Green Launch, a Hydrogen Cannon for Delivering Satellites and Supplies to Space at **$100/lb**

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PRESENTATION BY GREEN LAUNCH LLC FOR THE
INTERNATIONAL SPACE DEVELOPMENT CONFERENCE

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Motivation

- **Goal to be the FedEx of Space with just-in-time delivery of satellites and vital items to the ISS**
- **Deliver propellant at $100/lb to space depots to support space / refueling missions**
- **Zero hydrocarbon launch emissions for large scale space exploration**

Hydrogen Cannons will deliver payload to orbit affordably!

- Jules Verne had the right idea, but wrong propellant. We use hydrogen, not gunpowder to obtain much higher velocity

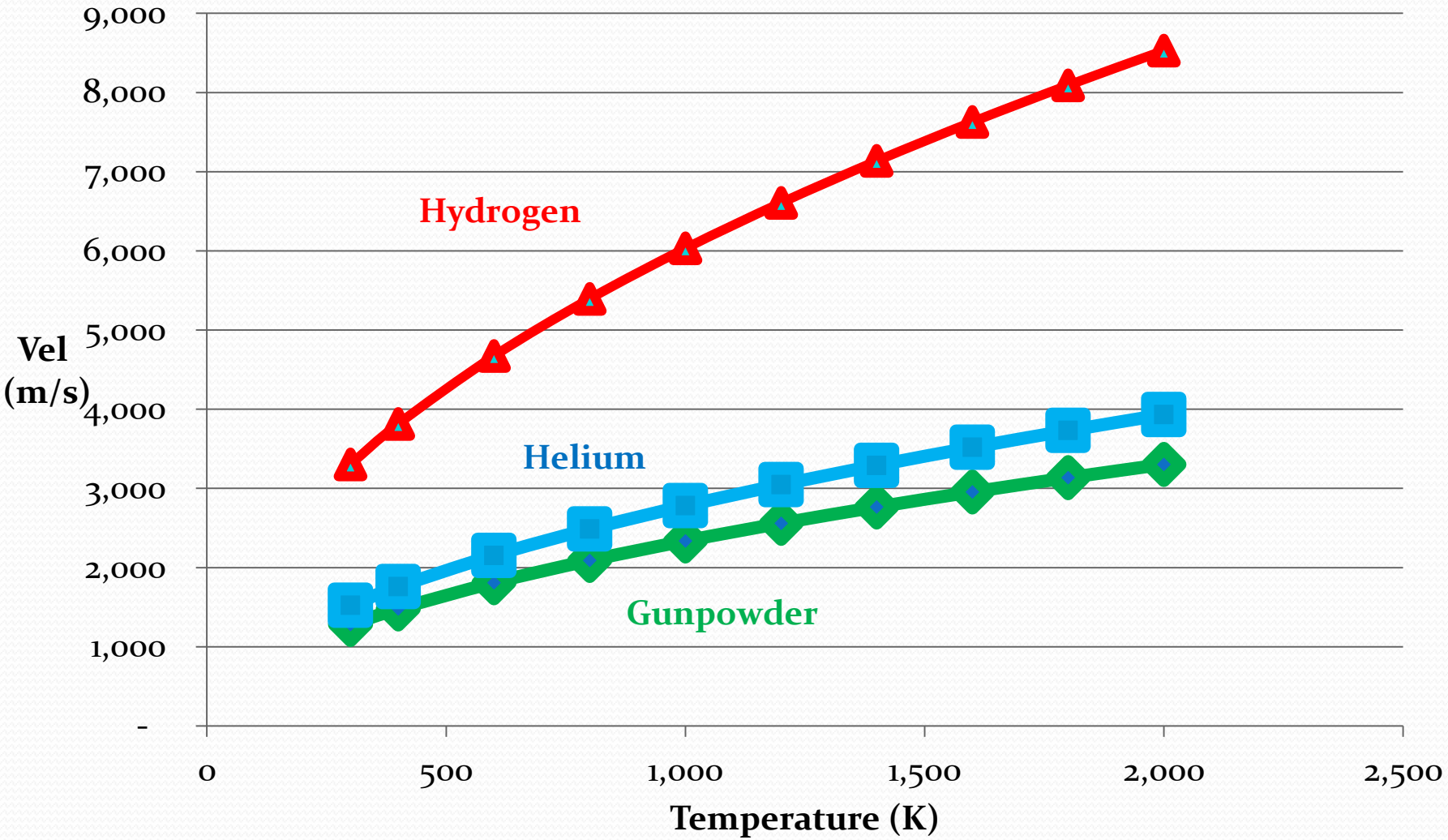
  - **Umax=2*Co/(Gamma-1)**
  - **Where Co=sqrt(Gamma*R*T/Molec))**
  - **$P=Po*(1-U/Umax)^{2*Gamma/(Gamma-1)}$**

