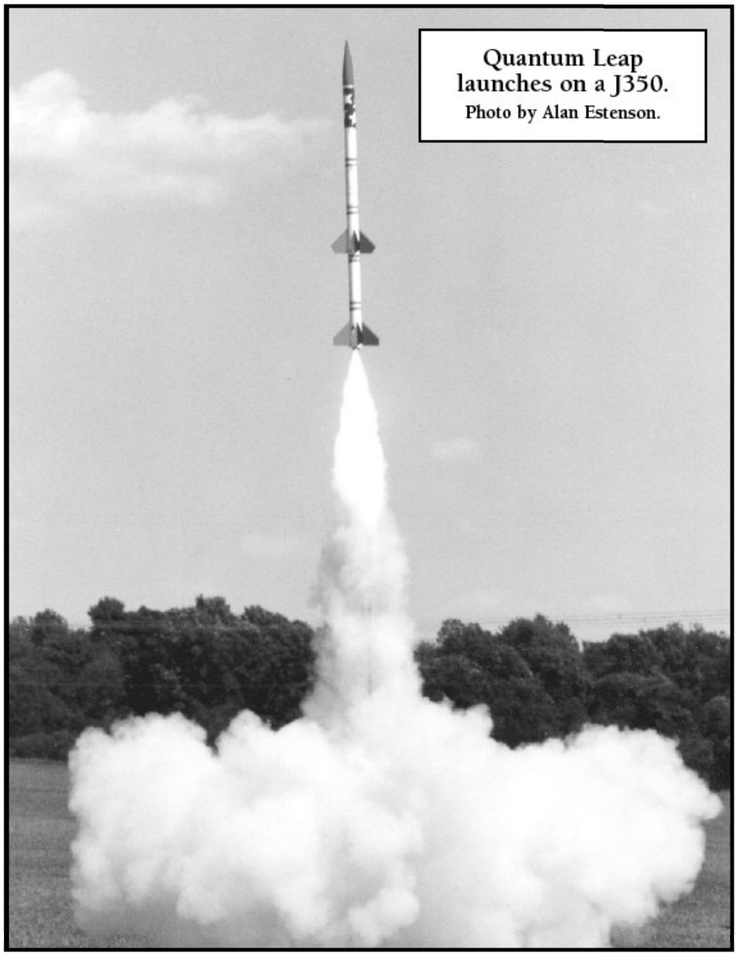


Quantum Leap launches on a J350.
Photo by Alan Estenson.

Two-stage Fun
Quantum Leap

by Ted Cochran NAR 69921

After certifying Level II with a PML Tethys, and flying it a few times on J350s, I was looking for the next step. Ultimately, I made a Quantum Leap. PML's Quantum Leap is a two-stage, 3" diameter, 87" long rocket with quick switch motor mounts (29mm, 36mm, and 54mm) in both stages. PML lists the completed weight at 91 ounces.

PML suggests building the rocket with the staging electronics in the interstage coupler. I was hesitant to do this, because I didn't want to worry about the booster drag separating before the sustainer ignited. Also, I wanted to use the staging electronics for back up sustainer recovery system deployment.

