Launching Safely in the 21st Century

Final Report

of the

Special Committee on Range Operation and Procedure

to the

National Association of Rocketry

October 29, 2005

Committee Terms of Reference

Article 11, Section 1 of the NAR Bylaws reads: "In addition to the Nominating Committee, the President shall appoint, subject to the ratification of the Board of Trustees, the Chairmen of the standing Committees and the Chairmen of such Special Committees as the President shall, from time to time, deem necessary or desirable."

On April 24, 2005, the NAR President acted as authorized by the above Section to appoint the NAR Special Committee on Range Operation and Procedure. The Executive Committee of the Board of Trustees ratified the appointment that date, and the full Board ratified the appointment at their next meeting, on July 29, 2005. The President directed the Special Committee

"To survey and review current NAR range practices, procedures and operations, to provide an accurate assessment of the relative safety and security of these practices, to objectively analyze any significant observed threats to NAR range safety, to recommend any changes to NAR range policy and procedures, NFPA Codes 1122, 1125, 1127 or NAR Safety Codes to the NAR Board of Trustees for consideration in a report to be presented not later than August 2005."

The draft report of the committee was presented to the NAR Board on July 29, 2005. Suggestions from the Board and final modeling by the committee members were incorporated in this final report.

The members of and advisors to the Special Committee are listed in Appendix A.

The NAR's commitment to range safety has been ongoing. This study is the latest in a series of technically oriented safety studies undertaken by the NAR whenever range safety policy, procedure or practice questions have been raised. Previous studies done for the NAR Board of Trustees include:

1978 Model Rocket Motor Shipping Safety
1985 High Power Rocket Safety
1991 Burn Tests of Reloadable Motors
1992 Model Rocket Motor Burn Tests
1994 Overall Safety of Reloadable Motors
1995 Hybrid Motor Technology
1996 Safety Analysis of Manufacturers' Maximum Recommended Liftoff Weight
1997 Radio Controlled Glider Safety Code Development
1999 Tests of Cleared Distance Required for High-Power Rocket Launches
1999 Implementation of the "Trained Safety Officer" program
2001 Model Rocket Safety Code End-to-End Review
2002 Standards and Testing Report on Water Rocket Safety Code

Acknowledgements

The members of the Special Committee are grateful for the assistance provided by the following individuals: Jennifer Ash-Poole, Jim Barrowman, Jack Bear, Bob Blomster, Drake Dameräu, Alan Estenson, Jerry King, Greg Lane, Gordon Mandell, Thomas Rau, and the 77 individuals representing NAR Sections who filled out the survey on hobby rocketry safety conducted as part of this study.

Table of Contents

Summary

Sport rocketry has been an exceptionally safe hobby for a half century, with roughly four hundred million flights conducted without a rocket-caused fatality.

However, from time to time people have been injured and property damaged by both model and high power sport rockets. Hobby rocket fliers have an ethical imperative to act responsibly toward children, spectators, and those off-site, as well as towards our own fliers and equipment.

This report is the result of recognition by the National Association of Rocketry that continued safety in sport rocketry requires periodic thorough evaluation of the hazard potential of the hobby as currently practiced and the measures used to mitigate these hazards.

No hobby is without hazards, and the purpose of this report is to break the accident chain in which hazards may lead to property damage or injury. The Special Committee has gathered both statistical and survey data. In an analysis of 6,169 flights over seven years at one Section, the Committee characterized the modes in which flights failed in a manner which could have created a hazard. This analysis was validated by examining records from two other Sections. Of these failures, roughly 25% occurred during the boost phase, and 75% were failures of the recovery system The 77 Sections responding to a web-based survey described many opportunities for improvement, the preponderance of which was in the recovery phase (but powered flight failures were responsible for a substantial number of reports as well).

Recovery system failures of rockets as light as one pound can lead to impacts with the energy required to cause injuries. Recent failures of recovery systems examined for this study have impacted with ten times the energy required to cause concern for skull injuries. There is a clear need for additional work on recovery system failures, both to gather detailed statistics on failure mode frequency and to develop better engineering and flight practices. Even fully functional recovery systems may present hazards. Heavy rockets are now being constructed of strong materials that would be less yielding in an impact with a person or vehicle than materials traditionally used to build lighter rockets

Unstable powered flights account for about 20% of all failures. In addition, underpowered rockets continue to present a stability hazard by leaving the launch guide at a low speed compared to the wind speed on launch day. Best practice would indicate that rockets should be guided by launch rods, rails, or towers until they have attained a forward velocity of at least 4 times the velocity at which the wind is blowing (or gusting) at the launch site.

When the angle of attack (AOA) of a rocket is not zero, the center of pressure moves forward from the location calculated at zero AOA. At an AOA of just 15°, for instance, the center of pressure moves forward by 1 to 1.5 calibers (rocket body diameters). If the wind is blowing at 10 mph at the time the rocket leaves a vertical launcher at 40 mph, the AOA is 14 degrees (at the 4-to-1 velocity ratio mentioned above). All sport rockets should have adequate static stability margins at the angle of attack resulting from the wind at the time of launch, while keeping the stability margin less than that which causes severe weathercocking. Significant reduction in the number of unstable and weathercocking sport rockets can be achieved if more attention is paid to these factors when selecting a static stability margin design and when launching in any wind. Launch devices which constrain the rocket to straight flight until high speed has been achieved will greatly reduce the number of unstable flights due to AOA shift.

Similarly, designers and range safety personnel should increase their knowledge of the inherent tradeoffs between static stability margins and dynamic stability. Resources are available (as cited in this report), but are not used by the large majority of sport rocket builders.

Despite improved efforts in recovery system reliability and stability during boost phase, which are both urgently needed, some sport rockets will fail. It is feasible to reduce the hazard posed by these failures by operating a rocket range with an eye to safety, recognizing that failures which occur over or near people and property present a danger.

One way to improve range safety is to use experience or analysis to prevent high power rockets from leaving the rocket range, given the winds prevailing on a particular day. Analysis tools can be run before launch or empirical data can be used to establish site-specific altitude limits for each launch day to ensure that high power rockets will not leave the field boundary. A number of NAR Sections already employ these techniques. No rocket with a liftoff weight larger than a pound should leave the defined range. There are inherent dangers if heavy or high power rockets do so (impact with houses or vehicles, impact with persons who cannot be made aware of the presence of an incoming rocket, landing on power lines with pieces within reach of passers-by, fire).

The Committee concludes that great reduction in the chance of either a boost-phase or a recovery-phase failure (for high power rockets) causing an accident can be achieved by ensuring that people and property are positioned crosswind from the launch pad. Ideally, two such areas should be planned, with the wind conditions on the day determining which is used. If the only available area is within the danger zone due to wind conditions on a particular day, best practice would indicate that the launch not take place, or be limited to small and light models.

Best practices include a post-flight review at the Section level of every incident, and the maintenance of flight logs which note nominal and deviant flights. Such logs can be analyzed for trends in both hardware and practice, which can be corrected before they lead to an accident.

There are many ways in which the knowledge gained by experienced rocket fliers, researchers, and analysis of log data can be used to reduce hazards. The role of the Association should be to develop best practices for safety (including requirements, recommendations, and possibilities). The role of the Section is to apply those practices and add constraints as necessary for local conditions. A national responsibility is to support the individuals who are directly responsible for safety (fliers and range operations personnel) by providing information and a support network.

In other organizations which operate in an environment where things are certain to go wrong, a problem reporting and corrective action mechanism has been generally found to be effective in ensuring that lessons are learned and passed along to other practitioners. An effective reporting system should be facilitated at the national level.

A number of Sections currently implement what the Special Committee has found to be best practices. To summarize:

- Position people and property crosswind from the launch site for launches of rockets heavier than approximately one pound.
- No high power rocket should leave the field during boost or recovery. If one does, it should cause an immediate halt to launch operations and a discussion of both why the unplanned flight occurred and how to prevent any other flights from leaving the field during the day.
- An early flight of the day should be a "weather flight" to check conditions aloft. Its purpose is to validate the judgment of the range team that the planned geometry is safe. If the

powered trajectory of this or any other rocket during the day penetrates the airspace over the prep area, spectator area, vendor area (if any) or the parking area, (whether the rocket functions as designed or not) best practice would indicate an immediate review of the flight, which should be treated as a failure. If the airspace penetration was not caused by something unique to the particular rocket, best practice would indicate that the launch be halted until conditions permit safe flying.

- The hazards presented by grass fires caused by bad flight trajectories after liftoff can be mitigated by having adequate fire suppression equipment on the range, training range personnel in its use, and having an emergency plan for suppression of fire by the Section which includes a contact plan for professional assistance should that be required.
- An audio system capable of reaching all areas in which people are in danger is required to communicate a warning. This can be a PA system, FM low power broadcast to remote receivers supplied by the launch team, or a hybrid. Only at the very smallest launches should warnings be solely via un-amplified voice communication. Air horns have been used with good effect by some clubs. At large launches, dedicated personnel with air horns in the spectator, prep, vendor, and parking areas with radio links to the RSO have been used to warn of incoming rockets. The ability to notify has great potential to reduce danger to people if properly used, and such a warning system should be audible in all spectator, preparation, and parking areas at launches of significant size. NFPA 1127 requires such notification. Since not everyone who is warned will be able to see an incoming rocket even if they are looking for it, a best practice is to have those who do see the rocket point to it.
- All too many "heads up" flights are called for airframes that are poorly constructed or are of questionable stability. Rather than launching such rockets with a "heads up" warning, a better practice would be to correct or mitigate the deficiency of the airframe prior to the flight. The use of a "heads up" warning is best reserved for cases such as clustered composite motor flights and multi-stage composite motor powered flights, where there will always be some uncertainty in motor ignition.
- "Separation", "Lawn Dart", and "No Chute" account for 93% of recovery failures. Initial findings of best practices applicable to high power rockets are as follows. To obtain the maximum strength and reliability, shock cords should be tubular nylon with sewn ends. They should be protected in the airframe by a Nomex or Kevlar sheath to prevent heat damage. Although the size and length will vary depending on the rocket, they should be as long and wide as practical. "U" bolts should be used for projects over 5 pounds. Forged eyebolts should be used for projects over 75 pounds. The major cause of lawn dart type failures in HPR is no or insufficient electronic event (including igniters which require more current than can be supplied by an altimeter), or improper ejection charges. Heat shields made of Nomex or Kevlar should be used to protect parachutes in all HPR rockets.
- Internal recovery systems present a difficult paradox for the RSO of a ready-to-go rocket at safety check in. For the heavier mass items, an approach used by several NAR Sections is to establish a community peer checking environment where common prep areas (versus isolated tables) are used. The fliers found technical benefit to the peer reviews, and the RSO waived any internal checks if the rocket was peer reviewed during internal preparations. The Canadian Association of Rocketry has instituted pre-inspections by a roving inspector and requires that a checklist be presented to the RSO showing such an inspection when the rocket is presented at safety check in.

- All sport rockets should have adequate static stability margins at an angle of attack of 15 degrees angle of attack. A maximum static stability margin of 3 calibers measured at an AOA of 15 degrees and an airspeed corresponding to the lowest forward velocity at which the rocket is expected to leave the launcher guidance (4 calibers as predicted by Barrowman analysis) should be used to protect against weathercocking. These two stability margins are essential to safe flight in any conditions except complete calm.
- Rockets must be guided by launch rods, rails, or towers until they have attained a forward velocity of at least 4 times the velocity at which the wind is blowing or gusting at the launch site.
- Flight logs of the type analyzed for this study are maintained by only a few NAR Sections. A standard set of log procedures should be developed and made available to Sections who wish to use them. Analysis of trends on a periodic basis at the national level should include changes in failure modes which may indicate a problem which can be addressed.
- The use of the Malfunctioning Engine Statistical Survey (MESS) form has declined in recent years. Rocket fliers' best practices would include making reports of all engine incidents on this form. A web-based version is now operational at http://nar.org/NARmessform.html, and may improve response rates. Frequent announcements to the membership about this program and periodic reports with summary data to the membership also have the potential to improve response rates for this important program.
- Best practices include a post-flight review of every incident.

In the opinion of the Special Committee, on-going analysis and dissemination of knowledge of this type can be facilitated by the creation of an NAR Safety Committee to facilitate networking, compile and disseminate best practices, perform an ongoing review of NAR Safety Codes and NFPA Codes 1122, 1125, and 1127, and provide an avenue for communication for the membership interested in improved safety practices. One near-term action of such a Safety Committee would be to produce a comprehensive best practices document.

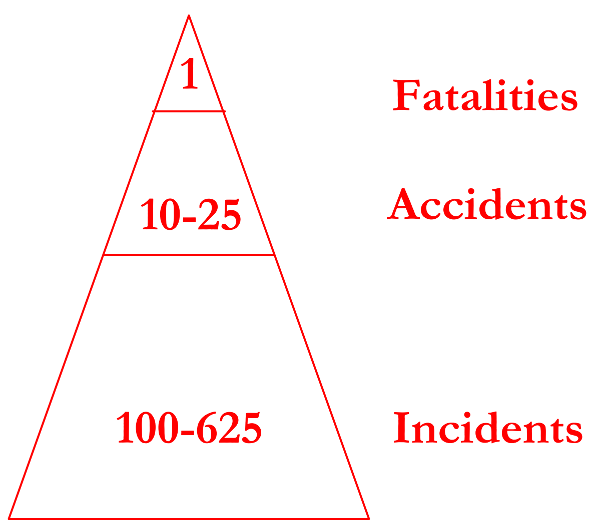
We reject the view that accidents are an inevitable consequence of a sport with imperfect reliability. We agree that flight failures in sport rocketry cannot be avoided, unless we stop flying. An attainable goal is to avoid the most serious consequences of those failures.

1. Introduction

Nearly 50 years ago, model rocketry was born as a safe, educational and fun hobby. Because the founders of model rocketry were especially concerned that the hobby be safe, they devised a Safety Code containing basic rules for range operations and flight procedures that has proven spectacularly successful in over 400 million sport rocket flights since 1957.

Nevertheless, a key part of every safety culture is the search for improvement in safety practices as a result of lessons learned from experience. Three potentially serious accidents occurred between September 2004 and April 2005.

Clusters of incidents give pause to safety professionals. Why? In 1931 H.W. Heinrich summarized safety statistics[1], finding that for every 330 incidents (close calls) there were 29 accidents (minor injury or property damage) and one fatal accident[2]. Studies of accident statistics since then have consistently shown that for every accidental death, there are many more accidental injuries, and for every accidental injury, there are many "near misses" that did not result in an injury, but that could have, had circumstances been slightly different. The relation between the numbers of incidents at each level depends on the study, but is typically in the range of 10 to 25. The specific ratios in this relation (known in the safety literature as the "accident triangle") are not as important as the understanding that the link between near misses, incidents, accidents, and fatalities is real, and holds for a variety of activities when accidents and incidents have similar causes[3].



---

[1] H.W. Heinrich, Industrial Accident Prevention: A Scientific Approach, New York, McGraw Hill, 1931, re-issued 1959.

[2] Thankfully, to our knowledge, fatalities in sport rocketry have been rare, and have all resulted from attempted retrieval of rockets from power lines, in violation of the Safety Code.

[3] The triangle model breaks down for some types of accidents (e.g., in industry), where fatal accidents have different causes than injuries.

We believe, based on the safety triangle, that we are seeing clusters of incidents at the base of the triangle, and occasional accidents in the middle of the triangle. The sort of incidents which occur on a sport rocket range (unstable rockets, failed recovery systems) do occasionally lead to accidents such as those described above, and such accidents could potentially be fatal. We wish to emphasize again that the hobby has had an excellent safety record. Vigilance is required to maintain it.

In sport rocketry, the base of the triangle is broad. There are thousands of imperfect rocket flights per year, nationwide, with a number of significant incidents (such as those described above) resulting from those imperfections.

So why do we need to do this study? While very few imperfect flights cause damage to anything other than the rocket itself, we need to be vigilant and do everything we can to ensure that our hobby never reaches the top of the accident triangle, because sport rockets – even model rockets – are capable of causing serious injury or death. A one-pound nosecone falling *under parachute* at 15 mph has roughly 14 joules of kinetic energy, enough to cause concern.

In other organizations that engage in activities that have the potential to cause serious injury or death, recognition of the link between incidents, accidents, and fatalities drives periodic re-evaluation of the ways these organizations operate to protect the safety of those engaged in the activity, as well as the safety of bystanders. Indeed, in organizations which have a keen understanding of this link, near misses are reviewed, and most incidents and all accidents are taken as an indication that safety improvements are required. Military and civilian flying organizations have "safety stand downs" after serious incidents to re-evaluate procedures and ensure that best practices have been incorporated. Oil refinery personnel begin every shift with a safety meeting to review the day's activities, discuss any recent incidents, and share safety practices.

There have been serious accidents in our hobby. Urban sprawl is encroaching upon more and more of our flying fields. This report is the result of the recognition by NAR leadership at the local and national level that we need to respond as have other organizations, with a careful hazard assessment, and with serious consideration of corrective action.

We reject the view that accidents are an inevitable consequence of a sport with imperfect reliability. We agree that flight failures in sport rocketry cannot be avoided, unless we stop flying. Our goal is to avoid the most serious consequences of those failures.

The first goal of this report is to ensure that flyers understand the frequency, causes, and consequences of flight failures, so that we have an informed basis for response.

The second goal of this report is to provide a list of safety measures that can be taken, when appropriate.

The final goal of this report is to begin to develop a means by which our knowledge about safety can be continually improved.

In the following sections, we will discuss the frequency of specific incidents reports, review a hazard analysis of the hobby, including causes, and present hazard mitigation methods, many of which are already in use by some Sections and that constitute best practices.

2. The Statistics of Flight Failures, Incidents, and Accidents

2.1. Individual Reports of Incidents and Accidents

As part of the work of this committee, Andy Eng and Keith Florig prepared a survey which was administered electronically to NAR Sections. The response rate was extremely high**:** 77 Sections out of 121 contacted electronically filled out the survey. The survey is detailed in Appendix B. One of the questions asked was "Please take a moment to recall adverse incidents that you have personally observed at launches sanctioned by your club. In the space below, please describe an incident (or set of similar incidents) that, in your view, has particularly significant implications for the future of safety in hobby rocketry." Responses to that question included 47 separate incidents, near misses, and concerns.

2.2. Statistical Analysis

Several NAR Sections have collected statistically significant data sets. For this report, the flight log database of the Minnesota Amateur Spacemodeler Association (MASA, NAR 576), representing over 6,000 rocket launches over a seven-year period, was analyzed by Ted Cochran to determine the incidence of eight types of failures as a function of total installed impulse and rocket complexity. The results were cross-validated in a number of ways, including against summary statistics from the Southern Arizona Rocketry Association's (SARA, NAR 545) independent database of over 4,500 flights over a five-year period. Failure rates as a function of rocket complexity, installed impulse, cause of failure and year of flight are presented and discussed in detail in Appendix C.

Based on the flight card check boxes and free form comments, the following categories were used in the analysis[4].

- **Unstable.** The rocket flies with at least part of the boost phase in a nose-down attitude. For the purposes of this study, based on the goal to characterize unsafe events, comments such as "kind of unstable" were *not* counted, nor were "horizontal", "cruise missile", or "coning" flights (unless they resulted in a crash; see below).
- **Lawn dart.** The rocket descends in ballistic flight with the nose cone still on. This category includes "No ejection" and a few "power prangs". Some rockets are designed to do this and these flights were not counted. Boosters on two stage rockets also did this.
- **Separation.** The rocket descends in multiple parts with at least one part not slowed by a recovery device. For the purposes of this study, the few flights with a comment of "stripped chute" were included here. The unplanned ejection of motor casings should also have been collected here, but MASA LCOs almost never recorded them as outcomes.
- **Motor CATO.** The motor failures catastrophically at ignition or during boost. The nature of the CATO (spit nozzle, forward closure failure, blow by, etc.) was sometimes recorded, but not consistently.

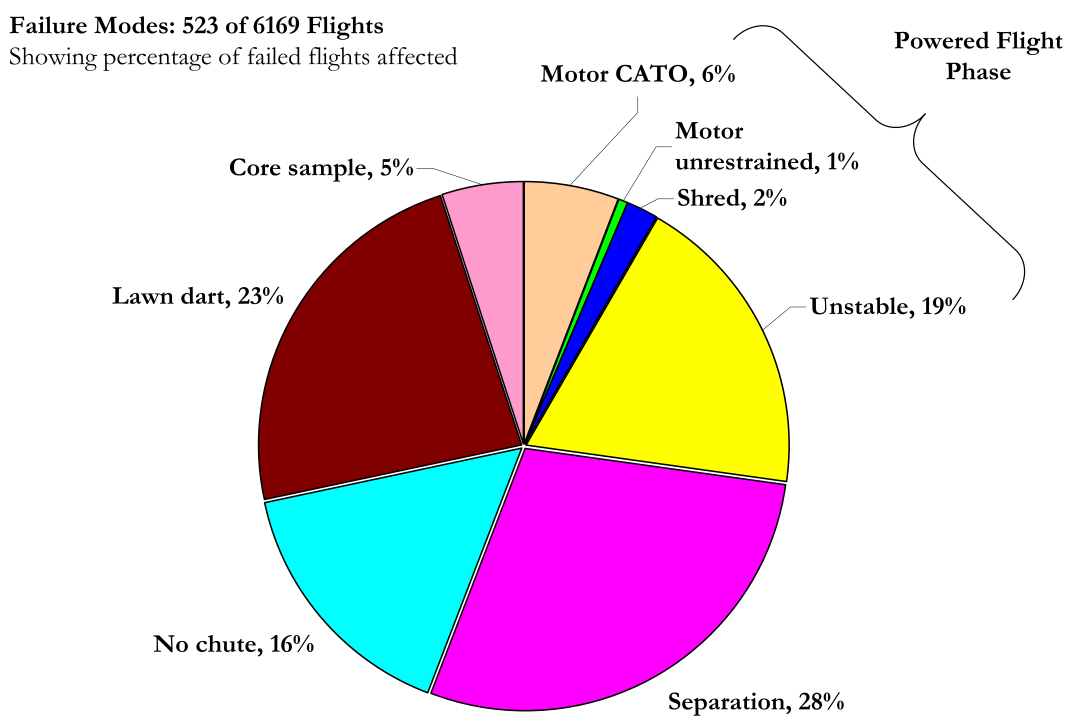
[4] These would be called "recordable incidents" in the jargon of safety professionals.

- **Core sample.** The rocket descends in ballistic flight, but with the nose cone off the rocket and acting as a (not very effective) streamer. These events typically have lower impact speeds, and higher surface areas at impact, than do lawn darts.
- **Motor unrestrained.** The motor exits the rocket at ignition or during boost (thankfully, this was rare).
- **Shred.** The rocket comes apart during ascent, other than by design.
- **No chute.** The rocket descends without a recovery device deployed, but is not ballistic. This category does not include chutes that were described as merely tangled, although it is likely that some LCOs write "no chute" in those circumstances. The rationale here is that if the LCO described the result as "No chute", it was potentially unsafe.

When more than one failure occurred during a flight (e.g., unstable flight leading to lawn dart), the most severe event was recorded.

MASA's flight distribution appears to be fairly typical. For example, it agrees[5] within about five percent with the proportion of flights within each impulse class by SARA over the past five years (4546 flights), as presented in Figure 5 of Appendix C. MASA flew a somewhat higher proportion of complex rockets (8% of flights vs. 4% of flights for SARA), and SARA flew a somewhat higher proportion of higher-impulse rockets (11.4% G and above, vs. 5.2% for MASA).

The overall MASA flight failure rate was 8.5% (523 of 6169). The following figure gives the incidence of failure modes for all flights as a percentage of the failures.



[5] In comparable categories. SARA has more categories of "recordable incidents", and therefore records a higher overall rate of anomalies (15% vs. MASA's 8.5%).

The powered flight phase accounted for 27% of all failures (143 of 523), while 73% (380) of the failures occurred after the termination of powered flight. Two of the common failure modes discussed above (inadvertent ignition of the rocket motor and ground fire) are not addressed in the MASA data set: MASA range procedures have prevented recordable incidents involving inadvertent ignition, and MASA's fields are rarely flammable[6].

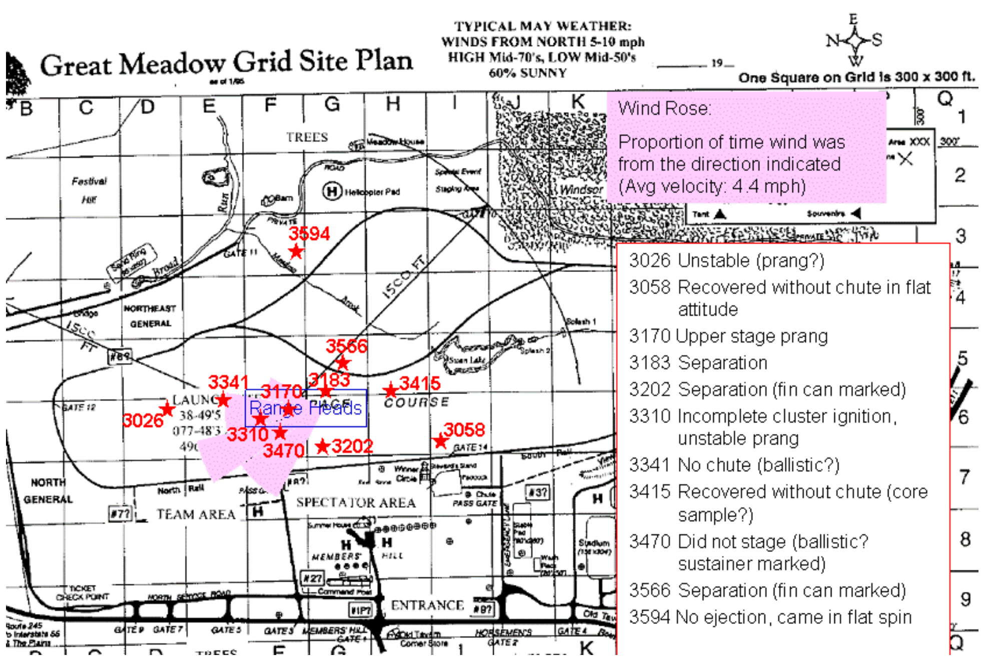
The best estimate of the overall failure rate for simple rockets flown by MASA was determined to be 7.7%; complex (staged and/or clustered) rockets failed 17.4% of the time – more than twice as often.

For simple rockets, 28.9% of failures were in the powered flight phase. Complex rockets experienced 20% of their failures during powered flight. MASA failure modes appear to be similar to SARA failure modes (see Figure 11 of Appendix C).

Separations were the most common cause of failure for simple rocket flights, accounting for about a third of all failures.

Complex rockets had a 10% chance of a lawn dart (52 of 518 flights had this failure mode) compared to only 1.2% of simple rockets (70 events in 5651 flights). Inspection of the logs leads to the conclusion that two stage black powder rockets that fail to stage account for most of this difference, and incomplete cluster ignitions account for most of the rest.

The high rate of failure for complex rockets is not unique to MASA. In the 2005 Team America Rocketry Challenge (TARC) finals, 11 of 103 rockets (10.7%) suffered failures of at least one component. All but 9 TARC models were two-stage dual egglofters; 68 had a cluster engine first stage. For this report, data were collected at the TARC finals (May 21, 2005) on failure modes and impact locations. These are summarized on the chart below, along with wind data. The wind rose was computed from 8 hourly recordings of wind speed and direction.



[6] MASA has used NOMEX® blankets under pads when fields are unusually dry.

2.3. Risk Analysis

The risks posed to property and people depend not only on the type of hazard and frequency with which the hazard occurs, but also on the location of the people and objects at risk, and the ability of the people to get out of the way of incoming rockets.

A Monte Carlo model was designed and implemented to explore the probability of human injury and vehicle damage from failure modes involving ballistic returns, namely, separations, lawn darts, and core samples. The risk model, described in Appendix D, combines plausible estimates of the frequency of NAR events, event attendance, site layout, wind conditions, launch volume, failure rates, flight trajectories, and warning effectiveness to estimate the number of times per year that people or vehicles are struck (or nearly struck) by ballistically returning rockets The model gives the following best estimates of annual incidence of untoward events, for the case of all NAR launches conducted with no wind and crowd-pad separation at the minimum for NAR rules. Estimates for collisions with people assume a 50% probability that people are successfully warned of ballistic returns. For other assumptions that went into this calculation, see the discussion that accompanies Table 1 in Appendix D.

Result of ballistically	Estimated annual incidence (cases per yr)			
returning flight	Low power, A-D	Med power, E-G	High power, H-J	Totals
Hit a person	9	1.3	0.04	10
Hit within 2 m of a person	1500	230	7	1700
Hit a vehicle	35	14	4	50

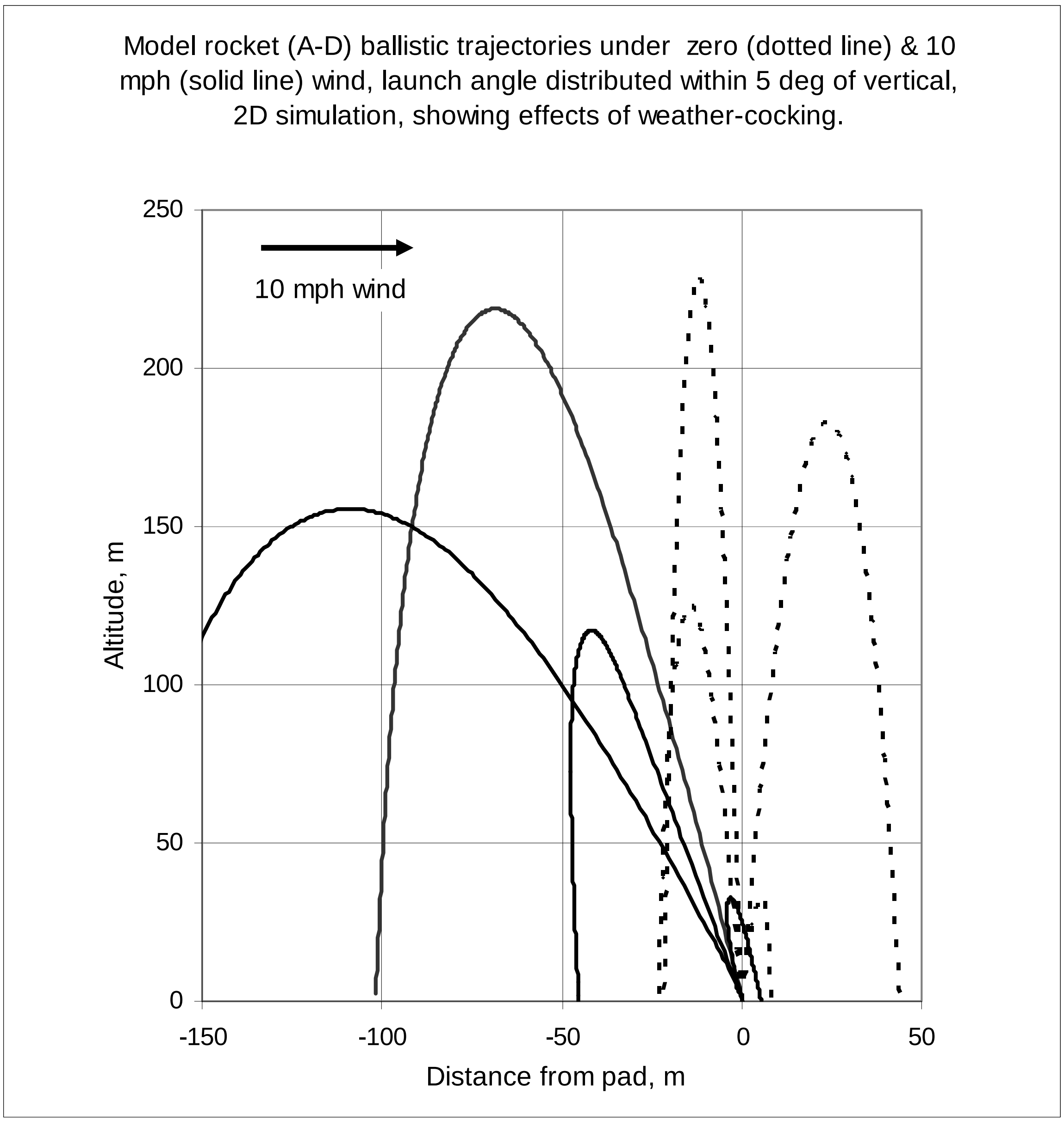
To put these estimates in context, the reader should note that there are approximately 135,000 flights per year at all NAR events, 84,000 of which are low-power flights.

These collision estimates seem compatible with the frequency of anecdotal reports of such events if one considers that roughly three-quarters of low-power flights are of rockets weighing less than 3 ounces. Collisions of such small rockets with people or vehicles are unlikely to be recorded or otherwise draw notice. Hence, the estimate of 9 collisions with people of low-power rockets per year may be reasonable, even though the history of anecdotal reports of such incidents suggests an recorded incidence of just a few cases per year. A similar argument applies to estimates of collisions of low-power flights with vehicles. The results for high-power flights suggests that we should expect one case of a person being hit every 25 years, which seems compatible with the fact that no such cases have yet been recorded.

The risk estimates in the above table assume that all NAR launches are run with crowd-pad separations at the minimum prescribed by NAR rules (15 feet, 30 feet, and 100 feet for low, medium, and high impulse, respectively). Doubling this distance roughly halves the estimated risk for low-power flights, somewhat reduces risk medium-power flights, but has little effect on risk for high-power flights. This reflects that fact that, when the splashprint becomes much larger than crowd-pad separation, it doesn't matter what the separation is.

Simulations of how ballistic return risks depend on direction of a 10 mph wind suggest that positioning crowds crosswind from the pads will significantly reduce risks compared to the case when wind is blowing from the crowd to the pads. Surprisingly, cross wind arrangements do not significantly reduce ballistic return risks compared to the case when wind is blowing from pads to crowd. This is because weathercocking in the latter case substantially shifts the splash zone away from the crowd. However, given that flights returning under chute drift substantially with the wind, configuring a site with pad-to-crowd winds can be expected to produce many chuted landings in the crowd and vehicle areas. As mentioned earlier in this report, even under chute, high-power rockets can cause injury and property damage because of their substantial mass. Thus, the cross-wind configuration is likely to result in the lowest overall risk.

To illustrate the substantial effect of weathercocking on trajectory, consider the figure below reproduced from Appendix D, which compares calculated trajectories of randomly sampled rockets of low impulse (A-D) flown with and without a 10 mph wind. Even with thrust-to-weight ratios ranging from 6 to 20, the effects of weathercocking are substantial.



3. Hazards and Causes

We now summarize the observed failure modes, their causes, and potential hazard mitigation methods.

The charts below present a first-level hazard analysis of the most relevant failure modes in sport rocketry. Hazard mitigation steps are associated in the tables below with each proximate cause, and are discussed in greater detail in the following sections of this report.

3.1. Hazards Associated With Propulsion and Pyrotechnics

Hazard	**Proximate Causes**	**Secondary Factors**	**Root Causes**	**Potential Mitigation**
Catastrophic rocket motor malfunction ("CATO")	1. Motor failure 2. Igniter positioning or improper igniter	1. Launch cables too short to support HPR distances 2. Improper assembly of reloadable motor 3. Improper storage of motor 4. Error in manufacturing (e.g. propellant voids)	Chamber pressure exceeds limits of motor hardware as assembled.	1.Pad-person distance based upon actual failure data 2., 3. Education on handling and storage procedures 4. Motor certification and failure reporting system.

Hazard	Proximate Causes	Secondary Factors	Root Causes	Potential Mitigation
Inadvertent rocket motor or pyrotechnic initiation.	1. LCO failure to deselect pad after previous launch. 2. Launch relay box failure. 3. Miswired onboard avionics. 4. Poor design of onboard electronics. 5. Failure of onboard avionics.	1. Use of misfire alley procedure with multipad controller. 2. No indication of voltage on leads. 3. User error, improper use of avionics. 4. Other problems leading to recovery of rocket with live pyrotechnics. 5. Inadequate disarming system for onboard avionics.	LCO inattention. Poor launch control procedures and/or system design. Poor avionics design or installation. Missing or inadequate disarming system.	1. Two-person verification of launch panel status; Pad selected indication at pad. 2. Welded relay alarm retrofits. 3., 4.Mandatory use of external disarming systems. Minimum personnel at pad. User education.

Hazard	Proximate Causes	Secondary Factors	Root Causes	Potential Mitigation
Fire	1. Blast deflection insufficient. 2. Motor failure. 3. Hot igniter falls onto grass. 4. Rocket motor impacts ground while thrusting. 5. Ejection occurs on the ground. 6. Incomplete ignition of clustered booster at launch; motor(s) ignite from top; burning booster impacts ground.	1. Fire suppression equipment unavailable. 2. LCO inadequate oversight. 3. RSO failure to take dry conditions into account for marginal flights. 4. Failure to cancel launch due to dry conditions.	Vegetation contacted by fire. Dynamic instability, structural failure, motor malfunction, incomplete ignition of clusters.	1., 2. Adequate blast deflectors. 1., 2., 3. Fire blankets under pads. 1., 2., 3. Adherence to NFPA 1127 Launcher Clear Distance table for HPR 1., 2. 3. Adequate post-launch pad watch. 4., 5., 6. Policy for restricting/prohibiting some flights in dry conditions (based on failure rate and/or failure mode). Standing policy on conditions for scrubbing launches. Adequate fire suppression equipment available for use. User education.

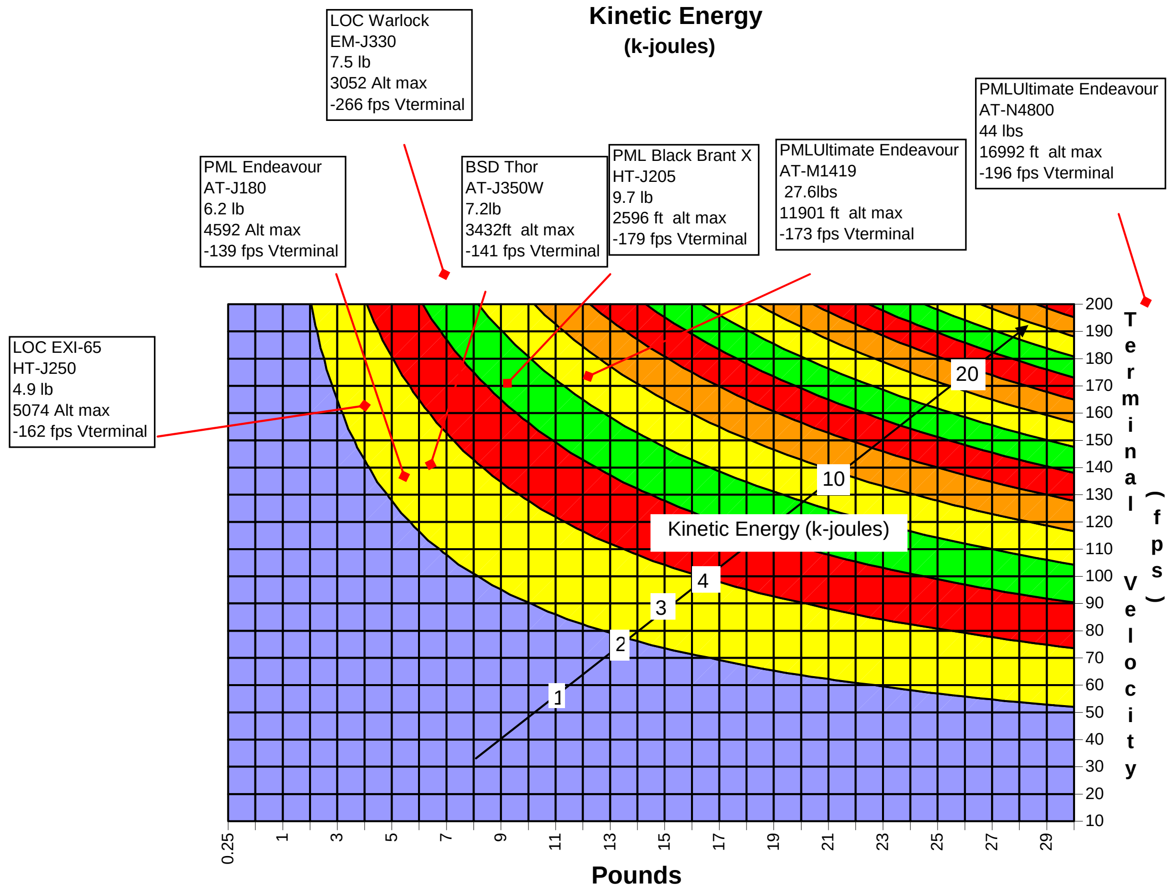
3.2. Hazards Associated with Flight

Hazard	**Proximate Causes**	**Secondary Factors**	**Root Causes**	**Potential Mitigation**
Impact during boost phase	1. Static instability 2. Dynamic instability 3. Structural failure 4. Partial ignition of cluster 5. Failure of or defect in motor 6. Slow initial thrust build-up. 7. Delayed staging	1. Loss of launch lug 2. Inadequate design for flight conditions 3. Work-manship. 4. Improper igniter positioning or performance. 5. RSO inadequate oversight. 6. People and/or property in impact area.	Inadequate knowledge of rocket design criteria. Inadequate knowledge of construction techniques.	1., 2. Improve available tools for dynamic stability determination. Launch policies and practices for setting up ranges and conducting launches RSO training program. User education.