    - Where Umax is the maximum speed of the gas expanding in vacuum
    - Co is the speed of sound in the gas just before the launch, Po is the initial pressure.
    - Gamma is the ratio of specific heats of the gas, i.e. Gamma=C_p/C_v

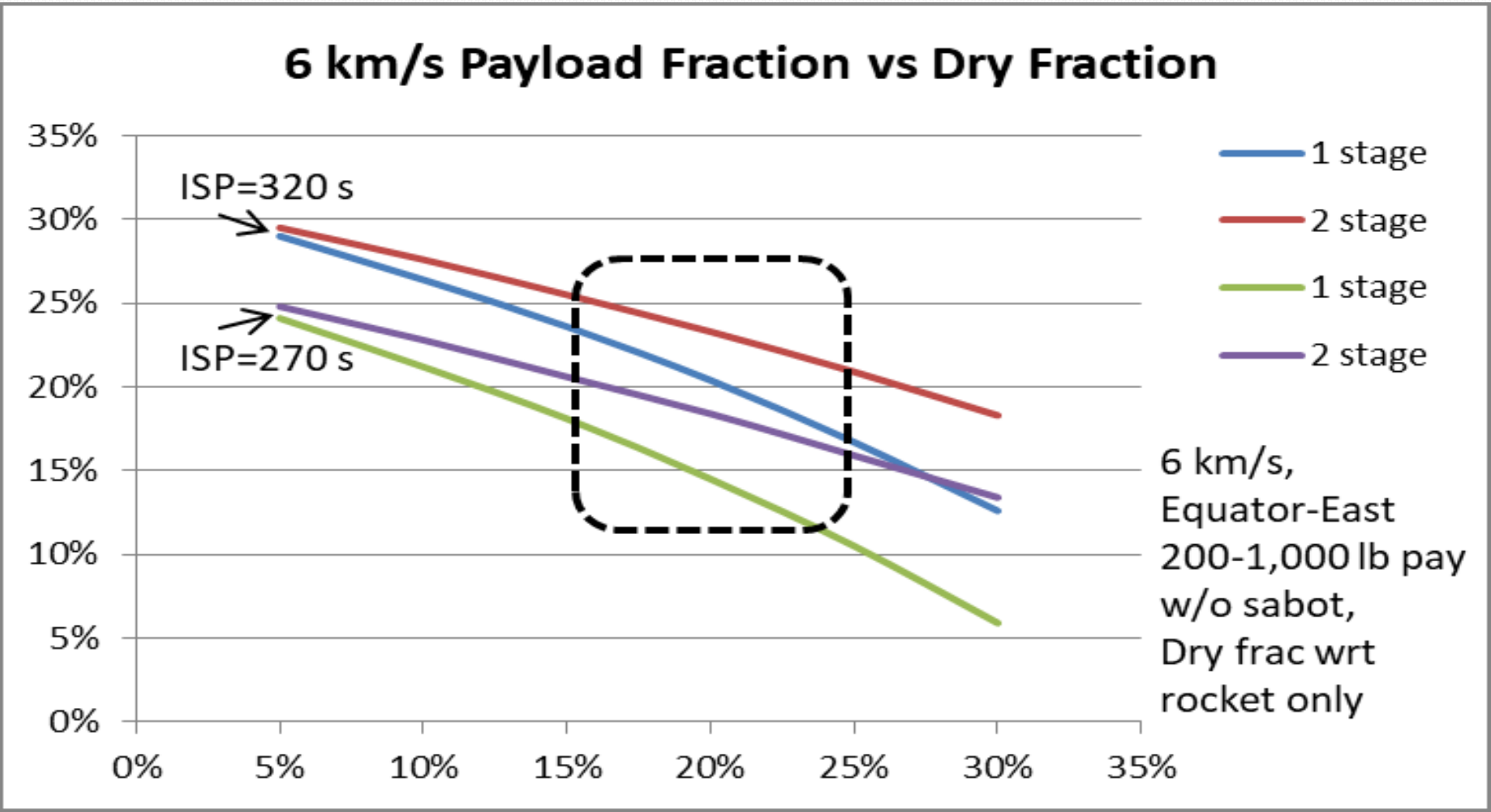
- This says that when U=Umax, pressure at the projectile is zero. As a practical matter it turns out the best you can achieve is about:

  Vpractical=Co/(Gamma-1)

Practical velocities of cannons
$V=C_0/(Gamma-1)$



On Orbital Green Launchers Cannon boost minimizes the rocket stage



Green Launch Cost/lb with 200 lb payloads

Mpay (lbs)		200	
Facility Cost	$	200,000,000	
Launches/year		5,000	
Payload/year		1,000,000	
Tons/year		500	
Launchercost/Mpay ($/Mpay)	$	20	(over 10 years)
Vehicle wt (lb)		800	
Vehicle cost/lb	$	20	(With total launch mass)
Vehicle cost	$	16,000	
Vehcost/Mpay ($/Mpay)	$	80	
Total Cost per lb in orbit	**$**	**100**	

Green Launch demonstrator phases

- Phase 1 is in process: Launch to the Karman Line
  - Demonstrates the first use of a hydrogen cannon to access space (suborbital)
  - Allows affordable delivery of science payloads to space
  - Demonstrates multiple launches/day
- Phase 2: Launch to 200 km / Break altitude record
  - Delivers sensor packages and atmospheric samplers to help diagnose climate change. Affordable and Quick!!!
  - Provides 1 month turnaround on sounding experiments
- Phase 3: Deliver 1 lb to Low Earth Orbit **$5M**
  - Allows cubesat delivery to orbit
  - Pioneers affordable delivery of payloads to orbit!
  - Will be scaled up for larger 100 lb to 1,000 lb payloads

Yuma Proving Grounds supplied a 55 ft cannon which we modified for light gasses

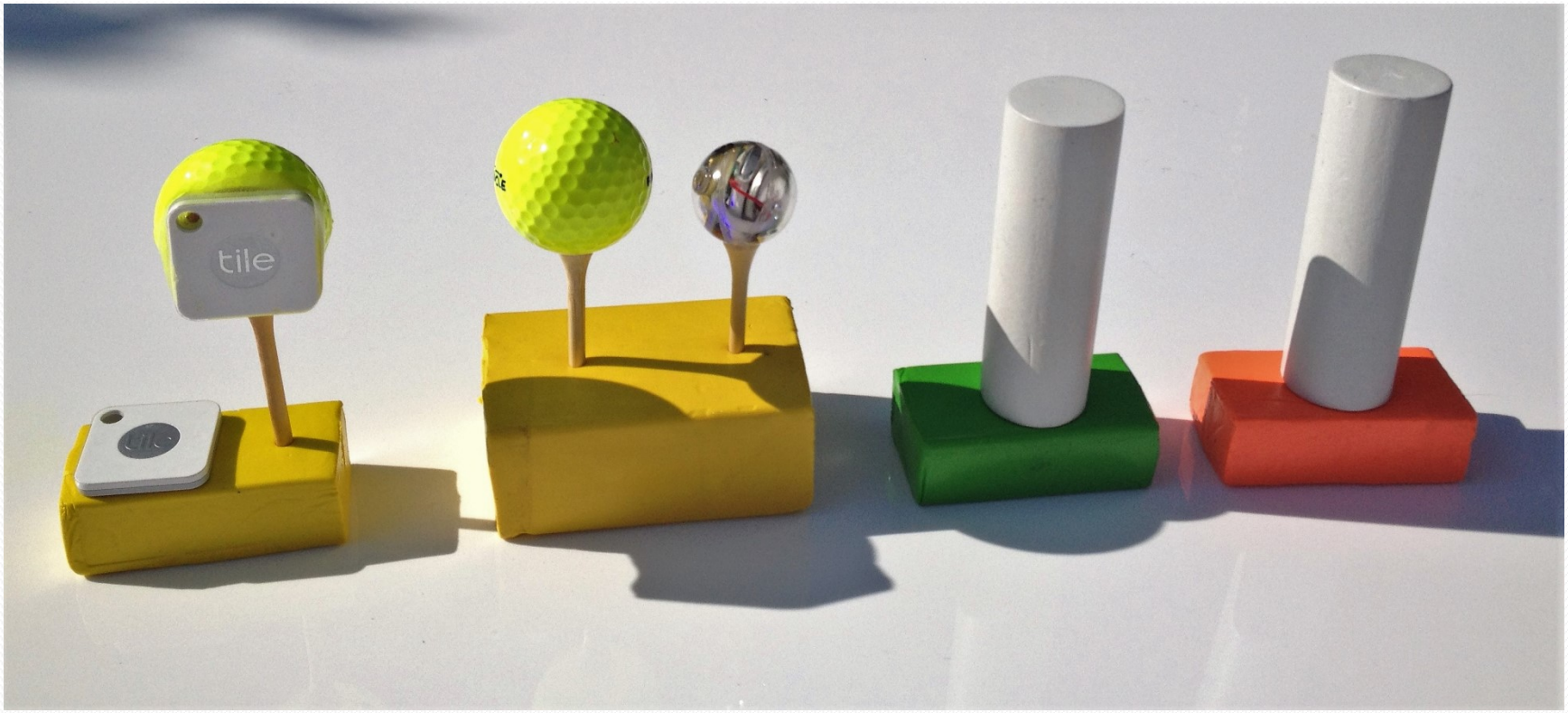
At the shop in Santee building the gas manifold