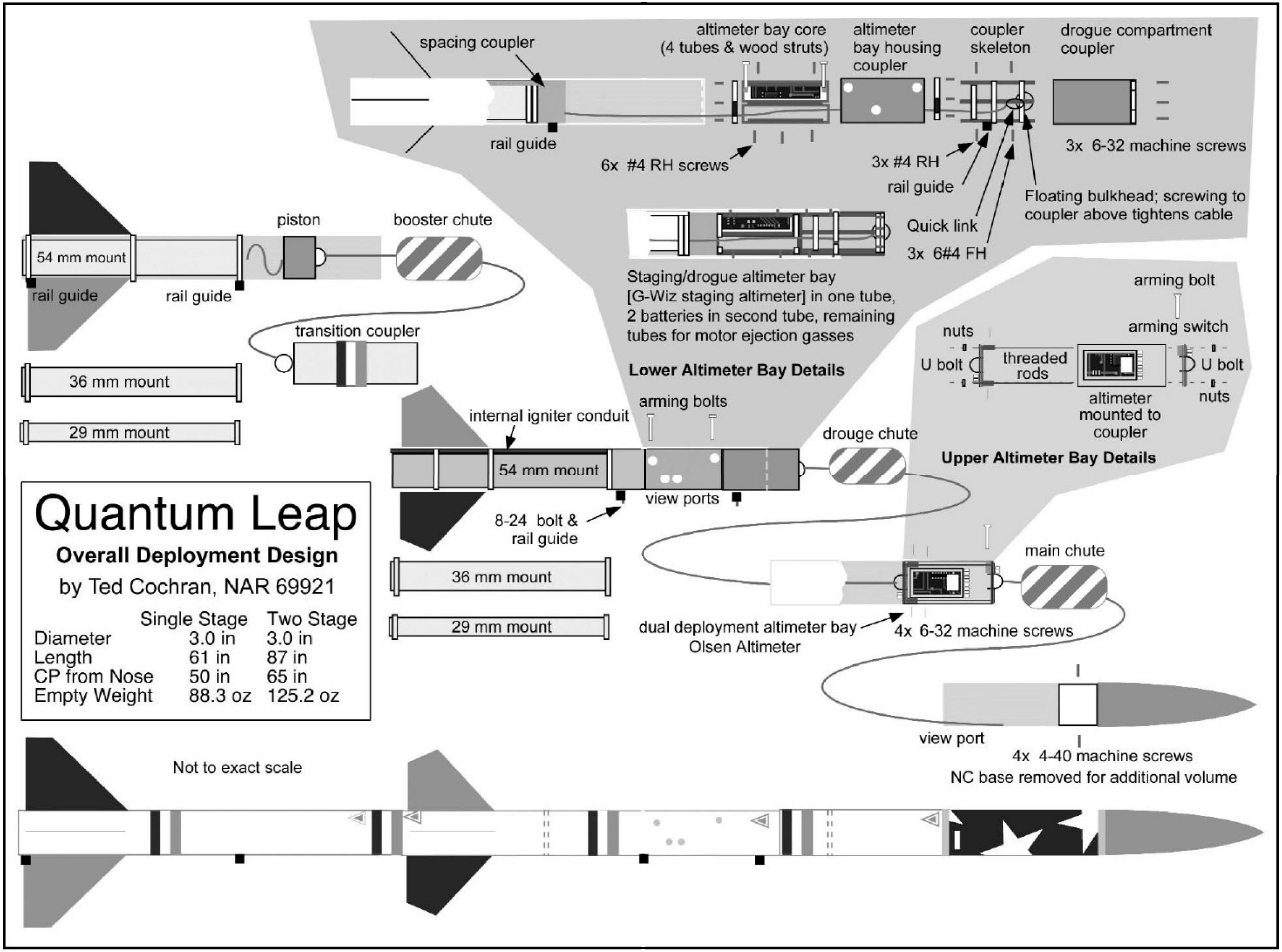
I did a formal risk analysis (see accompanying sidebar) and it ended up driving a number of design decisions. I decided to build the booster without any electronics at all—motor ejection would deploy the booster's chute. I designed an altimeter bay for the upper stage that was inserted just above the motor mount. This allowed the staging electronics to deploy the drogue, and it included ducts to permit the motor ejection charge to be used as a backup. I built a second altimeter bay above the drogue parachute compartment to provide for completely redundant drogue deployment and to deploy the main chute. The base of the nose cone was removed to provide for additional volume in the main parachute bay, and of course there are provisions for external arming. See the overall deployment design diagram.

Lower altimeter bay

The removable lower altimeter bay details are shown in an expanded view in the overall deployment diagram. It accommodates a G-Wiz LC altimeter. A length of brass tubing serves as a conduit from the altimeter bay to the base of the rocket; the igniter leads are run through this conduit from terminals on the outside of the altimeter bay. The altimeter bay is constructed from four 29mm tubes and two bulkheads glued into a 3" airframe coupler. Two of the tubes run through the bulkheads, and are used to duct the ejection charge. One tube holds the altimeter, and the remaining tube holds two 9-volt batteries. This altimeter bay is inserted from the top, and then screwed to the airframe of the sustainer.

Arming is accomplished using two double throw switches activated by inserting machine screws through the airframe. Three 1/4" windows permit viewing of the altimeter's status LEDs through matching windows in the airframe.

