MASA Planet

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Safety First!

Failure Modes and Effects Analysis

The formal assessment of risk

Ted Cochran, NAR 69921

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

Unusual situations require more analysis, depending on what's at stake. In response, risk analysis and related disciplines have become quite sophisticated. Some of the tools are pretty easy to use, and I've found one in particular to be helpful in rocketry. It's called *Failure Mode and Effects Analysis*, or FMEA for short.

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

FMEA, continued on page 2

Also in This Issue

Club Activities

Welcome Back!

MASA enters its seventh year

Despite a continuing shortage of APCP motors, the loss of a great flying field, and various unpleasantries involving regulation, MASA members last year added to our recreational and educational legacy. We conducted 13 organized launches (including a flurry of three launches in one week to bid farewell to the Fricke Sod Farm range). We collectively managed to burn up well over 1000 motors on over 900 flights, held ten club meetings and two club parties, conducted over a dozen outreach activities, mentored Team America Rocket Challenge and Rocket League teams, judged 4-H entries, and ran a rocketry summer school class. We also raised the number of our NAR members from 32 in 2002 to 41 in 2003!

Congratulations to all of us!

Welcome back, continued on page 3

2003 Dues

This issue of the MASA *Plane*t is the annual freebie. It is sent to all members registered as of December 2003, mostly to make sure that you have the chance to read this notice :-).

2003 Dues ($10 Individual, $12 Family, $5 Junior) are now due. We strive to keep dues at a minimum level. Your money goes to pay for such items as club informational printings, newsletter printing and mailing, yearly NAR section dues, educational materials, gifts to landowners, and contest prizes.

The next *Plane*t will be sent by U.S. mail only to those who have renewed their memberships and who have also requested that it be mailed to them. To renew, visit:

http://www.mn-rocketry.net/masa/joinmasa.htm

FMEA, continued from page 1

In its simplest form, an FMEA analysis starts with a list of possible failure modes. For each of these failure modes, a list of all possible causes is developed. For each of these possible causes, a list of controls--ways to prevent the cause from happening--is created. Finally, the failure modes, causes, and controls are each rated using a consistent scale, leading to an overall rating of risk.

The example below is part of an FMEA for the Quantum Leap project that is described elsewhere in this issue. The first potential failure mode listed in the chart is the failure of the sustainer motor to ignite. In a stock Quantum Leap, the staging altimeter is in the interstage transition, and deployment of the upper stage parachute relies on motor ejection. Thus, failure to light the sustainer motor results in the rocket flying a ballistic descent, resulting in a dangerous situation in which the best case is the loss of the rocket.

A number of potential causes of ignition failure are listed, including a bad igniter, various in-flight issues, and a miscellaneous ("motor won't light") category. For each of these causes, the current controls are listed.

For FMEA to be useful, it is important that the listed controls actually be carried out--no fair stating that continuity testing is a control for bad igniters unless it is actually done!

Now comes the interesting part: The risk has to be quantified. The *severity* of each failure effect is quantified using a systematic (albeit subjective) scale. In this example, I've chosen to use a scale from 0 to 100, in which 100 is the worst possible outcome (potential serious injury to bystanders). Since failure to light the sustainer always leads to this consequence, "100" is always assigned.

The likelihood of occurrence of each cause is rated next. In this example, I estimate likelihood on a scale from 0% to 100%, and I try to avoid minimizing the risk. Thus, I estimate that one in ten igniters is bad.

Finally, the chance that existing controls will fail to detect or prevent each cause from occurring is estimated. I used a ten point scale here, in which "0" means that there is no chance that the controls won't catch the cause ahead of time, and "10" means that the controls are not very helpful.

