Oral Presentation Cover for Abstract 1943

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The Gurney Velocity: A "Constant" Affected by Previously Unrecognized Factors

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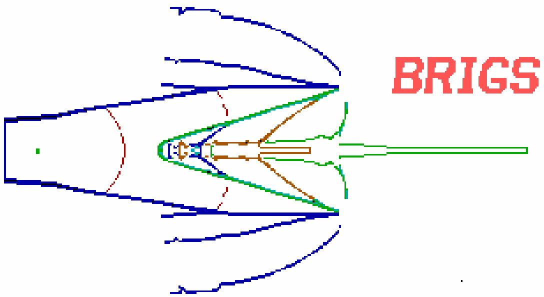

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The Gurney Velocity – Key to the Equations

$Vf = (2Eg)^{1/2} [(M/C) + 1/2]^{-1/2}$ *Cylinder*

$= Vg (\rho_{cyl} / \rho_{ex})^{-1/2} [(t_{cyl} / R_{ex})^2 + 2 (t_{cyl} / R_{ex}) + 0.5 (\rho_{ex} / \rho_{cyl})]^{-1/2}$

$Vf = (2Eg)^{1/2} [(M/C) + 1/3]^{-1/2}$ *Symmetric Sandwich*

$Vf = (2Eg)^{1/2} [(M/C) + 3/5]^{-1/2}$ *Spherical Shell*

Values for the Gurney Velocity $(2Eg)^{1/2}$ derived from experiments using different cylinder materials

	Steel (m/s)	Copper (m/s)
Comp. A-3 (RDX)	2416	2630
Cyclotol (75/25 cast)	2320	2790
Comp. B	2310	2700
TNT (cast)	2040	2370
Tetryl	2209	2500

Gurney Velocity / Detonation Rate relationships:

$Vg / D \cong 0.337$ (P.W. Cooper)

$Vg / D \cong (0.605 / [\Gamma - 1])$ (J. Roth per J.E. Kennedy)

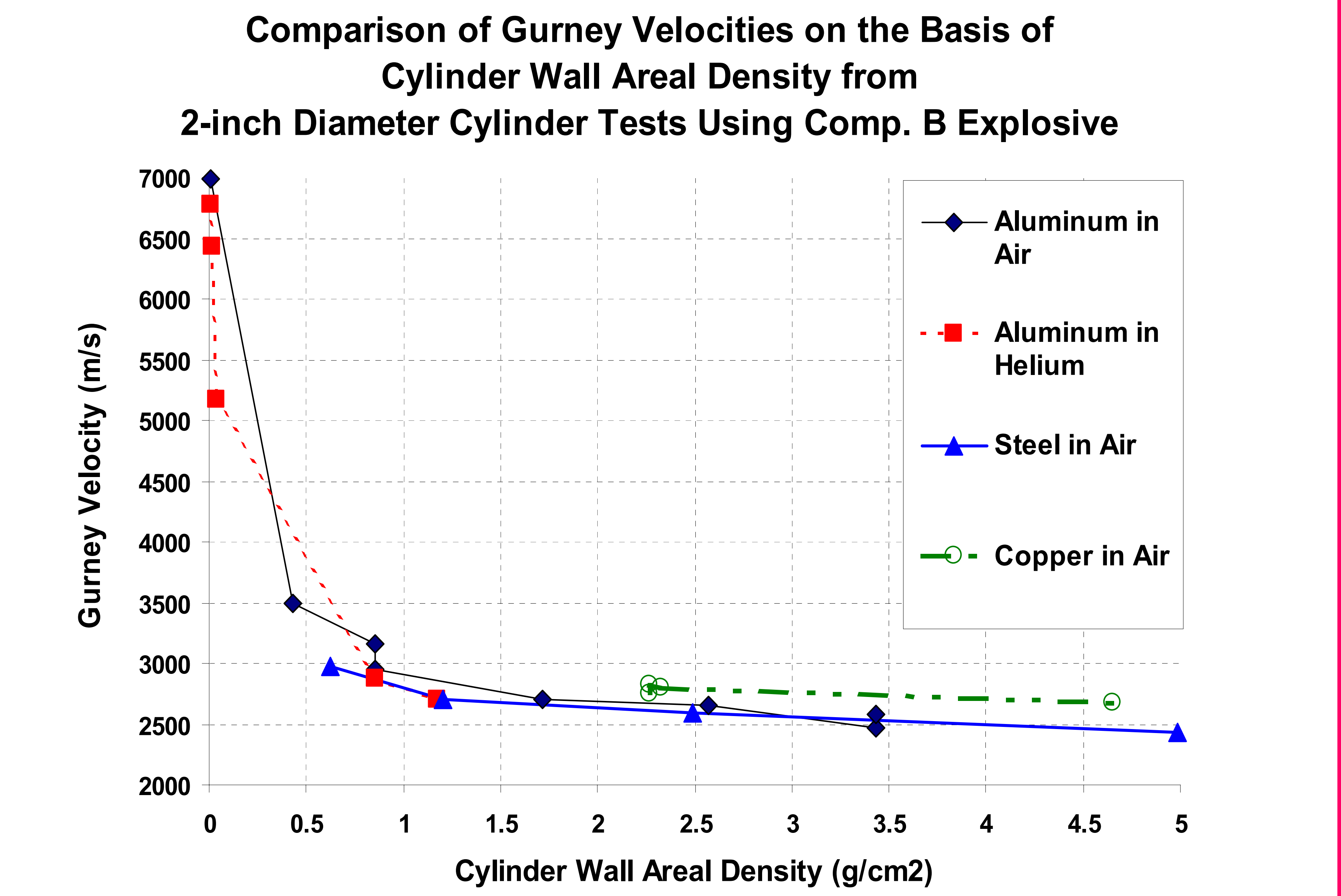
where Γ = the adiabatic exponent for the gaseous products