At the Yuma Proving Grounds near the launch location

Mini Mart Vehicle with Sabot and Payloads

- The Mini Mart launch vehicle is 4 inches in diameter and contains 3 payloads (4 inch long white cylinders)
- Payloads can sample the atmosphere, record atmospheric gas properties and transmit information to a ground station

Modern electronics can take 30,000 Gs with minor mods



The KOFA Range at Yuma Proving Ground has unrestricted air space

Yuma Proving Ground is affordable and convenient

Phase 1: Launch to the Karman Line.

- **Vehicle is launched at 2 km/s by Hydrogen Cannon within the KOFA test range**
- **Sabot separates from vehicle and petals land nearby. Vehicle ascends at 85 degrees. The Sonic boom is minimal and brief.**
- **Radar acquires vehicle and tracks it past Karman Line at 100 km**
- **Vehicle turns around at apogee and reenters atmosphere. Vehicle impacts 40 km downrange.**
- **Subsequent launches will have active payloads which eject at apogee and take data**

Phase 2: 200 km altitude record

- **Same as Phase 1 except:**
  - **Vehicle with sensor payload is launched at 3.0 km/s**
  - **Vehicle exceeds 200 km, ejects payload**
  - **Payload parachutes to ground while vehicle impacts downrange**

- **Launches have active payloads which eject at apogee and take data as well as sample atmospheric gasses**