FMEA, continued on page 4

Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Controls	DET	RPN
What ways could the process not proceed as planned?	What would be the impact of failure mode?	How severe is the effect ?	What program, product, or process weakness could cause the failure mode to occur?	What is the likelihood that the cause will occur?	What methods, tools, or measures will discover the cause before it occurs?	How difficult is it to detect the cause of/ prevent Failure Mode?	Risk Priority Number (SEV X OCC X DET)
Failure to ignite sustainer	ballistic descent	100	bad igniter	10	Pre-installation continuity test	0.5	500
[no backup)		100	Igniter mis-installed or dislodged	2	prevention only	5	**1000**
		100	altimeter malfunction	1	bench test	5	**500**
		100	dislodged battery	1	tape + block	2	**200**
		100	motor won't light	3	Care in assembly	10	**3000**
Failure to ignite sustainer	wasted booster motor	5	bad igniter	10	pretest	0.5	25
[with working		5	dislodged igniter	2	prevention only	5	50
backup altimeter]		5	altimeter malfunction	1	bench test	5	25
		5	dislodged battery	1	tape + block	2	10
		5	motor won't light	3	Care in assembly	10	**150**
Sustainer cato [no backup]	descent in pieces, some large	90	faulty grain (e.g., bubble)	0.1	visual inspection; weighing grains	5	45
		90	misassembly	1	checklists, visual inspection	1	90

MEETING SCHEDULE

THURSDAY, JANUARY 8
2004 MASA OFFICER ELECTIONS
Location: Science Museum of Minnesota, St. Paul
Time: 7 PM to 8:45 PM
Topic: 2004 Meeting topics

THURSDAY, FEBRUARY 5
Location: Science Museum of Minnesota, St. Paul
Time: 7 PM to 8:45 PM
Topic: TBD

THURSDAY, MARCH 4
Location: Science Museum of Minnesota, St. Paul
Time: 7 PM to 8:45 PM
Topic: TBD

FRIDAY, MARCH 13 - SUNDAY, MARCH 15
NARCON
Location: University of Wisconsin - Parkside, Kenosha, WI

LAUNCH SCHEDULE

NOTE: TIMES AND LOCATIONS SUBJECT TO CHANGE! CHECK THE WEB SITE FOR UPDATES

SATURDAY, JANUARY 24
Location: TBD
Time: 9 AM - 4 PM

SATURDAY, FEBRUARY 28
Location: TBD
Time: 9 AM - 4 PM

SATURDAY, MARCH 27
Location: TBD
Time: 9 AM - 4 PM
TARC Qualification flights

Welcome back, continued from page 1

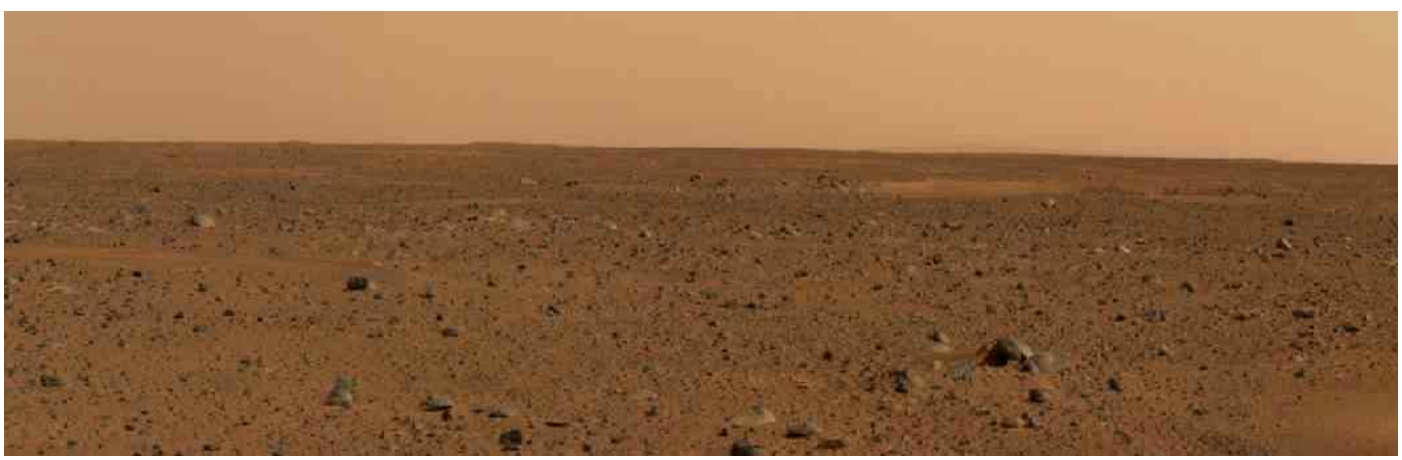
Believe it or not, this year looks to be just as eventful for Minnesota rocketry enthusiasts. Upcoming events include:

