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Theory and Detonation Products Equations of State for a New Generation of Combined Effects Explosives

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Outline

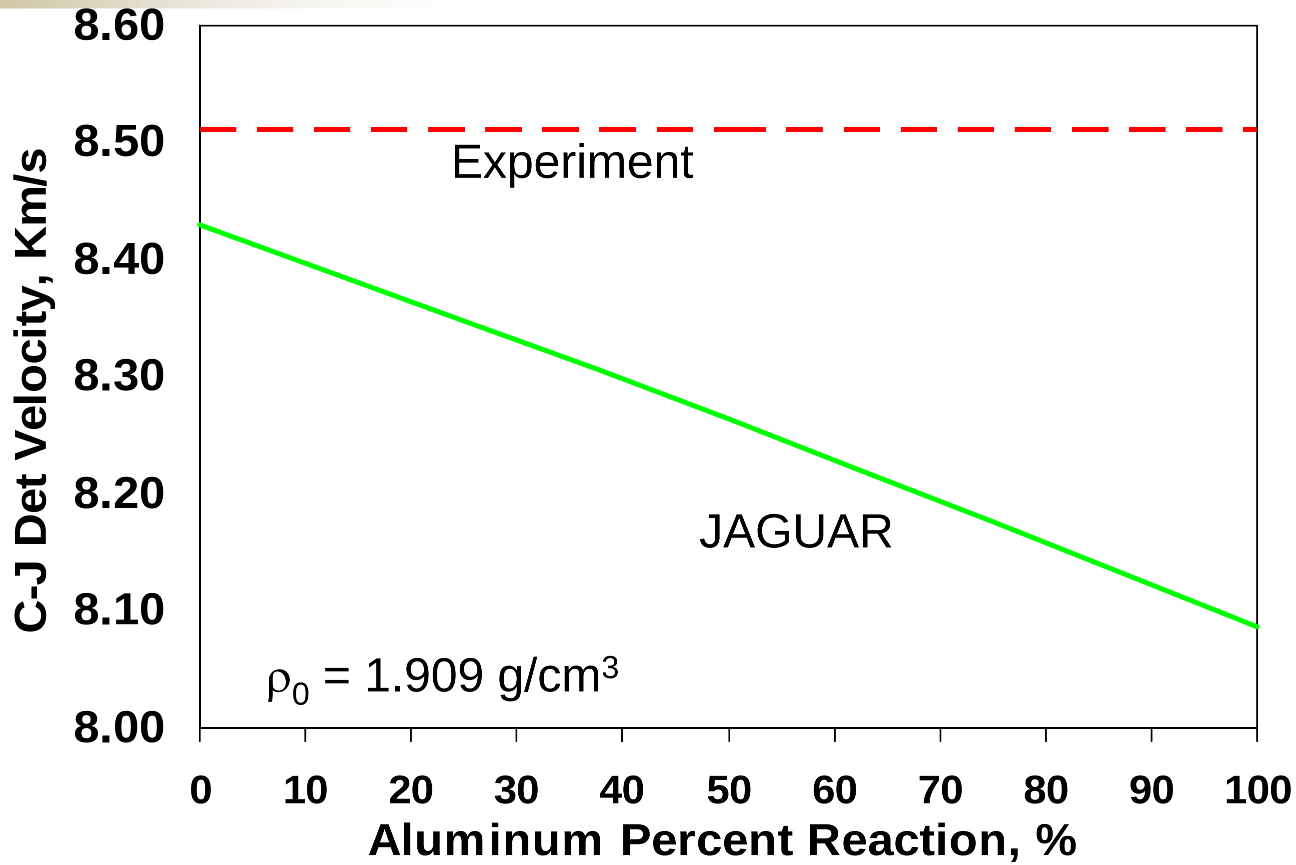
- Combined Effects Explosives
- Eigenvalue Detonation
- Detonation Velocities
- Cylinder Velocities
- Equations of State
- Conclusions

Combined Effects Explosive

- 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 Cl-20/Al
PAX-30: 77/15 HMX/Al
PAX-42 77/15 RDX/Al

