to the aircraft via a tow release mechanism at the end of the ramp. The C-17 has a small IR video camera installed within the end of the ramp to allow the loadmaster to verify the condition of the chute on a small monitor at the forward loadmaster station. An IR lamp is also installed in the ramp to illuminate the chute for viewing in darkness. Should a decision be made to abort the launch, the tow release allows the chute to be jettisoned. A backup guillotine provides an emergency riser cut option. In the event that the chute cannot be released and the mission is aborted, the C-17 is capable of towing and landing with a 15 ft diameter chute deployed and in tow. If the chute is OK and the decision is to launch, then either the pilot or loadmaster can release the tow release and transfer the parachute load to the rocket.

Extraction Method Trade

A simple, safe, reliable, and low cost method was sought to extract the launch vehicle from the C-17. We examined 5 different methods including 3 different means of pneumatic launch; see Table 6. Although high pressure pneumatic gas is used to successfully launch missiles from ground silos and from submarines we did not select these methods because of the extensive aircraft modifications needed. We also did not select parachute extraction because of a concern for tip off. If a parachute extraction experiences a chute failure and the launch vehicle is rolling out of the aircraft at a slow rate, then the front end of the rocket can rise and contact the aircraft structure.

Gravity was selected because it was simple, safe, reliable, and low cost. Airdrops of 60,000 lb loads have already been successfully dropped from the C-17 using only gravity for extraction. The aircraft flies at a 5 to 7-degree deck angle, and the rocket rolls out due to the afterward component of gravity. End speeds are 20 to 25 feet per second, depending on deck angle.

Carriage Method Trade

A reliable, low cost, and simple carriage method was sought that did not introduce point loads onto the vehicle. We examined 4 different methods; see Table 7. Air injection levitation was not selected because it involved the SLV riding on a cushion of air and requires an active air source that would leave the rocket stuck if it were to fail during the extraction. Levitation also could not handle the concentrated tip off loads at the teeter point when the rocket is halfway out of the aircraft. An alternate method that we rejected is rail carriage that would consist of a rocket with very strong and relatively heavy strakes on either side of the rocket rolling on wheels with flanges. A third rejected method was a launch sled that rolls on the aircraft's roller trays. Such a sled would not separate from the SLV during a forward facing launch since the sled's ballistic coefficient (weight divided by drag area) is much less than the rocket. The sled's weight would also be 10 to 20% of the rocket's weight and would generate a lot of TFOA (Things Falling Off of the Aircraft).

Our selected carriage method is reliable, low cost, and simple and its cushioned extraction does not introduce point loads onto the launch vehicle. It has the rocket rolling directly on wheels and pneumatic tires. The wheels remain in the aircraft. Only SLV and orientation chute leave the aircraft. By definition, a pneumatic wheel cannot exert more pressure on the side of the rocket than the tire's internal pressure. Also pneumatic tires will self adjust so that each wheel is supporting roughly an equal portion of the load. Pneumatic tires can deal with bumps on the side of the rocket with little problem. A single flat tire also causes no problems.

Pneumatic tires also reduce C-17 cargo ramp loads. *QuickReach*'s 17.5 inch diameter tires eliminates many of high frequency accelerations that the C-17 normally experiences during an airdrop that are caused by bumps on the underside of cargo pallets rolling over the aircraft's installed 2 inch diameter solid metal rollers.

Storage and Launch Canister

A ship and shoot Storage and Launch Canister (SLC) concept has been developed for *QuickReach*; see Figure 1. The SLC is mated to the rocket at the factory and unless depot repair is required, it never separates from the rocket until extraction. The SLC and *QuickReach* form a "Wooden Round" similar to Joint Direct Attack Munitions (JDAM) or a M26 Multiple Launch Rocket System (MLRS). The SLC and rocket are a self-contained system that has a long shelf life, require minimal field assembly or inspection before use, and are produced for low cost. Since they are stored with no propellants, they are considered as insensitive munitions.

