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Preliminary Assessment of the Use of Heavy Gases in Two-Stage Light Gas Guns

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Overview

- Need for data at muzzle velocities of 0.7 – 2.7 km/s
- There are issues when using a single stage gas gun or a powder gun to access this velocity range
- Examine powder gun data, check out incomplete combustion, muzzle velocity repeatability, ejection of unburned powder grains, high breech pressures
- Study use of two-stage gun with heavier working gas
- Study experimental data and CFD calcs for Marshall gun and Ames AVGR (Ames Vertical Gun Range) gun using H_2, He, N_2 and Ar
- Preliminary choice of best heavy working gas(es)
- Conclusions

Need for data at velocities of 0.7-2.7 km/s

- These relatively low muzzle velocities are useful for studies of:

  - Whipple shield performance – severe shield penetration can occur at impact velocities of 2 – 3 km/s
  - Secondary impacts on second wall of Whipple shield
  - Rain impacts on missiles
  - Long rod penetrators
  - Ship defense
  - Armor resistance

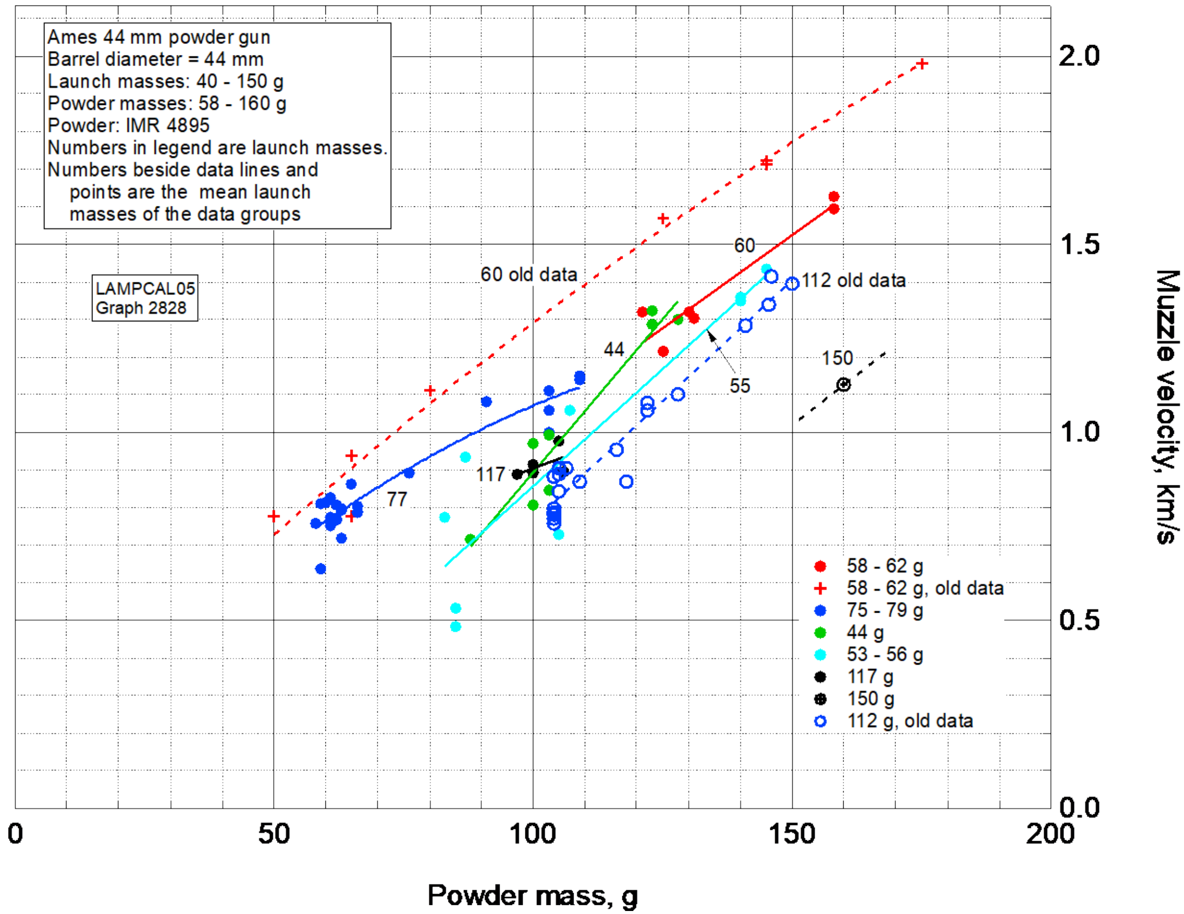
Attainment of muzzle velocities of 0.7-2.7 km/s

- One possibility is to use a single stage gun
- With heated (830 K) high pressure (70 MPa) H_2, 2.7 km/s attainable
- Many labs may be restricted to gases such as room temperature He at ~14 MPa; this would limit launch velocity for a representative launch mass ($M/D^3 = 1.0$ g/cm^3) to a max of ~1.3 km/s.
- Single stage gun needs a fast valve opening at a precise pressure - double diaphragm technique, lance, etc. Powder gun and two stage gun do not need this valve.

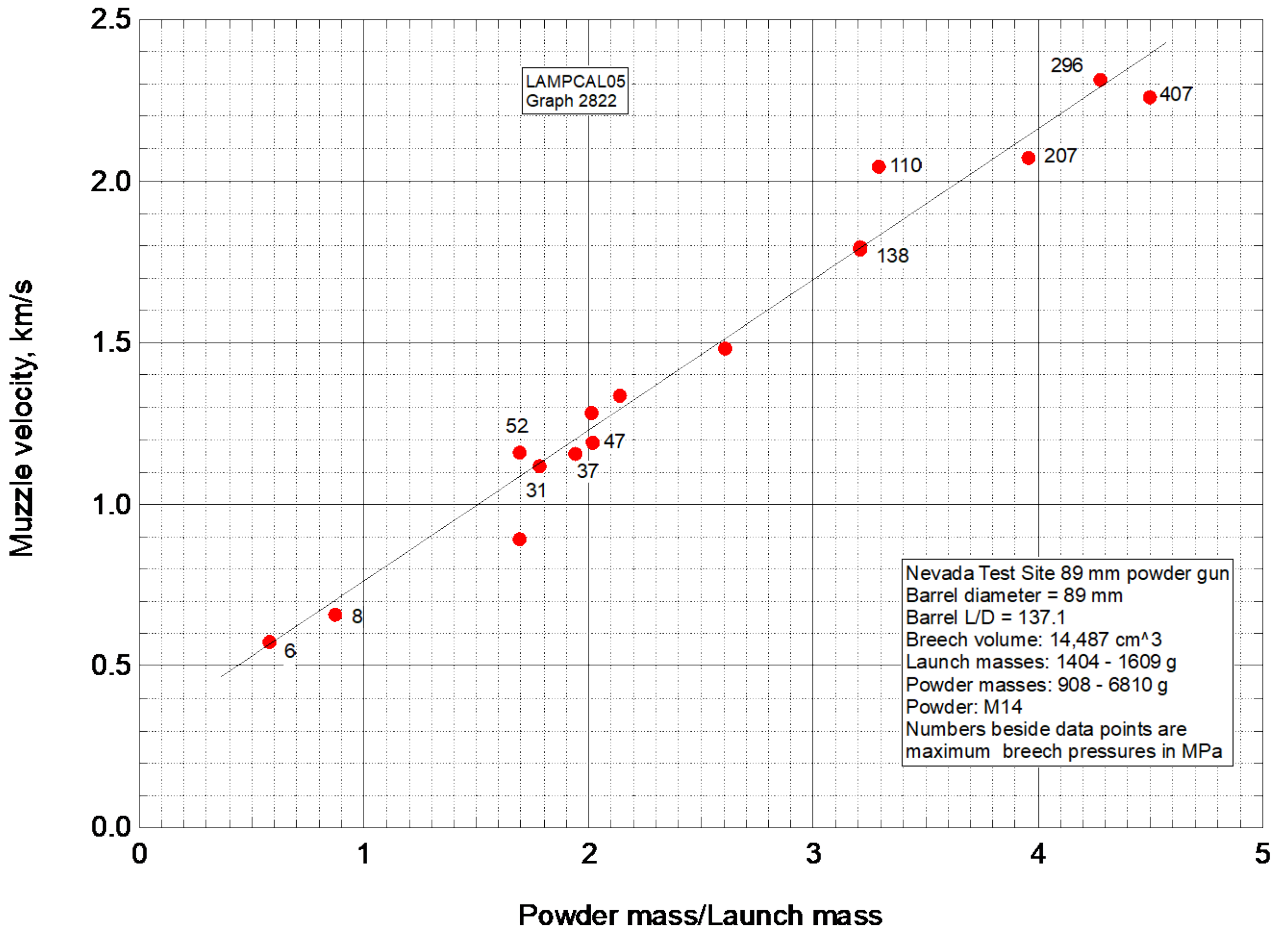
Attainment of muzzle velocities of 0.7-2.7 km/s

