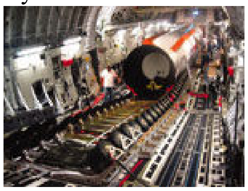
By Michael A. Dornheim



NEW PATH TO SPACE?

The Defense Advanced Research Projects Agency may be flight-testing an air-launched propane-powered rocket in 2-3 years as part of its Falcon concept to quickly and cheaply put 1,000 lb. of payload into orbit.

The novel Quick Reach I rocket was designed and may be built by the AirLaunch consortium of companies. AirLaunch and Darpa were in continuing negotiations last week and a company official expects a positive outcome soon.

Air launching has a history. In 1974 a partially-fueled Minuteman ICBM was dropped and ignited from a C-5 transport, and currently C-17s drop solid-rocket-powered Coleman targets for ballistic missile defense tests.

Late last month a full-scale dummy Quick Reach I was dropped out of a USAF/Boeing C-17 here as an operational check of the concept (AW&ST Oct. 3, p. 18). The Sept. 29 test was to ascertain if the rocket had adequate clearance to the C-17 as it slid off the aft ramp, see if it rotated to near the desired ignition attitude, and verify the motions were close to prior simulations.

Four companies were in the preliminary design and development phase (Phase 2A) of Darpa's Falcon small launch vehicle (SLV) project, which officially ended in July though activities continue. The Falcon SLV specification calls for enough performance to place 1,000 lb. into a 100-naut.-mi., 28.5-deg. inclination orbit from that latitude.

Darpa has not yet announced one or more winners for Phase 2B detail design, which Darpa program manager Steven H. Walker expects will run from fall 2005 to fall 2006. An orbital flight test would occur in a 2-2.5-year Phase 2C that may start in the first quarter of 2007, he says. Lockheed Martin, Space Exploration Technologies (SpaceX), and Microcosm are the other Phase 2A participants (AW&ST June 6, p. 20; Feb. 14, p. 21). These three companies' designs are all ground-launched.

Walker says an advantage of an air launch is the aircraft "can fly to the proper latitude and launch to any inclination with the least energy. It can put things where you want them." The relatively covert nature of a launch from an unmarked C-17 over the ocean is also of interest.

He notes potential drawbacks are that growth is limited by the size of the carrier aircraft, and the safety concerns about carrying and dropping a loaded liquid rocket.

The AirLaunch consortium includes HMX, Space Vector, Delta Velocity, Universal Space Lines, and Pacific Scientific. Gary C. Hudson is the Falcon Phase 2 program manager at AirLaunch and cofounder of HMX, which is designing most of the engines and tanks. He has started several attempts to build low-cost launchers, including the now-defunct Rotary Rocket Co. (AW&ST Oct. 25, 1991, p. 40)). Other key players include Bevin McKinney, the Phase 2 chief technical officer and chief engineer. He also confounded HMX and originated the Rotary Rocket concept. Marti Sarigul-Klijn is Phase 2 chief engineer for airdrop, and designed the technique to release the rocket from the C-17 and bring it to the proper ignition attitude.

The 65-ft.-long, 97-in.-dia. Quick Reach I weighs up to 72,000 lb. at ignition. The design has two stages and both use liquid propane and liquid oxygen (LOX) as propellants. The engines do not have expensive turbopumps to drive propellants into the combustion chambers from low-pressure tanks. Instead the tanks themselves are pressurized to force propellant flow.

PROPANE WAS CHOSEN because it will self-pressurize to 200 psia. at a practical 105F. That means the complexity and weight of a separate pressurization system, typically a flask of helium, is not required. The LOX tank similarly reaches 200 psia. at -233F. The propane/LOX combination has a relatively high bulk density to keep the size of the tanks small.

The engines are made of composites and slowly char inside as they run. This ablative cooling is cheaper than standard liquid cooling with its many fine passageways.

To keep the rocket short to fit in the C-17, the upper-stage engine is inside the first-stage propane tank, in contact with the fuel. Normally this engine would be in front of the first-stage tank, with the two stages connected by unpressurized interstage structure. For stage separation, Quick Reach I is to have a pyrotechnic cord sever the first-stage tank wall 2 ft. below where it transitions to the second-stage tank wall.

The first-stage engine produces an initial 171,000-lbf. vacuum thrust and the second stage makes 24,000 lbf. Chamber pressure in both is to be 150 psia. The engines have fixed nozzles but can vector thrust with a novel technique.