The SLC consists of a machined and welded aluminum frame. The SLC is compatible with the C-17A logistic rails, and like a Type 463L pallet, the SLC is 88 inches wide at the base. Hence two SLC's can be loaded side by side in the C-17A. The empty weight of the SLC is less than 10,000 lbs, which means that the C-17 has sufficient cargo lift capability to carry two SLCs and *QuickReach*'s plus additional cargo. There is sufficient room on either side and over the SLCs that a person wearing a parachute can get from the forward end of the aircraft to the rear end when two SLCs are carried.

The rocket rests on approximately 100 tire/wheel assemblies located inside the SLC. These assemblies are actually off the shelf aircraft nose wheels. The tires are pressurized to about 135 psi, thus avoiding concentrated loads. The teeter station has 12 tire/wheel assemblies arranged in 3 closely spaced rows to distribute the load as the rocket crests the end of the ramp. There are sufficient number of tires in contact with the rocket that it is restrained to, in accordance with Mil-Handbook 1791, "Designing for Internal Aerial Delivery in Fixed Aircraft," 4.5 g down, 2.0 g up, 1.5 g laterally, and 3.0 g forward and aft.

There are no explosive cut-a-ways or pyrotechnic cutters inside the SLC. The rocket is restrained in the fore and aft direction with latching pin release that is identical to that used on the Saturn V launch umbilical tower to restrain the Saturn V prior to liftoff.

The SLC is stored inside a Transporter. The Transporter width is 102 inches which means it can loaded onboard a C-17 with a SLC, i.e., the Transporter loads a rocket and SLC on one side of the aircraft, and then the Transporter is loaded on the other side. Thus a single C-17 can forward deploy an entire *QuickReach* launch system. The Transporter also meets highway requirements, i.e., height less than 13.5 ft, width less than 8.5 ft, and length less than 53 ft, taillights, and remote brakes, so that the rocket and SLC can be moved to and from the factory or depot by truck, rail, or sea transport.

Comparison with Current Methods

The current method of air launching rockets is to use standard heavy equipment airdrop procedures and equipment and to use parachutes to extract a rocket that is strapped onto an expendable sled. The SRALT (Short Range Air Launch Target) and LRALT (Long Range Air Launch Target) programs and the 1974 C-5A and Minuteman missile air launch demonstration used this method. Standard procedures are designed to slow down a load and lower it gently to the ground. This is opposite of the performance goal for air launching, which is to impart as much of the launch carrier aircraft's altitude and airspeed onto the rocket as possible.

The *QuickReach*'s launch method imparts maximum energy from the aircraft onto the rocket, while at the same time it greatly improves the simplicity, safety, and reliability of air launching from an unmodified cargo aircraft. It also eliminates dropping massive amounts of hardware into the ocean at every launch. Table 8 summarizes the differences between these launch methods.

Summary

A new method, called Gravity Air Launch (GAL), has been proposed that greatly improves simplicity, safety, and reliability of air launching from an unmodified cargo aircraft as compared to existing methods that rely on standard heavy equipment airdrop procedures and equipment. Unlike the standard 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.

Acknowledgments

The authors would like to thank Mr. Tom Brosz of AirLaunch LLC for his contribution of the first page illustration and Mr. Tom Ring of Space Vector Corporation for his contribution of Figure 1.