- The second year of Team America Rocket Challenge culminates in qualification launches by April and the finals in Virginia in May. There are seven Minnesota teams this year.
- INSciTE has plans for significantly expanding Rocket League this Spring.
- There's a relatively nearby NARCON in March.
- The national Girl Scout Jamboree build and fly this Summer (somewhere between a few dozen and a few hundred rockets will be built and launched over two days).
- And, there's talk of a regional launch in North Branch

We also have some challenges to face. It would be great to find another flying field, so keep your eyes open, and if you see something that could be suitable, let a club officer know. The BATFE will likely finalize its proposed rules regarding LEUPs sometime this year, and there may be some further actions in the long-running lawsuit brought by TRA and NAR against the BATFE.

Incidentally, January 24, 2004 is the sixth anniversary of the first official MASA launch on January 24, 1998 (the first meetings were held the previous fall). Please renew your membership again, come to the anniversary launch, and help us continue to carry on our mission!

Snapshot : We're Baaaaack!



Columbia Memorial Station, seen from Spirit.

FMEA, continued from page 2

The final step is to calculate a *Risk Priority Number* (RPN) by multiplying the Severity estimate, the Occurrence estimate, and the Detectability estimate.

Throughout the analysis, it is important to be consistent: The risk numbers can't be compared to each other unless they are all derived from the same basis of estimate.

It is also important to be thorough: You need to examine *all* of the possible failure modes, failure effects, causes, and existing controls. In the excerpt presented in the example, each of the failure modes has only a single effect listed, but the full analysis has more. For example, in the case of a sustainer CATO, another possible failure effect is a ballistic descent (if the CATO results in a spit nozzle, for example, and the ejection charge is not ignited in time). There are also more benign results that could result from a sustainer CATO: A blow by might result in abrupt termination of flight and descent under parachute, which only means that a booster motor has been wasted.

If you are thorough, you'll be able to assess all of these risks, and determine which of them deserve attention. Given a high RPN, you can work to reduce the severity of the effect, reduce the likelihood of occurrence, or increase the likelihood of prior detection.

It is important to be thorough.

From the example data provided, you can see why I concluded that flying a Quantum Leap without a backup for sustainer motor ejection represents an unacceptable risk. The analysis demonstrates that there is a single point of failure that is relatively difficult to prevent and that potentially results in severe consequences. As shown in the example, adding a sustainer altimeter to provide redundancy for sustainer recovery greatly reduces the overall risk.

Of course, in a full FMEA, the addition of an altimeter results in additional failure modes, some of which have relatively severe consequences of their own. For example, the use of electronic deployment introduces risks associated with using black powder, including ejection charges firing during preparation, ejection charges firing prematurely in flight, ejection charges not firing at all, and unfired ejection charges being lost with the rocket. A thorough FMEA is required to ensure that the risks associated with the addition of the backup altimeter are themselves minimized.

Further, the FMEA needs to be done for a specific altimeter system implementation, not a generic one. It should come as no surprise that a poorly designed backup system is worse than no backup at all, because additional failure modes may be added that outweigh the advantages of having the backup system.

People who say that arming switches add "needless complexity" haven't done their homework.

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

My FMEA for the Quantum Leap led to some unexpected conclusions:

- *Warning labels*. The Quantum Leap is capable of flying out of sight and drifting away. It may land or crash with unfired ejection charges and perhaps even an unfired sustainer motor, and therefore represents a danger if someone finds it who is unfamiliar with rockets.
- *Keyless arming switches*. The need for external arming devices may be obvious, but the use of key switches is a problem: In the scenario above, what can be done without the key?
- To achieve true redundancy, you need *completely* independent systems. Moving the staging altimeter into the sustainer allows it to be used for sustainer ignition and deployment, with motor ejection as a backup. But if the altimeter fails, the rocket may still crash!