$Vg / D \cong (0.60\, \phi^{-1/2} + 0.648\, \rho_o^{1/2}) / (1.01 + 1.313\, \rho_o)$

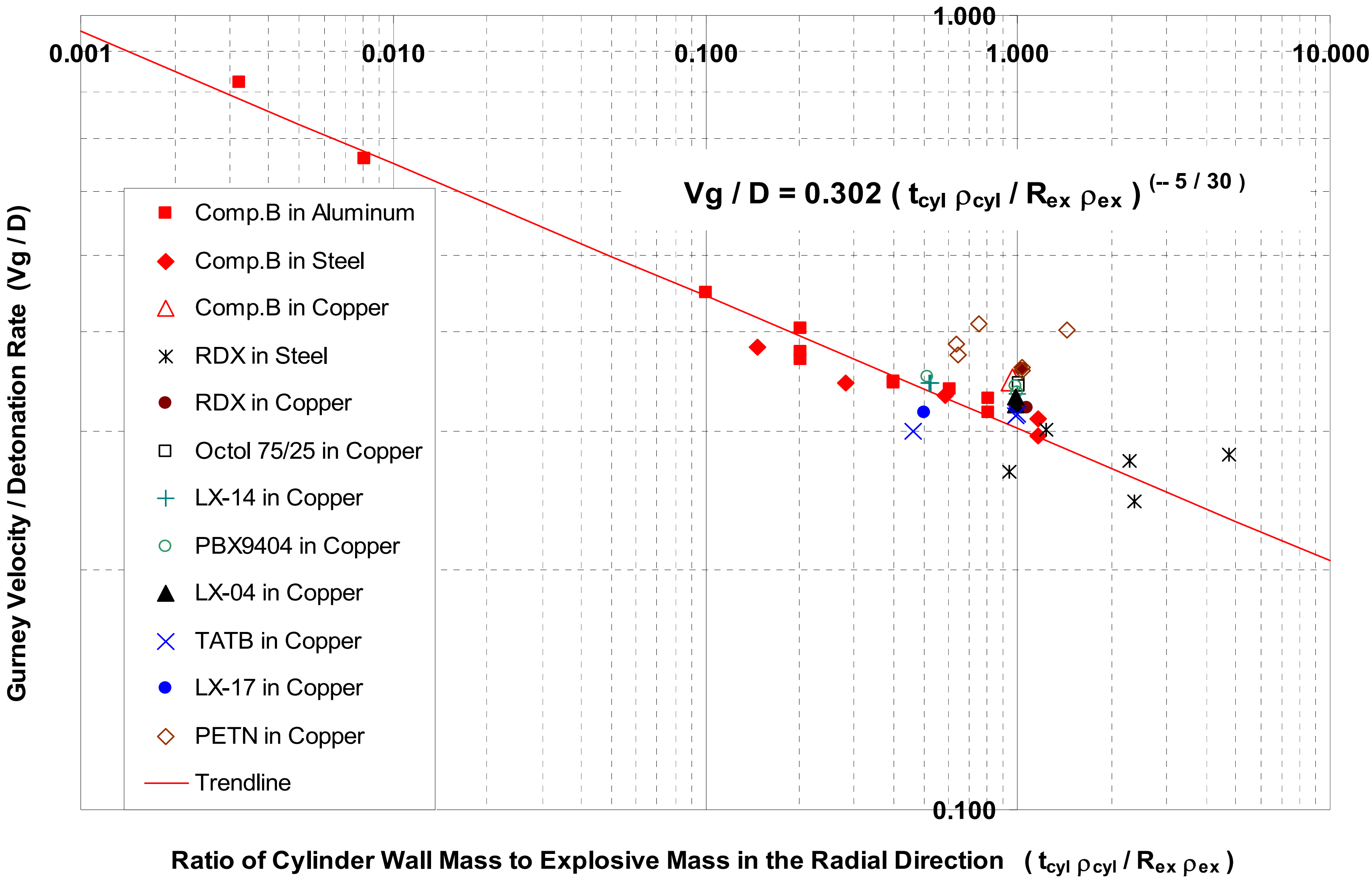
where $\phi = N\, M^{1/2}\, Q^{1/2}$; N = moles of gaseous detonation products
M = average weight of gases, and Q = chemical energy of detonation
(Hardesty & Kennedy / Kamlet & Hurwitz)