- A second possibility is to use a powder gun
- There can be a number of issues with powder guns:
  - incomplete combustion, particularly at lower powder loads, and variability in igniter energy output can lead to poor repeatability of muzzle velocity
  - ejection of unburned powder grains, can confound desired target damage information
  - very high breech pressures for the upper part of the desired muzzle velocity range
- We now briefly examine data from several powder guns.

Muzzle velocities versus powder load for Ames 44 mm powder gun.



Muzzle velocities versus normalized powder load for the Nevada test site 89 mm powder gun.



Maximum breech pressures versus muzzle velocities for the Nevada test site 89 mm powder gun.

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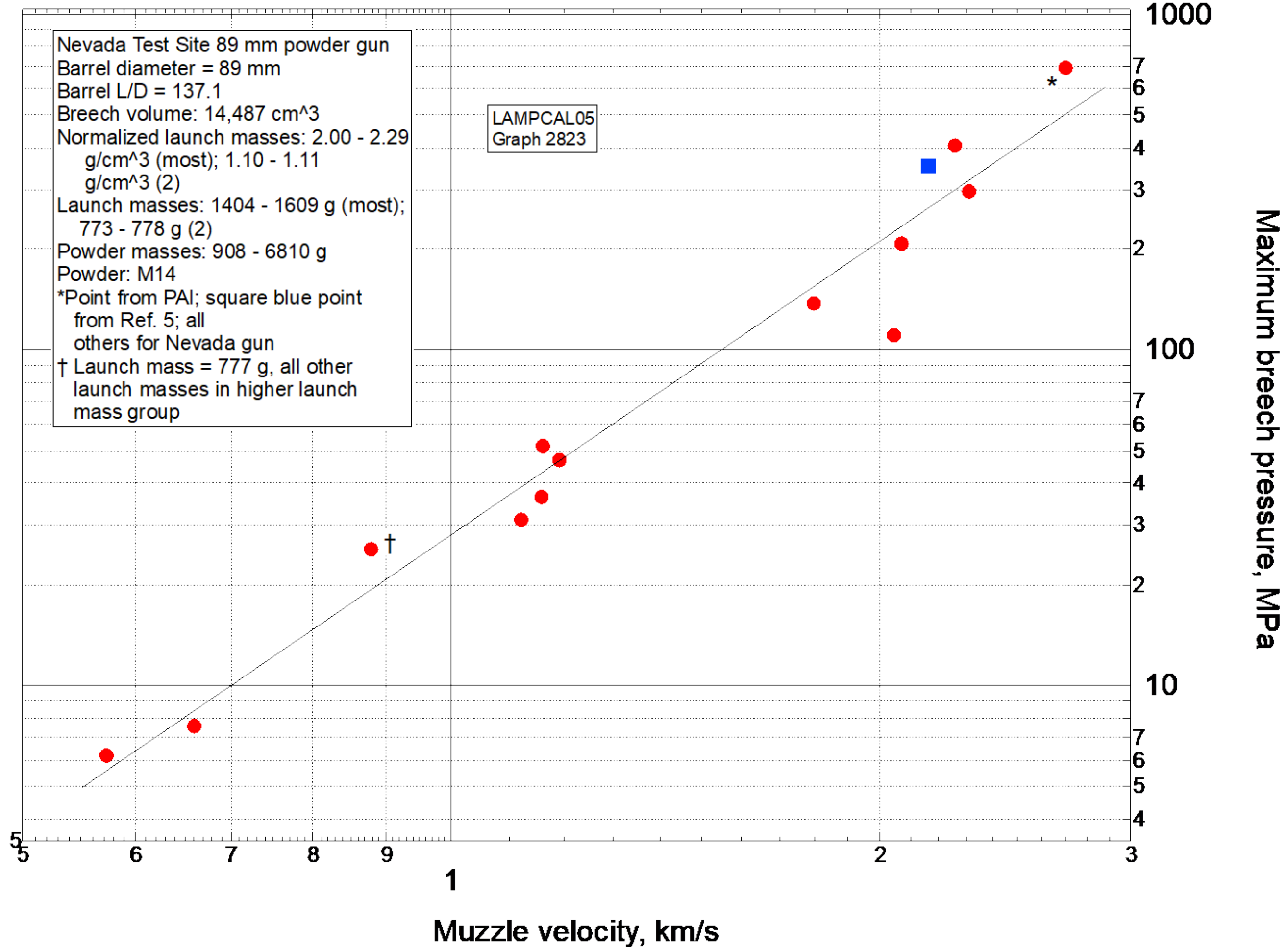


Some issues with powder guns

- It is noted that, repeatability of the muzzle velocity of powder guns can be poor, especially at lower powder loads, with variations of ±10 – 20%

- For muzzle velocities above 2.0 km/s, powder breech pressures are very high: 200 – 700 MPa (30 – 100 ksi)

Unburned powder

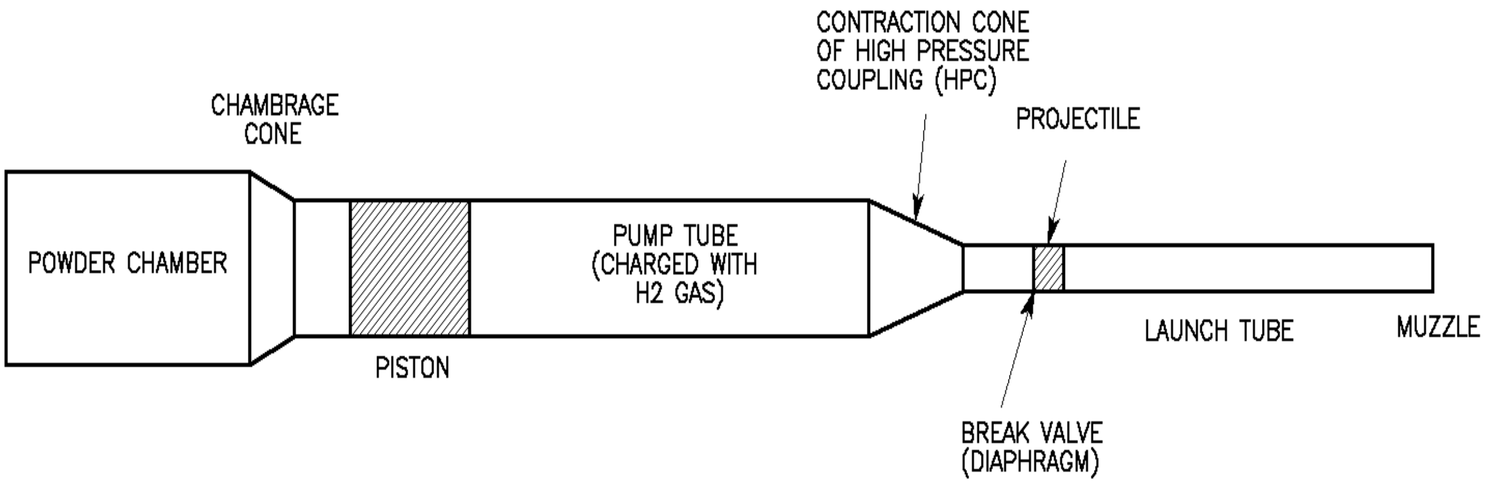
- **Gunners have observed substantial quantities of unburned powder**