Hazard	Proximate Causes	Secondary Factors	Root Causes	Potential Mitigation
Impact after boost phase	1. Failure of or inadequate recovery devices 2. Drag separation 3. Failure of or inadequate ejection charge 4. Staging failure 5. Failure to attach recovery device 6. Use of inappropriate delay time 7. Failure to install ejection charge 8. Failure to retain motor casing 9. Failure to constrain flight to designated rocket range	1. Inadequate construction for shock absorption 2. Premature or delayed deployment of main parachute and subsequent failure 3. Altimeter failure 4. Sizing of parachute inappropriate to ensure safe landing speed for people or vehicles 5. Inadequate notification of presence and location of incoming rocket 6. RSO inadequate oversight	Failure to delay or cancel launch if winds are unfavorable. Available flight path prediction tools not used.	1. RSO training program Launch policies and practices for setting up ranges and conducting launches: -- Air horns -- Spectator announcement -- All who see it point at the incoming rocket. -- Crosswind positioning of spectators and vehicles. User education.

To quantify hazards from impacts after boost phase, the following graph displays the impact kinetic energy as a function of weight and terminal velocity, along with some example rockets with estimated impact velocities.

For comparison, a batted baseball traveling at 100 miles per hour has a kinetic energy of 145 joules (0.145 k-joules). An unrestrained person in a 20 mph collision has 3200 joules (3.2 k-joules).


Kinetic Energy
(k-joules)
LOC Warlock
EM-J330
7.5 lb
3052 Alt max
-266 fps Vterminal
PML Endeavour
AT-J180
6.2 lb
4592 Alt max
-139 fps Vterminal
BSD Thor
AT-J350W
7.2lb
3432ft alt max
-141 fps Vterminal
PML Black Brant X
HT-J205
9.7 lb
2596 ft alt max
-179 fps Vterminal
PMLUltimate Endeavour
AT-M1419
27.6lbs
11901 ft alt max
-173 fps Vterminal
PMLUltimate Endeavour
AT-N4800
44 lbs
16992 ft alt max
-196 fps Vterminal
LOC EXI-65
HT-J250
4.9 lb
5074 Alt max
-162 fps Vterminal
Kinetic Energy (k-joules)
1
2
3
4
10
20
Terminal Velocity (fps)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0.25
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
Pounds

4. Hazard Mitigation Measures

4.1. Survey Responses to Hazard Mitigation Measures

Three of the questions in the survey of NAR Sections discussed above elicited judgments about the effectiveness, practicality, and prevalence of a number of specific measures to mitigate hazards. These measures were**:**

- At event set-up, position designated crowd areas crosswind from the pads
- Increase separation distance between crowd and pads to twice the minimums specified in the codes.
- Point launch rods/rails away from crowd by 5-10 degrees to guarantee outbound flight. Prohibit angle adjustment by flyers.
- Require presentation of simulation output to RSO for all rockets over 16 oz.
- Require flyer to use and sign standard pre-flight printed checklist.
- Require RSO to sign inspection checklist for each flight covering externally observable features (e.g., motor retention, nosecone fit, fin integrity).
- Establish a Buddy System/Peer Review check during prep of internals (recovery, motors, avionics).
- Review and discuss all incidents, near-misses, and close calls amongst the club membership Safety Circles.
- Weigh rockets at check-in for thrust-to-weight ratio.
- Use audible warning system with separate launch and errant flight tones.
- Prohibit tumble recovery for pieces heavier than 1 ounce.
- Use wind speed indicator at launch site to stop launches during windy intervals.
- Set minimum launch rod diameters and employ longer launch guides to reduce wind cocking.
- Keep fire extinguishing equipment on location.
- Limit maximum altitudes to below current guidelines to guarantee that all errant flights impact within landing zone.
- Flyer reports chute size and type to RSO. RSO consults reference table to assure that chute is of adequate size for rocket weight.
- Establish insurance premiums based on the club's safety program and site conditions.
- Record outcome of each flight on flight card. Periodically compile errant flight statistics and send report to association headquarters.

Respondents were asked to indicate if each hazard mitigation measure was already practiced by their club, to rate each measure's effectiveness on a scale of 1 (among least effective) to 5 (among most effective), and to rate how practical the proposed hazard mitigation methods is (impossible, very hard, hard, not too hard, easy, or already in place).

Each of the hazard mitigation measures is in place at no fewer than four NAR Sections. As many as 56 of the 72 Sections responding to this question have the most common measure (fire extinguishers) in place.

The table below lists each hazard mitigation measure, given in order by the number of Sections which report that they are using the measure. The first column is the hazard mitigation measure, followed by the percent of responding sections which indicate that they already use this measure. In survey work, a useful technique is to summarize the top two boxes or bottom two boxes of the responses. Following this usage, the next column adds the responses listed as 1 (among least effective) and 2 to get the "bottom 2-box" summary of which measures respondents consider least effective. Similarly, the next column indicates the top 2-box scores for what the respondents consider the most effective measures. The final two columns are the bottom and top 2-box responses to the question "How practical is each of the following proposed safety measures? That is, how easy or hard would it be to implement each measure in your local club?"

Mitigation Measure	Already in Place	Effectiveness		Practicality	
		Least Effective (bottom 2)	Most Effective (top 2)	Impossible or Very Hard	Already in Place or Easy
Fire Extinguishers	78%	43%	43%	0%	94%
Wind Speed Check	42%	50%	32%	7%	55%
Discuss all Incidents	40%	8%	62%	1%	68%
Crosswind Crowd	33%	38%	29%	20%	46%
RSO Checklist	29%	51%	32%	13%	46%
Minimum Rod Size	28%	35%	40%	10%	48%
Double Distance	26%	52%	28%	10%	44%
Audible Warning	25%	50%	24%	37%	31%
Thrust/Weight Check	22%	47%	26%	17%	27%
Limit Altitude per Wind	19%	55%	25%	23%	32%
Angle Launchers	15%	33%	34%	15%	44%
Flyer Checklist	14%	53%	22%	13%	25%
Buddy System	14%	32%	44%	15%	27%
Flight Statistics	14%	40%	34%	27%	34%
No Tumble Recovery	11%	61%	11%	14%	46%
Simulations for >1 lb	8%	68%	18%	43%	14%
Chute Size per Wind	7%	52%	23%	21%	24%
Risk-Based Insurance	6%	63%	23%	49%	21%

These responses indicate that there are a number of clubs which already have in place hazard mitigation measures which others consider impossible or very hard. The measure which believed to be most effective by the largest number of respondents, review and discussion of all incidents and accidents among the club membership, is used in only 40% of responding Sections. **While it is certainly reasonable to assume that local conditions preclude some measures in some places, there is clearly room for significant safety improvement by adopting best practices at all launches.**

4.2. Additional Measures Suggested by Survey Respondents

Survey respondents were also asked an open-form question: “Any additional safety measures you would recommend?” Specific suggestions included the following:

- Set up a designated fire crew trained in use of fire extinguishers and other fire control items (water, rakes, etc.).
- Provide training and buddy system for reloadable motors.
- Angle rods away from parking area and adjusted per prevailing wind conditions.
- Shut-down procedure established with the site if something does happen.
- Weigh large rockets on site to ensure they do not exceed weight limit.
- All launches required to have first aid kit. Post basic launch safety information at entry to launch area and at check in table. Establish "rapid response" person or persons in event of prangs, CATOs or fires.
- Do not allow individuals to launch their own rockets without ensuring the sky is clear.
- Have safety lines surrounding the range head and pads to limit travel to safe zones and prevent peripheral hazards (like tripping over the cables). Require club members to learn basic safety procedures before they are allowed inside the caution tape.
- Fly unusual/untested designs during periods of low attendance and wet range conditions
- High power flyers with bad safety records would be demoted one level and made to re-certify. Periodic review of all flight data to look for evidence of persistent or frequent problems by individual fliers.
- Relieve RSO and LCO (using alternates or assistants) at frequent intervals to assure alertness and freshness. Avoid distractions of these personnel.
- A ground school based safety training program for anyone that wishes to attend - maybe mandatory for HPR.
- On a reflight of a rocket that went astray before, always ask the question "What's different from last time?" If the answer is "nothing" then the rocket ought not to fly again. Alert people of launch of rockets not flown successfully on previous attempts.
- Use fire blankets under each pad to reduce fire danger.
- Make sure that in no uncertain terms the RSO's word is final. If this needs to be spelled out in the safety code or bylaws, then so be it.

- Keep a club history of each flier's safe vs. unsafe flights. Implement additional mandatory safety measures as the recent history of unsafe to safe flights increases.
- Under some wind conditions, rockets can and have drifted onto highways. Given the speeds on these highways, even a rocket experiencing a normally "safe" recovery, presents a hazard to traffic. My recommendation would be to establish a safe distance from the launch pads to any major highway. That distance may be affected by existing wind conditions.
- Is there a way to provide training to key individuals at, say, NSL and them have them act as mentors within individual clubs?
- Using Splash to keep rockets away from the crowd and cross wind is the best way so far.
- Base altitude limit on wind speed and say, 30fps descent rate.
- I agree with tilting rods away from the pad, but 5 degrees is excessive. Sets up too many high speed deployments.
- Minimum required black powder charge for defined recovery bay size.
- Require gradual vs. sudden energy absorption by shock cord.
- Require the separated main body to be unstable, so it will not return ballistic in the event of a separation, in mid and high power.
- Limit maximum rocket length to diameter ratio to reduce dynamic stability problems, especially in winds.
- RSO or safety check all rockets, not just high power.
- Holding flyers accountable for errant flights. No-Fly penalties for too low a ratio of good/bad flights.
- Add frangibility to the safety code. Rocket should break before object struck by rocket breaks. Since 1990, Kevlar, carbon fiber, fiberglass, graphite epoxy, and PVC pipe have been added to the list of components for sport rocket construction. These items can be stronger than steel when used properly. Projectiles made from such materials are able to penetrate cement block, windows, etc.
- Biggest safety measure is experienced RSOs checking each rocket no matter the size or experience of the flyer.
- Keep the cars at least 400' from the pads at larger launches.
- A short test on rocketry safety basics (chute sizing, rod/rail sizing, launch angles and the effects of wind) be required for a L1 certification.
- I remember seeing a photo one time of someone taking a spring scale and putting a known load on a model's shock cord before it would pass safety inspection.
- In my opinion, the recovery issue is the number one greatest threat to the hobby from a safety perspective, particularly on the HPR side where the airframes tend to be much heavier and more sturdy. I modified my L3 rocket design to include an aluminum bar that goes across the forward part of the motor tube and is attached to two of the four allthread rods that run the length of the fin can.

5. Trajectory Analysis: Wind, Rockets, and the Field

Recovery system failure-related impacts make up approximately three-quarters of all hobby rocket failures.

The NAR Section whose flying field is located on the NASA Johnson Space Center in Houston reported “We struck the Mission Control building with an eight pound Endeavour coming in ballistically. We were about a quarter bubble of angle and a half hour difference away from taking out [NASA Administrator] Dan Goldin. Anyway, this was telling because before then, the community said the flight ran astray whereas the simulation pointed out that the rocket simply went where Mother Nature told it to go... A subtle but key difference that helped us shape up our program down here.”

The simulation tools available include Apogee’s RockSim and Splash™ software, the venerable Windows™ version of RASP (wRASP), CompuRoc for the Macintosh, ALT4 for MS-DOS, RocFlight, SpaceCAD, and WinRoc. Motor data are available from a number of sources, including thrustcurve.org in a form readable by many of these programs.

With these tools, it is quite feasible to accurately predict the maximum altitude and landing probability distribution of rockets with realistic variations in winds, thrust, tip-off, and workmanship, given average ground winds and winds aloft[7]. Predicted winds are available from the National Weather Service online both for large number of points in the United States[8] and for a much larger number of sites through forecast models[9]. The former data set is available in numeric form, while the latter is graphical (but with numeric wind forecasts at 5 knot resolution). Both use 3,000 foot altitude increments starting at the surface.

These simulation tools can be used very effectively to make motor and chute choices which are appropriate to the rocket range and wind conditions. The following illustration is for an Upscale Vulcanite model launched from the NASA Houston Rocket Club range with an I453T motor and an I211. This high power rocket is approximately 8 feet in length, 4 inches in diameter, and has a launch weight of 6.5 pounds. The Splash™ program was used to simulate 1500 launches, with winds varying from 0-20 mph, from 320 degrees with a one-sigma variability of 45 degrees. The launch rod was vertical, with a 1-sigma variability of 5 degrees. RocSim’s predicted peak altitude was 2580 feet.

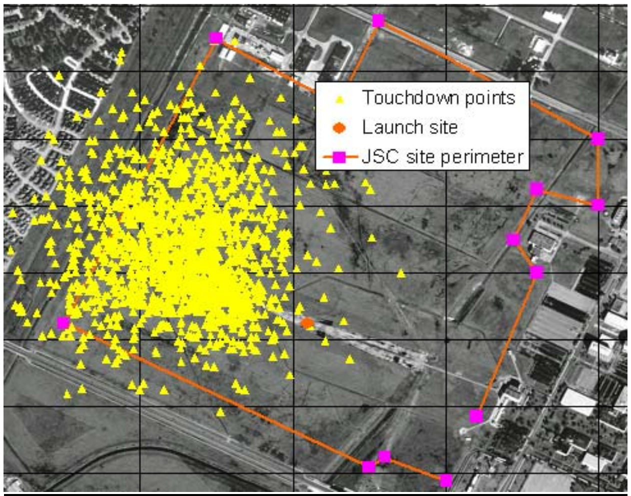
---

[7] While the primary charter of this committee is to address safety, the ability to determine flight corridors before a launch provides an interesting opportunity to address constraints within the present codes where occupied buildings and adjacent roads within a launch field are prohibited. If "guaranteed" flight corridors can be determined for a specific site in a feasible manner, the codes revised to legitimize the practice, and workable administrative procedures established, then additional launch site fields may become available.

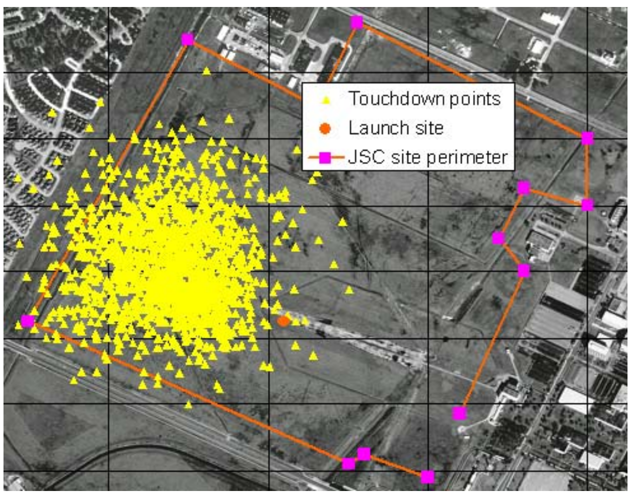
[8] http://aviationweather.gov/products/nws/fdwinds/

[9] http://adds.aviationweather.noaa.gov/winds/

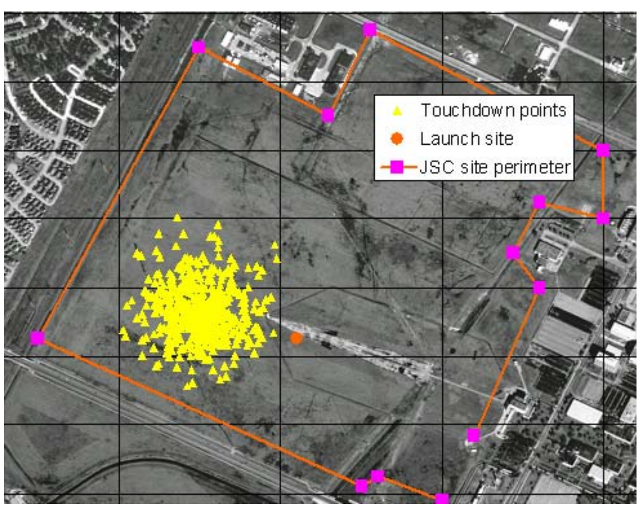
(1) With this initial scenario to 2580 feet, there is potential for easily out-flying the field:



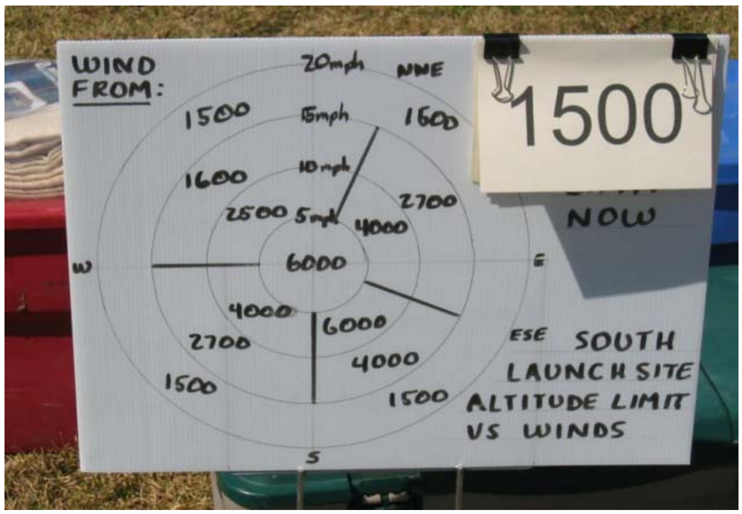
(2) This can be improved somewhat by switching to a smaller motor (I211) and flying to 1600 feet:



(3) But by switching to a smaller parachute (or, if it functions properly, dual deploy), the model stays well within the perimeter even after flying to 2580 feet.



<u>These analysis tools can be run before launch (or empirical data can be used) to establish site-specific altitude limits to ensure that large model rockets and high power rockets will not leave the field boundary.</u> An example is the work done by the South East Alabama Rocketry Society (NAR 572). Their rules specific to one of their launch sites state, in part "Site specific and wind specific altitude limits apply. Limits are based on 30 fps descent rate assuming a vertical flight, to stay in the field. We want ZERO rockets landing off the field." The following sign is posted prominently near safety check in at the South East Alabama Rocketry Society site:



The NASA Houston Rocket Club (NHRC, NAR 365, Tripoli 002) has published preflight charts for their members based on simulation software. This chart is reproduced below, from the NHRC member handbook, excerpts from which are in Appendix G.

A one-pound rocket with 140 feet per second terminal velocity will impact with 410 joules of energy, or approximately three times the energy of a batted baseball. The committee notes that rockets over a pound in liftoff weight, because of their mass and the size of their recovery systems, present significantly greater hazards if they leave the field than do small model rockets.

Ejection Charge Sizing Chart - 8PSI

- Use 8 PSI for drogue ejection - (Grams 4f powder).
Suggested use - twice this amount for main ejection

Tube diameter	Compartment length			
	12”	18”	24”	48”
3”	.35g	.53g	.7g	1.4g
4”	.62g	.93g	1.2g	2.5g
6”	1.4g	2.1g	2.8g	5.6g
7.5”	2.2g	3.3g	4.4g	8.8g

Descent Rate Guide - Assuming a parachute Cd of 1.5

Parachute Size (Domed chutes may have higher Cd)

Rocket weight	5”	10”	20”	30”	40”	50”	60”	70”
453g - 1lb	[illegible]	[illegible]	16	10fps				
906g - 2lbs	90	46	13	15	10fps			
2.2kg - 5lbs		72	36	24	18	15fps		
4.5kg - 10lbs		99	50	34	25	20	17fps	
7.7kg - 15lbs			62	42	31	25	21	18fps

Wind speed/direction vs. Altitude Pie Charts

-Sectors represent direction wind is from. -Use steady state winds + ½ the gusts

Rings represent speed:
Inner = 0-7 MPH
Middle = 8-11MPH
Outer = 12-15 MPH

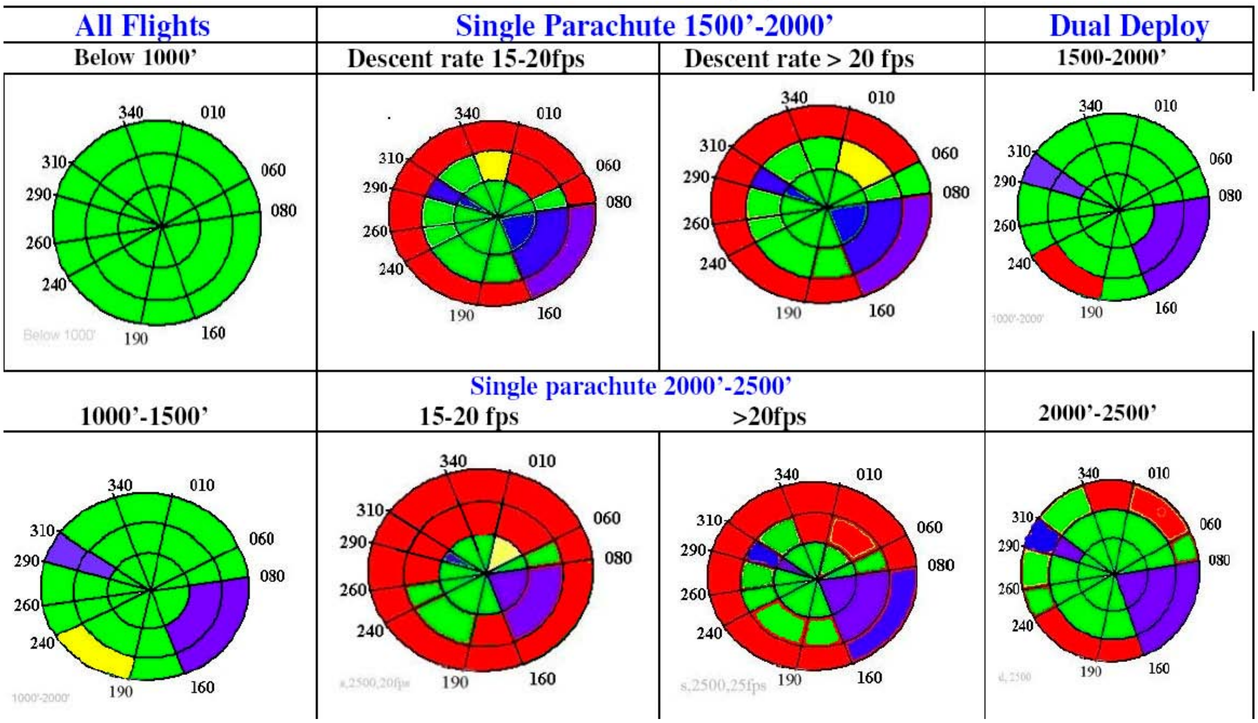
Color indicates safety :
Red…..No Go
Green…OK
Blue …Angle 8° North or Notify R/C fliers
Yellow…Angle 8° angle into wind (or weathervane)

Add 5-10 mph to reported winds for higher winds aloft (check bldg. 30 winds)

Wind drift distance per 1000’ altitude

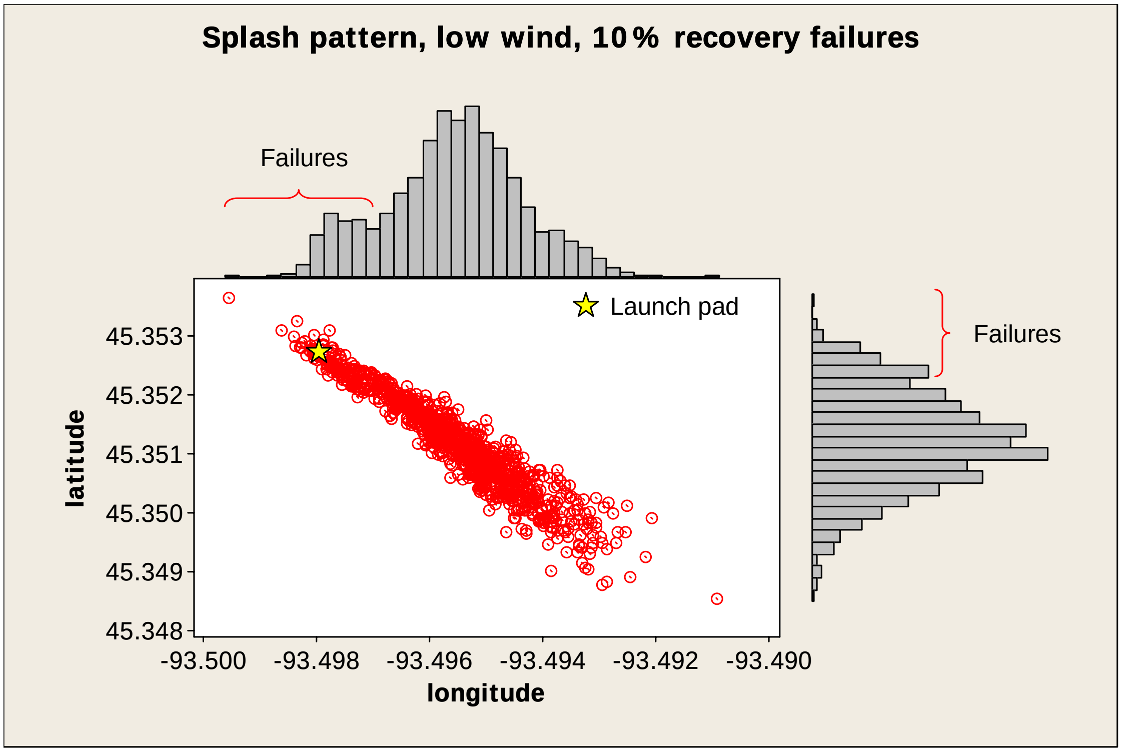
-Be sure to account for winds aloft!

Wind	Descent Rate 15fps	20fps	25fps	70fps
7 mph	685’	510’	410’	145’
11 mph	1075’	800’	645’	230’
15 mph	1460’	1100’	880’	315’
20mph	1935’	1465’	1170’	420’

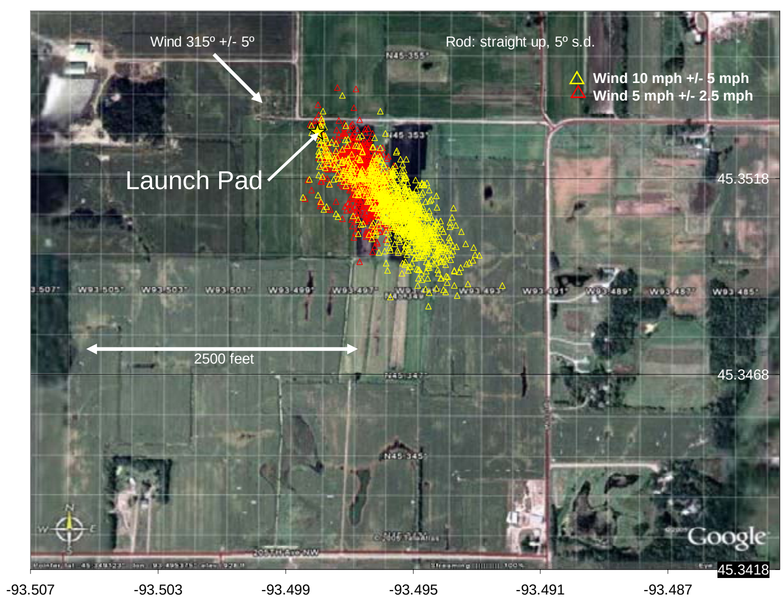


An analysis of both model rockets and HPR was performed for this study using RocSim and Splash™ for both powered flight (boost phase) and recovery (post boost phase).

The model rocket analysis used an Estes Alpha launched with a C6 motor in a wind of average speed 5 mph, with a standard deviation of ± 2.5 mph and a direction variation of ± 5 degrees. A failure to deploy the recovery system was introduced in 10% of the flights. The resulting distribution of landing sites is shown below. **It is evident that even in light winds that positioning vehicles and people crosswind from the launch site results in a very large reduction in the number of impacts close to people and property.**



The landing probability distribution shown below for a HPR MiniMagg (a small HPR kit approximately 3 feet long and 5.5 inches in diameter) powered by an I154J, also with a 10% chance of recovery system failure was computed for 5 mph (red points in the plot below) and 10 mph winds (yellow); both with a standard deviation of half the average speed.



<u>The Committee concludes that for wind conditions above 5 mph that very significant reduction of impact risk can be achieved by locating people and vehicles crosswind from the launch site for launches of rockets over one pound in liftoff weight.</u>

6. Static and Dynamic Stability Considerations

Boost-phase instability is responsible for roughly one-fifth of hobby rocket failures.

Rockets without thrust vector or active aerodynamic surface control of their trajectory must rely upon designs which allow the rocket to fly straight and true after leaving the launcher. With the exception of some radio controlled boost gliders, hobby rockets do not have active trajectory control.

6.1. Static Stability

In 1958, G. Harry Stine published a simplified discussion of rocket stabilization geared towards model rockets using fixed fins on the rear of a rocket. The fins, if properly designed, provide a means of inducing a return to the desired flight path when a disturbance acts to rotate the rocket around its center of gravity (CG or c.g.). The air forces acting on a rocket can be thought of as all acting at a center of pressure (CP). He suggested a method of approximating the CP by constructing a cardboard cutout of the model and balancing the plan-form cutout.

This method was used exclusively to determine whether a model in the design phase would tend to return to the desired flight path if disturbed (a stable design) until 1966. The generally accepted design practice was that the CG should be located forward of the CP by at least the diameter of the body tube (one diameter is referred to as one caliber).

The next advance in design came in 1966, when James Barrowman, then of NASA's Sounding Rocket Division, presented a closed form algebraic solution to equations based on potential flow theory. The approximations used to achieve the closed form solution rely on the assumptions that the rocket (a) is traveling at a speed below that at which shock waves are formed (somewhat below the speed of sound), and (b) has a small angle between its flight path and the relative wind (i.e. a small angle of attack, or AOA). The Barrowman Equations continue to be widely used, both in graphical form and as the basis for hobby rocket design analysis software.

James Barrowman's original intent in addressing stability calculations was to "tune" contest rockets to minimize weathercocking due to excess stability in order to get the highest altitude.

This method generally predicts a CP ½ or 1 caliber aft of the prediction of the plan-form cutout method approximation of the CP. Contest modelers quickly adopted the Barrowman equations, as they allowed them to design shorter models whose smaller weight and reduced wetted area allowed higher performance.

"Swing tests" were also used after the rocket had been constructed. In this method, a string is fixed at the CG and the model is swung around in a circle. This method, for model rockets, can provide an indication of stability if the string is long enough that all components of the model are at nearly the same AOA, and the model is light enough that realistic velocity can be obtained. The swing test method generally gives a conservative answer, and some models fail which can fly in a stable manner if the wind is light enough. Tim van Milligan discussed the swing test in a 2001 article[10].

---

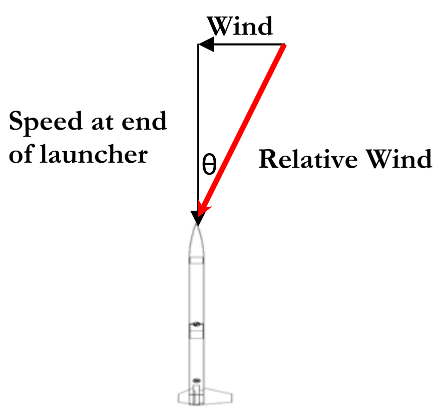
[10] http://www.apogeerockets.com/education/newsletter53.asp

It has been insufficiently recognized in the hobby rocketry community that there are several conditions under which the commonly-used measures of static stability may lead to rockets which follow hazardous flight paths.

First, the rocket must leave the launch system with sufficient velocity to allow the restoring torque provided by the fins to overcome disturbances. Rockets which fly well on a windless day may perform erratically on a gusty day if they have not attained high speed before leaving the constraining influence of the rod, tower, or rail. Software exists which can, using the thrust vs. time curve of the chosen engine, predict speed vs. distance from ignition. **Experience-based best practice indicates that all rockets should be guided by launch rods, rails, or towers until they have attained a forward velocity of at least 4 times the velocity at which the wind is blowing or gusting at the launch site. The 20 mph maximum wind velocity in the Safety Code does not protect against underpowered rockets, which may present a hazard at much lower wind speeds.**

This rule of thumb makes the assumption that the launch system is sufficiently rigid that "rod whip" does not disturb the rocket as it exits the system. Launch rods or rails must be sufficiently rigid that they will not deflect excessively due to inertial and aerodynamic forces resulting from a rocket launch (There is not yet sufficient study in hobby rocketry to provide designers with specific, useful information for this design, so experience continues to provide best practice information, but it is hoped that this situation will improve).

Second, hobby rocket builders must consider that the assumption of low angle of attack can be violated rather easily on any but a calm day. If a wind is blowing, the relative wind which the rocket feels is the vector resulting from its forward velocity and the wind.



Consider two designs. An Estes Alpha with a C6 motor will leave a 3 foot launch rod with a speed of 39 mph and will leave a 6 foot rod at 63 mph. On the HPR side, a 30 ounce, 2.6" diameter FAR 101 HPR design powered by an H180 reaches 45 mph from a 3' rod and 60 mph from a 6' rod. The speeds are similar for the two rockets.

If the wind is blowing at 10 mph at the time the rocket leaves a vertical launcher, the angle of attack (θ in the drawing above) is 13 degrees for the 3' launcher, and 9° for the 6' launcher. These angles both are large enough that the assumption of very small angles is violated.

If the wind at the time of launch is 20 mph, the angle of attack is 18° even when using the six foot launcher.

The angle of attack for a given wind and rocket velocity at the end of the launch system is decreased if the launcher is angled into the wind, and increased if it is angled downwind.

The "launch velocity greater than wind times 4" rule recommended above results in an angle of attack of 14 degrees. **When the angle of attack is not zero, the center of pressure moves forward from the location calculated at zero AOA.**

In a 1999 article, Robert Galejs (then at MIT) obtained fair theoretical agreement with wind tunnel data on the movement of CP with AOA[11]. As far as this Committee could determine, none of the commercial sport rocket design software programs has incorporated Galejs' formulation.

The forward movement of CP with AOA is significant. Careful wind tunnel tests by Bob Dahlquist[12] on six sport rocket configurations showed that the CP moves 1 to 1.5 calibers forward of the zero AOA location at 20° AOA, depending on the design. **At 15° AOA, the CP moves forward 0.75 – 1.25 calibers. This movement can be sufficient to cause designs which have been analyzed to be stable on a calm day (and which may have flown successfully on such a day) to become unstable at moderate winds.**

Best practice design would indicate that if the center of pressure of the rocket cannot be measured at an angle of attack of 15 degrees in a wind tunnel, or to be estimated by similarity to rockets for which wind tunnel data are available, that the CP should be estimated as 1 caliber forward of the center of pressure as computed by Barrowman analysis.

6.2. Dynamic Stability

The static stability discussion above does not consider the time history of how a rocket behaves. The details of how a rocket responds to the forces which act on it can determine whether the flight is safe or hazardous.

For example, a design with many calibers of static stability will respond so aggressively to reduce the angle of attack in a wind that it will "weathercock" and fly at an angle far from vertical.

If the rocket, in addition to having a large degree of static stability, does not have a high initial thrust-to-weight ratio it may follow a parabolic trajectory and impact the ground (or a person or vehicle) under power. This behavior is sometimes referred to as a "gravity turn."

Reduction of the CP-CG distance has been successfully used to increase altitude performance, as discussed above. However, as previously discussed, wind instability effects on heavy rockets with lower thrust, longer burning, engines present hazards as well.

Designers of sport rockets must understand the effects of both static and dynamic stability in order to reduce the number of stability-related hazards. An excellent illustration of the tradeoffs involved in safe design is given in Section 6.2 of "Topics in Advanced Model Rocketry.[13] "

---

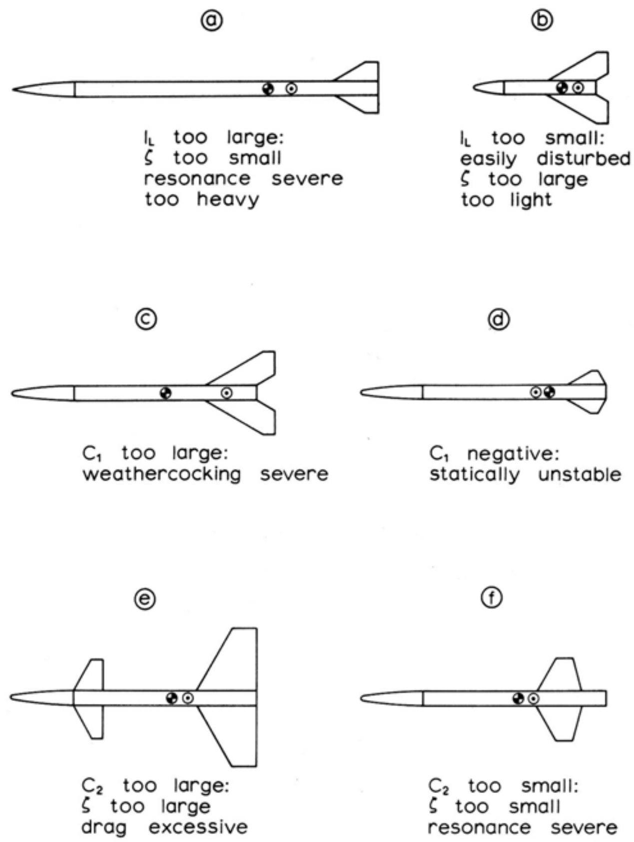
[11] R. Galejs, *Wind Instability: What Barrowman Left Out*, Sport Rocketry, May/June 1999, available at http://www.cmass.org/member/Robert.Galejs/sentinel39-galejs.pdf.

[12] B. Dahlquist, *Wind Caused Instability*, High Power Rocketry, March 1998. Updated version available at http://www.apogeerockets.com/education/instability.asp.

[13] G.K. Mandell, G.J. Caporaso, and W.P. Bengen, Topics in Advanced Model Rocketry, 631 pp., 1973, MIT Press, ISBN 0-262-63278-0, re-issued in softcover and currently available from MIT Press.

If a rocket in flight encounters a disturbance such as a wind gust, it will pivot around its center of gravity, with the nose oscillating in simple harmonic motion (if the rocket is stable). That motion is caused by the corrective force imparted by the wind acting at the center of pressure. This is called the corrective moment, whose coefficient is denoted C_1. (If C_1 is negative, the rocket is unstable.) Friction and other forces tend to damp this simple oscillation. This damping moment has a coefficient denoted C_2. These coefficients are under the control of the designer.

Also under control of the designer is the longitudinal moment of inertia, I_L. We can define a damping ratio, $\zeta = C_2/2\sqrt{C_1 I_L}$. It can be shown that the most rapid restoration to straight flight after a disturbance occurs when this ratio is equal to about 0.7. However, this creates a rocket whose performance is poor because it has too much drag. The greatest damping ratio for which a model rocket can be designed and still have good altitude performance is probably about 0.3. Examples of improperly designed rockets resulting from extreme variations in the relative values of the dynamic parameters are illustrated below[14].



Rapidly spinning the rocket is a method of control for a number of dynamic instability issues, but is not practical where maximum altitude or photography are objectives.

