FLIGHT TEST NOTES

Rocket Autopilot Project

Dave

24 July 2011, Brothers OR (OROC) – Flight #42, "Rev 4.2.1" hardware flight #8

LCO:	OROC
Still photographer:	None
Video photographer:	Marko

Flight configuration:

1. Booster: Thrud (3")
2. Motor: Cesaroni J395
3. Ejection: Electronic
4. Electronics: Rev4.2.1 hardware
5. Launch detection: Electronic
6. Recovery: NASA NPW5 steerable (SuperChute)

Objectives & results:

a. Evaluate telemetry radio signal strength at higher altitudes
   - Successful

b. Attempt GPS-steered parachute navigation back to launch site
   - Failed – parachute did not deploy

c. Evaluate system lag (servo update rate has been limited for this flight)
   - Failed – parachute did not deploy

d. Evaluate correlation between servo position and GPS fix-derived course (course was derived from GPS-reported course on last flight)
   - Failed – parachute did not deploy

Video of this flight is online at http://www.youtube.com/watch?v=5IAxYFVo0pg. No video was recovered from the on-board camera (rocket not recovered).

Summary:

Crash (probable lawn dart); rocket not recovered.

Results:

This was meant as a high-altitude, long-duration test flight, using a light (3") rocket on a large motor (J395).

Very high flight; 7316 feet AGL from telemetry. The flight was so high that I and the video camera operator both lost sight of the rocket near apogee. Other observers also lost sight of it, but some reported that "something broke off" or that the tailcone separated from the rocket.

Real-time telemetry reported a very high descent rate (120+ m/s; over 250 mph). Nobody saw any parts of the rocket land. We searched for it (both visually and looking for telemetry signals) for about 45 minutes, but didn't find it. It's in the desert – somebody will probably find it one day; data might be recovered then.

Post-flight analysis:

As planned, this rocket lifted off at a much higher acceleration than earlier flights. Launch mass was about 2.2 kg. Based on the published thrust curve of this motor, the rocket should have left the pad at about 22 Gs of acceleration; about 4 times more than on prior flights.

The video camera lost track of the rocket before apogee and never regained it. All we know is what was reported by observers and the telemetry data received in real-time.

The pad was at 4305 feet pressure altitude (0 feet AGL). From telemetry, launch (T=0) was detected at 1956.404 seconds from CPU boot, at a reported pressure altitude of 4397 feet (93 feet AGL).

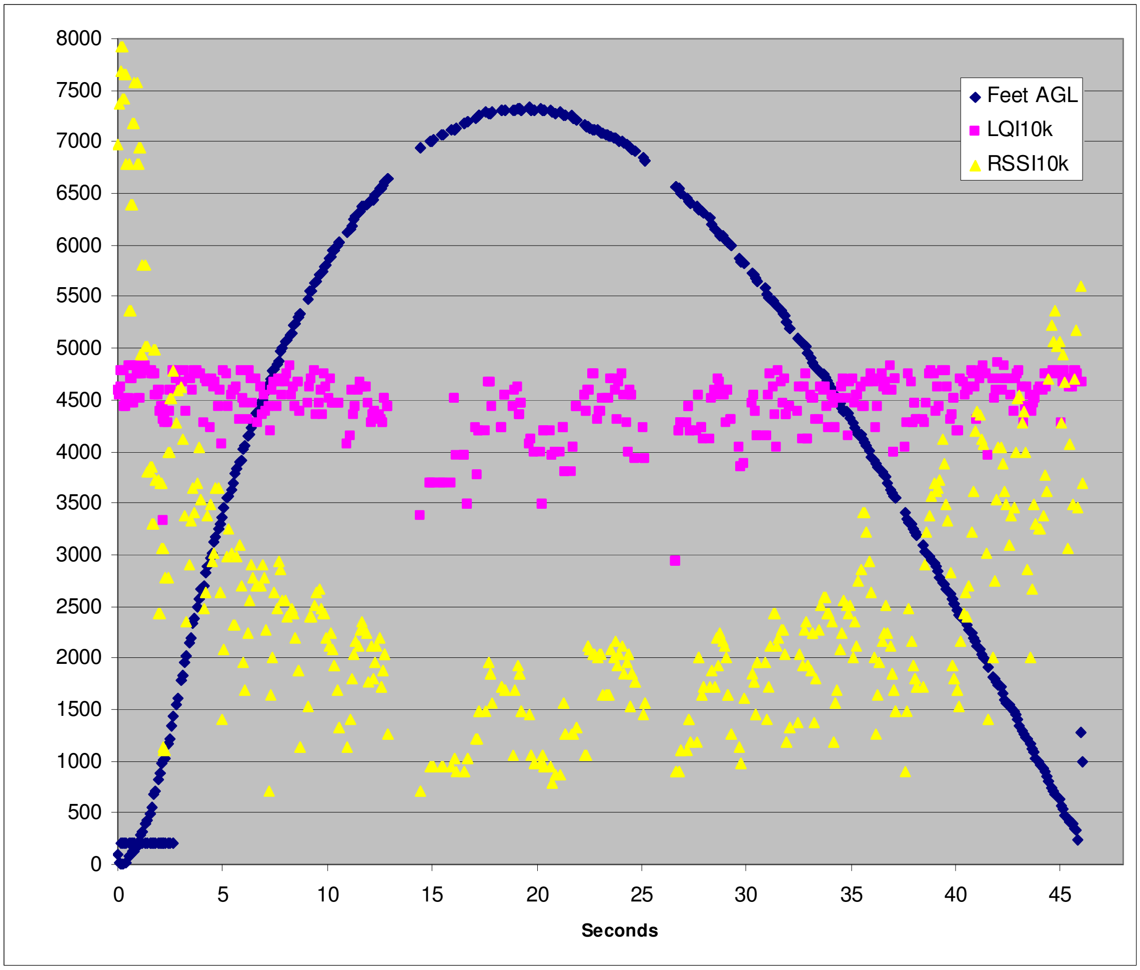
Just 40 milliseconds (one cycle) after launch, the rocket detected apogee and fired the ejection charge at a reported (but highly unlikely) pressure altitude of 4313 feet (8 feet AGL). The following two reports (at T+80 and T+120 milliseconds) were -3 feet AGL and then +207.2 feet AGL. This immediate and unexpected (and unreal) dip in reported altitude caused the false apogee detection.

Just after ejection, continuity on the ejection charge was lost (as expected), so in all likelihood the charge did fire. But there is no hint in the video that the parachute actually ejected. Most likely, the high (20+G) acceleration forces kept the nosecone firmly on the rocket despite the ejection charge.

Telemetry then reports a rapid ascent to 7316 feet AGL at T+20.159 seconds, followed by a similarly rapid descent to the last (likely valid) telemetry report of 237 feet AGL at T+45.893 seconds.

The only reasonable interpretation of this is a ballistic return without deployment, with impact immediately after the last telemetry report. The maximum climb rate on the way up was reported (by telemetry) as 302 m/s (676 MPH, about Mach 1) at T+3.479 seconds (a good fit for motor burnout). The maximum descent rate (again from telemetry) was 126.8 m/s (284 MPH), a reasonable drag-limited speed.

The flight was a useful radio range check; the graph below plots time against AGL altitude, RSSI, and LQI, both scaled to 10,000 as the max reading (all from telemetry). Radio link is a pair of Microchip MRF24J40MB boards. Line of sight range appears to be about 1.5 miles; maybe a bit longer.



The GPS lost lock at launch (as expected) and never regained lock for the whole flight, due to the high vertical speeds. So no GPS data was available to find the rocket (or wreckage).

My best guess at this time is that the false apogee detection was caused by the high G forces at launch. The pressure sensor is known to be sensitive to physical flexing – probably the G forces flexed the sensor, leading to the false reading.

The observer reports of breakup seem inconsistent with the flight path data from telemetry (as illustrated in the graph above). Perhaps a fin broke off from aerodynamic forces near Mach 1, but the rocket remained stable with only 2 fins.

Finally, the telemetry reports that the backup ejection charge fired, as programmed, at about 200 feet above pad elevation, as the descent rate (far) exceeded the safe limit. Unfortunately, 200 feet isn't much at 280 MPH – less than 500 milliseconds before projected impact. In fact the backup ejection happened just 200 milliseconds before the last telemetry record was sent – either the rocket descended behind a hill, or the impact point was at a slightly higher elevation than the pad. The last 2 altimeter readings (visible in the graph) are from after the backup ejection charge fired – likely they represent the overpressure from the backup charge. It is possible that the parachute partially ejected a few milliseconds before impact.

Navigation summary:

No navigation – parachute did not deploy.

Lessons learned:

a. Some kind of lockout or other prevention of premature apogee detection due to high G forces is needed.
b. Backup ejection charge should fire based on *estimated time to impact* (based on descent rate) instead of at a fixed altitude and descent rate. 100 feet is not much at 300 miles/hour.

24 July 2011, Brothers OR (OROC) – Flight #41, "Rev 4.2.1" hardware flight #7

LCO:	OROC
Still photographer:	None
Video photographer:	Marko

Flight configuration:

1. Booster: SuperHorizion (4")
2. Motor: Cesaroni I195
3. Ejection: Electronic
4. Electronics: Rev4.2.1 hardware
5. Launch detection: Electronic
6. Recovery: NASA NPW5 steerable (ThunderWing Danger)

Objectives & results:

1. Attempt GPS-steered parachute navigation back to launch site
    - Failed – line tangling
2. Evaluate system lag (servo update rate has been limited for this flight)
    - May have been around 2 seconds, but not enough data to be sure
3. Evaluate correlation between servo position and GPS fix-derived course (course was derived from GPS-reported course on last flight)
    - May have been some correlation, not enough data to be sure

Video of this flight is online at http://www.youtube.com/watch?v=cOWGP5sDWBQ.

Video from the on-board camera (looking at parachute) is here: http://www.youtube.com/watch?v=hUnUtBe9EC4.

Summary:

Useful flight, about 120 seconds of descent time. Verified that line tangling is the problem.

Results:

Nice ascent, ejection again a little late by video and a little early by the altitude log, at 1712 feet AGL. I tried to manually steer for most of the flight. At the start the parachute responded, but very slowly. Toward the latter two thirds of the descent I was unable to keep it pointed where I wanted.

Backup charge did not fire (nominal).

Post-flight analysis:

It is very clear from comparing the video shot from the ground (and my comments on the audio track) to the video from the on-board camera that control worked when the lines were untangled, and failed when the lines were tangled. Although the parachute fully inflated immediately, the line to the nosecone was draped across the key control line (clearly seen in the video), which offset the center position and probably contributed to the slow response. After about 1/3 of the descent, the lines can clearly be seen twisting together; after that point no control was possible.

Again, the pressure altimeter readings appear to lag the actual position of the rocket per the video shot from the ground. This tends to reinforce the idea of too-small static vent ports.

The GPS lost lock (as expected) at T+5.878s, ejection was at T+9.640s, and the GPS re-locked at T+16.500s. This seems typical – it takes about 7 seconds after ejection to regain GPS lock.

Navigation summary:

There is some sign of successful estimation of system lag (around 1.8 to 2.1 seconds, which fits with observed motion of parachute) and of correlation between steering command and motion. However there is only about 20 seconds of good data, which is not enough to draw any firm conclusions on. As well, the actual lag time for the system should have been a lot shorter, but the drag from the nosecone line may have affected this.

Lessons learned:

a. Tangling, and especially twisting, is *the* problem.

23 July 2011, Brothers OR (OROC) – Flight #40, "Rev 4.2.1" hardware flight #6

LCO:	OROC
Still photographer:	None
Video photographer:	Dave

Flight configuration:

1. Booster: SuperHorizion (4")
2. Motor: Skyripper J144
3. Ejection: Electronic
4. Electronics: Rev4.2.1 hardware
5. Launch detection: Electronic
6. Recovery: NASA NPW5 steerable (ThunderWing Danger)

Objectives & results:

1. Attempt GPS-steered parachute navigation back to launch site
   - Failed – twisted control lines.
2. Evaluate system lag (servo update rate has been limited for this flight)
   - Failed – twisted control lines.
3. Evaluate correlation between servo position and GPS fix-derived course (course was derived from GPS-reported course on last flight)
   - Failed – twisted control lines.

Video of this flight is online at http://www.youtube.com/watch?v=oCLrpQGhw2o.

Video from the on-board camera (looking at parachute) is here: http://www.youtube.com/watch?v=hUnUtBe9EC4.

Summary:

Very nice flight; about 150 seconds of descent time Parachute initially deployed tangled, but then fully inflated after a few seconds of fast descent. Some steering shown.

Results:

Excellent flight. About 2200 feet AGL per telemetry. Drogue fired near (maybe a little past) apogee. Parachute deployed tangled, but fully inflated about 8 seconds later. Despite near-ideal conditions for GPS navigation and a well-deployed parachute, both automatic parachute navigation and manual control didn't work well. Backup charge did not fire.

Post-flight analysis:

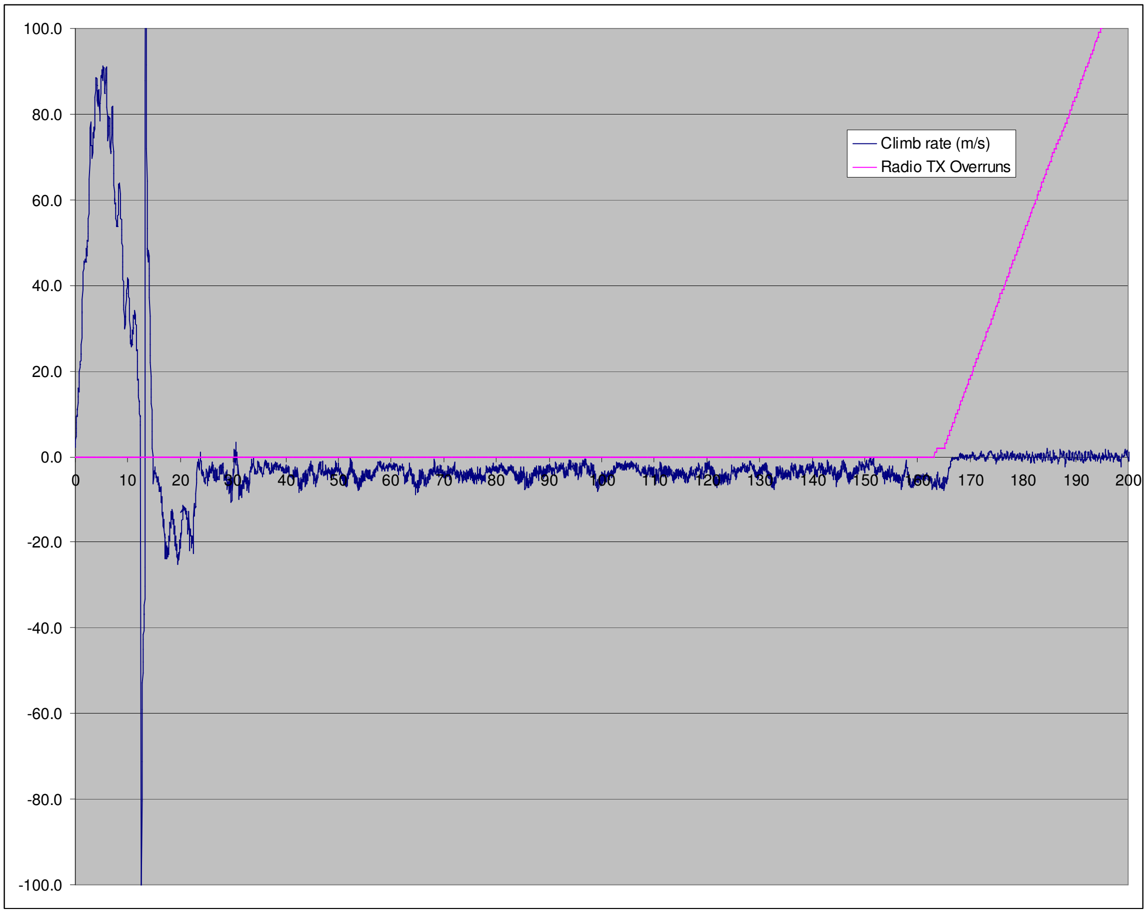
The logged altitude data seems to indicate the parachute deployment was if anything a tiny bit early (not late – see graph below); this conflicts with the video showing it a little late. I suspect the static port holes for the pressure altimeter are not large enough.