- **CFD calculations for the Ames 44 mm gun with a 22.2 mm insert and 14 g IMR 4227 powder indicate ~35% unburned powder**

- **If the fraction of unburned powder varies from run to run, say from 30% to 50%, this can result in very poor repeatability of muzzle velocity.**

Two-stage guns with heavy working gas

- A third possibility is to use a two-stage gas gun operated with a heavier gas than is normally used



Schematic sketch of representative two-stage gas gun

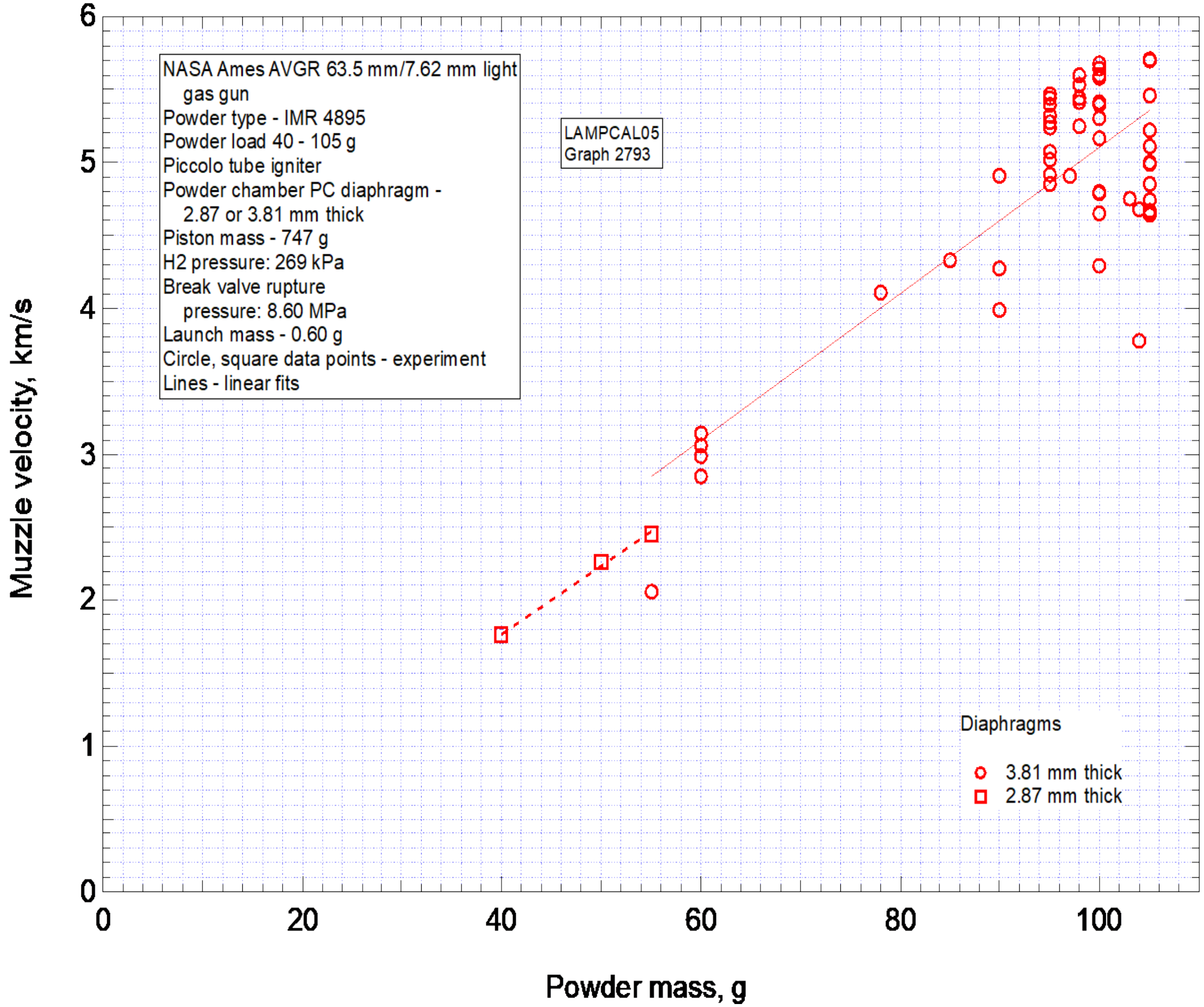
Two-stage guns with heavy working gas

- Many labs already have two-stage guns, usually used with hydrogen working gas for the muzzle velocity range of 3 to 8 km/s
- With the heavy working gas technique, it may be possible to use these same guns for muzzle velocities of 0.7- 2.7 km/s, thus avoiding the construction of new hardware
- In contrast, for some labs, the use of a single stage gun or a powder gun may require construction of new hardware