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

Reference:

Chowdhury, S. *Design for Six Sigma*. Chicago: Dearborn Trade, 2002.

Quantum Leap

Two-stage fun

Ted Cochran, NAR 69921

After certifying Level II with a PML Tethys, and flying it a few times on J350s, I was looking to try something a bit more challenging. I found it in the PML Quantum Leap. Quantum Leap is a two-stage, 3" diameter, 87" long rocket with PML's quick switch motor mounts in both stages. PML lists the completed weight at 91 ounces.

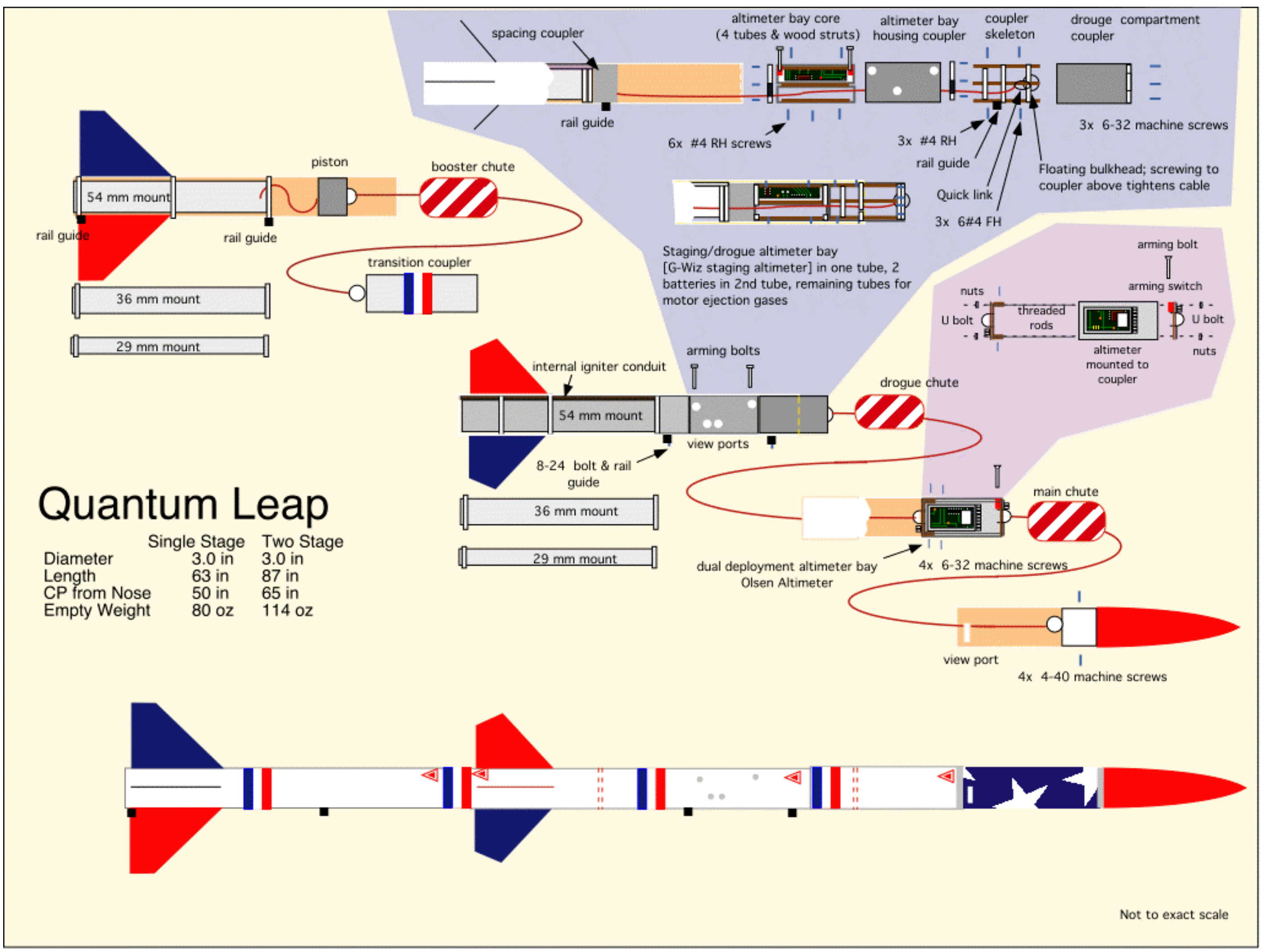
PML suggests building the rocket with the staging electronics in the interstage coupler. I was hesitant to do this, because I didn't want to worry about the booster drag separating before the sustainer ignited. Also, I wanted to use the staging electronics for back up sustainer recovery system deployment.