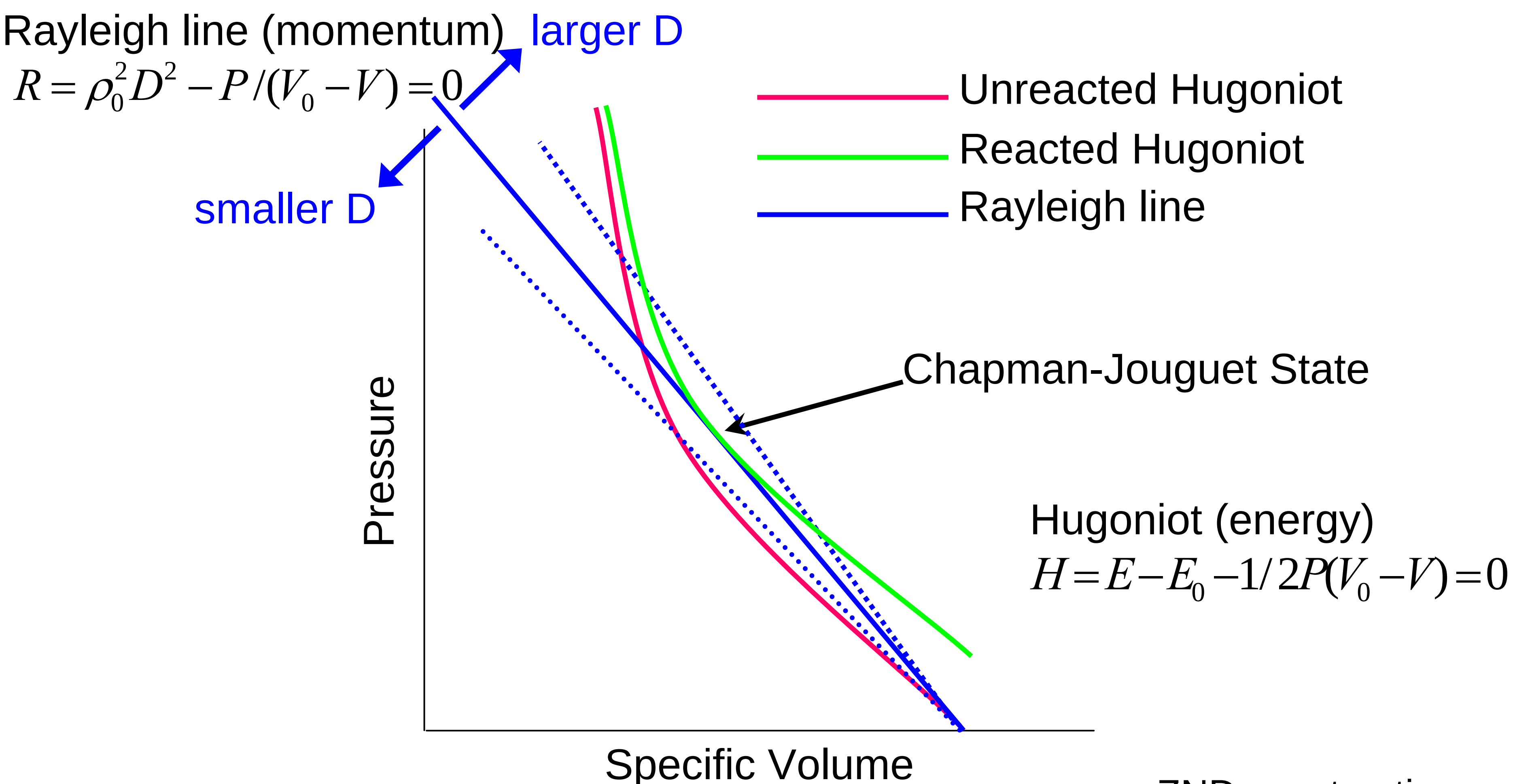
Combined Effects Explosives
PAX-30 (HMX, 15%Al)