Table 1. Air Launch meets Falcon Program Requirements

FALCON Requirements	Air Launch	Ground Launch	Sea Launch
Payload of 1,000 lbs to 100 nm, due east reference orbit launched from 28.5 deg latitude	Yes	Yes	Yes
Cost less than $5 million assuming 20 launches per year for 10 years, including all costs inc. fee that would be charged to a customer & any costs associated with launching from a test range or using range assets	Yes for *QuickReach*.	Maybe. However, historical data shows that range and "catch-all" mission support costs are already at $1.5 million for a ground launched Taurus. The cost of launch vehicle must be added to this	No. To achieve alert status within 24 hours of call-up, a ship must be deployed. 3 ships are required to maintain 1 ship deployed. Operational costs of each ship is roughly $2 M per month (assumes Ticonderoga class vessel)
Provide orbital insertion accuracy of ± 13.5 nm, ± 0.1 deg inclination	Yes	Yes	Yes
Accommodate a 40 inch diameter by 60 inch height spacecraft	Yes	Yes	Yes
Achieve alert status within 24 hours from call up	Yes. *QuickReach* can readied and loaded onboard a C-17 within 24 hours	Yes. Demonstrated with Minuteman, Thor, Atlas, Titan missiles	Maybe. Steaming a ship to a position so that it can achieve an all-azimuth launch may take >24hr
Launch satellite within 24 hours from alert status	Yes. C-17A can be positioned so that no maritime shipping interferes with a responsive launch	No. Maritime shipping in vehicle's lower stage splash down areas can prevent a responsive launch	Yes. Launch ship can be positioned so that no maritime shipping interferes with a responsive launch
Launch in less than 2 hours from alert status once execution order received	Yes	No. Maritime shipping in vehicle's lower stage splash down areas can prevent a responsive launch	Yes
Accommodate a high rate of 16 launches in 24 hours	Yes. Two C-17 aircraft can launch 2 SLVs per aircraft every 6 hours for 16 launches in 24 hours	Yes, but requires major infrastructure investment to provide 16 launch pads	Yes, if ship designed for 16 launches

Table 2. Candidate Aircraft Trade

Capabilities	C-17A	C-5	C-141	An-124
FY07 Inventory	134	126	0	17
# of launches in 1 mission	2	1	1	1
Gross Weight (lb)	585,000	840,000	343,000	892,857
Empty Weight (lb)	277,000	374,000	148,120	385,802
Maximum Payload (lb)	169,000	270,000	70,847	330,688
Unit Air Drop (lb)	72,000 (Note 1)	87,320	38,500	110,000
Service Ceiling (ft)	45,000	35,750	41,600	35,000 +
Cost ($/hr)	5,979	10,729	4,553	10,000
Note 1: The C-17 has demonstrated an airdrop of 60,000 lb as one unit, but this limit was due to the maximum number of descent parachutes (12) that could be put on a load. The ramp is structurally capable of 72,000 lb in normal operational use since that is the size of the loads that can be transferred across it on the ground.				

Table 3. Internal Air Launch from a Cargo Aircraft was selected for QuickReach

Results of Air Launch Method Trade Study	
	**Internal Air Launch from a Cargo Aircraft** Advantages include launch of the largest possible launch vehicle (up to 87,320 lbs already demonstrated) from a unmodified aircraft and no external indications that the cargo aircraft is carrying a launch vehicle. Propellant boil-off concerns are minimized since the launch vehicle is not subject to either radiation heating from the sun or convective heating from the air stream. The benign environment inside the carrier aircraft allows maintenance and safety problems to be detected prior to launch. An 84,289 lb LGM-30A Minuteman I missile and launch sled was successfully launched on 24 October 1974 from a C-5A Galaxy.
	**Captive on Bottom** Launch vehicle size is limited to 25,000 lbs from an unmodified B-52 wing pylon or 51,000 lb from a modified L-1011. Advantages include proven and easy separation from the carrier aircraft. Disadvantages include limits to launch vehicle size due to under the carrier aircraft clearance limitations and the high cost of carrier modifications for launch vehicles greater than 25,000 lbs. A new design carrier aircraft with tall landing gear can eliminate the clearance limitations. Examples include the X-15, X-34, Pegasus, and SpaceShipOne.
	**Captive on Top** No examples have been actually built, but the Space Shuttle's approach and landing demonstrator, the Enterprise, used this method. Advantage is the capability to carry a large launch vehicle. Disadvantages include the extensive modifications (high cost) to the carrier aircraft, the need for active launch vehicle controls at release to prevent hitting the aircraft, and wings large enough to support the launch vehicle at separation from the aircraft. Alternately a high performance carrier aircraft can eliminate the rocket wings by staging above the atmosphere. However, external carriage of the rocket destroys the fuselage lift and causes a large amount of drag that in turn limits launch altitude. The Enterprise was launched at 19,000 to 26,000 ft even though a clean 747 normally cruises at 38,000 to 45,000 ft.
	**Towed** Advantage is easy separation from the towing aircraft. Disadvantages are some modifications to the towing aircraft, the need for wings and wheels on the launch vehicle that are sized for takeoff with a full propellant load, and the need for a multi-stage launch vehicle with either a pilot or sophisticated flight control system in the 1st stage to maintain position behind the towing aircraft. Safety concerns include broken towlines and a towing aircraft takeoff abort. One of the first occurrences of towing a rocket-powered aircraft was during the summer months of 1942 at Peenemünde, Germany when twin-engine-powered Bf-110C fighters were used to tow prototypes of the Me-163 rocket fighter for flight tests, typically to altitudes of 16,000 ft.
	**Aerial Refueled** Only proven for kerosene fuels with cryogenic propellants like liquid oxygen having the potential of freezing the refueling probe to the refueling line. Aerial refueling reduces the size of a launch vehicle's landing gear and wing, but it does not reduce the size of the jet engines which must be large enough to maintain level flight for the fully fueled vehicle, and aerial refueling does not reduce the strength of the wings, which must be strong enough to support the fully fueled weight (hence wing weight is only partially reduced with aerial refueling). A multi-stage vehicle is needed with either a pilot or a sophisticated flight control system in the 1st stage to maintain position behind the refueling aircraft.
Balloon Balloon launch requires operating a very large balloon. Launch can occur only on calm days. Since the balloon comes back unmanned, the potential of damage to either the balloon or to things on the ground is high. Experience from round the world ballooning attempts have demonstrated that the balloons cannot be reused.	