Phase 3: Cubesat orbital delivery

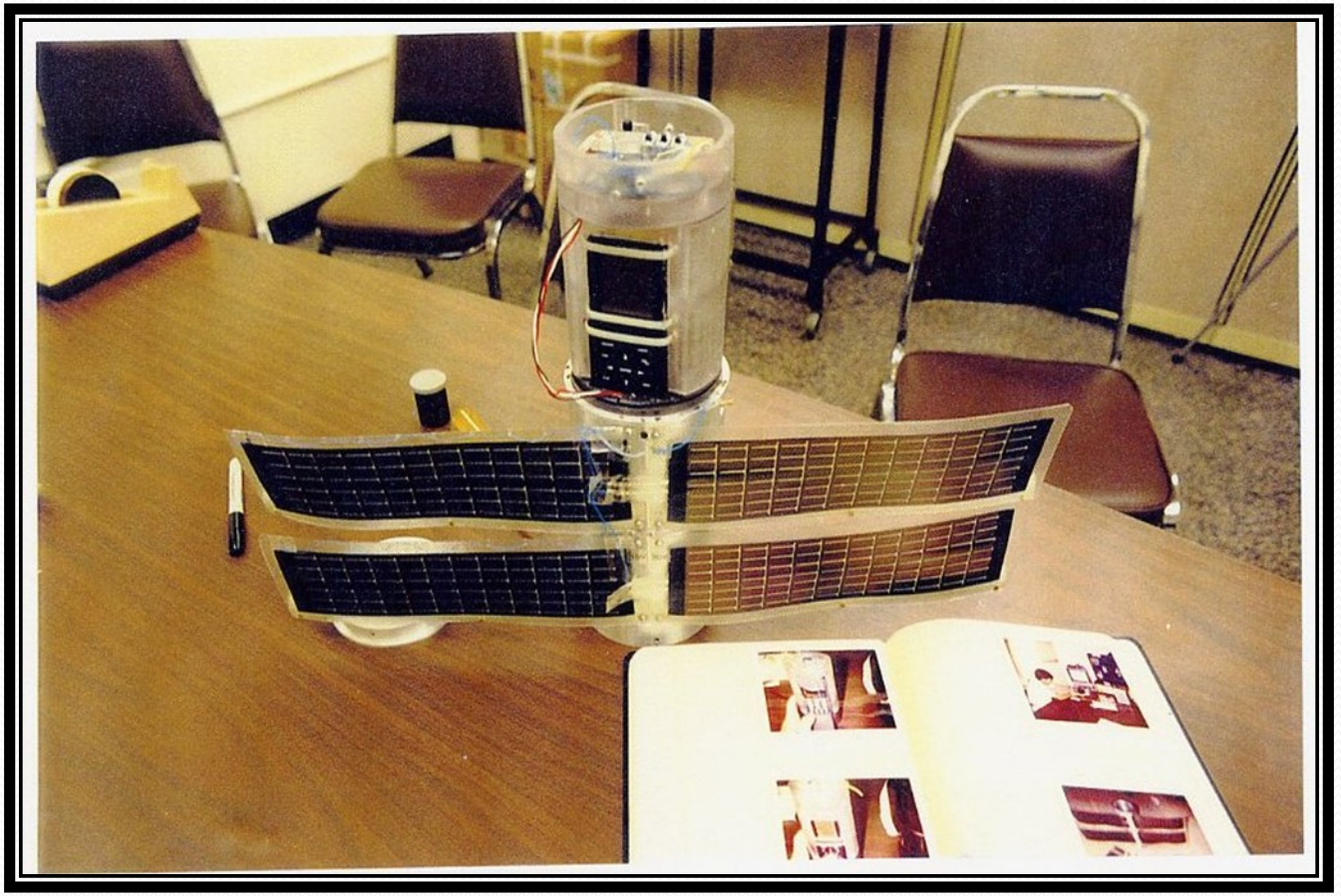
- **Vehicle is launched at 6 km/s by a hydrogen cannon.** **Hydrogen is captured and stored for next shot**
- **Sabot separates and petals land nearby.** **Vehicle ascends at 30 degrees. The Sonic boom is downrange.**
- **The aeroshell nose ablates several inches.** **Aeroshell is discarded at 100 km.**
- **The rocket motor burns for 100 sec.** **Vehicle delivers Cubesat to 300 km altitude earth orbit**

The Green Launch back story: Steps which **have been accomplished**

- **Build a 400 ft Hydrogen Cannon:** SHARP was built and operated 1992-1998 by Hunter and the SHARP team at *Lawrence Livermore National Laboratory.*
- **G-hardening the GN&C electronics**: Completed in 1998 for DARPA using commercial parts
- **G-Hardened rocket for orbital insertion**: Completed by CAES in 1998 for DTRA for "Star Wars"
- **Horizontal Shots at YPG this year:** Series of ***16 shots*** completed with different parameters up to ***2 Km/sec***

1. SHARP Launched 10 lbs at Mach 9 at LLNL in 1998

2. Satellite from COTS parts tested to 3,200 Gs for DARPA



3. Rocket Sustained 15,000 G Launch

Figure 5. DTRA Gun Launched Rocket After 15,000 G Launch

4. Active Green Launch testing at YPG

Green Launch cannon

(modified for light gas shots at YPG in 2018)

Gun Mounting on Carriage

Gun mounted with support

Connection to Gas Supply

Current horizontal testing for Phase 1

- The 55-foot cannon is successfully modified for light gasses
- Gas manifold and controls are working well
- Two shots per day using YPG personnel and our team
- Shots 14, 15 and 16 in April saw speeds up to 2 km/s
- Next horizontal test series in June will assure performance of vertical test series to Karman Line

- Contact or follow us at: https://greenlaunch.org/

Thanks to

- Jules Verne
- The SHARP team at Lawrence Livermore National Laboratory
- The Green Launch team
- Yuma Proving Ground (YPG) Test Directorate