This section of the airframe uses zipperless deployment. In order to be able to remove the lower altimeter bay, I built a removable coupler section above it. This section had to be strong, and had to transfer the forces of the shock cord to the fin can. A length of stainless steel aircraft cable runs from the motor mount through the ejection ducts and is attached via a quick link to a welded ring in a floating bulkhead. The floating bulkhead rides within an internal hardwood skeleton, which is bolted to the airframe and the coupler using external bolts and t-nuts in the hardwood skeleton. The floating bulkhead itself is bolted to a fixed bulkhead epoxied to the top of the coupler. The result is that forces on the recovery harness are transferred to the lower airframe through the welded ring, the steel cable, and the fiberglassed airframe itself.


spacing coupler
rail guide
altimeter bay core
(4 tubes & wood struts)
6x #4 RH screws
altimeter
bay housing
coupler
coupler
skeleton
drogue compartment
coupler
3x 6-32 machine screws
3x #4 RH
rail guide
Quick link
3x 6#4 FH
Floating bulkhead; screwing to
coupler above tightens cable
Staging/drogue altimeter bay
[G-Wiz staging altimeter] in one tube,
2 batteries in second tube, remaining
tubes for motor ejection gasses
Lower Altimeter Bay Details
arming bolt
arming switch
nuts
U bolt
threaded
rods
U bolt
nuts
altimeter
mounted to
coupler
Upper Altimeter Bay Details
piston
booster chute
54 mm mount
rail guide
rail guide
transition coupler
36 mm mount
29 mm mount
internal igniter conduit
arming bolts
54 mm mount
view ports
8-24 bolt &
rail guide
drouge chute
36 mm mount
29 mm mount
main chute
dual deployment altimeter bay
Olsen Altimeter
4x 6-32 machine screws
view port
4x 4-40 machine screws
NC base removed for additional volume
Quantum Leap
Overall Deployment Design
by Ted Cochran, NAR 69921
Single Stage Two Stage
Diameter 3.0 in 3.0 in
Length 61 in 87 in
CP from Nose 50 in 65 in
Empty Weight 88.3 oz 125.2 oz
Not to exact scale

Risk Analysis

Organizations that routinely carry out safety-critical operations develop standard operating procedures that incorporate precautions for common problems. The NAR Safety Code is an example. Compliance with the Safety Code provides reasonable safeguards against a variety of expected malfunctions, such as delayed ignition, motor malfunctions, and stuck parachutes.

Unusual situations require more analysis, and risk analysis can become sophisticated. Some of the tools are pretty easy to use, and I've found one in particular to be helpful in rocketry. It's called Failure Mode and Effects Analysis, or FMEA for short.

The purpose of FMEA is to explore all of the things that can go wrong, and thoroughly assess the consequences. The idea is to discover the failures with the worst consequences ahead of time, and to prevent them from happening. FMEA can save you a lot of grief (or at least enhance your peace of mind) when carried out correctly.

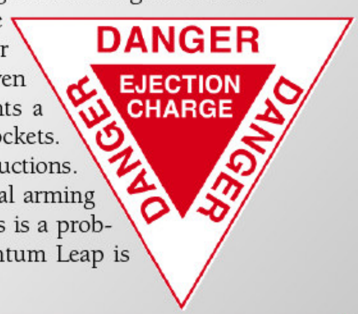
For example, in a stock Quantum Leap the staging altimeter is in the interstage coupler and deployment of the upper stage parachute relies on motor ejection. Failure to light the sustainer motor results in the rocket flying a ballistic descent, resulting in a dangerous situation in which the best case is the loss of the rocket. A sustainer CATO could also cause a ballistic descent, or less severe consequences (a blow-by might result in abrupt termination of flight and descent under parachute, which would only mean that a booster motor has been wasted). The point of an FMEA is to assess all of these risks, and determine which of them deserve the most attention.

My FMEA led me to conclude that flying a Quantum Leap without a backup for sustainer motor ejection would represent an unacceptable risk. There is a single point of failure that is relatively difficult to prevent and that potentially results in severe consequences. Adding a sustainer altimeter to provide redundancy for sustainer recovery greatly reduces the overall risk. Of course, the addition of an altimeter results in additional failure modes, some of which have relatively severe consequences of their own. For example, the use of electronic deployment introduces risks associated with using black powder, including ejection charges firing during preparation, ejection charges firing prematurely in flight, ejection charges not firing at all, and unfired ejection charges being lost with the rocket.

On the whole, well-designed risk management systems greatly mitigate risk. They make life more complicated, but there is still a return on the investment. People who say, "arming switches add additional failure modes" are correct, but people who say that they add "needless complexity" haven't done their homework. Either that, or NASA's use of launch abort systems and flight termination pyrotechnics is ill advised!

My FMEA for the Quantum Leap led to some significant design decisions:

Warning labels. The Quantum Leap is capable of flying out of sight and drifting away. It may land or crash with unfired ejection charges and perhaps even an unfired sustainer motor, and therefore represents a danger if someone finds it who is unfamiliar with rockets. As a result, it is well labeled with warnings and instructions.