<u>To reduce the number of boost-phase instability failures, designers and range safety personnel should increase their knowledge of these tradeoffs. Resources are available[15], but are not used by the large majority of sport rocket designers.</u>

---

14 Reproduced with permission of G. Mandell and MIT Press from Fig.50 of <u>Topics in Advanced Model Rocketry</u>, *op cit.*

15 An excellent collection is available at http://www.apogeerockets.com/education/rocket_stability.asp.

7. Best Practices

Approximately one in twelve launched sport rockets experience a flight failure which has the potential to endanger people or property. The experience of NAR and Tripoli members in launching several hundred thousand rockets each year can be examined for practices which tend to both lower the percentage of failures and to mitigate the consequences of those failures which are not eliminated.

The role of the Association is to develop best practices for safety (including requirements, recommendations, and possibilities). The role of the Section is to apply those practices and add constraints as necessary for local conditions. A national responsibility is to support the individuals who are directly responsible for safety (fliers and range operations personnel) by providing information and a support network (discussed in the next section of this report).

Another role of the Association is to set a tone for safety discussions which emphasize the overall points rather than blaming an individual or the details of one particular practice. The description of an accident shouldn't be focus on a discussion of ejection charge volume and transition tightness. Instead, it should start with, "Our rocket was launched on a trajectory that took it into a spectator area, and a van was hit," and end with, "here are the additional steps we are taking to ensure that rockets can not do that again, even given the kinds of failures rockets sometimes have."

Some excellent compilations of best practices have been made. At the national level, the NAR Safety Officer Training Program document has a superb set of guidelines, reproduced as Appendix E. An example of site-specific rules in effect at the South East Alabama Rocketry Society (NAR 572) is Appendix F, and excerpts from the member handbook produced by the NASA Houston Rocket Club is Appendix G.

7.1. Launch Site

7.1.1 Position people and property crosswind from the launch pads

Historically, sport rocket fliers have been concerned more with boost phase accidents than with those that are a result of failures later in the flight. As construction techniques and experience matured and the size of the airframes increased, a shift in the failure mode population has resulted. The statistics presented in this report indicate that 3 times as many failures occur in the recovery phase (when kinetic energy can easily reach levels which have to potential to cause injury) as during boost phase[16].

The NAR Safety Codes for model rockets and HPR contain two sets of distance limits, launch site dimensions and safe distances between the launch pad and the nearest person.

The intent of the launch site dimension table is to ensure that no rocket leaves the defined range. There are inherent dangers if large rockets do so (impact with houses or vehicles, impact with persons who cannot be made aware of the presence of an incoming rocket, landing on power lines with pieces within reach of passers-by, fire). As discussed above, experience can be used to set wind-

[16] Boost phase flight anomalies may disrupt the aerodynamics of the airframe resulting in a slower decent velocity of the airframe components and have an impact point that is generally closer to the launch pad as compared to airframes suffering deployment issues.

dependent limits on altitude reached by sport rockets. Simulations can also be used to set such limits, and the probabilistic outputs from such simulations allow many hundreds of flights to be studied rapidly. Simulation software can also be used to predict if specific designs and techniques can stay within the field. **Whether experience or simulation is used, no rocket with over a pound launch weight should leave the field during boost or recovery. If one does, it should cause an immediate halt to launch operations and a discussion of both why the unplanned flight occurred and how to prevent others from leaving the field that day.**

The safe distance between launch pad and the nearest people is intended to protect against both injury due to catastrophic motor failure and impacts under power from unstable rockets.

Neither set of distance limits fully protects against (1) a rocket in boost phase which does not follow a near-vertical trajectory and impacts people or property under power, or (2) a rocket whose recovery system performance allows impacts with people or property. Increasing the distance with a fixed number of people on the range would decrease their density, and thus the chance of either sort of accident. However, people and property are rarely evenly distributed on a rocket range; there are concentrations in the prep area, spectator area, vendor area (if any) and parking. The Canadian Association of Rocketry (CAR) requires for all HPR launches a sterile ballistic zone in which no people are permitted.

The simulations discussed above and careful recording of errant flights on a number of occasions (see the TARC 2005 plot above) make it clear that the greatest danger is downwind and upwind of the launch pad. Great reduction in the chance of either a boost-phase or a recovery-phase failure causing an accident can be achieved by ensuring that people and property is positioned crosswind from the launch pad for launches of rockets over a pound in launch weight. Ideally, two such areas should be planned, with the wind conditions on the day determining which is used. If the only available area is within the danger zone due to wind conditions on a particular day, best practice would indicate that the launch not take place, or be limited to small model rockets. Launch system tilt angle should be adjusted for large model rockets and HPR only by the RSO, as is the practice in Canada.

7.1.2 Check conditions aloft

An early flight of the day should be a "weather flight" to check conditions aloft. Its purpose is to validate the judgment of the range team that the planned geometry is safe.

If the powered trajectory of this or any other rocket during the day penetrates the airspace over the prep area, spectator area, vendor area (if any) or the parking area, (whether the rocket functions as designed or not) best practice would indicate an immediate review of the flight, which should be treated as an failure. If the failure was caused by something peculiar to that one flight (nozzle asymmetry, for example), safety check-in should be alerted and the launch proceed. If the penetration was not caused by something unique to the particular rocket, best practice would indicate that the launch be halted until conditions permit safe flying.

7.1.3 Improving fire avoidance and suppression

For HPR ranges, NFPA 1127 Code for High Power Rocketry (2002 Edition) contains a "Launcher Clear Distance" table which specifies the radius this clearance must be done, by motor power class. This table was tested at the low end by actual field experiments (by both NAR and TRA), and if these cleared distances are complied with the risk of grass fires at liftoff is minimal. The hazards presented by grass fires caused by bad flight trajectories after liftoff can be mitigated by having adequate fire suppression equipment on the range, training range personnel in its use, and having an emergency plan for suppression of fire by the Section which includes a contact plan for professional assistance in the cases it is required.

7.2. Communications

7.2.1 Adopt and consistently use a standard warning practice

If a rocket endangers people, it is sometimes feasible to avoid an accident by making the persons affected aware of the nature and location of the incoming rocket. There are several steps involved.

In order to ensure that all persons at the launch are aware of the actions required, an announcement of this type (used by one NAR Section) should be made periodically**:**

> "At any time during the day, if a flight returns toward the launch area a Heads Up will be issued. At that time your duties are to look up, locate the rocket, point to it, and ensure that you and your children move away from its flight path."

A system capable of reaching all areas in which people are in danger is required to communicate a warning. This can be a PA system, FM low power broadcast to remote receivers supplied by the launch team, or a hybrid. Only at the very smallest launches should warnings be solely via voice communication. Air horns have been used with good effect by some clubs. At large launches, dedicated personnel with air horns in the spectator, prep, vendor, and parking areas with radio links to the RSO have been used to warn of incoming rockets. The ability to notify has great potential to reduce danger to people if properly used, and such a warning system should be audible in all spectator, preparation, and parking areas at launches of significant size. NFPA 1127 requires such notification.

Since not everyone will see the incoming rocket, a best practice is to have those that do point to the rocket.

However, it must be emphasized that the "heads up" procedures are not a substitute for recognition that a rocket which penetrates the airspace over people or vehicles outside the immediate launch control area is a wake up call. Action should be taken to eliminate this hazard for subsequent flights.

All too many "heads up" flights are called for airframes that were poorly constructed or of questionable stability. The solution is not to launch these rockets and call a "heads up" flight, rather it should be to correct or mitigate the deficiency of the airframe prior to the flight. In cases such as clustered composite motor flights and multi-stage composite motor powered flights, where there will always be some uncertainty in the motor ignition, the calling of a "heads up flight is best applied.

7.3. Reducing Recovery Failures

The statistics presented above make a clear statement. Recovery system failures and under-design are responsible for the overwhelming majority of sport rocket failures. While crosswind rocket range layout and operations measures can greatly reduce the number of times people and property are put at risk, a thorough analysis of the detailed reasons for these failures and opportunities for improvement is in order.

The NAR L3CC group has been asked by this committee to coordinate suggestions for HPR recovery best practices.

Improvement in the high recovery system failure rate will require increase in knowledge of why the failures are occurring (statistics), development of more reliable systems, dissemination of this knowledge widely, and use of best practices developed in this effort by builders and range safety personnel.

Heavy rockets are now being constructed of materials which can withstand a greater impact than a person or vehicle. Maximum planned descent rates should be no more than ~15 feet per second.

"Separation", "Lawn Dart", and "No Chute" account for 93% of recovery failures. Initial findings applicable to high power rockets are listed below.

Separation

Shock Cords

To obtain the maximum strength and reliability, shock cords should be tubular nylon with sewn ends. They should be protected in the airframe by a Nomex or Kevlar sheath to prevent heat damage. Although the size and length will vary depending on the rocket, they should be as long and wide as practical.

Eye Bolts

"U" bolts should be used for projects over 5 pounds. Forged eyebolts should be used for projects over 75 pounds.

Lawn Dart

Lawn darts failure modes offer the highest injury potential, with failure of the motor ejection system or electronic deployment electronics being the primary causes. Observing the manufacturer's instructions for motor assembly, reviewing the electronic deployment system requirements and limitations, pre-flight check lists, ground testing, and redundant deployment systems will minimize the occurrence of ballistic recoveries. Further investigation is required to gather statistics and to find the root causes of electronic failures.

No Chute

Parachutes should be carefully packed to avoid tangles. It may be possible to develop a standardized practice for HPR chute folding. Heat shields made of Nomex or Kevlar should be used for all HPR rockets.

7.4. Static and Dynamic Stability

7.4.1 Improving Static Stability

All sport rockets should have adequate static stability margins at an angle of attack of 15 degrees angle of attack.

A maximum static stability margin of 3 calibers measured at an AOA of 15 degrees and an airspeed corresponding to the lowest forward velocity at which the rocket is expected to leave the launcher guidance (4 calibers as predicted by Barrowman analysis) should be used to protect against weathercocking.

These two stability margins are essential to safe flight in any conditions except complete calm.

7.4.2 Improving Dynamic Stability

Designers should take advantage of available resources to learn about the trade offs required to fly a straight flight path, rather than relying on past experience, which may have been acquired only on calm days.

Launch rods or rails must be sufficiently rigid that they will not deflect excessively due to inertial and aerodynamic forces resulting from a rocket launch (this criterion will require more work to provide designers with specific, useful information).

Rockets with launch lugs should have a single long lug extending from aft of the center of pressure at 15 degrees angle of attack to forward of the center of gravity, or one short lug centered aft of the center of pressure at 15 degrees angle of attack and one short lug centered forward of the center of gravity. Launch lugs must have a structural margin of safety of at least 1.5 under the greatest loads they will experience due to inertial and aerodynamic forces during launch (the launch lug strength criterion will also require more work to provide designers with specific, useful information).

The Committee notes that the Canadian Association of Rocketry (CAR) requires that all HPR flights be launched from rails, having found that rod motion during launch introduces unwanted dynamics.

7.4.3 Ensure That Initial Thrust is Sufficient

Underpowered rockets continue to present a hazard. They will often fly well in no-wind conditions and lull their builder into a false sense of security. As an example, most models powered by D motors will fail to achieve a safe speed when a 1 meter launch rod is used, but will do fine on a 2 meter rod.

Best practice would indicate that rockets to be guided by launch rods, rails, or towers until they have attained a forward velocity of at least 4 times the velocity at which the wind is blowing or gusting at the launch site (e.g. 36 m/sec if the maximum gust is 20 mph). Introducing a "4 x wind" requirement will require many models to use 8-foot or 10-foot rails or towers in significant crosswinds for all but the lightest rockets with high thrust/weight ratios.

Simulation software is readily available and affordable (and some manufactures have both site licenses and 30-day free trials), and can predict the velocity at which a rocket will leave the launch device of a specified length. If no such software is available, rough guidelines for thrust-to-weight limits should be used, such as the 5:1 or 6:1 rule of thumb for average thrust-to-weight used widely. Note that such a rule of thumb may not be conservative, because it is not sensitive to the initial thrust of the motor, nor to the time required to build up to that initial thrust level.

Cluster models are susceptible to delayed ignition of some motors, so that the velocity at which the rocket leaves the launch guidance may be lower than designed. Composite motors are harder to ignite than black powder. Considerable risk is incurred if the rocket separates from the ignition system before all composite motors are ignited.

Such thrust-to-weight guidelines should be recognized as inappropriate for designs such as radio-controlled boost-gliders, but they can provide a starting point for safety check-in judgment on whether a particular rocket requires an in-depth review.

7.5. Improve the Safety Culture

7.5.1 Collect and Analyze Safety Data

Flight logs of the type analyzed for this study are maintained by only a few NAR Sections. A standard set of log procedures should be developed and made available to Sections who wish to use them. Analysis of trends on a periodic basis at the national level should include changes in failure modes which may indicate a problem which can be addressed.

The use of the Malfunctioning Engine Statistical Survey (MESS) form has declined in recent years. Rocket fliers' best practices would include making reports of all engine incidents on this form. A web-based version is now operational at http://nar.org/NARmessform.html, and may improve response rates. Frequent announcements to the membership about this program and periodic reports with summary data to the membership also have the potential to improve response rates for this important program.

7.5.2 Review Incidents

Best practices include a post-flight review of every incident, and flight logs which note nominal and deviant flights. The MASA and SARA logs analyzed for this report are very helpful, but do not contain large numbers of HPR flights; such data would be useful in continually identifying failure modes and potentially dangerous hardware and practices. Data sets are not yet available to establish or refute the effectiveness of many hazard mitigation procedures.

One example of the results of a post-flight review is the corrective action steps taken by a NAR Section which experienced an incident. The problems that were found were to be discussed at the next meeting and new procedures put into place before the next launch:

> "1. A PA system will be used April to October, no exceptions. November - March are pretty lightly attended, so it will be up to the person in charge to decide if the PA is needed. We always have a PA when we are running a contest. (Which we sometimes hold in March, so March would have a PA)
>
> 2. A flight line will be used at the field. We have a circle the park has made that we can fly rockets out of. Most of the rockets landed to one side, and we had been a bit lax in getting people to set up their tents and such on the other side of the field circle.
>
> 3. The RSO on duty needs to take breaks, and if there a lot of people wanting to fly, then we need 2 people, on to check-in and one to RSO. Check-in will be moved away from the RSO table. (Most of the time, one person had been RSOing the whole day.) We need to institute a sign-up for RSO duty."

7.5.3 Provide for Peer Review of HPR

Internal recovery systems present a difficult paradox for the RSO of a ready-to-go rocket at safety check in. For the heavier mass items, an approach used by several NAR Sections is to establish a community peer checking environment where common prep areas (versus isolated tables) are used. The Sections presented this as a socially fun thing to do, the fliers found technical benefit to the peer reviews, and the RSO waives any internal checks if the rocket was peer reviewed during internal preparations. The CAR has instituted pre-inspections by a roving inspector and requires that a checklist be presented to the RSO showing such an inspection at safety check in.

8. Recommended Changes to Codes

8.1. NFPA Code 1127

Safe Recovery

Current text: 4.10.1 A high power rocket shall be launched only if it contains a recovery system that returns all parts of the rocket to the ground intact so it can be launched again.

Proposed text: 4.10.1 A high power rocket shall be launched only if it contains a recovery system that returns all parts of the rocket to the ground intact **and at a landing speed at which the rocket does not present a hazard to persons.**

Rationale: Heavy rockets landing at significant speeds, even with a deployed recovery system, have been shown in experience to have sufficient energy to be capable of injury to persons and damage to property. Nothing in NFPA 1127 currently requires a high power rocket to land at a slow enough speed to mitigate risk to any persons or property that it might land on; the current code simply requires that the recovery leave the rocket intact.

Safe Liftoff

Current text: 4.12.1 A high power rocket shall be launched from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a predictable flight path.

Proposed text: Add 4.12.1.1 When the wind at launch exceeds 5 miles per hour, the launch guidance device shall be of a length to ensure that the rocket reaches a speed of at least four times the wind speed before its departure from the device.

Rationale: The NAR Special Committee's analysis shows that the center of pressure of a rocket moves forward (toward a potentially unstable condition) and the flight trajectory of a rocket rotates significantly off of the vertical direction when the rocket is exposed to a crosswind while traveling at low velocities. If the crosswind is greater than 1/4 of the velocity at which the rocket departs the launch device, the rocket's trajectory will depart from vertical by as much as 15 degrees, and the rocket's center of pressure will move forward approximately one caliber (body diameter) compared to the position calculated by most commercial rocket design software. This non-vertical flight and reduction in stability could lead to an otherwise-safe rocket becoming a flight safety hazard. It is important to establish a requirement for safe launcher separation speed , in order to prevent the hazards of unstable flight or of flight outside the range of 20 degrees of vertical that is the limit established in paragraph 4.12.3 of this Code that could lead to impact outside the launch site.

Spectator Area

Current text: All spectators shall remain within an area determined by the range safety officer.

Proposed text: All spectators shall remain within an area determined by the range safety officer **to be safe with respect to the prevailing wind conditions and types of rockets to be flown.**

Rationale: Flight simulations and data collection done by the NAR Special Committee show clearly that the safest place for spectators to be is in the crosswind direction from the area from which rockets are being launched. Whether the flight safety anomaly is launcher tipoff, ballistic recovery, or simply landing with a recovery system that does not slow the rocket sufficiently, the distance to the point where such flights most probably will land is far greater in the upwind and downwind directions than in the crosswind direction. The spectator area's positioning must be carefully considered by the range safety officer with respect to winds and the types (and hazard level) of the rockets being flown, and not be simply the result of convenience.

Keeping the Rocket on the Launch Site

Current text: 4.17.1 No person shall ignite and launch a high power rocket horizontally, at a target, or so that the rocket's flight path goes into clouds, or beyond the boundaries of the launch site.

Proposed text: 4.17.1 No person shall ignite and launch a high power rocket horizontally, at a target, or so that the rocket's flight path **during ascent phase** goes into clouds, **over the heads of spectators**, or beyond the boundaries of the launch site, **or so that the rocket's recovery occurs in spectator areas or outside the boundaries of the launch site.**

Rationale: The number one source of safety risk from sport rockets is "ballistic" recovery resulting from total failure of the recovery system to deploy. If a rocket's powered flight trajectory takes it over the heads of spectators or outside the launch area, then if a ballistic return occurs the rocket could potentially land at extremely high speed in a spectator area or in a place where persons were unaware of the rocket's flight. Similarly, large high power rockets, even with deployed recovery systems, can land with sufficient energy to present some risk of injury or damage to persons and property on the ground. Spectator areas often contain people too closely spaced or unaware of rocket activities to permit evasion of descending rockets, and persons in areas outside the boundaries of the launch site are unlikely to have any warning of descending rockets that might present a hazard to them.

Range Safety Officer Duties

Current text: 4.18.1 A high-power rocket shall be launched only with the knowledge, permission, and attention of the range safety officer.

Proposed text: 4.18.1 A high-power rocket shall be launched only with the knowledge, permission, and attention of the range safety officer, **and only under conditions where all the requirements of NFPA 1127 *Code for High Power Rocketry* have been met**.

Rationale: Nothing in the Code currently requires that the RSO enforce the provisions of the Code. Paragraph 3.3.14 definition of the RSO gives him responsibility for launching, and the paragraphs of Section 4.1 on RSO requirements and responsibilities require competency and provide the authority to intervene and control a launch, but no provision places the direct responsibility for Code enforcement on the RSO. This requirement could alternatively be established as a new paragraph 4.1.4.

Providing "Heads Up" Warning of Safety Events

Current text: 4.18.3 The launching of a high power rocket shall be preceded by a 5-second countdown that is audible throughout the launching, spectator, and parking areas.

Proposed text: Add 4.18.3.1 An announcing system shall be provided that permits the range safety officer to immediately warn all participants and spectators of rocket flight event anomalies that might present a hazard to them.

Rationale: An audible means is needed to communicate a prompt and specific "heads up" warning to all persons in the launching area when flight anomalies occur after the countdown and liftoff of a rocket.

<u>**Launch Site**</u>

Current text: 4.14.1 A high power rocket shall be launched only in an outdoor area where tall trees, power lines, and buildings do not present a hazard.

Proposed text: 4.14.1 A high power rocket shall be launched only in an outdoor area where tall trees, power lines, buildings, **and persons not involved in the rocket launch** do not present a hazard.

Rationale: Within the area of a high-power rocket launch site, persons who are not aware of the activity and are not participants or spectators who are in areas where the specific safety and notification procedures of this Code provide them with a safe environment, are vulnerable to being struck by descending rockets or components that may have sufficient kinetic energy to be dangerous. The area of the launch site should be required to be clear of such persons.

Current text: 4.14.2 The dimensions of the launch site shall be one of the following:

(1) Not less than one half of the maximum altitude expected, calculated, or simulated, or as granted by an FAA waiver or the authority having jurisdiction.

(2) As specified in Table 4,14.2. [Note: this extends to 5 miles for an "O" motor!]

4.14.3 The minimum launch site dimension shall be not less than 457m (1500 feet).

Proposed text: 4.14.2 The minimum dimension of the launch site shall be permitted to be the greater of the following:

(1) One-half of the maximum altitude expected, calculated, or simulated for any rocket that is flown

(2) 457m (1500 feet) or twice the minimum spectator and participant distance specified in Table 4.16.4, whichever is greater, for any rocket that is flown.

[Table 4.14.2 and paragraph 4.14.3 would be deleted as a result]

Rationale: The NAR Special Committee's analysis found no linkage between the size of the motor used in a high power rocket and the distance at which persons and property not involved in the launch might be at risk from the primary area of risk from such rockets, which is their kinetic energy at landing. The increased risk associated with larger motors is from on-pad casing failure at ignition, and the "Minimum Spectator and Participant Distance" requirements of Table 4.16.4 cover this risk. The distance to which rockets present kinetic energy risk depends largely on the altitude that they attain, and the angle at which they are launched. Rockets launched within 20 degrees of vertical as required by paragraph 4.12.3 of this Code would normally impact within a launch site of one-half the maximum expected altitude if they fell ballistically, which is their highest-hazard configuration.

Current text: 4.15.3. The high-power rocket launch pad clear distance from the following locations shall be permitted to be equal to one-half the launch site dimension or 457m (1500 ft), whichever is greater:

(1) A building inhabited without the approval of the authority having jurisdiction and the documented approval of the owner(s) of the inhabited building(s), if the inhabited building(s) is unoccupied during the launch

(2) A public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch.

Proposed text: 4.15.3 The high power rocket launching area shall be permitted to be located at least 457m (1500 ft) or the minimum spectator and participant distance for the largest high power rocket permitted to be flown, whichever is greater, from the following locations:

(1) An inhabited building that is occupied

(2) A public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch.

Rationale: The main paragraph refers to "launch pad clear distance", which is not a defined term but is clearly intended to be "minimum spectator and participant distance" rather than "launcher clear distance". The current subparagraph (1) is unintelligible.

Proposed new text: Add paragraph 4.15.4. The high power rocket launching area shall be permitted to be located no closer to any boundary of the launch site than the minimum spectator and participant distance specified in Table 4.16.4 for the largest high power rocket to be flown.

Rationale: Currently there is no minimum for how close the launching area may be to the perimeter of the launch site, only a minimum dimension for the overall site and a required separation distance for the launching area from highways and inhabited buildings.

8.2. Proposed Draft of Revised NAR High Power Rocket Safety Code

1. **Certification**. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.

2. **Materials.** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.

3. **Motors.** I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will keep smoking, open flames, and heat sources at least 25 feet away from these motors.

4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launching or prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. If my rocket has onboard ignition systems for motors or recovery devices, these will have safety interlocks that interrupt the current path until the rocket is at the launch pad.

5. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.

6. **Launch Safety.** I will use a 5-second countdown before launch, and will ensure that everyone in the launch site is paying attention and that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable.

7. **Launcher.** I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight. IF the wind speed exceeds 5 milrs per hour I will use a launcher length that permits the rocket to attain a velocity of four times the wind speed before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that there is no dry grass within a clear distance of each launch pad determined by the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 if the rocket motor being launched uses titanium sponge in the propellant..

8. **Size.** My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.

9. **Flight Safety.** I will not launch my rocket at targets, into clouds, near airplanes, or on trajectories that take it over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.

10. **Launch Site.** I will launch my rocket outdoors, in an open area where trees, power lines, buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater.

11. **Launcher Location.** My launcher will be at least one half the minimum launch site dimension, or 1500 feet (whichever is greater) from any inhabited building, or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.

12. **Recovery System.** I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.

13. **Recovery Safety.** I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it may recover in spectator areas or outside the launch site, or attempt to catch it as it approaches the ground.

MINIMUM DISTANCE TABLE				
Installed Total Impulse (N-sec)	**Equivalent Motor Type**	**Minimum Clear Distance (ft.)**	**Minimum Personnel Distance (ft.)**	**Minimum Personnel Distance (Complex Rocket) (ft.)**
0.00 - 160.00	G or smaller	0	30	30
160.01 - 320.00	H	50	100	200
320.01 - 640.00	I	50	100	200
640.01 - 1280.00	J	50	100	200
1280.01 - 2560.00	K	75	200	300
2560.01 - 5120.00	L	100	300	500
5120.01 - 10,240.00	M	125	500	1000
10,240.01 - 20,480.00	N	125	1000	1500
20,480.01 - 40,960.00	O	125	1500	2000

Note: A complex rocket is one that is multi-staged or that is propelled by two or more rocket motors

9. Support of Best Practices

In a review of safety culture research done for the FAA, Wiegmann et al.[17] make a number of observations relevant to sport rocketry**:**

> "An effective and systematic reporting system is the keystone to identifying the weakness and vulnerability of safety management before an accident occurs. The willingness and ability of an organization to proactively learn and adapt its operations based on incidents and near misses before an accident occurs is critical to improving safety. …an organization with a good safety culture should have a formal reporting system in place and one that is actually used comfortably by employees. A good reporting system allows and encourages employee to report safety problems, and it also provides timely and valuable feedback to all employees.
>
> An organization's safety culture…is reflected by the extent to which it possesses an established system for reinforcing safe behaviors (e.g., through monetary incentives or public praise and recognition by management and peers), as well as systems that discourage or punish unnecessary risk taking and unsafe behaviors. However, an organization's safety culture is signified, not only by the existence of such reward systems, but also by the extent to which the reward systems are formally documented, consistently applied, and thoroughly explained and understood by all."

The NAR should facilitate networking among those within the membership with an interest and/or professional background in safety to monitor events, educate, collect best practices, provide tips on how to handle situations, and gather at national events to foster and promote a program of safely flying rockets. This effort should also include an Internet forum.

General knowledge of best practices among fliers is sometimes facilitated by local and national newsletters and NARTS reports. Targeting topics which have a significant impact on safety for such communication should be done on the national level. The work done for this study is only a beginning. Best practices in such areas as launch equipment standards beyond the minimum required (e.g. welded relay alarms, pad active lights at pad, booster boxes for clusters), recovery harnesses and attachments, flier and Section education (e.g. Safety First column in Sport Rocketry, tip sheets on using Splash, Incident reporting system, online discussion group, classes at NARCON, safety meetings/briefings at national events, FAQ on the website) should be compiled and disseminated.

In other organizations which operate in a dangerous environment where things are certain to go wrong, a problem reporting and corrective action mechanism has been generally found to be effective in ensuring that lessons are learned and passed along to other practitioners. An effective reporting system should be facilitated at the national level.

In the opinion of the Special Committee, these considerations argue for the creation of an NAR Safety Committee to facilitate networking, compile and disseminate best practices, perform an ongoing review of NAR Safety Codes and NFPA Codes 1122, 1125, and 1127, and provide an avenue for communication for the membership interested in improved safety practices.

---

[17] D. A. Wiegmann, H. Zhang, T. von Thaden, G. Sharma, and A. Mitchell, A Synthesis of Safety Culture and Safety Climate Research Technical Report ARL-02-3/FAA-02-2, June 2002, Aviation Research Lab, Institute of Aviation, University of Illinois at Urbana-Champaign.

Appendices

A. Special Committee Members and Advisors

B. Survey on Rocket Safety

C. Failure Rates in Model Rocketry: Towards a Statistical Model of Safety

D. Risk Model for Ballistically Falling Flights at NAR Launches

E. Excerpts from NAR Safety Officer Training Program

F. SARC Site-Specific Rules

G. Excerpts from NHRC Member Handbook

Appendix A

Background of Special Committee Members and Advisors

Jay Apt (Chairman) has been involved in model rocketry since 1962. He was a member of two NAR national championship teams. His undergraduate degree and Ph.D. are in experimental physics. He was a payload flight control officer at the Johnson Space Center's mission control before his selection as an astronaut in 1985. After the Challenger accident in 1986, he spent 16 months at Kennedy Space Center on flight safety review teams. He was a crew member on four space missions. He teaches and conducts research at Carnegie Mellon's Tepper School of Business and the Department of Engineering and Public Policy, where he is a Distinguished Service Professor.

Ted Cochran (Member) is a cognitive scientist with 25 years of R&D experience concerning human interaction with complex control systems and the impact of new technology and organizational culture on safety. As a certified Six Sigma Black Belt, he has led the application of Six Sigma to risk and vulnerability assessment in a variety of application domains. During his academic career, he also served for three years as a volunteer firefighter and paramedic in Long Island, New York. Dr. Cochran holds a Low Explosive User's Permit and a Level 2 high power rocketry certification. He first flew rockets in the early 1960s, has made over 860 sport rocket flights in the past ten years, and was elected as a NAR Trustee in 2004. He received his B.A. from Johns Hopkins University and his Ph.D. from the University of Minnesota.

Andy Eng (Member) has been involved with numerous projects including avionics production for Atlas and Centaur vehicles, space station development and operations, and post-Columbia thermal protection system sensors at Johnson Space Center. Recognitions include the NASA Silver Snoopy and the NASA Public Service Medal. Mr. Eng received his B.S.M.E at the University of Texas and a M.S. in Technical Management from Embry Riddle. He began building and flying model rockets the year the Mighty D13 entered the market.

Keith Florig (Member) holds degrees in Engineering and Public Policy (Ph.D.), Nuclear Science and Engineering (M.S.), Instrumentation (M.S.), and Physics (B.S.), all from Carnegie Mellon. Dr. Florig is a member of the Society for Risk Analysis and conducts research on risk assessment and risk communication in the Department of Engineering and Public Policy at Carnegie Mellon, where he is Senior Research Engineer. He launched model rockets in a ball field 40 years ago with the riveting attention to safety that one would expect from an unsupervised sixth grader. Today, Keith and his son Steven fly high power rockets safely with Tripoli Prefecture #1 in Pittsburgh, where Keith has a Level 2 HPR certification.

John Lyngdal (Member) first became involved in model rocketry in 1968, later returning to rocketry as BAR in 1994. Since his return to rocketry, he was selected as an original member of the NAR L3 Certification Committee in 1999, elected as a NAR Trustee in 2002, and has logged over a 400 HPR flights. He hold a Level 3 HPR certification. He has an undergraduate degree in chemistry and over a decade of industrial R&D experience in the semiconductor and material science fields. He is licensed by the Nuclear Regulatory Commission as a Senior Reactor Operator and has also been issued a BATFE Type 21 license for the manufacture of ammonium perchlorate composite propellant. He is a Senior Compliance Engineer at Tektronix with responsibility to monitor worldwide environmental compliance requirements for electronic instrumentation.

Trip Barber (Advisory Member) has been involved in rocketry since 1961 and has flown in 20 National Championship and 2 World Championship meets. He is a member of the National Fire Protection Association committee that writes the national codes on hobby rocket safety, and he developed and authored the NAR Model Rocket Safety Code and the national standards and procedures for hobby rocket engine safety certification. He has conducted four major engineering test projects over the last 25 years to provide a technical basis for language in these codes and in Federal regulations concerning rocketry. He has completed the NAR Trained Safety Officer Program, and holds a Level 2 HPR certification. His undergraduate degree is in Aero Engineering and he has a Master's in Weapon System Engineering. He served in the Navy for 28 years, commanding a guided missile destroyer and Norfolk Navy Base, and is currently a Senior Executive Service manager on the Navy headquarters staff.

Appendix B
Survey on Rocket Safety

Andy Eng
aeng@houston.rr.com

Keith Florig
florig@cmu.edu

In response to requests from the NAR President, a survey was developed and 136 NAR Sections were invited to participate. Responses were received from 77 individuals representing Sections. The members of the committee were impressed and gratified not only with the level of participation but also the quality of responses on the essay questions.

> **…I want the committee to asses, in a technically oriented, professional manner, the incidents occurring on NAR ranges, and then recommend to the NAR Board what action steps, if any, we need to take to reduce their occurrence by (hopefully) a couple of orders of magnitude. Without that technical background, and without more information from the field, I believe we're shooting in the dark at what I believe is a real, and serious problem…**
>
> **- Mark Bundick**

Snapshots of the survey along with results are provided along with comments, observations, and a few additional cross correlations. Major topics of the survey included the items listed on the right. Prior to release, the survey underwent several iterations including a trial run with a smaller group along with a read aloud session to assure clarity in the questions to satisfy the requested objectives.

- Introduction
- Launch Site and Event Frequency
- Flight Volume
- Crowd Size
- Crowd Composition
- How effective are Various Safety measures
- Applying Safety Measures at Your Club
- Additional Safety Measures? (Essay)
- Safety Responsibility and Management Style
- Murphy is Your Brother (Essay)
- Demographics
- Open Comments (Essay)

The survey was developed and hosted on www.surveymonkey.com, a web based survey site.

B.1 Introduction

The following introduction page was prepared with features noted:

Survey on Hobby Rocketry Safety — Exit this survey >>

Introduction

Each year, there are several hundred thousand rocket launches at club-sanctioned launch events across the U.S.. Some of these flights fail in various ways, occasionally resulting in injury to flyers or spectators. In other cases, damage to property has been reported. Although statistics on flight-related injuries at organized launch events are sketchy, there have been a number of anecdotal reports of injuries resulting from pad accidents (motor or deployment charge ignition during pad setup), excessive wind cocking, unstable flight, failure of chute deployment (lawn darts), unplanned detachment of components in flight, and fires. As all rockets contain burning materials and as many rockets and rocket components are massive enough to cause significant injury even at modest speed, it is important for rocketry clubs to occasionally evaluate and update safety procedures.

Introduction

Toward that end, the NAR Special Committee on Range Operation and Procedure has designed this survey to gather safety-related information and opinion from those with experience in hobby rocketry. The survey consists of the following sections:
- Conditions at your club's flying field(s)
- Launch volume and attendance
- Effectiveness & practicality of various safety measures
- Safety responsibility & management
- Errant flights you have witnessed
- Demographic information
- Comments and suggestions

Scope

The time required to complete the 11 questions in this survey is 30-40 minutes. This is an anonymous survey. No names, club affiliations, or computer ids are collected.

Expected time required

Confidentiality assurance

Contacts for survey integrity

You may proceed to the next screen by clicking the "Next" button. By clicking the "Prev" button at any time, you may review and change your answers as needed prior to submitting your completed survey.

Thank you for taking the time to participate!

B.2 Launch Site and Event Frequency

This question was in part to address concerns from insurance loss control professionals about the locations of various launches.

Table B.2-1

Launch Site and Event Frequency

Please check all that apply to the flying events sanctioned by your club in the past 12 months:

	1-2 events per year	3-4 events per year	5-7 events per year	8-13 events per year	13-20 events per year	more than 20 events per year	Response Average
Suburban Park	26% (8)	**32% (10)**	19% (6)	10% (3)	6% (2)	6% (2)	**2.58**
Suburban Empty Lot	25% (1)	0% (0)	25% (1)	**50% (2)**	0% (0)	0% (0)	**3.00**
Metropolitan Multiuse Park	**33% (2)**	0% (0)	17% (1)	**33% (2)**	0% (0)	17% (1)	**3.17**
Metropolitan Empty Lot	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	**0.00**
Rural Farm or Ranch Land	8% (3)	16% (6)	32% (12)	**34% (13)**	8% (3)	3% (1)	**3.26**
Educational Site (e.g., Schoolyard, University, etc.)	17% (4)	**29% (7)**	17% (4)	21% (5)	8% (2)	8% (2)	**3.00**
Airfield	**80% (8)**	10% (1)	0% (0)	0% (0)	0% (0)	10% (1)	**1.60**
Industrial or Business Facility Land	33% (2)	0% (0)	17% (1)	**50% (3)**	0% (0)	0% (0)	**2.83**
Non-Profit Enterprise Land (i.e. VFW, 4H, FFA, etc.)	**40% (2)**	20% (1)	20% (1)	20% (1)	0% (0)	0% (0)	**2.20**
Other Institutional Facility Land	**50% (1)**	0% (0)	0% (0)	0% (0)	0% (0)	**50% (1)**	**3.50**
Government Open Range	33% (3)	22% (2)	0% (0)	**44% (4)**	0% (0)	0% (0)	**2.56**
Other	12% (1)	0% (0)	25% (2)	**50% (4)**	12% (1)	0% (0)	**3.50**
						Total Respondents	**75**
						(skipped this question)	**2**

B.2.1 Launch Site and Event Frequency - Interpretation of the Results

Without detailed knowledge of each and every launch site, the reader can make educated assumptions as to the relative risk involved with respect to the areas surrounding the launch activities which may possibly be impacted by a wayward flight or a flight leaving the field:

Pranging harmlessly in a soft plowed field,
Penetrating building roofs,
Halting traffic on adjacent roadways
Etc.

The survey reviewers proceeded to group launch sites into related clusters. The frequency of events held was estimated based on the *mean* of the ranges provided. Finally, a general *assumption* as to the type of rockets flown at the particular location (i.e. Model or High Power) is illustrated.

Launch Site	Launches per Year	Fraction of Events Held
Suburban Park	187	19%
Suburban Empty Lot	28	3%
Metropolitan Multiuse Park	49	5%
Metropolitan Empty Lot	0	0%
Education site (e.g. Schoolyard, University, etc.)	179	18%
Industrial or Business Facility Land	39	4%
Non-Profit-Enterprise Land (i.e. VFW, 4H, FFA, etc.)	23	2%
Other Institutional Facility Land	22	2%
Other	71	7%
Airfield	48	5%
Government Open Range	52	5%
Rural Farm and Ranch Land	299	30%
	997	

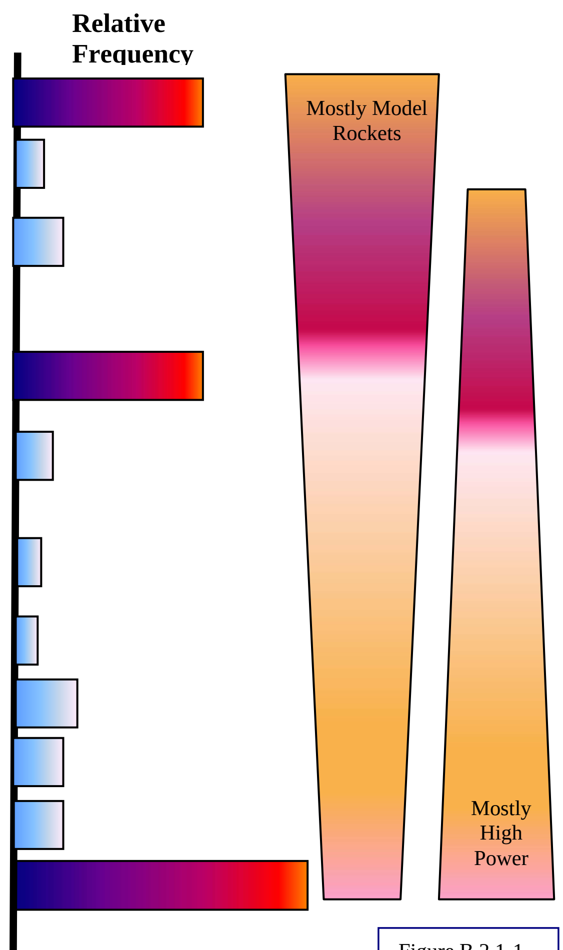


Figure B.2.1-1

Discussion - The variety of launch sites suggest that a single set of safety rules cannot apply everywhere. While the overarching rules of not causing physical bodily harm or property damage hold, it appears obvious that launch planners must use safe practices appropriate for their particular field. Obviously these practices also need to take into consideration their volume of flights, typical attendance, and other factors. Our survey asked about these issues.

