Rocket Stars

The guys who are making it cool to be a rocket scientist
Article and photos by Chris 'Xenon' Hanson. Supplemental photos by Will Pomerantz.

Armadillo Aerospace's Stealth Research Facility at Caddo Mills

A nondescript sign along an anonymous road east of Dallas announces the location of bustling and urbane Caddo Mills Municipal Airport (former home of Southwest Soaring, phone number now obscured by time or paint). A passing traveler might overlook the large white hangar with the doors wide enough to admit the reaching wings of delicate glider planes. Parked among the slumbering agricultural equipment and looking like yet another oversized bale of plastic-wrapped hay is a trailer-mounted tank of cryogenic methane. A refrigerated tank of LOX (liquid oxygen) hides bashfully in the shade of a dainty tree. The rain and wind beat down the unmown prairie grasses and form puddles on the narrow entrance road.

This is the home of Texas' most unusual rocket company, Armadillo Aerospace. All that outwardly heralds the presence of the company is a small sign over a few windows looking in on a sparse lobby decorated with a few trophies. Like a mad scientist's secret hideout, there is no obvious sign of the genius and frenetic activity going on inside the cavernous space. On a gloomy rainy day, I dropped by Armadillo to see firsthand the advances being made by an eclectic team of rocket visionaries.


Don't blink or you'll miss it.

Nine-year-old Armadillo is 100% owned by John Carmack, famous video-game developer of the well-known and highly-profitable Doom and Quake franchises. Armadillo has for its life so far, been a non-profitable endeavour, consuming around 4 million dollars of Carmack's own money along with various grants, awards and sponsorship monies. A team of eight (mostly volunteers but three full-timers) toils each week at pushing commercial spaceflight to where it has never gone before: affordability and availability.

Traditionally, lofting a pound of anything into space has been inordinately expensive, putting it mostly out of reach of anyone other than governments and large corporations. NASA's space shuttle, originally intended to democratize space access hoped to achieve a fantastic cost-per-pound of USD$590 (in 2009 dollars). In practice, the huge infrastructure required by the shuttle pushes this to an estimated $23,000. Less-expensive unmanned systems like the air-launched Pegasus XL achieve costs of $4,300 per pound. Russian launchers offer tantalizing prices as low as $1,400 per pound as long as you're launching 30,000 pounds. Many in the space industry foresee an event-horizon looming in the utilization of space, triggered by a dramatic reduction in the cost of lifting loads into various orbits. Tourism, research, commercial manufacturing and exploration all become more economical and feasible as the cost of space access drops. The semiconductor field has already demonstrated the profound changes caused by order-of-magnitude drops in the cost of technology and the commercial space industry is eager to follow on the heels of Moore's Law.

Flashback: DC-X

Sixteen years previous, in the blistering hot sands of White Sands Missile Range (just over the Texas border into New Mexico) astonishing strides towards low-cost high-access launch technology were *almost* made. The McDonnell-Douglas DC-X research project was geared at providing bulk orbital launch capability at lower per-pound cost and higher availability than NASA's space shuttle. Built quickly from existing technologies the DC-X demonstrated impressive results before running afoul of shifting political priorities and budgets. DC-X finally met its demise in 1996 from a spectacular fire stemming from a minor landing problem.

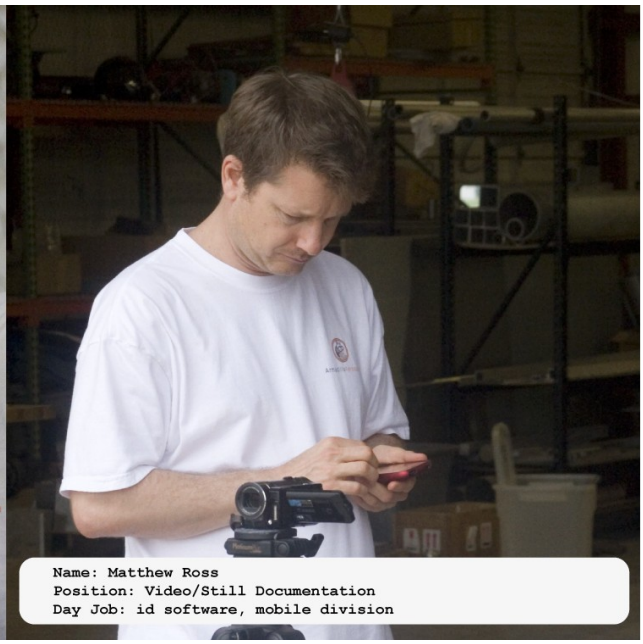
Armadillo and others like them (Burt Rutan's Scaled Composites, Jeff Bezos' Blue Origin, Elon Musk's SpaceX, XCOR, SpaceDev) are making a business case for the advantages of space launch technology developed by small nimble entrepreneurs rather than large government or military-industrial contractors. Several of these new space racers are prominent geeks who made their fortune in the heady days of the turn-of-the-millennium – when smart, agile and fearless could translate into vast monetary success. Armadillo is re-capturing the spirit of innovation found in early aviation and barnstorming by not being afraid to try new designs, fly them, crash them and make changes. Pulling together like-minded space innovators to meet, work and test on weekends, it's almost like a modern Royal Society in the fields of Texas.