Copper Cylinders

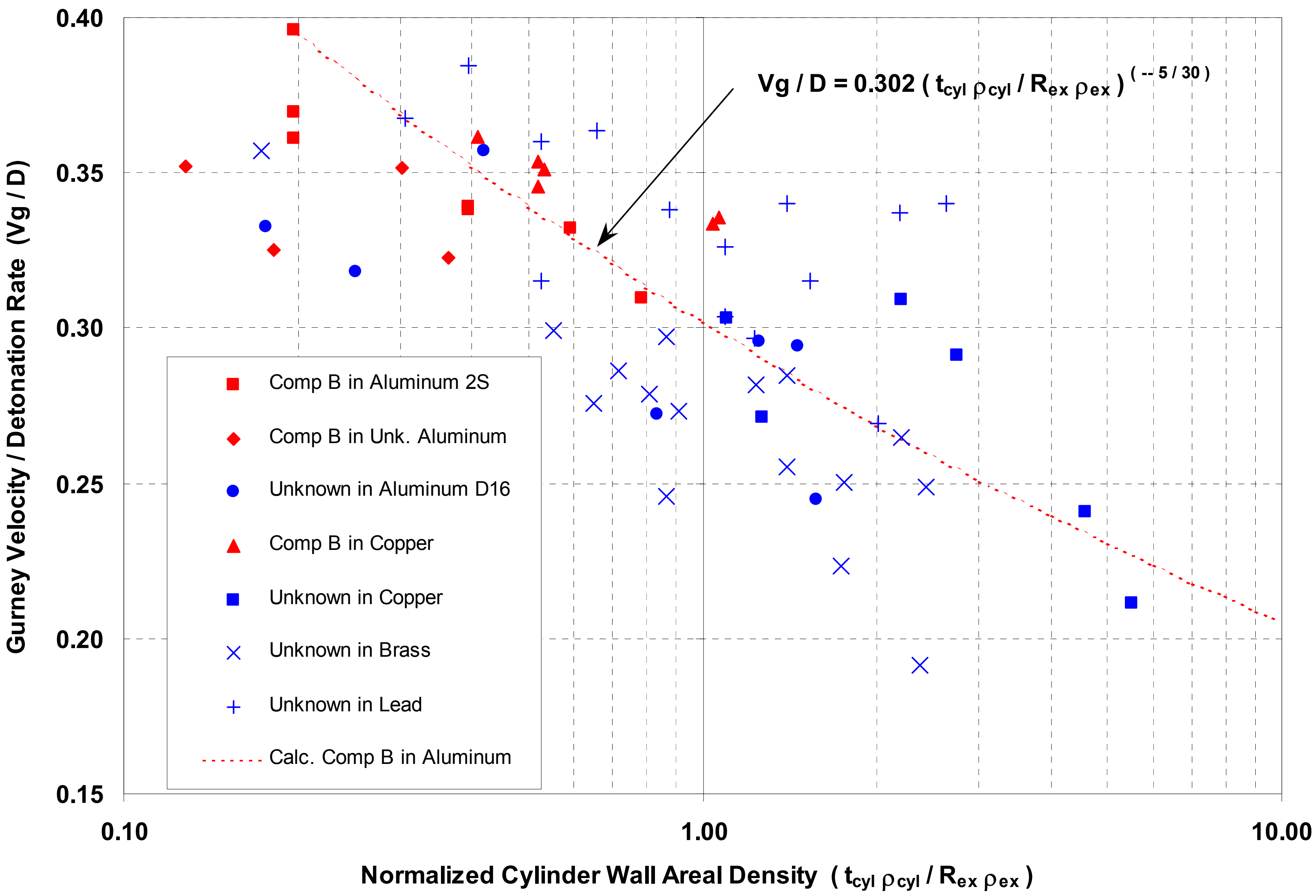
Vg / D	Exp. (Licht)	Cooper	Roth	HK/ KH
TNT	0.346	0.346	0.350	0.351
Comp B	0.345	0.343	0.355	0.385
Octol	0.335	0.330	0.331	0.328
LX-14	-----	0.326	0.348	-----
PETN	0.359	0.355	0.369	0.331


Comparison of Gurney Velocities on the Basis of
Cylinder Wall Areal Density from
2-inch Diameter Cylinder Tests Using Comp. B Explosive
Gurney Velocity (m/s)
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Cylinder Wall Areal Density (g/cm2)
Aluminum in Air
Aluminum in Helium
Steel in Air
Copper in Air

Ratio of the Gurney Velocity to an Explosive's Detonation Rate versus a Radial-Projection Areal Density Ratio



Normalized Gurney Velocity Data from Measurements of Cylinder Wall Velocity at Fracture Time