- ***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***

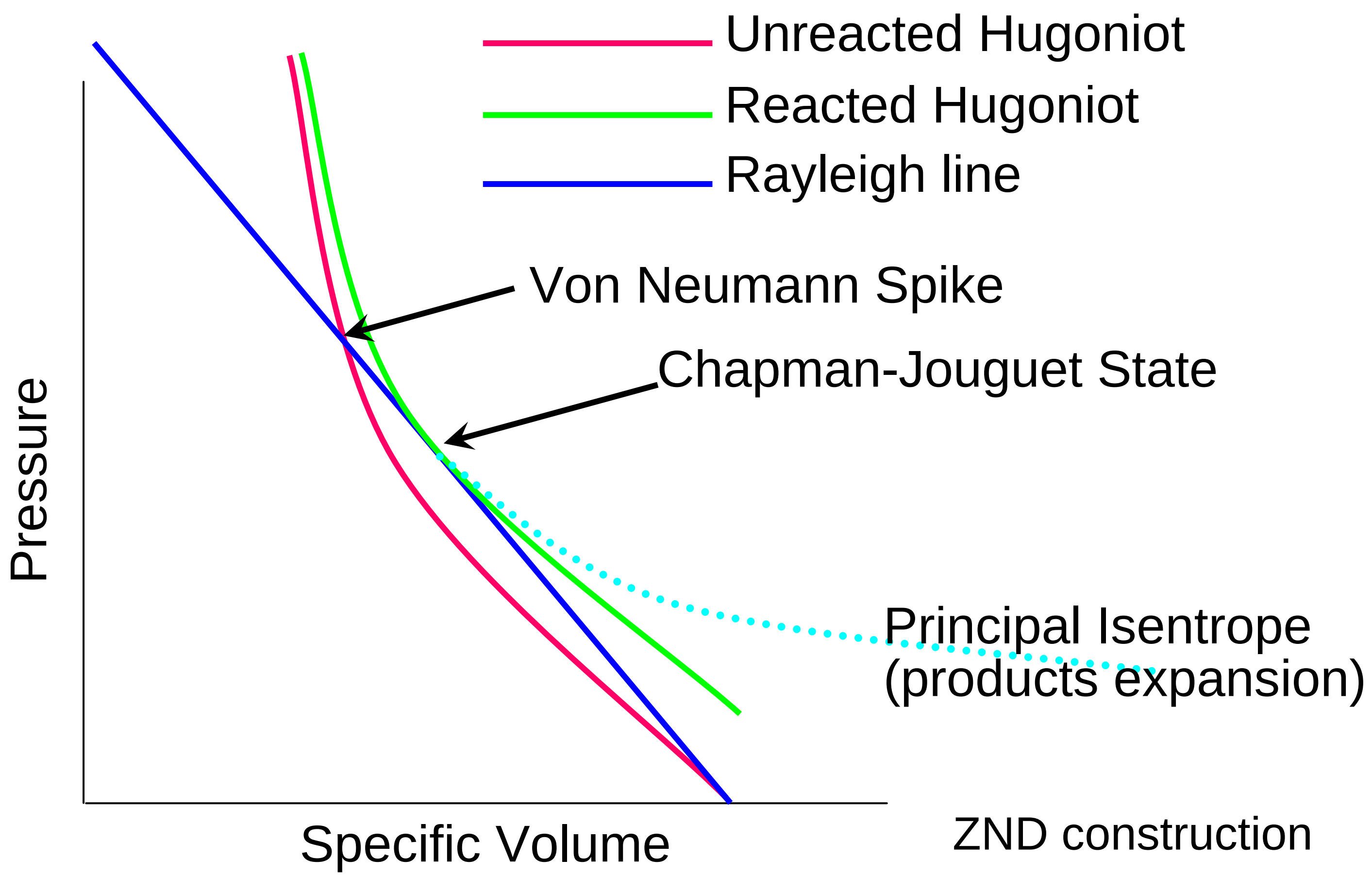
    0%: 1.69Km/s, 100%: 1.90Km/s, Experiment: 1.88Km/s