Tank structure is mainly 5000-series aluminum with composite overwrap of the warm propane section, where the aluminum is weaker than at the cold LOX sections. There are common bulkheads between the tank sections, with the propane tanks in the middle and the LOX on the ends. The temperature difference will be 338F across the LOX-propane bulkheads, and there will be about 1 in. of vacuum-sealed insulation on the propane side. Similar insulation is to be on the outside of the tanks and covered with fiberglass.

The clamshell carbon fiber fairing is to be made by Delta Velocity and weigh about 300 lb. The avionics shelf at the top of the second stage is to be made by Space Vector.

To make the 25,600 fps. speed of a 100-naut.-mi. orbit, the engines need to impart about 28,500 fps. to overcome the drag and gravity losses of an air launch, Sarigul-Klijn says. That's about 1,000 fps. less than a ground launch, comprising about 600 fps. savings from the air launch's altitude and speed, and 400 fps. for lower drag and gravity losses.

AirLaunch predicts a 72,000 lb. weight at ignition is enough to put 1,400 lb. into a 100-naut.-mi. 28.5-deg. orbit from that Cape Canaveral latitude. That's 2% of the initial weight, which is a reasonable payload mass fraction and more than the 1,000 lb. required by Darpa. But these estimates come from people with a track record of overly optimistic estimates, as exemplified by Rotary Rocket. Darpa has had independent checks made, but there is enough novelty that confidence is questionable until hardware is built and debugged.

The novel features have tradeoffs. The pressure-fed engines are simpler and cheaper, but the penalty is the tanks get heavier to withstand the pressure. Using self-pressurizing propellants is clever but loses performance. As the tanks drain and pressure drops, the fluid cools as liquid boils into vapor, further reducing the pressure, and thrust and efficiency drop off. The tanks are heavier than they need to be for the lower pressure of most of the engine run.

The submerged upper-stage engine is a clever idea used in the Russian R-27/SS-N-6 submarine-launched ballistic missile, which is also pressed to fit in a small space. The trick is making it separate without damaging the nozzle bell deep inside the tank or upsetting the attitude. "It violates every separation criteria," says one rocket expert. The bell will contact the tank with just a few degrees misalignment. The separation is to occur at an estimated 7,765 fps. at 161,000 ft., at a dynamic pressure of 70 psf. or 144 KEAS, enough to create significant aerodynamic forces. AirLaunch tested a pyrotechnic cutter on a generic aluminum tank at 20 psi. and reports a clean, straight separation that threw one half 150 ft. in the air. Hudson says "analysis and model testing have confirmed feasibility and full-scale testing will be performed within the program as well."

Liquid-fueled ablative engines are rare but were used on the Apollo lunar module ascent and descent engines, the Delta II second-stage engines, and others. They have also been chosen by Microcosm and SpaceX. The nozzle throat is under the most stress and conditions there should be more benign than in a solid rocket's ablative nozzle, where the flow is more abrasive. The mild 150 psia. chamber pressure will have a low heat flux giving low stress on the ablative, but the downside is that makes the engine big and heavy for the same thrust.

ENGINE EFFICIENCY benefits from the air launch at 33,000 ft. Designers want a high-expansion ratio nozzle for the maximum exhaust velocity and efficiency, but if they only have 150 psia. chamber pressure for lightweight tanks, then the pressure of the highly-expanded flow can drop below atmospheric before the end of the nozzle when near sea level, causing potentially disastrous flow separation. By starting the engine at 33,000 ft., where pressure is 26% that of sea level, they can have both lightweight tanks and a high-expansion nozzle without flow separation.

In operation, the launchers will be transported on normal 53-ft.-long tractor trailers. Minus nosecone and payload they fit completely inside, along with most other equipment for a launch.

The rocket sits on and rolls out of the C-17 on a set of 82 17.5-in.-dia. nosewheel tires, 52 of them on a removable chassis in the main cabin and 30 on a separate chassis on the aft ramp.

The launcher sits on the 52-wheel chassis most of the time, held down by fore and aft chains attached to a plate near the rocket center of gravity on each side. This chassis is fastened to the floor of the trailer for transport and storage.

To prepare for a mission, the payload-nosecone assembly is brought in a horizontal position to the front of the rocket, which is at the aft end of the trailer, and attached with a clamp band. Then the trailer takes the completed rocket to a fueling station to be filled with LOX and propane conditioned to the proper temperatures.

