



Safety in Sport Rocketry

NAR Safety Committee

April 2007

**Based on the recommendations of the NAR Special
Committee on Range Operation and Procedures**



Pop Quiz

1. How many people have died as a result of sport rocketry over the past 15 years?
 - A. No one has ever died doing sport rocketry.
 - B. One.
 - C. At least four.



Pop Quiz

2. A 40 pound rocket returning under an open chute at under 30 feet per second descent rate has about the same kinetic energy as
- A. A bullet from a .357 magnum revolver.
 - B. A batted baseball.
 - C. A bowling ball dropped on your foot.
 - D. An Alpha III lawn dart.



Pop Quiz

3. Repeated instances in which large rockets descend under full chute into the parking area, missing all the cars, demonstrate that
- A. The safety code works!
 - B. Wind is too unpredictable to worry about.
 - C. Insurance is a good thing to have.
 - D. We may be flirting with disaster.



Pop Quiz

4. Fill in the blank:

If someone on our club flies a rocket that kills someone, what would be the impact on the member, on our club and on our hobby?



Overview

- Pop Quiz
- Rationale
- Sport Rocketry Safety Data
- Best Safety Practices for Sport Rocketry



Safety Resources

- NAR Safety Codes and National Fire Protection Association (NFPA) Codes were designed to minimize safety risks – *if they are followed!*
- NAR Trained Safety Officer program contains extensive recommendations and procedures for how to run a safe range – *consult it!*
- NAR Safety Committee study of October 2005 is the single most comprehensive look at sport rocket flight safety ever done – *read it!*

These resources may not be enough.



Clusters of Incidents Require *Action*

- The sort of incidents which occur on a sport rocket range (e.g., unstable rockets, failed recovery systems) do occasionally lead to accidents.
- This hobby has had an excellent safety record; *vigilance* is required to maintain it.
- When a series of serious incidents occurs as they have recently, vigilance requires *action*.

- **Yes, rocketry is safe!**
- **But, is rocketry as safe as it can be?**



Near Misses Cause Concern

J forward closure failure
(missed the car)

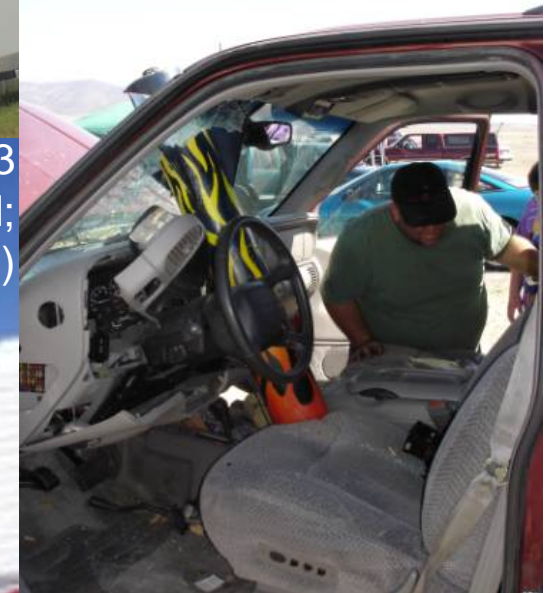


Late ejection in PMC (missed
the truck; hit the trailer)



No ejection, ballistic return
(missed the occupants)

No ejection, ballistic return of L3
rocket (missed the crowd;
more on page 19)



Skidmark-caused fire at NARAM



NAR Safety Study

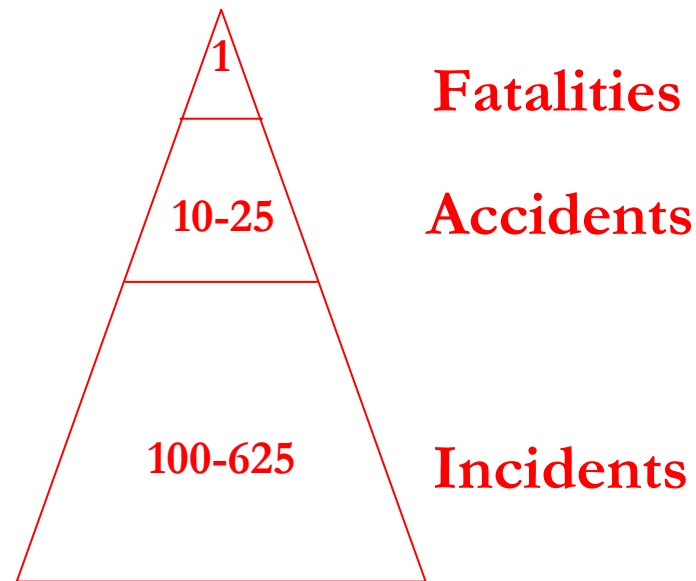
On April 24, 2005 the NAR President directed a 5-member Special Committee chaired by Dr. Jay Apt (NAR Trustee and retired NASA astronaut) to:

“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.”

This material is a result of their research and analysis ₀



The Accident Triangle



- The link between near misses, incidents, accidents, and fatalities is real.
- Active intervention is required to break it.



Overview

- Overview of Safety Practices
- Sport Rocketry Safety Data
- Best Safety Practices for Sport Rocketry



Data Collection Rationale

- If it isn't measured, it can't be improved
- There have been no good statistics available on safety-related failure rates in rocketry
 - No empirical basis for formal risk analysis
 - No quantitative basis for changes to safety practices, or even for measuring improvements to safety over time
- Goal: Start fixing this problem.
 - Develop solid empirical data
 - Begin developing principled basis for decisions