The difference in descent rate between the tangled state (first 8 seconds after apogee) and the fully deployed state is obvious in the data – the descent rate goes from about 20 m/s down to 4 m/s.

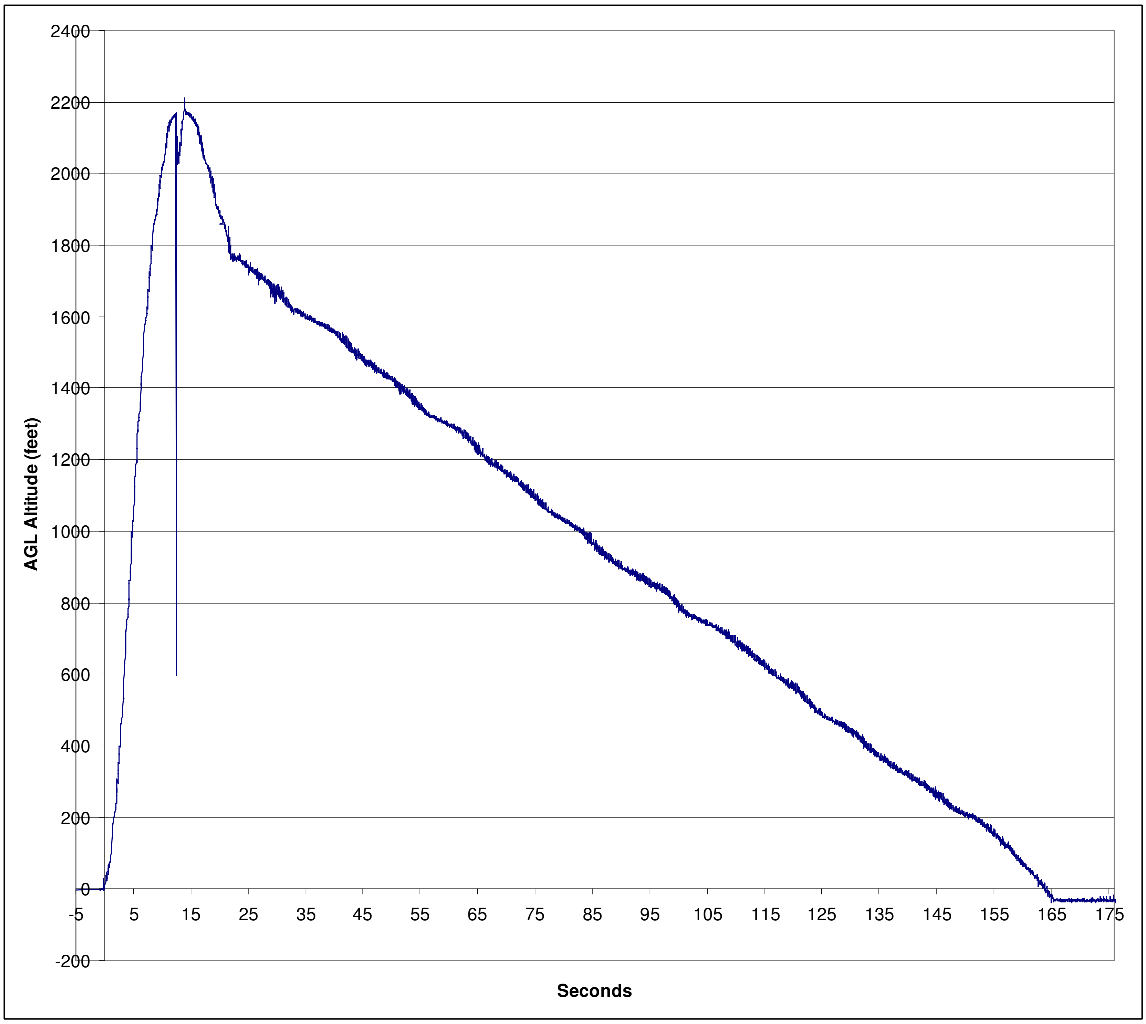
Video from the on-board camera clearly shows the parachute steering lines were twisted together for most of the flight. Not only do they often deploy twisted, but they can twist spontaneously in flight. Clearly this is a very serious problem – the parachute system needs to be redesigned with a much larger baseline between the control lines to prevent this.

The audio track from the on-board camera has an interesting whistle at the beginning (just before parachute deployment); the relative wind speed can be clearly heard decreasing in the whistle right up to deployment. This would seem to conflict with the video shot from the ground, which shows the parachute deployment happening a bit past apogee. At this point my best guess is that the *horizontal* component of velocity was the main contributor to the wind whistle – although the rocket was going down at deployment (and accelerating down under gravity), the side component of velocity was still decreasing from drag. At least that's my best guess.

The plot of time vs. climb rate and TX overruns is interesting. TX overruns begin as soon as signal is lost (over horizon).



The higher descent rate before full parachute inflation is seen clearly in the altimeter data (below). Note the big spike at parachute deployment – this is caused by the overpressure from the ejection charge (it's a pressure altimeter).



Navigation summary:

Failed. Parachute just turned slowly counterclockwise (as seen from below) for the whole flight, apparently due to twisted control lines preventing steering.

Lessons learned:

a. Try increasing size of altimeter vent holes to avoid late apogee detection.
b. A much larger than 4" baseline is needed between the parachute control lines to avoid twisting.
c. Investigate relationship between telemetry transmit overruns and loss of signal.

16 July 2011, Amesbury MA (CMASS) – Flight #39, "Rev 4.2.1" hardware flight #5

LCO:	CMASS
Still photographer:	None
Video photographer:	Ross

Flight configuration:

1. Booster: Thrud

2. Motor: Skyripper H124
3. Ejection: Electronic
4. Electronics: Rev4.2.1 hardware
5. Launch detection: Electronic
6. Recovery: NASA NPW5 steerable (SuperChute)

Objectives & results:

1. Attempt GPS-steered parachute navigation back to launch site
   - Failed – servo did not operate properly
2. Evaluate system lag (servo update rate has been limited for this flight)
   - Failed – servo did not operate properly
3. Evaluate correlation between servo position and GPS fix-derived course (course was derived from GPS-reported course on last flight)
   - Failed – servo did not operate properly

Video of this flight is online at http://www.youtube.com/watch?v=P0G6ov59Hl4.

Video from the on-board camera (looking at parachute) is here: http://www.youtube.com/watch?v=IBRQQxArG-s.

Summary:

Parachute deployed very early causing serious zipper, separation and crash of tailcone. Apogee detection too early.

Results:

Ascent wasn't very stable – a lot of swerving. Apogee at 549 feet AGL per beeper. Parachute deployed very early, causing severe zipper (payload tube had to be replaced). The kevlar line attaching the tailcone to the rest of the rocket severed, and the tailcone crashed with serious (but ultimately repairable) damage. The rest of the rocket came down under the parachute. The parachute continuously turned during descent. I tried to steer by hand, seemed to have some effect on rate of turn, but couldn't straighten it out.

Backup charge fired.

Post-flight analysis:

The descent rate was around 4 m/s (slow, as would be expected without the weight of the tailcone and motor case), but the filtering algorithm for descent rate doesn't seem adequate to produce a smooth number without a lot of peaks – at one point near the end of the flight the rate peaked at 14.4 m/s, enough to (incorrect) trigger the backup charge.

The on-board video from the 808 keychain wasn't able to see the parachute at all, so no info there. But the audio track makes it very clear there was a problem with the steering servo. Bench check of the servo post-flight showed there was a problem with the steering pulses going to the servo – they were out of range for the servo's limits. The servo would ignore commands for small movements (near the limits), while responding to command for large movements.

Navigation summary:

Because the servo wasn't moving the to commanded positions, no navigation was possible.

Lessons learned:

a. Need to correct servo output pulses to within limits of servo response.

b. Revise apogee detection algorithm (again) to prevent premature deployment and zippering.
c. Revise backup charge firing algorithm to be less sensitive to short-term peaks in climb/descent rate.

16 July 2011, Amesbury MA (CMASS) – Flight #38, "Rev 4.2.1" hardware flight #4

LCO:	CMASS
Still photographer:	None
Video photographer:	Ross

Flight configuration:

1.	Booster:	SuperHorizion
2.	Motor:	Skyripper H124
3.	Ejection:	Electronic
4.	Electronics:	Rev4.2.1 hardware
5.	Launch detection:	Electronic
6.	Recovery:	NASA NPW5 steerable (ThunderWing Danger)

Objectives & results:

1. Verify performance of new (faster) apogee detection algorithm.
   - It detects too soon.
2. Verify correctness of software changes to preserve logging data after shutdown.
   - Works.
3. Verify Climb Rate detection and working of backup ejection charge based on climb rate
   - Worked OK.
4. Attempt GPS-steered parachute navigation back to launch site (repeat of flight 36/37)
   - Failed – incomplete parachute deployment.
5. Evaluate system lag (servo update rate has been limited for this flight)
   - Failed – incomplete parachute deployment.
6. Evaluate correlation between servo position and GPS fix-derived course (course was derived from GPS-reported course on last flight)
   - Failed – incomplete parachute deployment.

Video of this flight is online at http://www.youtube.com/watch?v=N9C-57pKEhQ.

Video from the on-board camera (looking at parachute) is here: http://www.youtube.com/watch?v=Y1kDS2uoRfs

Summary:

Nice H-motor flight, parachute deployed (early) but did not fully inflate. Low speed crash, no damage.

Results:

Apogee at 485 feet AGL. Parachute again deployed clearly early. Parachute did not fully inflate. Rocket descended quickly under partly-inflated parachute, hard impact, but no damage at all.

Backup charge fired (as it should).

This was the first flight with the "808" keychain camera on board to record the parachute deployment and steering. It's clear from the video that the parachute lines were very tangled, causing the deployment problem and preventing any attempt at navigation.

Post-flight analysis:

Descent rate was around 15 m/s (peaks around 11 and 20 m/s); backup charge fired as it should have.

Navigation summary:

No useful data – incomplete deployment made navigation impossible.

Lessons learned:

a. Line tangling remains a serious unsolved problem.

30 April 2011, Amesbury MA (CMASS) – Flight #37, "Rev 4.2.1" hardware flight #3

LCO:	CMASS
Still photographer:	None
Video photographer:	Dave

Flight configuration:

1. Booster: SuperHorizion
2. Motor: Skyripper J144
3. Ejection: Electronic
4. Electronics: Rev4.2.1 hardware
5. Launch detection: Electronic
6. Recovery: NASA NPW5 steerable (ThunderWing Danger)

Objectives & results:

1. Verify Climb Rate detection and working of backup ejection charge based on climb rate
   - Partial success – charge fired, algorithm needs tweaking.
2. Attempt GPS-steered parachute navigation back to launch site (repeat of flight 36)
   - Failed – unstable parachute flight.
2. Evaluate system lag (servo update rate has been limited for this flight)
   - Failed (logging data lost).
3. Evaluate correlation between servo position and GPS fix-derived course (course was derived from GPS-reported course on last flight)
   - Failed (logging data lost).

Video of this flight is online at http://www.youtube.com/watch?v=MVKhG5WvzbI

Summary:

Good high-altitude flight. Logging data lost again due to problem seen on flight 1 today. From telemetry, pad was at -71 feet MSL and apogee 2075 feet MSL, for an apogee at 2003 feet AGL. Parachute deployed fine. Parachute was rigged with forward lines about 1" shorter than normal, hoping to get less angle of attack and a faster airspeed, but the parachute just became unstable instead.

Results:

Apogee at 2003 feet AGL. Parachute again deployed about 4 seconds after actual apogee; still not sure why.

Backup charge fired at frame 6821 of video (presumably at 100 meters AGL). Based on timing from backup charge to landing (assuming 100m AGL), descent rate was 7.75 m/s if landing site was at pad elevation (hard to tell). Threshold was 9 m/s so this is not too far off if there was some noise in the data. (No logging data can't tell exactly.). Based on apogee at 2003 feet AGL to landing (again assuming landing site is pad elevation), descent rate was 8.44 m/s – again a plausible number explaining the main firing. Probably 9 m/s is too low a speed to require the main to fire.

The following timing was derived from a combination of video and telemetry data:

Event	Frame #	C time (s)	T time (s)
Launch	2708		
Launch detect		234.003	0.00
Apogee	3257	242.65 (e)	8.65 (e)
Ejection	3494	246.603	12.60
Main fires	6821	302.081	68.078
Landing	7595	314.987	80.984
Landing detected		316.767	82.764

Post-flight analysis:

This was a good flight except for the loss of logging data and parachute rigging problem. No damage on landing.

Navigation summary:

No logging data obtained. Telemetry data shows a very confused navigation algorithm, with no consistent mapping of servo position to turn rate, and no consistent lag values. This is probably because of a combination of the unstable flight of the parachute, and severe swinging of the GPS under the long parachute lines, which confuse calculation of direction of flight.

Lessons learned:

a. Increase minimum descent speed needed to trigger main ejection charge (try 13 m/s).
b. Need a way to find system lag even in the face of severe GPS swinging under lines. Try manual steering (via radio) inputs to the nav system, use those to correlate servo position to turn rate.

30 April 2011, Amesbury MA (CMASS) – Flight #36, "Rev 4.2.1" hardware flight #2

LCO:	CMASS
Still photographer:	None
Video photographer:	Dave

Flight configuration:

1. Booster: Thrud
2. Motor: Cesaroni H100
3. Ejection: Electronic
4. Electronics: Rev4.2.1 hardware
5. Launch detection: Electronic
6. Recovery: NASA NPW5 steerable (SuperChute)

Objectives & results:

1. Verify LANDING detection
    - It doesn't work; needs fixing.
2. Verify Climb Rate detection and working of backup ejection charge based on climb rate
    - Seems OK, but more data needed.
3. Attempt GPS-steered parachute navigation back to launch site (repeat of flight 35)
    - Not enough data.
4. Evaluate system lag (servo update rate has been limited for this flight)
    - Not enough data.
5. Evaluate correlation between servo position and GPS fix-derived course (course was derived from GPS-reported course on last flight)
    - Not enough data.

Video of this flight is online at **http://www.youtube.com/watch?v=xadLv86GNYQ**

Summary:

Very nice flight. Apogee beeper reported 1577 feet. Very minor zipper (5mm or so). Green fin bond cracked a little on landing (despite soft landing; probably broken inside bond). Drogue charge fired, Main did not (as planned).

Results:

Launch was detected at 16:39:36 UTC, internal clock (C) time 723.553s. The decoder estimation of actual launch time (240 mS prior detection) seems too early by about 200 mS. Per altimeter data, apogee detection was just right. But per video, apogee detection was about 6.4 seconds late (way off). This is very strange, and so far unexplained.

The following timing was derived from a combination of video and reported data:

Event	Frame #	C time (s)	T time (s)
Launch	823	731.918	0.200
Launch detect		731.958	0.240
Apogee	1084	741.381	9.600
Ejection	1468	742.401	10.080
Landing	6100		88.0 (e)
Landed detected		791.283	59.565

The onboard log stops a T+59.48 seconds; the transition to LANDED (shown in the telemetry data but not the log) is premature by 28 seconds or so. From the video, landing happened at about T+88 seconds. From the log data, it appears that the swinging under the parachute was so strong at around T+59 seconds that the electronics module actually did go upward for a moment, triggering the LANDING state.