Table 4. Forward Launch in Level Flight selected for QuickReach

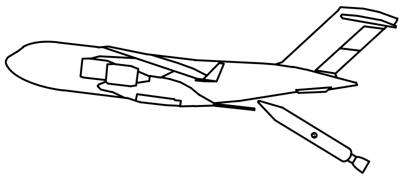
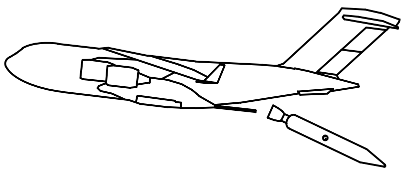
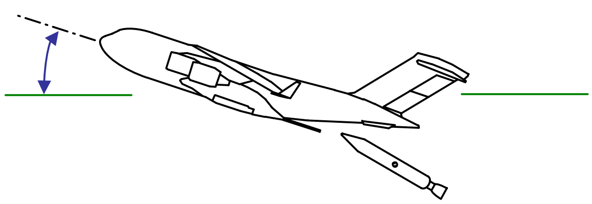
Results of Launch Direction Trade Study
 **Forward Facing Launch** Forward facing launch was selected due to its numerous advantages. Compared to a ground launch, payload can be up to 30% larger. The payload can be saved in the event the rocket needs to be jettisoned during either an aircraft or rocket emergency. This method eliminates dropping an expendable launch sled that weighs several thousands of pounds and costs several hundreds of thousands of dollars into the ocean. Reliability and safety are improved since all parachute disreefings, explosive cut-aways, and explosive line cutters are eliminated.
 **Aft Facing Launch** Although aft facing launch is currently used, this method was not selected because of its numerous disadvantages. Aft facing only improves payload mass by 10%. It subjects the rocket to high accelerations caused by parachute disreefings. The payload cannot be saved in the event of a rocket jettison, an expendable launch sled is required to protect the rocket's nozzle during extraction, and reliability and safety are lowered due to the numerous parachute disreefing, explosive cut-aways, and explosive line cutters required.
Level Launch Although payload mass is less, a level launch was selected because launch timing is not critical and less aircrew training is required.
 **Zoom Climb Launch** Although a zoom climb launch can improve *QuickReach* payload to orbit by 7 lb for every 1 degree of aircraft flight path angle, it was not selected because of the need for a highly trained crew that can execute a critically timed maneuver. A zoom climb would start with a 1.8 g level pull-up starting at Mach 0.6 (250 KIAS) and typically at about 23,000 ft altitude. After 10 seconds, the aircraft would have pitched up 25 degrees, climbed 1,500 ft, and slowed to about 220 KIAS. The rocket would be released at this point while the aircraft completes a turn and dive to escape.