BRIGS Two-Step Detonation-Driven Propulsion Model

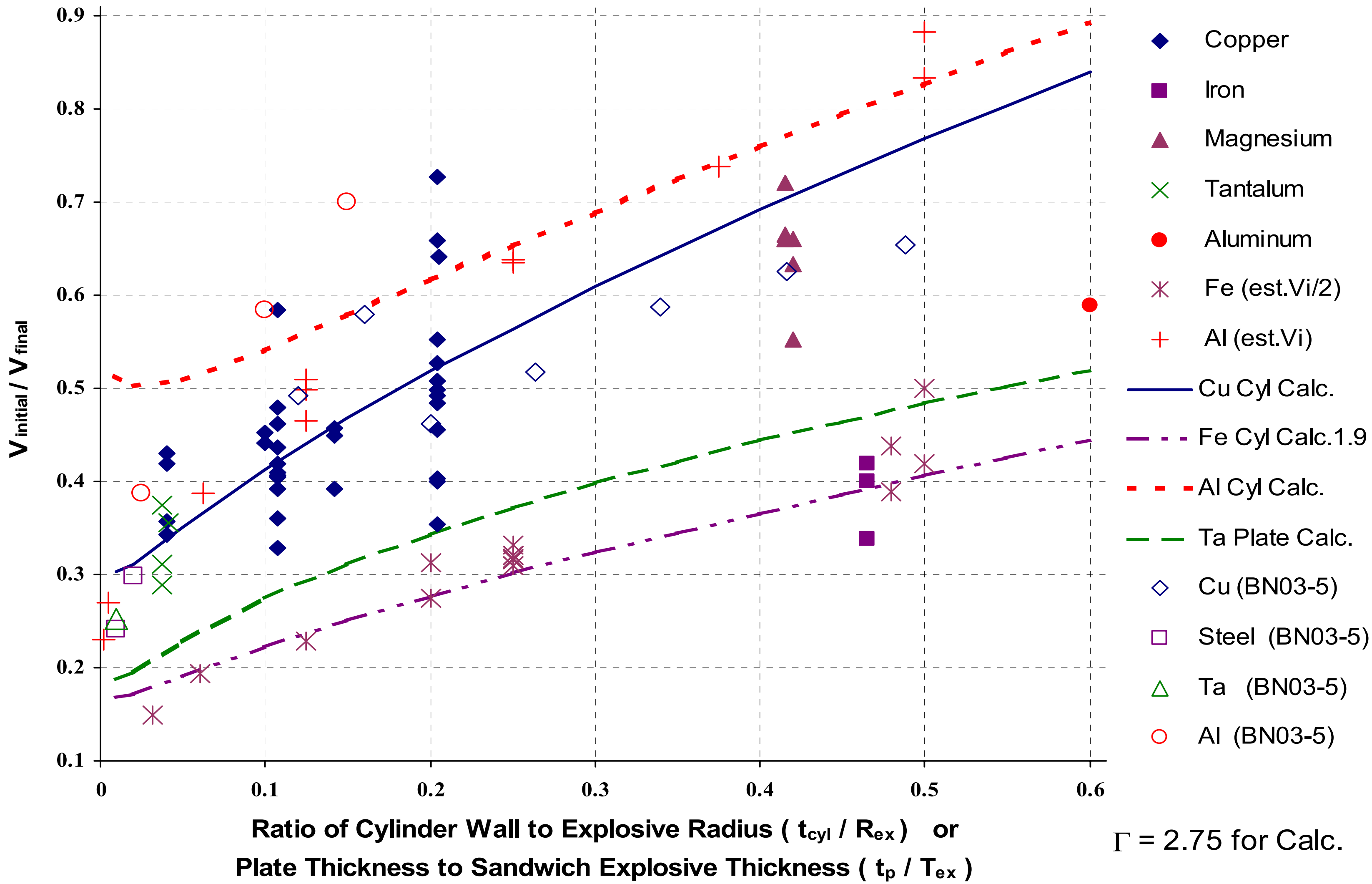
Initial motion:

- imparted by a brisant shock-dominated process that depends upon intimate contact of explosive with propelled material
- envisioned as caused by higher-pressure region of detonation front (envision the von Neumann spike or reaction zone region as a finite thickness of solid material squeezed at high pressure)

Gas-push (*gas-dynamic*) propulsion:

- envisioned similar to that assumed by Gurney modeling (gaseous product expansion from a homogeneous “all burnt” condition while pushing confining boundaries to a final “steady-state” velocity as the pressure drops)

$V_{initial}$ / V_{final} Data Plotted for Cylinders and Plates of Various Inert Materials and Explosives



New formulas improving insight into detonation-driven propulsion

Initial velocity imparted to cylinder wall

$$Vi / D = 0.2085 (\rho_{cyl} / \rho_{ex})^{-1/2} (t_{cyl} / R_{ex})^{(-3/40)}$$

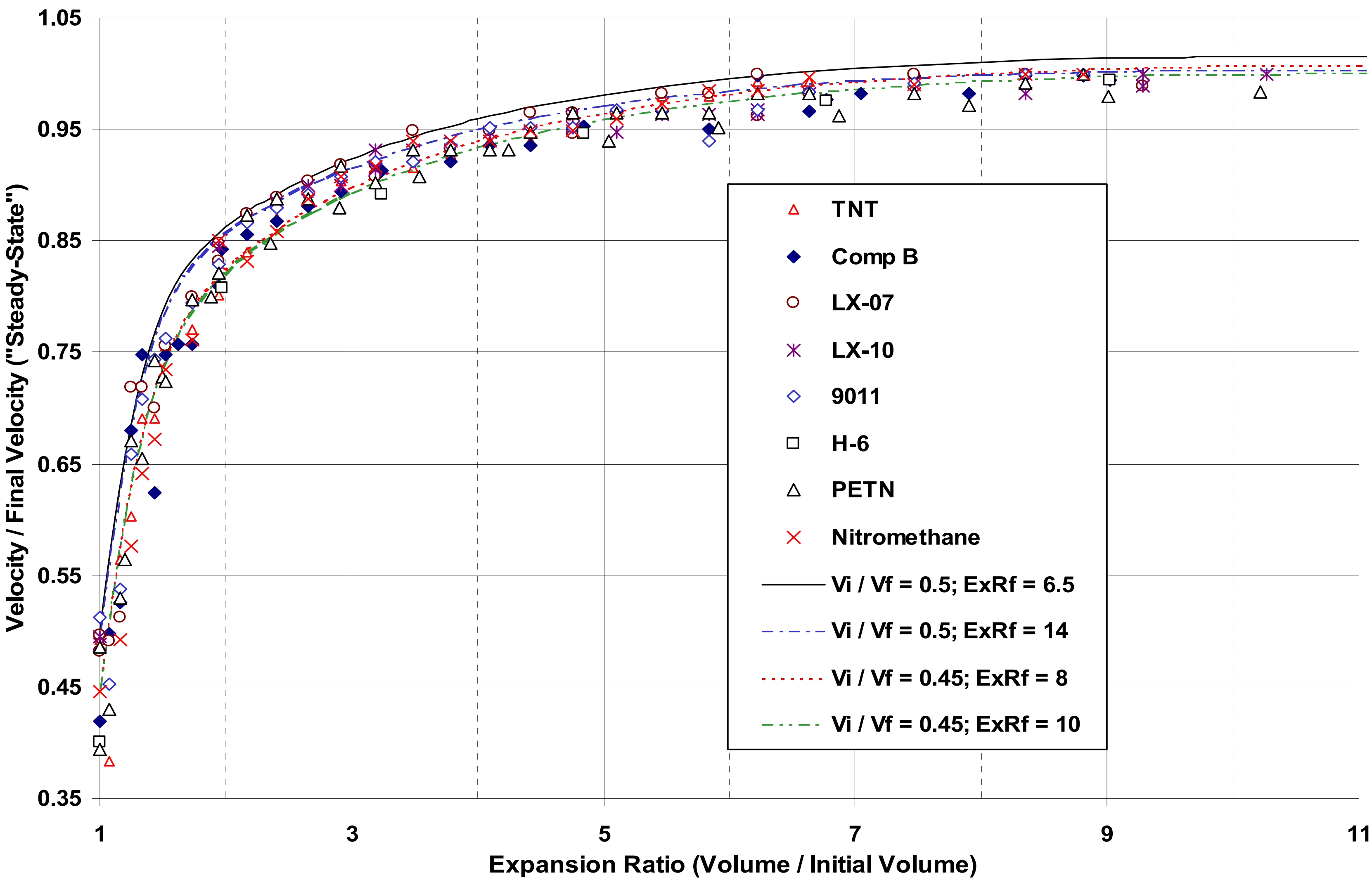
Equation for cylinders describing *ratio* of velocity imparted by *initial* coupling *to final* velocity