Main still reported continuity on landing. There was no response to radio commands after landing, probably because the landing site was behind a hill that blocked the signal. Radio worked fine after return to base table.

Radio dump of log didn't work with current software; log was extracted via serial I/O.

Parachute deployed nicely; appeared to be attempting to steer. Some kind of untangling event 2/3 of way to ground.

Lost one motor clip during flight.

Post-flight analysis:

The radio dump problem was due to transmit buffer overruns in the rocket comm software. This has since been fixed.

Navigation summary:

Per log, rocket did a rather good job of flying back toward the launch pad. So good, that it is possible this was simply the wind blowing it that way. From the video, the steering certainly wasn't as good as the ground track would imply (evidence for the wind hypothesis). After T+59 steering stopped (and the GPS was powered down), so the spins from that point on are not meaningful.

The rocket appeared to get a reasonable set of steering correlations with servo position, but the associated lags were all over the place, so this may have just been chance. The most stable lag seemed to be around 0.55 seconds (a plausible number).

Given the limited amount of data, it's too early to conclude if things were working or not.

Lessons learned:

a. Fix radio dump of log.
b. Investigate late detection of apogee
c. Adjust LANDING detection to avoid false signal due to swinging.

30 April 2011, Amesbury MA (CMASS) – Flight #35, "Rev 4.2.1" hardware flight #1

LCO:	CMASS
Still photographer:	None
Video photographer:	Dave

Flight configuration:

1. Booster: Super Horizon
2. Motor: Skyripper H155PP
3. Ejection: Electronic
4. Electronics: Rev4.2.1 hardware
5. Launch detection: Electronic
6. Recovery: NASA NPW5 steerable (ThunderWing Danger)

Objectives & results:

1. First flight of Rev 4.2.1 hardware. Verify in-flight function.
   - Succeeded (despite power failure).
2. Verify working of telemetry radio (802.15.4)
   - Succeeded.
3. Verify LANDING detection
   - Failed (loss of power).
4. Verify Climb Rate detection and working of backup ejection charge based on climb rate
   - Failed (insufficient data).
5. Verify working of new ASCENT and DESCENT states, ejection triggering
   - Succeeded (need to tweak detection algorithms for faster response).
6. Observe in-flight performance of new parachute
   - Succeeded.
7. Attempt GPS-steered parachute navigation back to launch site (repeat of flight 34)
   - Failed.

8. Evaluate system lag (servo update rate has been limited for this flight)
    - Failed (logging data lost).
9. Evaluate correlation between servo position and GPS fix-derived course (course was derived from GPS-reported course on last flight)
    - Failed (logging data lost).

Video of this flight is online at **http://www.youtube.com/watch?v=rao47KdX9EA**

Summary:

Good flight, apparent altitude about 800' as predicted. Rev 4.2.1 hardware and software worked well except for electronics power failure sometime during descent (see below for cause and fix). Backup charge (Main) fired. Logging data lost.

Results:

Launch was detected at 14:58:51 UTC, internal clock (C) time 623.964 s. Using -30 feet pressure altitude for pad, reported apogee was 845+30 = 875 feet AGL. The following timing was derived from a combination of video and reported data:

Event	Frame #	C time (s)	T time (s)
Launch	1181.0	623.278	0.000
Launch detect	1222.1	623.964	0.686
Apogee	1558.0	629.568	6.290
Apogee reported	1653.7	631.164	7.886
Ejection	1680.0	631.603	8.325
Last TX	3641.1	664.321	41.043
Landing	4628.0	680.786	57.508

Based on this timing, apogee of 875 feet AGL was reached at T+6.29 seconds, and landing was at T+57.508 seconds, for a descent speed (average) of 875/(57.508-6.29) = 17.1 feet/second, or 5.2 m/s. However this is a very rough figure, because the altitude at deployment (2s after apogee) is unknown, and the landing site was a bit below the elevation of the pad. The main deployment descent rate threshold was 9 m/s, with a maximum altitude of 100m. So this implies possible poor calculation of descent rate, but there is not enough data to be conclusive.

Launch detect was later than in previous software revisions; the current 6 meter (altitude gain in a short period) threshold can probably be reduced. Apogee detection (ejection) was about 2 seconds after actual apogee, indicating an excessively conservative detection algorithm. The last transmission was 16 seconds before landing – probably the battery failed at this point, stopping the navigation algorithm.

Received radio signal strength remained good during the whole flight; ranges considerably longer than seen in this flight seem usable.

“ThunderWing Danger” large parachute deployed nicely but just appeared to steer in a continuous turn for the whole descent. On the other hand, this was a very low-altitude flight and the software didn’t have much time to train. Post-flight, there was discovered a bug in the servo timing that could have caused the servo to lockup in the stowed position – this may have happened here.

Telemetry cut off abruptly during descent. On recovery, electronics were silent (no apogee beep) and found to be powered-down. Battery output was 4.1 volts on recovery (vs. 7.4v nominal).

Backup ejection charge fired. This was not visible on the video; possible fratricidal ignition. Not able to determine cause because of lost log.

Log was erased when I tried to extract it, but a good deal of data was returned via the real-time telemetry.

Post-flight analysis:

Power failure appears to be caused by over-current protection circuit in the battery marked “LiPo”. This caused that battery to appear short. Once this circuit was removed post-flight, cell was fine.

Navigation summary:

Because the logging data was lost and the short descent time before the power failure, the navigation performance for this flight wasn’t analyzed.

Lessons learned:

a. Remove any protection circuits from lithium cells preflight; these can falsely trigger under flight loads.
b. Apogee detect needs tweaking to respond faster – this algorithm was 2 seconds late.
c. Launch detect should respond quicker.
d. More complete real-time reporting is needed (status at least); move to binary protocol.
e. Code needs to be made more robust against log erasure.

21 November 2010, Amesbury MA (CMASS) – Flight #34, “Rev 4a” hardware flight #9

LCO:	CMASS
Still photographer:	None
Video photographer:	Dave

Flight configuration:

1. Booster:	Thrud
2. Motor:	Aerotech H180
3. Ejection:	Electronic
4. Electronics:	Rev4a hardware, PA6 GPS, AD4 altimeter (backup)
5. Launch detection:	Electronic
6. Recovery:	NASA NPW5 steerable (SuperChute)

Objectives:

1. Attempt GPS-steered parachute navigation back to launch site (repeat of flight 33)
2. Evaluate system lag (servo update rate has been limited to 1.0 seconds for this flight)
3. Evaluate correlation between servo position and GPS fix-derived course (course was derived from GPS-reported course on last flight)

Summary:

Electronics bay & parachute separated from rest of rocket on deployment. Booster and main body tube crashed, no damage. Electronics bay and nosecone drifted a long way under the parachute, bounced off a power line and landed in the swamp. Minor damage to electronics bay. Failed flight.

Post-flight analysis:

This was the last launch of the season, and would have been the last flight of the Rev4a board (even in the event of a successful flight). I plan an improved PCB for next year.

Because the AD4 backup altimeter wasn't working (see last flight), and my pressure based "no-deployment" detection algorithm wasn't ready in time, I wired two flashbulbs, with 0.5g of BP each, in parallel onto the apogee ejection output. This was my half-baked ejection redundancy. It seems that 1g of BP going off at once was too much for the kevlar cord retaining the electronics bay/piston. The cord ripped and the whole e-bay was ejected from the main body tube, together with the parachute and nose cone. The bottom plate of the e-bay (with the ejection charge holders and power switch) and the tube around it were ripped off and not recovered. The wires running to the flashbulbs and power switch were ripped off at the PCB. However the board kept running, as it's designed to turn off only when the power switch is closed (not open).

Apogee was about 1550 feet AGL. This was my last Aerotech H motor; I don't plan to fly them anymore because of the much more difficult post-flight cleanup compared to the hybrid or Cesaroni motors.

GPS SV lock went from 9 at launch to 5 at T+1.1s, then to 4 at T+3.5s (still in ascent). There were no formally bad fixes, but the GPS output was obviously bogus from launch until about T+19.8 seconds, about 11 seconds after ejection. Analysis of actual track vs. track implied by reported course and speed reinforces the idea that reported course & speed are not to be trusted.

Descent speed under the parachute was 15.5 feet/s. Due to this slow descent without the main rocket under the parachute, the log ran out (memory full) at T+99 seconds, before landing (at 184 feet AGL).

From ejection until about T+59s, there were unexplained very large noise spikes (+/-5000 feet) in the pressure readings, approximately every 4 to 5 seconds. In addition to the expected spike at ejection, there were 14 to 16 of these spikes, which did not recur after T+59s. The source of these is unknown, but may be an effect of damage to the sensor or PCB from the violent ejection.

Navigation summary:

Despite the 1 second servo change interval, there was essentially no correlation between servo position and measured turn rate. However, the turn rate was still being measured in 200 mS (single fix) intervals, rather than the improved method planned (but not yet fully implemented). There was no discernable navigation or detection of system lag. Parachute steering trim may have been messed up in the violent ejection.

Results:

Objective 1 – Failed.

Lessons learned:

a. Avoid excessively larger BP charges (esp. without extensive testing).
b. Avoid double BP charges for redundancy.
c. Improve turn rate estimation per previous flight.

6 November 2010, Amesbury MA (CMASS) – Flight #33, "Rev 4a" hardware flight #8

LCO:	CMASS
Still photographer:	None
Video photographer:	Dave

Flight configuration:

1.	Booster:	Thrud
2.	Motor:	Cesaroni 163H133BS-14A
3.	Ejection:	Electronic

4. Electronics: Rev4a hardware, PA6 GPS, AD4 altimeter (backup)
5. Launch detection: Electronic
6. Recovery: NASA NPW5 steerable (SuperChute)

Objectives:

1. Attempt GPS-steered parachute navigation back to launch site (repeat of flight 32)

Summary:

Probably the first successful navigation. Low apogee ~ 650 feet AGL as before on Cesaroni H133 motor (a very small H). Parachute appeared to deploy OK but was found on recovery to in fact have partially tangled lines. Soft landing with some applause from spectators, as it appeared that during descent the rocket was navigating successfully toward the launch pad. Analysis of logged data & simulation leads to the conclusion that the observed navigation was probably real. And a great deal learned.

Results:

On descent the parachute appeared to be actively navigating back toward the launch pad (Pad C), but this only became apparent at the very end of the descent. It was unclear if the line tangling prevented servo control of the parachute – the tangle looked bad but there seemed, post-recovery, to be smooth motion of the two key control lines thru the tangle. The low apogee didn't give enough descent time for the navigation algorithm to more than begin steering back toward the pad (consistent with the observed behavior of the parachute). Considering the line tangling and late, short, period of apparent steering toward Pad C, it wasn't clear if the seemingly-directed flight was accidental or the result of successful navigation.

Parachute was packed for this flight as follows:

1. Lines were bundled and installed in bay.
2. Parachute bridal lines were placed on left and right side of unfolded chute.
3. Chute was folded in from the outer left and right edges.
4. Chute was re-folded (again) from left and right.
5. "Z" fold of chute vertically.
6. Installed in parachute bay.

Post-flight analysis:

Apogee was recorded at ejection (T+5.43 seconds) as 655.9 feet AGL, but the familiar noise in the pressure sensor data made this value uncertain – the true value may be close to 630 feet. Post-ejection, apogee was reported as 690 feet AGL or so (with noise). Again, this discrepancy is probably due to changing mechanical stress on the pressure sensor (the whole electronics bay is used as a piston). Total flight time was 48.2 seconds.

As on the last flight, only the primary ejection charge had fired upon recovery. Post-flight this was realized to be due to software changes after flight 31 to reduce on-pad power consumption by powering down the servo until flight (after initially setting it to the stowed position at power-up). In Rev4a (but not 4d) the same circuit that powers the servo also supplies power to the AD4 backup altimeter, so this wasn't getting power pre-flight, and therefore didn't get a good pad altitude reading.

The GPS was locked on to 10 SVs at launch, which immediately dropped to 7 by T+0.484 seconds, 5 at T+6 seconds (apogee), and started recovery (to 6) at T+13.3 seconds. GPS location output was obviously bogus until around T+14.6 seconds (about 9 seconds after apogee and deployment). This is consistent with prior flights. There were no formally invalid fixes.

Navigation results:

The first attempt at navigation was made at T+6.365s, just after start of descent. GPS fix interval (and navigation steering interval) was 200 mS. The GPS output was clearly unreliable from launch until about T+14.6 seconds (about 9 seconds after ejection). The evidence for this is obviously-implausible output for rate-of-turn and fix-to-fix velocity. As a result, the first 8 seconds or so of navigation was based on invalid GPS data.

Extensive review of the logged navigational and GPS data (see file "f2.xls" from this flight) indicates:

1. Probably the control lines were at least partly entangled until about T+37 seconds, at which point the correlation between servo position and turn rate markedly improves. However even then this correlation is still poor. One likely reason is considerable swinging of the electronics bay (and GPS receiver) under the long parachute lines. This may both contribute to control lag and of course adds noise to the GPS results.
2. The directly reported GPS course deviates considerably from the course derived from the GPS location fix results. The GPS fix results are far nosier (standard deviation of the error seemed to be about 15 degrees/fix), but even when smoothed have significant mismatch with the direct course reports. The GPS course results may be smoothed or averaged internal to the GPS – it is not clear that these should be trusted. (It may be worth contacting the GPS manufacturer for more information about this.) To see this, plot reported course and derived course vs. time. (GPS reported speed has a similar issue.)
3. There is fairly good evidence for a lag time of around 0.8 seconds between control input and evidence of change of rate of turn. However there is also evidence that it may take considerably longer than that – perhaps up to 3 or 4 seconds, but this is based on very little, and very noisy, data – for the parachute turn rate to fully stabilize after a change of control input. (It may be useful to limit control input changes to ~ 1/second until this is characterized better.) This may be partly a function of the long parachute lines used (another reason to try shorter ones).
4. Filtering of the course and turn rate data derived from GPS location fixes may be best accomplished by comparing position fixes 3 to 5 fixes apart (at 200 mS/fix) . For example: Calculate course from Fix 1 to Fix 5, and Fix 2 to Fix 6 (column "4 D Trk" = 4 fix delayed track), then calculate turn rate from the course difference between those two results (column "4 D TR = 4 fix delayed Turn Rate). The integrated change in course over 3 to 5 fixes is also worth looking at – compare track at Fix 1 (derived from two successive fixes) to track at Fix 5, divide by 4 (for the 4 fix intervals) and multiply by 5 (5 Hz fix rate) to get turn rate/second (column "4 D I TR" = 4 fix delayed integrated turn rate). The first derivative vs. time of this result (turn rate acceleration) seems also useful to look at (column "4 D TA" = 4 fix delayed Turn Acceleration).
5. The large amount of noise in the GPS reported course (and therefore calculated turn rate) at first seemed to prevent the navigation algorithm from making a correct estimate of the system control time lag; if so the steering that did occur was more-or-less random with respect to the intended target. But simulation of the navigation algorithm with the observed GPS error characteristics gave valid (but sloppy) navigation qualitatively similar to what was observed on this flight. So, **probably the navigation observed was real**.

Results:

Objective 1 – Probably successful. Hard to be sure. Much useful data returned.

