



RDECOM



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Combined Effects Aluminized Explosives

Dr. Ernest L. Baker

L.I. Stiel, W. Balas, C. Capellos and J. Pincay

23 SEP 2008



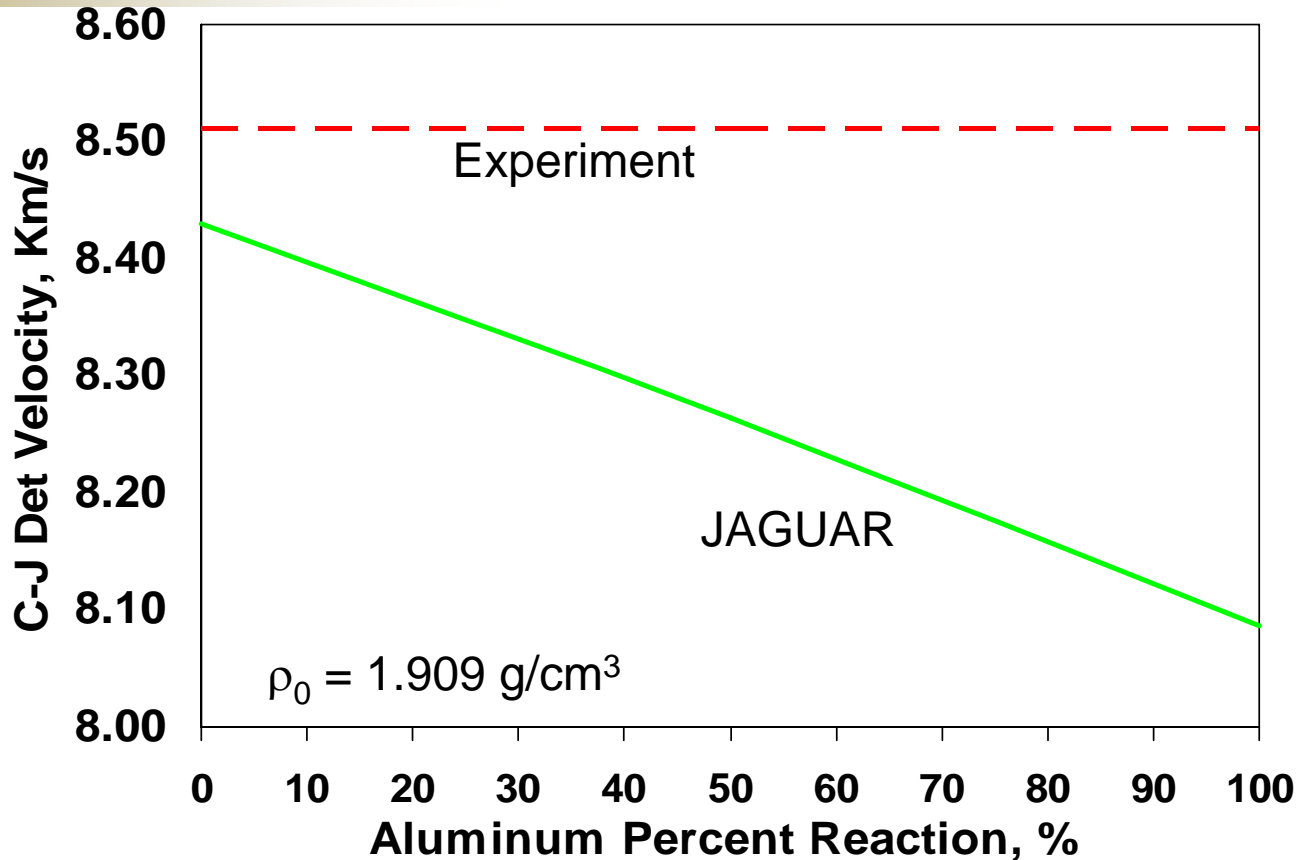
- Combined Effects Explosives
- Eigenvalue Detonation
- Detonation Velocities
- Cylinder Velocities
- Equations of State
- Conclusions

- High Energy Explosive
 - High nitramine content
 - High early work output (before 7V/V0)
- High Blast Explosive
 - Typically aluminum and additional oxidizer
 - Later work output (after 7V/V0)
- Combined Effects Explosive
 - Nitramine with fine aluminum: micron & submicron
 - Aluminum reaction occurs very early and contributes to early work