ZND Model



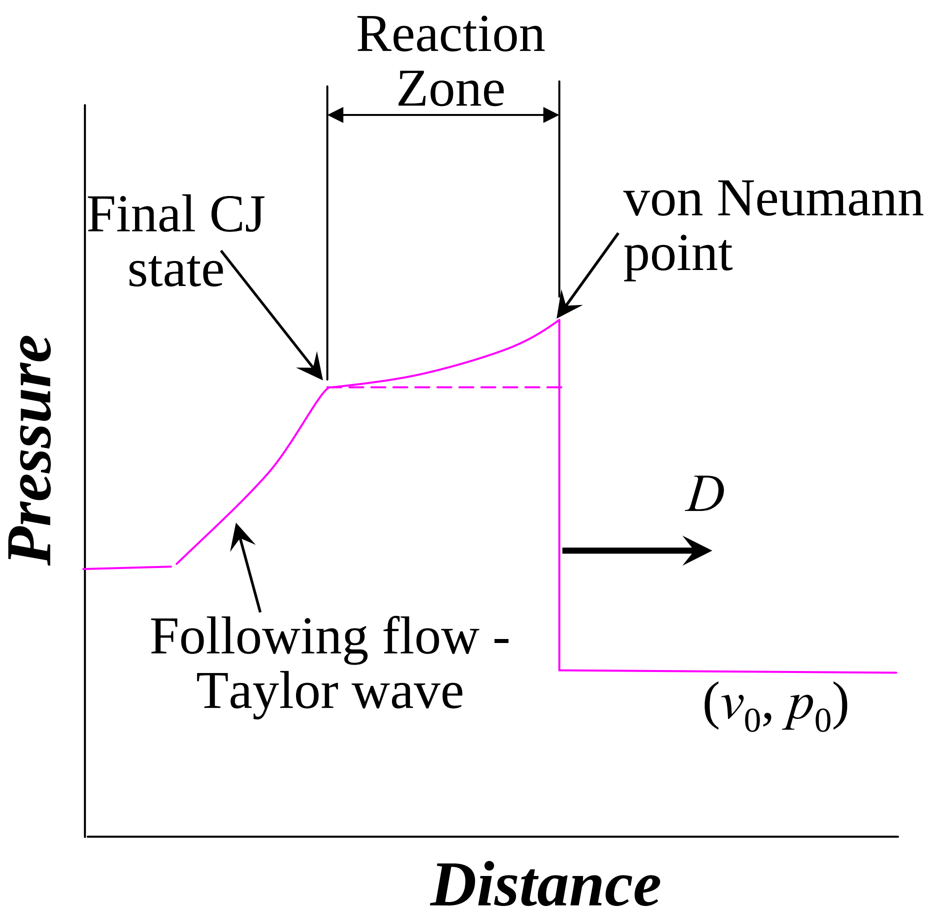
ZND construction

ZND Model

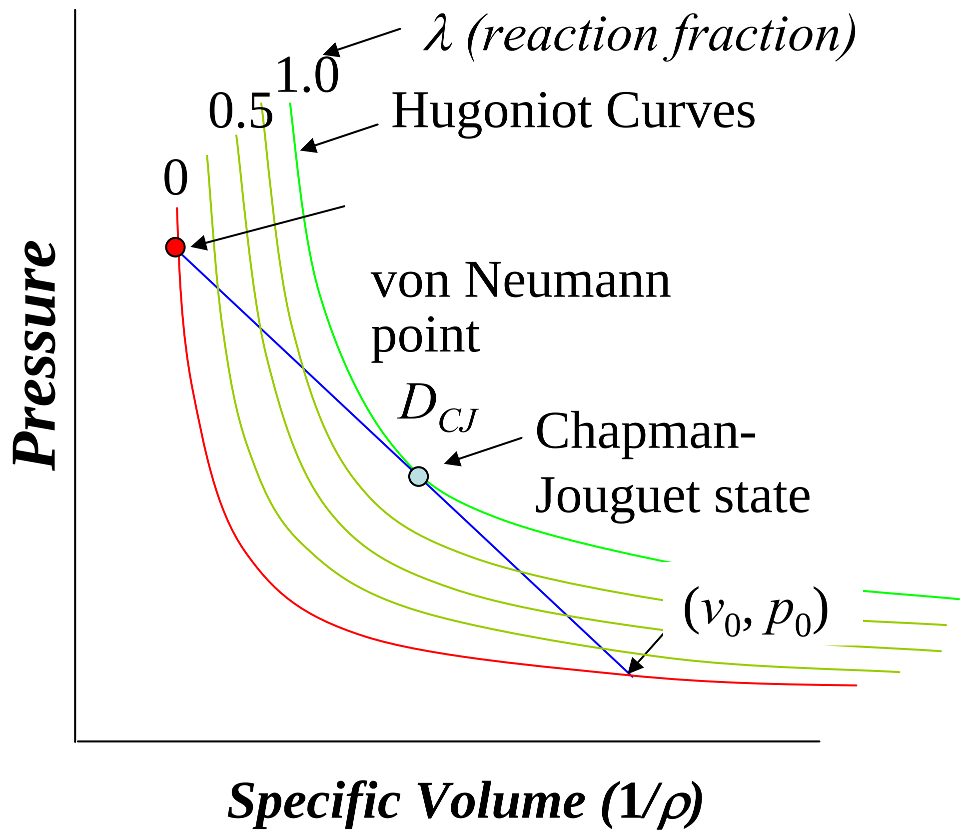


ZND construction

ZND Model