The Unusual Suspects

Name: Neil Milburn
Position: Government Liason/Office Manager
Day Job: Physics teacher, Plano ISD *(Photo: Will Pomerantz)*

Name: Mike Vinther
Position: Volunteer ground support
Day Job: Skydiving instructor

Name: Phil Eaton
Position: Engineering/Mechanical & Fabrication & ground crew
Day Job: Full-time, Armadillo



Name: Matthew Ross
Position: Video/Still Documentation
Day Job: id software, mobile division

Name: James Bauer
Position: Welding/fabrication and ground support
Day Job: Full-time, Armadillo

Name: Joseph LaGrave
Position: Hasmat-licensed logistics support and ground crew
Day Job: Tex Air Cryogenics

Fast Cars and Fast Rockets

John Carmack is notorious for his love of fast cars. First he owned a Ferrari Testarossa, but was unhappy with the performance until he had it hyped up with turbochargers to over 1000 horsepower. After then purchasing a Ferrari F50 and finding it unsatisfactory, he morally offended Ferrari by turbocharging it too. John has since kicked his Ferrari habit. “Armadillo wound up getting me out of the supercar world by taking over all of my discretionary spending and eventually making me fairly frugal and money conscious.”

Now Armadillo has combined *fast and rockets* as the rocket engine supplier for the Rocket Racing League (co-founded by X-Prize founder Dr. Peter Diamandis). The RRL will conduct 5-mile-per-lap air races with up to 10 rocketcraft piloted by world-renowned aerobatic aviators jockeying and jinking for first place. Armadillo now is equipping a pair of Velocity XL aircraft with modified rocket engines capable of emitting brilliantly colored exhaust plumes and climbing at 180 feet per second. These two craft will be used to demonstrate the viability of Rocket Racing and bring about the realization of the sport.

With all this high-velocity excitement Carmack has started falling off the supercar wagon again, enabled by his wife Anna giving him a birthday gift of a Tesla roadster (serial number 30). He doesn't seem perturbed by the situation, stating “My wife is awesome!” Some of Anna's previous gifts to make a geek drool were the $58,000 Hass CNC mill for making rocket parts and the three-axle crane truck used to move and hold down rockets for testing. The Tesla is a unique car, a high-performance electric roadster with DNA from the Lotus Elise sports car. The most unusual aspect of Tesla Motors is that it is headed by Elon Musk, a South African-born entrepreneur also known for his commercial space launch company, SpaceX, nominally a competitor of Armadillo Aerospace. Carmack's enthusiasm for competitors extends to him also being an investor in XCOR, another rocket development company.

Don't Mess With Texas

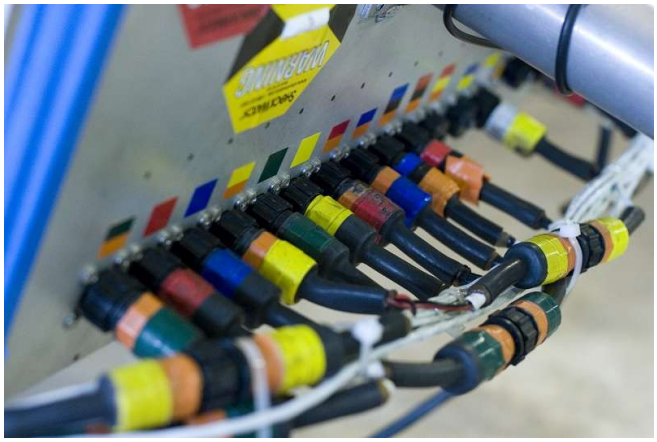
Texas has a special place in the annals of spaceflight, both real and fictional. NASA's Lyndon B. Johnson Space Space Center in Houston (Apollo 13's “Houston, we've had a problem here.”) has traditionally been the home of Mission Control for American manned spaceflight. On the other end of the spectrum, the 2007 movie “The Astronaut Farmer” chronicles the fictional adventures of Billy Bob Thornton's Charles Farmer character, an