B.3 Flight Volume

Having surveyed the range of fields flown by the 77 sections, the survey attempts to quantify an annual volume of flights. Once known, these flight rates may be judiciously applied to project flight volume for all 135 NAR Sections. The Survey form, responses, and discussion are provided:

Discussion - An interesting follow-up question for those sections conducting relatively infrequent launches would be to assess how they establish and maintain *safe protocols* for *sites infrequently used.*

Table B.3-1

Flight volume

Please check all that apply to the launches sanctioned by your club in the past 12 months.

	MODEL rockets, 1-100 flights/event	MODEL rockets, 101-200 flights/event	MODEL rockets, more than 200 flights/event	HIGH POWER rockets, 1-50 flights/event	HIGH POWER rockets, 51-100 flights/event	HIGH POWER rockets, more than 100 flights/event	Respondent Total
1-2 events/yr	14% (3)	29% (6)	24% (5)	**33% (7)**	24% (5)	14% (3)	**21**
3-4 events/yr	35% (7)	25% (5)	0% (0)	**60% (12)**	10% (2)	0% (0)	**20**
5-7 events/yr	**55% (11)**	10% (2)	0% (0)	45% (9)	15% (3)	5% (1)	**20**
8-13 events/yr	**87% (33)**	5% (2)	11% (4)	47% (18)	3% (1)	0% (0)	**38**
13-20 events/yr	**90% (9)**	10% (1)	0% (0)	70% (7)	10% (1)	10% (1)	**10**
> 20 events/yr	**80% (4)**	0% (0)	0% (0)	0% (0)	0% (0)	20% (1)	**5**
						Total Respondents	**74**
						(skipped this question)	**3**

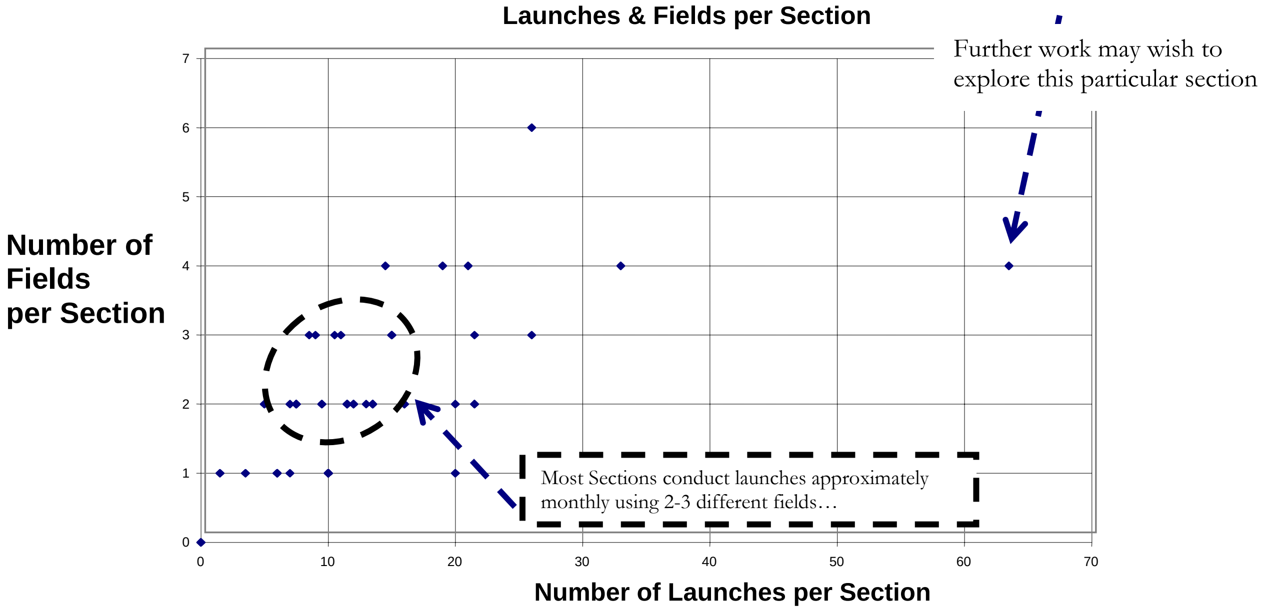
Modes

Discussion - Casual inspection of the results of the column for "HIGH POWER rockets, more than 100 flights/event on more than a monthly basis detects interesting instances of prolific amounts of HPR flying taking place. Further investigation to determine who these "fleet leaders" are and how they conduct launches could prove beneficial.

The following chart[1] cross correlates the data to help assess "just how busy" a particular section may be. For instance, maintaining multiple fields may distract from over all safety attention. Conversely, going into a new field may reinforce fresh revisiting of site layouts, launch protocols and other factors affecting safety.

[1] A good check would be to see if this distribution is similar to the number of field insurance certificates issued by the carrier.

Figure B.3-1



B.3.1 Analysis of Flight Volume – Treatment 1

In order to prepare the volume of flights to feed into Analytica Risk Assessment models, it was necessary to determine flight volumes based on the *mean* of given ranges. All derived numbers denoted in *italics*.

Table B.3.1-1

	Model Rockets			High Power Rockets		
Freq. Events/Yr	**1-100**	**101-200**	**>200**	**1-50**	**51-100**	**>100**
1-2	3 *(225 flights/year)*	6 *(1350 flights/year)*	5 *(1500 flights/year)* Note 1	7 *(263 flights/year)*	5 *(563 flights/year)*	3 *(450 flights/year)* Note 1
3-4	7 *(1225 flights/year)*	5 *(2625 flights/year)*	0	12 *(1050 flights/year)*	2 *(525 flights/year)*	0
5-7	10 *(3000 flights/year)*	2 *(1800 flights/year)*	0	9 *(1125 flights/year)*	3 *(1350 flights/year)*	1 *(600 flights/year)*
8-18	33 *(21450 flights/year)*	2 *(3900 flights/year)*	4 *(10400 flights/year)*	18 *(5850 flights/year)*	1 *(975 flights/year)*	0
18-20	9 *(8550 flights/year)*	1 *(2850 flights/year)*	0	7 *(3325 flights/year)*	1 *(1425 flights/year)*	1 *(1900 flights/year)*
>20	4 *(4000 flights/year)*	0	0	0	0	1 *(2000 flights/year)*
Projections	Total Model Rockets flights	*62875 Flights*		Total High Power Rocket Flights	*21401 Flights*	
	Applying an 8.5% incident rate:	*5344 Incidents*		Applying an 8.5% incident rate:	*1819 Incidents*	
	Applying a 1 in 300 accident rate:	*18 Accidents*		Applying a 1 in 300 accident rate:	*6 Accidents*	

Given projected flight volumes, an estimate at the number of incidents was made…

The derived estimates (in italics) should be roughly doubled to account for all 135 sections…

Further extrapolation may be attempted to cover not only NAR but also TRA and CRA launches.

(See Analytica for further details)

Regardless, the Presidential goal to reduce incidents by an order of magnitude has been quantified…

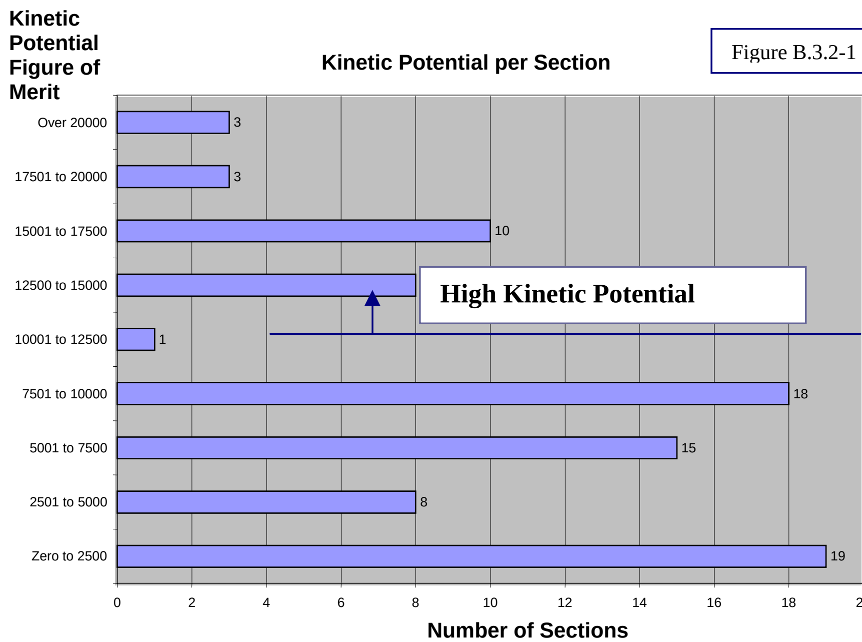
B.3.2 Analysis of Flight Volume – Treatment 2

Beyond preparing the survey data in to a useable form to be loaded in the Analytica modeling, a Figure of Merit was developed called ***Kinetic Potential*** which considers:

Kinetic Potential ~ *(Frequency of Flying)* ***and*** *(Quantity of Models Flown)* ***and*** {*segregates between (Model Rockets)* ***and*** *(HPR)*}

Kinetic Potential – By linearly combining the above variables, a *Kinetic Potential* figure of merit is obtained. Note that this relationship considers three classes of variable; thus the scores grow at cubic rates. Minor scoring differences were used comparing the Model Rockets versus the High Power rockets without regard for the actual mass. Sections possessing a high *Kinetic Potential* are the prolific flying groups launching considerable numbers of large vehicles frequently throughout the year. In a positive sense, possessing a high *Kinetic Potential* is good because it requires an active group with a broad participant base, two generally desirable characteristics for a Section. The inverse function of *Kinetic Potential* is also useful, as it provides insight to the number of occasions where things may go wrong as well as an estimate of the hazard potential. If a Section's *Kinetic Potential* score is known, necessary safety practices may be administered proactively and appropriately in a reasonable manner -- neither overbearing nor overly relaxed.

Figure B.3.2-1



B.4 Crowd Size & Composition [2]

Table B.4-1

Crowd Size & Composition

This section requests information about attendance at the launches that your club sanctions. To account for a variety of flying that may take place at your field, you may check off as many circles as apply. Note that each group size is broken into different ratios of fliers to spectators. Family and friends accompanying fliers should be counted as spectators, not fliers.

Please check all that apply to the flying events sanctioned by your club.

	Happens, but less than once per year	1-2 events per year	3-4 events per year	5-12 events per year	More than 12 events per year	Response Average
< 5 car groups, fliers < 50% of crowd	12% (2)	25% (4)	25% (4)	**31% (5)**	6% (1)	**2.94**
< 5 car groups, fliers > 50% of crowd	7% (2)	**38% (11)**	14% (4)	34% (10)	7% (2)	**2.97**
5-20 car groups, fliers < 50% of crowd	4% (1)	17% (4)	25% (6)	**42% (10)**	12% (3)	**3.42**
5-20 car groups, fliers > 50% of crowd	3% (1)	15% (6)	10% (4)	**56% (22)**	15% (6)	**3.67**
21-50 car groups, fliers > 75% of crowd	4% (1)	25% (6)	4% (1)	**46% (11)**	21% (5)	**3.54**
21-50 car groups, 25% < fliers < 75% of crowd	7% (1)	21% (3)	**36% (5)**	**36% (5)**	0% (0)	**3.00**
21-50 car groups, fliers < 25% of crowd	0% (0)	**60% (3)**	20% (1)	20% (1)	0% (0)	**2.60**
50 car groups, fliers > 75% of crowd (e.g., NSL, NARAM, LDRS)	0% (0)	**67% (2)**	33% (1)	0% (0)	0% (0)	**2.33**
> 50 car groups, 25% < fliers < 75% of crowd (e.g., TARC)	**60% (3)**	20% (1)	0% (0)	20% (1)	0% (0)	**1.80**
> 50 car groups, fliers < 25% of crowd (e.g., airshows, festivals)	**57% (4)**	43% (3)	0% (0)	0% (0)	0% (0)	**1.43**
					Total Respondents	**72**
					(skipped this question)	**5**

[2] Estimated activity is based on responses from 77 sections. The rate for the all 136 NAR sections may be approximated by doubling the appropriate figures.

B.4.1 Examination of Crowd Sizes - The responses were broken down to examine crowd size.

Figure B.4.1-1

Intuitively:

Larger target area + Most opportunities => Higher chance of an incident involving contact

Crowd Size	Happens, but less than once per year	1-2 events per year	3-5 events per year	5-12 events per year	More than 12 times per year	Tally
< 5 car groups	4	15	8	15	3	45
5-20 car groups	2	10	10	32	9	63
21-50 car groups	2	12	7	17	5	43
> 50 car groups	7	6	1	1	0	15
Tally	15	43	26	65	17	166

Larger launches occur on an infrequent basis

History suggests these activities receive sufficient upfront planning and support from the local, regional and national levels

Relatively broad range of launches

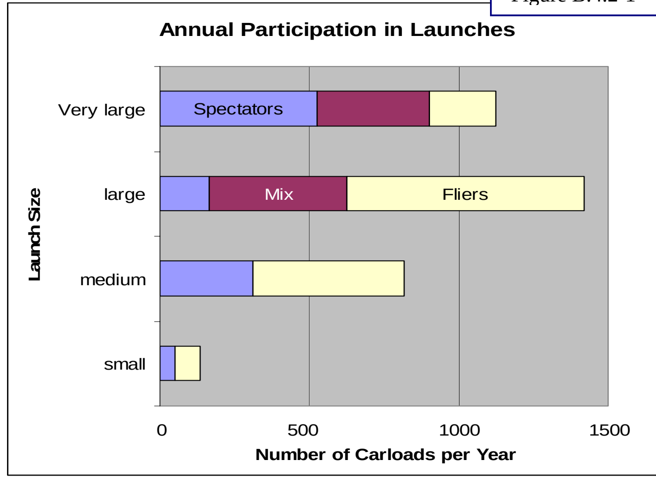
A single set of site rules can not be expected to adequately address all needs – A range of guides is appropriate.

Event organizers need to consider what makes sense for their particular activity in adopting these guidelines.

B.4.2 Crowd Composition - The responses were broken down to examine crowd composition and are presented below, along with some discussion.

Small Car Groups - Provides a *smaller target density* in terms of absolute vehicular square footage. *Spectators should* be able to *receive excellent communications from experienced fliers* on the proper conduct to assure personal safety.

Figure B.4.2-1



Medium Car Groups - Spectators should still receive good communications from experienced fliers on the proper conduct to assure personal safety. However, the increased number of vehicles, larger prep areas, (overall larger targets) raises the probabilities of being over-flown and possibly struck.

Large Car Groups - Spectators should still should be able to receive good communications from experienced fliers on the proper conduct to assure personal safety. Broadcast equipment (i.e. PA) becomes a necessity. However, the increased number of vehicles, larger prep areas, (overall larger targets) brings about the highest target area and vulnerability to over-flights and incoming rockets. Serious consideration should be given to safety issues in planning for parking, prep locations, wind conditions and outbound flight corridors.

Very Large Car Groups - Clearly significant (vehicular) target sizes involved, few prep areas, greatest number of wondering spectators to contend with. Additional launch announcers & PA would be very appropriate to educate the spectators on what to do (coordinate with the event announcer). Fewer fliers available to manage crowd control – Coordination with event security may be necessary.

From the numbers – A summary

Assumption #1:

a) Typical car size of 10'x15' and

b) Based on responses from 77 sections, approximately 3192 cars are at launches each year.

It can be estimated that a total of 478,800 sq. ft. of cars are in the launch vicinity each year.

Corollary: Parked vehicles are neither the brightest nor nimblest when air horn warnings are sounded

Assumption #2:

a) Each car group contains at least one and up to 15 participants

b) Based on responses from 77 sections and 3193 cars groups per launch, that between 3192 to 47,780 individuals (9579 on average) attend launches each year.

Discussion – This data should hold well for the majority of section launches. Clubs involved with air festival launching clearly typically encounter crowd sizes orders of magnitude higher, plus higher value targets, etc.

Figure B.4.2-1

B.4.3 Risk Exposure – By assigning relative weighting factors to *(crowd sizes)* ***and*** *(launch frequency)*, the *Risk Exposure* facing an individual Section on an annual basis was determined. Weighting factors were assigned linearly. Inspection of the graph to the right indicates that the allocated weighting factors are reasonable in terms of resolution and total range – neither too bunched or spread too thin. The *Risk Exposure* estimated here for each Section is a figure of merit to compare sections to each other. A Section's Risk Exposure may be viewed from two perspectives. In terms of outreach, education, and general sport flying enjoyment, a higher Risk Exposure score is desired. This means that a Section's activities are reaching a wide audience. The inverse function of *Risk Exposure* is also useful. By knowing a Section's *Risk Exposure* score, necessary safety practices may be administered proactively and appropriately in a reasonable manner -- neither overbearing nor overly relaxed.

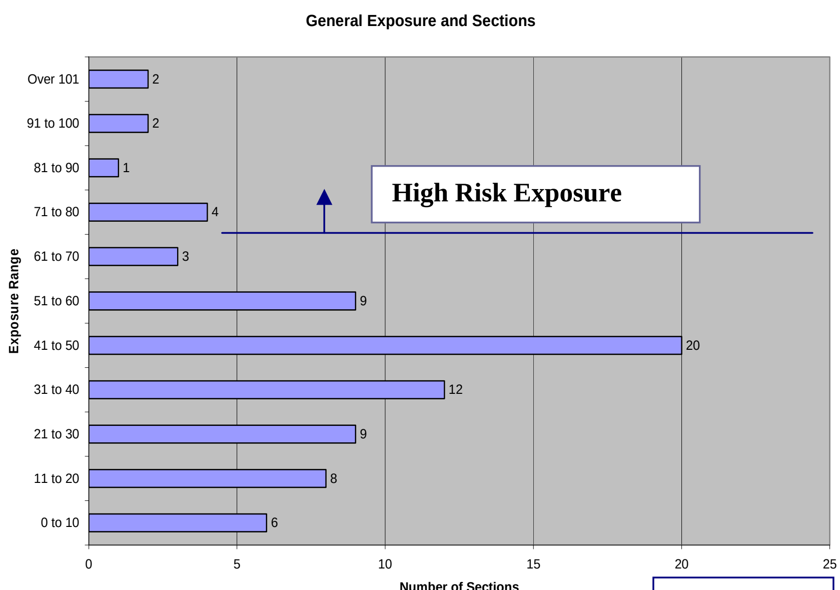


Figure B.4.3-1

B.5.1 Effectiveness of Various Safety Measures,

B.5.2 Applying Safety Measures at Your Club,

B.5.3 Additional Safety Measures

B.5.4 Actual Worse Case Scenarios

Pertinent results from this section of the survey are found in Section 2.1 of the main report. The following provides additional materials.

B.5.5 Safety Responsibility and Management Style[3]

Table B.5.5-1

Rank the following five groups by the degree of responsibility they should bear in assuring the safety of hobby rocketry. Assign "1" to the group that should bear the most responsibility, "5" to the group that should bear the least responsibility, etc.

	1	2	3	4	5	Response Average
Local clubs	37% (26)	**42% (30)**	10% (7)	7% (5)	4% (3)	**2.00**
Vendors of kits and motors	10% (7)	13% (9)	25% (18)	**31% (22)**	21% (15)	**3.41**
National headquarters	7% (5)	11% (8)	**32% (23)**	27% (19)	23% (16)	**3.46**
Individual spectators	10% (7)	10% (7)	20% (14)	24% (17)	**37% (26)**	**3.68**
Individual fliers	**79% (56)**	11% (8)	1% (1)	1% (1)	7% (5)	**1.46**
					Total Respondents	**71**
					(skipped this question)	**6**

b **c** **a**

Three areas stand out:

a) The number of participants that felt the individual fliers was the least responsible for assuring the safety of hobby rocketry appears surprisingly high. However, the overall number who made such a determination is within standard error; they may have merely been confused about the direction of the scale.

b) Defense in Depth[4] – It is possible that the majority of the survey participants believe that safety assurance is the responsibility of either the 1) the local clubs or 2) the individual fliers. However, establishing a synergistic safety program which compliments the abilities of the club *and* the flier by providing a defense in depth appears to be practiced by many Sections.

---

[3] Estimated annual activity is based on responses from 75 sections.

[4] Defense in depth is the proposition that multiple layers of security are better than a single protection mechanism. http://en.wikipedia.org/wiki/Defense_in_depth

c) Spectator Proofing – The number of participants who feels that the spectators bears the least responsibilities to assuring safety is noteworthy. The challenge therefore is for the club and fliers to keep spectators out of harms way through suitable crowd control, flight corridor and landing zone management. However, (the lack of) proper spectator action during “heads up” calls was expressed as a concern in several of the essay responses and requires attention.

B.5.6 Safety Layers - The Sections participating in the survey were asked to individually rate the effectiveness and ease of implementing 18 candidate safety measures. We mentioned previously in this Appendix and throughout the report the importance of a Section tailoring specific safety details to suit the specific needs of the pertinent launch event.

Regardless of the applicability and effectiveness of the individual safety methods, we felt it would be interesting to determine how many of the sections are already using the proposed safety measures. This “Benefit Function” can give policy makers and insurance underwriters a partial sense of a section's preparedness in the overarching goal to reduce or eliminate accidents. Some of the proposed measures were admittedly unachievable (i.e. insurance premiums dependent upon accident history). Follow up studies should assess if those sections implementing a greater number of safety measures do experience lower accident and close call rates

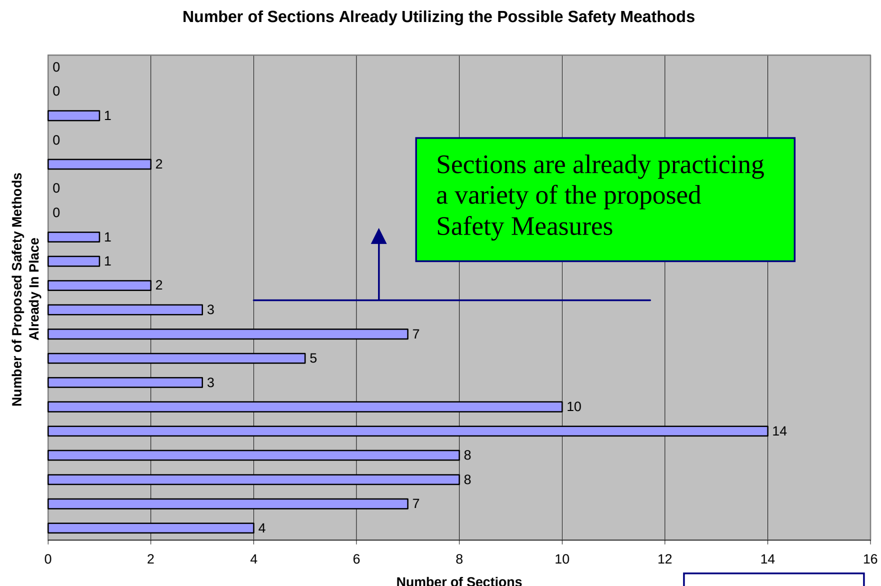


Figure B.5.6-1

B.6 Demographics

B.6.1 - Participation by Regions [5]

On this question, the survey participants were asked simply,

"Where do you live?"

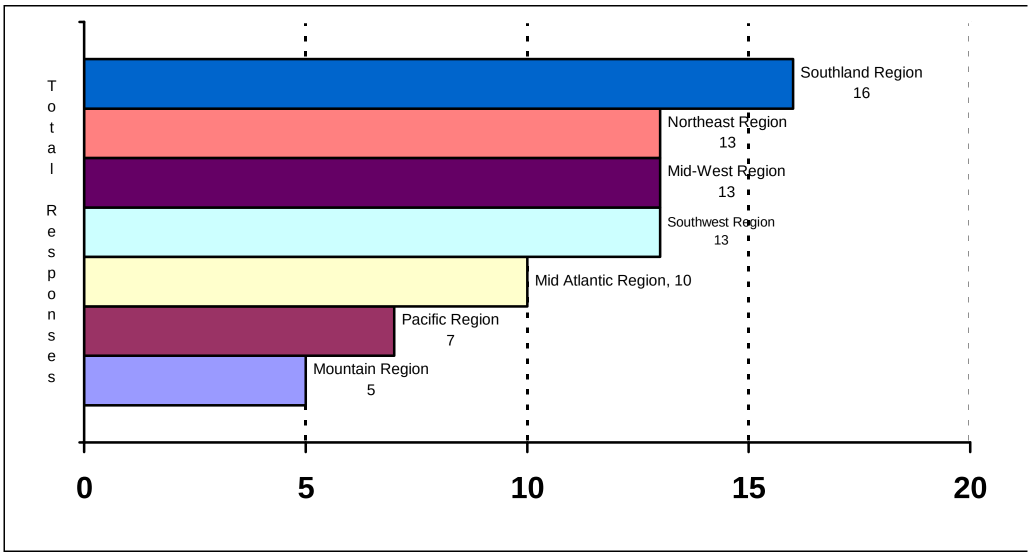


Figure B.6.1-1

B.6.2 - Structure & Guidelines

Everyone has different views on how safety issues should be managed. Some prefer that specific rules and procedures be established and uniformly applied to all clubs and all fliers (e.g., all launch guides shall be angled 10 degrees away from crowd, all rockets shall be weighed before launch). Others prefer that more general safety guidelines or goals be articulated (e.g., no over flight of crowds, no underpowered configurations), with local clubs and individual fliers being responsible for implementing them.

"What is closest to your view?"

The results (Table B.6.2-1) were then correlated with the participant's region.

[5] Note – The survey failed to include a selection button for the Mid-West Region. We believe there were between 8 to 13 participants from this region. The estimate of 13 participants is based on the number of participants that "skipped" this question. However, throughout the other parts of the survey, the number of participants "skipping" those questions was most often 5.

Table B.6.2-1

	Total	Mountain	Pacific	Mid Atlantic	Midwest	Northeast	Southwest	Southland
I prefer specific safety rules prescribing launch site setup and detailed safety procedures for prepping, inspection, and launch	8 (11.3%)	2	0	1	2	2	0	1
I prefer something in between.	**47 (66.2%)**	**3**	**5**	**8**	**4**	**10**	**8**	**9**
I prefer a less formal arrangement, leaving it largely up to fliers themselves to learn and use safe practices	16 (22.5%)	0	1	1	2	1	5	6

B.6.3 - Survey Participants - Flier Experience Tenure

In this question, we asked the participants to select the number of years they have been involved in rocketry. The results (Table B.6.3-1) were then correlated with the participant's region.

Table B.6.3-1

How many years have you been involved in rocketry?	Total	Mountain	Pacific	Mid Atlantic	Midwest	Northeast	Southwest	Southland
0 to 2	0 (0%)	0	0	0	0	0	0	0
2 to 4	6 (8.3%)	0	0	1	0	2	1	2
4 to 8	12 (16.7%)	0	1	1	1	2	2	4
8 to 15	16 (22.2%)	1	2	2	3	5	1	2
More than 15	38 (52.8%)	4	4	5	4	4	9	8

Inspection of the responses clearly indicate that the majority of participants qualify as "senior level hobby fliers" This bodes well as one would expect to receive more contributions representative of actual experience, especially in the open ended survey questions.

The survey did not inquire as to the regular occupations of the participants – Beyond having a common interest in hobby rocketry, knowing the membership's skills inventory would help recruit individuals suited for Safety assignments based on their professional occupations. This may warrant follow up at a later date.

B.7 Summary

A survey was prepared and administered to assess the "incidents occurring on NAR ranges to support recommendations to the NAR Board what action steps, if any, are needed to reduce their occurrence by (hopefully) a couple orders of magnitude."

Also, in response to a request from the insurance industry, the survey was designed to help us understand the locations of various launches, the makeup of the individuals attending the activity (members or observers) and the risk exposures for the sites.

Furthermore, the survey sought to ascertain the expected launch volume and target sizes (spectators and property) during NAR sanctioned launches in order to properly inform a risk analysis.

The survey went on to explore various aspects of safe launch practices used across the nation.

Finally, the survey produced various Figures of Merit for each section in order to allow a trained observer to quickly recognize the amount of risk facing a particular section. Once this is known, Safety measures may be applied proactively in an appropriate amount. The three Figures of Merit include:

Kinetic Potential – Directly proportional to the product of launch volume and rocket size.

Risk Exposure – Directly proportional to the product of spectator number & vehicles.

Safety Layers – A summation of the number of proposed safety methods already in use by a section.

Figure B.7-1

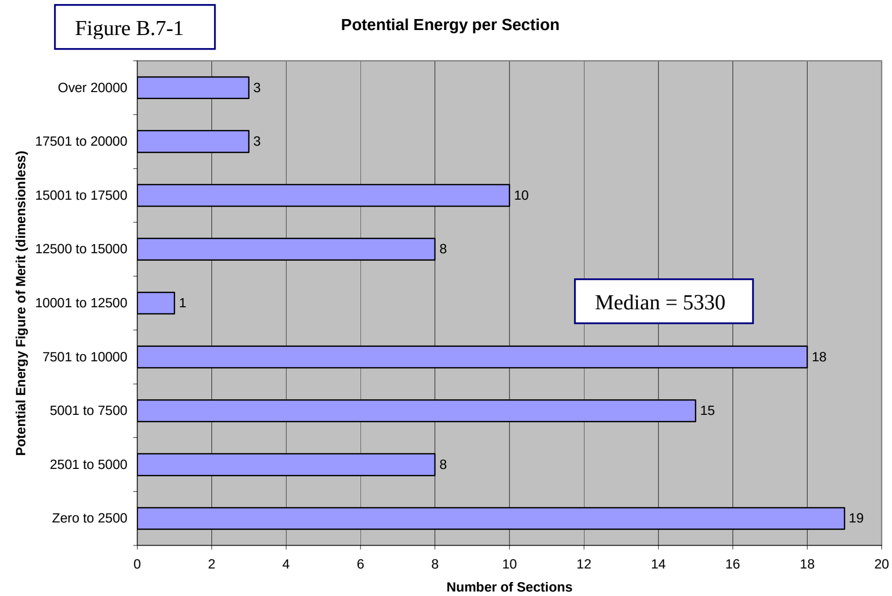


Figure B.7-2

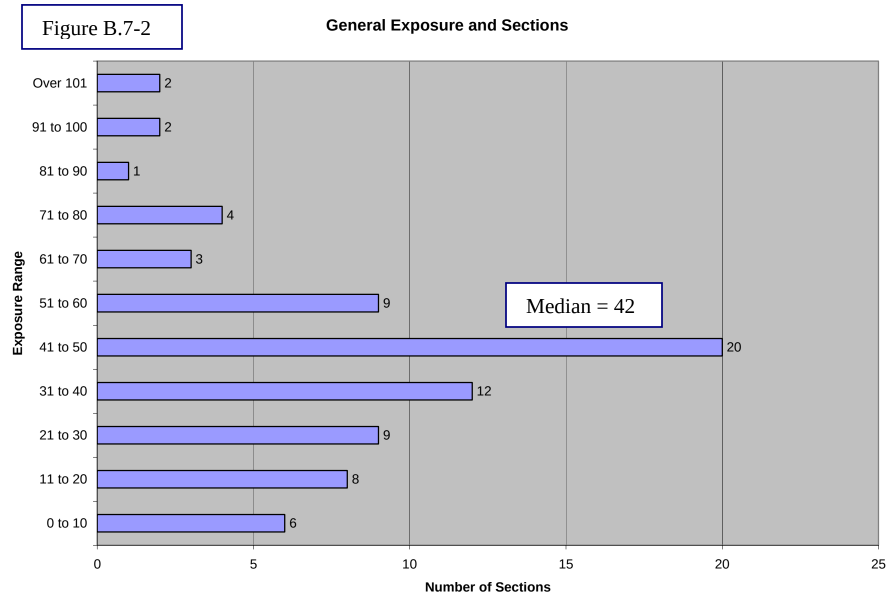
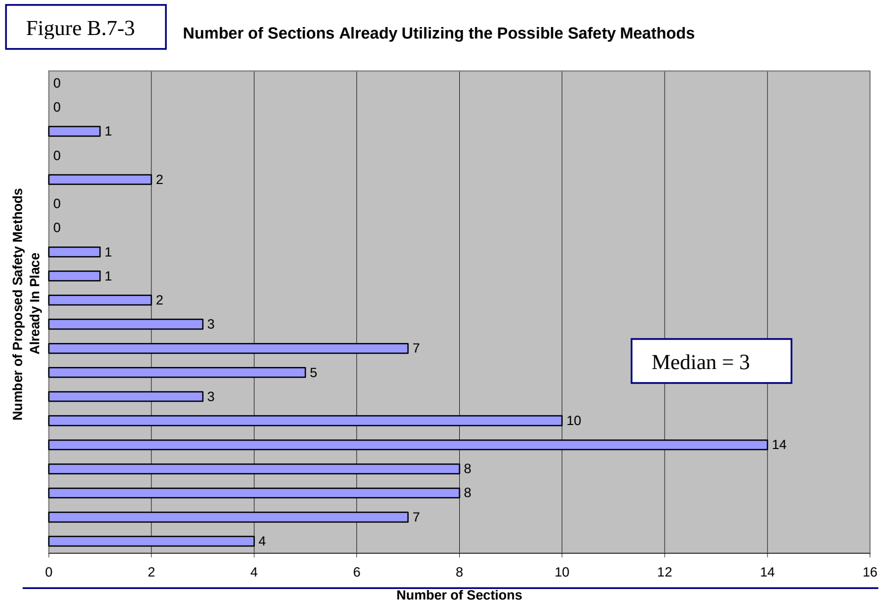


Figure B.7-3



The three Figures Of Merit for each section are summarized in Table B.7-1 which provided the actual score and the score normalized against the median value (i.e. values greater than 1 indicates higher than average). From a safety perspective, the *Kinetic Potential* and *Risk Exposure* reflect hazard functions which are offset by *Defensive Layers*. While a unifying relationship between these three Figures Of Merit hasn't been established, it is now possible to make a general assessment of the risk a Section is carrying.

Table B.7-1

	Kinetic Potential		Risk Exposure		Defensive Layers	
Section	Gross Score	Normalized Against Median Value	Gross Score	Normalized Against Median Value	Gross Score	Normalized Against Median Value
1	1250	0.23	52	1.24	6	2.00
2	3528	0.66	42	1.00	12	4.00
3	8450	1.59	52	1.24	4	1.33
4	16250	3.05	44	1.05	8	2.67
5	16000	3.00	36	0.86	3	1.00
6	5260	0.99	36	0.86	11	3.67
7	3500	0.66	12	0.29	3	1.00
8	1800	0.34	28	0.67	6	2.00
9	10000	1.88	66	1.57	0	0.00
10	5200	0.98	24	0.57	0	0.00
11	17000	3.19	48	1.14	2	0.67
12	3500	0.66	48	1.14	14	4.67
13	8450	1.59	138	3.29	5	1.67
14	7050	1.32	52	1.24	3	1.00
15	800	0.15	12	0.29	4	1.33
16	8450	1.59	37	0.88	1	0.33
17	1400	0.26	20	0.48	7	2.33
18	16000	3.00	44	1.05	4	1.33
19	7400	1.39	42	1.00	4	1.33
20	5200	0.98	28	0.67	2	0.67
21	3500	0.66	62	1.48	6	2.00
22	3500	0.66	52	1.24	4	1.33
23	5200	0.98	56	1.33	0	0.00
24	200	0.04	2	0.05	3	1.00
25	4200	0.79	84	2.00	3	1.00
26	8450	1.59	94	2.24	1	0.33
27	5200	0.98	54	1.29	4	1.33
28	2100	0.39	36	0.86	0	0.00
29	2500	0.47	28	0.67	3	1.00
30	16000	3.00	48	1.14	9	3.00
31	0	0.00	0	0.00	0	0.00
32	5260	0.99	72	1.71	3	1.00
33	5260	0.99	36	0.86	4	1.33
34	0	0.00	0	0.00	0	0.00
35	16000	3.00	48	1.14	7	2.33
36	8450	1.59	95	2.26	4	1.33
37	28250	5.30	372	8.86	16	5.33
38	7900	1.48	42	1.00	1	0.33
39	1400	0.26	0	0.00	1	0.33
40	17400	3.26	58	1.38	1	0.33

Table B.7-1

	Kinetic Potential		Risk Exposure		Defensive Layers	
Section	Gross Score	Normalized Against Median Value	Gross Score	Normalized Against Median Value	Gross Score	Normalized Against Median Value
41	19400	3.64	72	1.71		
42	0	0.00	0	0.00	0	0.00
43	5260	0.99	24	0.57	1	0.33
44	2800	0.53	18	0.43	4	1.33
45	15800	2.96	48	1.14	3	1.00
46	14300	2.68	49	1.17	3	1.00
47	18850	3.54	58	1.38	7	2.33
48	5200	0.98	26	0.62	2	0.67
49	2300	0.43	26	0.62	2	0.67
50	2100	0.39	22	0.52	6	2.00
51	25800	4.84	70	1.67	2	0.67
52	19200	3.60	44	1.05	7	2.33
53	8450	1.59	68	1.62	7	2.33
54	5260	0.99	18	0.43	7	2.33
55	8450	1.59	48	1.14	8	2.67
56	8450	1.59	45	1.07	3	1.00
57	4600	0.86	31	0.74	0	0.00
58	16000	3.00	41	0.98	6	2.00
59	8450	1.59	12	0.29	0	0.00
60	27000	5.07	72	1.71	2	0.67
61	5260	0.99	48	1.14	3	1.00
62	200	0.04	0	0.00	14	4.67
63	9560	1.79	55	1.31	0	0.00
64	1400	0.26	16	0.38	2	0.67
65	10850	2.04	80	1.90	2	0.67
66	5200	0.98	24	0.57	4	1.33
67	8450	1.59	36	0.86	3	1.00
68	5400	1.01	32	0.76	1	0.33
69	2100	0.39	48	1.14	5	1.67
70	9850	1.85	46	1.10	11	3.67
71	2100	0.39	36	0.86	3	1.00
72	1400	0.26	12	0.29	1	0.33
73	6600	1.24	36	0.86	0	0.00
74	8450	1.59	36	0.86	5	1.67
75	7250	1.36	42	1.00	9	3.00
76	6400	1.20	38	0.90	3	1.00
77	2000	0.38	48	1.14	6	2.00

Appendix C

Failure Rates in Model Rocketry: Towards a Statistical Model of Safety

Ted Cochran[1], NAR 69921

Summary

This report describes a systematic effort to determine the actual failure rate of model rocket launches as the first step in a larger undertaking to develop a statistical model to improve rocketry safety. MASA's (NAR 576) flight log database of over 6000 rocket launches over an eight-year period was rigorously processed to determine the incidence of eight types of failures as a function of total installed impulse and rocket complexity. The results were cross-validated in a number of ways, including against summary statistics from SARA's (NAR 545) independent database of over 4500 flights over a five-year period, and against a contest manager database of the results of 9,622 comparable flights flown over eight years. The best estimate of the overall failure rate for simple rockets flown by MASA was determined to be 7.7%; complex (staged and/or clustered) rockets failed 17.4% of the time--more than twice as often. Contest rocket failures were significantly higher than sport rocket failures. Separations were the most common cause of failure for simple rocket flights, accounting for about a third of all failures. However, more than half of the failures of complex rockets were lawn darts: 10% of all complex rocket flights ended in this unfortunate and potentially dangerous way.

Failure rates as a function of rocket complexity, installed impulse, cause of failure and year of flight are presented and discussed in detail, as are the limitations of these data for a variety of applications. Finally, the potential use of these failure data in the context of a statistical model of safety that could be customized on a section-by-section basis is described, and an implementation approach that uses failure statistics in combination with flight modeling and risk severity is outlined.

"What are the chances that this rocket will fly well?" "How often do motors CATO?" "What are the odds that the rocket will prang into the prep area?" If answers to questions such as these were known, or could be estimated with precision, rocketry enthusiasts could develop a better set of safety practices that reflect experience, allowing us to address potential hazards without causing unnecessary expense or inconvenience. If the answers are guessed at, hazards may go undetected and opportunities for prevention may be missed.

---

[1] The opinions in this paper are those of the author, and may not reflect those of NAR.

Objective

In order to carry out formal risk analyses, the availability of historical failure data is essential. Although model rocketry is undoubtedly "one of the safest activities that can be conducted outdoors", it is surprisingly difficult to determine exactly what exactly that means, at least in quantitative terms, because well-characterized (and therefore statistically reliable) failure data are apparently unavailable. I therefore undertook to develop a statistical estimate of the incidence of failures in model rocketry.