Two-stage guns with heavy working gas – AVGR gun

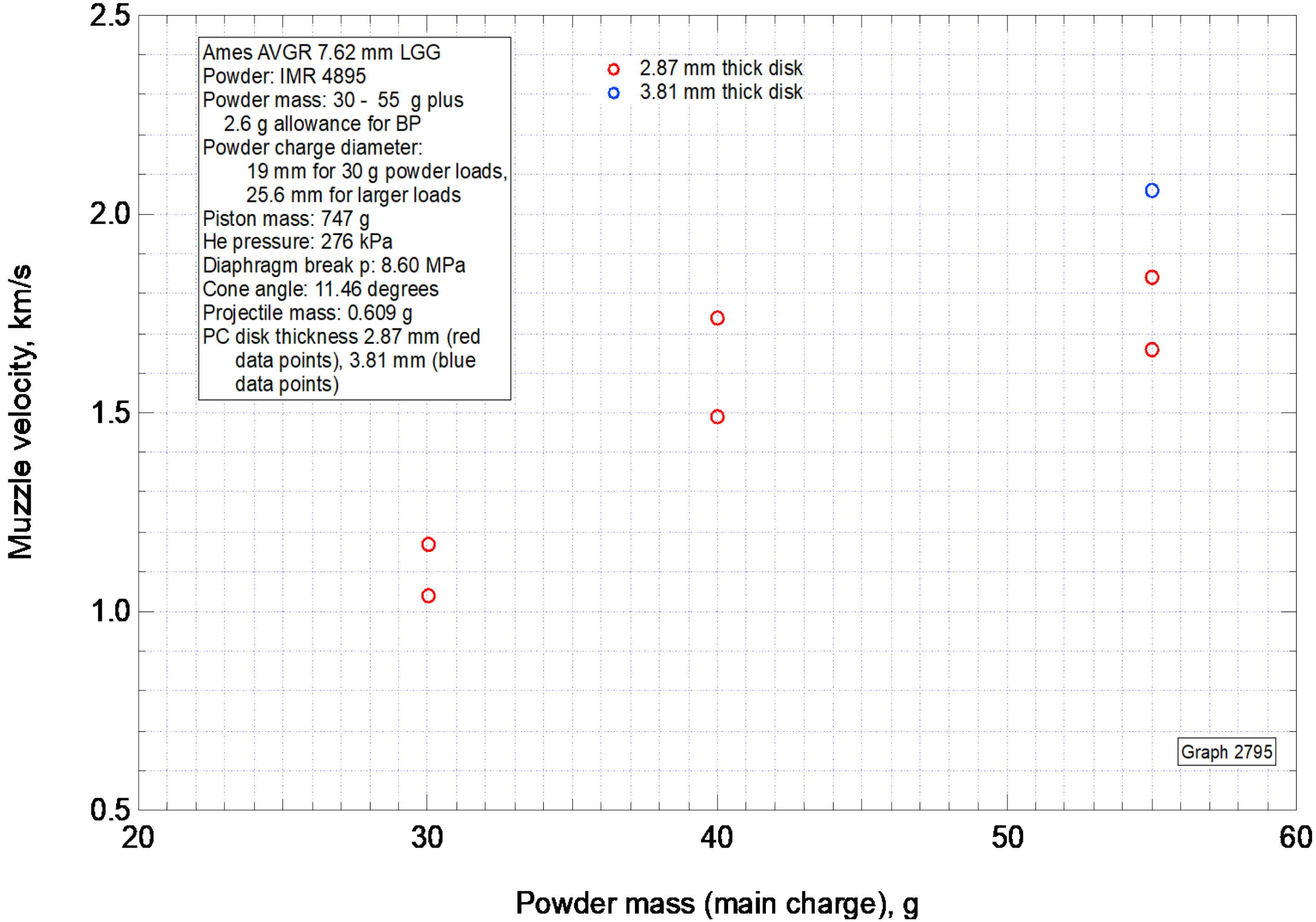
- **NASA Ames AVGR (Ames Vertical Gun Range) gun**
  - **Pump tube diameter = 63.5 mm**
  - **Launch tube diameter = 7.62 mm**
  - **Powder breech volume = 1242 cm^3**

AVGR gun with H_2



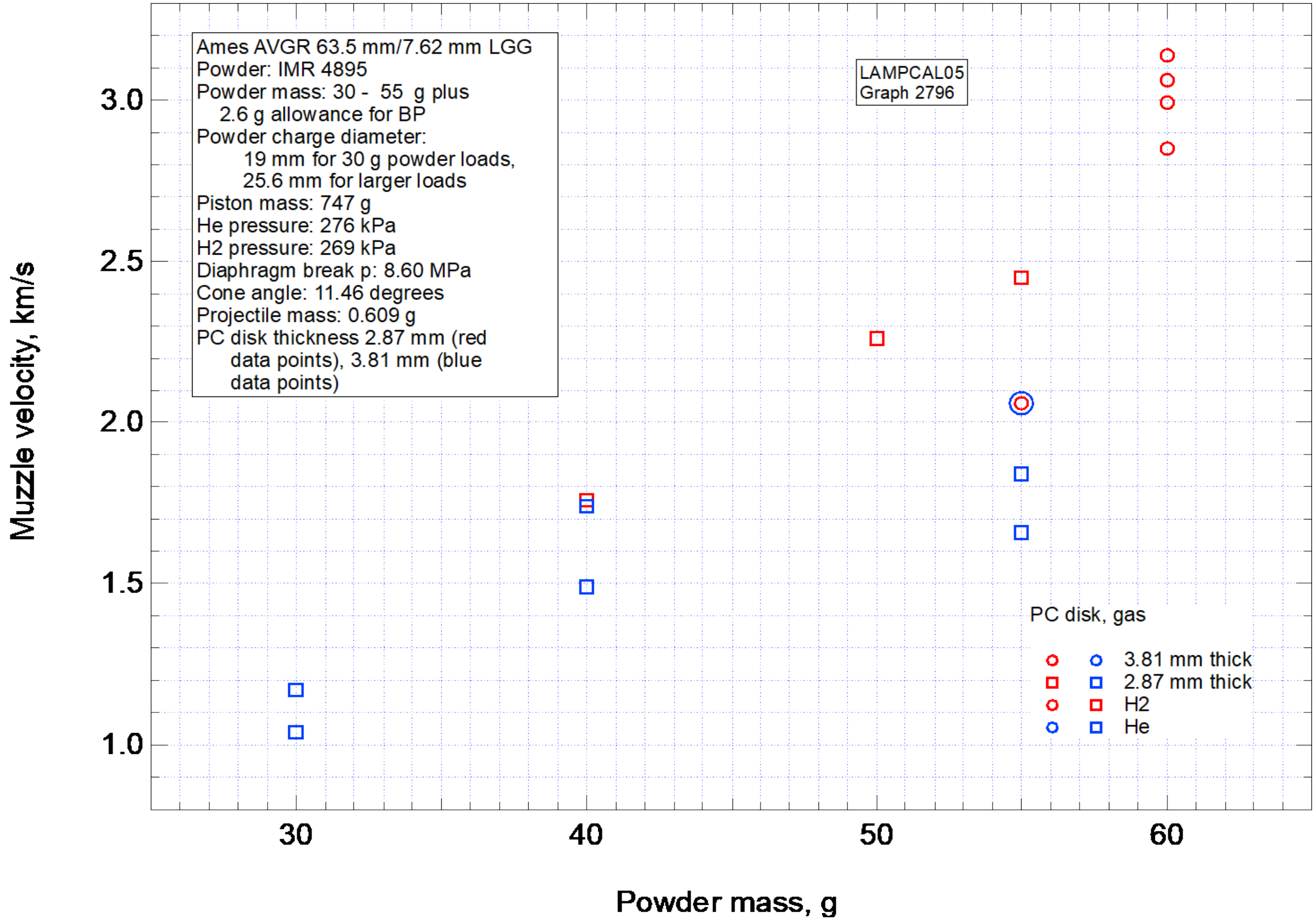
Muzzle velocity versus powder load for the Ames AVGR gun operated with hydrogen. Launch mass ~0.60 g.