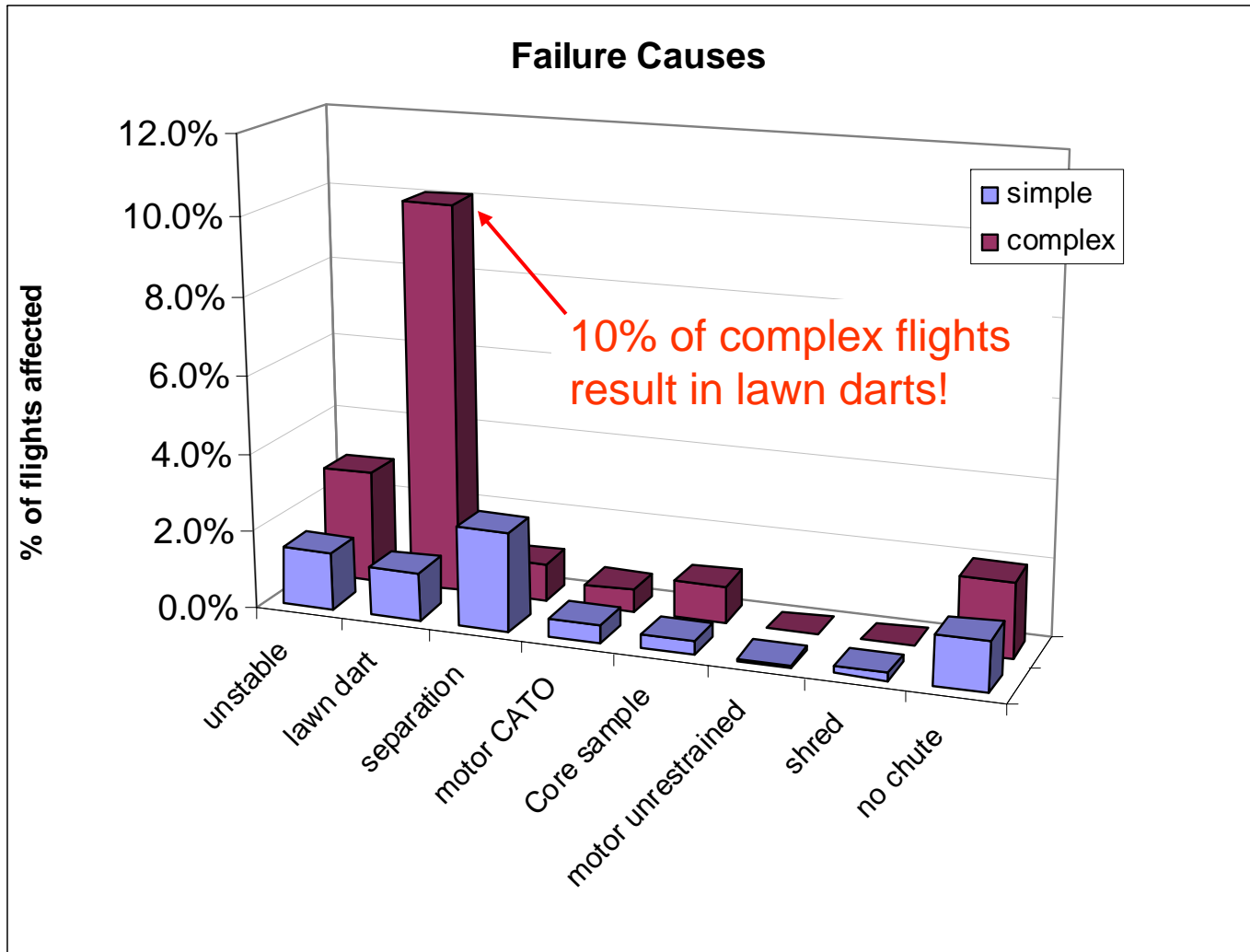


Failure Modes

- Safety Committee reviewed results of 6169 flights
 - Validated against 2 independent data sets of 4546 and 9622 flights
- Average flight failure rate was 8.5%
 - Complex (multi-motor) rockets twice as likely to fail as simple rockets
- $\frac{3}{4}$ of all failures were recovery system failures
- $\frac{1}{4}$ were powered flight phase failures
 - Unstable rockets predominate



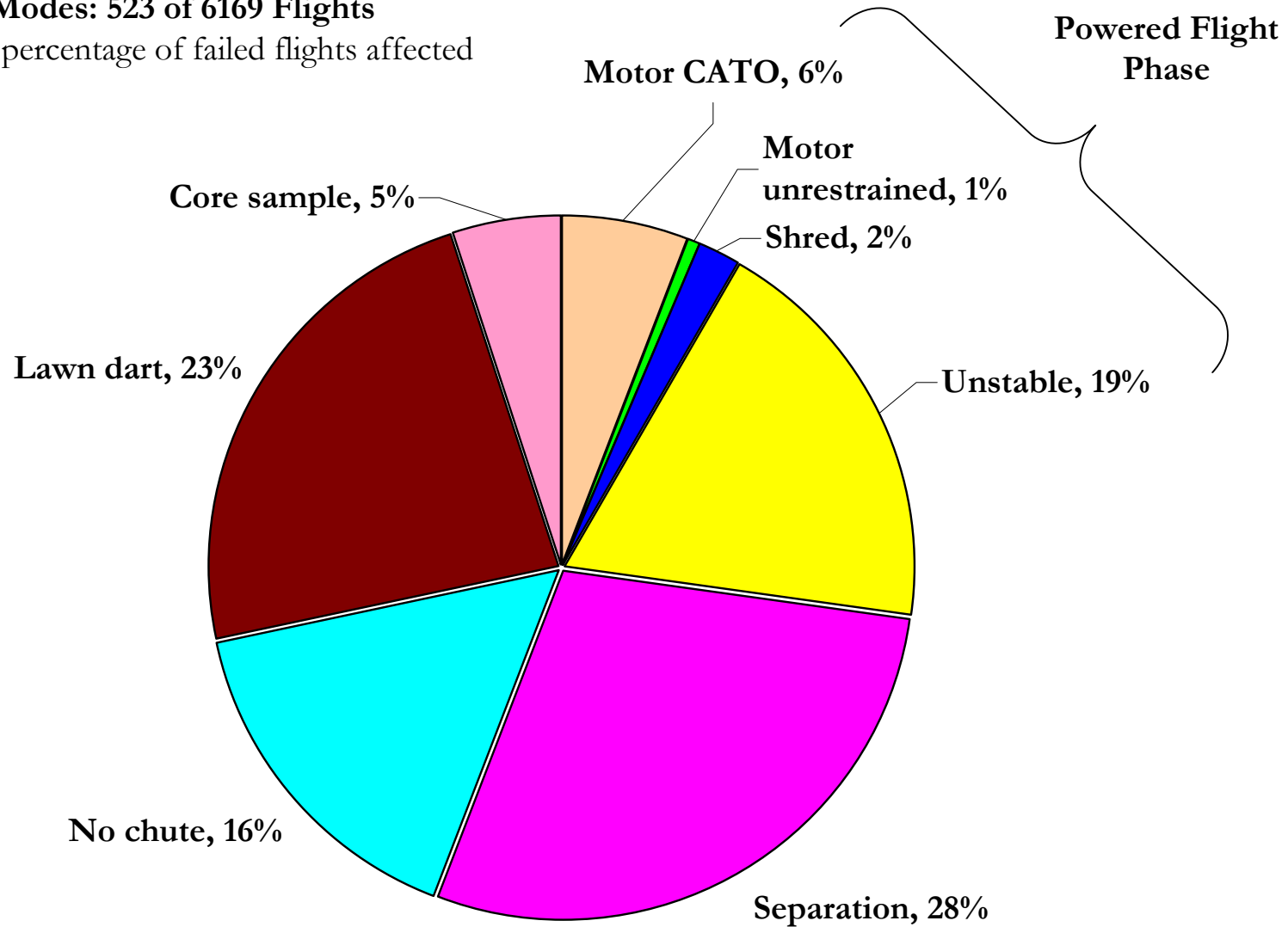
Likelihood of Failures





Distribution of Failures

Failure Modes: 523 of 6169 Flights
Showing percentage of failed flights affected





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Best Practices Concept

- Best practices *start* with Safety Codes and add experience-based practices tailored to specific local circumstances and individual rockets/fliers
- When a safety problem occurs, change the practice that let it happen
 - **STOP** and conduct a post-event review of significant safety incidents (including frightening near-misses)
 - Lessons forgotten or unimplemented from safety incidents may be relearned the hard way at the wrong time



Range Safety Officer

- The RSO is the single person responsible for ensuring that fliers' "right to fly" is limited by their "duty of safety" to others
 - Must just say NO: if a rocket is not safe don't let it fly; if a situation does not look safe, ***STOP and take action*** to change it
- Bigger safety decisions are made at safety check-in than at the point of flight control
 - Focus RSO expertise and attention at both



Historical Risks

- Electrocution from power lines
 - Four *fatalities* in past ten years due to attempts to retrieve rockets from power lines
 - Often overlooked, because “the safety code prohibits it”
- Fires
 - More attention to prevention is required
- Being struck by rockets
 - Probability may be on our side, but adverse consequences in the event of injury are huge!