Table 5. A Stabilizing Parachute was selected as the Best Method to Orient the QuickReach

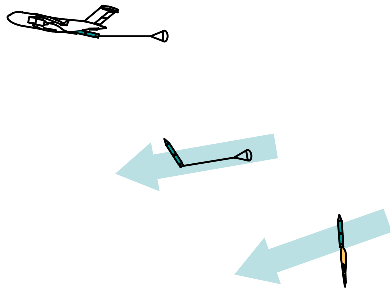
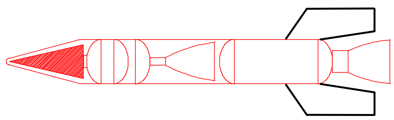
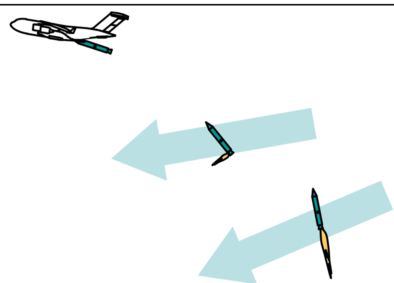
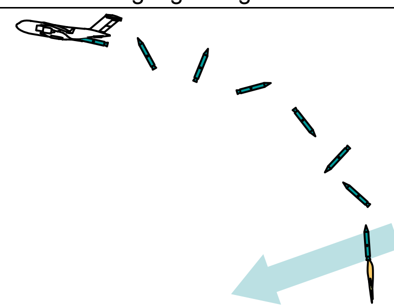
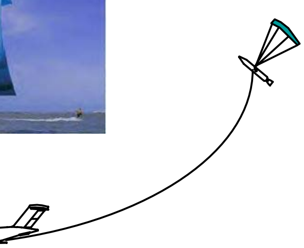
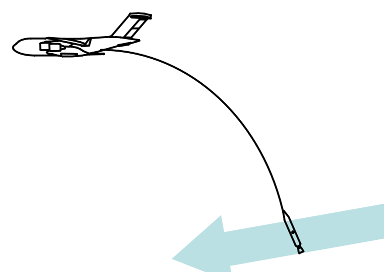
Results of Orientation Trade Study
 **Stabilizing Parachute** A stabilizing parachute was the selected orientation system because it is a lightweight, reliable, and passive system. A small drogue chute is deployed and its proper inflation is checked prior to releasing the rocket. The orientation chute is currently base lined as a standard 15-foot diameter drogue chute that is used for USAF and Army airdrop missions. The chute is reefed to provide the correct amount of force to stop the rockets pitch-up as it exits the aircraft. The parachute risers are attached to the 1st stage nozzle and are released by the simple expedient of having the risers burn off at engine start (previously demonstrated in 1997). Parachute riser loads onto the nozzle are less than 10% of the engine thrust loads.
 **Fins** Fins large enough to stabilize a launch vehicle without the engine producing thrust are too large to fit inside the aircraft. After the engine starts, then they are too large to allow the launch vehicle to fly the optimum trajectory for best payload. Lattice fins were investigated and found to have poor capability at high angles of attack, as well as having high drag.
 **Reaction Control System (RCS)** The RCS thrusters would have to be large, about 4,000 lbf thrust for a 145 KIAS launch and 15,000 lbf for a 250 KIAS launch. This orientation method was also dropped because of the need for an active control system.  **Somersault** This method relies on waiting until the vehicle rotates to the proper pitch attitude before firing the engine. Simulation shows that this involves too much time, which meant too high of a downward velocity, which adversely effects payload to orbit.
  **Sling Blade** The Sling Blade concept could potentially increase inserted mass to orbit. It was dropped from consideration due to the need for an active control system and difficulties with deploying the kite.  **Static Line** The Static Line concept consisted of a line attached to the launch vehicle's nose and at the other end to a water brake (similar to those used in engine dynameters). This concept was dropped because the aircraft cannot maneuver until after the launch vehicle's engine is ignited.