almost-astronaut determined to build his own orbital rocket. Somewhere in between falls Armadillo as well as their larger Lone-Star brethren, Blue Origin. Both are working on rockets that take off and land vertically. But there the resemblance ends.

Blue Origin is a secretive company operating on a gigantic 165,000 acre ranch in West Texas, not terribly far from the White Sands Missile Range. Funded to the tune of over $100 million, the tight-lipped company has had some prominent successful flights and some very quiet setbacks. Their New Shepard/Goddard vehicle design is heavily inspired by the DC-X and they employ several former DC-X engineers. Current plans forecast unmanned flights in 2011 and commercial manned suborbital tourist flights by 2012.

Armadillo's modus is quite different. From its inception, the company's activities have been blogged about in detail by John (with occasional substitutes) on the front page of their web site – successes, failures, designs, formulas and trade secrets. It's Open Source Rocketry. They take a different approach to technical hurdles too. Initial designs pursued catalyzed monopropellant motors using hydrogen peroxide and differential throttling. Catalytic engines require no ignition and half the plumbing, a considerable savings in cost, weight and complexity. Differential throttling eliminates thrust vectoring or control surfaces in favor of multiple engines utilizing their built-in throttle capabilities. However, difficulties obtaining pure enough peroxide turned them towards more conventional bipropellant combustive motors with gimbal mounts.

Armadillo's current “modules” look decidedly unfinished – like the research prototypes they are. Plans call for modules to be usable singularly, or ganged together (probably four to six at a time) to increase payload capacity. Comparing the Rube-Goldberg-appearing modules to Blue Origin's svelte-looking New Shepard vehicle is quite a contrast. The current Armadillo “SuperMod” module is designed to test and fly today and quite possibly crash and burn tomorrow, as happened in January 2009. But even in failure, the SuperMod delivered valuable data about how to design, build and fly a successful rocket, and the latest design incorporates new features gleaned from the demise of its ancestor.



Color-coded SuperMod electronics box connectors

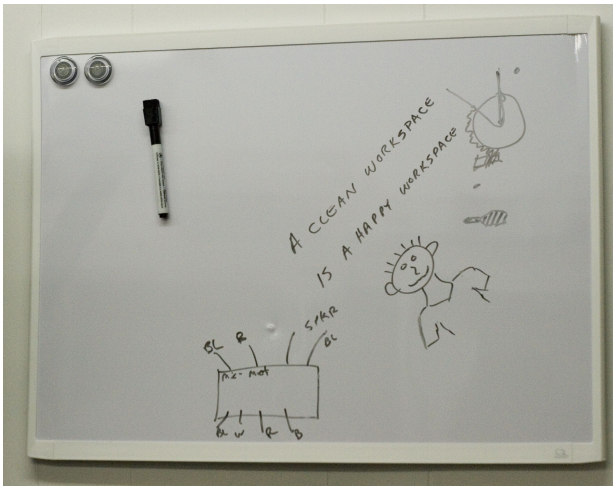
You can even buy your own SuperMod today for a cool half of a million dollars, which includes ground-support equipment. Such an investment would be a great head-start for an entrepreneur looking to get a leg up by leveraging Armadillo's hard-won expertise for their own projects. Russ Nelson explains that from the beginning, Armadillo Aerospace didn't actually want to get into the engine design and fabrication business. If it were possible at the time to purchase a ready-made, performing, reliable engine they would have done so at the start. While designing and manufacturing your own propulsion system is sort of a coming-of-age task for rocket builders, it is also a time (and money) consuming task. Carmack elaborates, “you aren’t likely to do it yourself for less, even if you spend a couple years at it. Several intelligent and competent people thought otherwise, and have been proven incorrect.” This adage was demonstrated by Ansari X-Prize winner (and Armadillo competitor), Burt Rutan's Scaled Composites. Rutan's SpaceShipOne flew its way to 100Km of altitude and $10 million of prize money powered by a SpaceDev hybrid rocket motor burning synthetic rubber with nitrous oxide.