Power lines: Follow the Safety Code!

STAY AWAY!

Call the power company; let them recover the rocket (even the models you don't want back might attract kids.) Even if it costs you, it is money well spent!



Shorted power line causes arc



Fires: Prevention is Key

- Have adequate firefighting equipment, and *know how to use it!*
 - Fire extinguishers alone will not stop a grass fire – tools needed.
 - Observe burn bans: If dry & windy, fires may be unstoppable –don't fly.
- Clear the area around the pads
 - NFPA requires blast deflector and cleared area near launch pads.
 - Specific cleared distances specified for HPR (extra for “sparky” motors).
 - Pad blankets, pre-soaking of ground can also help.
- Assign a fire watch for the pads; don't just watch the flights.
- Fires at crash sites get momentum if people do not hurry to the site expecting to find one.



NARAM-47



Injury Risk From Being Struck



A potentially lethal event:
Failed L3 attempt with
ballistic return to range
head.

Three frames from:
<http://www.youtube.com/watch?v=bfcud62ct6M>



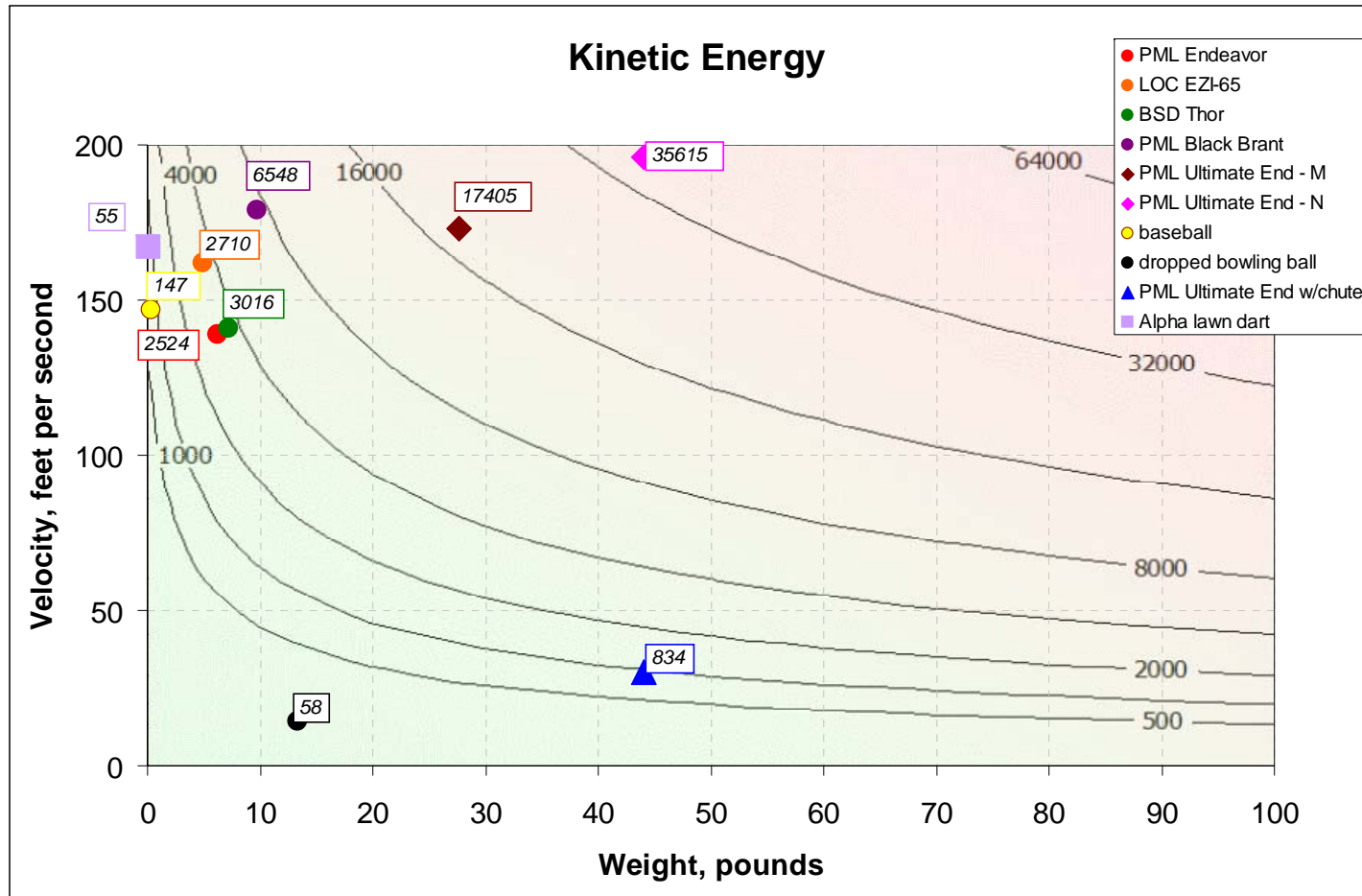
Injury Risk From Being Struck

- Risk of injury depends on kinetic energy and how it is absorbed by body: No fixed danger level.
 - Batted baseball: ~150 joules *
 - .357 Magnum: ~750 joules
 - 40-pound rocket under chute at 30 ft/sec: 759 joules
 - Adult falling out of a second story window: ~3,500 joules
 - The rocket that penetrated the SUV: ~7,700 joules
 - The rocket on the previous page: >15,000 joules
- Impacts ***must*** occur where people are not.
- Recoveries of heavy rockets ***must*** occur at slow speeds and only in safe places !

*Kinetic energy, $\frac{1}{2}MV^2$, is measured in joules. A 1-pound object impacting at 100 feet per second (68 mph) has a kinetic energy of 210 joules.