Lessons learned:

d. Either power AD4 separately (so it gets power even if servo doesn't) or move to a backup ejection using the Rev4 board instead of the separate AD4.

e. To avoid tangling and reduce GPS "swing", try shortening lines as much as possible, and folding loose line into the parachute folds so it doesn't flop around during deployment. Consider deployment bag or similar. Consider a separate anchor point for nose cone line.
f. Fly to higher altitudes to get more descent time for data acquisition.
g. Contact GPS mfr regarding accuracy and filtering of GPS-reported speed and course. Is it filtered? Can this be disabled? Is it based on the whole inter-fix interval, or is it meant to be an instantaneous value? Why does it diverge from the fix-derived results?
h. Try reducing the interval between control changes to allow the system to fully stabilize (at least until the system is better understood.)
i. Consider lockout of navigation until GPS output stabilizes post-ejection.

6 November 2010, Amesbury MA (CMASS) – Flight #32, "Rev 4a" hardware flight #7

LCO:	CMASS
Still photographer:	None
Video photographer:	Dave

Flight configuration:

1. Booster: Thrud
2. Motor: Skyripper H155PP
3. Ejection: Electronic
4. Electronics: Rev4a hardware, PA6 GPS, AD4 altimeter (backup)
5. Launch detection: Electronic
6. Recovery: NASA NPW5 steerable (SuperChute)

Objectives:

1. Attempt GPS-steered parachute navigation back to launch site

Summary:

Parachute did not deploy properly, again, due to line tangling. Crash with no damage.

Results:

Good liftoff. Parachute ejected near apogee. Parachute was again tangled (not quite as bad as last time, but bad enough) and did not inflate. Landing a little slower than last time; no damage. Beep code gave apogee at 1578 feet AGL.

Post-flight analysis:

Only the primary ejection charge had fired upon recovery. Per on-board altimeter, apogee was at 1586 feet AGL, which was also the ejection altitude. Post-ejection, the apogee was reported as 1644 feet AGL; a similar discrepancy as seen on the last few flights. Descent (and impact) speed was 35.1 mph. Total flight time was 41 seconds.

Satellite lock went from 10 at launch to 4 at T+2.855 seconds, recovering to 6 at T+7.667s (still in ascent). Then at T+11.86s it dropped to 0 (just after apogee) but recovered to 7 one second later and 9 at T+17.05 seconds. GPS results were clean from then on. There seems to be a consistent pattern of invalid GPS fixes until a second or two after apogee.

Results:

Objective 1 – Failed

Lessons learned:

a. A system to avoid line tangling is needed. Really.

2 October 2010, Amesbury MA (CMASS) – Flight #31, "Rev 4a" hardware flight #6

LCO: CMASS
Still photographer: None
Video photographer: Dave

Flight configuration:

1. Booster: Thrud
2. Motor: Cesaroni 163H133BS-14A
3. Ejection: Electronic
4. Electronics: Rev4a hardware, PA6 GPS, AD4 altimeter (backup)
5. Launch detection: Electronic
6. Recovery: NASA NPW5 steerable (SuperChute)

Objectives:

1. Attempt GPS-steered parachute navigation back to launch site

Summary:

Parachute did not deploy properly due to line tangling. Crash with minor damage.

Results:

Rocket spent a lot of time on the pad with servo running prior to launch, due to 3 failed attempts to launch N2O hybrid motor (there wasn't enough N2O in the tank). On the 4th launch attempt, rocket flew on a Cesaroni conventional motor.

Good liftoff. Parachute ejected near apogee (maybe a little past). Parachute was badly tangled and did not inflate. High speed landing in draggy configuration; minor damage.

Post-flight analysis:

Both ejection charges had fired upon recovery. Battery was at 8.02 volts (unloaded) several days after flight (still mostly charged).

Per on-board altimeter, apogee was at 767.5 feet AGL, which was also the ejection altitude. Descent (and impact) speed was 36.3 mph – enough for minor damage. Total flight time was 22.5 seconds.

Satellite lock went from 9 at launch to 5 (at apogee) then 1 (after ejection). This recovered during descent to 5 at 200 mS after ejection, then 6 for one sample about 2.3 seconds after that. At about 300 feet AGL 8 satellites were locked, at about 8 seconds after apogee. This seems adequate for navigation.

Results:

Objective 1 – Failed

Lessons learned:

a. A system to avoid line tangling is needed.

18 September 2010, Amesbury MA (CMASS) – Flight #30, "Rev 4a" hardware flight #5

LCO: CMASS
Still photographer: None
Video photographer: Dave

Flight configuration:

1. Booster: Thrud
2. Motor: Skyripper H155PP
3. Ejection: Electronic
4. Electronics: Rev4a hardware, PA6 GPS, AD4 altimeter (backup)
5. Launch detection: Electronic
6. Recovery: NASA NPW5 steerable (SuperChute)

Objectives:

1. Verify flight software improvements (repeat)
2. Verify function of piston ejection system (repeat)

Summary:

Good flight, but ejection was visibly late by about 3 seconds. Landed in rocket-eating tree.

Results:

Good liftoff, ejection was late by about 3.0 (+/- 0.1) seconds; reason unknown. Both ejection charges had fired upon recovery.

Rocket landed in tree; parachute seriously damaged during recovery, rocket otherwise intact and re-flyable.

Post-flight analysis:

Apogee was at 1323 feet AGL as measured prior to ejection, about 1354 feet AGL after ejection. The reason for the discrepancy, this time only about 25 feet, is still unknown. Best theory at this time is that this is related to changing stress on the PCB and pressure sensor; when an ejection charge occurs the electronics bay shifts, which causes a shift in the stresses applied to the PCB.

Descent rotation rate was about 3.2 to 3.3 seconds/turn (a little quicker than last flight).

Altitude sine noise was again present – period was 1.47 seconds. Strange battery voltage readings were present – battery behavior was nominal until T+5.95 seconds (simultaneous with the ejection charge), when it spiked from 8.23 to 8.31 volts. Then at T+32.115 (simultaneous with the backup charge), it spike again from 8.25 to an impossible 10.19 volts. Clearly this is not a real reading but some kind of sensing error – perhaps carbon from the charges conducted some voltage across the sensing voltage-divider resistors. Both voltage spikes showed a gradual return toward nominal readings after the spikes. The back of the PCB post-flight showed some ejection charge residue near C10, R11 and R12 and perhaps near R24 and R25. The first three components relate to the GPS power supply, the latter 2 to the battery voltage measurement. It is possible this is the cause of both the GPS failure today and the strange battery voltage readings. (Log indicates that the GPS started running again spontaneously around 15 seconds after landing.)

From video, actual apogee was at about T+6.1 to T+6.5, and ejection was at T+9.9 seconds. Log record shows ejection at T+9.595 seconds. From the video, there is absolutely no question that the rocket was headed downward for well over 1 second prior to ejection, yet this doesn't fit the altitude record in the log. The only explanation I can think of is insufficient venting of the electronics bay, leading to late pressure equalization and late deployment.

Results:

Objective 1 – Successful.

Objective 2 – Successful.

Lessons learned:

a. Double-check altimeter chamber venting to avoid late deployment.
b. Be very sure no ejection charge residue can reach PCB; it is conductive.

18 September 2010, Amesbury MA (CMASS) – Flight #29, "Rev 4a" hardware flight #4

LCO:	CMASS
Still photographer:	None
Video photographer:	Dave

Flight configuration:

1. Booster: Thrud
2. Motor: Skyripper H155PP
3. Ejection: Electronic
4. Electronics: Rev4a hardware, PA6 GPS, AD4 altimeter (backup)
5. Launch detection: Electronic
6. Recovery: NASA NPW5 steerable (SuperChute)

Objectives:

1. Verify flight software improvements
2. Verify function of piston ejection system

Summary:

Original flight goal was GPS-steered return to pad, but GPS was inoperative prior to flight, so this flight was used to verify other software changes and new piston ejection system. Excellent flight; good ejection at apparent apogee.

Post-flight analysis:

Ejection was just at apogee, as far as could be determined. Both ejection charges had fired upon recovery. Apogee was at 1084 feet AGL as measured prior to ejection, about 1146 feet AGL after ejection. The reason for the discrepancy is unknown – here are some theories:

- Possibly the ejection charge itself raised the altitude of the electronics bay by 100+ feet, but this seems unlikely (only 0.5g of BP was used).
- This may be an effect of changing stress on the Rev4 PCB; the pressure sensor is known to be sensitive to mechanical stress. Perhaps ejection changed the direction and magnitude of stress – this might also explain the 100+ foot jump in altitude reading upon landing (also unexplained).

In this configuration the servo wasn't routed thru a pulley but instead was directly connected to one of the control lines. The rotation rate in the idle (stowed) position was measured at 3.6 seconds/turn from the video.

Firing of the backup charge (AD4) can clearly be seen at about 883 feet AGL (as measured by the Rev4 altimeter).

On descent there was a distinct sinusoidal noise pattern seen in the altitude readings, similar to what was seen on the previous flight. The period of this noise was 1.3 seconds, which doesn't obviously correlate with anything and is different from the period on the last flight. **This is worth some lab bench investigation.**

There is no obvious correlation between the number of pressure samples taken and the pressure/altitude error**.**

Results:

Objective 1 – Successful.
Objective 2 – Successful.

Lessons learned:

a. Use fresh igniters (had to borrow a "twiggy" for this flight).
b. Make preflight setup checklist (nearly forgot to install bolts).

17 July 2010, Amesbury MA (CMASS) – Flight #28, "Rev 4a" hardware flight #3

LCO:	CMASS
Still photographer:	None
Video photographer:	Dave

Flight configuration:

1.	Booster:	Thrud
2.	Motor:	Aerotech H180W
3.	Ejection:	Electronic
4.	Electronics:	Rev4a hardware, PA6 GPS, AD4 altimeter (backup)
5.	Launch detection:	Electronic
6.	Recovery:	NASA NPW5 steerable (SuperChute)

Objectives:

1. Re-verify flight software stability after improvements
2. Test performance of GPS receiver in close proximity to servo (RF or power line interference?)
3. Observe GPS lag in flight, for course, speed, and position measurement.
4. Determine if 200 mS GPS samples are interpolated or "real".
5. Test adequacy of servo range of motion for parachute steering
6. Test steering with very small (~ 2.5 inch) baseline (low expectations).
7. Observe in-flight performance of parachute (airspeed, descent rate at this weight)

Summary:

Good flight, but rocket stuck high in a pine tree, not recovered until 4 days after launch. Good parachute deployment at apogee. Video shows some steering control, probable severing of steering control line by backup charge (oops).

Post-flight analysis:

Good liftoff, rocket appeared to attain a bit higher altitude than expected: 1444 feet at T+8.3 seconds by the (uncalibrated) altimeter, vs. 1100 expected. Good deployment of NPW5 at apogee, no problems with tangling that were visible from the ground. From the video it appears that the navigation algorithm was steering the rocket both left and right, or at least was learning to do so. At about 800 feet AGL the backup charge fired (by the AD4 backup altimeter) as expected (meaning the primary charge didn't ignite the backup), but from the video it appears that the backup charge may have severed the steering control line, as the parachute immediately went into a very sharp right turn, and never got out of that turn for the rest of the flight.

From the video (http://www.youtube.com/watch?v=dZsnk5mG3lc), it appears that even with the tiny 2.5" baseline, steering was possible and that twisting of the rocket body on the control lines was not a problem. This was not expected (I'd thought that a much larger baseline would be needed). The range of steering control given by the servo layout seemed more than adequate – in fact, a smaller range would probably yield more useful steering results.

The performance of the Rev4 hardware and software as an altimeter seems reliable enough that I can get rid of the AD4 backup in future flights, and just have dual (primary and backup) ejection charges driven directly off the Rev4 hardware.

Winds aloft were much faster than expected. This alone would have prevented navigation back to the launch site, as the winds were almost certainly faster than the airspeed of the parachute. The rocket drifted far off the field downwind, landing high in a pine tree off the field. The rocket was recovered 4 days later with the help of a 30 foot fiberglass pole with a hook on the end.

The control line was in fact severed upon recovery, and a close examination shows signs that it was probably burnt (or at least severely weakened) by one of the ejection charges – I can't be certain however.

Both batteries had 0.00 volts on them upon recovery. Despite this, a slow charge at 0.05 C seemed to bring them back without problems.

Video analysis:

Post-flight analysis of the video gave the following timeline:

T+0s	Launch
T+6.5s to T+7.0s	Ejection (apogee detected in software at 6.959)
T+25s	Straight-ish navigation flight
T+48.7	Hard right turn begins
T+49.4	Backup charge smoke visible

The rotation speed of the parachute after the hard right turns started was measured at 1.4 seconds per 360 degree turn.

Data analysis:

It appears that parachute ejection was early – the rocket was still ascending at about 84 feet/second (57 mph) at deployment. This seems to be due to more noise than expected in the altitude readings. **Tweaking of the apogee detect algorithm is needed**. The noise oscillation period is about 2.5 seconds, which doesn't seem to correlate with anything (it might be some kind of beat frequency). For the next flight the **number of raw pressure readings incorporated into each altitude reading will be logged**, to help find the source of the noise.

The GPS altitude data is uselessly filtered, as expected.

Wind speeds seems to have been in the range of 12 to 16 mph, and parachute airspeed about 11 mph (possibly higher; very little data to go on here). So this flight would not have been expected to navigate correctly even if everything worked perfectly. **It is probably worth looking into trimming the parachute for faster flight**.

The rapid rotation of the parachute (seen on the video) does seem to be reflected in the 200 mS sampled GPS ground speed readings. The rate was measured both by analysis of the video and by GPS course/speed, with one rotation per 1.41 seconds.

Regarding GPS data during and after high acceleration (loss of tracking? ITAR limits are 60,000 feet and 1000 knots), the last clearly valid GPS reading (8 SVs) was at T+4.4 seconds (still in ascent), and the next clearly valid reading (7 SVs) was at T+15.0 seconds. This might imply a 10-second "lockout" period after detection of high acceleration. On the other hand, in between these two events there were, first, 4 successive "invalid" fixes (0.8 seconds) with 2 SVs each and plausible-looking course data (but interpolated-looking speed and position data). The remainder of the period yielded "valid" fixes with similar characteristics – 2 SVs each, implausible position and speed, but plausible-looking course data. (Note that these "valid" fixes were not used for navigation, as the code requires a minimum of 5 SVs for a fix to be used for navigation). GPS position fixes were used to derive course and speed between fixes, in order to compare position-derived course/speed to GPS-reported course/speed. As hoped, the GPS-reported course and speed was consistent with the position-derived data, but much smoother and less noisy. It appears that the GPS firmware is deriving course and speed directly from the GPS signals. So I'll use the GPS-reported values in the future.

The navigation logs showed 11 "implausible GPS fixes", from the fix received at T+15.174s through the one at T+17.173. These fixes were ignored by the navigation algorithm (They appeared to show an implausible ground speed > 5x the average ground speed.) On investigation, this was a false interpretation based on a starting average speed of 0 and slow adaptation of the average. **The algorithm will be fixed for the next flight.**

The navigation system was unable to determine a meaningful value for GPS latency due to the wind speed being greater than the airspeed of the parachute.

Results:

Objective 1 – Successful (mostly; see "data analysis").
Objective 2 – Successful.
Objective 3 – Successful.
Objective 4 – Successful.
Objective 5 – Successful. If anything there was too great a range of steering control.
Objective 6 – Successful. (This was unexpected.)
Objective 7 – Successful.