John's sophisticated custom flight software and unsophisticated launch control station.

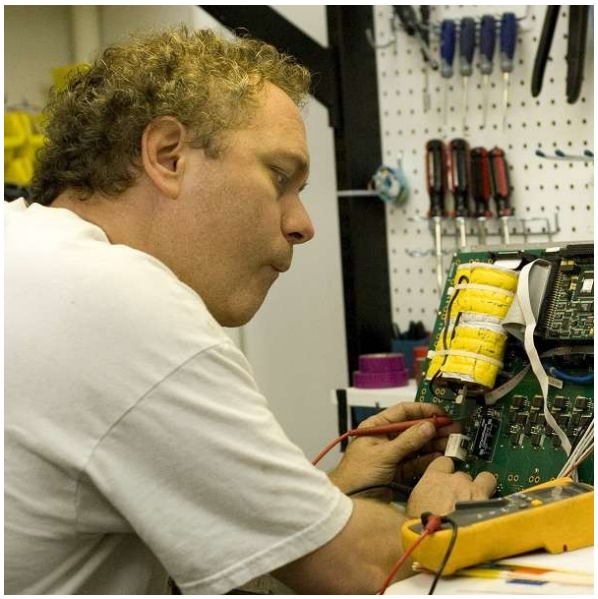
Armadillo's practicality and simplicity extend to other aspects too. John writes code and flies the rocket from the same ruggedized laptop at a card table and folding chair. Test flights are tethered by huge links of rusty anchor chain, a simple and gentle way of reining in a runaway rocket. Propellant feed is driven by pressure rather than multiple pumps with lots of precise moving parts. The SuperMod's legs are simply rigid tubular pipe, in stark contrast to the sophisticated 12G-shock-cushioning legs of competing rockets. Russ believes that typically a vehicle will either be coming down more or less under control, or in total failure mode. There's only a slim window where it won't be landing perfectly gently, and yet it will be still nominal enough that fancy shock absorbers will help. The simpler design is lighter and less prone to failure, a fact proven ironically by the demise of the DC-X which was destroyed when a hydraulic retractable landing leg failed to extend.

The same philosophy is embodied in the safety measures onboard the SuperMod. The flight control software is designed to keep the engine operating in flight even if it senses the engine is failing in a destructive way. John summarizes this preserve-the-payload-at-all-costs attitude, “For vehicle flights, we want the engine to keep firing, even if it is eating itself alive. An extra couple seconds … might get the vehicle back on the ground.” During flight testing, regulations (and common sense) require the vehicle to aggressively shut down the engine when certain conditions mandate an abort, such as tipping over or computer crashes.

But even this wisdom sometimes runs afoul of Murphy as happened with the Quad vehicle “Pixel” at the 2008 Lunar Lander Challenge level-two flight. As part of the safety systems, numerous electromechanical relays are prepared to forcibly shut down the fuel valves at any moment. The physical moving parts of these relays are susceptible to vibration which caused an unintended motor shutdown during a perfectly normal flight and resulted in a damaging crash. Carmack weighs in on the double-edged sword, “This is a good example of how safety systems can have negative consequences. We have seen several other examples of this over the years, and most people don't really appreciate it.”