PAX-29: 77/15 CI-20/Al

PAX-30: 77/15 HMX/Al

PAX-42 77/15 RDX/Al

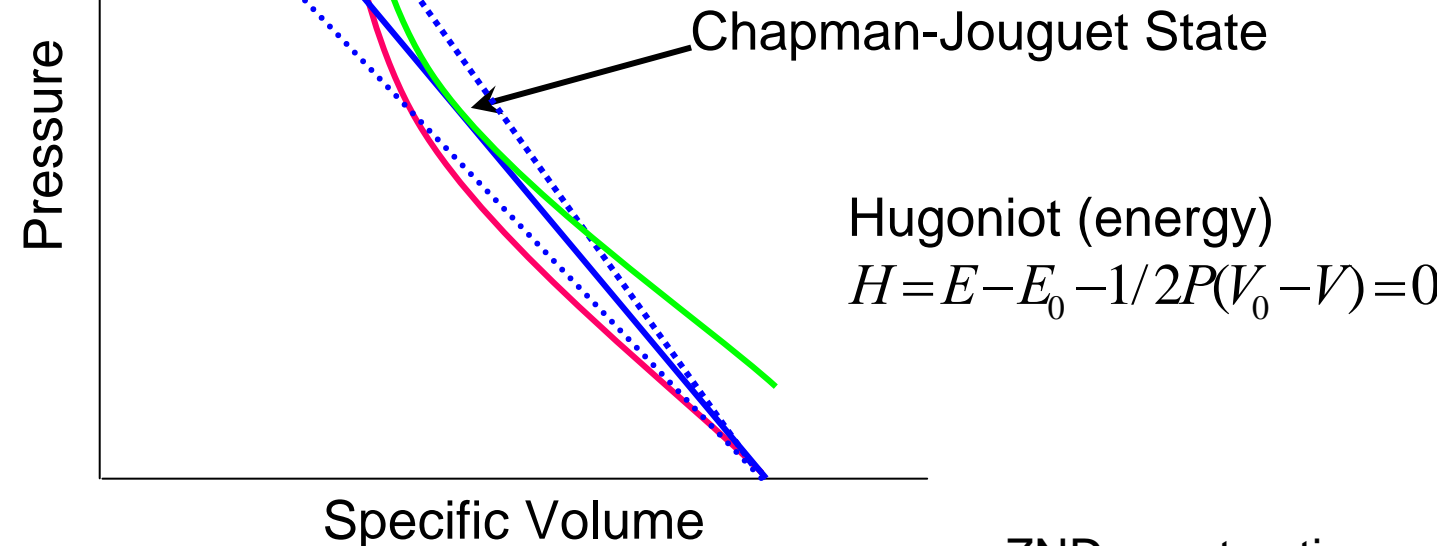


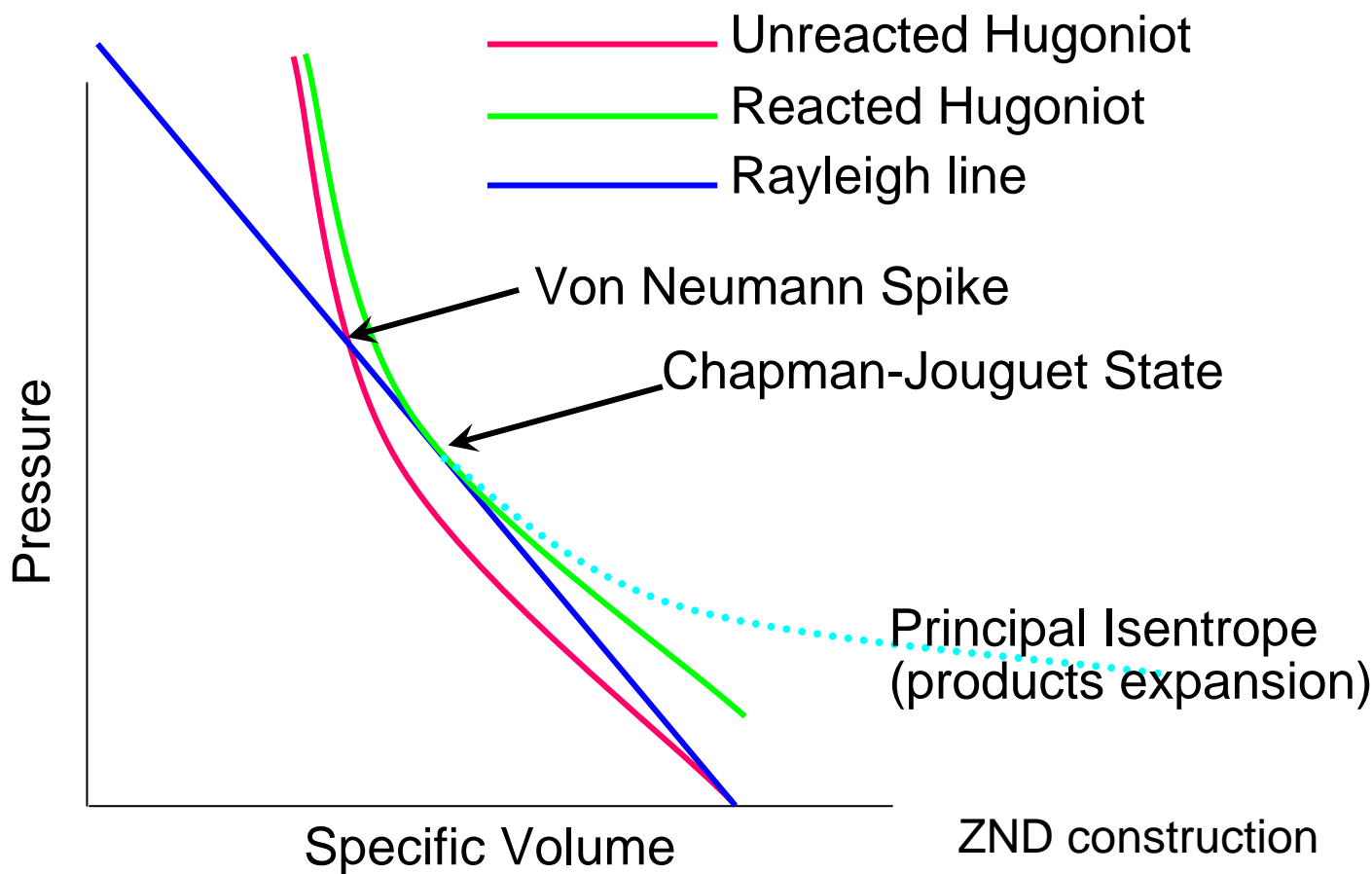
- **C-J Detonation velocity decreases with extent of Al reaction**
 - **Experiments:**
 - **Detonation velocity agrees with 0% Al reaction**
 - **Cylinder velocity agrees with 100% Al reaction @ 7V/V0**
- 0%: 1.69Km/s, 100%: 1.90Km/s, Experiment: 1.88Km/s

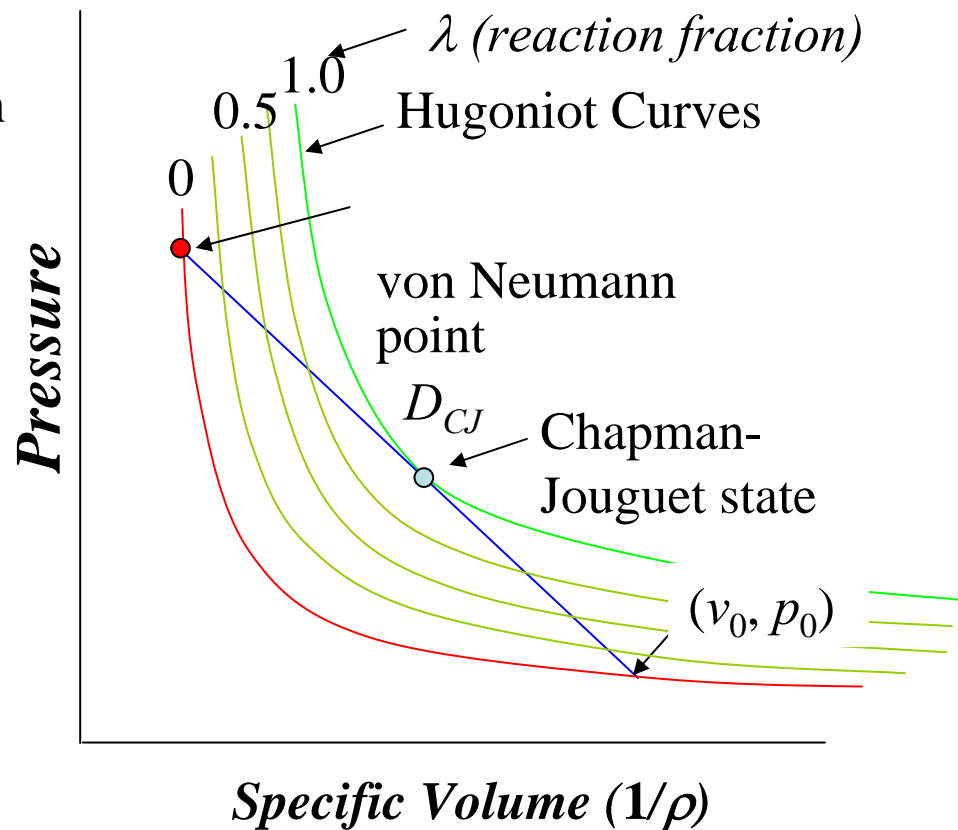
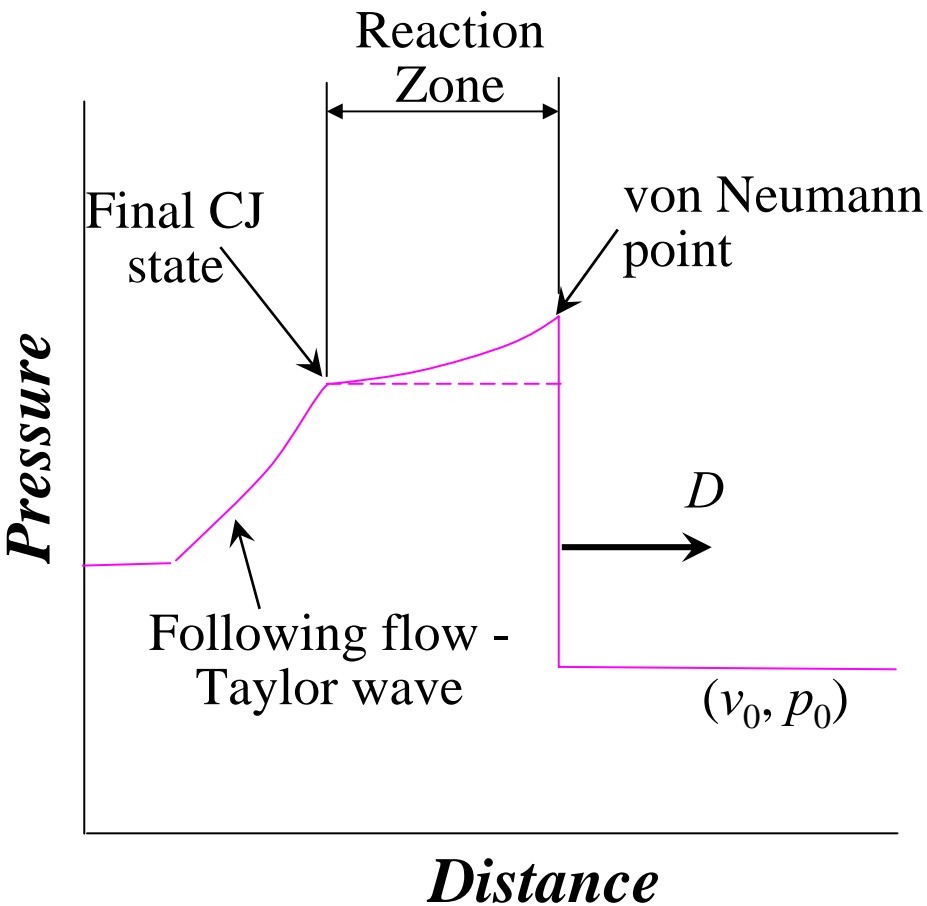
Rayleigh line (momentum) $R = \rho_0^2 D^2 - P/(V_0 - V) = 0$