Lessons learned:

1. Get radio telemetry working on the Zigbee radio before future flights (at least until navigation is debugged and working). Telemetry would have reported the GPS position on landing, making the rocket findable. As well, logging data would have been reported by telemetry, even if the rocket ended up unrecoverable high in a tree.
2. Existing steering range on servo is more than adequate.
3. A small baseline of 2.5" may be adequate (needs more testing).
4. Re-design steering control line and ejection charge layout to avoid damage to control line from backup charge.
5. Consider rigging parachute for faster airspeed.
6. On future flights, either remove AD4, or disable it in flight via Rev4 control of AD4 power, so that the AD4 doesn't fire the backup charge in the case that the primary charge was clearly successful – monitor descent rate to determine this.
7. GPS reported course and speed appear more reliable (and much less noisy) than position-derived course and speed.
8. Detect "landing" in software. Use to:
   a) Put electronics in "power conserve" mode once rocket is landed (at least if not recovered in a reasonable time). Turn off GPS, servo, etc., run radio in short bursts occasionally, clock CPU at minimum speed, etc.
   b) Turn off electronics off when LiIon battery drops dangerously low in voltage after landing. This will prevent damage to the batteries in the event that the rocket isn't recovered for a while.

24 April 2010, Amesbury MA (CMASS) – Flight #27, "Rev 4a" hardware flight #2

LCO: CMASS

Still photographer: None
Video photographer: Dave

Flight configuration:

1. Booster: Thrud
2. Motor: Aerotech H128W
3. Ejection: Electronic
4. Electronics: Rev4a hardware, PA6 GPS, AD4 altimeter (backup)
5. Launch detection: Electronic
6. Recovery: Standard round parachute, 54”

Objectives (repeat of Flight 26):

1. Test performance of Rev4a hardware & software in flight
    a. Launch detection
    b. Ejection
    c. Logging
    d. GPS
    e. Battery
2. Retest PA6 in flight (4th flight of PA6 GPS; 1st for this unit)

Summary: Successful flight, but data lost post-flight due to software design error.

Results:

Somewhat wobbly ascent to an altitude visibly lower than previous flight – perhaps 900 to 1000 feet AGL. Perfect apogee deployment. Nominal landing, no damage.

Post-flight, it was observed that both ejection charges had fired, and apparently both flashbulbs as well. It was impossible to determine when the backup charge fired, as no data was recovered from the Rev4a hardware, due to a software design flaw. This flaw caused immediate erasure of stored logs upon boot with the switch in the ARMED position (that is, with no switch connected). Entry to the TIMEDLAUCH state erased the logging memory.

Objective 1 – Successful.
Objection 2 – Failed (no data acquired).

Data analysis:

None – no data recovered.

Lessons learned:

1. Do not fly code that has been modified less than one week ago. This would have provided sufficient time to discover the design flaw and determine a workaround.

Electronics bay design flaws to be revisited:

1. Place terminal strips in “clean” area of e-bay; this will obviate need for protective tape and keep connections cleaner.
2. Make e-bay operable with a single thumbscrew.
3. Bill S’s design for an integrated e-sled/e-bay is much better – it allows switches and wires to avoid flexing and disconnection when servicing the e-bay. See 2010-04 iPhone photos.
4. Mark e-sled with current draw (this rev draws 100 mA).

24 April 2010, Amesbury MA (CMASS) – Flight #26, "Rev 4a" hardware flight #1

LCO: CMASS
Still photographer: None
Video photographer: Dave

Flight configuration:
1. Booster: Thrud
2. Motor: Skyripper H155PP
3. Ejection: Electronic
4. Electronics: Rev4a hardware, PA6 GPS, AD4 altimeter (backup)
5. Launch detection: Electronic
6. Recovery: Standard round parachute, 54"

Objectives:
1. Test performance of Rev4a hardware & software in flight
    a. Launch detection
    b. Ejection
    c. Logging
    d. GPS
    e. Battery
2. Retest PA6 in flight (3rd flight of PA6 GPS; 1st for this unit)

Summary: Good flight, 1388 feet AGL apogee. Primary flashbulb failed to ignite, despite good connection and good hardware/software. Backup AD4 saved flight at 800 feet.

Results:

It was very difficult to hear piezo status buzzer on the pad – needs to be much louder. It was observed that accidental launch without arming the electronics was quite possible.

Launch was detected nominally.

FLIGHT APOGEE was entered at 1360.9 feet AGL. Flashbulb continuity was good until then. Battery voltage dropped consistent with current flow to flashbulb, but ejection charge did not fire. Rocket descended tumbling until about 800 feet AGL, when the AG4 backup altimeter ejected the main parachute. Nominal landing, no damage.

Field download of data was extremely difficult in full sunlight due to poor sunlight readability of LCD screen.

Logging data clearly showed no ejection charge firing at apogee, but the backup charge at about 800 feet AGL.

GPS data looked clean, with no obvious anomalies other than failure to significantly update position prior to apogee. This may be an intentional result of DoD (ITAR) compliance.

Post-flight inspection showed that both primary and backup charges had fired (2.5 grams of BP each); probably the primary was ignited by the backup. The failed flashbulb had hairline cracks visible in the glass. Likely this was the cause of the failure. This may have resulted from mechanical damage to the bulb during pre-flight prep; the glass bulb extended considerably beyond the ejection canister.

Objective 1 – Successful, other than flashbulb failure.
Objection 2 – Successful.

Data analysis:

Peak ascent speed was about 165 mph. Apogee was at 1388.4 feet AGL.

Tumbling descent rate was about 61 feet/s (41.7 mph). This dropped to 24.4 feet/s (16.7 mph) upon parachute deployment, which was safe and acceptable.

Flight was otherwise nominal.

Lessons learned:

1. Piezo status sounder needs to be much louder (by 10 to 15 dB).
2. Method to prevent accidental un-armed launch is needed (gated ignition, "Remove Before Flight", etc.)
3. Daylight-readable computer screen is needed for field work (or dark box/cloth, etc.)
4. Design ejection canister to physically protect entire ejection charge package.

1 November 2008, Amesbury MA (CMASS) – Flight #25, "Rev 3" hardware flight #20

LCO:	CMASS
Still photographer:	None
Video photographer:	Dave

Flight configuration:

1. Booster: SuperHorizon
2. Motor: Skyripper H155PP
3. Ejection: Electronic
4. Electronics: Rev3 hardware, PA6 GPS, Pentax camera, AD4 altimeter
5. Launch detection: Electronic
6. Recovery: Standard round parachute

Objectives (repeat of Flight 24):

1. Test PA6 in flight (second flight of PA6 GPS)
2. Obtain images in-flight from camera

Summary: Successful flight. No images obtained. More PA6 data quality testing is needed.

Results:

Apogee was 832 feet AGL per AD4 altimeter, apogee ~890 feet per Rev3 hardware altimeter. Upon landing, camera was observed to be off and shut. Probably the battery ran out during flight.

Post-flight analysis:

Again the PA6 GPS seemed to perform well (in lat/lon, not so much in elevation, as expected), except for two data points that were badly off, close to landing. Cause of this is unknown, but may be related to antenna shadowing or the 5 Hz PA6 update rate. This problem does seem to be consistent, at least at the 5 Hz rate.

No images were recovered upon landing. Either the camera was not powered up preflight (possible but unlikely) or a low battery condition caused the camera to shut down before the first image was recorded.

Objective 1 – Successful.
Objection 2 – Failed.

Data analysis:

Apogee ~ 890 feet AGL.

Lessons learned:
1. Further analysis of PA6 performance is needed.
2. Fully charge camera battery before each flight.

1 November 2008, Amesbury MA (CMASS) – Flight #24, "Rev 3" hardware flight #19

LCO:	CMASS
Still photographer:	None
Video photographer:	Dave

Flight configuration:

1. Booster:	SuperHorizon
2. Motor:	Aerotech H180W
3. Ejection:	Electronic
4. Electronics:	Rev3 hardware, PA6 GPS, Pentax camera, AD4 altimeter
5. Launch detection:	Electronic
6. Recovery:	Standard round parachute

Objectives:
1. Test PA6 in flight (first flight of PA6 GPS)
2. Obtain images in-flight from camera

Summary: Fully successful flight. Some PA6 "noise" data points observed.

Results:

Pre-flight, during prep, the AD4 trigged the ejection charge on the ground. No damage done.

Good flight, no problems. AD4 altimeter apogee was not recorded. Apogee ~970 feet AGL Upon landing, camera was observed to be off and shut. Probably the battery ran out during flight.

Post-flight analysis:

The PA6 data was generally good but with a scattering of at least 5 clearly invalid data points. Some simple sanity-check filtering (look for wildly inconsistent velocity changes) may be able to identify and remove these. Another possibility is to run the PA6 update rate at slower than the maximum of 5 Hz – see if this will reduce or eliminate the bad data points.

Several good images were recovered, but with many dark ones (as on earlier flights).

Objective 1 – Successful.
Objection 2 – Successful.

Data analysis:

Apogee ~970 feet AGL.

Lessons learned:

1. Provide method to disarm AD4 on the ground.

2. Try testing PA6 with slower update rates than 5 Hz.

4 October 2008, Amesbury MA (CMASS) – Flight #23, "Rev 3" hardware flight #18

LCO:	CMASS
Still photographer:	None
Video photographer:	Dave

Flight configuration:

1. Booster: SuperHorizon
2. Motor: Skyripper H155PP
3. Ejection: Electronic
4. Electronics: Rev3 hardware, GPS, Pentax camera, AD4 altimeter
5. Launch detection: Electronic
6. Recovery: Standard round parachute

Objectives (repeat of Flight 22):

1. Test new status logging system in flight
2. Obtain images in-flight from camera

Summary: Successful flight. No usable images.

Results:

Good flight, no problems. Only 2 in-flight images recorded, neither of usable quality. All other images were dark.

Post-flight analysis:

Best guess is that control of both focus and exposure are going to be needed to get reliably good quality images. A much faster frame rate would be helpful, too.

Objective 1 – Successful.
Objection 2 – Failed.

Data analysis:

Apogee was 714 feet per data, but only 304 feet per AD4. 714 foot number is consistent with ground observation, video, theory and experience.

Lessons learned:

1. Use a better camera. Try Canon DIGIC 2 models with CHDK for full control.

4 October 2008, Amesbury MA (CMASS) – Flight #22, "Rev 3" hardware flight #17

LCO:	CMASS
Still photographer:	None
Video photographer:	Dave

Flight configuration:

1. Booster: SuperHorizon
2. Motor: Aerotech H210R
3. Ejection: Electronic
4. Electronics: Rev3 hardware, GPS, Pentax camera, AD4 altimeter
5. Launch detection: Electronic
6. Recovery: Standard round parachute

Objectives:
1. Test new status logging system in flight
2. Obtain images in-flight from camera

Summary: Forward casing CATO. No serious damage.

Results:

There was a more than 10 second delay between ignition current and liftoff, accompanied by chuffing and puffing. Rocket smoked and lifted off to a peak altitude of about 60 feet AGL, separating just after clearing the launch rail. Parachute ejected immediately at apogee (almost immediately after liftoff), soft landing.

Post-flight analysis:
Problem was caused by failure to install the delay element in the motor, resulting in combustion gasses emerging from both ends of the casing (forward casing CATO). There was remarkably little damage to the rocket – it was still flyable.
No usable photos recovered.

Objective 1 – Partially successful.
Objection 2 – Failed.

Data analysis:
Apogee was 79 feet per data, probably in fact less.

Lessons learned:

1. Install delay element.

26 July 2008, Geneseo NY (NYPOWER 13) – Flight #21, "Rev 3" hardware flight #16

LCO: NYPOWER 13 / MARS
Still photographer: Dave

Flight configuration:
1. Booster: Creamsicle One
2. Motor: Skyripper H155PP
3. Ejection: Electronic
4. Electronics: Rev3 hardware, GPS, Pentax camera, AD4 altimeter
5. Launch detection: Electronic
6. Recovery: Standard round parachute

Objectives:

1. Obtain images in-flight from camera

Summary: Ejection charge did not fire.

Results:

Launch was beautiful and majestic. Altitude was visually estimated at 800 feet. Ejection charge did not fire. Rocked descended in an unstable configuration, crashed on its side with moderate to severe damage (nothing like flight 18)

Flight was a little wobbly on ascent but otherwise good. Parachute deployed right at apogee. Descent and landing were fine.

PCB was not running upon recovery, camera was still powered on and apparently undamaged.

Post-flight analysis:

Several flight images where recovered, but none of them were any good. Probably if the parachute had deployed and the camera had a longer time to capture images, more would have been better.

E-sled was somewhat damaged after the flight. PCB would not power up post-flight – LEDs blinked once momentarily then went dark.

The PicKit2 would not read data off the PCB due to a "voltage Vdd error". LiIon voltage was 7.99v post-flight, so it appears there was sufficient power to run the PCB. The PCB did operate OK and data was readable after disconnecting the daughterboard.

AD4 altimeter reported a max altitude of 752 feet.

The flashbulb did not fire – the cause of this could not be determined. The bulb fired just fine in a post-flight ground test using the flight hardware.

GPS _again_ did not record any data – reason could not be determined.

One month after the flight, the cause of the ejection failure was discovered. The 0.1" header pins on the daughterboard which connected to the flashbulb had become de-laminated from the perfboard PCB. (See image IMG_6252_crop.jpg.)

Objective 1 – Failed.

Data analysis:

Apogee was 795 feet per data. Log indicates proper detection of launch and firing of ejection charge (similar to flight 18), but charge did not fire. Vertical impact speed was approximately 39 MPH.

Lessons learned:

1. Fully redundant ejection system is needed
2. Logging of continuity is needed for failure analysis
3. Electronics construction must be done with an eye toward reliability:
    a. All mechanical connections must be designed for repeated strain.
    b. Consider potting final boards.

26 July 2008, Geneseo NY (NYPOWER 13) – Flight #20, "Rev 3" hardware flight #15

LCO: NYPOWER 13 / MARS

Still photographer: Dave

Flight configuration:

1. Booster: SuperHorizion
2. Motor: Skyripper H124PVC
3. Ejection: Electronic
4. Electronics: Rev3 hardware, GPS, Pentax camera, AD4 altimeter
5. Launch detection: Electronic
6. Recovery: Standard round parachute

Objectives:

1. Evaluate new Rev3 software that computes and beeps out AGL apogee (feet)
2. Obtain images in-flight from camera

Summary: Nice flight.

Results:

During pre-flight SAFE/ARM switch was observed to stay armed regardless of position. Given that the rocket was already on the pad when this was discovered, it was deemed safest to fly the rocket rather than to attempt to disassemble it, which likely would have set off the ejection charge on the pad (since there was no way to disarm it).

Rocket stayed armed on the pad for about 30 minutes due to a hybrid fill problem and a long wait for launch.

Flight was a little wobbly on ascent but otherwise good. Parachute deployed right at apogee. Descent and landing were fine.

Upon recovery the motor casing was found to be no longer secured by motor clips. This was of no consequence since the shock cord retained the top end of the motor, but it could have led to loss of the motor in flight if the motor attachment was not in use. The camera was still taking images on recovery (and continued to do so for another 15 minutes or so, then shut down and retracted the lens). The Rev3 PCB was beeping out the altitude 776 feet, which seems very plausible.

Post-flight analysis:

The safe/arm switch problem was caused by plugging the connector into the wrong pins (the rightmost 3 pins instead of the leftmost 3 pins).

Several high-quality in-flight images were obtained.

The AD4 altimeter indicated 744 feet.

Objective 1 – Accomplished.

Objective 2 – Accomplished

Data analysis:

For some reason the GPS seems never to have acquired a good fix.

Lessons learned:

1. An improved motor retention system (probably just better clips) is needed.
2. A better method of attaching the safe/arm switch is needed (nail polish markings?).

3. Mastech bench power supply does NOT like being powered from a sawtooth AC inverter – do not use in field.

19 July 2008, Amesbury MA (CMASS) – Flight #19, "Rev 3" hardware flight #14

LCO:	CMASS
Still photographer:	Dave

Flight configuration:

1. Booster: SuperHorizion
2. Motor: Aerotech H210T (circa 2000)
3. Ejection: Electronic
4. Electronics: Rev3 hardware, GPS, Pentax camera
5. Launch detection: Electronic
6. Recovery: Standard round parachute

Objectives:

1. Evaluate new Rev3 software that computes and beeps out AGL apogee (feet)
2. Obtain images in-flight from camera

Summary: Nice flight, Battery disconnected (or failed) sometime after ejection.