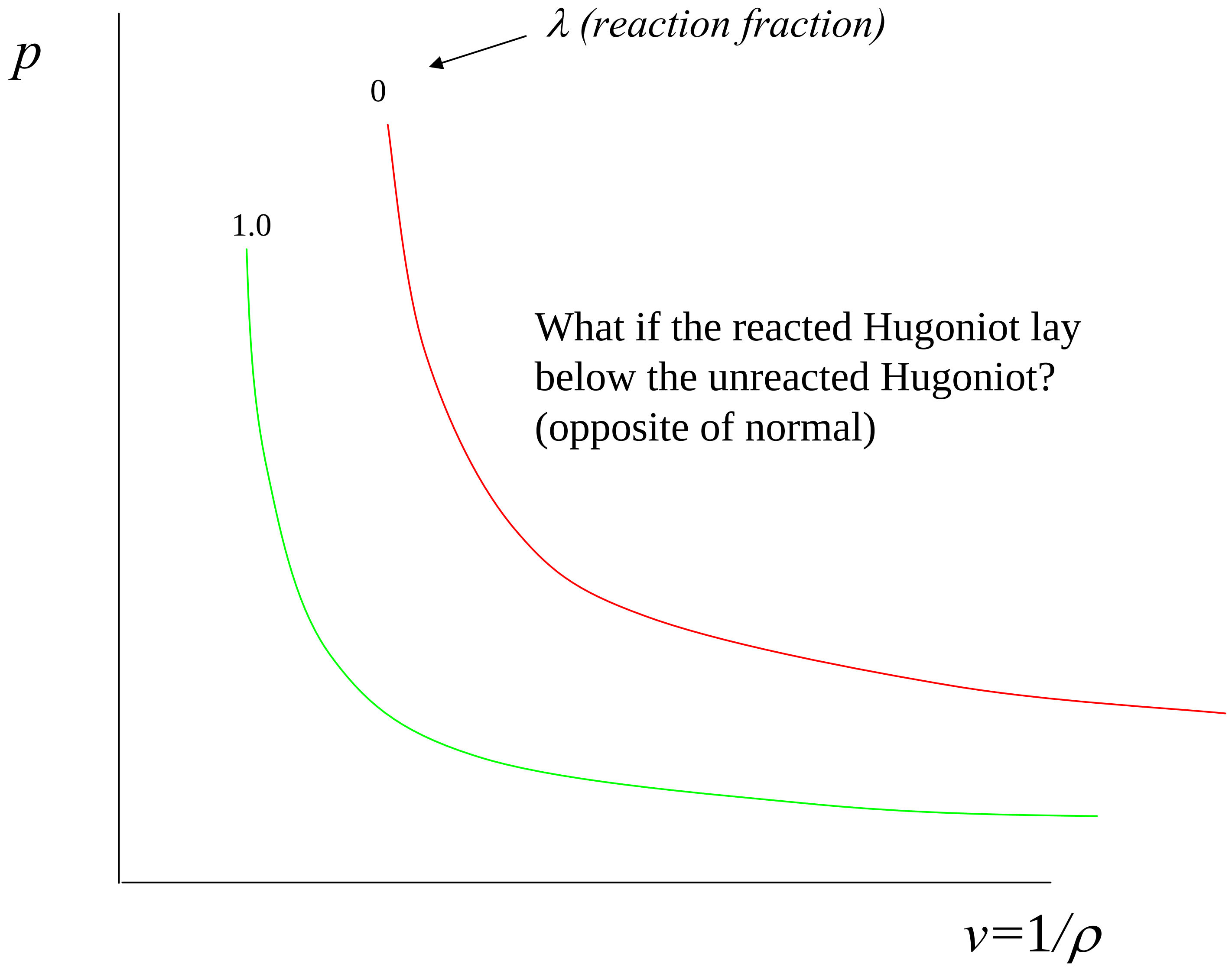


Reaction
Zone
Final CJ
state
von Neumann
point
Pressure
D
Following flow -
Taylor wave
(v_0, p_0)
Distance