The goal of the study was to determine the incidence of a variety of failures as a function of the size (total installed impulse at launch) of the rocket and its complexity, with sufficient rigor to support future safety studies and risk modeling efforts. In addition, I attempted to determine whether significant differences in failure incidence exist between NAR sections, in order to determine the extent to which the data from this study could be generalized.

Approach

Identifying records

Ideally, in order to determine failure incidence, a large number of flights would be launched of rockets of varying characteristics, and the results carefully recorded. In the safety profession, such contemporaneous reporting of incident data often lies at the core of an organization's operating practices. In order to capture low-incidence events, large numbers of baseline events (thousands, in this case) are necessary. Clearly, conducting such a study is beyond the financial resources of one person, or even of the NAR itself.

Fortunately, retrospective data already exist in the form of launch logs, assuming that the data in the logs can be determined to be reasonably accurate, complete, and representative. For a launch log to be usable, data need to be available on the installed motors, and reliable data on the outcome of each flight--or at least, of the unsuccessful ones--is important. As will be seen, contest records are helpful for validation of primary data but, alas, insufficient, because notations like "UNS" are too vague[2]. Further, for the data to be representative, it is important that the logs reflect the population of fliers: Contest logs reflect a more experienced sample of fliers, and a higher-performance sample of rockets, than is typical. Personal flight logs also probably reflect systematic bias (people who keep flight logs may be more skilled and/or more deliberate than the average rocket enthusiast) and are therefore unsuitable for this task. Launch logs are therefore needed in which every flight is recorded for a large group of fliers, under a variety of launch conditions, and with consistent criteria for success or failure.

My own NAR section, MASA, has kept consistent launch logs almost since its inception in 1998, thanks to our founders' culture and the zeal of webmaster and founding member Alan Estenson[3]. Nearly every flight[4] at a MASA launch since late 1998 is represented. In total, 6169 flights flown at over 60 launches conducted over nearly 7 years have been recorded,

[2] However, some notations, such as "SEP" are useful in partial validation studies, and "UNS" notations are helpful in assessing overall failure rates, as will become clear.

[3] Huge thanks to Alan!

[4] Exceptions include flights for which flight cards were missing and a launch or two for which all of the flight cards were missing.

representing a total impulse of over 117,000 Newton seconds (see Table 1). Alan has estimated that the approximate retail value of the motors burned is over $25,000.

Since it's always possible that MASA members are different in some systematic way from the general population of rocketry enthusiasts, I sought to validate the estimates that resulted from this study using data from other sources. To do this, I sought out samples from other clubs for validation purposes. I conducted an informal survey of NAR section sites, looking for suitable launch logs, and I also asked for pointers on internet forums. Somewhat surprisingly (to this

	1998	1999	2000	2001	2002	2003	2004	2005
Launches	2	8	7	9	11	13	9	4
Flights	262	780	1040	963	1168	866	799	291
Impulse	6307	8855	26023	22749	21542	17195	8689	5704

Table 1. Launch logs incorporated into this study.

statistician, at least), very few organizations appear to record data in sufficient detail[5]. However, I was able to locate enough data from other NAR sections to validate the primary results.

There remain a number of ways that the analysis reported below may incorporate estimation errors. These are discussed in the discussion section of this paper.

Processing data

MASA launch logs are available on line at http://www.mn-rocketry.net/masa/lreports.htm. They all[6] have the same format, shown in Figure 1 below.

MASA launch, Blaine, July 27, 2002					Total #	Total
#	Name	Rocket	Motor(s)	Comment	Motors	Impulse
1	Alan Estenson	Xactron Projectile	B6-4	first flight	1	5
2	John Kutzke	Snake	1/4A3-3t	first flight	1	0.63
3	Kirsten Hoyme	Polaris	B6-2	first flight	1	5
4	Ed Eastman	Nike Smoke	B6-4		1	5
5	Stuart Lenz	scratchbuilt	A8-3	first flight	1	2.5
6	Alan Estenson	EZC6-5	B4-4	tangled chute	1	5
7	Mike Kutzke	Dragon	B6-4		1	5
8	Derek Lynch	Apollo	B6-4	2 chutes	1	5
9	Alissa Hoyme	Nemesis	A8-3	first flight	1	2.5
10	Micaah Rostrom	Starhawk	A6-4		1	2.5
11	Travis Eischen	Viper	A8-3		1	2.5
12	Chad Fernandez	Skywinder	C6-3		1	9
13	Dave Lynch	Beemer	D12-3	scratchbuilt	1	17
14	Derek Lynch	Comanche-3	C6-0; C6-5	1st flight, core sample	2	18
15	Stuart Lenz	SR-98	B6-4	2nd flight	1	5
16	Dan Nolen	Venom	A8-3	Bronze parachute flight - 11 sec	1	2.5
17	Mark Thell	Astron Omega	D12-0; B6-6	clone of old Estes kit	2	22
18	David Whitaker	SR-71	C6-5	2nd flight	1	9
19	John Carlson	WAC Corporal	B6-6		1	5
20	Alan Estenson	Fat Boy	C5-3	first flight	1	9.5
21	Kirsten Hoyme	WAC Corporal	D12-7	first flight	1	17
22	Chad Fernandez	Banshee	C6-7		1	9
23	Grant Hermes	Gemini DC	B6-4	first flight	1	5
24	Craig Hansen	Pip Squeak	A8-3	first flight	1	2.5
25	Dave Lynch	Beemer	D12-3	core sample	1	17
26	Tom Lawell	Fat Boy	C6-5	wadded chute	1	9
27	Ben Oelschlaeger	Bandit	B6-6	good flight	1	5
28	Nick Oelschlaeger	Alpha 3	B6-6		1	5
29	Alissa Hoyme	Gemini DC	B6-4		1	5
30	David Whitaker	Astra	B6-6	Bronze streamer flight - separation	1	5
31	Mike Kutzke	Harpoon	D12-3		1	17
32	Ellison Lenz	Fat Boy	B6-2	drag race	1	5
33	Ellison Lenz	Mini Fat Boy	A8-3	drag race	1	2.5
34	Ellison Lenz	Super Mini Fat Boy	A10-3t	drag race	1	2.5
35	Chad Fernandez	Astrocam	C6-7	first flight	1	9
36	Stuart Lenz	Red White & Blue	D12-3	Bronze D flight - separation	1	17
37	Dan Nolen	Viking	B6-4	Bronze parachute flight - 94 seconds!	1	5

5

6 ses of

Figure 1. Typical MASA flight log.

Flights

Since the logs were designed more to record activity than to record safety data, the appropriate safety statistics had to be extracted.[7] In order to ensure that the data were consistently analyzed, a formal data processing protocol was developed: For the purposes of this study, each log was subjected to the same procedures to identify relevant information, categorize flights, and extract outcome data. For the most part, this data processing was done by hand[8].

For each flight log,

- All complex flight attempts (rockets with more than one motor) were identified and segregated so that the statistics for those flights could be calculated separately. MASA logs do not specifically separate complex flights, but since logs separately list motors installed, and the number of motors burned, the logs can be filtered by hand to separate complex flight attempts.
- All flights were categorized (from MicroMaxx through "H") by installed impulse at attempted ignition. This step involved calculating installed impulse for complex flights based on the list of installed motors.

The result was a flight summary table for each launch, such as that shown below.

year		MM	1/4A	1/2A	A	B	C	D	E	F	G	H	Flights	Engines	Impulse
2/23/2002	simple	1	1	2	6	12	16	12					50	57	466
	complex						2	1					3		

Figure 2. Flight statistics for a single launch.

Failures

The next step was to identify all of the failures. MASA uses standard flight cards that include check boxes for the outcome for each flight, and additional space for LCO comments. These results are listed in the launch log for every flight[9]. Since the objective of this study was to develop the incidence of failures, it was important to define the events that "count" as a failure. The goal is to identify a relatively complete, relatively non-overlapping set of major failure descriptions.

Failure is defined here to be an unsafe (or potentially unsafe) event, that is, one that has the potential to damage property or cause injury. This is not necessarily the same as an outcome that is merely hard on the rocket. "Drag separation" and "hard landing," for example, were not included as unsafe events in this study[10]. Note also that unsafe events need only have the *potential* for damage; they were counted whether or not they resulted in any actual damage. In fact, there were no instances of property damage (excluding the rocket involved) or injury during any of these flights. There were several instances of significant failures (e.g., lawn darts

[7] The term currently in vogue for this activity is *data mining*.

[8] More accurately, it was done by manual manipulation (data conversion, abstraction, and sorting and filtering) of spreadsheets.

[9] Because some LCOs are more thorough than others, there is a concern that the failure data reported represent an underestimation; this issue is discussed in the discussion section of this report.

[10] Data on such events probably should be recorded in the future, if it can be done so reliably.

of G-powered rockets) that did not result in any damage to the rockets involved. Those events are nevertheless potentially unsafe.

The final step was to categorize the failures. Based on the flight card check boxes and free form comments, the following categories were used:

- **Unstable.** The rocket flies with at least part of the boost phase in a nose-down attitude. For the purposes of this study, based on the goal to characterize unsafe events, comments such as "kind of unstable" were *not* counted, nor were "horizontal", "cruise missile", or "coning" flights (unless they resulted in a crash; see below).
- **Lawn dart.** The rocket descends in ballistic flight with the nose cone still on. This category includes "No ejection" and a few "power prangs". Some rockets are designed to do this[11] and these flights were not counted. Boosters on two stage rockets also did this.
- **Separation.** The rocket descends in multiple parts with at least one not slowed by a recovery device. For the purposes of this study, the few flights with a comment of "stripped chute" were included here. The unplanned ejection of motor casings should also have been collected here, but MASA LCOs almost never recorded them as outcomes.
- **Motor CATO.** The motor failures catastrophically at ignition or during boost. The nature of the CATO (spit nozzle, forward closure failure, blow by, etc.) was sometimes recorded, but not consistently.
- **Core sample.** The rocket descends in ballistic flight, but with the nose cone off the rocket and acting as a (not very effective) streamer. These events typically have lower impact speeds, and higher surface areas at impact, than do lawn darts.
- **Motor unrestrained.** The motor exits the rocket at ignition or during boost (thankfully, this was rare).
- **Shred.** The rocket comes apart during ascent, other than by design[12].
- **No chute.** The rocket descends without a recovery device deployed, but is not ballistic. This category does not include chutes that were described as merely tangled, although it is likely that some LCOs write "no chute" in those circumstances. The rationale here is that if the LCO described the result as "No chute", it was potentially unsafe.

When more than one failure occurred during a flight (e.g., unstable flight leading to lawn dart), the most severe event was recorded. Sometimes it was clear that an event had occurred, but the nature of the event wasn't clear (e.g., a log entry such as "R.I.P."). These events were not included in this study. Other events that were *not* defined as unsafe for the purpose of this study include comments about delays (too long or too short) and motor performance (chuffs, "underpowered"), unless one of the unsafe outcomes listed above resulted.

---

[11] MASA has a long and glorious tradition of experimentation with powered stomp rockets. UFOs and badminton birdies were likewise excluded.

[12] For example, Estes' *Cato* and *Death Star* and Seattle Rocket Works' *MIRV Gryphon* are examples of rockets that are designed to separate into pieces during ascent.

It is important to note that this particular failure taxonomy was created retroactively, and resulted at least partly from the "culture" shared by MASA LCOs and the launch cards we've all used for years. An incident reporting system designed from the ground up would almost certainly incorporate a slightly different set of categories, and would also incorporate more rigorous reporting requirements.

It is also clear that the risk involved in these different failure modes differs, both in general and as a function of rocket size. For example, lawn darts are almost always potentially unsafe, but unstable Micromaxx rockets are rarely so, and the level of risk may range from "none" to "severe" for "No chute", depending on rocket size. For each failure event, the rocket complexity and total impulse were therefore recorded.

Because failures are relatively infrequent, the resulting matrix was sparsely populated (that is, there were many empty cells). Because it is difficult to perform reliable statistical analyses on sparse matrices, failures were aggregated across each calendar year[13]. The result was a failure summary table for each year, such as that shown below in Figure 3. Data extraction for the MASA logs required approximately 40 hours.

year			MM	1/4A	1/2A	A	B	C	D	E	F	G	H	N Fails	% of fail	% of flts
2002	simple	unstable				7	4	4	2	2				19	19%	1.8%
2002	simple	lawn dart					1	6	2					9	9%	0.9%
2002	simple	separation			1	4	17	13	4		1	2		42	43%	4.0%
2002	simple	motor CATO						2	1					3	3%	0.3%
2002	simple	Core sample				1	2	1	1		1			6	6%	0.6%
2002	simple	motor unrestrained														
2002	simple	shred														
2002	simple	no chute	1			4	3	5	4		1	1		19	19%	1.8%
			1		1	16	27	31	14	2	3	3		98		
			25%		5%	11%	9%	11%	11%	3%	5%	8%		9%		

year			MM	1/4A	1/2A	A	B	C	D	E	F	G	H			
2002	complex	unstable						1	2	1		1		5	5%	
2002	complex	lawn dart					1	3	4	1	2			11	11%	
2002	complex	separation						1			1			2	2%	
2002	complex	motor CATO														
2002	complex	Core sample						1	1			1		3	3%	
2002	complex	motor unrestrained														
2002	complex	shred														
2002	complex	no chute								1		1		2	2%	
							1	6	7	3	3	3		23		
							33%	21%	21%	10%	23%	43%		20%		
					1	16	28	37	21	5	6	6		120		
					5%	11%	9%	12%	13%	6%	8%	13%		10%		

Figure 3. Failure statistics for a single year.

Validation data

In order to help assess the extent to which MASA data is representative, a number of other sources of data were examined. These include contest data[14] and summaries of launch logs from SARA (Section 545)[15].

Contest Manager flight data was obtained for over 17,500 flights flown over an eight-year period. In order to identify a comparable event data base, contest data were filtered to remove flights involving rocket gliders, boost gliders, flex wing gliders, helicopters, and events for which impulse could not be determined (e.g., sport scale, open spot landing). The remaining 9,622 flights were sorted by impulse class and divided into three general categories: Simple

[13] In addition to convenience, aggregation by year ensures that any cyclical variation associated with climate is treated appropriately--a not insignificant factor when dealing with Minnesota launches.

[14] Thanks to Andy Eng for a partially-processed compilation of Contest Manager results.

[15] http://www.sararocketry.org/; special thanks to Jerry King for providing additional analyses of this data.

flights, cluster flights, and egg loft events. "Simple[16]" flights here are primarily for altitude and duration events, and included Super-roc and standard payload competitions.

Unsuccessful contest flights are coded as to the reason for the failure. For the purposes of this analysis, the codes that are directly comparable to MASA's are *SEP*, for separation, and *CAT*, for CATO. *NDP* is relatively comparable to "No chute"[17]. The *UNS* (unsafe) code is used for a variety of safety related problems, as is *SAF*. In actual use, these are often used instead of the more specific *LOP* (Loop), *NEJ* (no ejection), *SHR* (Shred), and *PRG* (Prang), which appeared relatively rarely in the contest results database. Contest RSOs are also, unlike sport range RSOs, much more vigilant about reporting motor ejections (*EJ*) than are sport range RSOs, so these failures are probably not directly comparable. *DQ* involves a variety of issues, which should not really involve safety issues, but which in practice often do. For example, failure to use a blast deflector may be coded as *DQ* instead of *SAF* or *UNS*. Finally, in egg lofting events, there is sometimes a tendency to "let the eggs decide" whether a flight was truly unsafe. Thus, the failure code *EGG* may also include flights that might be coded "No chute" on a sport range. These issues all make contest data failure modes difficult to compare directly to the flight logs maintained by sections. Nevertheless, some comparisons are worthwhile.

In order to develop the most comparable failure indices, contest data was categorized by unsafe flights (*UNS, LOP, NEJ, SHR, PRG*), with *CAT* and *SEP* outcomes segregated for some analyses and combined for others, as appropriate. These analyses will be presented in the next section.

Results

The results of the data mining exercise are presented below. First, flight statistics will be presented, followed by failure statistics.

Flight Rates

Of 6169 total flights by MASA assessed in this study, 518, or 8%, were of complex rockets (more than one motor in a staged and/or clustered configuration). The distribution of these flights by installed impulse is presented in Figure 4 below. As expected, complex flights had a higher impulse, on average, than simple flights--the typical complex flight uses two or three black powder motors.

To be reliable, incidence statistics must be based on a representative base of events. For example, safety statistics derived from MASA's flight logs would not be expected to be comparable to those derived from a club that flies a large number of J through M flights, even for rockets of the same impulse, because of the different experience levels of the members of those clubs.

[16] Because some contest events allow staged entries, this definition of "simple" is different than that used for MASA and SARA. There was no way to identify staged entries in the competition data base.

[17] This is especially true since contests involving helicopters and Flexwing gliders were removed from the database.

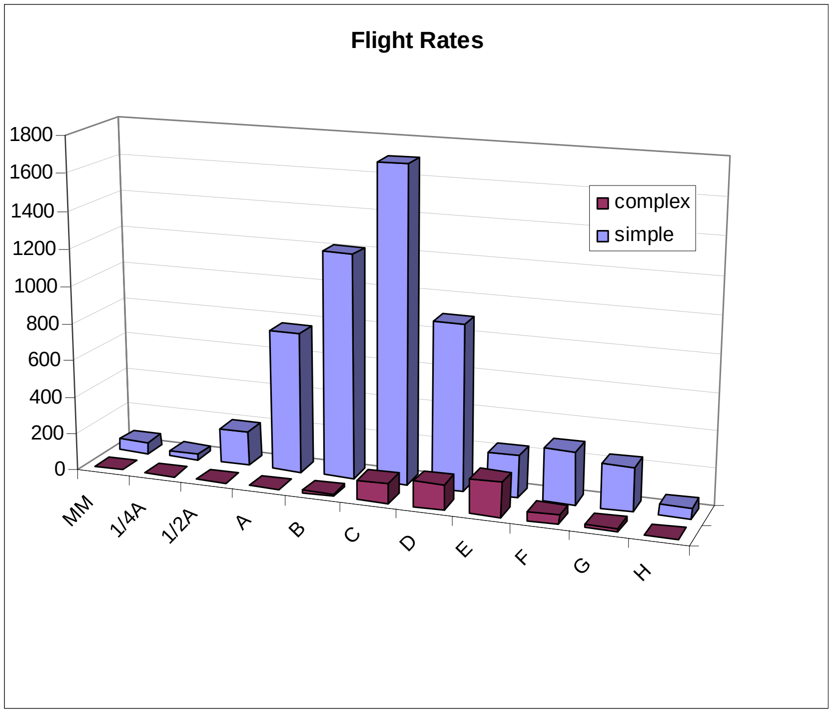


Figure 4. MASA's simple and complex rocket flights by total installed impulse.

How representative is MASA's flight distribution? It appears to be fairly typical. For example, it agrees within about five percent with the proportion of flights within each impulse class by the Southern Arizona Rocketry Association (SARA) over the past five years (4546 flights), as presented in Figure 5 below. MASA flew a somewhat higher proportion of complex rockets

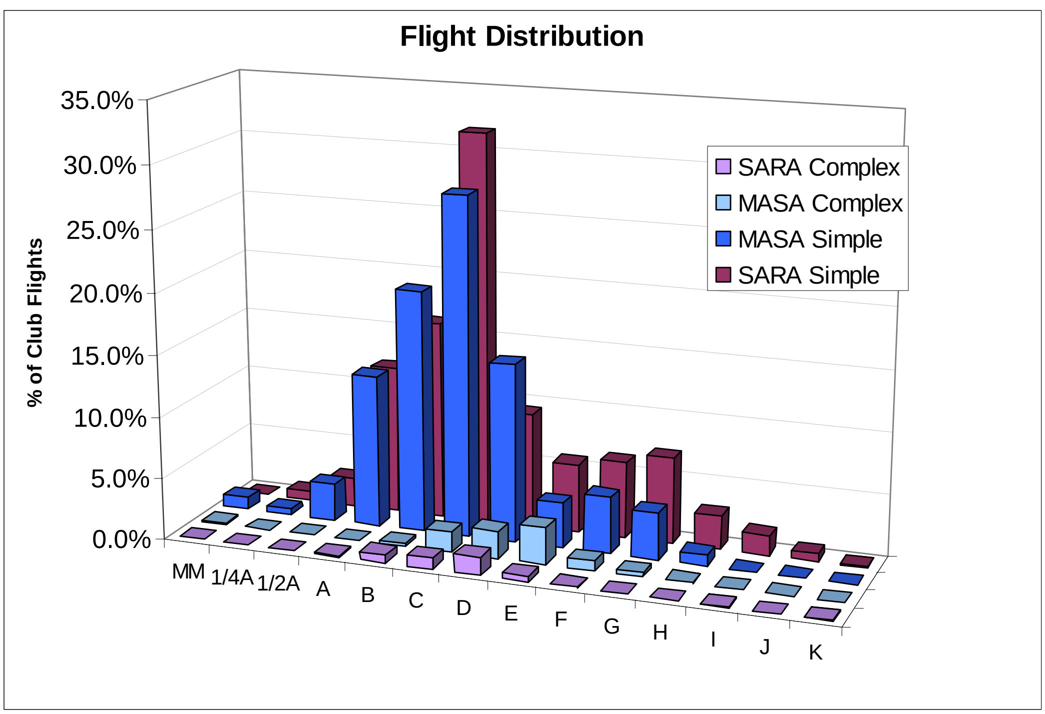


Figure 5. MASA (NAR 576) and SARA (NAR 545) Flight distributions compared.

(8% of flights vs. 4% of flights for SARA), and SARA flew a somewhat higher proportion of higher-impulse rockets (11.4% G and above, vs. 5.2% for MASA). Part of the reason for the difference in high power flights is due to MASA's inexperience in high power in its first years of existence, and the loss of its high power-capable field in early 2003. MASA members were thus prevented from flying high power rockets at MASA launches for about two years.

Contest flight rates (Figure 6) are less comparable. Contest flights tend to involve smaller rockets; higher impulse rockets are therefore under-represented.

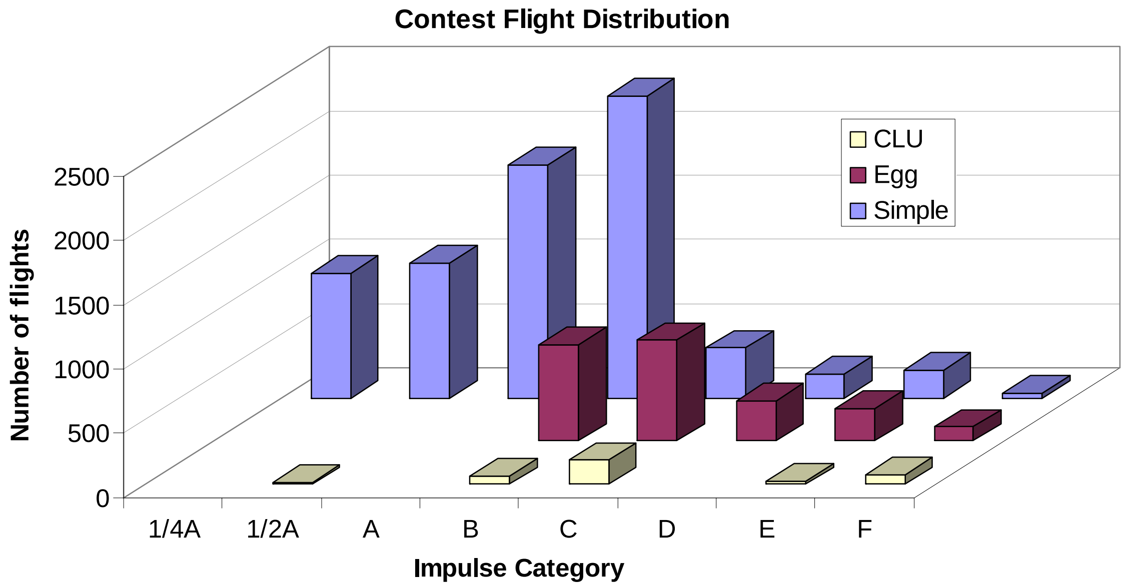


Figure 6. Contest rocket flight distribution

Clubs also go through fads, and MASA is no exception. The flight distributions broken out by year (Figure 7 and Figure 8) clearly show fluctuations from year to year, especially for complex rockets. MASA members flew a lot of two and three stage rockets in the summer of 2000, and a lot of MicroMaxx rockets in 2003. Overall, however, the data are more than stable enough to support a failure incidence analysis.

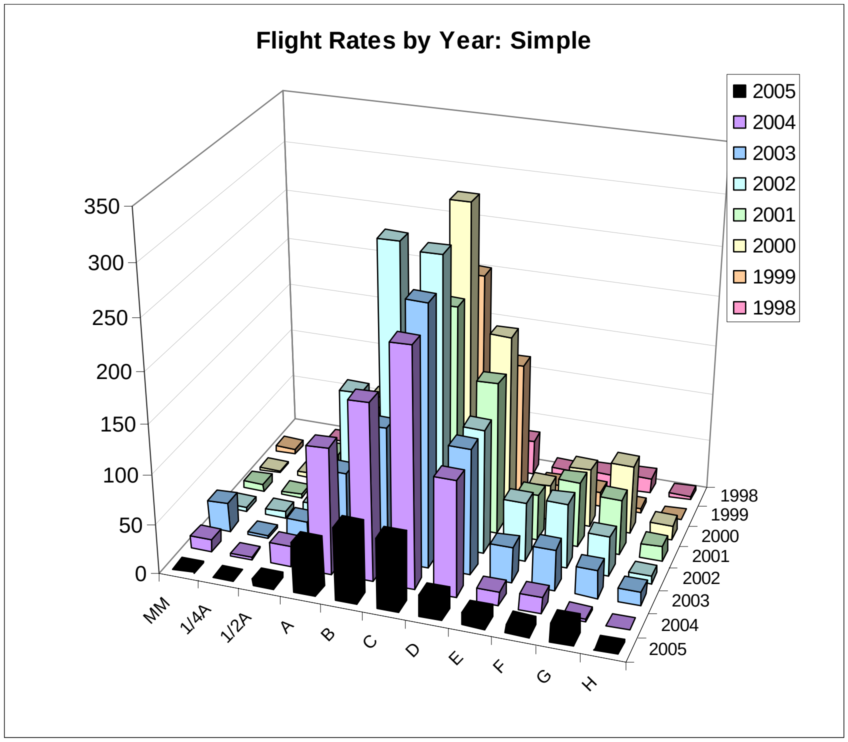


Figure 7. Simple MASA rocket flights by year and total installed impulse.

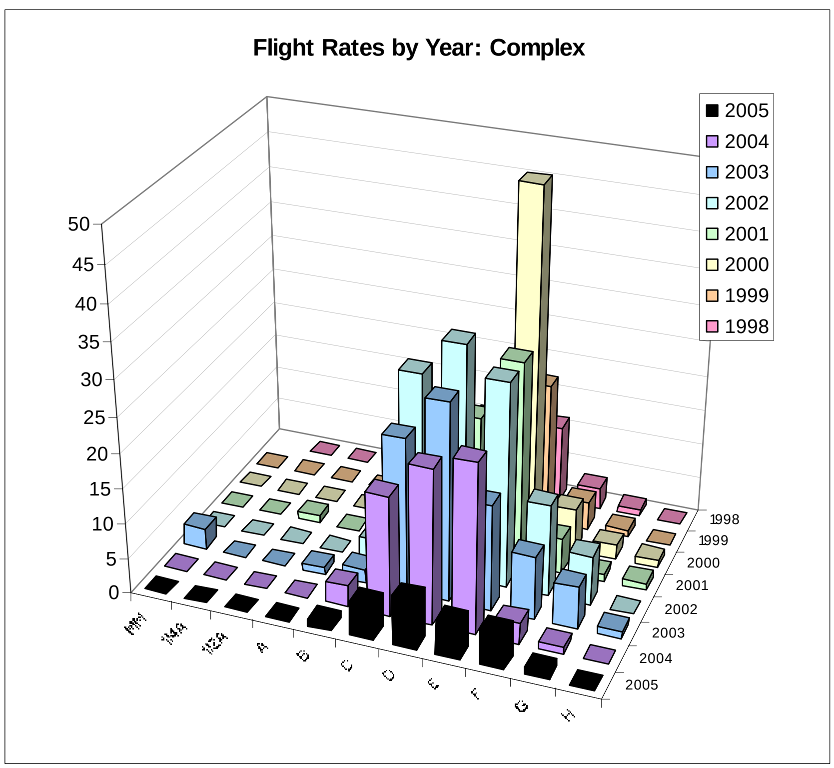


Figure 8. Complex MASA rocket flights by year and total installed impulse.

Failure Rates

The overall rate of failure for MASA rockets, as defined above, is 8.5% (523 failures in 6169 launch attempts). For simple one-stage, one motor rockets, the rate is 7.7%, and for clustered and/or staged rockets, the rate is 17.4%.

Aggregated MASA failure data categorized by impulse is presented in Figure 9. The data are presented as the rate of failure for all rockets of the same complexity in the same impulse class. For example, there were 107 C-impulse complex rocket flights flown since 1998, and 22 of them (21%) suffered failures. The failure rate is reliably higher for complex rockets than for simple rockets across the board.

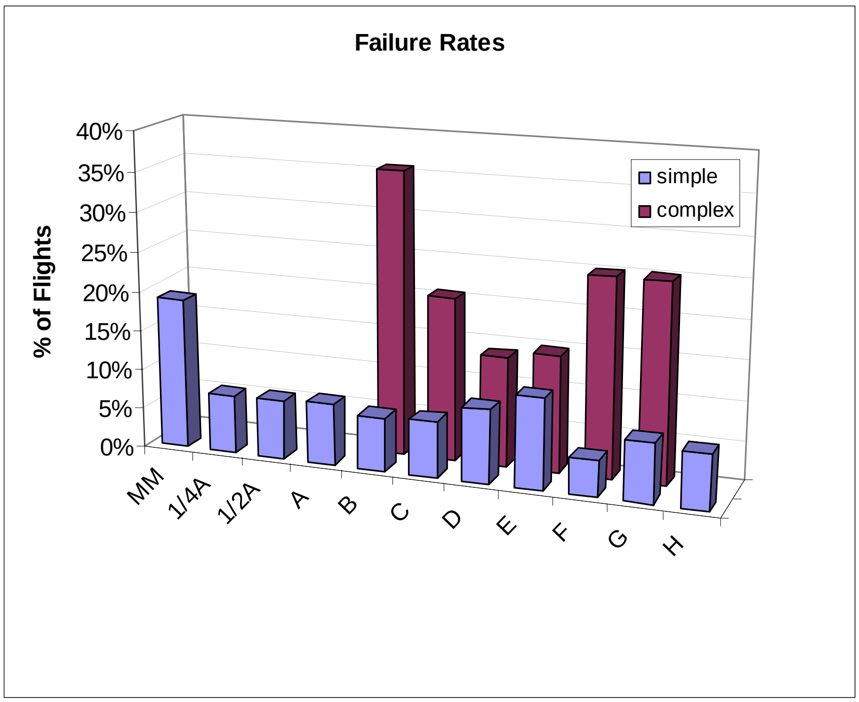


Figure 9. Failure rates for simple and complex MASA rockets by total impulse.

How consistent are these failure rates? How confident can we be in these numbers? Could we expect MASA to have the same failure rates this year as it has in the past? Since the incidences are low, it is challenging to determine the level of consistency for these data, and the data is also subject to longer-term trends in the types of rockets flown, the impact of the introduction of new motors, and the like. However, to the extent that data for the past eight years is similarly affected, we can determine the level of confidence in the MASA data by calculating a standard error-based confidence interval for the failure rate data. In order to do this, we need to limit our analysis to years and impulse categories for which there are sufficient numbers of flights. This limits us to considering only the simple rockets, and only a subset of these. But there is a sufficient base of experience to calculate variability statistics on incidence data for A through G flights, and these data are presented in Figure 10 below.

These data indicate that MASA failure rates are relatively consistent: The highest values of the confidence intervals are all less than twice the mean failure rate, usually much less. And, our confidence in the overall failure rate of 7.7 % for simple rockets is excellent: The standard error of this estimate is less than one percent.

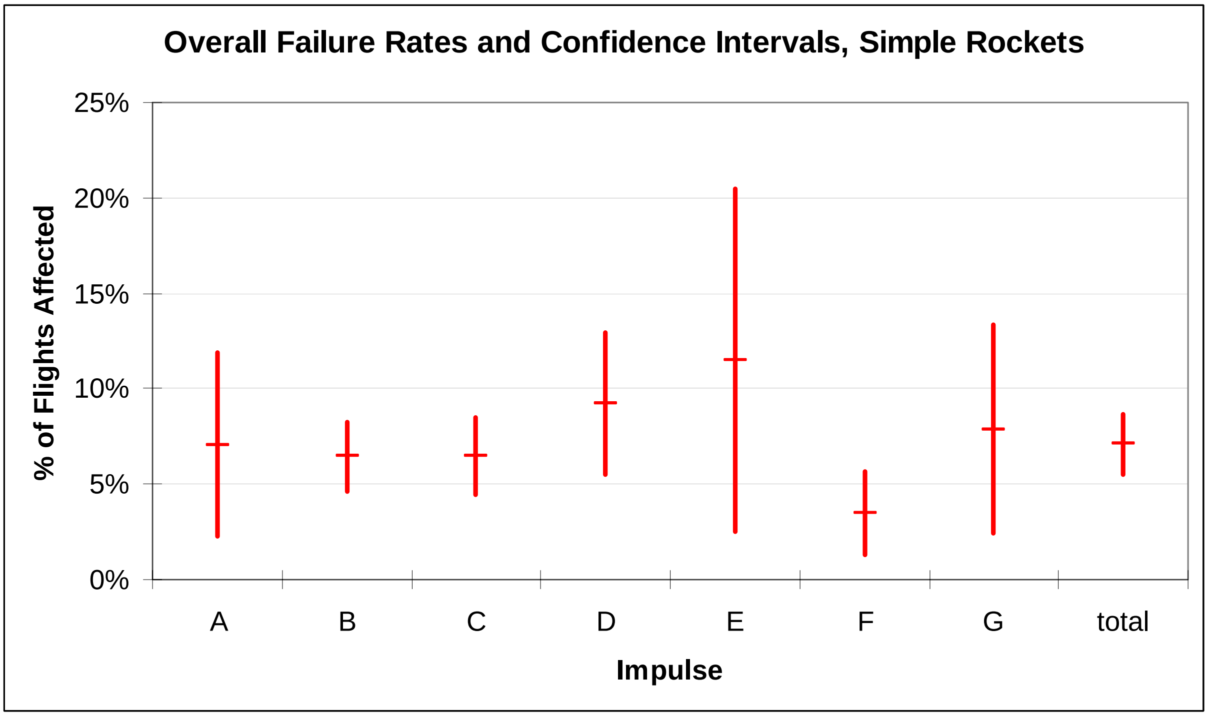


Figure 10. 95% confidence intervals around the mean failure rates for simple rockets.

How representative are these failure rates? How similar would we expect other clubs to be? Again, a comparison with SARA's data is instructive. SARA categorizes failures slightly differently than does MASA: Unlike MASA, SARA counts tangled chutes, spit motors, and early ejections, resulting in about a 6% higher failure rate overall[18]. Correcting for that 6% overall difference, and looking only at categories for which both clubs had at least ten flights[19] as a baseline, SARA failure rates are quite comparable to those of MASA, as presented in Figure 11. For simple flights, with the sole exception of F-impulse flights, the failure rates are all within three percent; for the smaller sample of complex failures, the failure rates are within six to ten percent.

Contest rocket failures present an entirely different picture. For a first-order comparison on overall safety-related failures, contest flights marked "*UNS*[20]" were combined with those marked *SEP*, *CAT*, and *NDP* in order to create an overall index of safety-related failure. These data are presented in Figure 12 for simple contest rockets, including egg lofters, and in Figure 13 for complex contest rockets.

---

[18] To be more precise, SARA is more effective at identifying and reporting failures that do occur. Like crime rates, reported failure rates can change as a function of reporting practices with no change in the underlying problem.

[19] Given a failure rate near 10%, incidence rates for sample sizes smaller than ten are expected to vary too much to make direct comparisons meaningful.

[20] Recall that this category already includes *NEJ*, *LOP*, *SHR*, *SAF*, and other obviously-safety related codes.

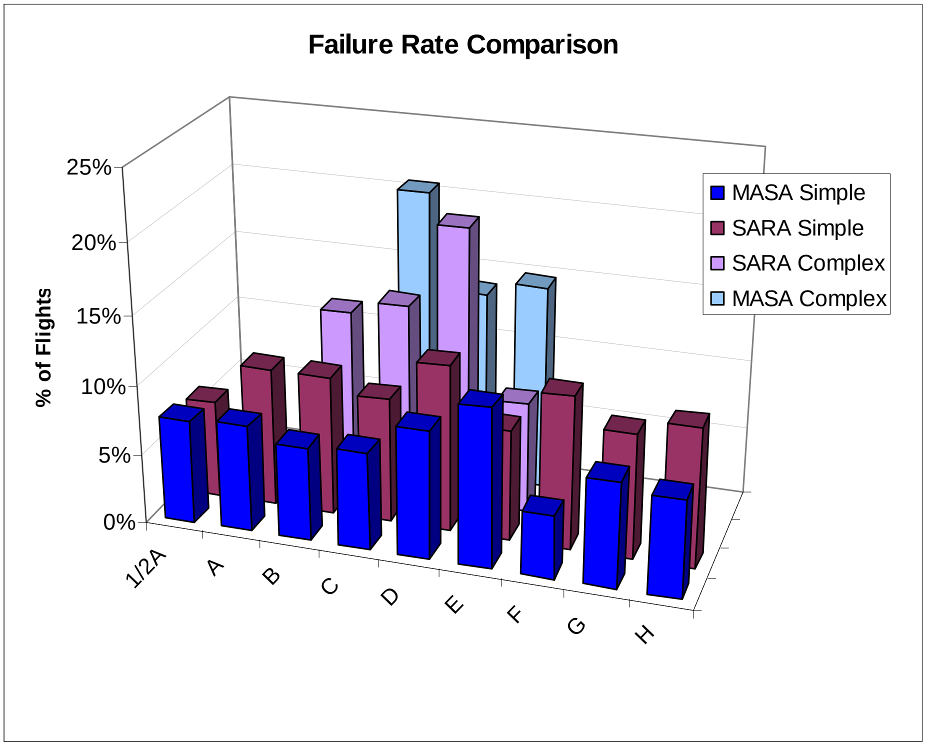


Figure 11. Failure Rate comparison, MASA vs. SARA (categories with n>10)

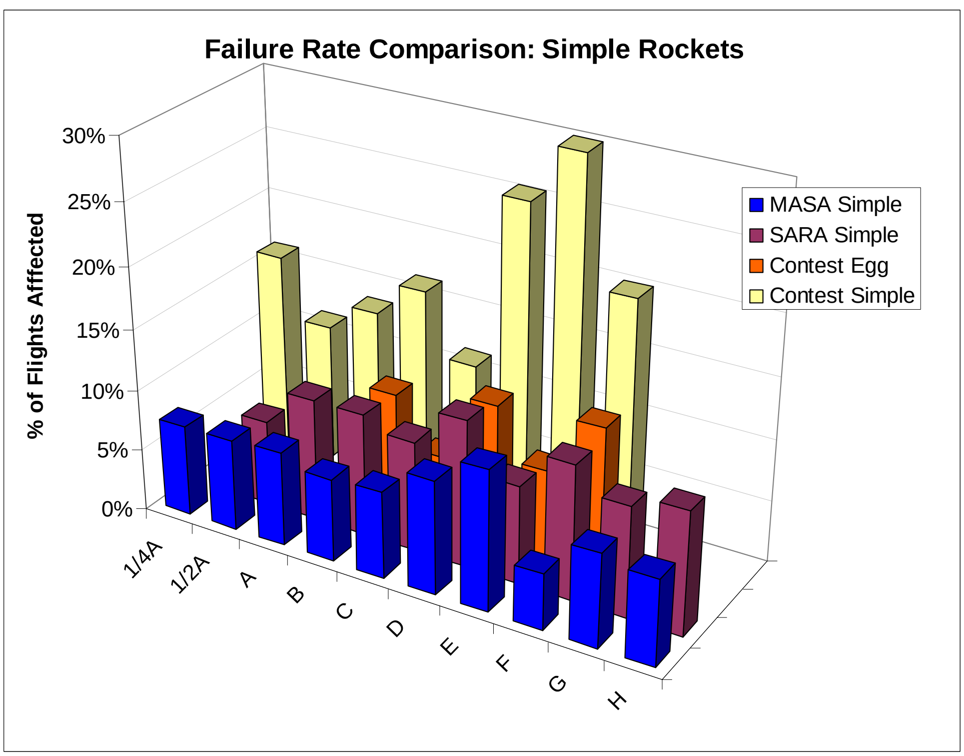


Figure 12. Failure rates for simple rockets, including contest rockets.