Results:

Pre-flight setup was simple and effective. Despite 8 year old motor, ignition was reliable and burn was smooth. Fast, high acceleration liftoff. Nice stable flight. Ejection right at apogee. Rocket landed just inside tree line – no damage. At recovery, CPU was not beeping out anything. CPU was shut down due to 0.0 volts on battery as measured at CPU input.

Post-flight analysis:

12 in-flight images were recorded, at intervals of 3 to 6 seconds. One or two are of excellent quality, most are underexposed, some badly. The first in-flight image appears to have some motion blur (shutter speed 1/640 second); the rest appear sharp.

From the timestamps on the images (as well as their content), it seems that any CPU/battery failure occurred either upon landing or afterwards. (Rocket was briefly handled by spectators from pick-up truck visible in frame IMGP1307 – it is possible this was a factor, but seems unlikely).

Logging data showed clearly that the CPU failed exactly on landing; this is consistent with the image timestamps. Upon post-flight inspection of the e-sled it was found that the 6xNiMH cell battery pack had an intermittent open connection that could be triggered by impact.

Objective 1 – Failed.
Objective 2 – Accomplished.

Data analysis:

A very nice data set was obtained. Apogee was at 860 feet AGL.

Lessons learned:

1. A more reliable camera trigger mechanism than IR is desirable – consider complete removal of camera shutter button & replacement with soldered connections.
2. Underexposure is a problem (possibly caused by exposure to direct sunlight or sky). Try pre-launch fixed exposure, or a camera with a smarter exposure system.
3. Avoid battery packs with many welded series connections – these are prone to failure. Either double-solder each connection or use higher voltage (soldered) packs, or both. Or use redundant packs in parallel.

19 July 2008, Amesbury MA (CMASS) – Flight #18, "Rev 3" hardware flight #13

LCO:	CMASS
Still photographer:	Dave

Flight configuration:

1. Booster: Mjolnir
2. Motor: Skyripper H124 PVC (38/220) hybrid
3. Ejection: Electronic
4. Electronics: Rev3 hardware, 5 Hz G33 GPS, Futaba RX, Pentax camera, AD4 altimeter
5. Launch detection: Electronic
6. Recovery: NPW5 kite

Objectives:

1. First flight of Mjolnir
2. First flight of new 3" E-sled
3. Evaluate flight characteristics of 3" E-sled with servo (via radio control)
4. Evaluate new Rev3 software that computes and beeps out AGL apogee (feet)
5. Evaluate performance of GlobalTop G33 GPS in flight (set to 2.5 Hz)
6. Obtain images in-flight from camera
7. Evaluate max altitude recording capability of AD4 altimeter

Summary: Prang. Got 2 images, a max altitude (probably). Lots of tiny parts.

Results:

Pre-flight setup was a bit of a nightmare. This is NOT a good design – far too much to do on the pad, too many fiddly things, 30 min GPS timeout (if no Bluetooth signal) is too short. Continuity on the ejection charge (flashbulb) and CPU running were clearly established before launch.

Nice liftoff, good speed on the H124-PVC. Visually, apogee seemed to be at about 800 feet. There was no parachute deployment. The rocket turned around and came down like an arrow, impacting about 400 feet from the launch site at 150 MPH (per altimeter data). Distinct whistling sound on descent. Impact was associated with a solid thump.

On inspection, the rocket was utterly destroyed, with the fore 2/3 of the rocket crushed and parts scattered in a debris field. Nosecone was embedded about 6" into packed earth, had to be kicked several times before being able to be pulled loose. See photos.

Post-flight analysis:

The flashbulb did not fire. Speculation was that the cause was either software related (probably non-detection of launch due to 3.7v supply to pressure sensor) or a loose connection. Another possibility is that the battery disconnected under launch acceleration (as in Flight #3), despite a far better connector.

Several pre-launch images (interval 20 seconds) and two in-flight images were recovered from the SD card (which was intact and extractable despite the utterly destroyed camera). Per the image timestamps, the first in-flight image was recorded 12 seconds after the last pre-launch image, and the 2nd (and last) in-flight image was recorded 6 seconds after that - the launch must have been properly detected, and the CPU did not reset upon launch.

Data analysis of the logs (see below) clearly show that launch was detected properly and the ejection charge was triggered at apogee.

The best guess for the failure cause is that the flashbulb connector at the payload/parachute interface detached under launch acceleration – this was intended to separate at ejection, but may have been too loose. It seems unlikely that the current supplied at 3.7v was insufficient to fire the flashbulb, as the flight bulb fired immediately at 3.6v when tested post-flight.

Objective 1 – Failed.
Objective 2 – Failed.
Objective 3 – Failed.
Objective 4 – Failed.
Objective 5 – Accomplished (see below).
Objective 6 – Partially accomplished (2 images).
Objective 7 – Accomplished.

Data analysis:

Max altitude from AD4 was 811 feet AGL. (Fits well with RockSim estimates.) The PIC18LF2620 was inserted in another PCB and the logging data was found to be present. Max altitude from onboard altimeter was 796 feet AGL (remarkably good fit with the AD4 results).

Lessons learned:

1. Do not mount self-detaching connectors such that launch forces may cause them to detach prematurely.
2. Avoid complex pre-flight riggings – this design involved 4 separate line connections (shock cord, left parachute, right parachute, control line).
3. Avoid complex pre-flight electronics setup – this design required separate start of CPU, GPS, camera, and pad connection of flashbulb only after CPU compartment was closed. Only way to confirm continuity was to switch to ARM (not very safe).
4. Power up camera and GPS under CPU control.
5. Use berg-clip power switches (not sliding switches) – more reliable.
6. Design future PCBs for mounting against inside of body tube (edgewise), so header pins can be externally exposed (for switches, testing, berg clips, etc.). This will also allow exposure of LEDs to outside.
7. Emit special beep sound when continuity is bad – ensure clear indication (this used to be done with the horn output, before horn was removed).
8. Avoid e-sled/camera configurations that require precise alignment for installation – this is too tricky. Instead, consider "V-channel" setups that self-align automatically.
9. Use a design that can easily be prepared before getting to the pad – pad prep should be a single switch (or close to that).
10. Use a parachute design less likely to tangle.

11. Ensure sufficient baseline for steering (< 3" is probably not enough).
12. Avoid electrical connectors that must separate at ejection.
13. Log ejection continuity during flight (for diagnostics).
14. Use redundant backup ejection systems.

19 April 2008, Amesbury MA (CMASS) – Flight #17, "Rev 3" hardware flight #12

Flight configuration:

1. Booster: SuperHorizion
2. Motor: H155PP
3. Ejection: Electronic
4. Electronics: Rev3 hardware, Pentax Optio camera
5. Launch detection: Altimeter

Objectives:

Second flight of Pentax Optio camera.

Summary:

Good flight, but PIC data lost due to uploading to PIC instead of downloading from it (operator error).

Only 1 in-flight image and 2 post-flight images obtained. Not sure why.

19 April 2008, Amesbury MA (CMASS) – Flight #16, "Rev 3" hardware flight #11

Flight configuration:

1. Booster: CreamsicleOne
2. Motor: H155PP
3. Ejection: Electronic
4. Electronics: Rev3 hardware, Pentax Optio camera
5. Launch detection: Altimeter

Objectives:

First flight of Creamsicle One.

Summary:

Good flight, reached altitude of about 520 feet AGL. Good ejection and deployment.

19 April 2008, Amesbury MA (CMASS) – Flight #15, "Rev 3" hardware flight #10

Flight configuration:

1. Booster: SuperHorizion
2. Motor: H97J
3. Ejection: Electronic
4. Electronics: Rev3 hardware, Pentax Optio camera
5. Launch detection: Altimeter

Objectives:

First flight of Pentax Optio camera.

Summary:

Good flight, reached altitude of about 470 feet AGL. Good ejection and deployment. Only 2 in-flight images obtained, both underexposed (one unrecoverable). Images much sharper than with Canon camera (focus set to infinity in landscape mode).

20 October 2007, Amesbury, MA (CMASS) – Flight #14, "Rev 3" hardware flight #9

LCO: CMASS
Still photographer: Dave

Flight configuration:
1. Booster: SuperHorizion
2. Motor: Skyripper J144 (38/540) hybrid
3. Ejection: Electronic
4. Electronics: "Rev3" PCB, horn

Objectives:
1. Level 2 certification attempt (3rd)
2. Verify operation of electronic ejection based on apogee detection

Summary: Successful flight, but took 9 days to find & recover rocket.

Results:

Pad setup was much simpler than on previous attempts, as the electronics were started and enclosed in bay during pre-flight prep rather than on the pad. (Arming switch was left in "safe".) N2O loading took a long time – maybe 30+ seconds.

Liftoff was excellent, flight was very stable. J144 motor burns a very long time. Rocket achieved altitude estimated at between 2000 and 3000 feet AGL (3154 feet AGL per onboard altimeter), according to experienced observers. Parachute deployed at apogee (using Rev3 hardware to trigger) and deployed perfectly. Descent appeared gentle and photographs indicate all components deployed properly and appeared intact. Rocket drifted a long way under parachute, far outside field to the north. After 3 hours of searching, recovery attempts were abandoned.

The rocket was ultimately recovered, intact and re-flyable, 9 days later, after landing 50+ feet up a pine tree about 750 meters from the launch site.

Objective 1 – Accomplished.

Objective 2 – Accomplished.

Post-flight analysis:

In retrospect, it was extremely unwise to attempt to fly any 4" rocket on a J motor at this field – under *any* wind conditions – without dual deployment or other means of limiting downwind drift.

Future J motor flights on 4" rockets must either use dual deployment, drag discs (should have been tried this time), or guided return.

On 2007-10-23 (3 days after launch) the rocket was found about 50+ feet up in a pine tree, about 750 meters from the launch site. This was found via triangulation & photogrammetry from two photos of the rocket descending below the horizon (landmarks in view, lens focal lengths & sensors sizes known, photo locations roughly known). A reward offer was attached to the trunk, offering $20 for recovery, $30 if intact.

On 2007-10 -29 (9 days after launch), the rocket was recovered, intact and flyable. (I was out $30 reward money.)

Data analysis (based on altimeter data only):

```
Launch time (T):           158.44 seconds after power-on

Launch detect:             T +   0.36 seconds
Motor burnout:             T +   5.8  seconds
Apogee:                    T +  14.54 seconds
Apogee detect:             T +  14.70 seconds
Ejection:                  T +  15.34 seconds
Landing:                   T + 155.75 seconds

Data memory full:          T + 156.86 seconds

Average positive Gs:          3.5
Maximum altitude:          3154 feet AGL
Maximum vertical speed:     300 mph
Descent vertical speed:       7.785 mph
```

Lessons learned:

1. Don't fly J motor rockets at Amesbury without either dual deploy, very draggy rocket (6"+ or equivalent drag disc), or guided recovery.
2. Bring a GPS to the launch field; in case of lost rocket, take a photo of it going over the horizon (with landmarks) and the position from which the photo was taken. This can be used for photogrammetry to determine the distance when last seen (assuming you know the dimensions of the rocket and the EXIF data or equivalent). Also, after taking the photo, walk toward the landmark directly in line with last location of rocket and take another GPS fix – these two pairs of fixes will provide a direction for the lost rocket.
3. If rocket is lost, offer a reward for return.

2007-10-06, Amesbury MA (CMASS) – Flight #13, "Rev 3" hardware flight #8

LCO: CMASS
Still photographer: Dave

Flight configuration:
1. Booster: Saturn Zero (no drag disc)
2. Aerotech A-RMS F40-4 motor
3. ~1-gram additional ejection charge, attached with "packing" tape
4. "Rev3" PCB, GPS, Canon SD200 camera, horn
5. Launch detection via pressure
6. NASA NPW-5 "SuperChute" parachute
7. Nomex cloth parachute protector

Objectives:

1. Verify new software code prior to use in L2 attempt for electronic ejection
2. Observe performance of Freescale MPX4105A pressure sensor (altimeter)
    a. For pressure-based apogee detection
    b. Observe performance of launch detect algorithm
    c. Observe performance of apogee detect algorithm

Summary: Successful electronics test. Parachute deployment problems. Moderate damage.

Results:

OK flight, F40-4 is a little short (knew that already, but it was what was available). Parachute didn't deploy fully (got tangled). Some damage on impact.

After software corrections, electronics appear to have worked perfectly (except for known camera problems). Launch and apogee detected perfectly.

Objective 1 – Accomplished.

Objective 2 – Accomplished.

2007-10-06, Amesbury MA (CMASS) – Flight #12, "Rev 3" hardware flight #7

LCO: CMASS
Still photographer: Dave

Flight configuration:

1. Booster: Saturn Zero (no drag disc)
2. Aerotech A-RMS F40-7 motor
3. ~1-gram additional ejection charge, attached with "packing" tape
4. "Rev3" PCB, GPS, Canon SD200 camera, horn
5. Launch detection via pressure
6. NASA NPW-5 "SuperChute" parachute
7. Nomex cloth parachute protector

Objectives:

1. Verify new software code prior to use in L2 attempt for electronic ejection
2. Observe performance of Freescale MPX4105A pressure sensor (altimeter)
    a. For pressure-based apogee detection
    b. Observe performance of launch detect algorithm
    c. Observe performance of apogee detect algorithm
3. Observe performance of Canon SD200 3 Mpixel camera in flight
    a. Acquire flight images

Summary: Unsuccessful flight, no damage. No launch detect.

Results:

This was a first flight with revised software after Black Rock NV failures on flights 10 and 11. Fixed were a broken wire (on SuperHorizon) for ARM/SAFE switch, and a wrong switch statement that allocated PortC I/O pins in the wrong direction. Belief pre-flight was that these fixes would correct launch detect problem.

OK flight, delay was a little long. Altimeter failed to detect launch (again). A couple of blurry in-flight photos (focus problem again) acquired in ARMED state. Camera switched into "movie" mode on impact, this was not correctable in the field due to knob alignment problem.

This was the last flight of this SD200 camera – after this flight camera was damaged during attempted modifications to shutter connections.

Objective 1 – Failed. (Lack of launch detect meant no apogee trigger in flight.)
Objective 2 – Failed. (Data acquired seems meaningless.)
Objective 3 – Partly accomplished (just 2 or 3 images; blurry).

Post-flight analysis:

There were two main problems observed – both have occurred on every attempt since flight 10:

1. False triggering of camera on pad. This seems to be caused at least partly by pressure on zoom ring of camera - something loose or nearly short inside, probably. Note that record/play switch seems stuck in record, too. Later disassembly of camera confirmed shorting problems with shutter switch, and misaligned control knob on record/play switch.

2. Failure to detect launch. The log again shows a cycling between ARMED and FLIGHT, with two lagged log entries being recorded each time. Initially this appeared to be caused by some kind of pressure applied to e-sled in body tube – it was seemingly reproducible intermittently by pressing; when it happens, the green and yellow LEDs flash back and forth quickly (as would be expected). Probably this is NOT caused by loose power, as that would cause a reset each time. In fact, the problem was a combination of two things:
    a. Software error in state machine code – when launch was detected (and it was indeed detected), machine entered FLIGHT state but then continued executing remainder of ARMED code – which detected a mismatch between the arming switch and the current state, and "corrected" that by re-entering ARMED state. This was the main cause of the problem.
    b. Insufficient wait time in IDLE after power-up before entering ARMED state. This didn't allow the time constants for the pressure sensor to stabilize, and therefore false detection of launch occurred during testing by "pressing".