Table 6. Gravity was selected as the Best Method to Extract the *QuickReach*

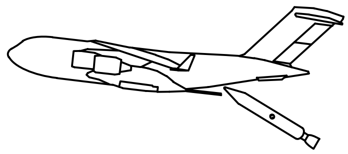
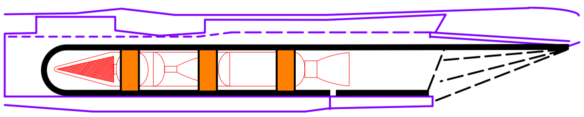
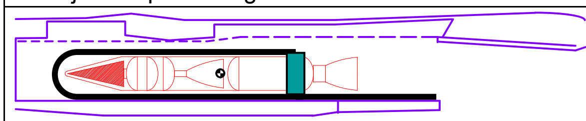
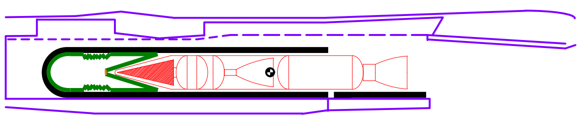
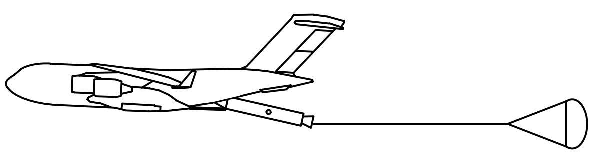
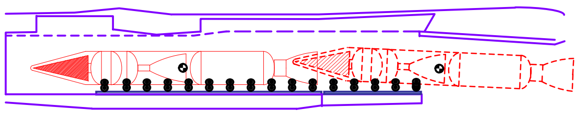
Results of Extraction Trade Study
 **Gravity Air Launch (GAL)** A simple, safe, and reliable extraction method was sought that would allow the extraction. Gravity has been around for billions of years so it is very reliable. Jettison of loads up to 60,000 lbs using gravity as the only means of extraction have already been demonstrated using the C-17A. The aircraft flies at a 5 to 7-degree deck angle, and the load rolls out without assistance from any other force.
 **Pneumatic Launch using Sabots** The drawing at the left is the cargo bay of the C-17. A high velocity and high pressure pneumatic launch tube using Sabots has been successfully used to launch missiles from ground silos and from submarines. The Sabots (shown in orange) surround the launch vehicle and prevent the high-pressure air used to eject the missile from escaping pass the vehicle. The use of sabots meant that the tube would have to be extended all the way out of the aircraft, otherwise sabot debris could damage the inside of the aircraft's cargo compartment. This method was not selected because to extend the tube aft meant extensive aircraft modifications. Modifications included a modified aft ramp, an inflatable bellows plug, and a roll-up muzzle door. In addition, the pressure needed to effect the ejection placed high loads on the launch vehicle's payload faring.
 **Pneumatic Launch using a Muzzle Seal** An improved method of using pneumatic ejection that eliminated the need to extend the tube all the way out of the aircraft was found. In the Muzzle Seal version, the sabots are eliminated and replaced with a muzzle seal (shown in blue) that is fixed to the open end of the launch tube. This method could be used without any aircraft modifications. However it was not selected because the requirement for a smooth vehicle body to allow the use of a muzzle seal became a problem.
 **Pneumatic Launch using a Bellows** In the Bellows version the muzzle seal is now replaced by a low pressure balloon or bellows located in front of the launch vehicle. The launch vehicle is pushed out as the balloon is inflated. This method does not require a smooth launch vehicle body. As the QuickReach mission trajectory analysis and orientation analysis matured, the rocket end speed requirement continually dropped from an initial value of 100 fps relative to the aircraft to about 20 fps relative to aircraft. The pneumatic tube approach was eventually deselected for risk given that the simpler and more reliable gravity air launch (GAL) met requirements.
 **Parachute Launch** Parachute extraction was not selected because of the concern for tip off. If a parachute extraction experiences a chute failure and the launch vehicle is rolling out of the aircraft at a slow rate, then the front end of the rocket can rise and contact the aircraft structure. Also large parachute forces prevent the pendulum motion needed to pitch the rocket up to the proper nose up attitude for engine start.