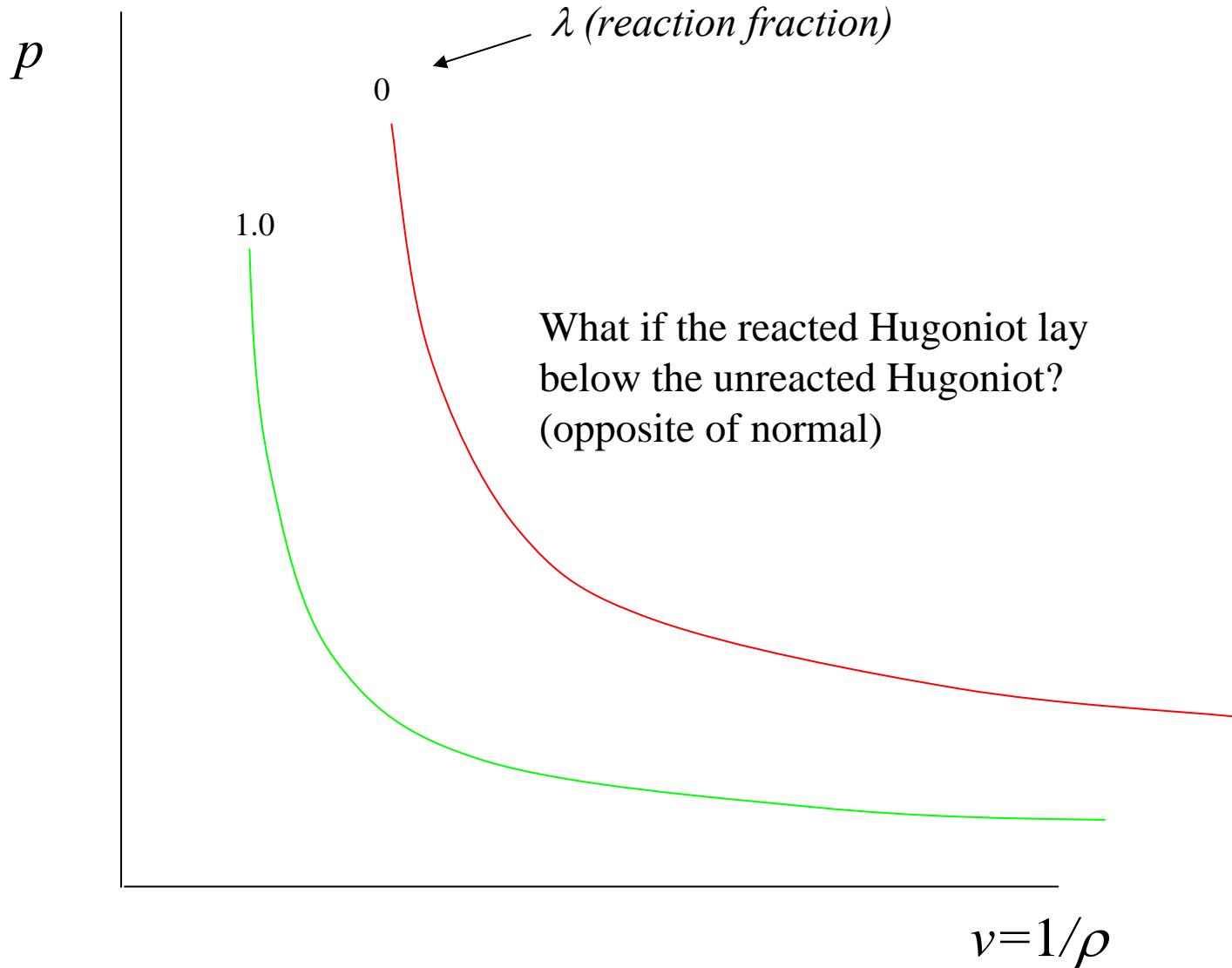
larger D
smaller D

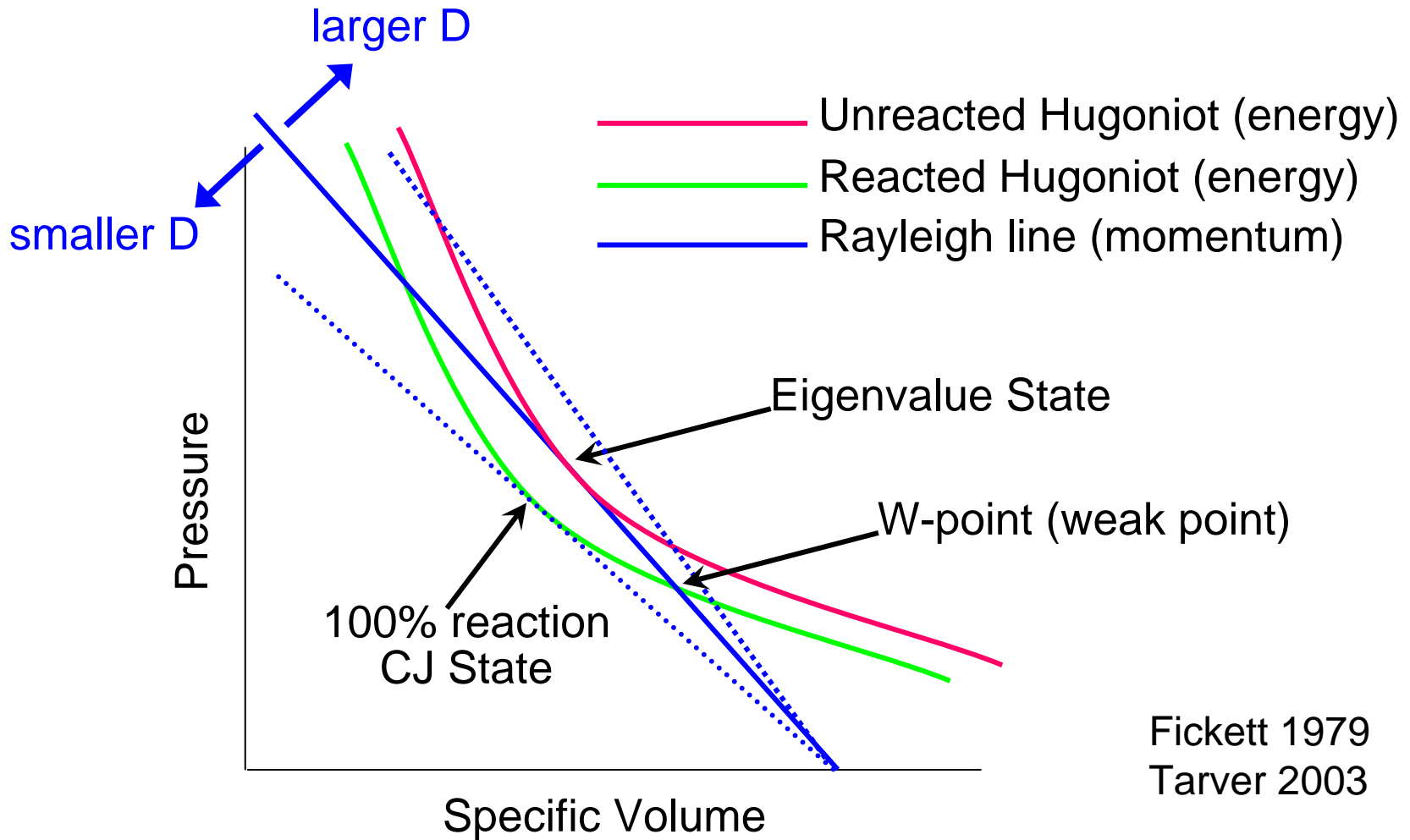
- Unreacted Hugoniot
- Reacted Hugoniot
- Rayleigh line