To load it on the C-17, the aircraft's rear ramp is set horizontal. The trailer is backed to the rear of the aircraft, with the nose cone pointing into the cargo bay. Jacks on the trailer raise it to be level with the C-17 and the aircraft's forward winch pulls the 52-wheel chassis and attached rocket into the bay.

The conveyor chassis is then secured, usually to the center Aerial Delivery System (ADS). The ADS has a set of guides and rollers for sliding airdrop packages out the back, but these are not used for a Quick Reach launch. It is the conveyor wheels that take the rocket out the back. The final step is to put the separate 30-wheel aft conveyor onto the rear ramp.

The rocket is extracted by a combination of gravity and a parachute, each providing about 0.1g of acceleration. It's important the rocket leave at a high enough speed that the nosecone doesn't jam into the aircraft ceiling as the rocket teeters off the edge. Extraction force is strong enough that even if one wheel jams, the launcher will leave with sufficient speed.

The goal is to put the rocket near a vertical attitude with low angular rates and then light the motor and let thrust vectoring maintain stability. The pitchup to vertical is achieved by the teetering as the rocket drops off the aft ramp. This pitch rate is halted at vertical by a properly-sized parachute attached to the engine nozzle. Large chines on the rocket are to make it weakly stable at 90 deg. angle of attack (AOA) and stabilize it in body axis roll at high AOA. When pitch rate starts to reverse, the engine fires and the chute is cut away.

The C-17 slows to fly at a 6-8 deg. nose-up angle at 33,000 ft., which requires extending the leading edge slats. Airspeed will be about 190 KEAS.

The chute is deployed, the chains holding the rocket are released, and it slides out, reaching about 30 fps. as it exits 5 sec. after release. The rocket reaches maximum pitch attitude about 3 sec. later and the motor fires. The rocket falls about 750 ft. before it starts climbing, and when it recrosses drop altitude 15 sec. after leaving the aircraft the C-17 is 1,300 ft. ahead, Sarigul-Klijn says.

He studied the effects of the rocket blowing up at ignition, with data from an Atlas/Centaur pad explosion, and concluded debris should miss the aircraft by at least a fuselage length. To prevent the rocket from flying into the aircraft, a separate flight safety system with an independent attitude source cuts the thrust if attitude or trajectory limits are exceeded.

C-17 officials were worried about the launcher nose hitting the cabin roof as it fell out, the rocket getting stuck on the way out and throwing off the aircraft center of gravity, and other concerns. AirLaunch conducted a full-scale ground test at Mojave, Calif., with a dummy rocket on the conveyor wheels. It was successful and closely matched Sarigul-Klijn's simulations. "What got us on the aircraft was the ground demonstration in Mojave," he says.

I observed the Sept. 29 drop test here from the ground. The drop conditions were 145 kt. at about 8,500 ft., with a deck angle of 6.1 deg. when the chains were released. By the time the 50,000-lb. dummy rocket reached the exit the C-17 had pitched up to 8.6 deg. due to the aft shift in center of gravity, and reached a maximum of 8.8 deg., Sarigul-Klijn says. That was a little more than the 7.5 deg. maximum expected.

The rocket rolled along the wheels without incident, though there was brief rubber squealing and large lateral tire deflection as all the weight was concentrated on the last sets of tires just before the rocket fell out, taking them well beyond their normal rated load of 3,750 lb. One outer tire on each of the last two rows had little marks on the sidewalls.

THE LAST THREE rows have the wheels doubled--four per row--to handle the extra load. Strain gauges indicated the load was less than expected, probably due to the higher C-17 pitch rate.

A main concern--clearance of the nose to the cabin roof--appears to be acceptable. It was predicted to miss by 36 in., which is just 4 in. less than the clearance when loading the launcher on the ground. But video to confirm this had not been given to AirLaunch as of Oct. 18.

The rocket reached a maximum pitch angle of 67 deg., close to the predicted 65 deg., and the parachute released properly when the onboard gyros sensed pitch rate reversal. One unexpected motion was a body axis yaw to the left, which had reached 17 deg. when the chute released. The yaw continued through the rocket pointing nose-down. Sarigul-Klijn believes this is due to asymmetric nose vortices and can be aerodynamically fixed, but is within the capability of thrust vectoring to recover.

More C-17 flights are expected in 2006, working the weight up to 72,000 lb. and the drop altitude to 33,000 ft.