Energy of Falling Bodies

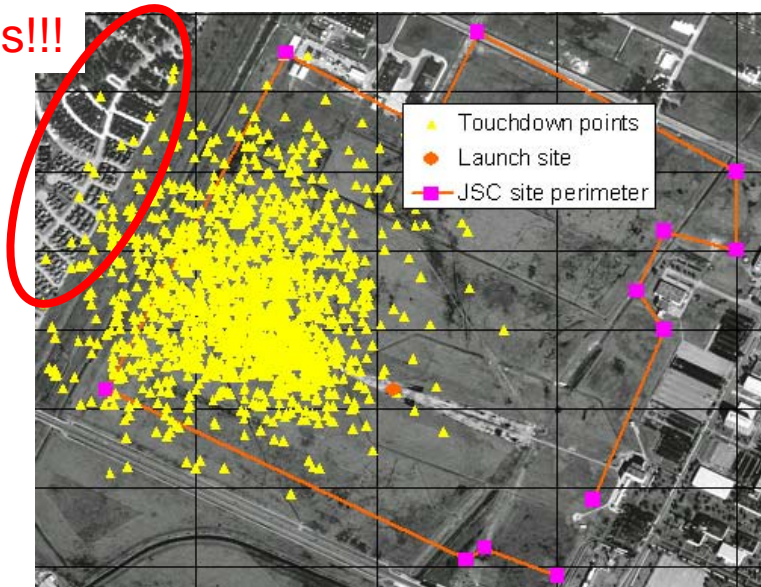




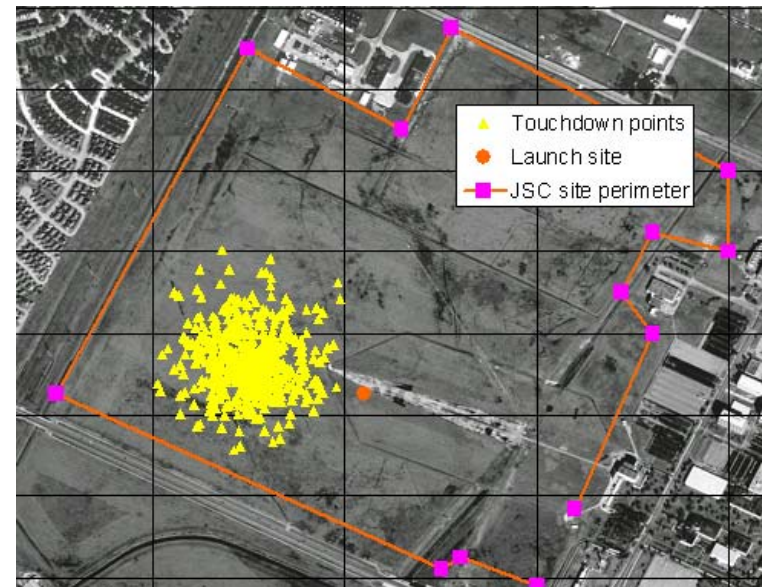
Keep Rockets on the Field

SPLASH-predicted landing location for HPR on an I453 to 2580 ft. Both parachute recoveries and ballistic trajectories can impact over 2580 ft. away!

Houses!!!



Standard Recovery
Many flights out-fly the field



Smaller Parachute or Dual Deploy
All flights stay within the boundary

1500 runs, with winds varying from 0-20 mph, from 320 degrees with a 1-sigma variability of 45 degrees²⁶



Mitigation Example

NASA Houston Section

Wind speed/direction vs. Altitude Pie Charts

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

Rings represent speed: Color indicates safety :

Inner = 0-7 MPH

Red.....No Go

Middle = 8-11MPH

Green...OK

Outer = 12-15 MPH

Blue ...Angle 8° North or Notify R/C fliers

Yellow...Angle 8° angle into wind (or weathervane)

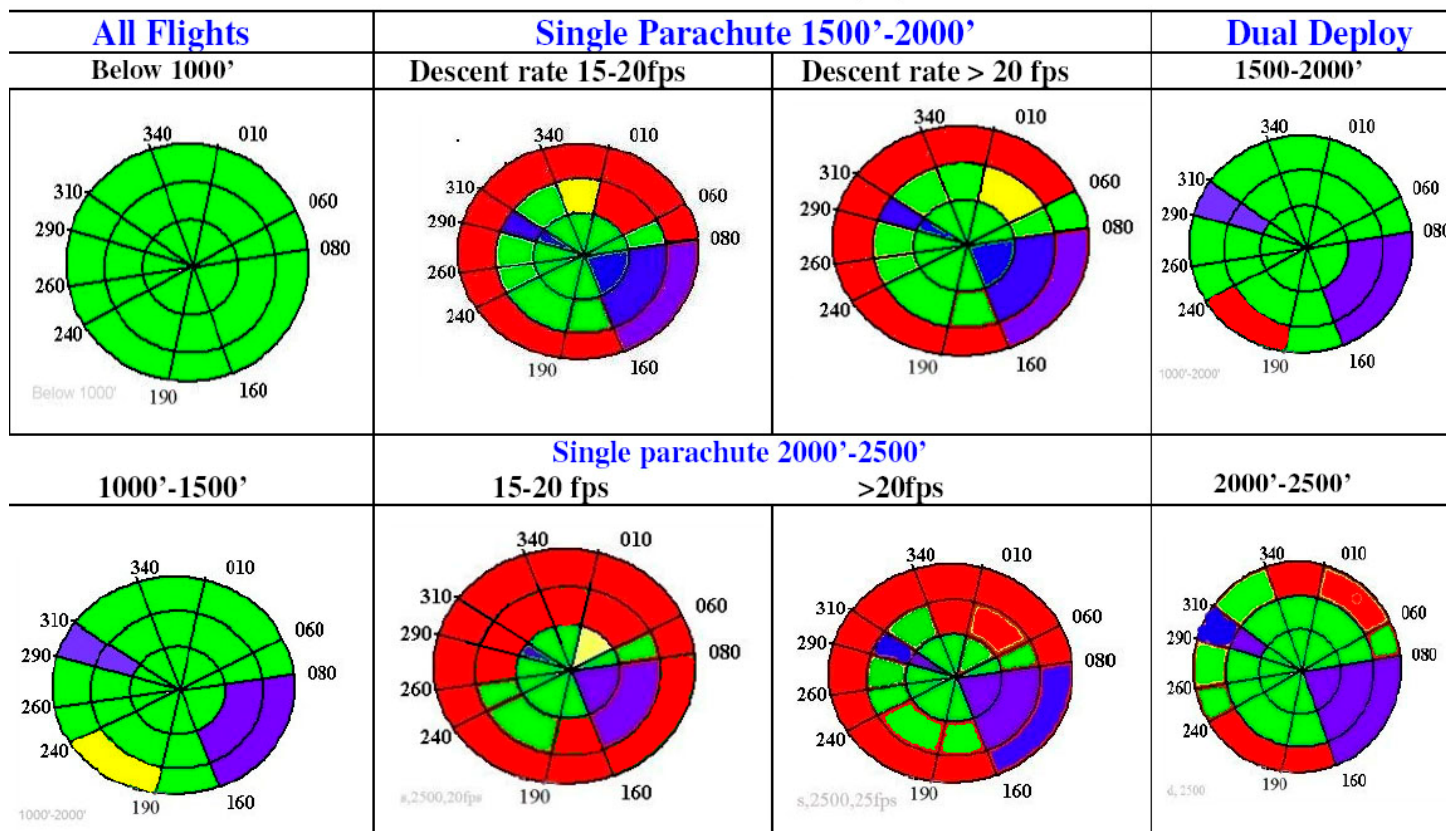
Add 5-10 mph to reported winds for higher winds aloft (check bldg. 30 winds)

Wind drift distance per 1000' altitude

-Be sure to account for winds aloft!