Egg lofting failure rates are comparable to the sport rocket failure rates of MASA and SARA, but simple contest rockets fare far worse. Part of the explanation may be related to the data:

Recall that so called "simple" contest rockets include, in this analysis, staged altitude rockets, as well as super-rocs, which (at least in the earlier contests reflected in the data) tended to be (under) powered by low thrust, long-burning motors. However, even if there is some bias built into the analysis, I believe that there is a real difference in failure rates: Contest rockets are lighter, and tend to outperform sport rockets so much that available motor delays result in high speed deployments, resulting in flight failures. This hypothesis can be confirmed by analyzing individual failure modes, which will be presented later in this paper.

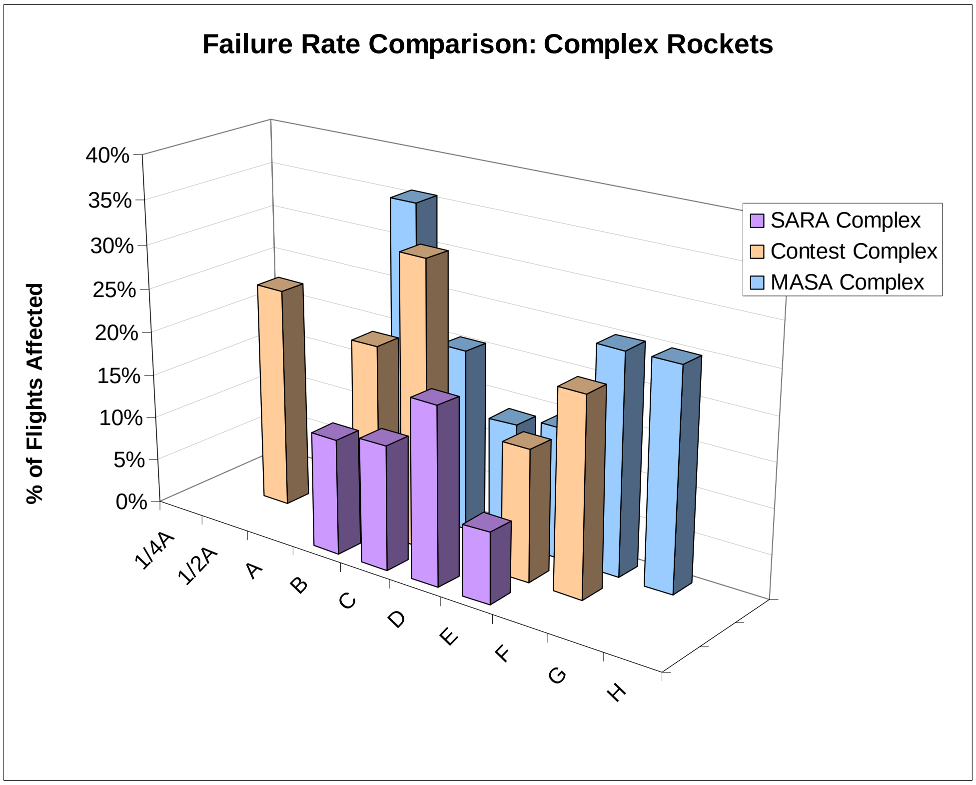


Figure 13. Failure rates for complex rockets, including contest rockets.

Overall failure data for complex contest rockets is presented for completeness. These rockets have overall failure rates that are fairly comparable to those of MASA and SARA. Recall, however, that contest data reflects only Cluster Altitude events, not staged rockets, thus leaving out a large base of rockets with a high failure rate.

Failure Causes

Figure 14 presents data for MASA on the types of failures for simple and complex rockets. A key finding is that complex rockets have a 10% chance of a lawn dart (52 of 518 flights met this sad end) compared to only 1.2% of simple rockets (70 events in 5651 flights). Inspection of the logs leads to the conclusion that two stage black powder rockets that fail to stage accounts for most of this difference, and incomplete cluster ignitions[21] accounts for most of the

[21] These often lead to lawn darts because the rocket is underpowered and does not reach sufficient altitude for the delay to work, although outright prangs due to asymmetric thrust are also possible.

rest. The high rate of failure for complex rockets is not unique to MASA: In the 2005 TARC finals, 11 of 103 rockets (10.7%) suffered ballistic returns of at least one component.

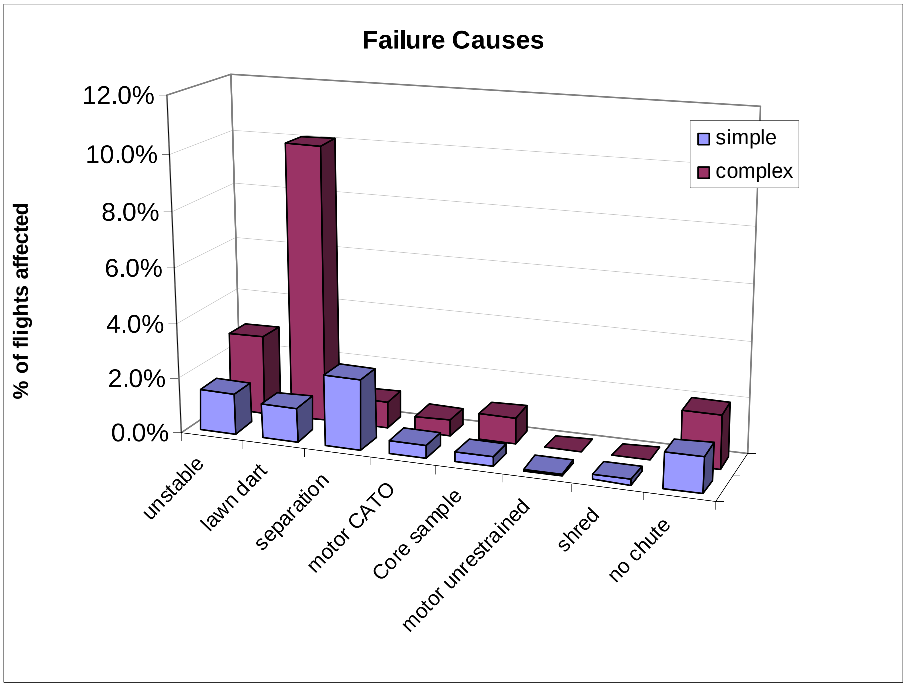


Figure 14. Causes of failures for simple and complex MASA rockets.

Again, a comparison with SARA summary data is useful. A simple vs. complex breakdown wasn't available, but, when the aggregate failure rates were compared for the failure categories in common (see Figure 15 below), SARA and MASA appear to be quite similar. Failure rates were within 1% for every category except separation. It is not clear why the incidence of separations might vary between the clubs, although SARA is described as having a large number of youngsters who make many flights on the same rockets at each launch, which may result in more wear and tear on the rockets.

For contest rockets, the most comparable failure categories are *CAT*, *SEP*, and *NDP*. Separation failure rates in simple contest rockets averaged 6.9%--higher even than SARA's. CATOs, at 0.1%, and No Deploys, at 2%, were comparable. This supports the hypothesis advanced earlier that contest rockets are subject to failure when ejection charges fire too early, given the rocket's performance. Motor issues (failure and ejection), on the other hand, appear to occur at the same overall rate.

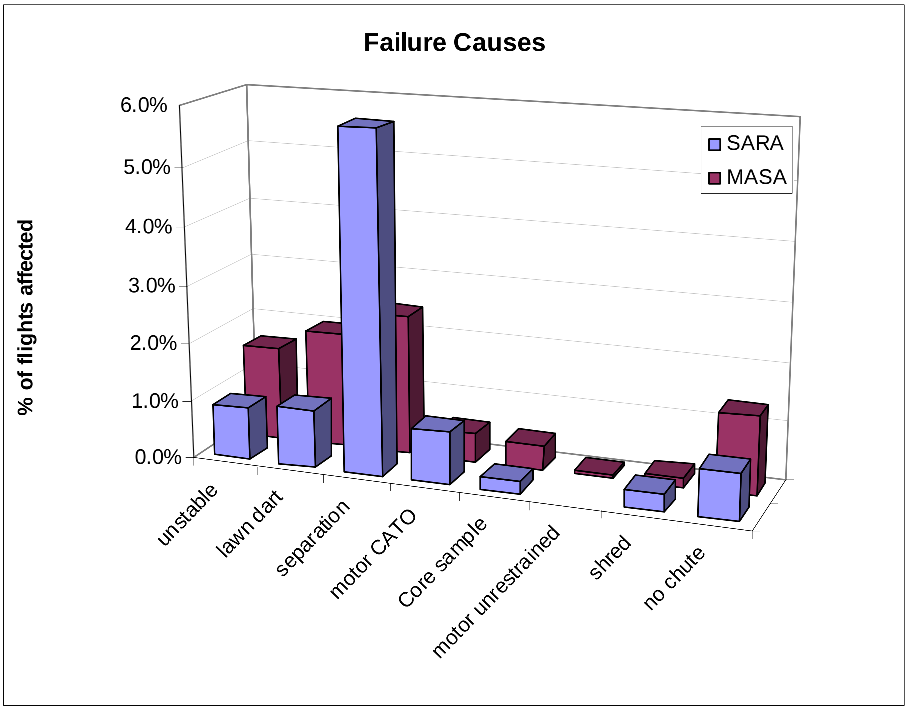


Figure 15. Comparison of failure rates by cause: MASA and SARA, simple rockets

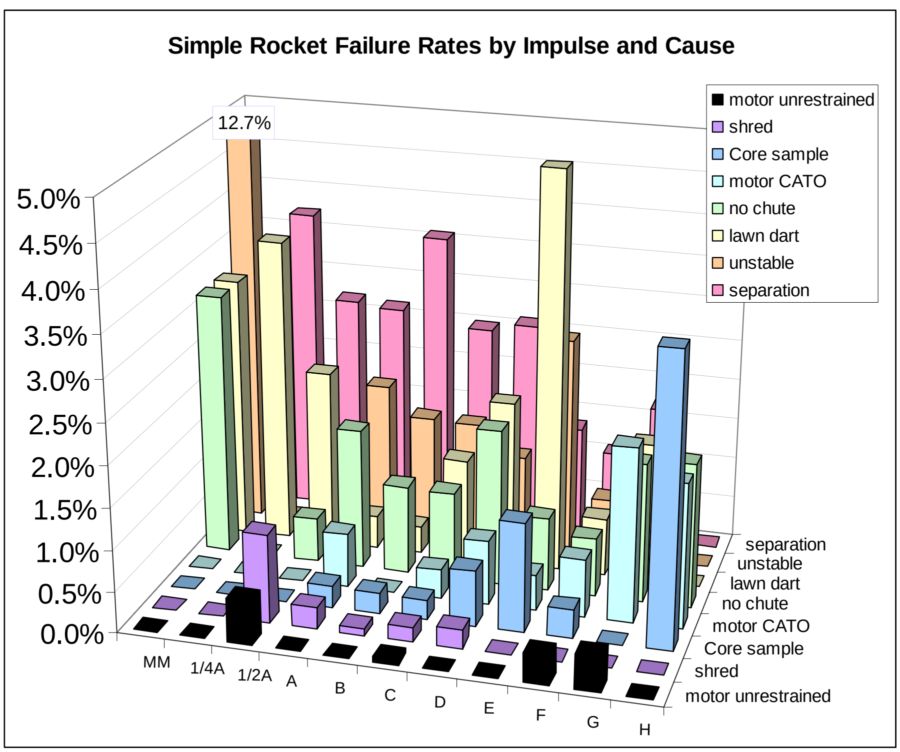


Figure 16. Failure modes for simple rockets, by installed impulse.

Figure 16 above breaks out failure rates for simple rockets as a function of motor type as well as failure type. These data are also presented in Table 3. A key point for this graph is that the motors that are the most often flown by MASA also tend to be the ones with the lowest failure rates. There is also an obvious spike in lawn darts by E-impulse rockets, which appears to be due to a combination of factors, including inappropriate use of Estes E motors as heavy lifters and the use of composite E motors on fairly heavy models. As will be seen later, this spike was especially apparent in MASA's early years, and has been eliminated in recent years.

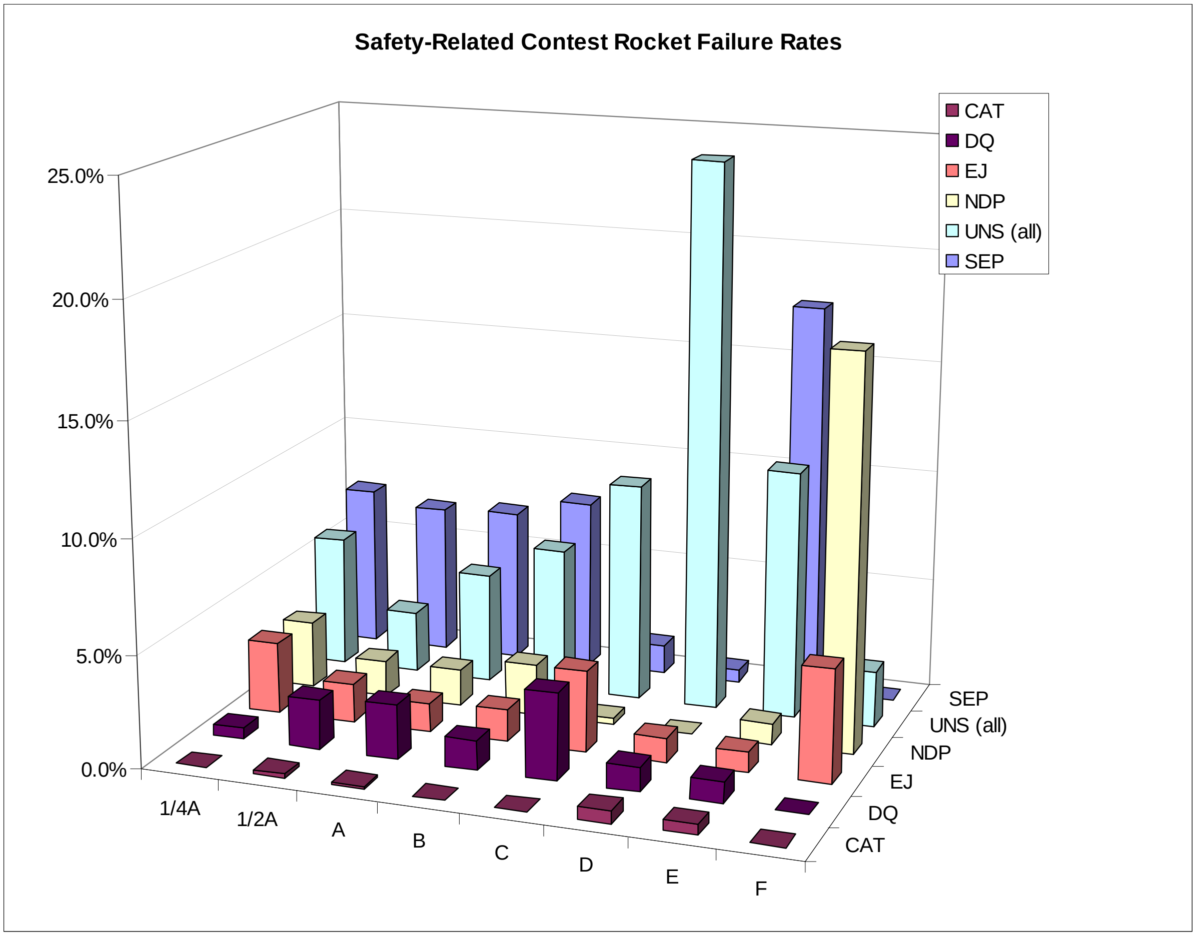


Figure 17. Safety-related failures of simple contest rockets.

Figure 17 above is presented for comparison. It shows safety-related failures for simple contest rockets as a function of impulse class. Motor CATO rates are comparable, but other variation may be a result of unique combinations of events and available motors. For example, the high NDP rate for F impulse rockets represents 7 of 40 FSD rockets in a single event, and the high SEP rate for E motors occurred at NARAM 45 in ESD and may also be anomalous.

Figure 18 below breaks out failure rates for complex rockets as a function of motor type as well as failure type. These data are also presented in Table 4. Again, the failure rates are lower for impulse categories with which MASA has more experience.

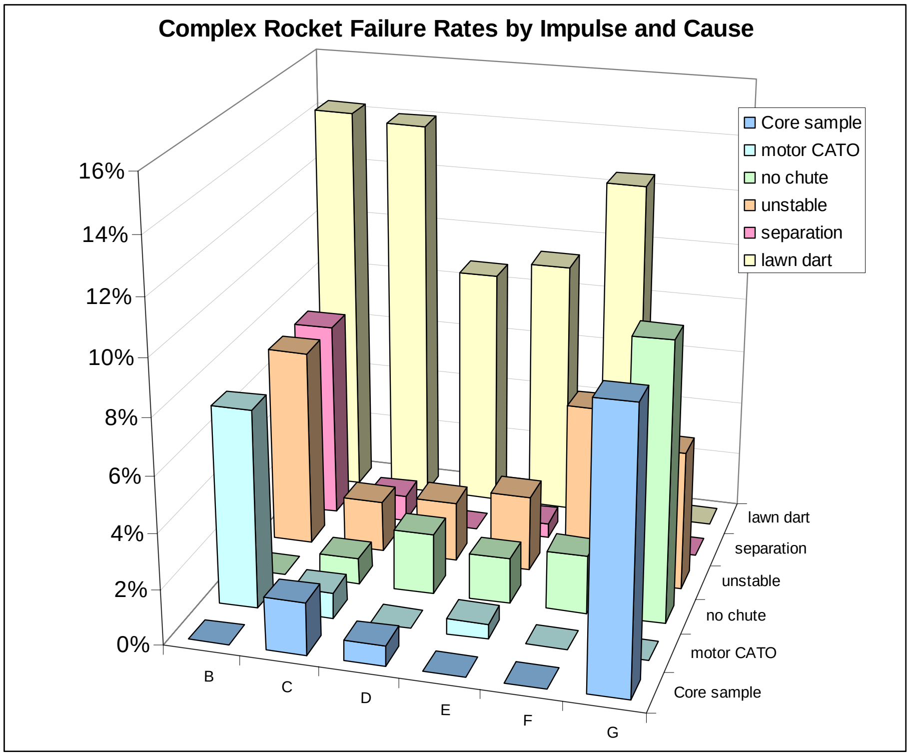


Figure 18. Failure modes for complex rockets, by installed impulse.

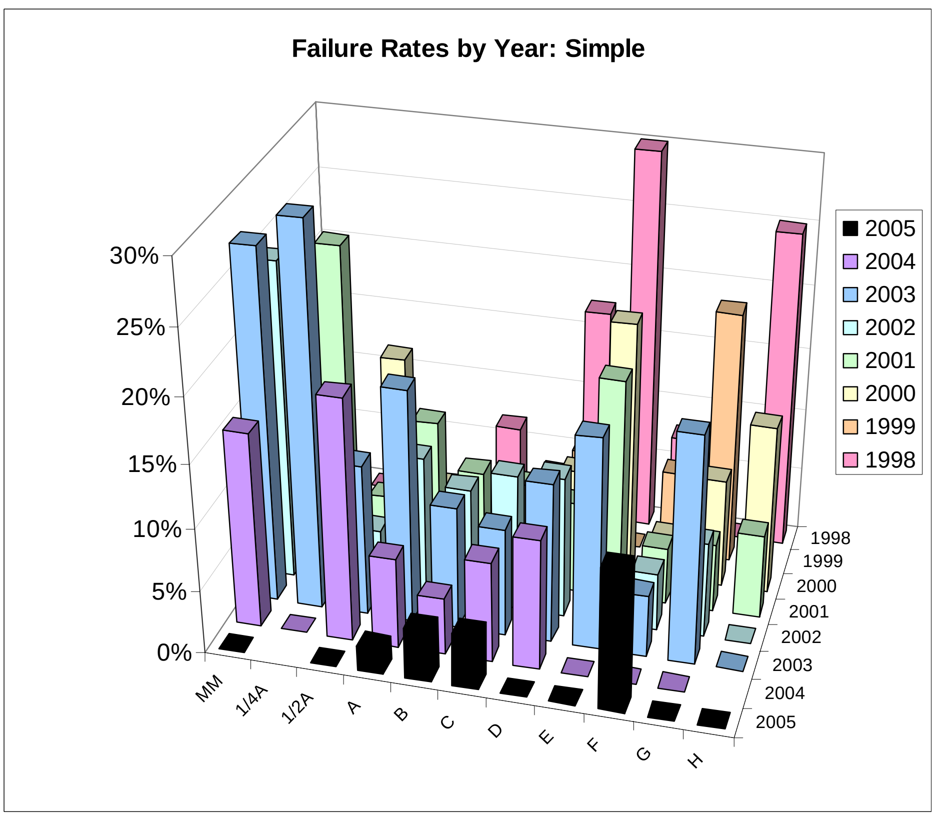


Figure 19. Failure rates by year for simple rockets.

Finally, Figure 19 above and Figure 20 below depict failure rates by impulse and year for simple and complex rockets, respectively. If this kind of data were consistently collected and rigorously assessed by clubs, trends over time could be useful in identifying emerging safety issues.

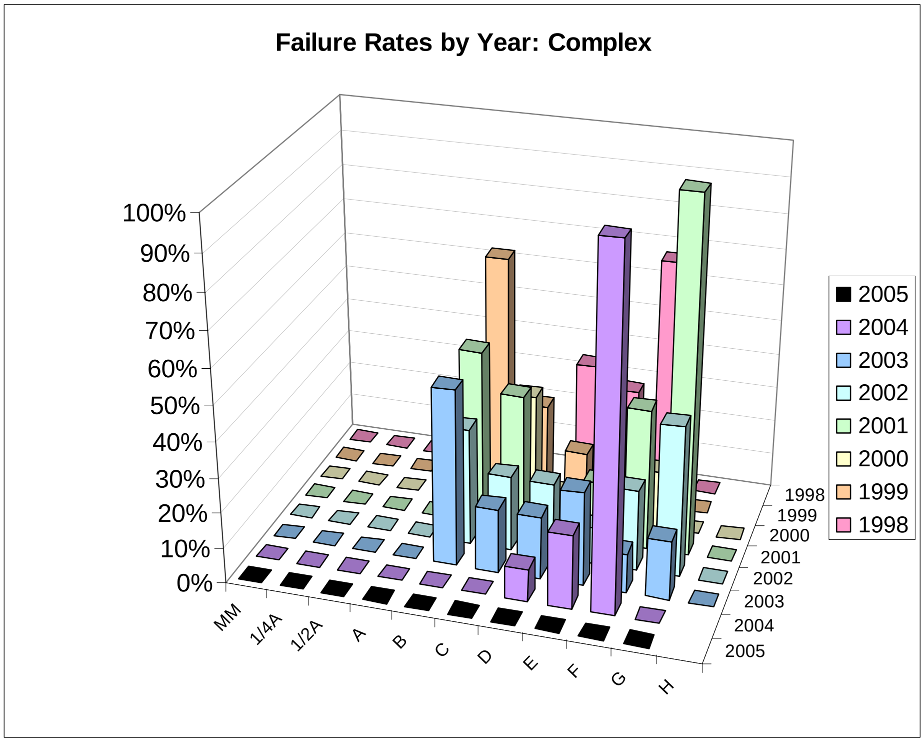


Figure 20. Failure rates by year for complex rockets.

Discussion and Next Steps

The core effort in this research was the painstaking derivation of failure statistics that have sufficient statistical validity for use in subsequent risk analyses. In the absence of careful, systematic collection of incident data over a wider population, the failure rates developed in this study must serve as the current best estimates of failure rates in model rocketry.

It is important that this data be more extensively validated: It would help us to refine the precision of the estimates for rocketry as a whole. Even more importantly, more systematic data collection across NAR Sections would help us determine the extent to which sections vary in their failure rates. Although there are similarities between the two sections compared in this study, there are also differences. If sections indeed vary, then there are likely cultural differences that affect safety practices, and these can be identified and used to our advantage[22]. Once identified, those practices that most contribute to safety (called *Best Practices*) can be publicized, and adopted, and used to reduce NAR's overall failure rate. Without this careful,

[22] Cochran, E., & Bullemer, P. Advanced Technology in Complex Systems: Automation, People, Culture. In T. Samad & J. Weyrauch (Eds.), *Automation, Control, and Complexity: An Integrated Approach.* New York: John Wiley, 2000.

factual basis for action, changes intended to improve safety may be ineffective and therefore unnecessarily inconvenient.

Further, given validated failure rate data at either the Section or National level, it will become possible to develop more sound approaches to risk modeling. Consider the following example of the benefit that good failure data can have. Table 2 below depicts a highly simplified relative risk chart that is primarily based on deliverable event energy. The idea is to assign a weight to each combination of impulse and failure mode that approximates the potential risk of that event. Thus, risks double for each impulse class, and lawn darts are, because of the higher velocities involved, roughly twice as bad as core samples within a class[23]. For purposes of this discussion, I have applied colors to the table to categorize the relative risk: The risk of serious injury increases as one moves across the chart from the bottom left to the top right. Table 2 thus attempts to characterize the risk of a bad outcome, should a specific failure occur in a specific size of rocket.

Relative Risk	MM	1/4A	1/2A	A	B	C	D	E	F	G	H
Lawn Dart	2	5	10	20	40	80	160	320	640	1280	2560
Core Sample	1	2	5	10	20	40	80	160	320	640	1280
Separation	0	1	2	5	10	20	40	80	160	320	640
No Chute	0	0	1	2	5	10	20	40	80	160	320
Shred	0	0	0	1	2	5	10	20	40	80	160
Unstable	0	0	0	0	1	2	5	10	20	40	80
CATO	0	0	0	0	0	1	2	5	10	20	40

Table 2. A candidate relative risk chart.

What is the likelihood that the event will actually occur on any given flight? Our best estimate, as of now, is derived from the present study: The flight failure rates that were depicted in Figure 16 and Figure 18 above (and listed in Table 3 and Table 4 below).

In general, it does not matter how likely a failure is if the risk represented by that failure is minimal. A separation in a 1/4A rocket--even if it happens every time--does not deserve the same respect that even a rare separation in an H-powered rocket deserves.

Failure Rate--simple	MM	1/4A	1/2A	A	B	C	D	E	F	G	H
lawn dart	3.2%	3.7%	2.1%	0.4%	0.3%	1.2%	2.0%	4.8%	0.7%	1.7%	0.0%
Core sample	0.0%	0.0%	0.0%	0.3%	0.2%	0.2%	0.7%	1.3%	0.4%	0.0%	3.5%
separation	0.0%	3.7%	2.7%	2.6%	3.6%	2.5%	2.6%	1.3%	1.1%	1.7%	0.0%
no chute	3.2%	0.0%	0.5%	1.7%	1.1%	1.1%	1.9%	0.9%	0.7%	1.7%	1.8%
shred	0.0%	0.0%	1.1%	0.3%	0.1%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%
unstable	13%	0.0%	0.5%	1.8%	1.5%	1.5%	1.1%	2.6%	0.7%	0.0%	0.0%
motor CATO	0.0%	0.0%	0.0%	0.7%	0.0%	0.4%	0.8%	0.4%	0.7%	2.1%	1.8%

Table 3. Incidence statistics for simple rockets.

[23] The numbers in the risk chart are very loose approximations. Obviously, a rigorous approach that actually calculates the typical energies involved could certainly be undertaken.

Failure Rate--complex	MM	1/4A	1/2A	A	B	C	D	E	F	G	H
lawn dart	0.0%		0.0%	0.0%	14.3%	14.0%	8.7%	9.3%	12.5%	0.0%	0.0%
Core sample	0.0%		0.0%	0.0%	0.0%	1.9%	0.7%	0.0%	0.0%	10.0%	0.0%
separation	0.0%		0.0%	0.0%	7.1%	0.9%	0.0%	0.5%	4.2%	0.0%	0.0%
no chute	0.0%		0.0%	0.0%	0.0%	0.9%	2.2%	1.6%	2.1%	10.0%	0.0%
shred	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
unstable	0%		0.0%	0.0%	7.1%	1.9%	2.2%	2.7%	6.3%	5.0%	0.0%
motor CATO	0.0%		0.0%	0.0%	7.1%	0.9%	0.0%	0.5%	0.0%	0.0%	0.0%

Table 4. Incidence statistics for complex rockets.

One way to estimate the actual risk of a rocket launch, then, is to simply multiply the relative risk matrix in Table 2 by the appropriate failure rate table to get a measure of combined risk. This is depicted below, in Table 5 for simple rockets, and Table 6 for complex rockets.

Combined risk	MM	1/4A	1/2A	A	B	C	D	E	F	G	H
lawn dart	0	0	0	0	0	1	3	16	4	22	-
Core sample	-	-	-	0	0	0	1	2	1	-	45
separation	-	0	0	0	0	0	1	1	2	5	-
no chute	-	-	0	0	0	0	0	0	1	3	6
shred	-	-	-	0	0	0	0	-	-	-	-
unstable	-	-	-	-	0	0	0	0	0	-	-
motor CATO	-	-	-	-	-	0	0	0	0	0	1
Total Risk	0	0	0	0	1	2	5	19	8	30	51

Table 5. Combined risk for simple rockets (values in Table 2 multiplied by values in Table 3).

Combined risk	MM	1/4A	1/2A	A	B	C	D	E	F	G	H
lawn dart	-	-	-	-	6	11	14	30	80	-	-
Core sample	-	-	-	-	-	1	1	-	-	64	-
separation	-	-	-	-	1	0	-	0	7	-	-
no chute	-	-	-	-	-	0	0	1	2	16	-
shred	-	-	-	-	-	-	-	-	-	-	-
unstable	-	-	-	-	0	0	0	0	1	2	-
motor CATO	-	-	-	-	-	0	-	0	-	-	-
Total Risk	-	-	-	-	7	12	15	31	90	82	-

Table 6. Combined risk for complex rockets (values in Table 2 multiplied by values in Table 4).

These tables describe the rockets that clubs should worry the most about--the ones that fail a lot, are dangerous when they do fail, or (especially) both. The numbers in the chart can even be used as a measure of how much more worry is justified: An RSO could, for example, justifiably spend four times the effort to check a simple E rocket than he/she does for a simple D rocket, based on club experience.

The combined risk charts presented here can be improved further. First, the charts should take the experience base into consideration. For example, the entries for complex H rockets are all based upon just three flights, none of which failed. That's obviously not enough experience to justify giving complex H rockets a free ride. A workable solution to lack of experience is to modify the values in the failure rate table so that failure of the next rocket is *assumed*. If there are 500 flights and only 10 failures for the combination under consideration, this change will have almost no effect. However, if there are only 3 flights and no failures for the combination under consideration, the estimated failure rate with this change will jump from 0 to 25%.

Also, the risk consideration should be much more attuned to the launch conditions. Table 2 reflects the worst case outcome if a failure occurs, but offers no help in predicting whether the failure will occur this time. Table 3 and Table 4 reflect the chances that a failure will happen based on past experience, but does not take current conditions into consideration.

But the outcomes of launches *can* be statistically modeled, even given uncertainty about initial conditions. Figure 21 below shows the output of *Splash*, a program sold by Apogee. *Splash* has plotted 200 impact points for a single rocket given modest variability in a variety of factors

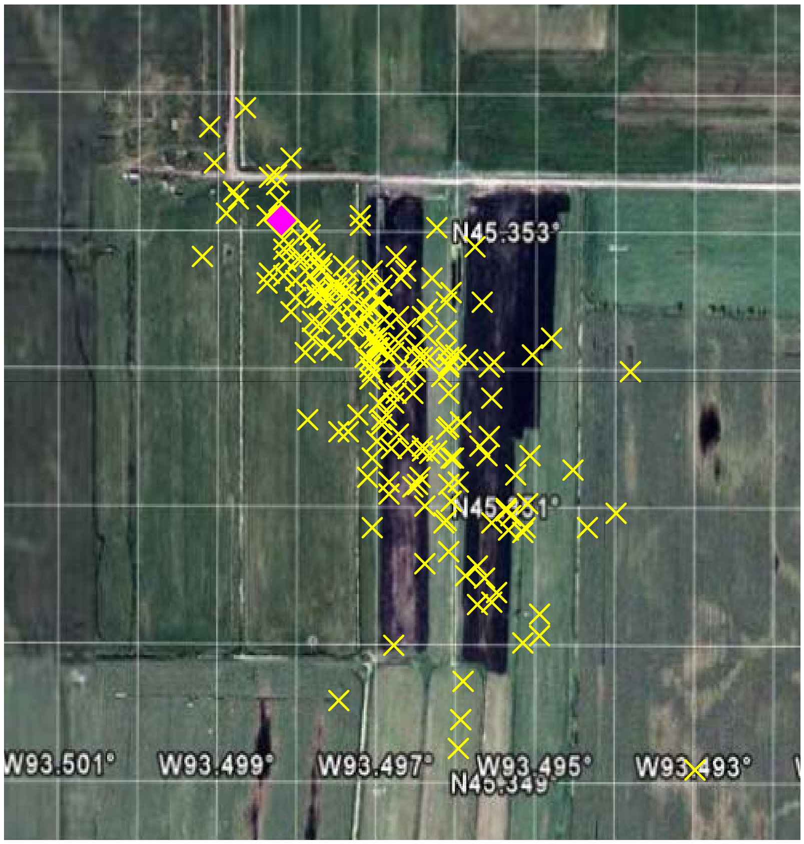


Figure 21. Simulated distribution of the landing points of 200 Alpha flights on C6-7 motors in light northwest winds. The launch point is the pink diamond.

such as fin alignment, weight, motor thrust, recovery system failure probability, and launch rod angle--18 variables in all. *Splash* provides landing coordinates in longitude and latitude; an aerial photograph of a MASA launch site has been superimposed for convenience[24]. In the example, wind was set as mostly northwesterly, which accounts for the dispersal of the recovery points downwind.

Most of the landing points represent nominal recoveries, but note that several landing points are upwind of the launch pad. Some of these are lawn darts. If the club sets up the prep area along the road behind the launch pad, then the lawn darts could fall into the prep area. If the rockets are very small, the club may not care. If the rockets are larger, the club may restrict the prep area so that it does not extend upwind of the launch pad. If the rockets are still larger, the

[24] It is often easier to visualize recovery distances by referring to specific, known, landmarks (e.g., "two ditches east and one ditch south") than by referring to abstract measures (e.g., "650 feet downwind").

club may elect to take additional action, such as moving the launch pad or angling it so that the rockets all land farther downwind.

If systematic data is collected, supplemented by judicious use of simulation programs, a set of splash patterns could be developed ahead of time for various combinations of wind direction, impulse, and rocket type. These data could be used in conjunction with historical failure rates and the parameters of each rocket to improve safety by ensuring that each flight falls within preset safety parameters. For example, in Figure 22 below, a set of splash patterns for various initial conditions is shown, based on outputs from the *Splash* program[25]. Nearly all of these are well clear of the road, which is the default prep area. However, there is a cluster of open purple triangles, all associated with recovery failures on flights launched with upwind rod tilt in fresh breezes. This cluster could be a signal for the club to modify its practices for those (and only those) conditions. Note that launches need not be entirely prohibited under those conditions; there are several alternative actions that could be taken to reduce risk under those conditions:

- The club could restrict rod tilt,
- The club could restrict the boundaries of the prep area,
- The club could launch rockets only with advance warning ("heads up")

Thus, when armed with accurate information, the RSO, knowing the experience of the flyer, the history of the model, the level of attention of the spectators, can if necessary modify the launch parameters for specific flights to reduce risk, without affecting the majority of flyers.[26] To the extent that the club collects, reviews, and disseminates its own safety data, a fact-based club safety culture can emerge, and RSO decisions can be consistently made and socially enforced.

[25] The data could also have been collected from actual flights, and should certainly be validated that way.
[26] The NASA/Houston Rocket Club (NAR 365) already uses Splash to predict landing zones, but does not factor in failure rate statistics.

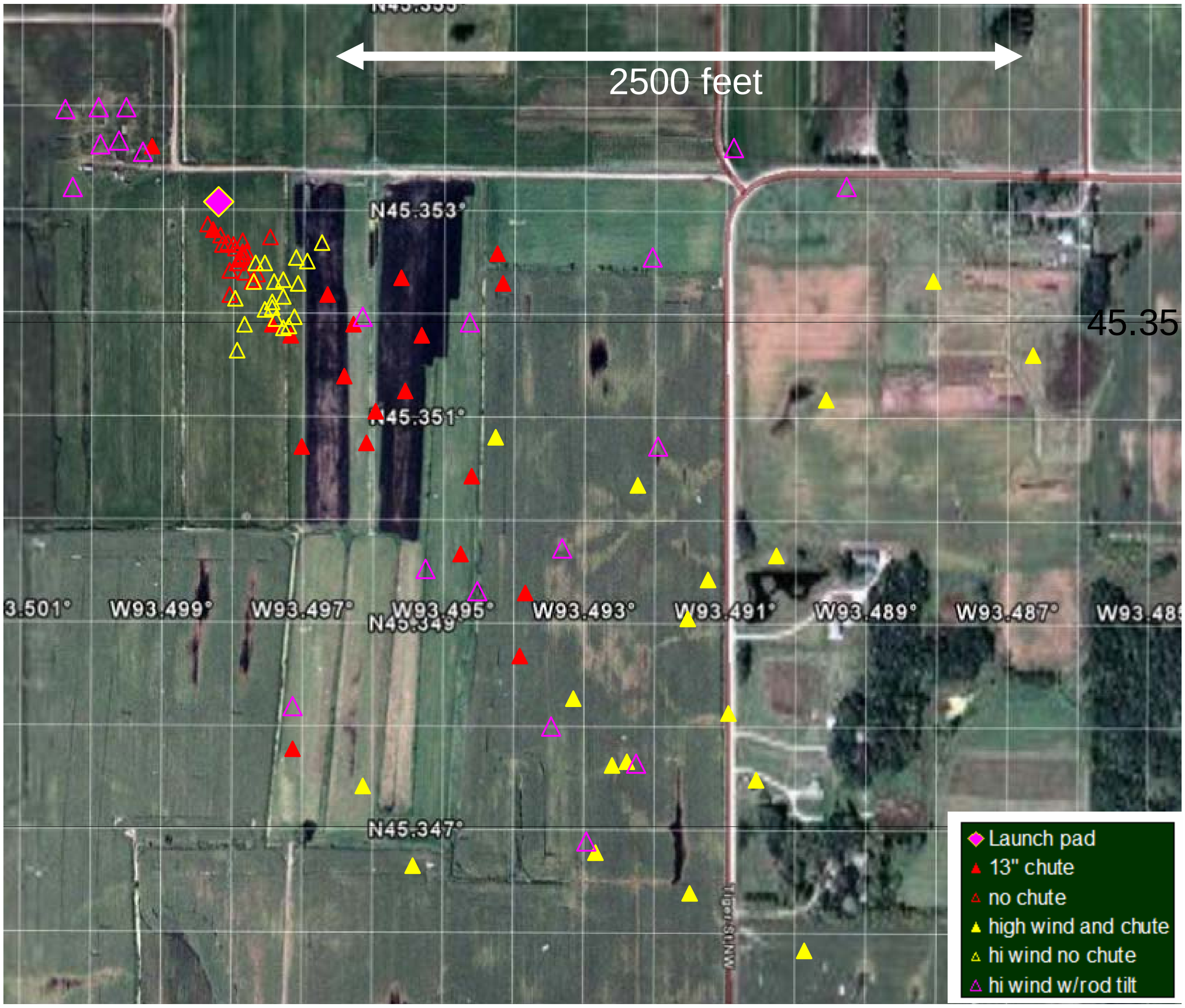


Figure 22. Splash patterns for a model rocket for various initial conditions.

Conclusions

The example above describes the beginning of a fact-based safety policy based on past failure rates, risk potential, and predicted outcome given current conditions. This sort of policy is tailored to the risk presented by each flight, taking the rocket, the flyers, and the flying conditions into account. It allows resources to be focused where they are most useful, and enables the sharing of best practices throughout NAR.