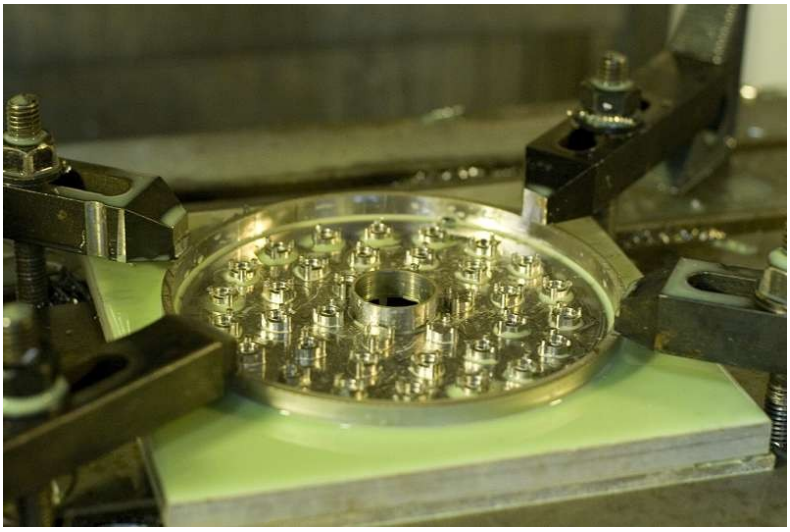


Today Russ is sparring with the very same fickle safety systems. The embedded PC-104 microcontroller computer that runs the onboard flight systems continually signals its health by twiddling (toggling on and off) a single powered wire that leads to the shutdown circuitry. Should this watchdog circuit fail to see twiddle activity for a few microseconds, it pulls the plug on the engine immediately. The only problem? “My twiddle line isn't twiddling.” Russ reports into a walkie-talkie to John at the flight control laptop at the other end of the hanger. After much poking and prodding it is determined that the twiddle line is only driving to 3.6 volts when active, not the expected 5 volts the receiving opto-isolator expects. Upon consulting reference manuals, no one can explain why they're seeing 3.6 volts instead of the 5 (or even 3.3 volts, another common circuit voltage). Russ finds a quick hack workaround bypassing the optoisolator and driving a less-picky transistor directly, and the watchdog is back on the watch.



My twiddle line isn't twiddling.

The second engineering task of the day is the fabrication of injector plates for new engines. The current engine design is the result of years of iterative design and involves two different injector/swirler plates to atomize and mix fuel with oxidizer and feed it to the combustion chamber of the engine. The Haas CNC mill churns all afternoon cutting a slab of high-grade stainless steel into a disk perforated with 36 individual holes across its face. Each hole has opposing inlets that spiral inward, using centripetal force to fling the liquid through an expanding-diameter cone and tear it apart into a fine droplet stream for optimal mixing. This is a proven Russian design in contrast to typical American techniques that use direct impingement – aiming the streams of fuel and oxidizer to collide, fragment and mix. Russian rocket motors have always had the reputation of being somewhat more efficient than the American method.



An engine injector plate being milled.

The worktable next to the mill is littered with burned and eroded attempts at impingement and mixing designs. A single injector plate used to take an entire day to fabricate as the mill carefully, cautiously and exactingly executed its tasks. The situation was unacceptable in a company headed by an action game designer, so Russ has taken to hand-optimizing the primitive assembly language code that directs the milling operations. The milling process now takes half the time, but is still fraught with peril due to the differences between the ideal world of CAD and the the real world of stainless steel. Sometimes the mill decides to take a different route from point A to point B than anticipated, and if there's an obstacle in the way, the precise tool bit can be a casualty.

Even rocket scientists suffer the same mundane problems as the rest of us. Throughout the day the team overcomes gratingly trivial issues like dead batteries, broken CNC tool bits, flat plates that aren't flat, tools that aren't the right size or aren't calibrated, a broken garden-hose fitting and of course, the fickle Texas spring weather. Late in the afternoon the ongoing dreary weather causes John to scrub a planned hot engine firing in favor of a static pressure test of the high-pressure tank central to the newest SuperMod design.

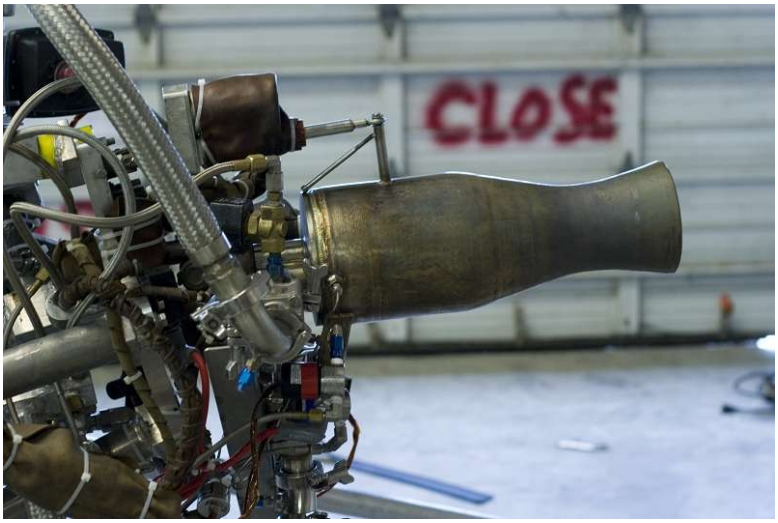
Starfield of Dreams

Armadillo is anxiously awaiting a long-awaited approval certificate from the FAA's Office of Commercial Space Transportation to allow them free flight within the airspace of the Caddo Mills Airport, and it still hasn't arrived. Right next door to the airport is a rural baseball field complex which is often busy on summer evenings. Joseph explains that when Armadillo is ready to do a late-afternoon rocket test, they sound the air horn on the crane truck three times and all games in progress come to a halt so spectators can watch the excitement from the outfield fence. Perhaps the next generation of astronaut is peering through the chain link, with a glove in hand and dreams of the stars in their eyes.