Descent Rate

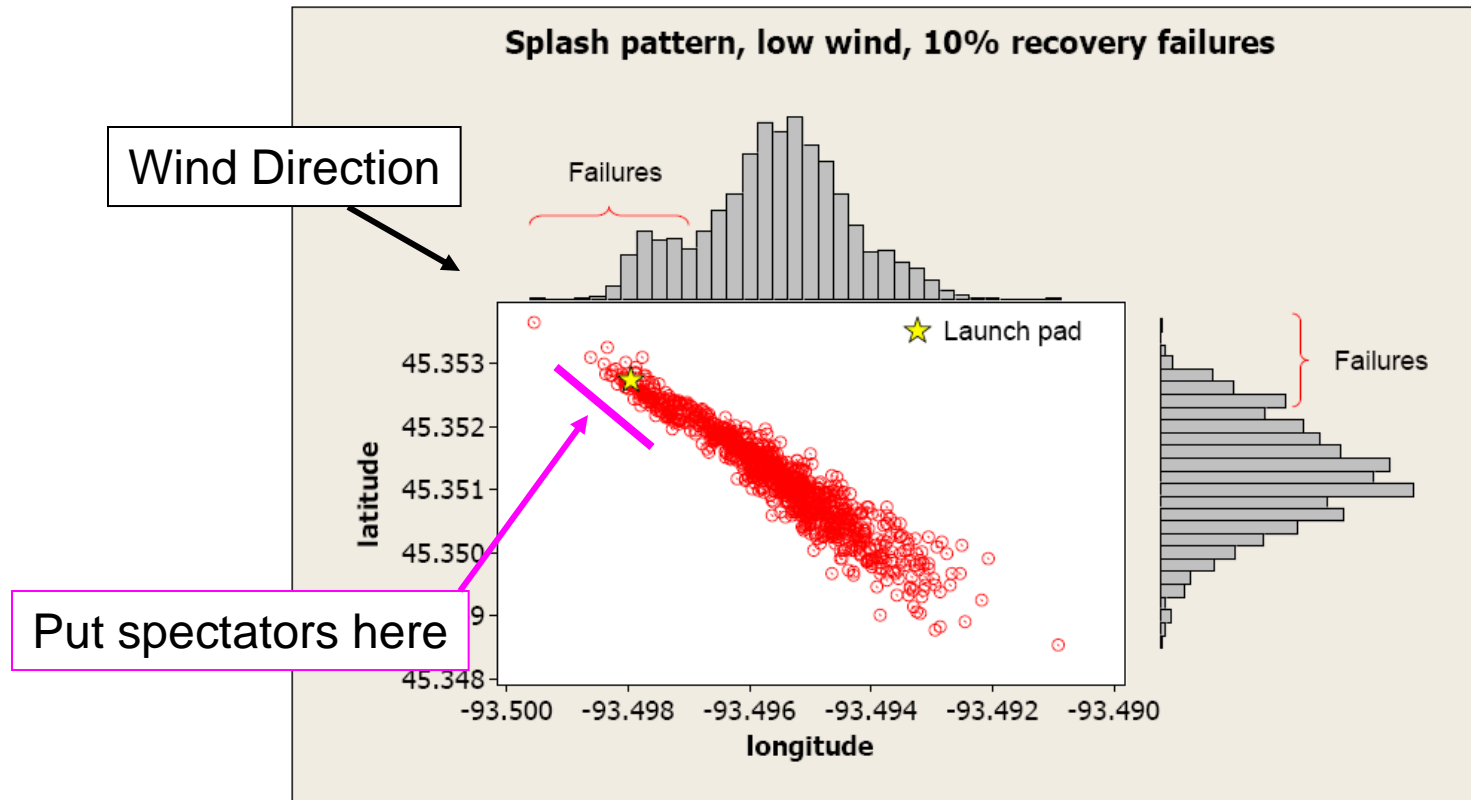
Wind	15fps	20fps	25fps	70fps
7 mph	685'	510'	410'	145'
11 mph	1075'	800'	645'	230'
15 mph	1460'	1100'	880'	315'
20mph	1935'	1465'	1170'	420'





Keep Spectators Safe

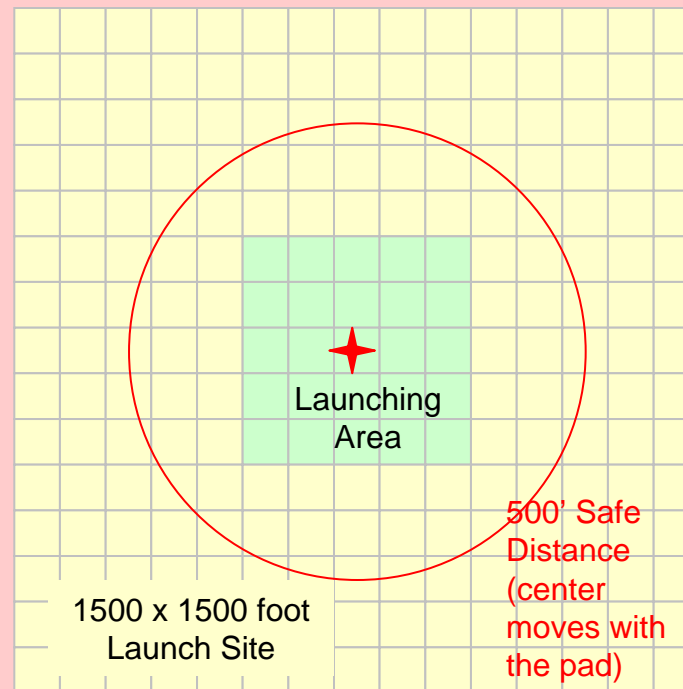
Very significant risk reduction can be achieved by positioning people and vehicles crosswind from the launch pads.





New Field Dimensions

1500 x 1500': Good for Simple M rockets up to 3000' AGL
No inhabited buildings or highways within 1500' of launch pad
Pad can be placed anywhere within green circle, spectators anywhere outside the inner red circle, which moves with the pad.