Appendix D

Risk Model for Ballistically-Falling Flights at NAR Launches

Keith Florig[1], Tripoli #9932
Carnegie Mellon University, florig@cmu.edu

A Monte Carlo model was designed and implemented in Analytica[2] to explore the probability of human injury and vehicle damage from failure modes involving ballistic returns, namely, separations, lawn darts, and core samples. Data collected by the Minnesota Amateur Spacemodeler Association (MASA, NAR 576) over a seven-year period and by the Southern Arizona Rocketry Association (SARA, NAR 545) over a five-year period show that these failure modes represent more than 50% of all errant flights.[3] The risk model described here combines estimates of the frequency of NAR events, event attendance, site layout, wind conditions, launch volume, failure rates, and flight trajectories to estimate the annual incidence of rocket collisions with people and vehicles. The various components of the model are shown in Figure 1 and described below.

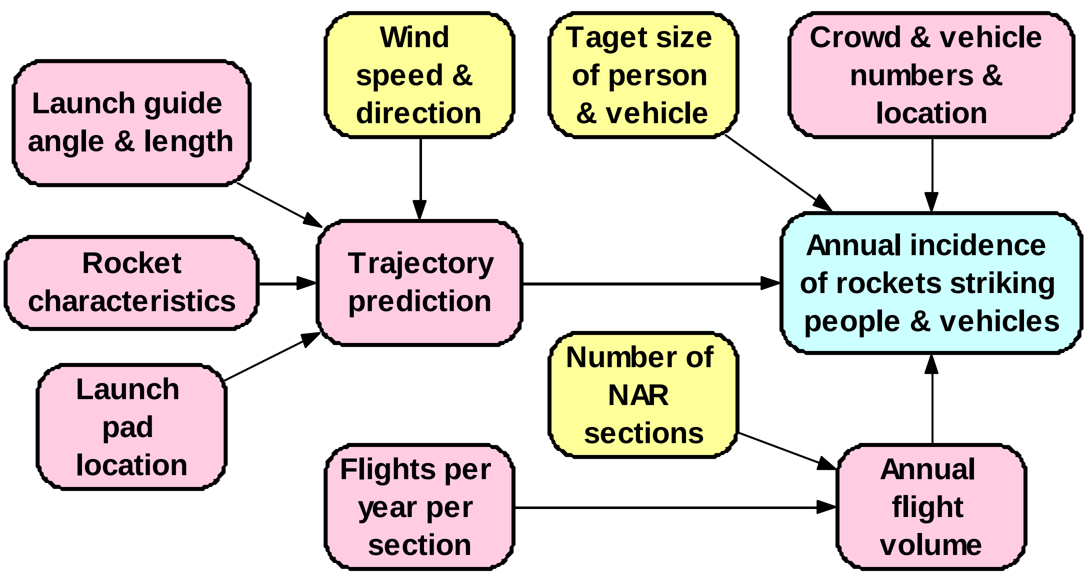


Figure 1. Components of model for estimating the incidence of ballistic returns striking people or vehicles (blue node). Pink nodes are under control of local section, yellow are not..

[1] The opinions in this paper are those of the author, and may not reflect those of NAR.
[2]The Analytica model that generated the results described herein can be obtained by contacting Keith Florig at florig@cmu.edu. Those wishing to run the model can download the free Analytica Reader from www.lumina.com and use Analytica Reader to open the model file Lumina Decision Systems, www.lumina.com.
[3] See Appendix C for details.

Trajectory prediction. Rockets are grouped into three impulse classes: Low (A-D), Medium (E-G), and High (H-J). Within each class, a sample of trajectories is generated by randomly choosing total impulse, burn time, thrust-to-weight ratio, rocket length, and length-to-diameter ratio, from class-appropriate distributions. From these rocket properties, other rocket properties (e.g., total mass) are generated from an ensemble of rocket kit data. 3-D trajectories are computed by iteratively combining forces of gravity, thrust, drag, and wind and numerically integrating the resulting acceleration over the flight period. A ballistic trajectory is assumed. Trajectory predictions of the Analytica model were checked against those of RockSim 7 for identical rocket and launch conditions and found to be in good agreement.

The azimuth and elevation of the launch guide is an input to the model. The model allows these to be randomly assigned from a distribution to simulate the limited accuracy with which fliers can point a launch guide. The rocket trajectory is constrained to the launch guide until the rocket reaches the end of the guide. The guide length is an input to the model.

Following Caporaso and Mandell (1973),[4] weathercocking is simulated by instantaneously adjusting the velocity vector to produce zero angle of attack at the moment the rocket leaves the launch guide, keeping speed unchanged. Thereafter, the rocket is assumed to point in the direction of the velocity of its center of mass. Lateral wind forces subsequent to the weathercock adjustment are assumed to act through the center of mass, not the center of pressure.

All three failure modes: lawn dart, separation, and core sample are assumed to have the same ballistic trajectory. Separations and core samples are assumed to have the mass, drag coefficient, and attack angle of a complete rocket. This can be expected to create estimated splash prints for these two failure modes that extend further downrange and less far downwind, than the real thing. Other factors that might influence trajectory, such as a rod whip, fin misalignment, and centering misalignment, are not included in this risk model. Thus, the splash prints predicted by the model are tighter than if these additional sources of variation were considered. We believe, however, that the model captures those flight phenomenon that contribute most to variability in impact location.

Failure rates. MASA and SARA data suggest that ballistic returns of one type or another (lawn dart, core sample, or separation) occur about 4-5 % of the time. The numbers of cases of each failure type in each impulse class are too few to observe statistically significant differences in ballistic return failure rates by impulse class. Further, MASA and SARA represent only two of NARs dozens of active section. Until failure rate data are collected and compiled by several other NAR sections, it will not be possible to judge how typical the MASA and SARA experience is.

[4] G.J. Caporaso and G.K. Mandell, "An Introduction to the Dynamics of Model Rocket Flight," in Mandell et al (eds.), Topics in Advanced Model Rocketry, MIT Press, Cambridge, MA, 1973, pp. 45-46.

Flight volume and attendance. The annual number of flights of various impulse classes at NAR events are estimated from several sources: the MASA dataset cited above, web-posted launch reports by various NAR sections, and the web-based survey of NAR section heads, described earlier in this report, which elicited information on the frequency of launch events and attendance at launch events (as implied by the number of vehicles present). These may create upward bias in flight frequency, because more active sections might be more likely to collect data, post launch reports, or participate in a survey than less active sections. Combining all sources, best estimates for launch frequency and attendance at NAR events are as follows.

NAR sections: 110
Average flights per event: 59, 24, and 12 for A-D, E-G, and H-J impulses classes
Average number of events per year per NAR section: 14
Average number of flights per year: 89,000, 36,000, 18,000 for A-D, E-G, and H-J impulses classes, respectively
Vehicles and attendees per event: 21 vehicles and 40-100 people, depending on the number of persons per vehicle

Launch site layout and coordinate system. The relative locations of pads, people, and vehicles is shown in Figure 2. People are assumed to be uniformly distributed in a rectangular area (the "crowd swath") that extends along the flight line and away from the pads. Vehicles are assumed to be uniformly distributed in a rectangular swath located adjacent to the crowd swath, but more distant from the pads. The pads lie at the origin of the model's coordinate system. Model inputs include the distance from pads to the flight line, and the dimensions of the swaths containing the crowd and vehicles.

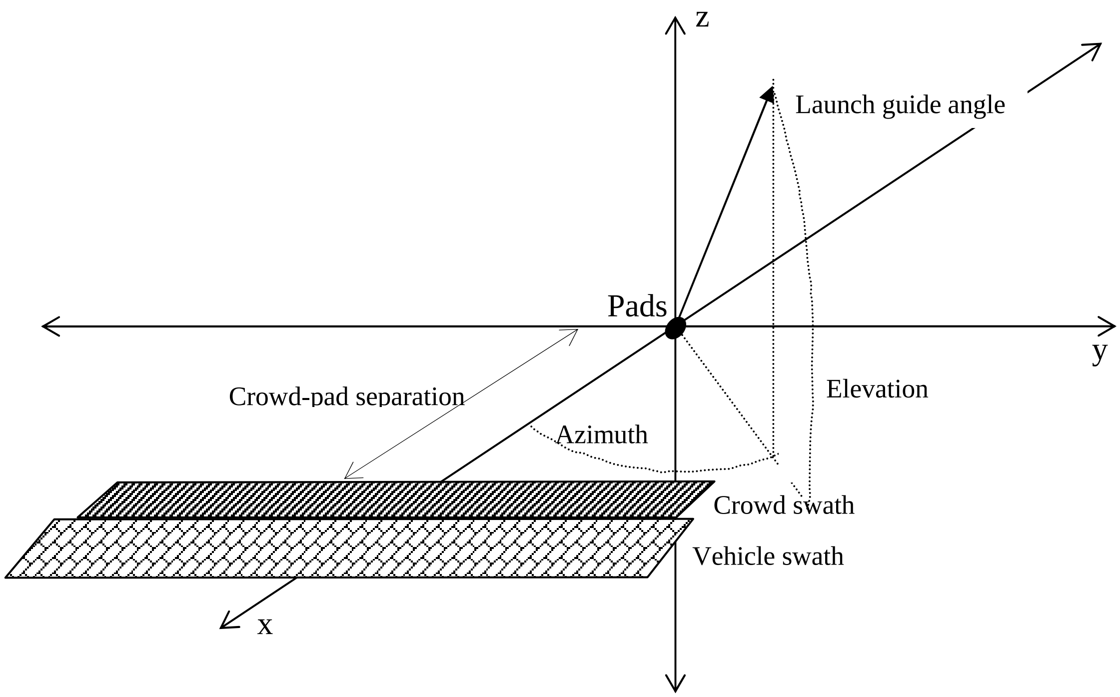
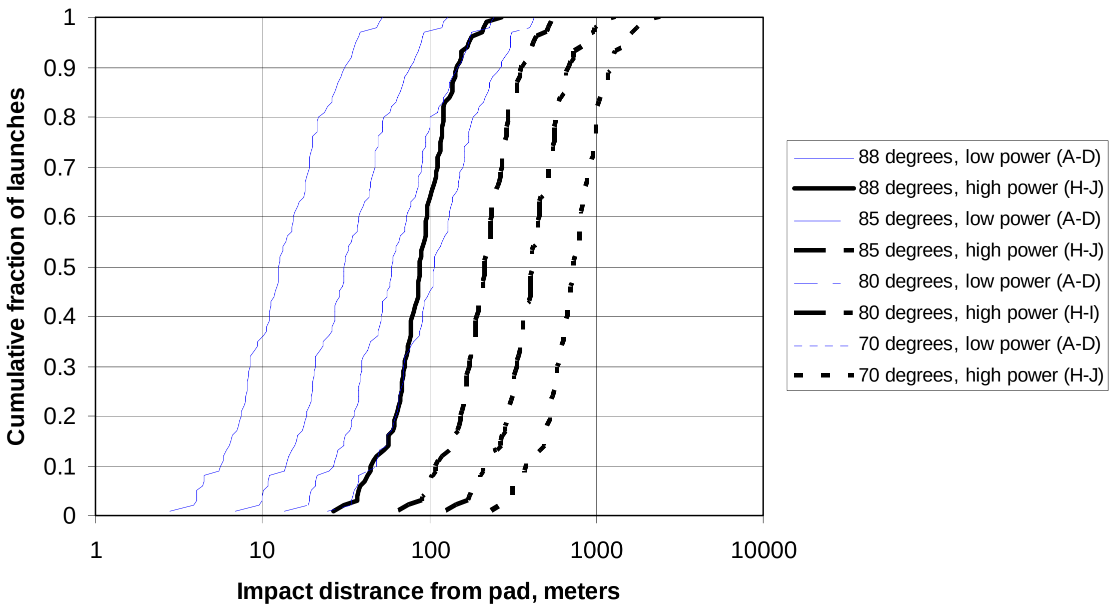


Figure 2. Launch site layout and coordinate system used in risk model. Launch guide angle is specified by azimuth and elevation angles as shown. Wind direction is specified by azimuth angle alone.

Results – No Wind

The trajectory function of the risk model was used to estimate the distribution of impact distances for ballistic returns of different impulse class, launched at different angles from the vertical. These results are shown in Figure 3 for the case of no wind.

Fig 3. Distribution of ballistic impact distances from pad as a function of launch elevation and impulse class, no wind.



These results show that small changes in launch angle result in substantial shifts of impact location. This suggests that control of launch angle in the field might be an effective means of reducing risk. Measurements of launch guide angles found in the field would help to determine how tightly clustered launch-guide angles actually are in current practice.

The risk function of the Analytica model combines trajectories with locations of people and vehicles to estimate the number of incidents in which people and vehicles are struck by plummeting rockets (or rocket sections) each year. Table 1 shows the model's best estimates of impact incidence for the case of no wind and crowd-pad separation equal to the rule minimum for each impulse class. Given the concern generated when a rocket impacts close to someone, Table 1 also includes an estimate of the incidence of impacts within 2 meters of a person.

Table 1. Best estimates of the annual incidence of ballistic return failures striking people or vehicles at NAR launches for low (A-D), medium (E-G), and high (H-J) power flights, assuming no wind and crowd-pad separation at rule minimum. Other assumptions are described below.

Result of ballistically returning flight	Estimated annual incidence (cases per yr)			
	Low power, A-D	Med power, E-G	High power, H-J	Totals
Hit a person	9	1.3	0.04	10
Hit within 2 m of a person	1500	230	7	1700
Hit a vehicle	35	14	4	50

In addition to the best estimates for flight volume and attendance given above, the above results assume the following:

Launch guide angle uniformly distributed within 5 degrees of vertical
Launch guide lengths are 1 m, 1.5 m, and 2 m for low, medium, and high power, respectively
Wind speed = 0
Persons per vehicle = 4
Crowd-pad separation: 5, 10, 30 m for low, med, high power, respectively
Crowd swath: 10 m x 40 m
Vehicle swath: 20 m x 60 m
Target area of person (average of standing and sitting postures) = .15 m^2
Target area of vehicle = 9 m^2
Probability that person is warned and gets out of the way of incoming rocket = 0.5
Thrust to weight ratio is uniformly distributed between 6 and 20

The greater incidence of model rocket compared to higher-powered strikes reflects not only the higher frequency of model rocket flights, but also the fact that they travel shorter distances than high power flights, and are thus more likely to impact within the crowd area.

Moving the pads further from the flight line decreases risk for model rocket flights more quickly than for higher power rockets because the splash footprint of the latter is so large compared to practical crowd-pad separation distances. Table 2 shows the sensitivity of impact incidence to changes in crowd-pad separation. Other input conditions are identical to those used for Table 1.

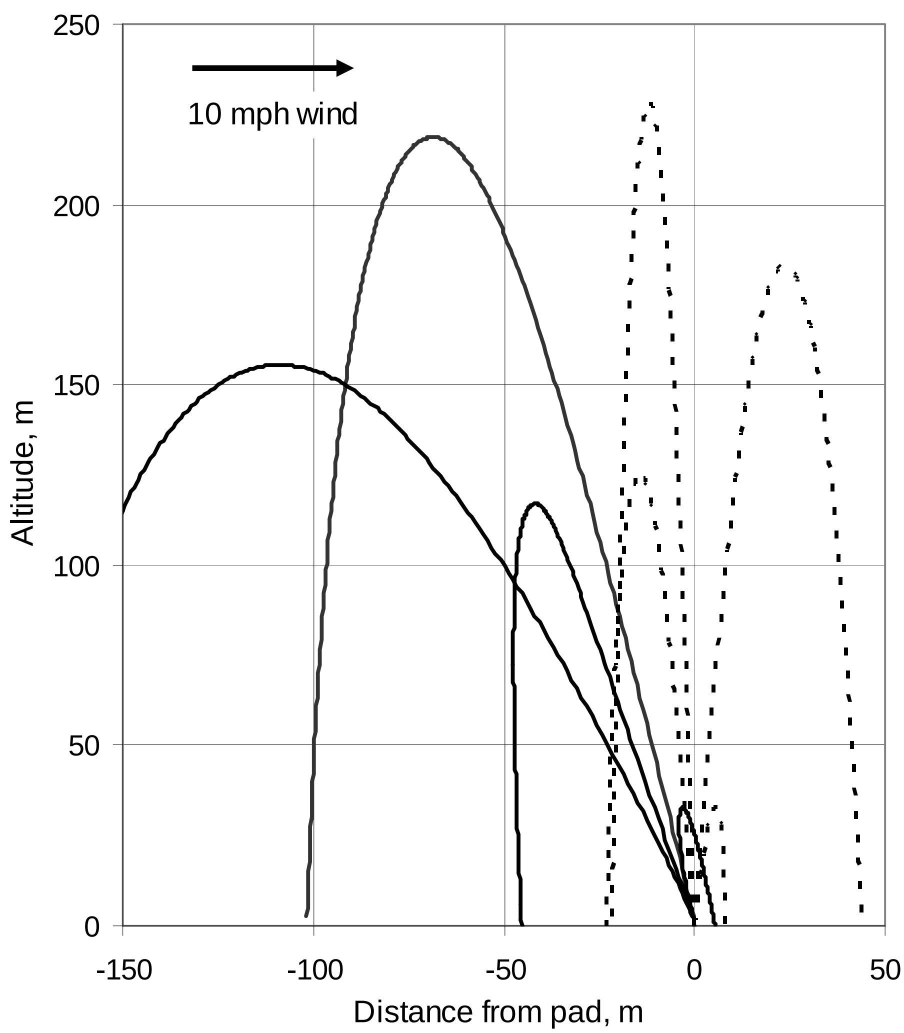
Table 2. Best estimates of the annual incidence of people struck by ballistic return failures of low (A-D), medium (E-G), and high (H-J) power flights at NAR launches, as a function of crowd-pad separation, assuming no wind.

Crowd-pad separation for low, med, & high power, respectively	Cases per year of people being hit			
	Low power	Med power	High power	Total
5 m, 10 m, 30 m	9	1.3	0.04	10
10 m, 20 m, 60 m	5	0.5	0.08	6
20 m, 40 m, 120 m	2	0.4	0.04	2
40 m, 80 m, 240 m	0.2	0.2	< .003	0.4

Results – 10 mph (4.47 m/sec) Wind

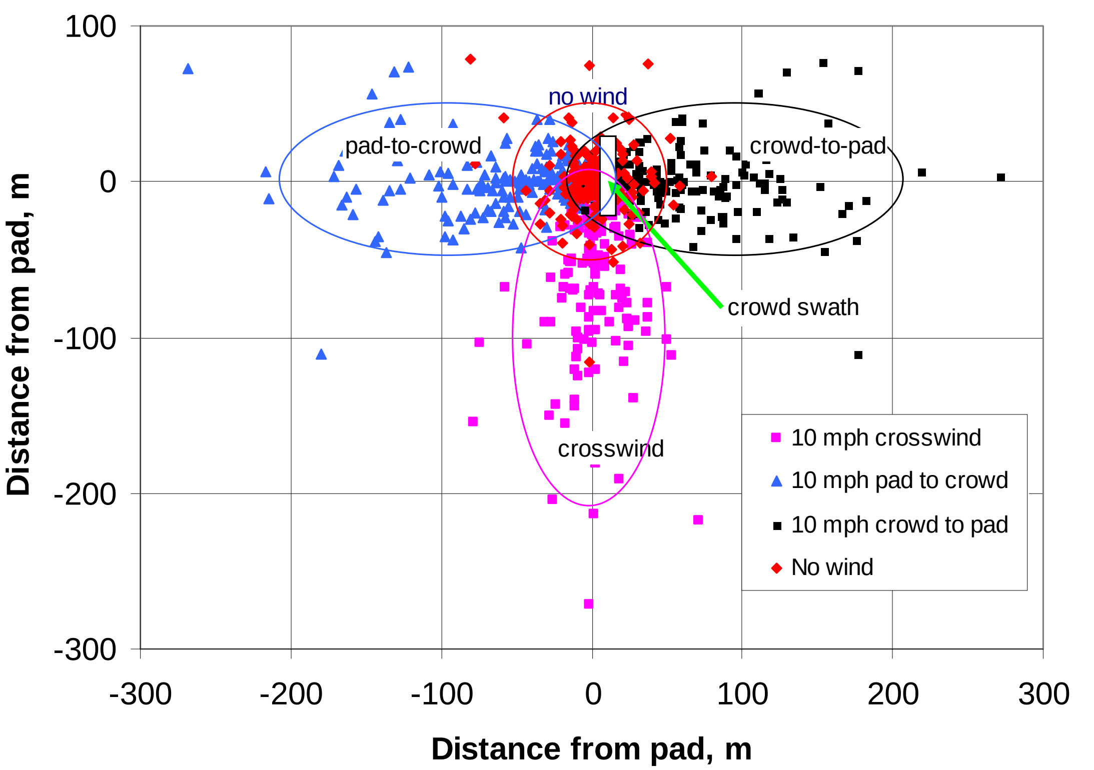
Ballistic impact patterns were investigated with a 10 mph wind blowing in various directions. Figure 4 compares samples of four randomly-sampled flight trajectories for flights with and without wind. Thrust-to-weight ratio ranges from 6 to 20. The effect of weathercocking is clearly evident.

Fig. 4. Model rocket (A-D) ballistic trajectories under zero (dotted line) & 10 mph (solid line) wind, launch angle distributed within 5 deg of vertical, 2D simulation, showing effects of weather-cocking.



The effect of wind is to substantially elongate and displace the splash print over the windless condition. Figure 5 shows how the splash print changes with wind direction, again for a 10 mph example with launch angle uniformly distributed within 5 degrees of vertical, and within 0-360 degrees azimuth.

Fig. 5. Clustering of model (A-D) rocket ballistic impacts vs 10 mph wind direction with weather cocking. Boundaries contain 95% of impacts.



Trajectories under various wind conditions were next used to estimate the annual incidence of ballistic returns striking people or vehicles. These results are shown in Table 3. They suggest that a crosswind launch site configuration will significantly reduce ballistic return risks compared to the case when wind is blowing from crowd to pads. Cross wind arrangements do not significantly reduce ballistic return risks compared to the case when wind is blowing from pads to crowd. However, given that flights returning under chute will drift substantially with the wind, configuring a site with pad-to-crowd winds can be expected to produce many chuted landings in the crowd and vehicle areas. Even under chute, high-power rockets can cause injury and property damage because of their substantial mass. Of course, people can more easily avoid a chuted rocket than a ballisticall- returning rocket, provided they are alerted in time.

Table 3. Estimated annual average incidence rates for ballistic returns striking people and near people at NAR launches, as a function of wind conditions and crowd-pad separation. The Monte Carlo sample size for each condition is 300, so risks smaller than .003 cases per year could not be estimated. Launch guide elevation is uniformly distributed within 5 degrees of vertical. Azimuth is uniformly distributed across all compass points. Other conditions are the same as in Table 1.

Person impact incidence vs wind conditions [cases per yr]					**Near miss incidence (hits within 2 m) vs wind conditions [cases per yr]**				
Crowd-pad separation	Low power	Medium power	High power	Totals, rounded	Crowd-pad separation	Low power	Medium power	High power	Totals, rounded
	No wind					**No wind**			
Minimum	9	1.3	0.04	10	Minimum	1500	230	7	1700
Typical	5	0.5	0.08	6	Typical	882	80	13	1000
Far	2	0.4	0.04	2	Far	327	66	7	400
Very far	0.2	0.2	< .003	0.4	Very far	33	40	< .003	70
	10 mph crowd-to-pad					**10 mph crowd-to-pad**			
Minimum	7	0.6	< .003	7	Minimum	1110	106	< .003	1200
Typical	5	1.6	< .003	7	Typical	914	266	< .003	1200
Far	4	0.4	0.04	5	Far	686	66	7	800
Very far	4	0.2	0.12	5	Very far	718	40	20	800
	10 mph pad-to-crowd					**10 mph pad-to-crowd**			
Minimum	3	0.2	< .003	3	Minimum	457	27	< .003	500
Typical	0.6	< .003	< .003	0.6	Typical	98	< .003	< .003	100
Far	< .003	< .003	< .003	<.01	Far	< .003	< .003	< .003	<.01
Very far	< .003	< .003	< .003	<.01	Very far	< .003	< .003	< .003	<.01
	10 mph crosswind					**10 mph crosswind**			
Minimum	4	0.6	< .003	5	Minimum	686	93	< .003	800
Typical	1.4	0.2	< .003	2	Typical	229	40	< .003	275
Far	0.4	0.2	< .003	0.5	Far	65	27	< .003	90
Very far	< .003	< .003	< .003	<.01	Very far	< .003	< .003	< .003	<.01

Crowd-pad separation distances, meters			
	Low power	Med power	High power
Minimum	5	10	30
Typical	10	20	60
Far	20	40	120
Very far	40	80	240

Controlling Launch Rod Angle

Variations in launch guide angle from flight to flight reflect both differences in users' mental models of how to account for wind and other factors as well as differences in users' ability to correctly "eyeball" the desired angle. One option for managing risk of ballistically returning flights would be to consistently adjust the angle of all launch guides to minimize risk, taking into account wind conditions and site layout. The Analytica risk model was used to examine the impact of this strategy on the incidence of ballistic returns striking people. Four conditions are compared, each with the launch guide pointed 10 degrees away from the crowd.: (1) no wind, (2) 10 mph crowd-to-pad wind, (3) 10 mph pad-to-crowd wind, and (4) 10 mph crosswind. The results, shown in Table 4, suggest that this strategy can significantly reduce risk over the case in which launch angle is eyeballed to be vertical (Table 3).

Table 4. Estimated annual average incidence rates for ballistic returns striking people and near people at NAR launches, as a function of wind direction for a launch guide pointed 10 degrees away from the crowd. The Monte Carlo sample size for each condition is 300, so risks smaller than .003 cases per year could not be estimated. Other conditions are the same as in Table 1.

Person impact incidence vs wind conditions [cases per yr]					**Near miss incidence (hits within 2 m) vs wind conditions [cases per yr]**				
Crowd-pad separation	Low power	Medium power	High power	Totals, rounded	Crowd-pad separation	Low power	Medium power	High power	Totals, rounded
	No wind					**No wind**			
Minimum	< .003	< .003	< .003	<.01	Minimum	< .003	< .003	< .003	<.01
Typical	< .003	< .003	< .003	<.01	Typical	< .003	< .003	< .003	<.01
Far	< .003	< .003	< .003	<.01	Far	< .003	< .003	< .003	<.01
Very far	< .003	< .003	< .003	<.01	Very far	< .003	< .003	< .003	<.01
	10 mph crowd-to-pad, 10 deg away					**10 mph crowd-to-pad, 10 deg away**			
Minimum	6	1.0	0.4	7	Minimum	1000	170	60	1200
Typical	4	1.0	0.3	5	Typical	600	170	45	820
Far	3	0.7	< .003	3	Far	450	120	< .003	600
Very far	2	0.2	< .003	2	Very far	260	40	< .003	300
	10 mph pad-to-crowd, 10 deg away					**10 mph pad-to-crowd, 10 deg away**			
Minimum	0.19	< .003	< .003	0.2	Minimum	33	< .003	< .003	30
Typical	< .003	< .003	< .003	0.0	Typical	< .003	< .003	< .003	0.0
Far	< .003	< .003	< .003	0.0	Far	< .003	< .003	< .003	0.0
Very far	< .003	< .003	< .003	0.0	Very far	< .003	< .003	< .003	0.0
	10 mph crosswind, 10 deg away					**10 mph crosswind, 10 deg away**			
Minimum	< .003	< .003	< .003	<.01	Minimum	< .003	< .003	< .003	<.01
Typical	< .003	< .003	< .003	<.01	Typical	< .003	< .003	< .003	<.01
Far	< .003	< .003	< .003	<.01	Far	< .003	< .003	< .003	<.01
Very far	< .003	< .003	< .003	<.01	Very far	< .003	< .003	< .003	<.01

Crowd-pad separation distances, meters			
	Low power	Med power	High power
Minimum	5	10	30
Typical	10	20	60
Far	20	40	120
Very far	40	80	240

Appendix E
Excerpts from
NAR Safety Officer Training Program

Available at http://www.nar.org/pdf/TSO.pdf

Safety Check-in Officer Guidelines:

The items below offer guidance for the acceptance and rejection of models presented for inspection. In addition to the inspection, question the modeler about his model. Ask him if he has any worry areas and what, if anything, he has done to minimize that worry. Other questions may be directed towards specific features of the model. Ask if he has flown the model before with the installed motor and recovery system. If, for example, electronic recovery or staging are being attempted for the first time ask the modeler how he tested their operation prior to flight. If a lack of knowledge or skills is evident from the conversation then consider performing a more extensive inspection of the model.

Items A1 through A3 provide administrative guidance. Items A1 and A2 are necessary to assure compliance with Consumer Product Safety Commission (CPSC) and NFPA 1127 user requirements. Item A3 guidance is intended to assure compliance with the Federal Aviation Administration (FAA) Part 101 requirements.

A1) Is the modeler over 18? If not, the modeler cannot legally use high power motors, reloadable motors of any power class, or "G" motors. "G" motors and reloadable motors may be used if the individual is accompanied by a parent or legal guardian.

A2) Is the modeler certified to the power level being flown? Ask to see his membership card to verify the certification level. Make sure that the membership card is current. Note that some events will verify the certification level at registration. In that case, the person will have event identification showing the certification level. Individuals flying models meeting the following criteria will require high power certification:

- a) Launches models containing multiple motors with a total installed impulse of 320.01 Newton-seconds or more, or
- b) Launches models containing a single motor with a total installed impulse of 160.01 Newton-seconds or more, or
- c) Launches rockets that weigh more than 53 ounces (1500 grams), or

d) Launches models powered by rocket motors not classified as model rocket motors per NFPA 1122, e.g.:

- Average thrust in excess of 80.0 Newtons
- Contains in excess of 2.2 ounces (62.5 grams) of propellant
- Hybrids

Note that some “F” and “G” motors fall into this category.

A3) Does the model fall within the FAA limitations? Models with less than 4 ounces of propellant and weighing less than 1 pound at launch do not require any additional interface with the FAA.

Models with 4 to 4.4 ounces of propellant or which weigh 1.0 to 3.3 pounds at launch require a notification to have been previously submitted to the FAA. Verify with the event director or RSO that the notification has been submitted prior to accepting these models. Models should be weighed prior to flight to verify that they fall within the weight limit. Motor data, typically available on certification lists, must be consulted to verify compliance with propellant limits.

Models containing in excess of 4.4 ounces of propellant or weighing over 3.3 pounds can only be flown with a FAA waiver. The waiver will specify a maximum altitude for flights. Verify with the event director or RSO that a waiver has been approved prior to accepting these models. Models must be weighed and motor propellant weight determined to verify that the model needs a waiver for legal flight. The performance of the model must be evaluated to determine compliance with the waiver altitude limit. Tables listing the motor type and model diameter may be available to indicate a minimum weight for the model. Models under the minimum weight must add ballast or reduce power to stay within waiver limits. Computer software may also be available on the field to estimate performance.

When estimating performance be conservative by using a lower value for the drag coefficient (C_D). Most airframes will have a C_D between 0.65 and 0.75. Use a C_D value between 0.45 and 0.50 for a conservative estimate of airframe performance.

Cluster combinations will not be addressed on most performance tables. A computer simulation will provide the best estimate of model performance. If a simulation prediction is not available then total the impulse of all motors and the average thrust of all motors. Use this number to identify a similar single motor model for comparison. If the model performance is within 15% of the waiver altitude limit do not permit it to fly without a higher fidelity prediction. Staged models have a similar issue. Since staged models will typically have less drag and higher performance than clustered models the method described above is less reliable. Use the method suggested for evaluating clusters but allow a larger margin for error; if the model is within 25% of the waiver altitude limit do not permit it to fly without a higher fidelity prediction.

Items A4 through A7 concern the rocket motor(s). The NAR safety code requires the use of certified rocket motors. Item A4 addresses this requirement. Items A5 and A6 are intended to verify the correctness of the motor choice and to identify potential safety hazards associated with the igniter. Item A7 addresses a potential hazard with some reloadable designs.

A4) Is the motor certified? Certification lists are available on the Internet or in publications from the certifying organizations. Verify the motor certification status by consulting the certification lists. Note that certification status may not extend to all delays within a motor type.

A5) Is the motor or motors adequate to safely fly the model? If available, consult the manufacturer's recommended liftoff weight. Model drag and weather conditions should be considered. High drag models (caused by basic model design, poor finish) will not go as high as streamlined models. Low average thrust motors in windy conditions allow more weathercocking of the model. The altitude may be limited due to weathercocking and the delay may be too long. Remember that motors with longer delays have lower recommended liftoff weights than the same motor with a shorter delay. If still in doubt, ask the modeler for his performance predictions and the prediction method for the model.

A6) Is the igniter a low current type? Flash bulbs and electric match current requirements are low enough that some launch systems my set them off with continuity power. Verify with the RSO or LCO whether the launch system is "flash bulb safe". Annotate flight cards if required to show the presence of a low current igniter.

A7) Ask the modeler if he is using the motor ejection charge. If he is, verify that he installed the black powder. Also, some motors rely on a tape disk to retain the powder in its cavity. Disks with dry adhesive or lubricant contamination on the forward face of the cavity may reduce the paper disk adhesion. Deceleration forces may cause the paper disk to come free and disperse the black powder. This will cause an ejection failure. It is suggested that the modeler backup the paper disk with masking tape around the edge to prevent it from coming free.

Items B1 through B8 cover the inspection of the basic model structure and recovery system. The check-in officer will need to handle the model during this phase of the inspection. Ask the model builder if there are any safety hazards, e.g. electronic systems, which may be activated while handling the model. The check-in officer needs to use his judgement when pulling and pushing on model parts; the effort needs to be sufficient to find marginal installations or construction but not so great as to damage a properly built model.

B1) Examine all "slip-fits", e.g. nosecone or payload shoulder, which are intended to separate in flight.

Turn the model nose down. It is unacceptable if the nosecone (or payload) can separate under their own weight. If it does, the nosecone (or payload) may "drag separate" just after motor burnout. Drag separation typically occurs at the highest velocity; the effect is often recovery system failure from excessive loads. A loose nose cone (or payload) can be tightened by the addition of tape to the shoulder.

Does the nosecone (or payload) slide free without excessive effort? A tight nosecone (or payload) can be caused by several problems. Paint overspray in the tube or on the shoulder may cause stickiness in the sliding area. A light sanding or a dusting with talcum powder can reduce the stickiness or remove the overspray. A burr may also form at the edge of the body tube. Again, a light sanding can correct the problem.

Check that the nosecone, if used as part of a payload section, is firmly installed. The object is to prevent loss of the nosecone and the payload contents in flight.

Consider the comment "it's flown before" with caution. Temperature and humidity affect the fit of airframe parts (parts swell or contract, finishes may soften in the heat). A smooth fit in an Arizona winter may become a test of muscle and patience in an Alabama summer.

B2) Examine the launch lugs. Are the launch lugs firmly attached to the model without evidence of cracking in the joints? Are the lugs adequately sized for the model?

Suggestions are 1/4" minimum for models up to 3.3 pounds; 3/8" to 1/2" lugs for models up to 20 pounds, 3/4' or larger lugs for models over 20 pounds. Single launch lugs should be at least 6 inches long and mounted at the model's CG. 2 lugs, each spaced a minimum of 2 body tube diameters from the CG are preferred. The separated lugs are preferred because they better resist rotation (from winds) of the model on the launch rod. Rotation of the model on the launch rod may cause binding during launch.

Check the lugs for paint buildup or burrs inside the lug(s). Paint or burrs may cause binding on the launch rod. A rolled sheet of sandpaper can be used to remove burrs or paint.

B3) Examine the fins. Are the fins mounted parallel to the roll axis of the model? Attempt to wiggle the fins at their tips. There should be no movement and minimal deflection. If the fins deflect is the fin material appropriate for the model? Models powered by H, I, or J motors should use 1/8" plywood or fiberglass at a minimum. Higher powered models and high aspect ratio fins (large fin span versus fin chord) require additional strength to resist launch loads and possible flutter problems. Laminated or built-up fins should be checked for delaminations. Bubbles may indicate delaminations. Tapping the fin with a heavy coin (e.g. half-dollar) will give a "dead" thud if a delamination is present. Examine the fin roots for cracks; minor "hairline" cracks may be acceptable if the fins are not loose or if the fins are mounted using "through the wall" construction. Check the fins for warpage; their should be little, if any, warpage.

B4) Examine the engine installation. Verify, if possible, that the engine is what the flight card indicates. If in doubt, ask that the engine be removed from the model. Pull on the motor to make sure it is firmly restrained in the model. If the motor is friction fitted then it should not move when strongly pulled. A positive means of engine retention, e.g. motor clip, bolted washers, is preferred. Verify that the motor cannot deflect the retention device and then eject. A wrap of tape around motor clip(s) to restrain the them against the motor is suggested.

B5) Can the motor "fly through" the model? Push on the nozzle end of the motor. The motor should not move forward in its mount nor should the mount move within the model. Try to determine the type and quantity of adhesive used in construction. Any evidence of "hot melt" adhesives should make the model suspect. Motor mounts should typically be mounted with epoxy adhesives with a sufficient quantity to form fillets at the centering ring to body tube joints.

B6) Is the model stable? Find the CG (center of gravity) of the flight ready model (motors installed, recovery system packed) by finding the model balance point. Where is the CG relative to the leading edge of the fins? On a single staged model with only a rear set of fins the CG should typically be forward of the forward root edge of the fins.

Canards, wings, forward swept fins, and strakes will require the CG to be further forward. Multi-staged models must be evaluated for each stage. Ask the modeler to show the CP (center of pressure) location on the model (and less each stage for a staged model). Request to see the calculations if in doubt. The CG must be a least one body tube diameter forward of the CP in each flight phase. Note that a subscale model may, in most cases, also be flown to show stability of the full size model.

Hybrid powered models must also be examined carefully for stability. Unlike most solid fueled models the CG of a hybrid model may actually move aft during flight. The rearward CG shift may destabilize the model. To be conservative, determine the CG of a hybrid model with the solid fuel component in place but without the oxidizer loaded.

B7) If the model appears neglected or of marginal construction or the builder does not display good knowledge of model practices ask to inspect the recovery system. Pull on the shock cord several times. The shock cord must not be cracked, cut, frayed, or burnt. Discoloration from ejection operation is typically not a problem. Make sure that the shock cord is securely mounted in the model. Make sure any knots in the recovery system will not loosen or slip. Recovery system hardware, including screw eyes and swivels, needs to be strong enough for recovery loads, mounted to solid structure as necessary, and all fasteners are tight. Inspect “quick links” to verify that they are not likely to pull apart under recover loads. Is parachute protection from the ejection charge adequate and nonflammable? Verify that the parachute is undamaged including no loose suspension lines and no tears or burns which may spread during recovery. Is non-flammable, bio-degradable (no fiberglass) wadding being used?

B8) Does the booster section have a vent hole? Typically, a 1/8 to 3/16 inch hole is drilled in the booster section just behind the nosecone or payload shoulder area. This hole is intended to vent the rocket internal pressure to the outside. It is recommended practice on high performance (high altitude) models because it prevents the internal pressure from prematurely separating the nosecone or payload section.

Items C1 through C4 concern check-in items peculiar to cluster models.

C1) If the model is a cluster look for any open holes between the motor mounting tubes. Are the holes sealed to prevent ejection charge gases from venting out?

C2) If black powder and composite motors are mixed in a cluster are the composite motors the first to be ignited? Composite motors are harder to ignite than black powder. The model must not separate from the ignition system before the composite motors are ignited.

C3) Are the motor igniters for the cluster wired in parallel (not in series)? Check for shorts which may prevent igniter function.

C4) Are the igniters "matched"? Igniters having different current requirements may not light at the same time. Igniters that light quickly may ignite their rocket motors prior to ignition of other motors in the cluster. The model may leave the pad before all the motors are started.

Items D1 through D6 concern the use of radio control equipment.

D1) If radio control is used for flight functions, is the operating frequency in the 27, 50, 53, or 72 megahertz bands? 72 megahertz radios using the "old" 2 color flag system for frequency identification are not legal. 75 megahertz frequencies may not be used for flight functions. Note that 27 megahertz usage, while legal, is discouraged due to the possible interference from citizen band (CB) radios.