Table 7. Tires and Wheels were selected as the Best Method for QuickReach Carriage

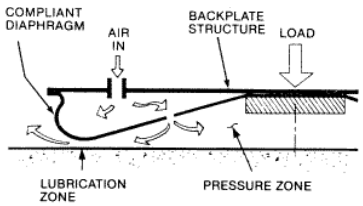
Results of Carriage Trade Study

Wheels and Pneumatic Tires



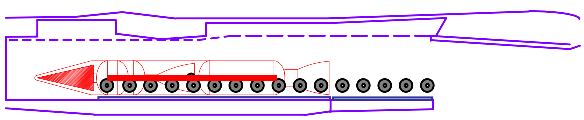
Our selected carriage method is reliable, low cost, and simple and its cushioned extraction does not introduce point loads onto the launch vehicle and reduce loads into the aircraft. It has the rocket rolling directly on wheels and pneumatic tires. The wheels and Storage and Launch Canister (SLC) remain in aircraft. Only rocket and orientation chute leave the aircraft. By definition, a pneumatic wheel cannot exert more pressure on the side of the rocket than the tire's internal pressure. Also pneumatic tires will self adjust so that each is supporting roughly an equal portion of the load. Pneumatic tires can deal with bumps on the side of the rocket with little problem. A single flat tire also causes no problems.

Air Injection Levitation



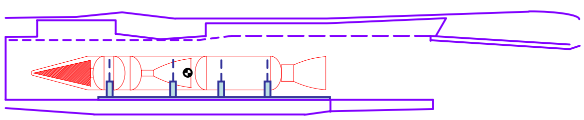
Air injection levitation requires an active air source that would leave the rocket stuck if it were to fail during the extraction. Levitation cannot handle the concentrated tip off loads at the teeter point. The rocket must be very smooth since air levitation has only small clearance tolerances. Also both the aircraft and rocket must be very rigid to avoid concentrating load onto one air levitation pad.

Rails



Rail carriage consists of locating wheels with flanges on either side of the rocket. The rocket has to have very strong and hard strakes on either side of the rocket. At the teeter point, all of the loads are concentrated at one location on the rocket's strakes, which means that they would be relatively heavy.

Expendable Launch Sled



In a forward facing launch, a launch sled that rolls on the aircraft's roller trays would not separate from the rocket. The sled's ballistic coefficient (weight divided by drag area) is much less than the rocket. The only way separation would occur is if the rocket and sled combination rolls 180 degrees as it pitches up. The sled's weight would be 10 to 20% of the rocket's weight and would generate a lot of TFOA (Things Falling Off of the Aircraft).