Camera blur problems were determined to be caused by failure of the camera auto-focus system. Theory is that the AF system can't focus on fast-moving scenes, such as when rocket is in motion.

Lessons learned:

1. Greater ground testing of all states is needed after each software revision. Regression testing is needed.
2. Lockout of ARMED state should be enforced until TCs have stabilized. Possibilities:
    a. Modify TC algorithm to have TC = max(TCdesired, actual # of samples)
    b. Lock out (with alarm?) arming for a while after boot.
    c. Revise checklist procedures.
    d. Some combination of the above.
3. Means to force the camera to focus at infinity need to be found. One idea is to focus camera on infinity, then cut wires to focus motor (forcing position to stay fixed).

2007-09-15, Black Rock NV (XPRS 2007) – Flight #11, "Rev 3" hardware flight #6

LCO: XPRS

Still photographer: Dave

Flight configuration:
1. Booster: Saturn Zero (no drag disc)
2. Aerotech A-RMS G64-10 motor
3. ~1-gram additional ejection charge, attached with "packing" tape
4. "Rev3" PCB, GPS, Canon SD200 camera, HM55B compass, horn
5. Launch detection via pressure
6. NASA NPW-5 "Superchute" parachute
7. Nomex cloth parachute protector

Objectives:
1. Verify new software code prior to use in L2 attempt for electronic ejection
2. Observe performance of Freescale MPX4105A pressure sensor (altimeter)
    a. At ~4000 feet MSL pad altitude
    b. For pressure-based apogee detection
    c. Observe performance of launch detect algorithm
    d. Observe performance of apogee detect algorithm
3. Observe performance of Canon SD200 3 Mpixel camera in flight
    b. Acquire flight images

Summary: Unsuccessful flight, minor damage. No launch detect.

Results:

Nice ascent on G64-10, delay seems OK. Parachute did not fully inflate; damage minor - one fin broken off on landing, another loosened; hard surface combined with (known) poor fin design.

Altimeter again did not detect launch - investigate.

Camera is STILL prematurely trigged by rubbing of shutter button against body tube – adjust more.

Camera got two or three in-flight images via ARMED mode imaging (since there was no launch detect). Camera was set to ISO 400 to decrease shutter speed. Images are still very blurry; apparently a focus problem – source not yet determined.

Objective 1 – Failed. (Lack of launch detect meant no apogee trigger in flight.)

Objective 2 – Failed. (Data acquired seems meaningless.)

Objective 3 – Partly accomplished (just 2 or 3 images; blurry).

Lessons learned:
1. Pack parachute with more care. Adjust bridal lines for straight flight (or use round parachute).
2. Much more understanding of launch detect failure is needed before further flights.

2007-09-14, Black Rock NV (XPRS 2007) – Flight #10, "Rev 3" hardware flight #5

LCO: XPRS
Still photographer: Dave

Flight configuration:
1. Booster: Saturn Zero (no drag disc)
2. Aerotech A-RMS F40-4 motor

3. ~1-gram additional ejection charge, attached with "packing" tape (better yet)
4. "Rev3" PCB, GPS, Canon SD200 camera, HM55B compass, horn
5. Launch detection via pressure
6. NASA NPW-5 "Superchute" parachute
7. Nomex cloth parachute protector

Objectives:

1. Verify new software code prior to use in L2 attempt for electronic ejection
2. Observe performance of Freescale MPX4105A pressure sensor (altimeter)
    a. At ~4000 feet MSL pad altitude
    b. For pressure-based apogee detection
    c. Observe performance of launch detect algorithm
    d. Observe performance of apogee detect algorithm
3. Observe performance of Canon SD200 3 Mpixel camera in flight
    a. Acquire flight images
4. Observe GPS data acquisition in flight

Summary: Unsuccessful flight, minor damage. No launch detect.

Results:

This was the first flight of heavily revised firmware supporting an "ARM/SAFE" switch and apogee ejection.

F40-4 delay is a bit short. Good flight, but strong rotation on descent, probably due to unequal bridal lengths of NPW5 parachute. Hard landing; two fins broken on landing (one lost); hard surface combined with (known) poor fin design.

Altimeter did not detect launch - investigate.

Camera is prematurely trigged by rubbing of shutter button against body tube - adjust.

Camera didn't record any useful images due to rotation of e-sled upon launch; could have been prevented by locking sled into position, but this was omitted due to pad prep time pressure.

Objective 1 – Failed. (Lack of launch detect meant no apogee trigger in flight.)

Objective 2 – Failed. (Data acquired seems meaningless.)

Objective 3 – Failed. (No useful pictures returned.)

Objective 4 – Accomplished.

Lessons learned:

1. Need a way to externally power & arm electronics, so prep can be done BEFORE getting to the pad. Camera failure was caused by inadequate prep.

2007-08-18, Acton MA (CMASS) – Flight #9, "Rev 3" hardware flight #4

LCO: CMASS
Still photographer: Dave

Flight configuration:

1. Booster: Saturn Zero (no drag disc)
2. Aerotech A-RMS E28-4 motor
3. ~1-gram additional ejection charge, attached with 3M "Scotch" tape (better)
4. "Rev3" PCB, GPS, Canon SD200 camera, HM55B compass, horn
5. Launch detection via launch rod pin
6. NASA NPW-5 "Superchute" parachute

7. Nomex cloth parachute protector (plus wadding)

Objectives:

1. Observe performance of Freescale MPX4105A pressure sensor (altimeter)
    a. Acquire sensor calibration data for pressure-based launch detection
    b. And for pressure-based apogee detection
    c. Observe performance of launch detect algorithm
    d. Observe performance of apogee detect algorithm
2. Observe performance of Honeywell HM55B compass
3. Observe performance of Canon SD200 3 Mpixel camera in flight
    a. Acquire flight images
4. Observe GPS data acquisition in flight

Summary: Successful. Good flight path, good data acquired.

Results:

Liftoff good, nice safe flight path but not at all dangerously high for small Acton field. Altimeter showed apogee at about 250 feet AGL. Good parachute deployment, good parafoil flight, soft landing. Engine retained. One fin slightly damaged on landing.

Data/images acquired – All electronics worked perfectly. Launch was detected promptly via pressure sensing (using new firmware with time constants and thresholds derived from simulations). Apogee was detected correctly. Camera triggered correctly. Horn was running fine on recovery (could be louder), but it stopped before e-sled could be removed and powered down. Images not yet fully analyzed, but appear blurry – not sure why (focus, shutter speed or both). Data not yet fully analyzed, but appears good.

Objective 1 – Accomplished.
Objective 2 – Accomplished.
Objective 3 – Accomplished
Objective 4 – Accomplished.

Lessons learned:

1. Modify horn algorithm to be intermittent; horn appears to run only for a few minutes before stopping.

2007-08-18, Acton MA (CMASS) – Flight #8, "Rev 3" hardware flight #3

LCO: CMASS
Still photographer: Dave

Flight configuration:

1. Booster: Saturn Zero, with 6 inch drag disc (first flight of drag disc)
2. Aerotech A-RMS E28-4 motor
3. ~2-gram additional ejection charge, attached with masking tape
4. "Rev3" PCB, GPS, Canon SD200 camera, HM55B compass, horn
5. Launch detection via launch rod pin
6. NASA NPW-5 "Superchute" parachute
7. Nomex cloth parachute protector (plus wadding)

Objectives:

1. 3rd flight of "Rev3" PCB hardware – observe flight performance
2. Observe performance of Freescale MPX4105A pressure sensor (altimeter)
    e. Acquire sensor calibration data for pressure-based launch detection
    f. And for pressure-based apogee detection
    g. Observe performance of launch detect algorithm
    h. Observe performance of apogee detect algorithm
3. Observe performance of Honeywell HM55B compass
4. Observe performance of Canon SD200 3 Mpixel camera in flight
    b. Acquire flight images
5. Observe GPS data acquisition in flight
6. Observe performance of drag disc

Summary: Mostly successful. Flight path too low, somewhat unstable. Parachute ejected too close to ground, insufficient time to deploy. Minor damage. Good data acquired.

Results:

Liftoff OK, but flight path appeared somewhat (but not completely) unstable, with a wobbling motion. This was not observed on earlier (or later) flights without the drag disc, so this was an effect of the drag disc. Not clear if this was because of the reduced airspeed caused by the drag disc, or a more direct effect. Flight path was very low (apogee at about 100 feet per the onboard altimeter). Parachute deployed very close to the ground, resulting in insufficient time to inflate. Rocket impacted at moderately high speed, resulting in minor damage.

Motor ejected upon parachute deployment, despite being well secured with wired clips. Probably the ejection charge was too large.

Low flight was due to presence of drag disc, which if anything worked too well.

Damage – one broken fin, two weakened fins, crack in payload bay tube. All were fixed on-site. No damage to electronics.

Data/images acquired – All electronics worked perfectly. Launch was detected promptly via pressure sensing (using new firmware with time constants and thresholds derived from simulations). Apogee was detected correctly. Camera triggered correctly. Horn was running upon landing. Images not yet fully analyzed, but appear blurry – not sure why (focus, shutter speed or both). Data not yet fully analyzed, but appears good.

Objective 1 – Accomplished.
Objective 2 – Accomplished.
Objective 3 – Accomplished
Objective 4 – Accomplished.
Objective 5 – Accomplished.
Objective 5 – Partly accomplished. Test with larger motor would be useful.

Lessons learned:

1. Drag disc works too well for use on Saturn Zero with an E28-4; use a larger motor.
2. It would be very useful to have a way to power & configure the electronics (both PIC and camera) external to the rocket.
3. Avoid use of fins that extend below base of booster section; these tend to break off on landing.
4. Avoid excessive ejection charges. (2 grams is excessive for Saturn Zero.)

2007-07-28, Geneseo NY (NYPOWER12) – Flight #7, "Rev 3" hardware flight #2

LCO: MARS
Still photographer: Dave

Flight configuration:

1. Booster: 4" BSD Horizon (rebuilt; booster section extended somewhat)
2. Animal Motor Works J440-BB motor, drilled to 7 second delay
3. ~2-gram additional ejection charge, attached with masking tape
4. "Rev3" PCB, GPS, HM55B compass, horn
    a. Enclosed in jury-rigged "e-sled" made from cut-up Dunkin Donuts polystyrene coffee cup
5. Launch detection via pressure sensor, estimated time constants and thresholds
6. BSD round 36" diameter, nylon
7. Nomex cloth parachute protector (plus wadding)

Objectives:

1. 2nd flight of "Rev3" PCB hardware – observe flight performance
2. Observe performance of Freescale MPX4105A pressure sensor (altimeter)
    a. Observe launch detect algorithm performance
    b. Acquire sensor calibration data for pressure-based launch detection
    c. And for pressure-based apogee detection
3. Observe performance of Honeywell HM55B compass
4. Observe GPS data acquisition in flight

Note: This was also my 2nd Level 2 qualification flight attempt, after rebuilding booster after motor CATO previous day. I failed.

Summary: Unsuccessful flight. Motor burnthru, premature ejection, crash (spectacular).

Results:

Good liftoff (estimated 21 Gs), achieved perhaps 150 feet altitude (much better than 30 or so feet previous day), then forward casing of motor burned thru, which caused high-pressure exhaust gasses to exit both the nozzle and forward casing.

This resulted in immediate trigger of ejection charge & violent parachute ejection (while still accelerating), severe burning of forward booster tube (see IMG_2602 thru IMG_2618), and separation of booster section from parachute/payload bay/nose cone. Booster section crashed (see image sequence), forward section landed softly under parachute.

Presumed cause of failure was excessive drilling of delay element, which may have led to premature burn-thru (or burst-thru) of delay element. Alternative explanation (suggested by Bill S., 2007-08-18) is possible use of incorrect nozzle for motor reload (he says there are two). Failure was very similar to previous day's failure on my 1st Level 2 qualification attempt. On that flight (with no electronics onboard, so not logged in these notes), motor CATOed in a similar manner at about 30 feet AGL. At the time, this failure was attributed to an overly restrictive engine retainer – a strip of stainless steel drilled with an insufficiently large exhaust hole, which was believed to have created an overpressure in the motor (see IMG_2577 thru IMG_2583 – these photos do seem to support this theory). This flight used a conventional motor retention mechanism.

Damage – Forward end of booster section severely burned (see photos). Nosecone/payload section undamaged. The Rev3 PCB hardware was still running on recovery, and logged data during the flight. On recovery, the MPX4105 pressure sensor was found to be physically broken due to high impact forces – most likely this occurred at motor burnthru, not the landing.

Data acquired – Pre-launch (pad) data appears valid, then there is what appears to be a single valid high-rate sample acquired immediately after launch. This sample indicates an altitude of approximately 40 feet AGL. All data recorded after that nonsensical (altitude > 50,000 feet, GPS location changing at thousands of miles/second, etc.). Clearly something very bad happened to the hardware immediately after launch – presumably this was simultaneous with the motor burnthru and premature ejection, which must have been very violent judging from the damage to the MPX4105 pressure sensor. (However, the 40 feet AGL sample is not a good fit with the simulated flight path; it's possible that this sample was partly acquired during the burnthru event, and its high value may be a result of the MPX4105 being broken during the sample period.) Launch detect via pressure sensing appears to have worked, as the sample rate does go into flight mode (25 Hz vs 0.5 Hz pre-launch) based on the single sample of data acquired before the burnthru event.

Objective 1 – Mostly failed (one single data point acquired).
Objective 2 – Mostly failed (one single data point acquired).
Objective 3 – Failed (not enough data to evaluate compass).
Objective 4 – Failed (no valid GPS flight data).

Lessons learned:

1. Don't drill out delay elements; use electronic deployment.
2. Double-check that correct nozzle is in use (esp. with unfamiliar motor hardware; this was a borrowed motor casing).
3. Avoid nozzle restrictions.

2007-07-27, Geneseo NY (NYPOWER12) – Flight #6, "Rev 3" hardware flight #1

LCO: MARS
Still photographer: Dave

Flight configuration:

1. Booster: Saturn Zero (then called "Black Pill")
2. Aerotech A-RMS E28-4 motor
3. ~1.5-gram additional ejection charge, attached with masking tape
4. "Rev3" PCB, GPS, Canon SD200 camera, HM55B compass, horn
5. Launch detection via launch rod pin
6. NASA NPW-5 "Superchute" parachute
7. Nomex cloth parachute protector (plus wadding)

Objectives:

1. First flight of "Rev3" PCB hardware – observe flight performance
2. Observe performance of launch rod pin detection method
3. Observe performance of Freescale MPX4105A pressure sensor (altimeter)
    a. Acquire sensor calibration data for pressure-based launch detection
    b. And for pressure-based apogee detection
4. Observe performance of Honeywell HM55B compass
5. Observe performance of Canon SD200 3 Mpixel camera in flight
    a. Observe stability effect of ~1 inch camera viewing hole

    b. Acquire flight images
6. Observe GPS data acquisition in flight

Summary: Unsuccessful flight. Crash. No useful data acquired.

Results:

Pre-flight: Difficult pad setup caused by too-small holes for rivets holding nose cone.

Good, low (but adequate) flight path. No stability problems caused by camera view hole. Good parachute ejection, good deployment. Payload section separated from booster/parachute - payload section crashed. Very nice smooth parafoil flight (with only booster section as weight – quite a small weight compared to total rocket weight).

Cause of payload section separation was a failed snap ring (see photos), apparently overstressed during parachute ejection.

Damage - Payload section body tube destroyed, no damage to e-sled. GPS was still running upon recovery, but PIC chip popped out of socket (presumably upon impact). Post-recovery, hardware worked fine after re-installation of PIC chip.

Data/images acquired - None. Launch detect activated prematurely on pad. As a result, entire PIC flash memory was filled up with pre-launch data, and entire SD card in camera was filled with pre-launch images. Apparent cause of premature launch detection was the launch detect pin slipping off the launch rod due to wind.