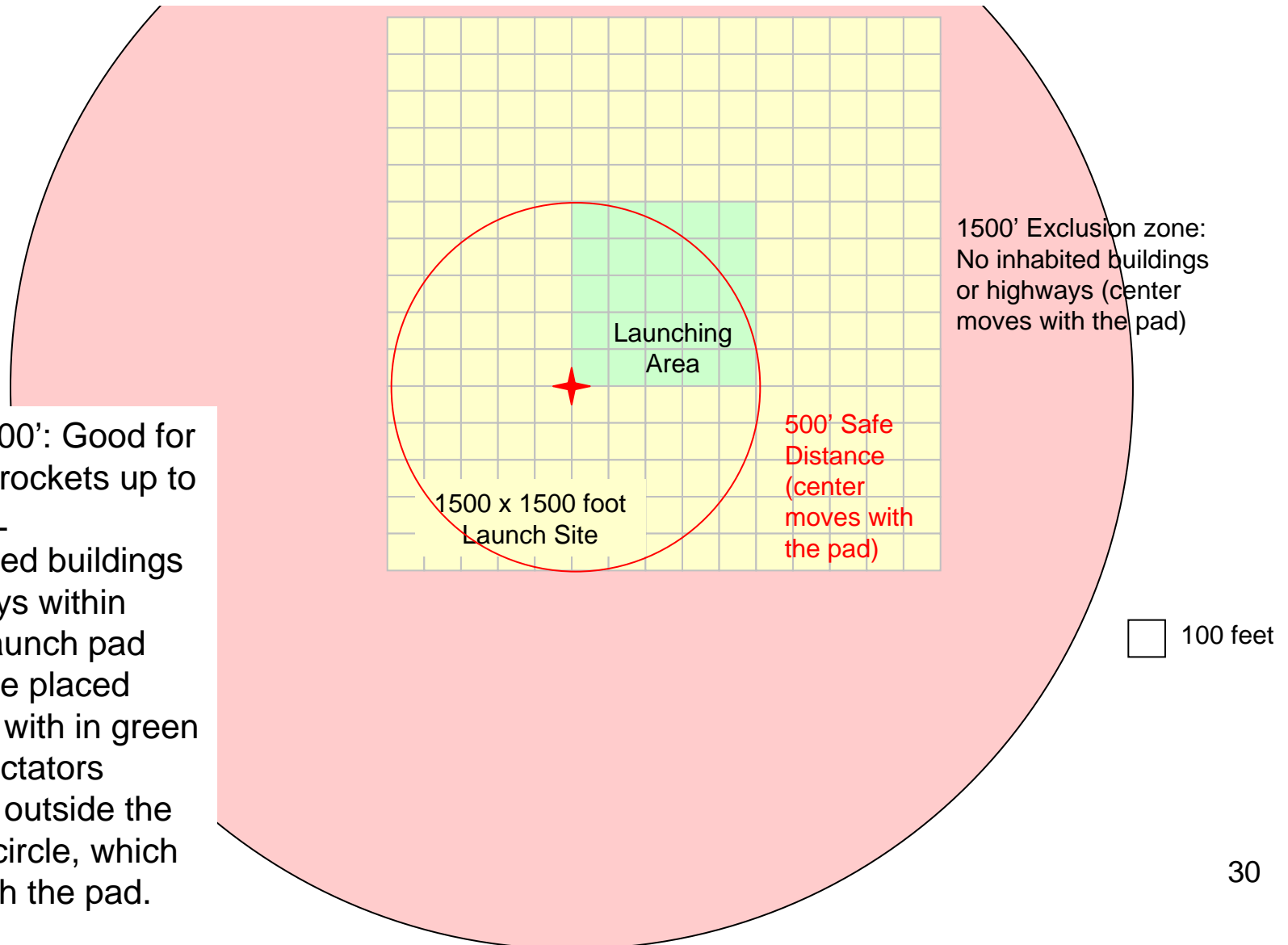


□ 100 feet



New Field Dimensions

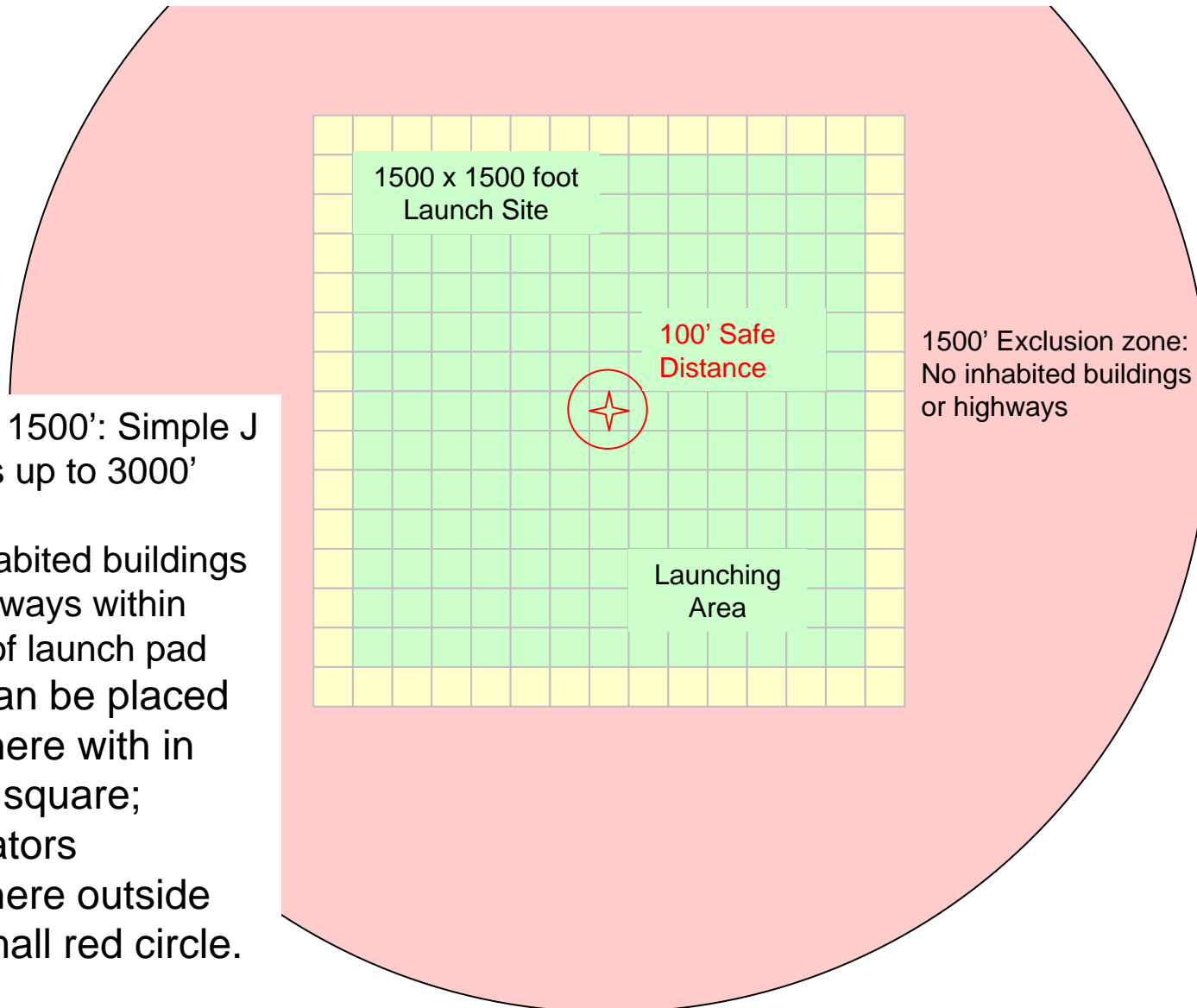
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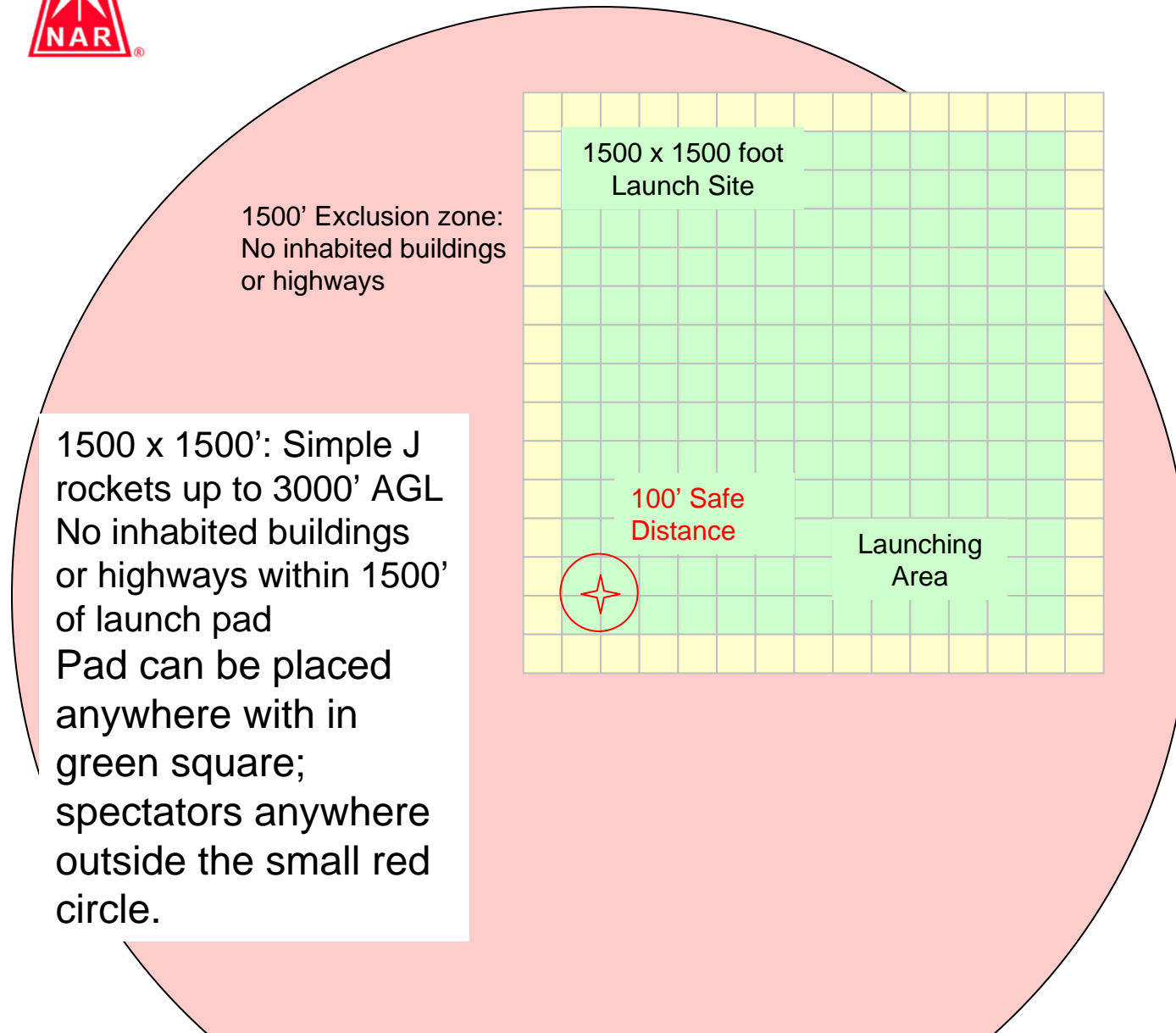
1500 x 1500': Simple J rockets up to 3000' AGL
No inhabited buildings or highways within 1500' of launch pad
Pad can be placed anywhere within green square; spectators anywhere outside the small red circle.