AVGR gun with He



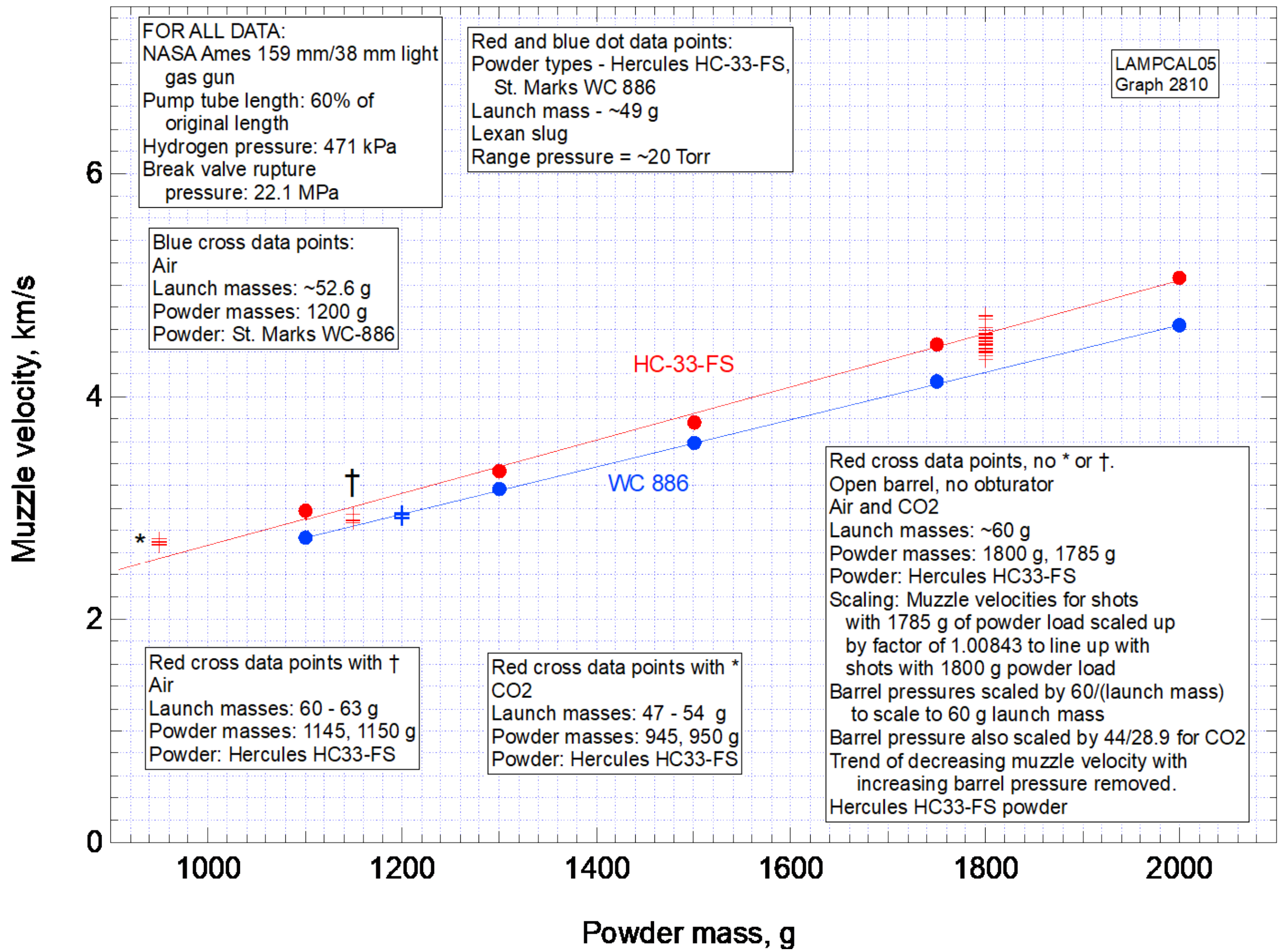
Muzzle velocity versus powder load for the Ames AVGR gun operated with helium. Launch mass ~0.60 g.

AVGR gun with H_2 and He



Muzzle velocity versus powder load for the Ames AVGR gun operated with hydrogen and helium. Launch mass ~0.60 g.

159 mm/38 mm gun with H_2



Muzzle velocity versus powder load for the Ames 159 mm/38 mm gun operated with hydrogen.

Two-stage guns with H_2 and He

- For AVGR gun operated with He and H_2, variations in muzzle velocity are ±5 – 8% to ±10 – 15%

- For the Ames 159 mm/38 mm gun operated with hydrogen, variations in muzzle velocity are ±1 – 3% with Hercules HC-33-FS powder and with St. Marks WC 886 powder.

- The data for the Ames 159 mm/38 mm gun shows that repeatable muzzle velocities can be obtained using a two stage gun with hydrogen at muzzle velocities down to ~2.7 km/s.

AVGR gun with H_2

- CFD results for muzzle velocity for IMR 4895 powder agree roughly with experimental data.
- Predicted fraction of unburned IMR 4895 powder ranges from ~0.34 to ~0.47, increases with decreasing powder mass

AVGR gun with H_2, He, N_2 or Ar

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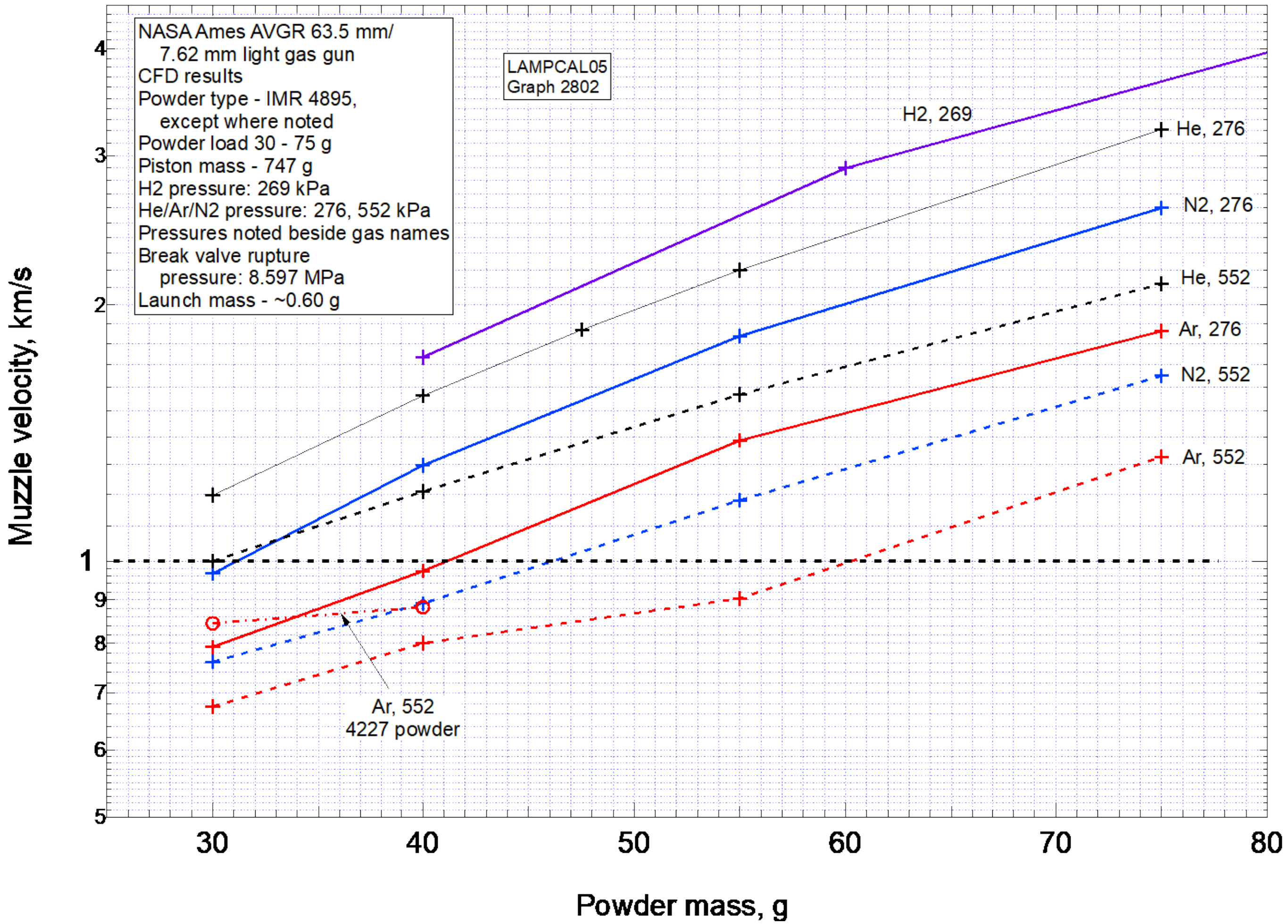

Results from CFD calcs of muzzle velocities versus powder load for the Ames AVGR gun with H_2, He, N_2 and Ar working gases at two different pressures.