Objective 1 - Mostly failed. Hardware & GPS did appear to survive flight.

Objective 2 – Accomplished. Launch rod pin system doesn't work reliably. One possibility is to add wide adapter (paper? cardboard?) to launch detect pin to avoid premature trigger from wind. Alternatively, use pressure-based launch detection instead of a mechanical switch.

Objective 3 – Failed. No data acquired.

Objective 4 – Failed. No data acquired.

Objective 5 – Failed. No data acquired.

Objective 6 – Failed. No data acquired.

Notes for future flights:

1. Code software LDET & Apogee Detect routine using pressure sensor; log results for comparison with pin result.
2. Bring masking tape to pad (to hold down launch detect pin)
3. Bring needle-nose pliers to pad (to assist with rivet insertion)

Lessons learned:

1. Widen nose cone rivet holes to ease rivet insertion on pad.
2. Attach camera strap (to make it possible to bring camera to pad, avoid having to retrieve camera from vehicle pre-launch).
3. Use larger camera SD card and/or slower frame rate in ARMED state (card filled) - allow AT LEAST 20 min from pad setup to launch.
4. Avoid weak snap rings.
5. Have spare payloads available in case of crashes.
6. Consider soldered PICs (not socketed)
7. Add wide adapter (paper? cardboard) to LDET pin to avoid premature trigger from wind.

2006-11-18, Amesbury MA (CMASS) – Alpha Test #5

LCO: CMASS
Radio control: Dave
Videographer: None
Still photographer: Dave (post-flight only)

Flight configuration:
1. Booster: Saturn Zero (then called "Test Rocket")
2. Aerotech A-RMS F24-4W motor
3. 1-gram additional ejection charge, attached with masking tape
4. NASA NPW-5 "Superchute" parachute
5. Nomex cloth parachute protector (plus wadding)
6. Calm winds

Objectives:
1. Get parachute under positive steering control
2. Observe parachute forward airspeed
3. Observe parachute steering response to control inputs
4. Observe GPS data acquisition in flight

Summary: Fully successful flight.

Results:

Launch was at approximately 3:40pm local time. Good liftoff, a little slow, but not a problem considering the light winds. Stable flight, good altitude (not as much higher than Flight #4 as expected). Parachute deployed perfectly.

During initial decent, parachute entered a slow spin, estimated at perhaps 1 turn per second. When radio control was switched on, initially steering control seemed to influence rate of turn, and then soon direction of turn as well. With experience during flight, operator was soon able to not only get the desired rate and direction of turn, but also stabilize flight direction in a given direction – this was not difficult. However even when steered "straight" there was some small turning rate that the operator was unable to correct (possibly simply from lack of flight experience). The turning rate varied from about (very approximately) 2 or 3 turns/second to zero. The forward airspeed of the parachute seemed quite low – less than 10 miles/hour. Again, there was no video so this is hard to estimate from observation and memory.

Steering response was observed to be fairly fast and responsive, with servo motor actuation time probably the largest factor. There was observable change in turn rate within 500 ms of control input, possibly less. The rate appeared to stabilize almost immediately.

When the rocket was within 200 feet of the ground, the operator was able to put it into straight flight, headed for the operator. Soft landing, no damage. On initial inspection ejection detection did occur in flight (to be verified by recorded data).

Motor was retained, wire tie was recovered.

Objective 1 accomplished.

Objective 2 accomplished.

Objective 3 accomplished.

Objective 4 accomplished, although CPU reset upon landing (same cause as in flight #4). However all flight data (except perhaps for the last 1 or 2 seconds before landing) was retained. Possibly there was no reset on launch due to the lower initial thrust of this engine. (Just a guess.)

On this flight (as with Flight #4), the parachute packing method was quite simple, and appeared to work well. The procedure used was:

a) Attach lines to servo, shock cord to sled, nose cone to sled.
b) Power up and test electronics package.
c) Insert sled into payload bay, heading toward nose cone.
d) Extend parachute lines to maximum length.
e) Grasp parachute at center point (point furthest from electronics sled), make "cone" from that point.
f) Fold over top ¼ to 1/3 of parachute.
g) Insert fold into Nomex cloth, and insert into booster stage.
h) Tuck all the way down to bottom of booster stage.
i) Fold remaining loose bits of parachute and lines into booster stage to the extent possible. At this point > 95% of the parachute is in the booster stage. Most of the lines are still outside and loose.
j) Stretch lines taut and fold them over into compact bundle (avoiding tangles) and tuck them into payload bay.
k) Close rocket carefully, avoiding trapping any lines in closure.

Lessons learned:

1. When automatically steering under program control, be aware that turn rate could be more than 360 degrees per second (and the GPS rate is only 1 Hz). Consider an algorithm that detects "unreliable" servo positions based on successive dissimilar estimated turn rates. Consider finer servo position granularity near center position. Consider smaller servo motion range.
2. Higher altitude flights would be desirable – consider use of G motors or larger.
3. Ejection detection should be made more sensitive to light. (Or, possibly, detector position should be changed).

Notes for future flights:

1. At this point the RC Receiver can be removed (replace with camera).
2. Look for simpler methods to pack and deploy the parachute (avoid extra charge , or consider launch detection and electrical deployment.)
3. Look for ways to reduce risk of lines tangling.

Post-flight data analysis:

1. On flight #5 it is apparent that CPU was reset upon landing (despite fairly soft landing). Result was loss of about 11 seconds of GPS data (last 2 seconds of so of which was prior to landing). It appears that the cause for this is either a loose connection on the CPU board or the spring-loaded battery contacts momentarily disconnecting on impact.
    a. Fix 1 – Mount batteries at 90 degrees to direction of landing
    b. Fix 2 – Solder in batteries
    c. Fix 3 – Install capacitor capable of powering CPU for a few milliseconds
    d. Fix 4 – Move to PCB construction; solder in (and pot) components
2. GPS altitude data lags actual altitude severely – 10 seconds or more, highly smoothed. Not usable for navigation or ejection.
    a. Fix 1 – Install barometric altimeter instead.
    b. Fix 2 – Install accelerometer instead.
    c. Fix 3 – Install launch detector and use timer instead.

d. Fix 4 – Rely on engine ejection charge (as now).

2006-11-18, Amesbury MA (CMASS) – Alpha Test #4

LCO: CMASS
Radio control: Dave
Videographer: Suzana
Still photographer: Dave (post-flight only)

Flight configuration:

1. Booster: Saturn Zero (then called "Test Rocket")
2. Aerotech A-RMS E28-4T motor
3. 1-gram additional ejection charge, attached with masking tape
4. NASA NPW-5 "Superchute" parachute
5. Nomex cloth parachute protector (plus wadding)
6. Calm winds

Objectives:

1. Get parachute under positive steering control
2. Observe parachute forward airspeed
3. Observe parachute steering response to control inputs
4. Observe GPS data acquisition in flight

Summary: Good flight, limited control, but CPU reset.

Results:

Good liftoff. Stable flight, good altitude. Parachute deployed perfectly.

During decent, parachute spun continuously. Radio operator observed that the rate of spin was very controllable, but the range of control was insufficient to get the turn rate to zero (or to reverse). Position of the servo trim was not noted – it may not have been centered, and there was no attempt to use servo trim to extend the range of control.

Landing was soft, but one fin was damaged. Damage was repairable at the launch site. It appeared that ejection detection did not occur until more than a minute after landing (during manipulation on the ground, just before CPU power down).

Motor was retained, wire tie was recovered.

Objective 1 partially accomplished.

Objective 2 failed, since the spin made estimate of forward airspeed difficult.

Objective 3 partially accomplished.

Objective 4 not accomplished – it was determined after flight that sharp accelerations to the CPU board cause the CPU to reset; probably due to the battery springs compressing under acceleration, or possibly due to a loose connection. It appears that on this flight the CPU reset on ejection (losing all but the first 2 or 3 seconds of the flight), and again on landing.

Lessons learned:

1. Care must be taken to avoid line tangling – this may have been the cause of the turn bias.
2. Higher altitude flights are desirable.

2006-11-04, Amesbury MA (CMASS) – Alpha Test #3

LCO: CMASS
Radio control: Dave
Videographer: None
Still photographer: Dave (post-flight only)

Flight configuration:

1. Booster: Saturn Zero (then called "Test Rocket")
2. Aerotech A-RMS E28-4T motor
3. 1-gram additional ejection charge, attached with masking tape
4. NASA NPW-5 "Superchute" parachute
5. Nomex cloth parachute protector (plus wadding)

Objectives:

1. Observe parachute forward airspeed
2. Observe parachute steering response to control inputs
3. Observe GPS data acquisition in flight

Summary: Crash, no parachute deployment, CPU reset.

Results:

Good liftoff, stable flight, good altitude. Parachute failed to deploy due to being packed mostly in e-sled bay; crash.

When packing parachute, there was apparent difficulty in stuffing the parachute into the booster – it is not clear what was the cause of this, but it might have been solved by pushing the wadding deeper into the booster with a stick. The parachute was therefore mostly packed behind the e-sled in the e-sled bay.

On deployment, the 1-gram charge fired properly, and a good separation occurred, but the parachute remained in the e-sled bay. A hard crash followed.

The crash resulted in major damage to the e-sled. The CPU was still running. It is not yet clear if ejection detection occurred. The GPS stopped running – cause not yet determined. No data analysis has been done yet.

Motor remained in mount after the crash – wire tie seems to help.

Objective 1 and 2 not accomplished.

Objective 3 not accomplished – it was determined after flight that sharp accelerations to the CPU board cause the CPU to reset; probably due to the battery springs compressing under acceleration, or possibly due to a loose connection. It appears that on this flight the CPU reset on ejection just after 40m 32s past the hour (losing all but the first 2 or 3 seconds of the flight). Data didn't resume as GPS cable was disconnected upon impact.

Lessons learned:

1. Pack parachute into booster only.

2006-11-04, Amesbury MA (CMASS) – Alpha Test #2

LCO: CMASS
Radio control: Dave
Videographer: None

Still photographer: Dave (post-flight only)

Flight configuration:

1. Booster: Saturn Zero (then called “Test Rocket”)
2. Aerotech A-RMS D24-4T motor
3. 1-gram additional ejection charge, attached with masking tape (didn’t use red Aerotech charge cap)
4. NASA NPW-5 “Superchute” parachute
5. Nomex cloth parachute protector (plus wadding)
6. “Flight Test” firmware in PIC – new version with time of day information
7. New e-sled payload bay (since flight #1); larger, painted black for opacity.

Objectives:

1. Test parachute deployment using 1-gram additional ejection charge
2. Test electronics bay deployment (to free swing arm)
3. Observe parachute forward airspeed
4. Observe parachute steering response to control inputs
5. Observe GPS data acquisition in flight
6. Observe altitude achieved on D24 motor

Summary: Low altitude flight, CPU reset.

Results:

Flew to very low apogee altitude (estimated at less than 50 feet AGL), followed by perfect parachute deployment and descent to a soft landing. Unfortunately, parachute deployment occurred only about 15 to 20 feet AGL, so descent time was less than 5 seconds; too short to even being testing of parachute steering.

Launch was off of ¼” rod from Pad 6, landing was adjacent to Pad 4 (see post-landing photographs). Launch rod departure appeared to have sufficient velocity for stable flight.

After landing, it was observed that not only did parachute fully deploy in an untangled configuration, but the e-sled also fully slid out of the payload bay into the proper configuration for steered gliding – a perfect deployment. Swing arm was still in the stowed configuration after landing (radio transmitter was never turned on).

All electronics unharmed and working fine after landing. Not yet clear if ejection detection occurred – possibly not. Data was successfully downloaded to laptop via Pickit2 in field (not analyzed yet).

Objective 1 and 2 achieved. Objectives 2, 3, 4 not accomplished due to low altitude deployment and short glide time.

Objective 5 not achieved. Liftoff was at 47m 53s past the hour, and data was recorded until (and including) 47m 58s past the hour (at most the first 5 seconds of the flight was recorded), but CPU reset apparently upon ejection, with data not resuming until 48m 10s past the hour, after landing.

Objective 6 achieved (won’t do that again).

Lessons learned:

1. Install igniter against motor fuel grain, affix firmly in place with masking tape to avoid pull-out or misfire upon firing lead attachment.
2. Use at least an E motor for this rocket; too little altitude for safe or informative flight is attained otherwise.

2006-10-08, Amesbury MA (NEMROC) – Alpha Test #1

LCO: CMASS
Radio control: Dave
Videographer: Suzana
Still photographer: Gary

Flight configuration:

1. Booster: Saturn Zero (then called "Test Rocket")
2. Aerotech A-RMS E28-4T motor
3. 1-gram additional ejection charge, above red Aerotech charge cap
4. NASA NPW-5 "Superchute" parachute
5. Nomex cloth parachute protector (plus wadding)
6. "Flight Test" firmware in PIC
7. Mass 560 grams without engine

Objectives:

1. Test rocket flight stability
2. Test parachute deployment using 1-gram additional ejection charge
3. Test electronics bay deployment (to free swing arm)
4. Observe parachute forward airspeed
5. Observe parachute steering response to control inputs
6. Observe GPS data acquisition in flight

Summary: Crash, no parachute deployment.

Results:

Parachute did not deploy due to additional ejection charge ignition failure. Crashed with minor to moderate damage.

Flight duration approximately 13 seconds (from video).

Max altitude unknown, likely close to RockSim prediction of 133 meters.

LSO complained of high placement of launch rod tube – feared insufficient for stable flight. Next time use 3/8" tubes for high power pads, position at least one near trailing edge of rocket to allow full launch rod length.

Good liftoff, no stability problems, sufficient speed off launch rod. Video of launch captured with partial success (lost rocket at one point). Altitude reached unknown (GPS logs may have some data – not analyzed yet). No reason to think RockSim predicted altitude is off. D24 motor may be acceptable for low-altitude flights.

During coast phase, radio operator () incorrectly powered transmitter prior to e-sled ejection – this could have caused e-sled to hang up on payload tube. In the event, this didn't matter since the parachute didn't deploy (and therefore the e-sled didn't either). Post-crash, swing arm appeared to still be in neutral (free) position – this could indicate a radio problem.

On motor ejection charge firing, rocket payload section separated from booster, but parachute did not deploy. Post-crash, it was observed that the additional ejection charge didn't fire because red Aerotech ejection cap insulated the additional ejection charge.

Rocket fell to a crash in unstable configuration with booster separated from payload. Crash was not too violent – one booster fin was snapped off, booster was otherwise intact. Payload section tube crushed at one end, some wood splintering and crushing of aft e-sled centering ring. All electronics unharmed – all electronics were still running after crash.

On arrival at crash site, recovery crew observed that the motor had ejected – apparently the two motor retention clips are insufficient. Possibly the motor ejected in flight, which may have contributed to parachute ejection failure.

Objective 1 achieved. Objectives 2-5 not accomplished.

Objective 6 had inconclusive results. It was difficult to tell if the GPS data retrieved post-flight represented flight data (in which case data was apparently collected only up to a few seconds after the crash).

Lessons learned:

1. Install 3/8" launch rod guides, with at least one near trailing edge of booster
2. Use single layer of masking tape to hold in A-RMS ejection charge (avoid use of red Aerotech cap) – this will allow burn-thru & ignition of additional charge.
3. Less tight packing of parachute would be helpful.
4. Test battery hold-down cable tie straps for clearance and easy e-sled ejection
5. Improved motor retention method is needed – try wire ties to hold in motor clips.
6. A-RMS motors are complex to assemble in the field – pre-assemble as much as possible.
7. Bring paper towels & water for cleaning A-RMS casing post-flight
8. Bring petroleum jelly for lubricating A-RMS casing, threads and gaskets

[end]