□ 100 feet



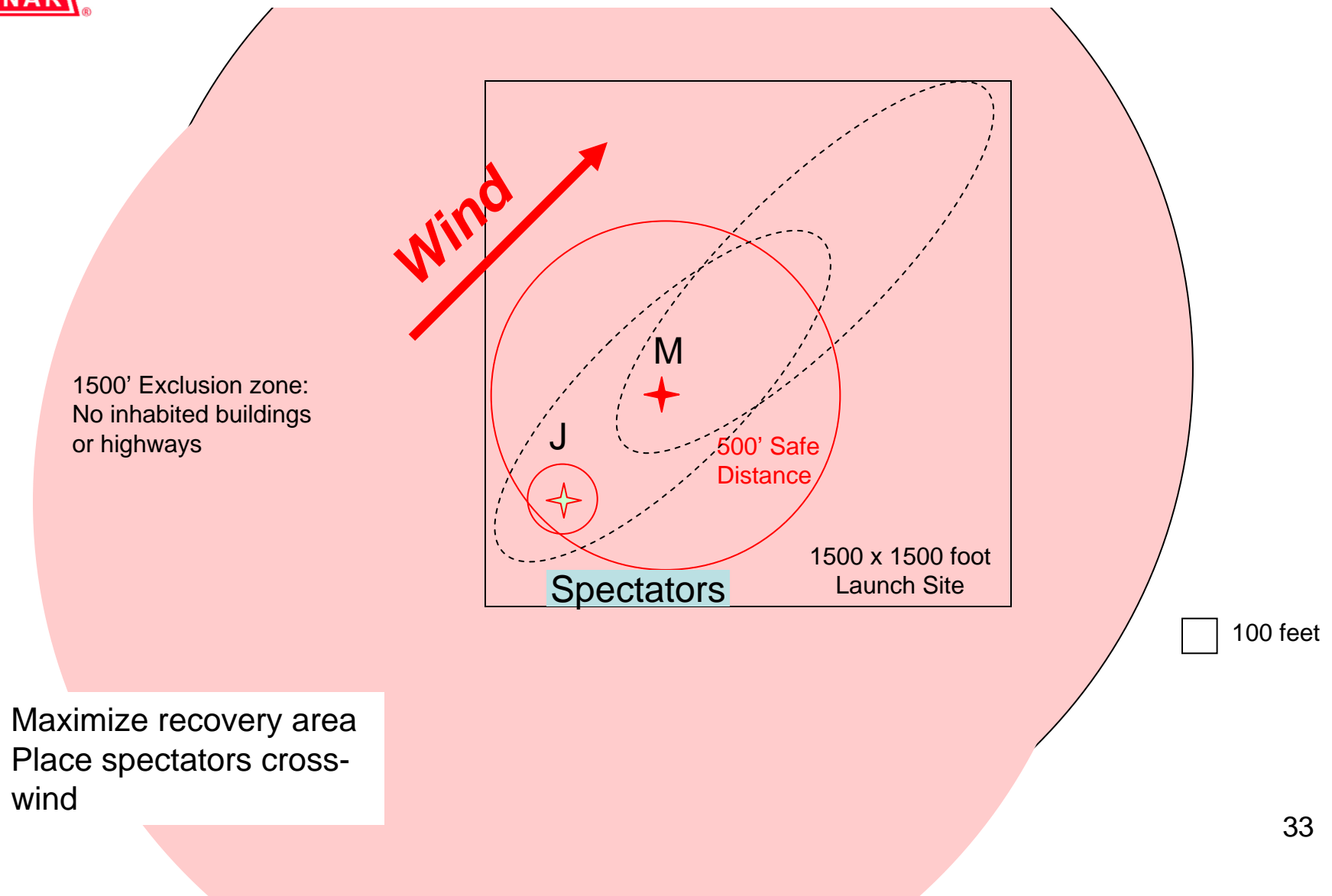
New Field Dimensions



□ 100 feet



Ideal launch site layout for small fields





Other Best Practices

- Have a standard and effective procedure for warning all people on the launch site of dangerous events.
- Reduce recovery system failures for heavy rockets through prior inspection.
- Increase pre-flight attention to rocket flight stability
- Ensure initial thrust and launcher length and stiffness are sufficient to achieve safe trajectory.
- Review safety incidents, and collect and review safety data from all flights to detect trends and problems.