$$Vi / Vf = 0.3446 [\Gamma - 1] (t_{cyl} \rho_{cyl} / R_{ex} \rho_{ex})^{(5/30)} (t_{cyl} / R_{ex})^{(-3/40)} [(t_{cyl} / R_{ex})^2 + 2 (t_{cyl} / R_{ex}) + 0.5 (\rho_{ex} / \rho_{cyl})]^{1/2}$$

Vi = initial free-surface velocity
Vf = final “steady-state” velocity

	Transition Pressure (Gpa)
Aluminum	20.5
Carbon (pressed graphite)	23
Iron (0.2 wt% Carbon)	14.7
Iron (0.5 wt% Carbon)	13
Titanium	9.4

Normalized Velocity Data for Eight Explosives Driving Copper Cylinders



Equation for *instantaneous* velocity (Ver) as a function of the gaseous detonation products expansion ratio (ExR)

$$\mathrm{Ver} / \mathrm{Vf} = \mathrm{V1} / \mathrm{Vf} + \mathrm{V2} / \mathrm{Vf}$$

$$\mathrm{V1} / \mathrm{Vf} = (\mathrm{Vi} / \mathrm{Vf}) \left[\left(e^{-\mathrm{ExR}} - e^{-\mathrm{ExR}\,\hat{}\,3}\right) + \left(\{ \mathrm{ExR} / \mathrm{ExRf} \}^{-1/2} / [1 / \mathrm{ExRf}]^{-1/2} \right) \right]$$

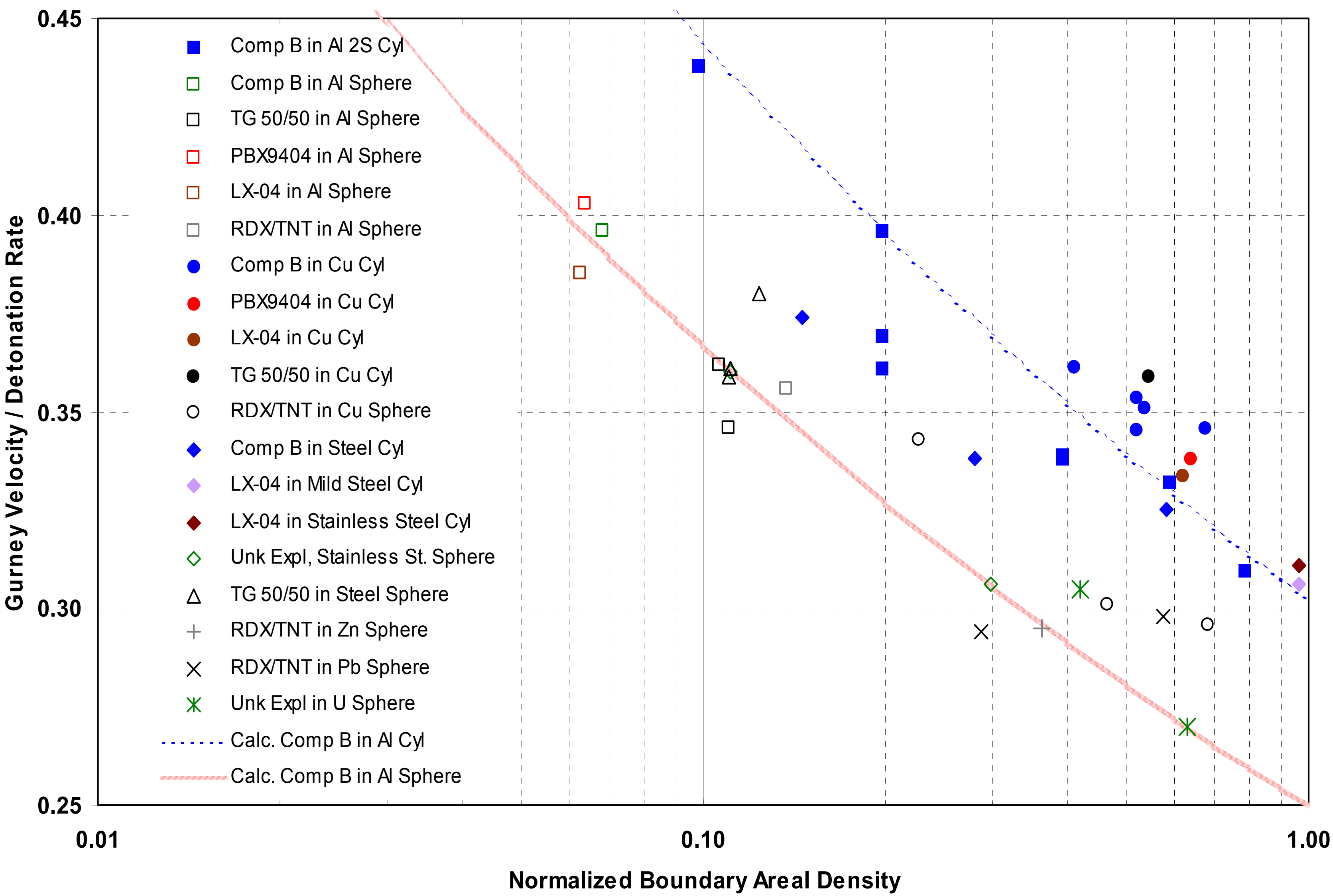
$$\mathrm{V2} / \mathrm{Vf} = \left[1 - \{ (\mathrm{Vi} / \mathrm{Vf}) / (1 / \mathrm{ExRf})^{-1/2} \} \right] (\mathrm{ExR} / \mathrm{ExRf})^{-1/3} \left[\log (\mathrm{ExR}) / \log (\mathrm{ExRf}) \right]$$