AVGR gun with H_2, He, N_2 or Ar

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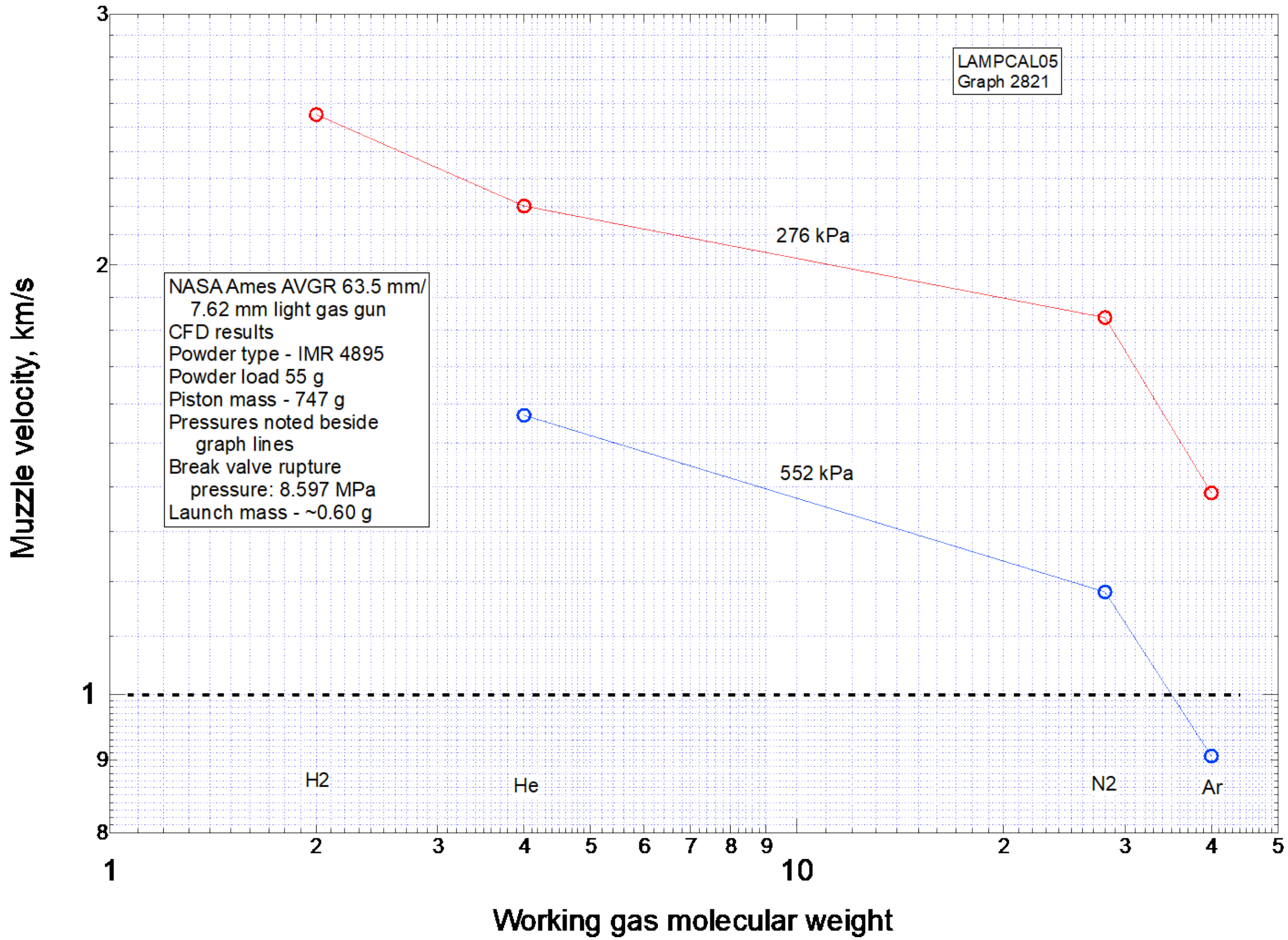

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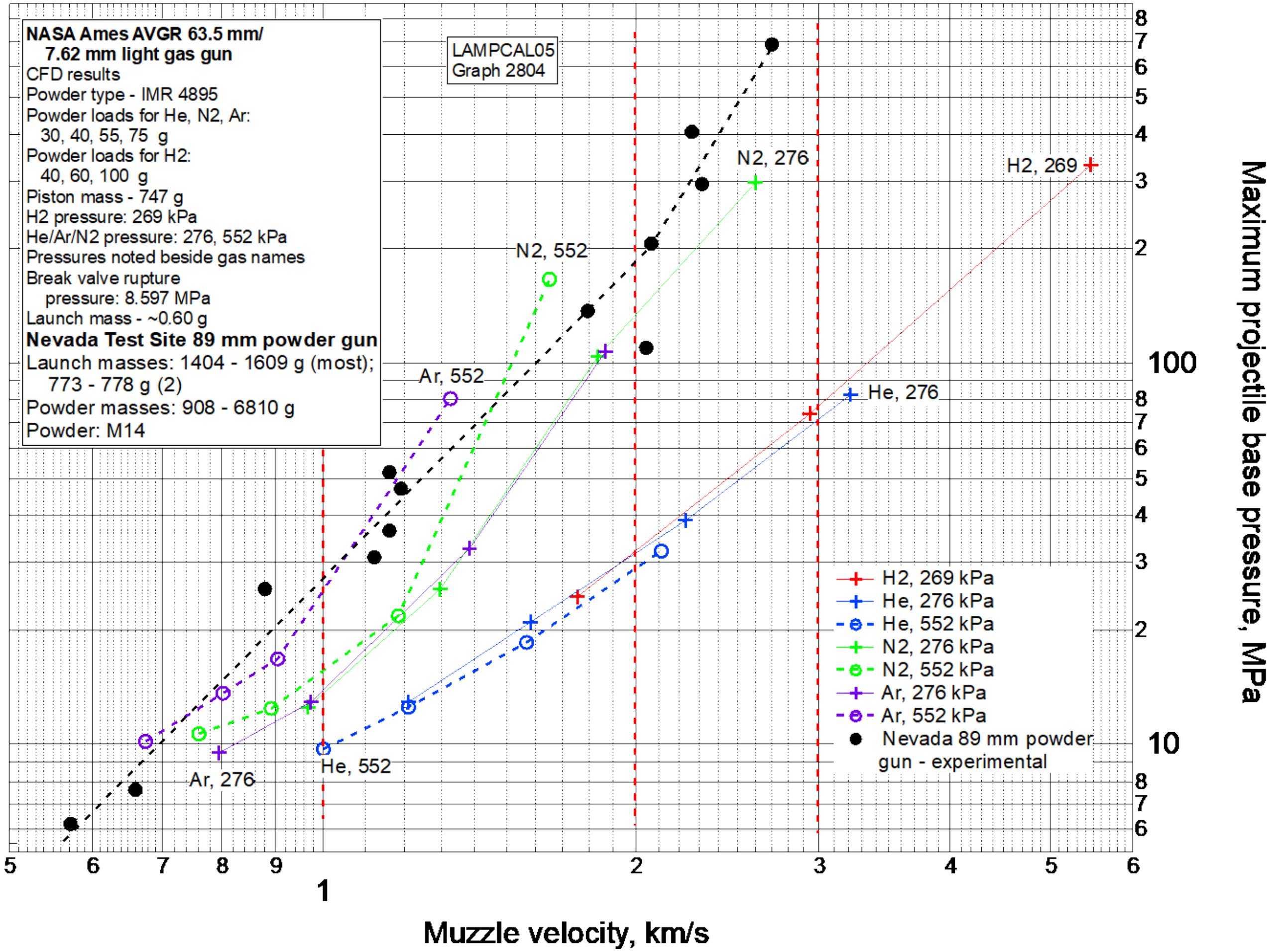

Maximum CFD projectile base pressures vs muzzle velocities for the Ames AVGR gun with 4 working gases. Also shown are experimental breech pressures for the Nevada gun.