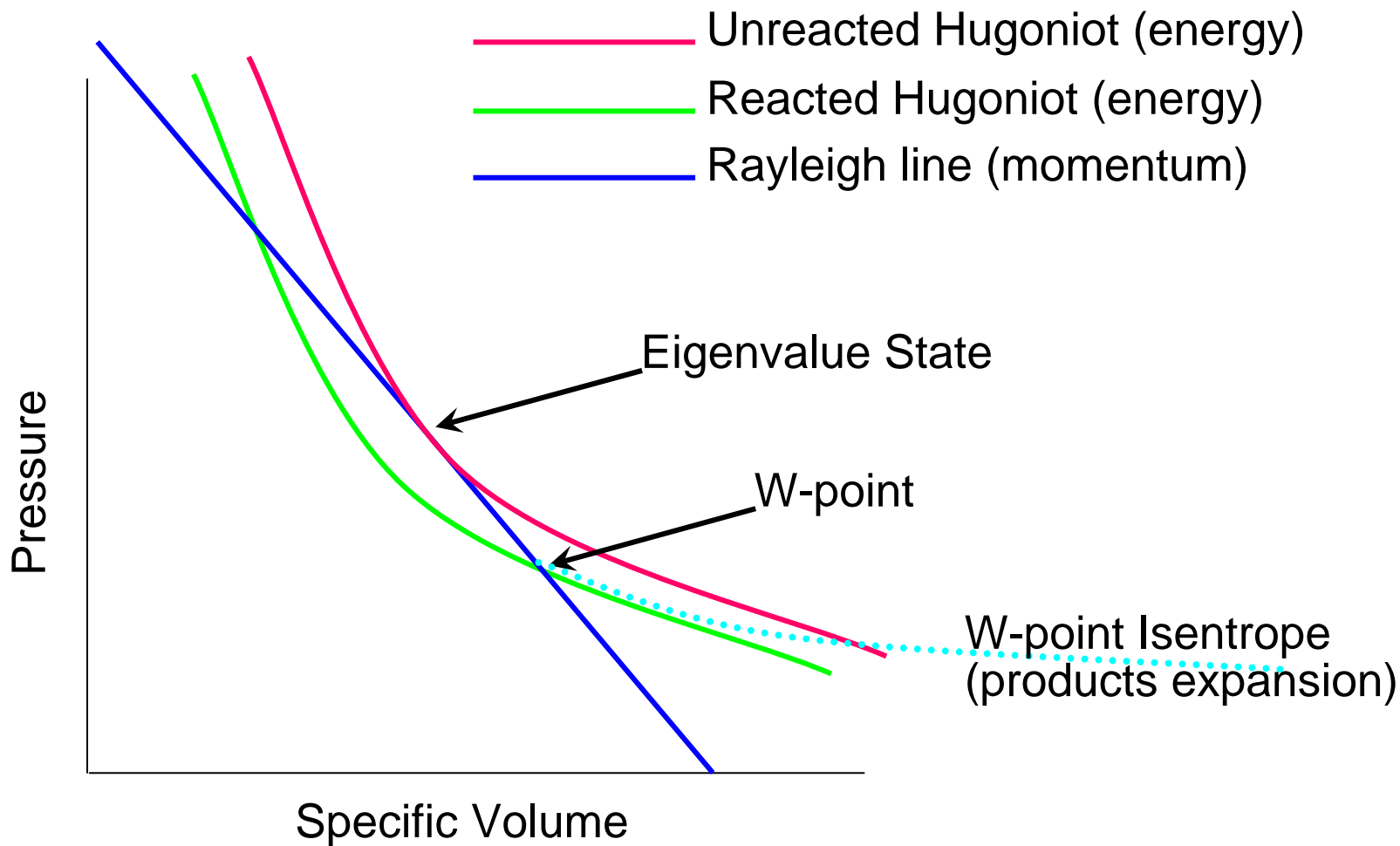


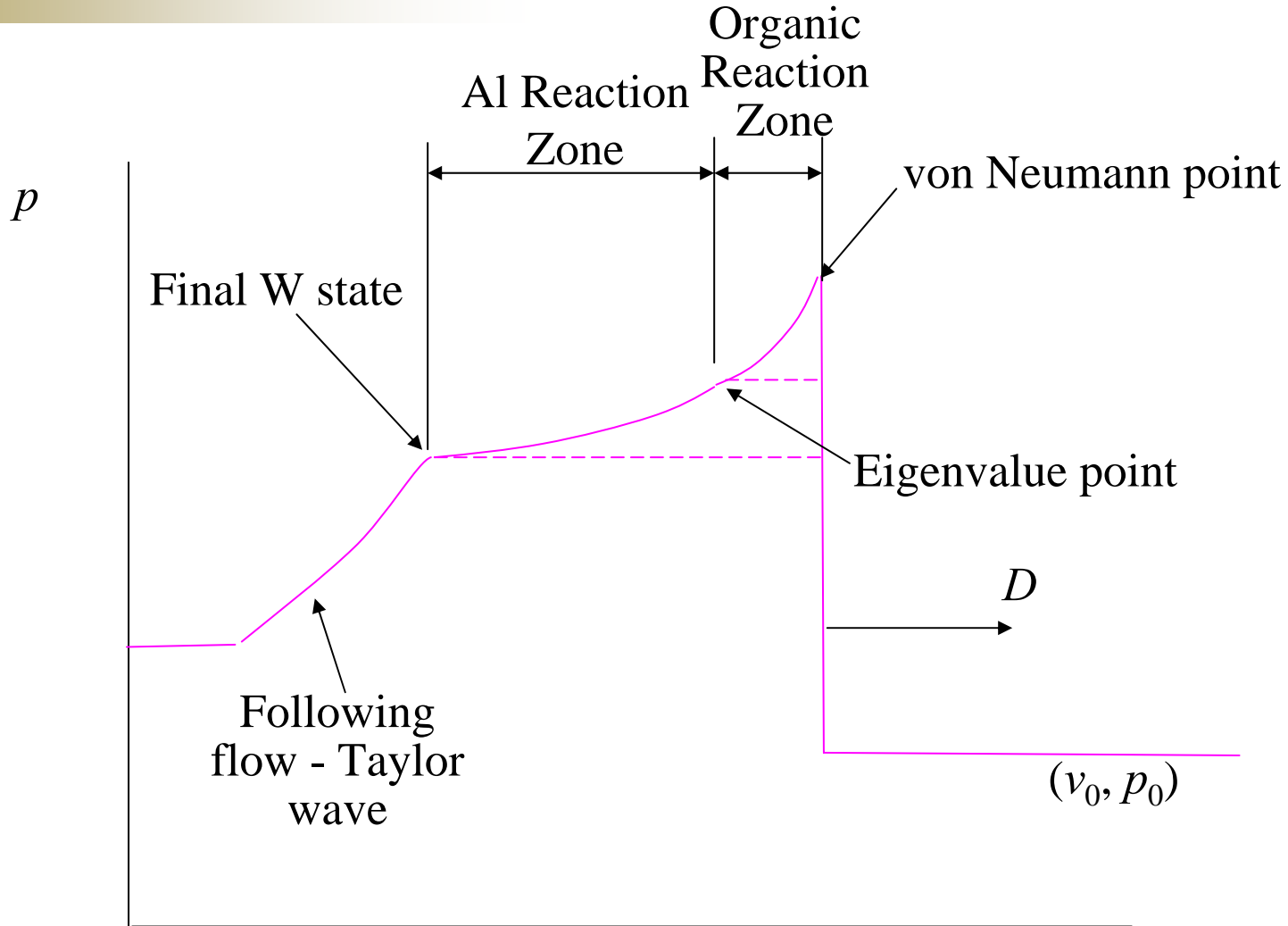


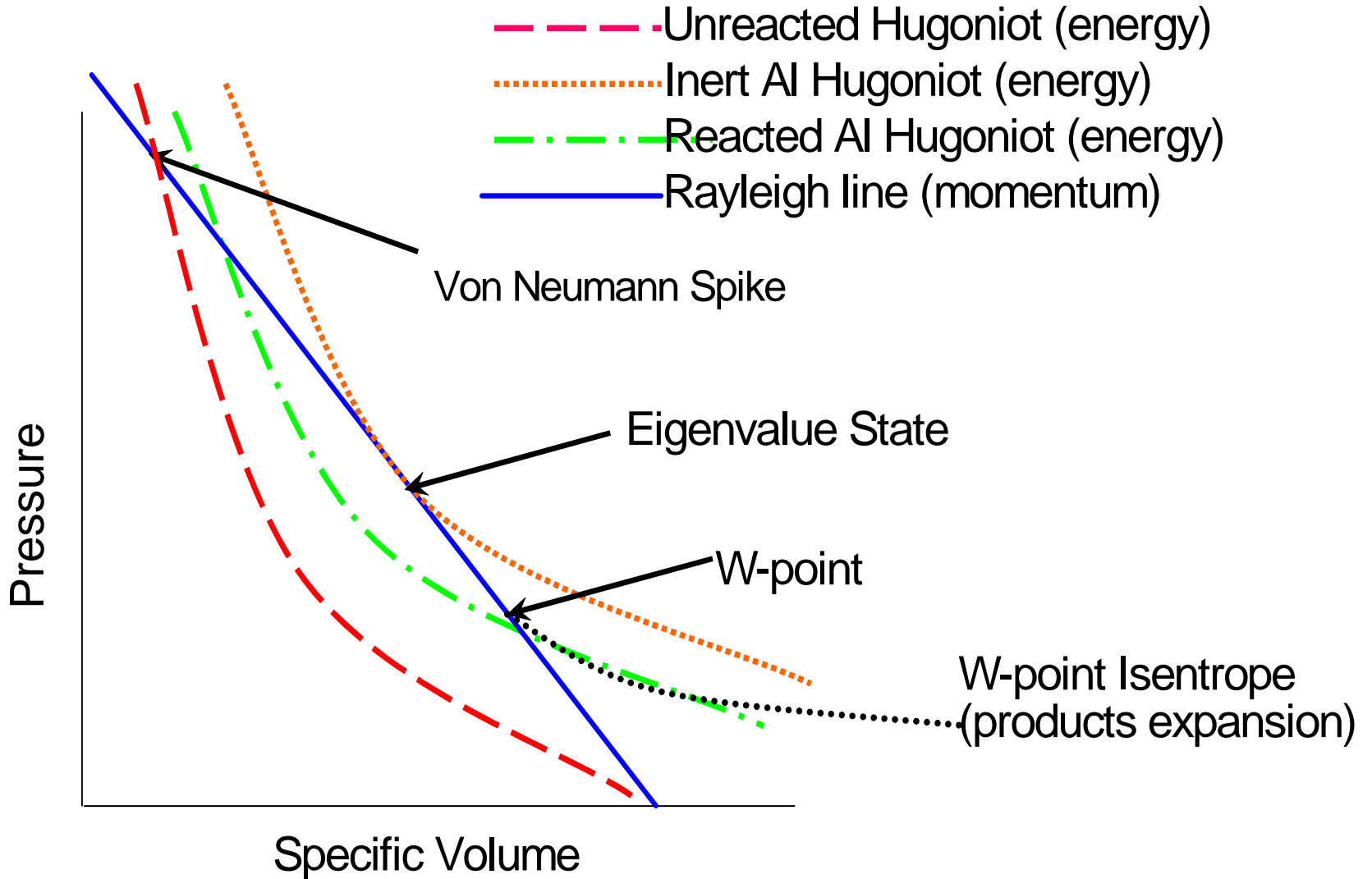




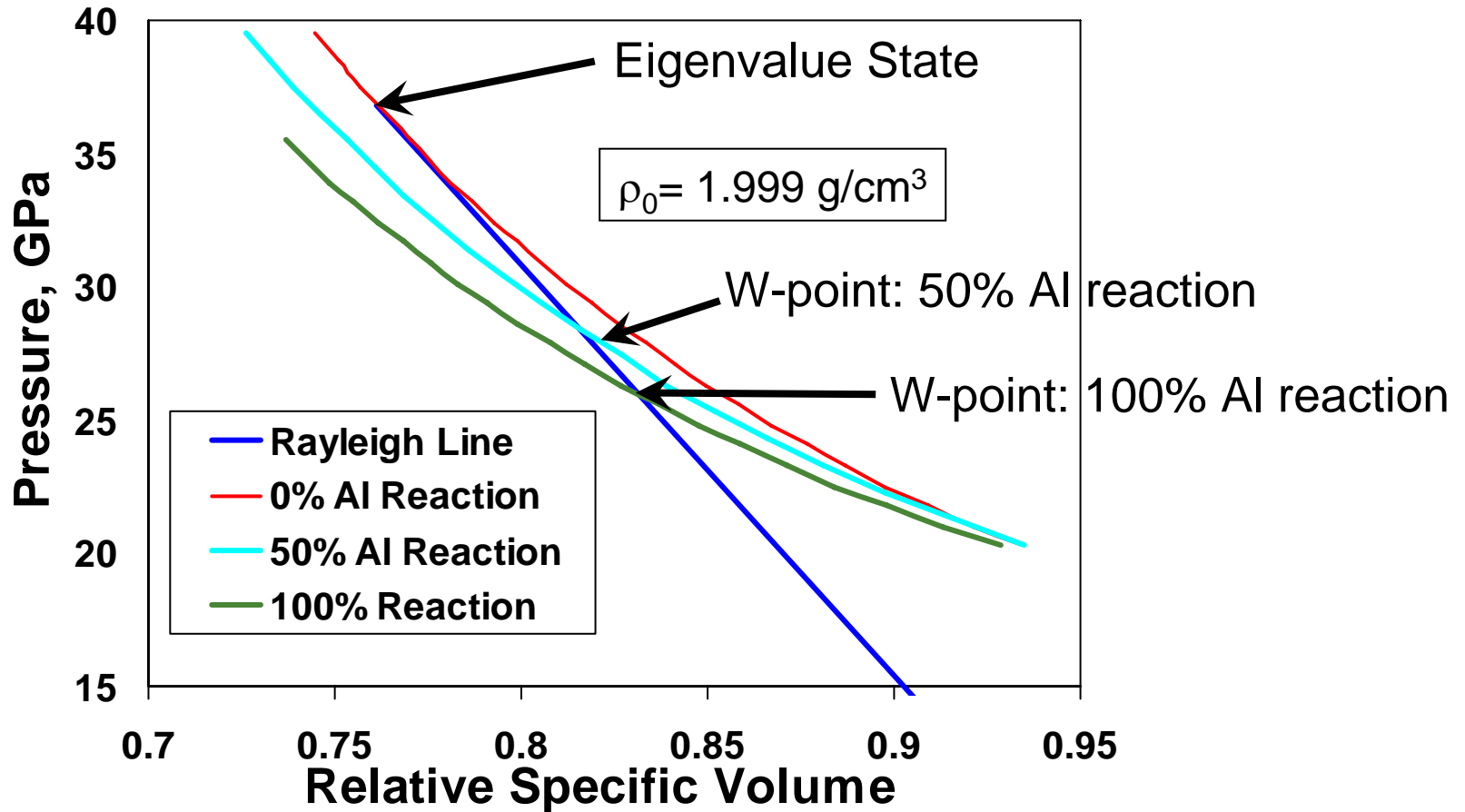
Fickett 1979
Tarver 2003





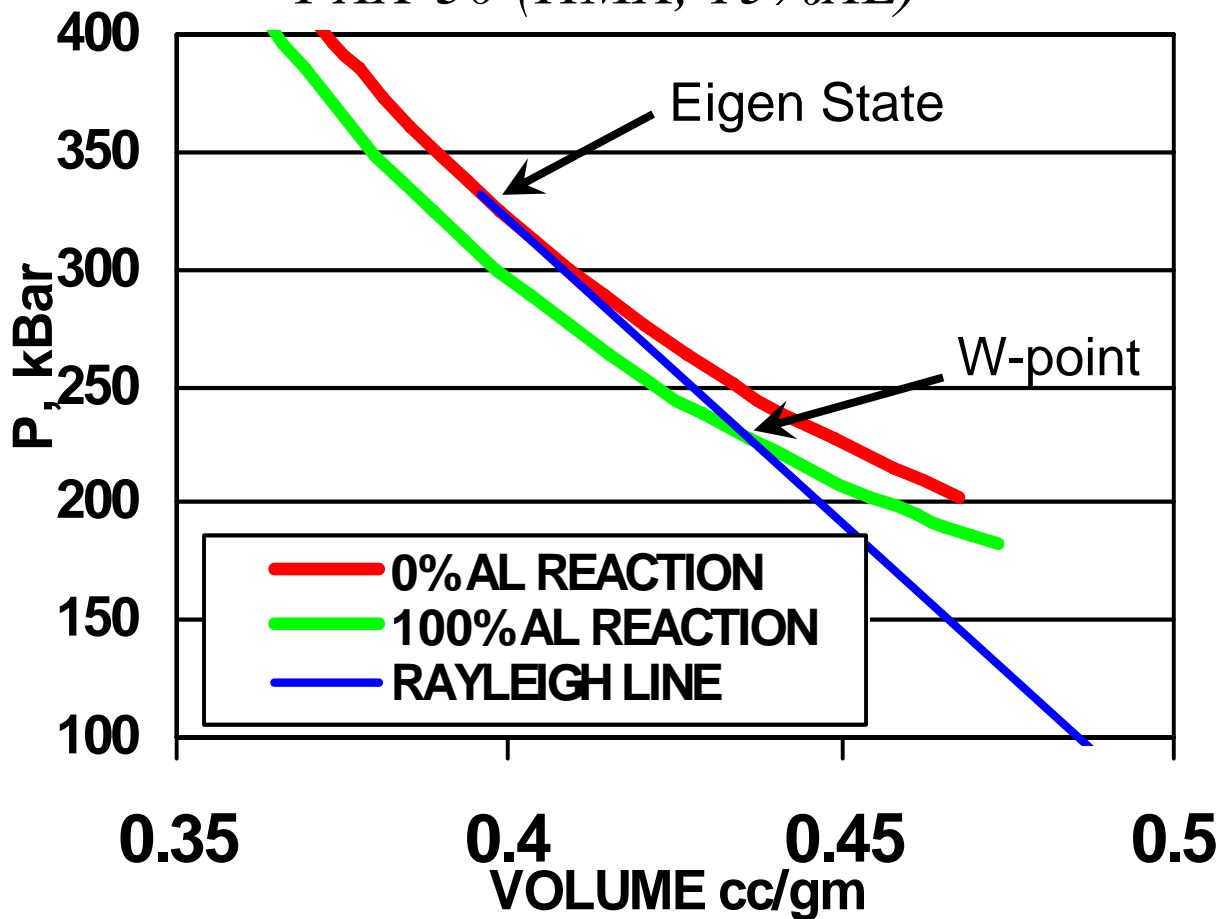


JAGUAR Calculations PAX-29 (CL-20, 15%Al)



Aluminum reaction produces lower Hugoniot

JAGUAR Calculations PAX-30 (HMX, 15%AL)