Vi = initial free-surface velocity

Vf = final “steady-state” velocity at final expansion ratio (ExRf)

(Equation was fitted “by eye” using MathCad™ software.)

Normalized Gurney Velocity Data for Some Explosives in Cylinders and Spheres of Different Materials



The important message is …..

material properties and geometry
affect Gurney Velocity measurement

The trend of these effects was demonstrated in:

- Cylinder tests (copper, aluminum, and steel)
- Fragmentation tests (copper, aluminum, etc.)

New data and analysis are needed:

- Published data were not specifically taken to reveal the effects
- Most copper cylinder test data taken at

$$(t_{cyl}\,\rho_{cyl} / R_{ex}\,\rho_{ex}) \cong 1.0$$

- Gurney (Lagrange) assumptions may not be valid

New opportunities:

- Gurney values would reflect materials & geometry
- To define effect of cylinder wall phase transitions

Another important message is …..

that *gas-dynamic* propulsion by many explosives is similar

Differences between explosives arise from:

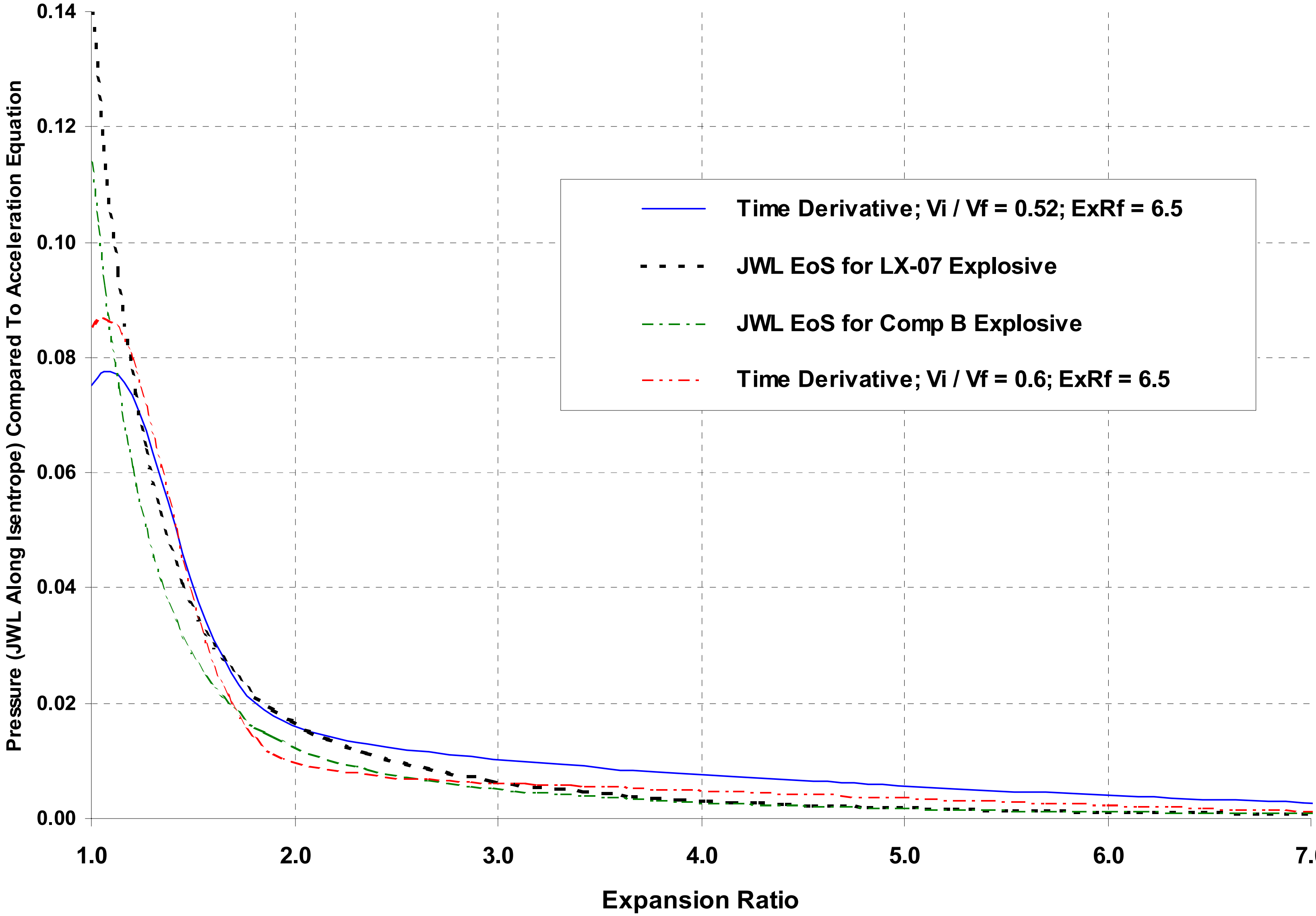
- Vi (solid-state detonation coupling effects)
- Total convertible energy (i.e. Vg from Vf at ExRf)
- Time needed to convert total energy to kinetic energy of boundary materials & detonation products