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

Lower altimeter bay

The removable lower altimeter bay is highlighted in blue in the accompanying figure. It accommodates a G-Wiz LC altimeter. A length of brass tubing serves as

Quantum Leap, continued on page 6



Quantum Leap, continued from page 5

a conduit from the altimeter bay to the base of the rocket; the igniter leads are run through this conduit from terminals on the outside of the altimeter bay. The altimeter bay is constructed from four 29mm tubes and two bulkheads glued into a 3" airframe coupler. Two of the tubes run through the bulkheads, and are used to duct the ejection charge. One tube holds the altimeter, and the remaining tube holds two 9-volt batteries. This altimeter bay is bolted to the airframe of the sustainer.

Arming is accomplished using two double throw microswitches activated using external bolts. Three 1/4" windows permit viewing of the altimeter's status LEDs through matching windows in the airframe.

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

Upper altimeter bay

The upper altimeter bay is of more conventional design and is highlighted in purple in the accompanying figure. Two bulkheads and a coupler held together with threaded rod. The threaded rod passes through two aluminum plates, into which U-bolts are inserted for shock cord anchors to the drogue below and the main above. The metal plates ensure that the deployment loads are carried through metal parts, as opposed to wooden bulkheads or phenolic tubing. The altimeter, an Olsen M1, is enclosed in its own plastic compartment. A small window enables viewing of the LCD display; the coupler and the airframe have corresponding cut outs. Arming is provided for using a double pole, double throw microswitch, activated by an bolt inserted through the airframe.