Crowd Safety

- Launch standoff ranges apply to spectators, photographers, and to people returning with rockets.
 - Use flag line liberally.
- Make sure launch rods and flight paths (with weathercocking) point away from the crowd.
 - Ensure heavy rockets are landing only within launch site.
 - Don't let boost trajectories over-fly spectator/parking areas.
 - If a rocket does over-fly spectators, **STOP** and FIX THE PROBLEM!
- Use RSO “heads up” calls, but don't abuse them.
 - Ensure they are audible in the spectator area (PA/FM).
 - Have people point to the hazard to cue everyone else.
- Know who to call and what to do if an accident or injury (of any kind or cause) happens.



Recovery System Safety

- Recovery system failure is the hardest mode to prevent – and the most dangerous!
 - Rockets normally have system already packed at check-in.
 - Do “peer review” of packing and structural integrity before check-in – and if in doubt, disassemble.
- Common failure causes are detectable & preventable:
 - Drag separation of heavy nose at burnout or failure of a tight-fitting nose to separate at all.
 - Weakness in shock-absorbing/anchoring system.
 - Inappropriate delay time and/or trajectory = excessive ejection velocity.
 - Electronics malfunction (usually user-induced) for HPR.
 - Failure to adequately restrain motor at ejection.



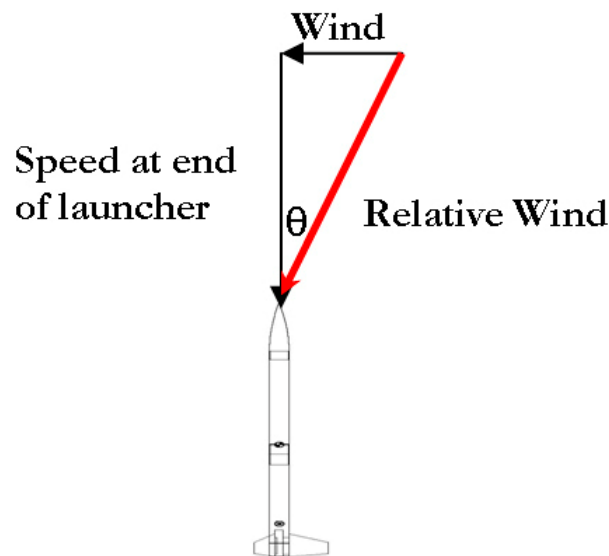
Stability Safety

Significant reduction in risk of having unpredictable trajectories can be achieved by:

- Use of existing simulation tools to determine rocket static/dynamic stability before flight.
- Using long-enough, stiff-enough rods (better yet, rails!)
- Compensating for effect of wind in reducing stability and causing non-vertical flight.
 - Crosswind moves Center of Pressure forward
 - Increased velocity off the launcher required in wind



Stability vs Wind

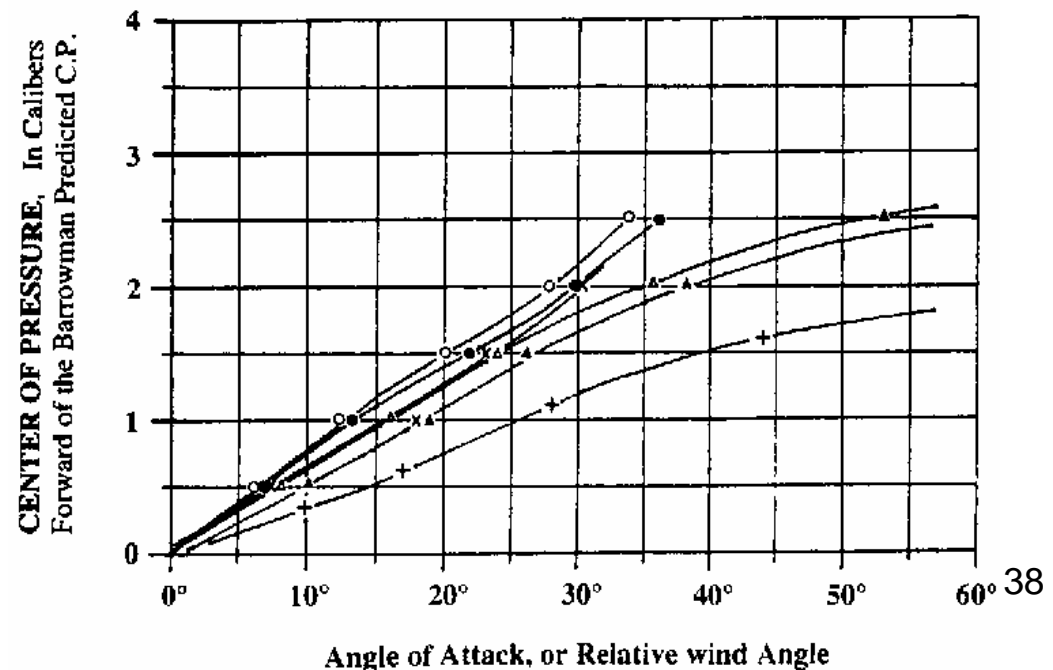


A rule of launch velocity at least 4 times the wind speed (14° AOA) limits the CP shift to ~ 1 caliber.

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.

If the wind is 10 mph, the angle of attack θ is 13 degrees if a 3 foot rod is used, and 9 degrees with a 6 foot rod.

FIGURE 1 - WIND TUNNEL STABILITY TESTS
JANUARY 25-28 1998





Launch Control Safety

- Test every pad before a launch, measure battery charge, and clean/replace all clips.
 - Know if the launch system is “electric match” safe.
 - Know what happens to launch voltage if a relay fails.
- Take care in designing safety keys, interlocks, and pad selection.
 - It is very dangerous to fire one pad on a system when other pads controlled by that system are still loading.
 - Make sure LCOs understand the system each shift.
- Make sure spectators within rocket’s ballistic range are aware of impending launches and can be warned instantly if a dangerous event occurs.
 - Public address and/or FM radio announcement.



Summary

- Our hobby's survival in our litigious society depends on its real and perceived safety.
- Safety occurs only when responsible people understand the risks of their activities and make mature, informed decisions to manage them.
- Our hobby's safety is in our hands.



What Can You Do?

- Each section should apply the lessons of this study in ways that suit their local circumstances and fliers
- Hold a meeting with safety as the agenda and ask:
 - How can we do safety check-in better to catch and correct rockets with potential safety issues before they fly?
 - How can we lay out or operate our range better to reduce the chances of a failed rocket hitting something?
 - How can we communicate better with participants and spectators to inform them of our safety procedures and warn them rapidly of unsafe flights?
 - How can we better collect accurate data on safety incidents and use it effectively to learn how to prevent them in future?



Answer Key: Pop Quiz

1. How many people have died as a result of sport rocketry over the past 15 years?

A. No one has ever died doing sport rocketry.

B. One.

C. At least four.

[All from electrocution by power lines]



Answer Key: Pop Quiz

2. A 40 pound rocket returning under an open chute at under 30 feet per second descent rate has about the same kinetic energy as
- A. A bullet from a .357 magnum revolver.
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3. Repeated instances in which large rockets descend under full chute into the parking area, missing all the cars, demonstrate that
- A. The safety code works!
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Answer Key: Pop Quiz

4. Fill in the blank:

If someone on our club flies a rocket that kills someone, what would be the impact on the member, on our club and on our hobby?

It is up to us to make sure we never have to answer this question!