New, more accurate data are needed:

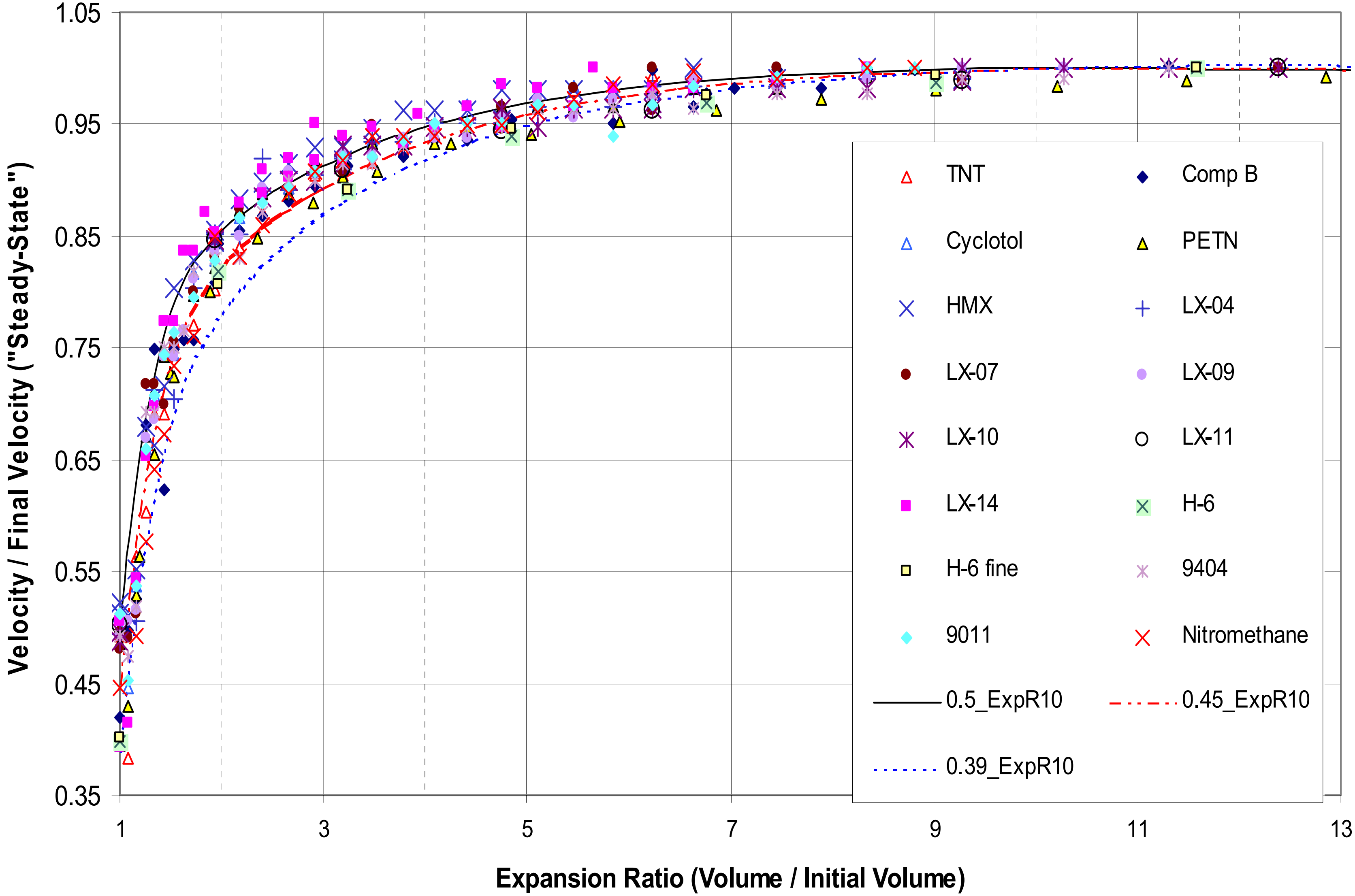
- Vi [grazing wave] using interferometry and various materials subject to phase transitions
- Vf data at larger ExRf [beyond 6.5 to 10 - 14]
- Not sure that Gurney (Lagrange) assumptions valid [need more data from Vi to ExR = 2 & beyond]