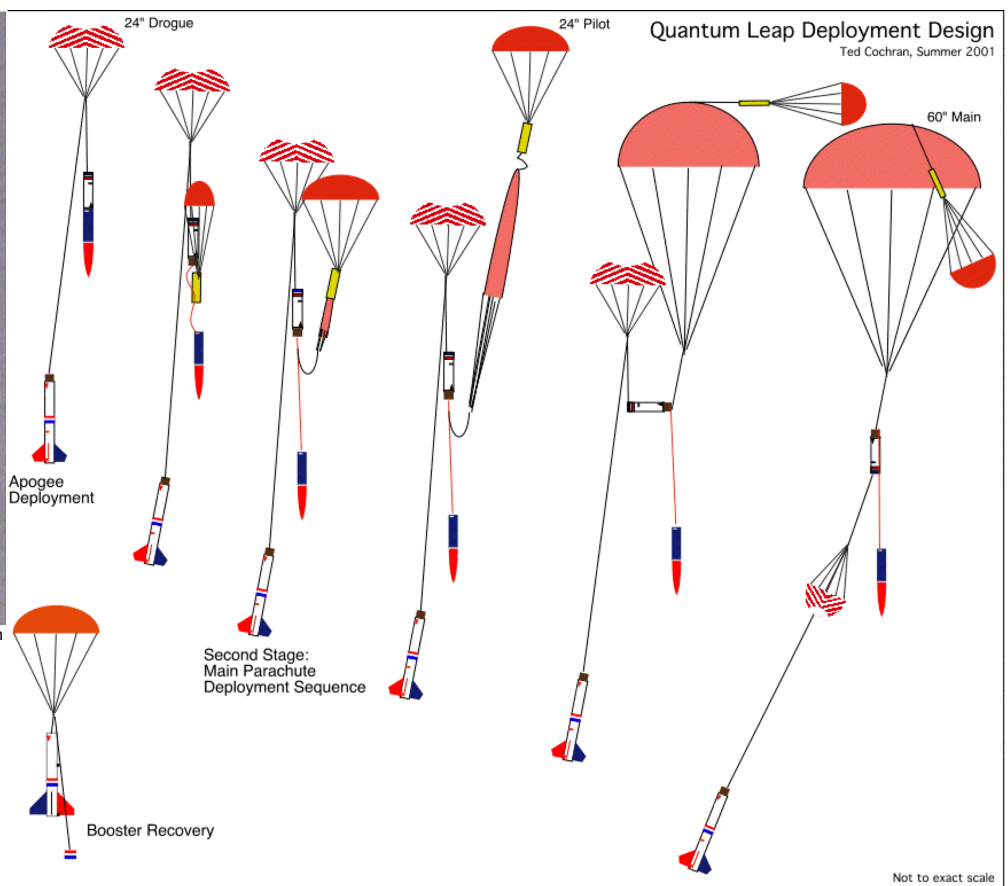
Recovery System Design

The design of Quantum Leap's recovery system was somewhat tricky. A fairly sizable parachute had to be

Quantum Leap, continued on page 7

Ted Cochran

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



Quantum Leap, continued from page 6

stuffed into a 3" tube, and it was important that the chute be able to get out reliably and avoid fouling with the previously deployed drogue.


Ted Cochran

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

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

Airframe

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

The airframe was finished using the paint scheme that I first used on my Tethys. Several color coats followed several coats of Krylon primer with wet sanding in between coats.

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

Flights

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

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


Glen Overby

Anomalies

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

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

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

Competition

Fall Contest Reports

Michael Erpelding
NAR 79922 T#345

2003 Midwest Regional Championships

MWRC was the first contest of the calendar year for the newly formed Team Challenger. I picked up my new partner, Glenn Scherer Jr., at his home in Moline, IL. on Friday Sept, 26. We then traveled 5 hours to Kenosha, WI. The set up for the contest started Saturday morning at 8 A.M. at the Bong State Recreation Area. The weather was a little iffy with variable winds from 5 to 16 mph. There were scattered clouds throughout the day. Some brought brief rain showers in the afternoon that didn't last more than a couple minutes at a time. I got to launch the very first competition rocket of the meet, my E-powered streamer spot landing rocket. With the variable winds, and forgetting how much my large fins might make my rocket weathercock; I over-tilted my launch rod into the wind. The resulting near horizontal flight earned me ìthe farthest from the spot" flight. Our next flight was Glen's random duration flight. He didn't place in the top four. My B Helicopter Duration model placed 3rd. My 1/4 A Super-Roc Altitude model placed 2nd. Glen's 1/2 A Streamer Duration models placed 2nd. Both of Glen's B Eggloft Altitude flights ended with a hard landing on Bong's runway.

Mike Erpelding

A good turnout for MWRC!

Mike Erpelding

The contest range at Bong.

We managed to get all of our flights done on Saturday. Saturday night we all met at The Wolf's home for a pizza party and rocket talk ìbull" session. Sunday Glen went to fly HPR with Tripoli WI. I volunteered to help as needed with contest range duty. Sunday's weather was basically the same as it was on Saturday. The awards ceremony was held at a local restaurant. Due to a laptop battery problem, the results were tabulated by hand using the charts in the pink book. We had a safe trip back to IL. I returned home on Monday. I had a lot of fun and I'm looking forward to next years contest.

2003 October Fly III

October Fly III, hosted by the St. Louis Rocketry Association, was postponed one week due to rain delaying the harvest. Glen Scherer Jr. And I drove down to Elsberry, MO on Halloween. That night it rained. In the morning it was cloudy with scattered showers in the forecast. The temperature was in the 50's. Glen and I arrived early at Sadies, the local cafe, for the breakfast and contestant/ flyers briefing. Giant Leap Rocketry was an onsite vendor. The range was suppose to open around 9 A.M. October Fly III was going to be held in conjunction with a Tripoli launch. A few minutes before 9 A.M. it began to rain. Glen and I helped the vendor cover his wares as we all stayed on the field, waiting out the storm. Giant Leap was only going to be onsite on Saturday. All of us did our best to make it worth his while for driving here from Kansas. I purchased the 1, 2, and 3 grain Pro 38 casings from him; as well as 4 G69-12A reloads, one 38mm HPR tube, matching nosecone, and phenolic fin can. We all ate lunch at Sadies. The rain would let up a little

Competition, continued on page 9

Competition, continued from page 8

and then it would pour again. A little before 4 P.M. it was decided that the night launch would be canceled and that we would try the contest again in the morning.