This afternoon there are no ballgames in progress, and the test will hopefully be unspectacularly tame. Joseph prepares the crane truck and John and Mike roll out the new SuperMod to fill the tanks with water (as a proxy for fuel) for the static pressure test. The garden hose won't quite reach, and tugging on it breaks the brass fitting attaching it to the building spigot, resulting in a frantic search for a substitute. Joseph pressurizes the system to see if something pops. The team clusters around John's un-ergonomic laptop card-table as he commands the rocket open the throttles. The water gushes out the bottom of the engine like a science-project water rocket, but without the liftoff. Everyone looks over John's shoulder as they review the performance of the plumbing, and the ubiquitous iPhones come out to calculate the results.

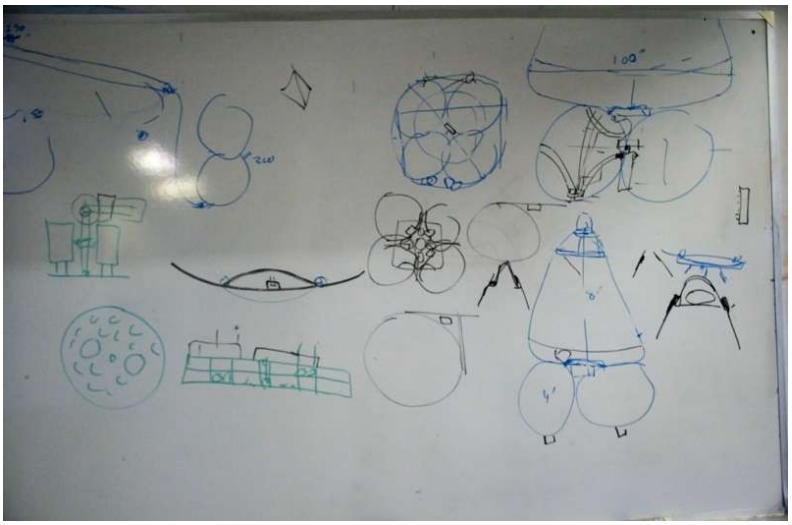
Reflections in a pool of static-pressure test

In mid-2008 Armadillo had three full-time staff and was running at a slight operating profit. Since then they have netted multiple six-figure prizes and payments for achieving significant launch milestones. They are “Close”.



Foreshadowing hanger spraypaint.

Where is Armadillo going from here? Only one direction – up. Russ predicts that “In a year, I'd like to see us doing 100Km flights. Regularly, like it was no big deal. Maybe I've ridden the first one and gotten up there.” As the de-facto company test pilot, Russ first flew the early four-engine peroxide-powered VTVL vehicle. Originally, Carmack's wife Anna was designated to be the first pilot – a move motivated not by her own aspiration to flight, but to ensure “the boys” were taking extra-good care to make sure the pilot was safe.


Armadillo's Plans for Orbital Domination. That's no moon, it's a swirler plate.

Fast-forward five years into the future and the horizons widen to encompass breaking Joe Kittinger's world-record balloon skydiving jump from 102,000 feet and launching actual science payloads. Russ envisions payloads like 10 kilogram nanosats and academic research experiments. And the holy grail of civilian spaceflight, flights carrying tourist passengers (similar to competitor Virgin Galactic).

Armadillo has now worked out the regulatory kinks in their FAA/AST waiver and have completed a major paying contract milestone. On September 12th, 2009 they demonstrated a spectacular qualifying flight for the Northrop Grumman Lunar Lander Challenge, though they ended up taking second place (and only a half million dollar prize) to equally plucky competitor Masten Space Systems of Mojave, CA. NASA's own Review of Human Spaceflight Plans Committee in the “Augustine Commission Report” directly acknowledges that “Commercial services to deliver crew to low-Earth orbit are within reach.” and suggests they might be useful to plug “the human spaceflight gap”. Armadillo's future is going higher and higher. These Rocket Stars are headed for the stars.