D2) If using 50 or 53 megahertz does the operator have a valid Technician or higher (General, Extra, Advanced) ham license in his possession?

D3) Did the operator range check his equipment? A range check is performed by collapsing the transmitter antenna and walking away from the model while an observer watches the function of one of the radio controlled channels. Modern receivers will generally operate without glitches or loss of control between 75 and 100 feet from the transmitter.

D4) Does the operator have authorization to use the frequency? "Clothespin" frequency control and/or radio impound may be used to prevent unauthorized frequency use. Find out from the event director or RSO what the frequency control procedures are.

D5) Is the radio (transmitter) compliant with AMA narrow band guidelines? Older radios will have gold stickers on the radio. All radios built since 1991 will comply with the narrow band requirement even if they do not have gold stickers.

D6) Are receiver antennas protected from breakage (not flopping freely, do they have strain relief)?

Items E1 through E4 concern the use of electronic systems for parachute or staging operations. Item E4 addresses problems peculiar to the use of mercury switches. Although generally obsolete and unreliable, less sophisticated modelers may still attempt to use a mercury switch for staging.

E1) Ask if electronics are used in the model (e.g. for parachute deployment, staging). Examine the electronics for items that may dislodge (e.g. motor igniters) or break during flight. Are heavy items, e.g. batteries, adequately supported to prevent coming loose from "g" loads.

How did the modeler verify the functionality of his electronics? When was the last time the electronics were checked? Are the batteries fresh? If the recovery is altimeter based, has the modeler verified its operation, e.g. in a bell jar with a vacuum pump?

E2) Does the modeler expose himself to accidental discharge during arming/disarming the electronics? Do the electronics indicate whether or not they are armed?

E3) Does the modeler have a checklist or reminder to arm the system prior to flight and disarm the system upon landing?

E4) Does the model use mercury switches to initiate staging. Mercury switches rely on the deceleration after motor burnout to activate the upper stage. Some motors have a gradual thrust decay that will not provide a sufficiently "sharp" deceleration to activate the mercury switch. In this case the model will arc over in flight prior to upper stage ignition.

Verify that the modeler has chosen an motor with a "sharp" thrust decay. Verify that the modeler has some means by which to deactivate the system in the event of a flight failure or aborted launch.

Mercury is toxic. Most mercury switches use a relatively fragile glass envelope to contain the metal. The envelope can be made more rugged by shrinking a piece of heat shrink tubing over the switch and sealing the ends with epoxy.

Items F1 and F2 concern the launch pads. Modelers will occasionally use their own launch pads to support their models. Verifying the below items during check-in removes a potential burden from the RSO.

F1) If tower launchers are used verify that the model cannot "escape" from between the rails.

F2) Verify that modeler supplied launchers have blast deflectors to prevent exhaust impingement on the ground.

The safety check-in officer has no obligation to allow models to fly. If, in his best judgement, a model is unsafe then it shall not pass through check-in. If technical doubts are present then the safety check-in officer should consult with the range safety officer. Modeler's excuses, including long drives and event entry expenses should not compromise the safety check-in officer's decisions.

Range Safety Officer Guidelines:

Items G1 through G16 concern the basic range setup and facilities. The RSO should review the range setup prior to the start of launch activities to identify potential safety issues. The RSO also needs to be familiar with the location of safety equipment, e.g. fire extinguishers, first aid kit, and telephone.

G1) Is a means of measuring wind speed or getting weather reports available?

G2) Do all launch pads have blast deflectors to prevent exhaust impingement onto the ground? Do launch pads restrict travel of the launch rod to prevent angles greater than 20 degrees from the vertical? Are launch rods securely fastened to the launch pad to prevent lofting of the launch rod with the rocket? Are the launch rods unbent and clean to minimize the likelihood of a rocket binding on the pad?

Do the launch pad numbers match the numbers on the launch controller. Mismatches may allow confusion regarding which pad is active and cause the launch of the wrong model.

Are launch pad numbers visible from all directions? Visibility allows individuals to determine if they are near "hot" pads if they are approaching from outlying areas.

G3) Does launch equipment have sufficient current output to light igniters with large current demands? Clusters are a concern because multiple igniters in parallel will draw more current than single igniters.

G4) Is the launch controller "flashbulb safe"? Some igniters, e.g. flashbulbs and electric matches, have very low current requirements for ignition. Launch equipment, which is not flashbulb safe, will ignite these igniters with the continuity current flow. Continuity currents of 10 milli-amperes or less are generally considered flashbulb safe. This is a general guideline because there are no specified "no-fire" currents for flashbulbs. If a question exists about the safety of the launch control equipment a representative igniter (without motor) should be tested for the possibility of accidental ignition.

G5) Is the ground cleared of all flammable materials around the launch pad? If not, have provisions been made to water down the area to prevent fire? Launch areas will have to be periodically re-watered to compensate for evaporation. Minimum clear distances are 50 feet for "H" through "J" motors, 75 feet for "K" motors, 100 feet for "L" motors, and 125 feet for "M" through "O" motors.

G6) Are launch pads located away from personnel per the distances specified in the safety codes? Are barriers, e.g. flag lines, in place to prevent entry into launch areas? Is pad access planned to minimize personnel crossing launch control wiring or approaching other "hot" pads.

G7) Will the model trajectory cause models to land in spectator or non-participant areas? Remember that fin stabilized rockets will weathercock into the wind. Consider the trajectory possibilities for models which have recovery failures and those that drift in the wind after recovery. Where possible, locate spectator, preparation, and parking areas away from the likely impact points for recovery failures.

G8) Is fire fighting equipment available? Water is the preferred fire fighting agent for grass fires. An A:B:C: dry chemical extinguisher should also be available to fight electrical or fuel fires (e.g. gasoline from a generator). Does a fire fighting plan exist? At a minimum, all personnel on the range should be told to stop whatever preparations or launch activity they are doing and assist in containing a range fire.

G9) Are battery terminals protected from accidental shorts, which can cause a fire or battery explosion? If used, are 110 VAC supplies protected to prevent electrical shock (e.g. ground fault interrupter). Extension cord connections should be raised above wet grass. The use of 110 VAC power should be suspended in the event of rain.

G10) Is a first aid kit available? Are emergency telephone numbers for fire and ambulance easily available? Is a phone nearby to call for assistance?

G11) How are participants and spectators made aware of an incoming model? Public address announcements work but consider a siren or air horn as a heads up signal.

Some ranges use a broadcast band FM transmitter to allow reception of countdowns and range head information. Consider setting up inexpensive FM radios at the edges of the range area to make announcements more audible in those areas.

G12) Is smoking controlled? Safety codes prohibit smoking with 50 feet of launch and preparation areas. Be aware of other flammable materials on the site where smoking may be a hazard. Are "butt" cans available to prevent discards of lit smoking materials on the ground?

G13) If applicable, is the FAA waiver activated? Is a copy of the waiver available on the launch range? Do all participants know the waiver limits? Is a contact point and method (e.g. cellular phone) available to the FAA in the event of a problem?

G14) Does the RSO have a means of clearly and consistently communicating with the launch control officer (LCO)? The communications must be clear to allow coordination of pad access and launch permission.

G15) Are binoculars available to allow the RSO to better assess the safety of a airborne rocket?

G16) Where are models with electronic systems prepared/armed for flight? Is there a preparation/arming area positioned and/or isolated from event participants to minimize exposure in case of inadvertent activation of an upper stage or recovery system? Radio emissions can cause inadvertent electronic system activation. Are any controls in place for the use of radio transmitters around electronic staging or recovery systems?

Items H1 through H7 concern activities immediately prior to the launch of a rocket. The RSO should be constantly scanning the launch pad areas for personnel and skies for aircraft.

H1) Is the launch angle within 20 degrees of the vertical?

H2) Is the model stable on the launch pad? Verify that the model is not twisting around its launch lug in a manner that may cause binding on the launch pad. Verify that the model and launch rod are not “whipping” around in the wind. This may be indicative of too small a launch rod diameter. Does the launch rod look adequately long for the model on the launch pad? How close is the upper launch lug to the end of the rod? Many 1/4 inch launch rods are at least 4 feet long; many 1/2 inch launch rods are at least 6 feet long.

H3) Are winds within safety code requirements (no greater than 20 miles per hour)? Staged models and models with large fin areas may weathercock significantly into the wind; consider the possible trajectories of such models before launch.

H4) Are spectators or modelers within the safe distance of the launch pad? Make sure that adjacent launch pad preparations are not too close to the active launch pad. Hold the launch until people are clear of the pads.

H5) Are the skies clear of aircraft? Ask for assistance from other launch participants to scan for aircraft. Has the tower or other FAA facility been notified of the launch if required by the waiver conditions?

H6) Is the model being launched a hybrid? Hybrid motors are more sensitive to ambient temperatures than solid rocket motors. Cold temperatures will significantly reduce performance as compared to a solid rocket motor. Consider giving launch priority to hybrid powered models because of their environmental sensitivity.

H7) Are required model electronics armed for flight? Are there any “Remove Before Flight” streamers hanging from the model? Does the modeler need to arm his electronics manually prior to launch; ask if he has done so? Are all umbilical and lanyard connections attached (or detached) as required for model operation?

Items J1 through J5 concern observations of the flight. The RSO should observe the model’s operation at least until the recovery system has fully operated and the rocket’s safe descent is verified. Even after verifying the rocket’s safe descent it should be periodically observed to ensure that its touchdown is not a threat to personnel or property.

J1) Are models penetrating the cloud cover? If models are penetrating the cloud cover there is a hazard to aircraft (and a violation of most FAA waivers). Identify the altitude where the cloud cover exists and modify the allowable power and weight requirements to prevent cloud penetration.

J2) Are models trajectories taking the models over spectator or parking areas? Adjust pad angles to prevent models from entering these areas.

J3) Remember that staged models will have multiple pieces requiring recovery. Observe all pieces to verify that their recovery systems have deployed. Warn range personnel if incoming parts are a hazard.

J4) Models with electronic recovery systems may have multiple deployment events. A drogue parachute may be deployed at apogee and a main parachute may be deployed at some preset distance above the ground. Observe the model to verify that all planned recovery events occur. Warn range personnel not to handle a model that has not completed all planned deployment events because live charges and armed electronics may present a hazard. Only the model builder or people familiar with the rocket’s systems should handle a model with electronic deployment after a flight.

J5) Is there a common thread to any flight failures, e.g. a particular modeler, model, or motor? Notify the check-in officer to prevent potential problems from reaching the launch pad.

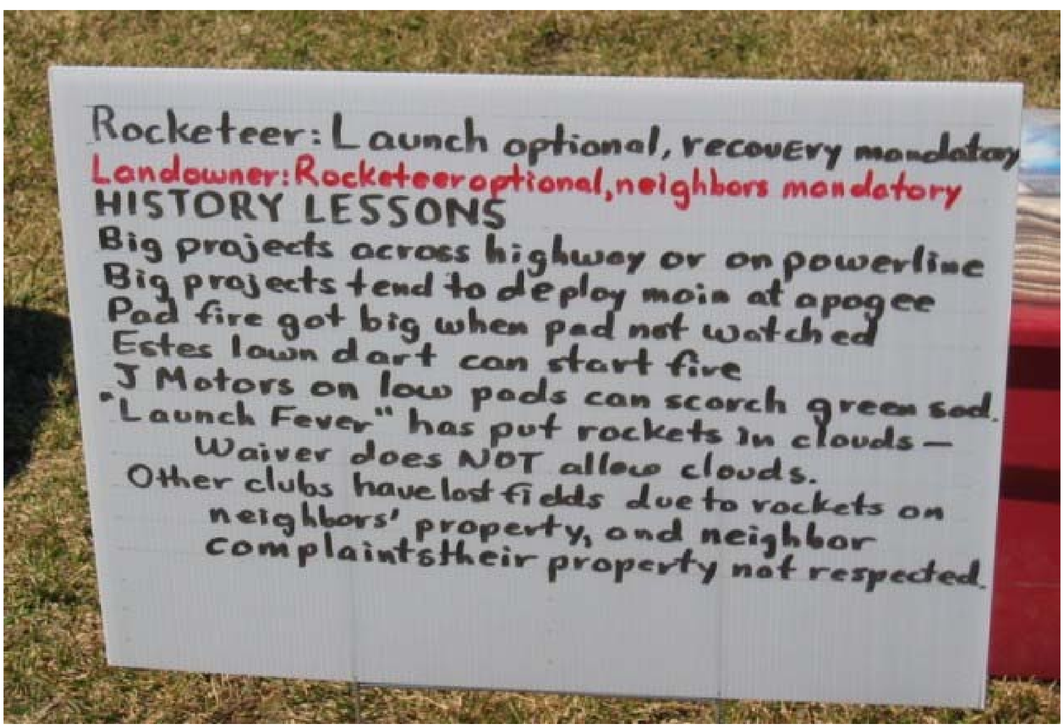
Appendix F
South East Alabama Rocketry Society NAR 572
Green's Grass Farm Launch Site Specific Rules

Safety:
These rules apply IN ADDITION TO NAR Safety Code.

1. Pad fire watch- person designated to watch the pad for fire, not watch the rocket, will be in effect for all launches of any size motor.
2. Site specific and wind specific altitude limits apply. Limits are based on 30 fps descent rate assuming a vertical flight, to stay in the field. We want ZERO rockets landing off the field and aggravating the neighbors or the landowner. Additional actions such as tilting into the wind may be needed for slower descent rates, which are common.
3. NO Exceptions to posted altitude limits for winds blowing towards the south or west property boundary, where neighbors are on the other side of the woods. RSO may grant exceptions for flights away from populated site boundary.
4. RSO will give no credit for dual deployment for returning a rocket in the field, for large (5" and up) diameter projects. Our history shows large projects tend to deploy the main at apogee even if dual deployment is intended,
5. Estes lawn darts can start fires. Therefore all complex rockets regardless of size (multi-engine staged or clustered) will be RSO'd to make sure they will ignite reliably, have sufficient speed not to weathercock off the rod, until the rocket is proven in flight.
6. All new flyers, first time at the field, will be RSO'd, all flights, regardless of motor size.
7. High power rockets can scorch the grass particularly with a low blast deflector. Therefore the Magnum pads (low, blue) will have a maximum of "I" motor, and a maximum of 4" diameter rocket.
8. J motors and larger diameter rockets off the Magnum pads require the pad to be on a fire blanket or on bare dirt.
9. J motors and up should normally be launched off the Quad Pod or larger pad.
10. K motors and up require a fire blanket under the pad, or bare dirt.
11. In dry grass conditions ALL high power pads will be placed on blankets or bare dirt (e.g., road).
12. Igniters should be secured to the pad such that a thrown igniter cannot strike dry grass.
13. Projects over 6000' require advance approval by the Site RSO (Section Advisor).
14. LCO is to verify the following before launch
15. RSO check has been performed if required
16. Rod angle is correct
17. Pad watch is observing the pad for fire at the launch of every rocket
18. Range and sky are clear
19. RSO position is either (a) Level 2 certified Local Club Member, or (b) Level 2 certified visitor who is standing the Pad Fire Watch position.
20. Visiting flyers will be RSO'd by local club member.

Other Site Rules:

- Absolutely no driving on grass, to dodge potholes or for any other reason.
- Park in designated areas only where ground is hard, to avoid making ruts in the turf.
- All adult flyers are expected to stand a watch as LCO or Pad Watch, or to help with range setup and takedown.
- Pick up all trash now matter how minor, including Estes igniter plugs, etc.
- Fire extinguishers will be places at all pad banks, and appx. 100 yards upwind of the low power pads, where a typical Estes lawn dart will most likely land.
- Range and parking will not be set up on newly seeded ground, nor on turf nearly ready for harvest.



Appendix G

Excerpts from NASA Houston Rocket Club Member Handbook

Available at http://www.nhrc.homestead.com/Handbook_2005-3.pdf

1. Only a person who is a certified flyer shall operate or fly a high power rocket.
2. Must comply with United States Code 1348, "Airspace Control and Facilities", Federal Aviation Act of 1958 and other applicable federal, state, and local laws, rules, regulations, statutes, and ordinances.
3. A person shall fly a high power rocket only if it has been inspected and approved for flight by a Safety Monitor for compliance with the applicable provisions of this code.
4. <u>Motors</u>
   I. Use only certified commercially made rocket motors.
   II. Do not dismantle, reload, or alter a disposable or expendable high power rocket motor, not alter the components of a reloadable high power rocket motor or use the contents of a reloadable rocket motor reloading kit for a purpose other than that specified by the manufacture in the rocket motor or reloading kit instructions.
5. A high power rocket shall be constructed to withstand the operating stresses and retain structural integrity under conditions expected or known to be encountered in flight.
6. A high power rocket vehicle intended to be propelled by one or more high power solid propellant rocket motor(s) shall be constructed using lightweight materials such as paper, wood, plastic, fiberglass, or, when necessary, ductile metal so that the rocket conforms to the other requirements of this code.
7. A person intending to operate a high power rocket shall determine its stability before flight, providing documentation of the location of the center of pressure and center of gravity of the high power rocket to the Safety Monitor, if requested.
8. <u>Weight and Power Limits.</u>
   I. Ensure that the rocket weighs less than the rocket motor manufacturer's recommended maximum liftoff weight for the rocket motor(s) used for the flight. During pre-flight inspection, The Safety Monitor may request documentary proof of compliance.
   II. Do not install a rocket motor or combination of rocket motors that will produce more than 40,960 newton-seconds of total impulse (4.448 newtons equals 1.0 pound).
9. <u>Recovery.</u>
   I. Fly a high power rocket only if it contains a recovery system that will return all parts of it safely to the ground so that it may be flown again.
   II. Install only flame resistant recovery wadding if wadding is required by the design of the rocket.
   III. Do not attempt to catch a high power rocket as it approaches the ground.
   IV. Do not attempt to retrieve a high power rocket from a place that is hazardous to people.
10. <u>Payloads</u>
    I. Do not install or incorporate in a high power rocket a payload that is intended to be flammable, explosive, or cause harm.
    II. Do not fly a vertebrate animal in a high power rocker.
11. <u>Launching Devices</u>
    I. Launch from a stable device that provides rigid guidance until the rocket has reached a speed adequate to ensure a safe flight path.
    II. Incorporate a jet deflector device if necessary to prevent the rocket motor exhaust from impinging directly on flammable materials.
    III. A launching device shall not be capable of launching a rocket at an angle more than 20 degrees from vertical.
    IV. Place the end of the launch rod or rail above eye level or cap it to prevent accidental eye injury. Store the launch rod or rail so it is capped, cased, or left in a condition where it cannot cause injury.
12. <u>Ignition Systems</u>
    I. Use an ignition system that is remotely controlled, electrically operated, and contains a launching switch that will return to "off" when released.
    II. The ignition system shall contain a removable safety interlock device in series with the launch switch.
    III. The launch system and igniter combination shall be designed, installed, and operated so the liftoff of the rocket shall occur within three (3) seconds of actuation of the launch system. If the rocket is propelled by a cluster of rocket motors designed to be ignited simultaneously, install an ignition scheme that has either been previously tested or has a demonstrated capability of igniting all rocket motors intended for launch ignition within one second following ignition system activation.
    IV. Install an ignition device in a high power rocket motor only at the launch site and at the last practical moment before the rocket is placed on the launcher.
13. <u>Launch Site.</u>
    I. Launch a high power rocket only in an outdoor area where tall trees, power lines, and buildings will not present a hazard to the safe flight operation of a high power rocket in the opinion of the Safety Monitor.
    II. Do not locate a launcher closer to the edge of the flying field (launch site) than one-half the radius of the minimum launch site dimension stated in Table 1.
    III. The flying field (launch site) shall be at least as large as the stated in Table 1.
    IV.
14. <u>Launcher Location</u>
    I. Locate the launcher more than 1,500 feet from any occupied building.

II. Ensure that the ground for a radius of 10 feet around the launcher is clear of brown grass, dry weeds, or other easy-to-burn materials that could be ignited during launch by the exhaust of the rocket motor.

15. Safe Distances
    I. No person shall be closer to the launch of a high power rocket than the person actually launching the rocket and those authorized by the Safety Monitor.
    II. All spectators shall remain within an area determined by the Safety Monitor and behind the Safety Monitor and the person launching the rocket.
    III. A person shall not be closer to the launch of a high power rocket than the applicable minimum safe distance set forth in Table 2.
16. Launch Operations.
    I. Do not ignite and launch a high power rocket horizontally, at a target, or so the rocket's flight path goes into clouds or beyond the boundaries of the flying field (launch site).
    II. Do not launch a high power rocket if the surface wind at the launcher is more than twenty (20) miles per hour.
    III. Do not operate a high power rocket in a manner that is hazardous to aircraft.
17. Launch Control.
    I. Launch a high power rocket only with the immediate knowledge, permission, and attention of the Safety Monitor.
    II. All persons in the launching, spectator, and parking areas during a countdown and launch shall be standing and facing the launcher if requested to do so by the Safety Monitor.
    III. Precede the launch with a five (5) second countdown audible throughout the launching, spectator, and parking areas. This countdown shall be given by the person launching the rocket, the Safety Monitor, or other flying site operating personnel.
    IV. Do not approach a high power rocket that has misfired until the safety inter-lock has been removed or the battery has been disconnected from the ignition system, one minute has passed, and the Safety Monitor has given permission for only a single person to approach the misfired rocket to inspect it.

TABLE 1: LAUNCH SITE DIMENSIONS

Installed Total Impulse (N-sec)	Equivalent Motor Type	Minimum Site Distance (feet)	Equivalent Distance (miles)
160.01 - 320.00	H	1,500	.28
320.01 - 640.00	I	2,500	.50
640.01 - 1280.00	J	5,280	1.00
1280.01 - 2560.00	K	5,280	1.00
2560.01 - 5120.00	L	10,560	2.00
5120.01 - 10240.00	M	15,480	3.00
10240.01 - 20480.00	N	21,120	4.00
20480.01 - 40960.00	O	26,400	5.00

TABLE 2: SAFE DISTANCE

Installed Total Impulse (N-sec)	Equivalent Motor Type	Minimum Safe Distance (feet)	Complex Minimum Safe Distance (feet)
160.01 - 320.00	H	50	100
320.01 - 640.00	I	100	200
640.01 - 1280.00	J	100	200
1280.01 - 2560.00	K	200	300
2560.01 - 5120.00	L	300	500
5120.01 - 10240.00	M	500	1,000
10240.01 - 20480.00	N	1,000	1,500
20480.01 - 40960.00	O	1,500	2,000

NAR High Power Safety Code

1.Certification. I will fly high power rockets only when certified to do so by the National Association of Rocketry.
2.Operating Clearances. I will fly high power rockets only in compliance with Federal Aviation Regulations Part 101 (Section 307, 72 Statute 749, 49 United States Code 1348, "Airspace Control and Facilities," Federal Aviation Act of 1958) and all other federal, state, and local laws, rules, regulations, statutes, and ordinances.
3.Materials. My high power rocket will be made of lightweight materials such as paper, wood, rubber, and plastic, or the minimum amount of ductile metal suitable for the power used and the performance of my rocket.
4.Motors. I will use only commercially-made, NAR-certified rocket motors in the manner recommended by the Manufacturer. I will not alter the rocket motor, its parts, or its ingredients in any way.
5.Recovery. I will always use a recovery system in my high power rocket that will return it safely to the ground so it may be flown again. I will use only flame-resistant recovery wadding if wadding is required by the design of my rocket.
6.Weight and Power Limits. My rocket will weigh no more than the motor manufacturer's recommended maximum liftoff weight for the motors used, or I will use motors recommended by the manufacturer of the rocket kit. My high power rocket will be propelled by rocket motors that produce no more than 40,960 Newton-seconds (9,204 pound-seconds) of total impulse.
7.Stability. I will check the stability of my high power rocket before its first flight, except when launching a rocket of already proven stability.
8.Payloads. My high power rocket will never carry live animals (except insects) or a payload that is intended to be flammable, explosive, or harmful.
9.Launch Site. I will launch my high power rocket outdoors in a cleared area, free of tall trees, power lines, buildings, and dry brush and grass. My launcher will be located at least 1,500 feet from any occupied building. My launch site will have minimum dimensions at least as great as those in the Launch Site Dimension Table. As an alternative, the site's minimum dimension will be one-half the maximum altitude of any rocket being flown, or 1,500 feet, whichever is greater. My launcher will be no closer to the edge of the launch site than one-half of the minimum required launch site dimension.
10.Launcher. I will launch my high power rocket from a stable launch device that provides rigid guidance until the rocket has reached a speed adequate to ensure a safe flight path. To prevent accidental eye injury, I will always place the launcher so the end of the rod is above eye level or I will cap the end of the rod when approaching it. I will cap or disassemble my launch rod when not in use and I will never store it in an upright position. My launcher will have a jet deflector device to prevent the motor exhaust from hitting the ground directly. I will always clear the area for a radius of ten feet around my launch device of brown grass, dry weeds, or other easy-to-burn materials.
11.Ignition System. The system I use to launch my high power rocket will be remotely controlled and electrically operated. It will contain a launching switch that will return to "off" when released. The system will contain a removable safety interlock in series with the launch switch. All persons will remain at a distance from the high power rocket and launcher as determined by the total impulse of the installed rocket motor(s) according to the accompanying Safe Distance Table.
12.Launch Safety. I will ensure that people in the launch area are aware of the pending high power rocket launch and can see the rocket's liftoff before I begin my audible five-second countdown. I will use only electrical igniters recommended by the motor manufacturer that will ignite rocket motors within one second of actuation of the launching switch. If my high power rocket suffers a misfire, I will not allow anyone to approach it or the launcher until I have made certain that the safety interlock has been removed or that the battery has been disconnected from the ignition system. I will wait one minute after a misfire before allowing anyone to approach the launcher.
13.Flying Conditions. I will launch my high power rocket only when the wind is no more than 20 miles per hour and under conditions where the rocket will not fly into clouds or when a flight might be hazardous to people, property, or flying aircraft. Prior to launch, I will verify that no aircraft appear to have flight paths over the launch site.
14.Pre-Launch Test. When conducting research activities with unproven designs or methods I will, when possible, determine the reliability of my high power rocket by pre-launch tests. I will conduct the launching of an unproven design in complete isolation from persons not participating in the actual launching.
15.Launch Angle. I will not launch my high power rocket so its flight path will carry it against a target. My launch device will be pointed within 20 degrees of vertical. I will never use rocket motors to propel any device horizontally.
16.Recovery Hazards. If a high power rocket becomes entangled in a power line or other dangerous place, I will not attempt to retrieve it. I will not attempt to catch my high-power rocket as it approaches the ground.
LAUNCH SITE DIMENSION TABLE Same as the table in the Tripoli High Power safety code (opposite page).

Special notice regarding high power flights at the Johnson Space Center

The JSC rocket field is limited in size and surrounded by houses and multi billion dollar space exploration equipment. Therefore we must utilize higher safety standards than normal. The following rules are designed to insure we will not have a ballistic impact on any building, and to reduce the possibility of an impact of a heavy rocket under parachute as much as humanly possible.

Please remember that due to the higher level of safety that we must maintain, **WAIVERED LAUNCHES WILL ONLY WE HELD AT JSC ON A LIMITED BASIS. The normal limits and procedures for our regular first and third saturday launches have not changed.**

Here are the basic limitations:
Impulse: "I" motors, No weight limit, Altitude restriction is always 2500' and may be further restricted by winds. For instance with winds over 7 mph from the south, we'll be limited to 2000' for ballistic flight concerns over Saturn Ln. Single parachute flights will be limited to 1500' or 2000' in some wind conditions (chute size will effect this a lot). Splash simulation data and wind charts will be used to determine allowable flights.

A wRASP printout for each high power rocket / motor combination is required. Rocksim or other data is needed for CP and parachute drift performance is also needed. To prevent flights from going above predicted altitudes, simulations must use a Cd of .7 or less. Parachutes must use a Cd of 1.5 or more. These should give good margins of error for both altitude and drift performance in most cases.

Other requirements are that a rocket achieve at least 45 fps off the launch guide, and stability margins must be between .75 and 5.0 Calibers. Rail launching is highly encouraged, there will be a 10' rail available at all NHRC HPR launches. Safety check-in officers will carefully check the rockets expected flight path considering wind effects on weathervaning and parachute drift. All flights must be expected to land within the JSC boundaries.

Of course, all NAR and Tripoli rules as well as JSC and club rules including use of a checklist must be followed at all times.

- Range Officer Duties for High Power Launches

Range Safety Officer (RSO)

--Verify proper clearance from launch controller/spectators

-Perform a preflight PA briefing for the spectators before any flights are to occur that day. This includes but is not limited to insuring that everyone knows that a "Heads Up" means to look up and spot the off nominal condition of the rocket. Also egress to a safe location.

-Remind parents to keep close track of their children, especially during HPR launches

-Briefing should include warning about snakes and fire ants in the area. If bitten, walk calmly back to launch central, apply ice and call JSC emergency (Also Check for ticks and chiggers after launch).

-Repeat briefing throughout the day as new people show up

- Insure all safety equipment in place – Water fire extinguisher, PA system with two speakers, Cell Phone, First aid kit.

- Insure launch controller is compatible with low current igniters

-Insure barriers are in place to keep spectators out of launch area

Safety Check-in Officer (SCO)

- See HPR Checklist

Launch Control Officer (LCO)

- Back up RSO and SCO for all safety rules
- Insure controller is disarmed between flights
- Back up RSO to monitor flight
- Check Cloud bases and winds
  - Insure flight will not enter clouds
- Skies and Launch Area.....Clear
  - Listen and Look for possible aircraft in the area
  - Ensure flight witnesses / spotters are in place
  - Make "Heads Up" PA briefing before each high powered launch .

-Give a **LOUD** countdown, 5..4..3..2..1..Launch!
-Monitor flight path – use binoculars as necessary.
Call loud HEADS UP for any rockets approaching prep area or spectators.

Pad Manager

- Insure controller is disarmed prior to installing rocket on pad
- Insure Launch Pad is stable and adequate size for rocket
- Insure that adequate electrical current will reach igniters
- Verify rocket moves smoothly on launch rail
  - clean as necessary
- Verify igniter clips are clean and leads are secured to pad
- Insure HPR flights are angled away from spectators

High Power Rocket Checklist for JSC -updated Dec 2004

Use Planning and Construction check after prepping avionics and reloads. Use Flight Check at the Safety table.

JSC Emergency: 218 483-3333

Planning Check

-Certification ……..Check flier's certification
-Computer simulation… Check wRASP and Rocksim:
- Use Cd = .7 or less for altitude simulation estimate
  -Max altitude…2500' - lower limits may apply.
  -Launch Guide velocity……. > 45fps, 30mph
  -Stability Margin………….. .> . 75
-Winds……15 mph maximum
-Flight path - Analyze both normal and ballistic scenarios
  – Use computer simulations, tables on reverse to insure safe flight path
-Obtain wind reports from Ellington tower, Bldg.30, 3000' winds aloft, and local observations as needed.

-Motor Impulse, Delay.....Checked
-Insure proper motor and ejection selection for desired flight profile
-Check reload motor for proper build up (O-rings!).
(Reloads - Eject. Charge…Installed)
(Cessaroni…..case installed)
-Ejection charge…proper amount – see chart on back.

Construction Check

Special Instructions.......Checked
-Check the manufacturer's instructions for any non-standard procedures.

Motor Mount……………………... Secure
- Motor retention device …..Check general condition,
  - will not deflect motor thrust.

Fins and Lugs……………..…..Secure and Aligned
Body tube ……………………Good condition
Recovery System.........................Checked
-Shock cord, recovery systems ……Securely attached.
-Shock Cord………. Not cracked, burned, or frayed.
-Shroud lines ………Not burned or tangled.
-Hardware (snap swivels, screw eyes, etc.)…Check.
- Sufficiently strong to withstand recovery loads.

Parachute Protection………… Installed

Electronics Bay (as installed)........Checked
-Avionics……Initially disarmed
(use "Arm Before Flight" reminder flag)
-Bay area properly vented, wires don't cover any ports.
-Drogue and main wiring …….Checked
-Hardware and electrical connections….. Secured against acceleration forces.
-Mach lock-out ……….Check settings if appropriate.
-Batteries……….....….Charged
-Ejection charges…….Loaded – See chart on back.

Flight Check

Planning and Construction Check…. Complete

Nose Cone, Couplers...........Proper fit
- Nose cone, stage or payload couplers ………...Check

Motor Installation ………..Secure
-Igniters ….check for continuity, resistance, and cracks or flaws in pyrogen.
-If Clustering:
  -Insure that adequate electrical current will reach igniters
  - all igniters must touch the propellant, and have no shorts
  -Insure thrust symmetry
-Staging or Airstarts:
  Check staging delay - less than one second recommended

CG/CP................checked

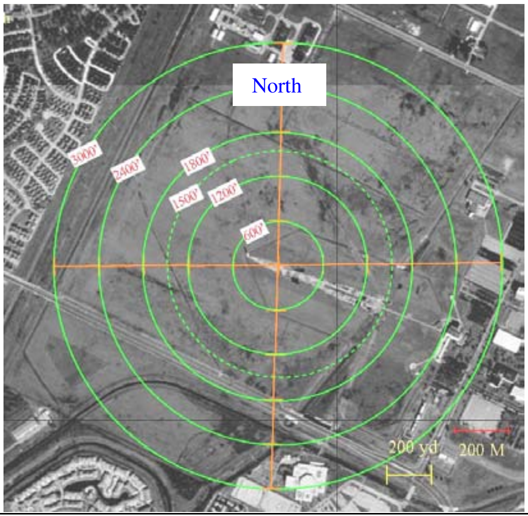
Avionics ………….Check
-Perform manufacturer's checkouts – Continuity check.
-Shear pins………installed for Main 'chute compartment
- Insure drogue ejection will not cause main to deploy

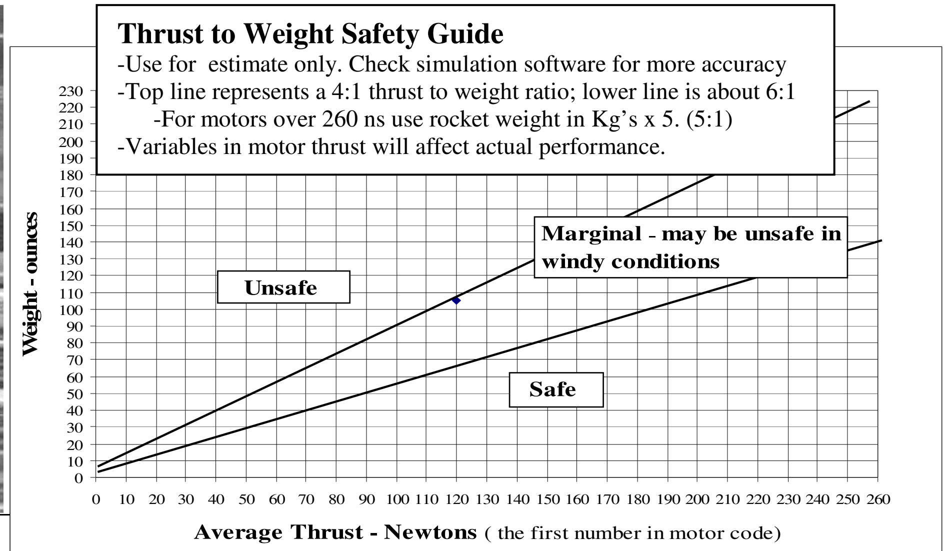
Pad Check.........Complete
-Controller ……..Check Disarmed
-Proper clearance from launch controller/spectators…..Verify
-Launch Pad …….Stable and adequate size for rocket flown
-A adjust launch angle as necessary to insure non-normal flights will not return to spectator or R/C area.
-HPR launches must be angled away from spectators
-Rocket moves smoothly on launch rail - clean as necessary
-Igniter clips ………………Check clean and secure to pad
- Avionics…….Arm on pad

Launch Check.........Complete
-Ensure cloud ceilings are adequate for flight profile
-Check winds…..Confirm drift planning still valid
-Listen and Look for possible aircraft in the area
-Ensure flight witnesses / spotters are in place

Launch..............Announce
-Required PA briefing……………….. complete
-Ensure all spectators are aware of launch - Parents are in close contact with all children
-Give a **LOUD** countdown, 5..4..3..2..1..Launch!
-Monitor flight path; call loud **HEADS UP** for any rockets approaching prep area or spectators
-Disarm controller, place cap on launch rods

Misfire procedures
-Wait a minimum of one minute
-Disarm launch controller and avionics if present
-Remove failed igniter and motor if necessary





Ejection Charge Sizing Chart - 8PSI

- Use 8 PSI for drogue ejection - (Grams 4f powder).
Suggested use - twice this amount for main ejection

Tube diameter	Compartment length			
	12"	18"	24"	48"
3"	.35g	.53g	.7g	1.4g
4"	.62g	.93g	1.2g	2.5g
6"	1.4g	2.1g	2.8g	5.6g
7.5"	2.2g	3.3g	4.4g	8.8g

Descent Rate Guide - Assuming a parachute Cd of 1.5

Parachute Size (Domed chutes may have higher Cd)

Rocket weight	5"	10"	20"	30"	40"	50"	60"	70"
453g - 1lb	[illegible]	[illegible]2	16	10fps				
906g - 2lbs	90	46	13	15	10fps			
2.2kg - 5lbs	72	36	24	18	15fps			
4.5kg - 10lbs	99	50	34	25	20	17fps		
7.7kg - 15lbs	62	42	31	25	21	18fps		

Wind speed/direction vs. Altitude Pie Charts

-Sectors represent direction wind is from. -Use steady state winds + ½ the gusts

Rings represent speed:
Inner = 0-7 MPH
Middle = 8-11MPH
Outer = 12-15 MPH

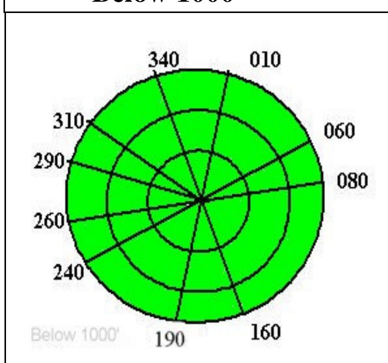
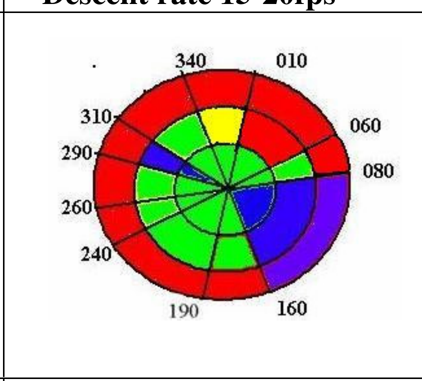
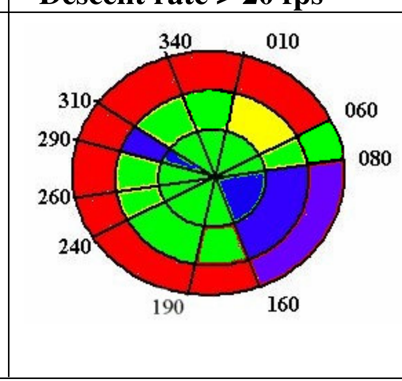
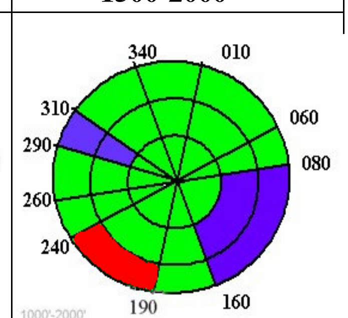
Color indicates safety :
Red…..No Go
Green…OK
Blue …Angle 8⁰ North or Notify R/C fliers
Yellow…Angle 8⁰ angle into wind (or weathervane)

Add 5-10 mph to reported winds for higher winds aloft (check bldg. 30 winds)

Wind drift distance per 1000' altitude

-Be sure to account for winds aloft!

Wind	Descent Rate 15fps	20fps	25fps	70fps
7 mph	685'	510'	410'	145'
11 mph	1075'	800'	645'	230'
15 mph	1460'	1100'	880'	315'
20mph	1935'	1465'	1170'	420'

All Flights	Single Parachute 1500'-2000'		Dual Deploy
Below 1000'	Descent rate 15-20fps	Descent rate > 20 fps	1500-2000'
			
1000'-1500'	Single parachute 2000'-2500' 15-20 fps	>20fps	2000'-2500'