AVGR gun with H_2, He or Ar

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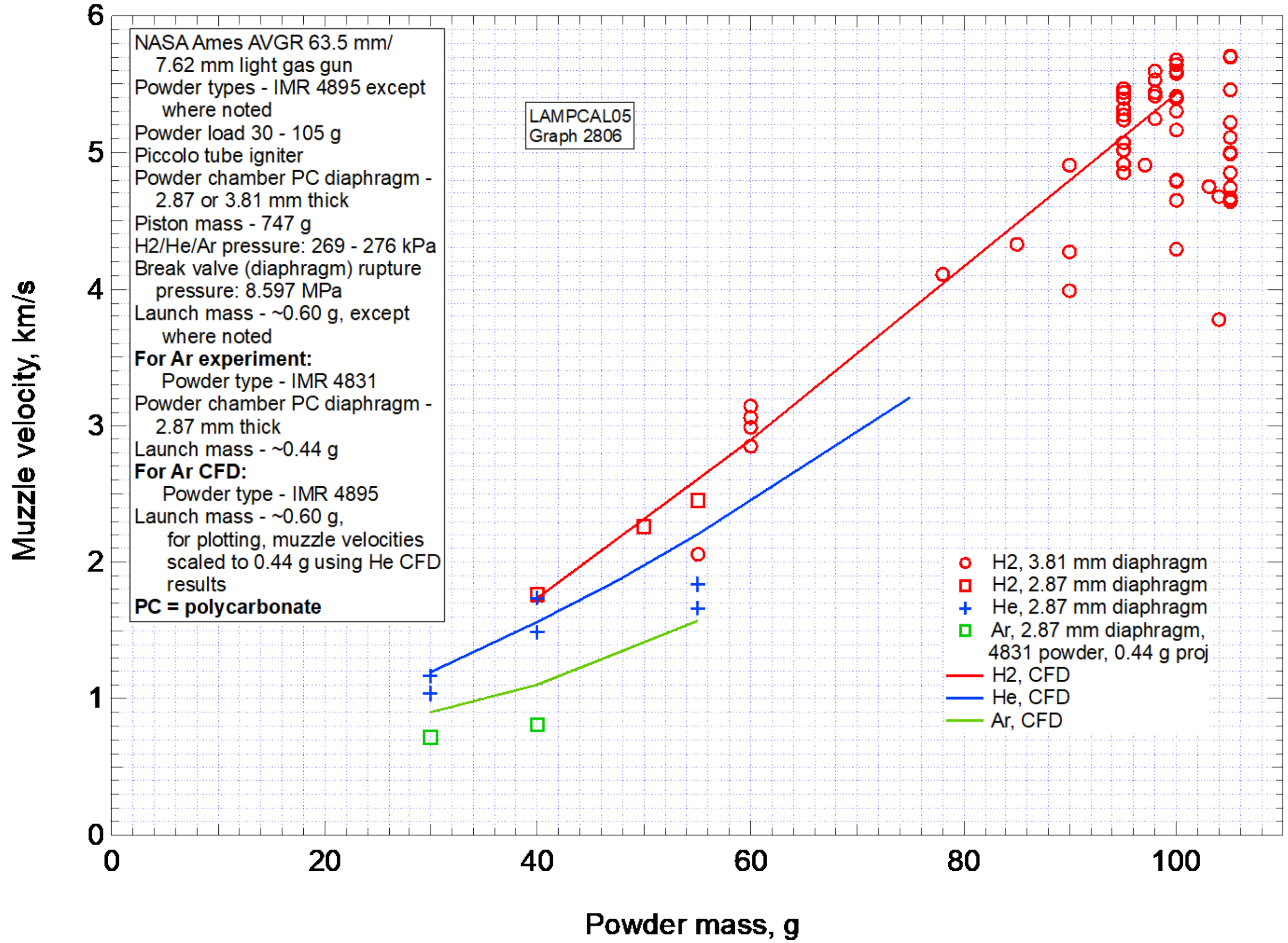

Experimental data for the Ames AVGR gun operated with H_2, He and Ar. Muzzle velocity versus powder load. Launch masses ~0.44, ~0.60 g.

Two-stage guns with heavy working gas – NASA Marshall gun

- NASA Marshall gun
  - Pump tube diameter = 20 mm
  - Launch tube diameter = 5.59 mm
  - Powder breech volume = 45.93 cm^3

- Working gases:
  - Ar at 241 kPa - 4 shots
  - Ar at 483 kPa - 3 shots
  - He at 483 kPa- 16 shots
  - N_2 - no shots to date

- Powder load: 2 - 4.6 g Unique
- Piston mass: 37 g
- Launch mass: 0.22 - 0.24 g

NASA Marshall gun with H_2, He, N_2 and Ar

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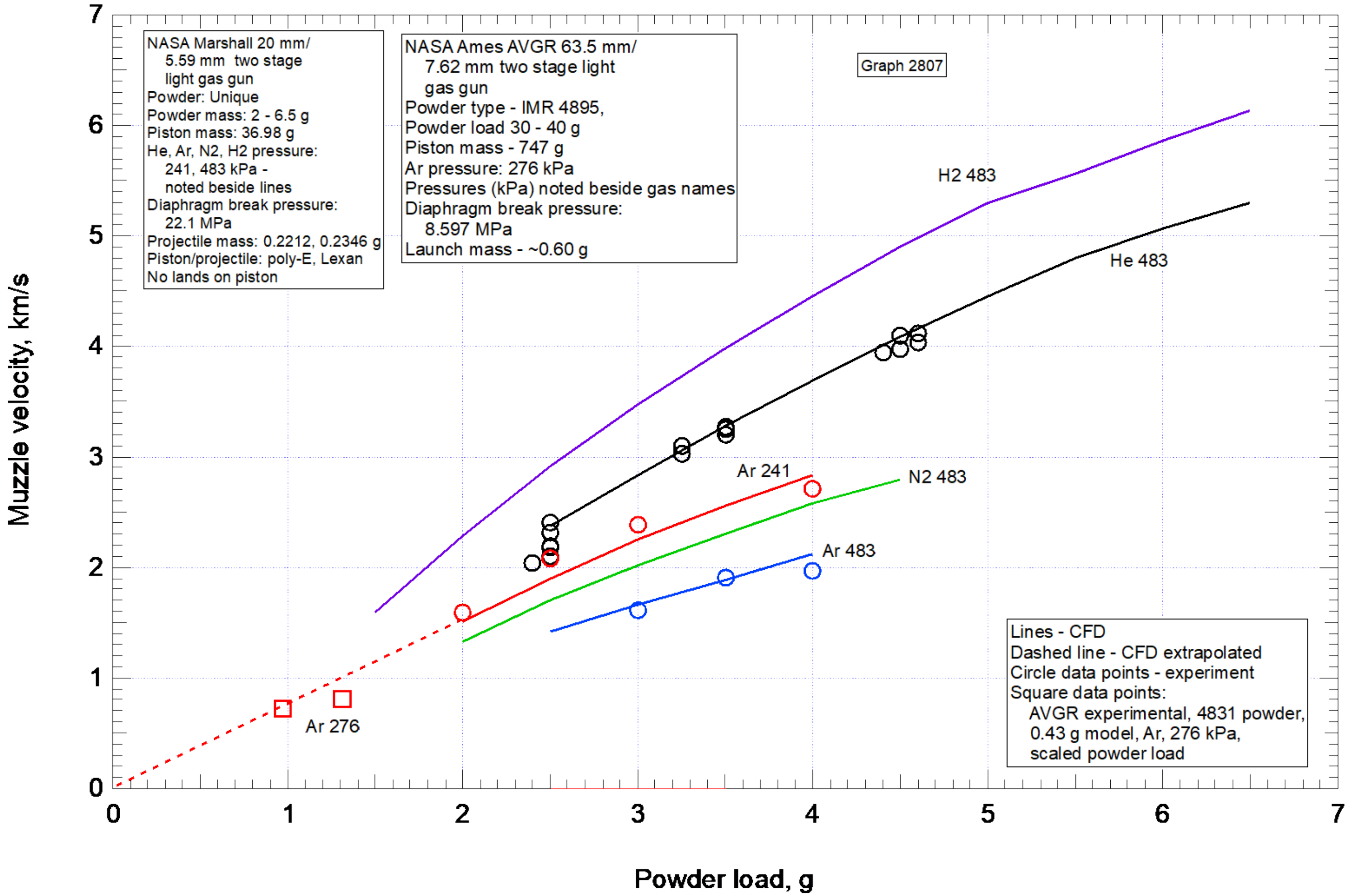