Keyless arming switches. The need for external arming devices may be obvious, but the use of key switches is a problem: What can be done without the key? My Quantum Leap is disarmed from the outside with a screwdriver.

Redundant altimeter. To achieve redundancy, you need completely independent systems. Moving the staging altimeter into the sustainer allows it to be used for sustainer ignition and deployment, with motor ejection as a backup. But if the altimeter fails, the rocket will still crash! Hence I added a redundant altimeter for backup deployment.

FMEA is a lot of work, and really isn't necessary for simple model rockets. But it's a great way to minimize the risks on your larger, more complex projects!

Upper altimeter bay

The upper altimeter bay is of more conventional design (see the expanded detail view in the overall deployment diagram). Two bulkheads and a coupler are held together with threaded rods. The threaded rods passes through two aluminum plates, into which U-bolts are inserted for shock cord anchors to the drogue below and the main above. The metal plates ensure that the deployment loads are carried through metal parts, as opposed to wooden bulkheads. The altimeter, an Olsen M1, is enclosed in its own plastic compartment. A small window enables viewing of the LCD display; the coupler and the airframe have corresponding cutouts. Arming is provided for using a double pole, double throw switch, activated by a machine screw inserted through the airframe.

Recovery System Design

The design of Quantum Leap's recovery system was somewhat tricky. A fairly sizable parachute had to be stuffed into a 3" tube, and it was important that the chute be able to get out reliably and avoid fouling with the previously deployed drogue.

To maximize the chances for success, I made a deployment bag for the main chute and designed a recovery system in which a pilot chute pulls the main chute out of the parachute bay, and then pulls the deployment bag off of the main.

It matters how the parachutes are packed, and what goes in on top of what. The deployment sequence drawing shows how the system is designed to work. It has worked well on all but one of the Quantum Leap's flights.

Airframe

My Quantum Leap kit was one of the early kits, with phenolic tubing. I glassed the entire airframe with two layers of medium weight fiberglass and West Systems epoxy. The LED windows over the lower altimeter bay were glassed but not painted; they're transparent enough to easily see the status signals from the altimeter.

The airframe was finished using the

paint scheme that I first used on my PML Tethys. Several color coats followed several coats of Krylon primer with wet sanding in between coats.

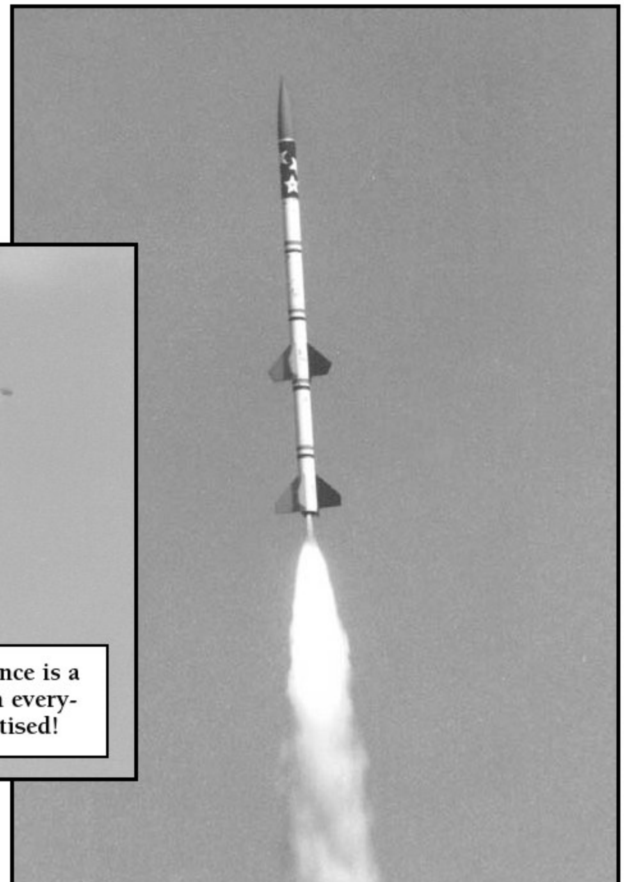
Finally, I applied a set of decals that I had printed up by Tango Papa. The decals include various logos, warnings about ejection charges, instructions for the finder of the rocket, and labels for all of the vents and bolt holes in the airframe to help me remember what screws and bolts go where. A couple of coats of wax completed the finish.