Mike's GDED entry (rear) waits to fly. Mike Erpelding

Sunday was a beautiful day! We had just a little breeze with a forecast high around 80 degrees. We even had a few thermals on the field that day. We took 1st place with my model for Set Duration (45 sec) with a time of 58 sec, instead of the 50 sec that I got at home during testing. We took 1st place in B Parachute Duration Multi-round with my model. I used my new tube fin payload rocket kit I bought at NARAM 45 for my back up model for G Dual Eggloft Duration. This flight earned us 2nd place. My shroud egglofter shredded a couple seconds before apogee. I guess a G35-7W was a little too much for it. :-) Glen's 1/2 A Streamer Duration models earned us 2nd place. Glen's D Boost Glider crashed on both attempts.

Glen was able to get on HPR flight in on Sunday. He launched the rocket that he got his level 2 on with an older Pro 38 J360. It was a great flight and came in handy for helping the range crew see what the upper air currents were like for the pending launch of a fiberglassed Estes Phoenix on a K 550. The fun part was the recovery of this rocket. It landed somewhere in the flooded fields past the row of trees a half mile down range. I went in after it while Glen went back to fly our last entry, his 1/2 A SD flights. Most of the corn and soybean field was under ankle-deep water. It was deeper the closer you got to the drainage ditches. I found Glen's rocket in shin-deep water, next to a couple left rows of corn, about 30 feet from a drainage ditch. The nosecone and parachute were floating. The fin can was under water with the end of the tube bobbing up and down as I splashed toward it. I drained out as much water as I could and packed it back together to make it easier to carry. Next I started the long walk back. I noticed a field approach leading to the berm that went around the fields. I headed towards it so I could walk on the berm back, rather than through the water. Before I made it up the approach the water came up to just below my pants pockets! That's why I asked for a pair of fishing waders for Christmas. :>)

Mike Erpelding

Why Mike wished he had packed waders in his range box!

The awards ceremony/ supper was also at Sadies. It rained all the way back to IL., all night, and changed over to snow by the time I reached Owatonna, MN on Monday morning. I had a great time! Hopefully next year is a little drier!

The *MASA Planet* is the official newsletter of the Minnesota Amateur Spacemodeler Association, Section 576 of the National Association of Rocketry. It is published bimonthly as a service to its members. MASA authors and photographers retain rights to their submissions, which are used by permission. The *Planet* is available in color on MASA's web site:

http://www.mn-rocketry.net/masa/

MASA's 2003 Officers:

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Mike Erpelding	**Vice President**
Lee Frisvold	**Secretary/Treasurer**
Russ Durkee	**President Emeritus**
Alan Estenson	**President Emeritus & Webmaster**
Ted Cochran	**MASA Planet Editor**

Submissions may be made to the editor at: masa.planet@mn-rocketry.net. (Volunteer quickly, lest you be asked to enter contest data by hand!)

If your email address, U.S. Mail address, or phone number changes: Please send notice of your change to masa@mn-rocketry.net. Include your name, old email address, and new address. We depend on email for communicating important information. When an email address starts "bouncing", we lose contact with you.

Milestones

Contest Results

Challenger (NAR Team #345, which includes MASA member Mike Erpelding) scored two seconds and a third at Midwest Regional Championships and two firsts and two seconds at October Fly III. Congratulations!

Mike Erpelding

Parting shot

Challenger's *spot landing entry, built by Mike Erpelding, prior to its competition flight. Alas, the rocket misunderstood the event rules and landed* farthest *from the spot :-)*

MASA Planet

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Minneapolis, MN 55409

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