Detonation velocity controlled by 0% AL reaction Hugoniot!

EXPLOSIVE	Al%	ρ_0 (gm/cc)	Experiment D (Km/s)	JAGUAR Calculations	
				Inert Al D (Km/s)	Reacting Al D (Km/s)
HMX	5	1.84	8.71	8.66	8.53
HMX	15	1.87	8.45	8.42	7.95
HMX	25	1.95	8.55	8.35	7.32
BTNEN	15	1.96	8.29	8.38	7.45
BTNEN	15	1.91	8.06	8.16	7.24
NG	15	1.74	7.94	8.07	7.93
TNT	20	1.64	6.41	6.38	5.77
TNT	30	1.84	6.74	6.63	4.92
TNT	10	1.67	6.51	6.68	6.52
PAX-3	18	1.87	7.96	8.05	7.65
PAX-29	15	2.0	8.95	8.79	8.16
PAX-30	15	1.91	8.51	8.43	8.09
PAX-42	15	1.83	8.25	8.14	7.75
AVERAGE ERROR %				1.22	7.52

Detonation velocities agree with little or no aluminum reaction

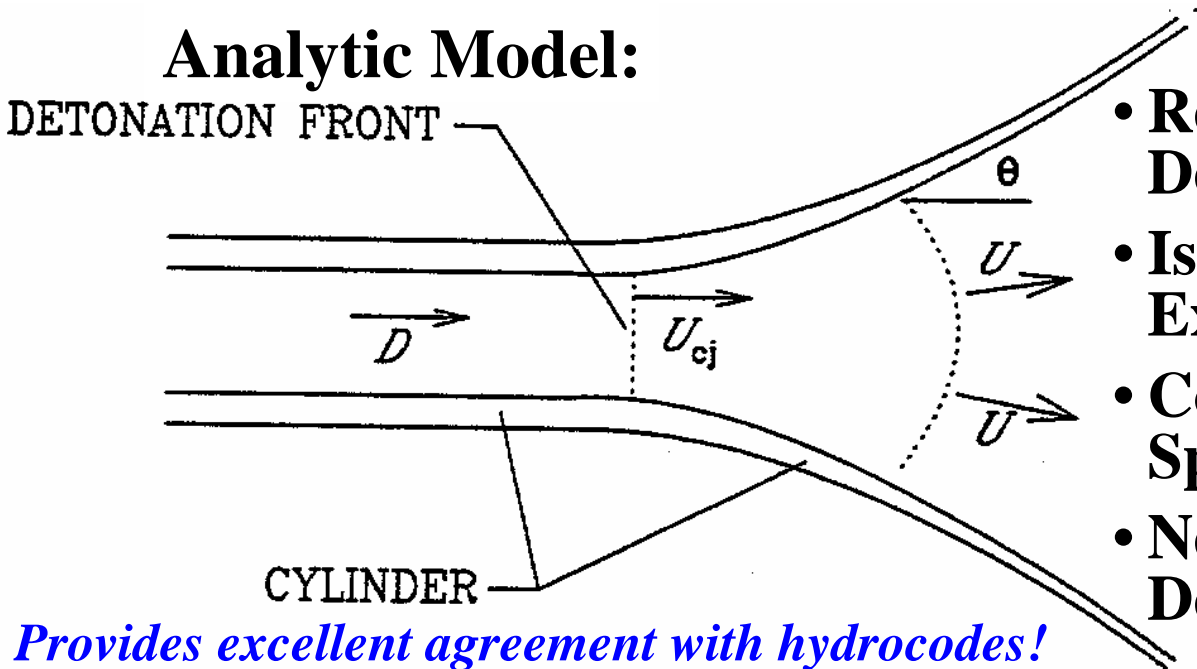
JWL E Equation of State:

$$P = \sum_i A_i \left(1 - \frac{\lambda}{R_i V^*} \right) e^{-R_i V^*} + \frac{\lambda E}{V^*} + C \left(1 - \frac{\lambda}{\omega} \right) V^{*-(\omega+1)}$$

Gruneisen Parameter:

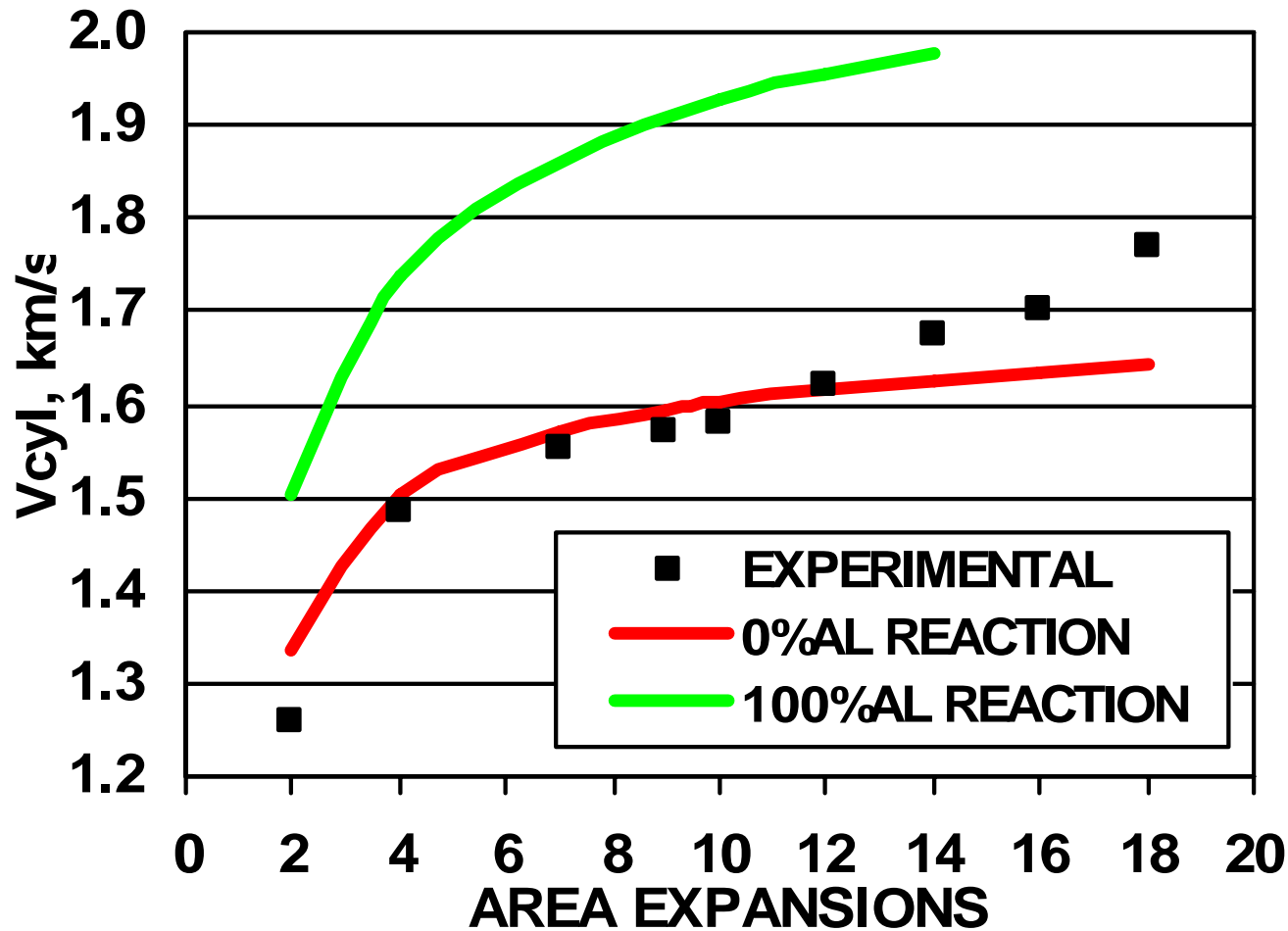
$$\lambda \equiv \sum (A_{\lambda i} V^* + B_{\lambda i}) e^{-R_{\lambda i} V^*} + \omega$$

Analytic Model:

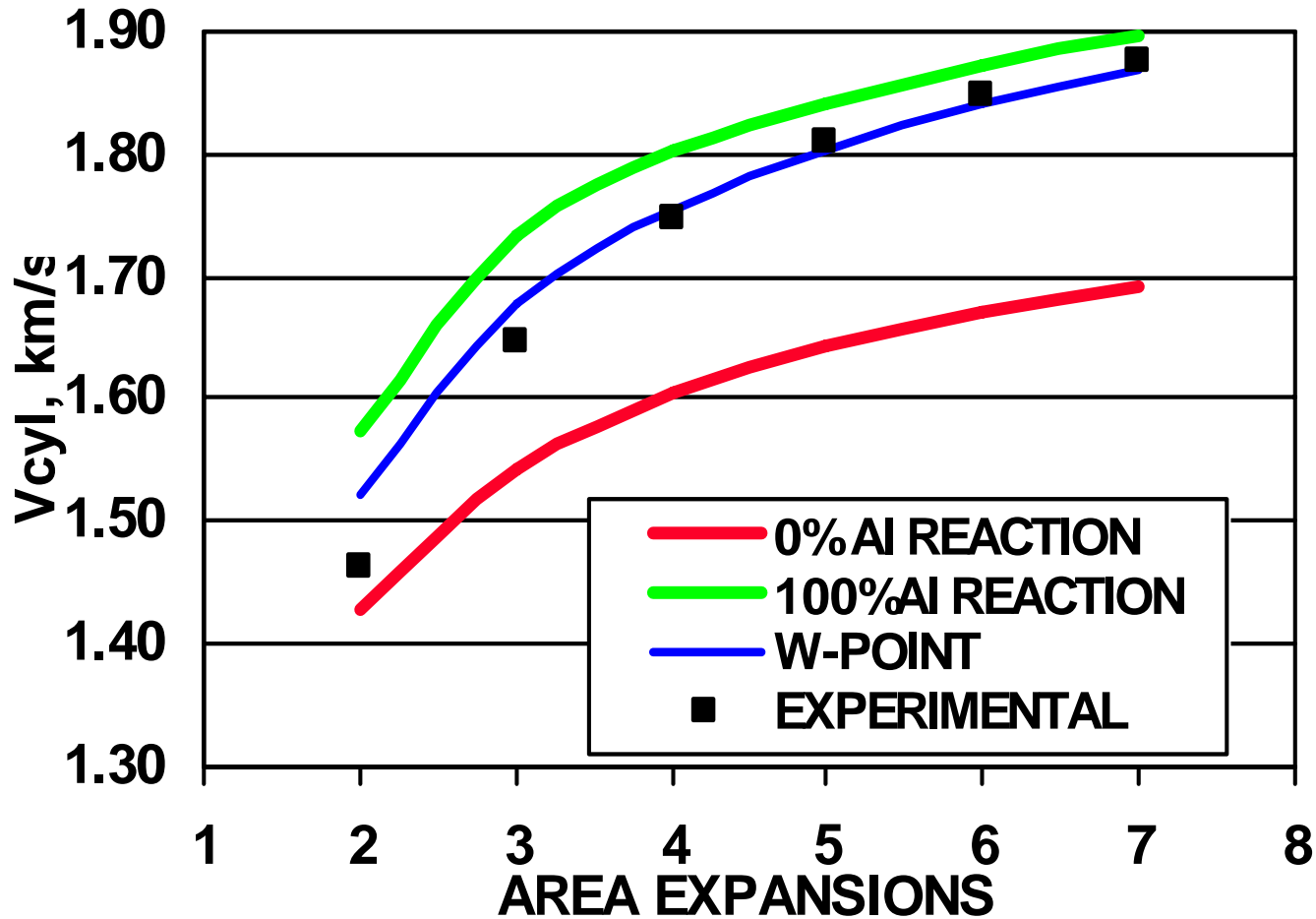


- Reference Frame at Detonation Velocity
- Isentropic Products Expansion
- Constant Properties Along Spherical Surfaces
- New: Modified for Eigen Detonation W-point

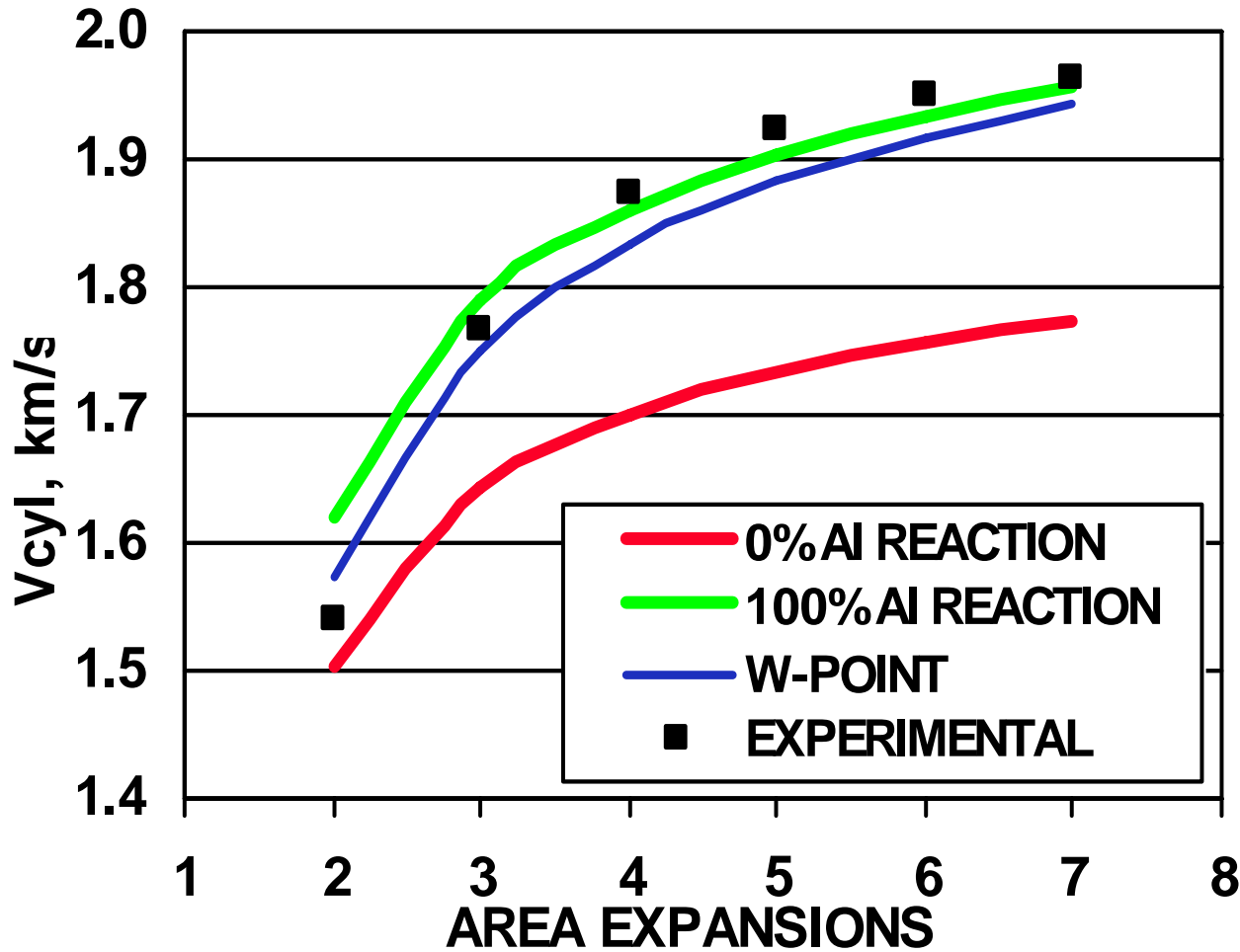
Provides excellent agreement with hydrocodes!



HMX with large particle size Aluminum: AL reacts late!



HMX with small particle size aluminum: AL reacts early!



CL-20 with small particle size Aluminum: AL reacts early!

	PAX-3 (Al INERT)	PAX-29	PAX-30	PAX-42
ρ_0 (g/cc)	1.866	1.999	1.885	1.827
E0 (Mbar)	0.08223	0.14611	0.13568	0.13109
D (cm/ μ s)	0.8023	0.8784	0.8342	0.8137
P (Mbar)	0.2937	0.2599	0.2419	0.2339
A1 (Mbar)	601.643	400.407	406.224	400.717
A2 (Mbar)	3.9482	82.630	135.309	16.5445
A3 (Mbar)	0.9403	1.5507	1.311	1.45169
A4 (Mbar)	0.049688	0.006126	0.006772	0.006103
R1	13.6055	20.9887	26.9788	13.6945
R2	3.69901	9.6288	10.6592	8.67402
R3	24.9093	24.2441	2.52342	2.5320
R4	1.04285	0.328128	0.335585	0.33570
C (Mbar)	0.007691	0.014626	0.013561	0.014057
ω	0.27780	0.24286	.234742	0.242371

D and P are from
W-Point
(not C-J values)

	LX14	PAX-2A	PAX-29	PAX-30	PAX-42
ρ_0 (g/cc)	1.819	1.770	1.999	1.885	1.827
E_0 (Mbar)	0.10213	0.09953	0.14714	0.135755	0.12994
D (cm/ μ s)	0.8630	0.8391	0.8784	0.8342	0.8137
P (Mbar)	0.3349	0.3124	0.2599	0.2419	0.2339
A_1 (Mbar)	26.1406	27.0134	8.58373	7.19151	13.8484
A_2 (Mbar)	.763619	.762675	0.168261	0.097112	0.145102
R_1	6.93245	7.22237	4.7726	4.59098	5.74864
R_2	1.94159	1.95979	1.03613	0.84089	0.99404
C (Mbar)	0.010994	0.010919	0.014556	0.013492	0.015193
ω	0.384193	0.375812	0.242252	0.233665	0.253095

Combined effects explosives: note large blast energies!



- New combined effects explosives produce both high metal pushing (early) and high blast (late) work output.
- Detonation velocities agree with little or no Al reaction even with sub-micron particles
- However, with small particles, complete Al reaction is indicated during early products expansion
- Eigen detonation theory used for EOS development