Experimental data and CFD results for the Marshall gun operated with H_2, He, N_2 and Ar. Muzzle velocity vs powder load. Launch masses 0.22 – 0.24 g.

NASA Marshall gun with H_2, He, N_2 and Ar

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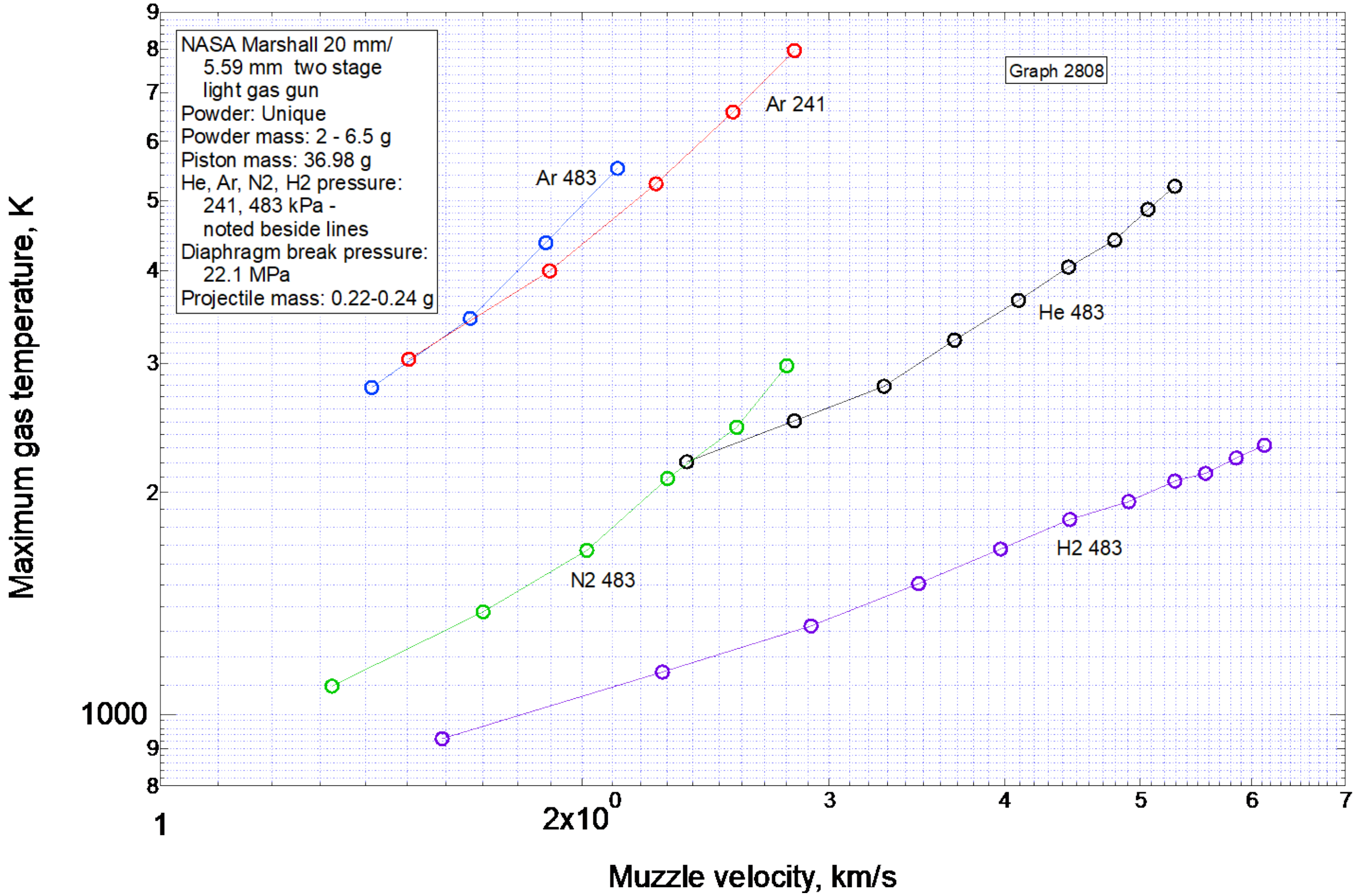

CFD results for the NASA Marshall gun with H_2, He, N_2 and Ar working gases. Maximum gas temperatures vs muzzle velocity. Launch masses 0.22 - 0.24 g.

NASA Marshall gun with H_2, He, N_2 and Ar

- **Note very high CFD-predicted maximum temperatures with argon - up to 8000 K.**
- **This may well be connected with the observed barrel erosion with argon.**
- **The CFD code does not predict erosion for shots with argon but does not include radiation.**
- **A separate calculation of radiative heating of the barrel wall was made.**
- **This indicated that that radiative heating at 8000 K could cause significant wall erosion.**
- **CFD-predicted maximum gas temperatures are limited to 2500 – 3000 K for He and N_2.**

Preliminary choices of heavy working gases

Muzzle velocity range km/s	Suggested working gas	Notes, constraints
0.7 - 1.4	Ar	Ar gives lowest velocities
1.4 - 2.4	Ar	Ar too hot above 1.4 km/s
1.4 - 2.4	He	Repeatability seems poorer below ~2.7 km/s
1.4 - 2.4	N2	N2 cooler than He
2.4 - 2.7	He at 483 kPa	Repeatability must be checked
2.4 - 2.7	He at 760 kPa	Repeatability must be checked
2.4 - 2.7	N2 at 483 kPa	Accept temperatures of up to 2740 K, vs 2430 K for He
> 2.7	H2	H2 has good repeatability above 2.7 km/s

Green	Preliminarily judged good
Yellow	Further study needed to get best choice
Red	Preliminarily judged bad

Summary and Conclusions - II

- It was decided to study the use of the two stage gas gun operated with a heavier than normal working gas in order to lower the muzzle velocity range of the gun from the usual 3 to 8 km/s to the desired low velocities of 0.7 – 2.7 km/s.
- Preliminary results were presented from firings with two NASA guns
- Muzzle velocities of 1.1 to 4 km/s were obtained with helium and velocities of 0.7 to 2.7 km/s were obtained with argon.
- CFD calculations for shots with argon predict gas temperatures up to 8000 K – gunners have observed erosion with argon
- For velocities above 1.4 km/s, probably better to switch from argon to nitrogen - CFD-predicted maximum gas temperatures with N2 are ~3000 K – there are no nitrogen shots to date.
- More firings are needed to fill out the database.

Preliminary choices of heavy working gases

Muzzle velocity range km/s	Suggested working gas	Notes, constraints
0.7 - 1.4	Ar	Ar gives lowest velocities
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