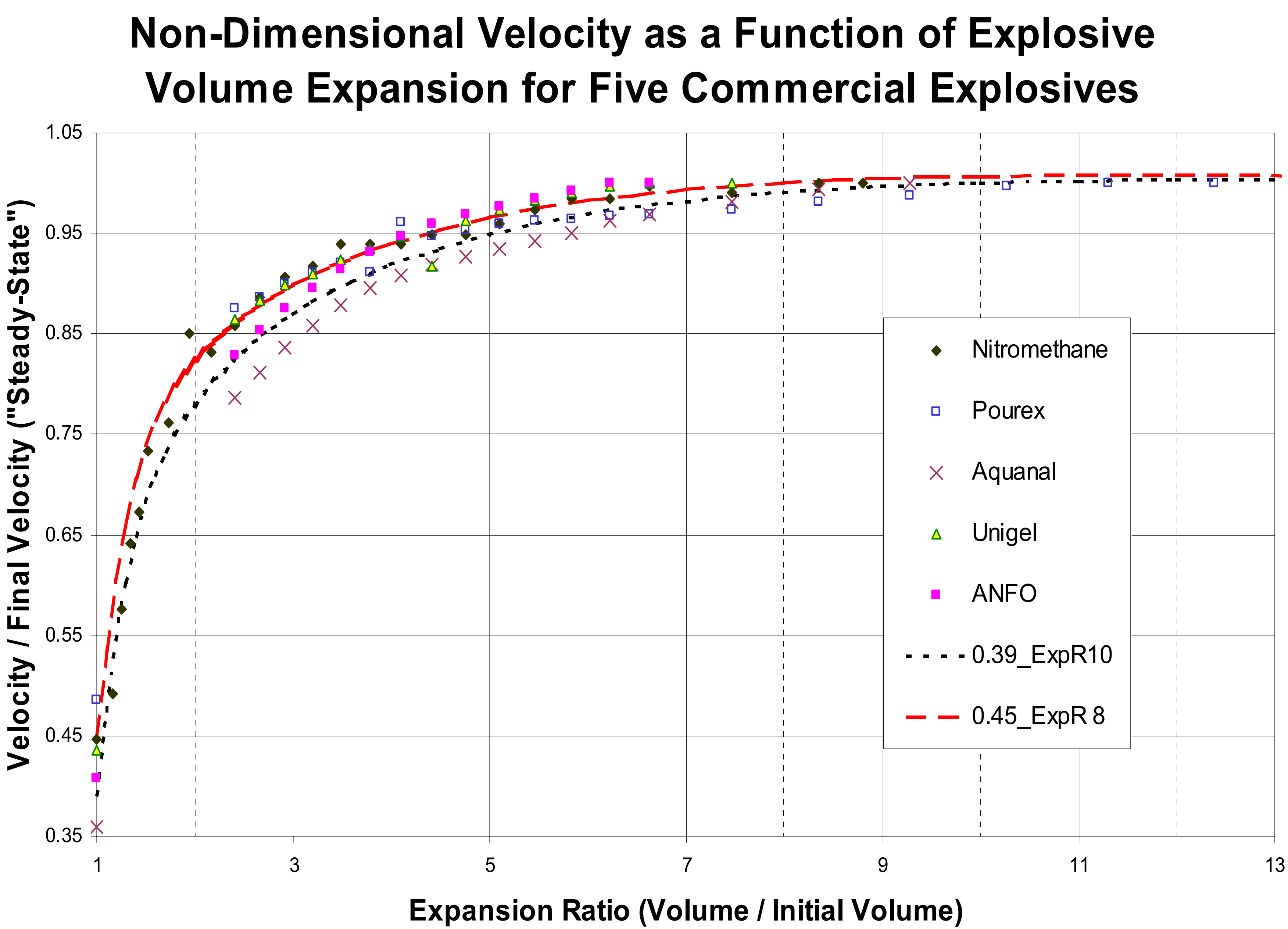
Additional Backup Information Follows …….

Comparison of JWL Calculated Pressures to the *Time Derivative* of the *Instantaneous Velocity* Equation for an Expanding Cylinder



Non-Dimensional Velocity as a Function of Explosive Volume Expansion for Sixteen "Ideal" Explosives




Non-Dimensional Velocity as a Function of Explosive Volume Expansion for Five Commercial Explosives
Velocity / Final Velocity ("Steady-State")
1.05
0.95
0.85
0.75
0.65
0.55
0.45
0.35
1
3
5
7
9
11
13
Expansion Ratio (Volume / Initial Volume)
Nitromethane
Pourex
Aquanal
Unigel
ANFO
0.39_ExpR10
0.45_ExpR 8

Currently available trend-line

$$Vg / D \cong (0.605 / [\Gamma\text{-}1])\ (t_{cyl}\ \rho_{cyl} / R_{ex}\ \rho_{ex})^{(-5/30)}$$

(J. Roth per J.E. Kennedy) -- expanded

For use with

$$Vf = Vg\ (\rho_{cyl}/\rho_{ex})^{-1/2}\ [(t_{cyl}/R_{ex})^2 + 2\ (t_{cyl}/R_{ex}) + 0.5\ (\rho_{ex}/\rho_{cyl})]^{-1/2}$$

Future work

$$Vg / D \cong (0.60\ \phi^{-1/2} + 0.648\ \rho_o^{\ 1/2}) / (1.01 + 1.313\ \rho_o)$$

(Hardesty & Kennedy / Kamlet & Hurwitz)

$$Vg\text{-}p / D \cong (0.541 / [\Gamma\text{-}1])\ (t_{cyl}\ \rho_{cyl} / R_{ex}\ \rho_{ex})^{(-5/30)}$$

(Gas - push contribution model)