Figure 1. QuickReach's Storage and Launch Canister

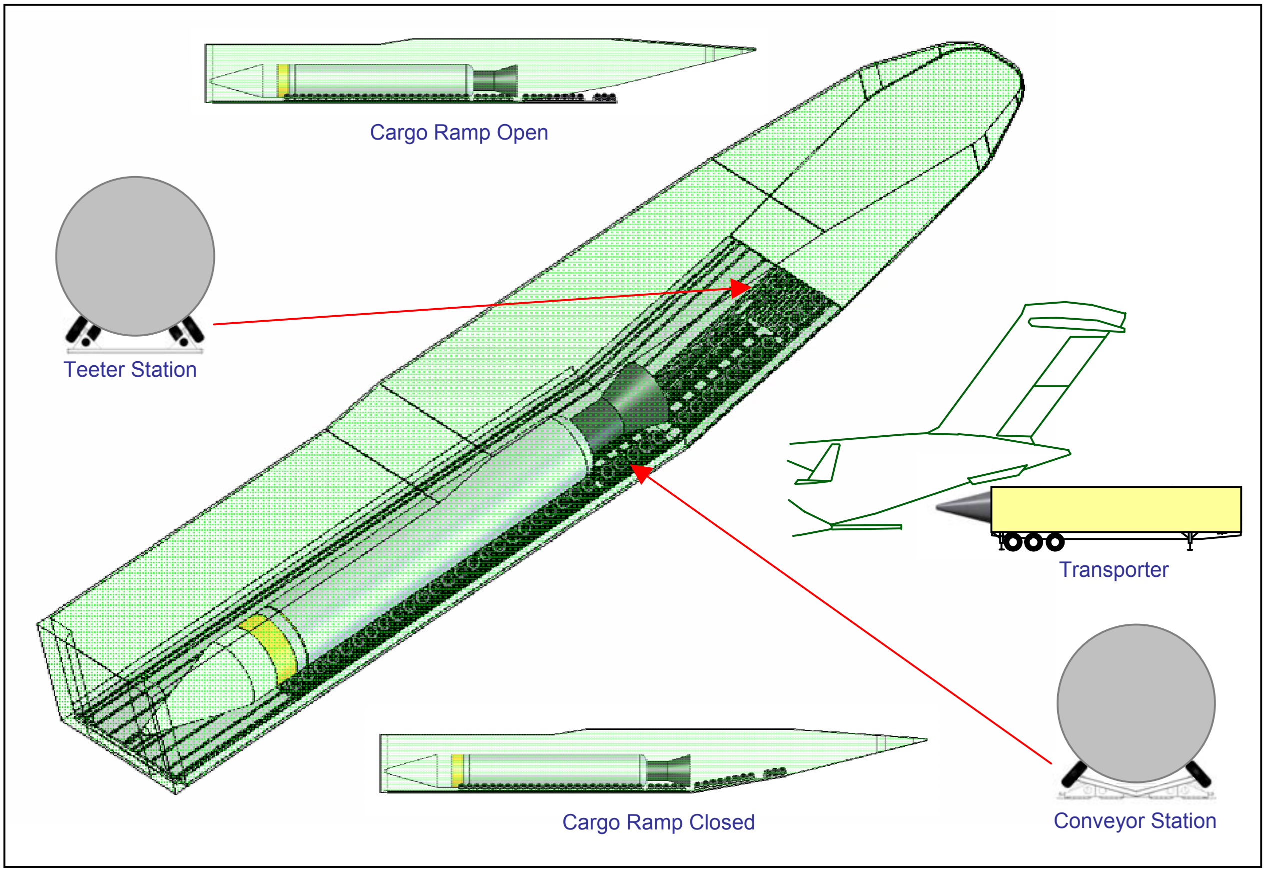


Table 8. Comparison of QuickReach's launch method with an existing air launch method

QuickReach	Comparison	SRALT / LRALT
None	Number of Explosive Cutaways and Explosive Line Cutters	More than 30
More than 30%	Payload Percent Increase to Orbit over Ground Launch	Less than 10%
Less than 25 lbs	Mass Dropped into Ocean	More than 6,000 lbs
None	Number of Chute Disreefings	11 (*Note 1*)
Up to 2	Number of SLV's Carried on C-17	Limited to 1 (*Note 2*)
2,000 lbs	Payload to Orbit	200 lbs (*Note 3*)
Two	Number of Stages	Three + (*Note 4*)
Less than 0.1 g	Acceleration Applied to Rocket during Extraction & Orientation	Greater than 3.0 g
Yes	Able to Jettison Rocket and Retain Payload	No

SRALT = Short Range Air Launch Target. LRALT = Long Range Air Launch Target.
Note 1: Includes 2 extraction chutes and 3 disreefings of the 3 descent chutes.
Note 2: SRALT / LRALT limited to C-17 Aerial Delivery System (ADS) centerline rails.
Note 3: Refers to Coleman Aerospace's Air Launched Orbital Delivery Vehicle (ALODV), which would consist of two SR19 motors and one Star 37 motor.
Note 4: Refers to ALODV. The Long Range Air Launch Target (LRALT) has two stages using two SR19 motors. Short Range Air Launch Target (SRALT) is a single stage using a single SR19 motor. SR19 motors are decommissioned Minuteman 2nd stages.