Flights

Quantum Leap takes a few hours to prepare for each flight: It takes time to build two motors and install them along with three batteries, two altimeters, a couple of dozen screws and bolts, three ejection charges, the sustainer igniter, and four parachutes. It gets easier each flight, but it still takes time.

The rocket has flown five times since May 2001. A completely successful single-stage flight was followed by four flights to increasingly higher altitudes, beginning with a flight in 2001 to 2430 feet on an I211W staging to an H180, and most recently last July to 4983 feet on a J420R staging to an I285R. The rocket is capable of flying on two 54mm motors to over 13,000 feet, but that's a bit high for the available sites in Minnesota!

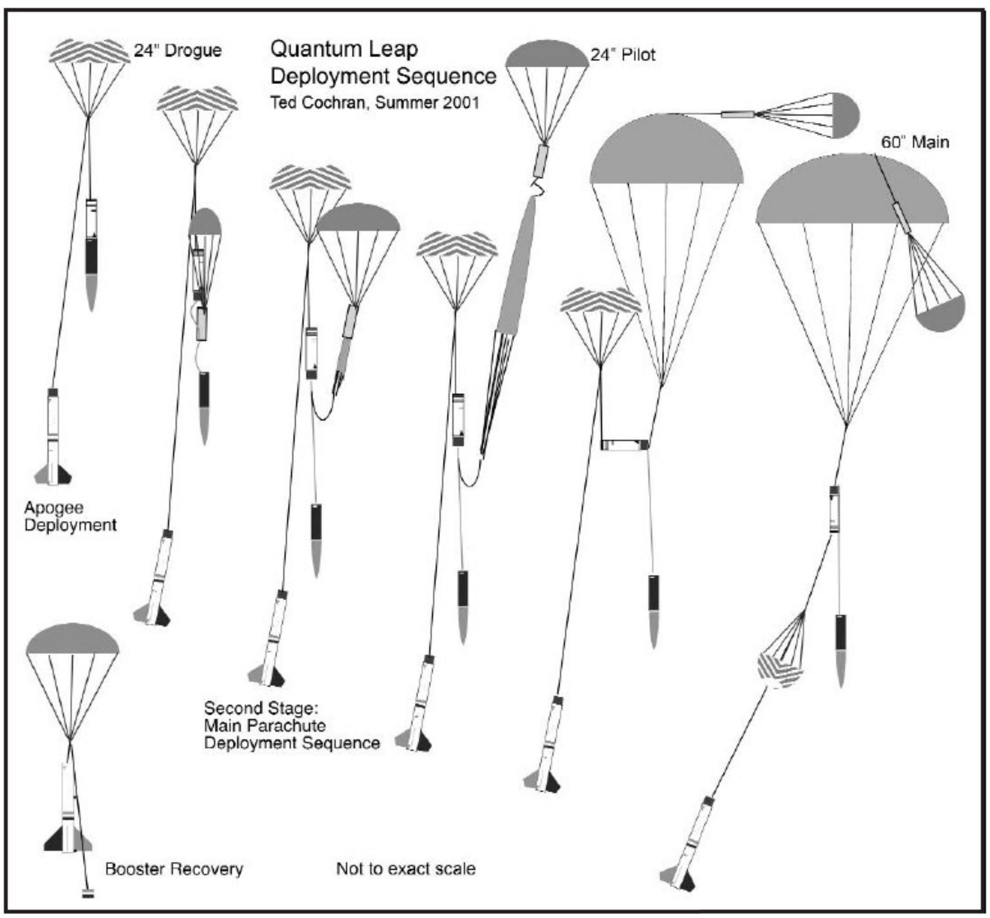
The deployment sequence is a thing of beauty—when everything works as advertised!



Quantum Leap boosting on a J350.

Anomalies

Two of the two-stage flights were perfect in every respect. One flight was slightly marred by an early deployment of the drogue—caused by the motor—which led to early main deployment and a 3" zipper of the main chute section. There is a lesson here: Motor ejection is a good for redundancy, but is not without failure modes of its own (none of which is as bad as a ballistic descent, however).



The second problem occurred when I switched the drogue chute to my fancy homemade ring-slot chute, which made the rocket descend too slowly for the pilot to work properly. The good news is that the rocket was descending slow enough to be completely undamaged (once it was found in the adjacent cornfield—Thanks, Mark!).

It just goes to show that there is only so much planning you can do, unless you have the resources of NASA at your disposal (and maybe not even then).