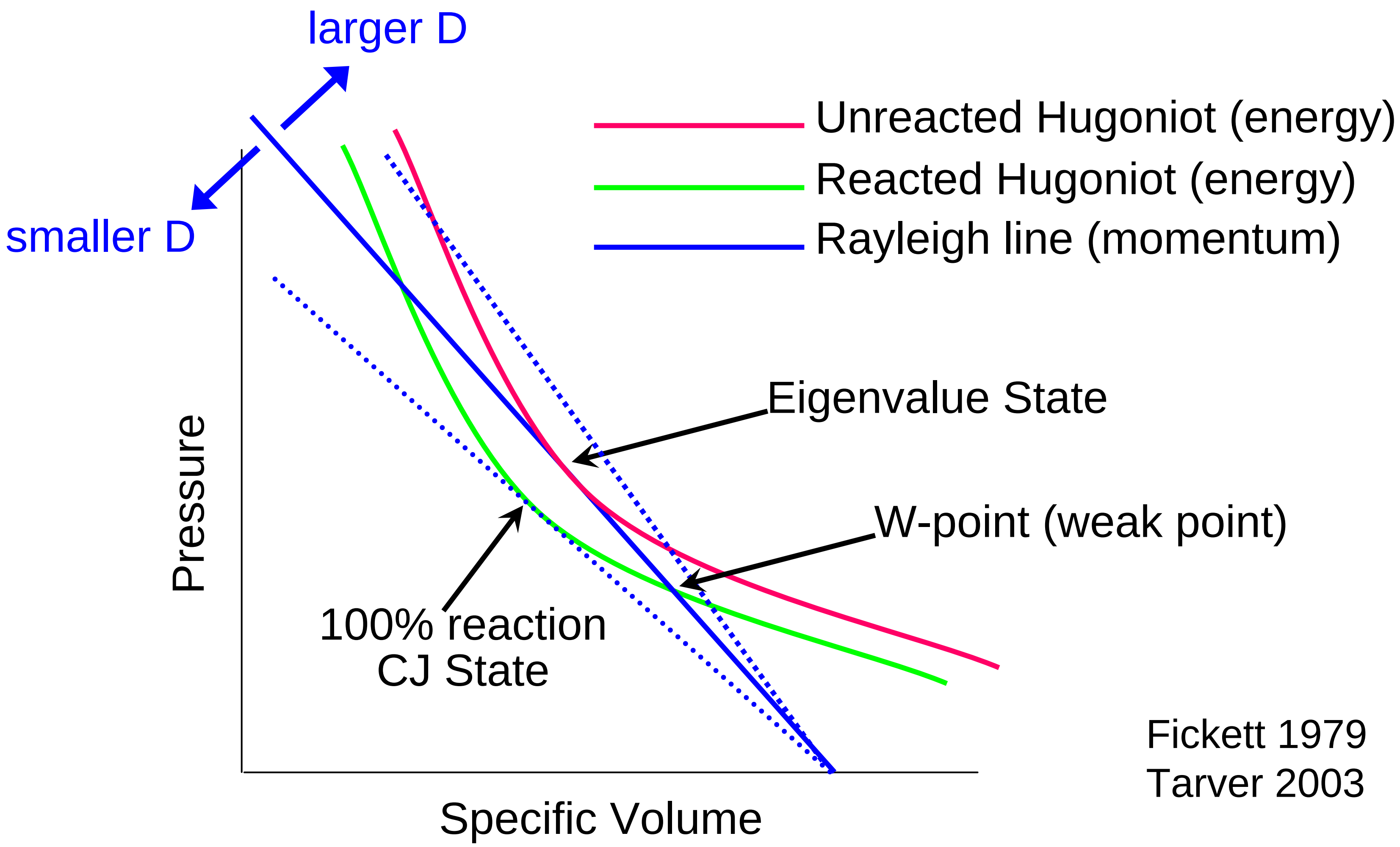
λ (reaction fraction)
1.0
0.5
0
Hugoniot Curves
Pressure
von Neumann
point
D_{CJ}
Chapman-
Jouguet state
(v_0, p_0)
Specific Volume (1/ρ)

Eigenvalue Detonation



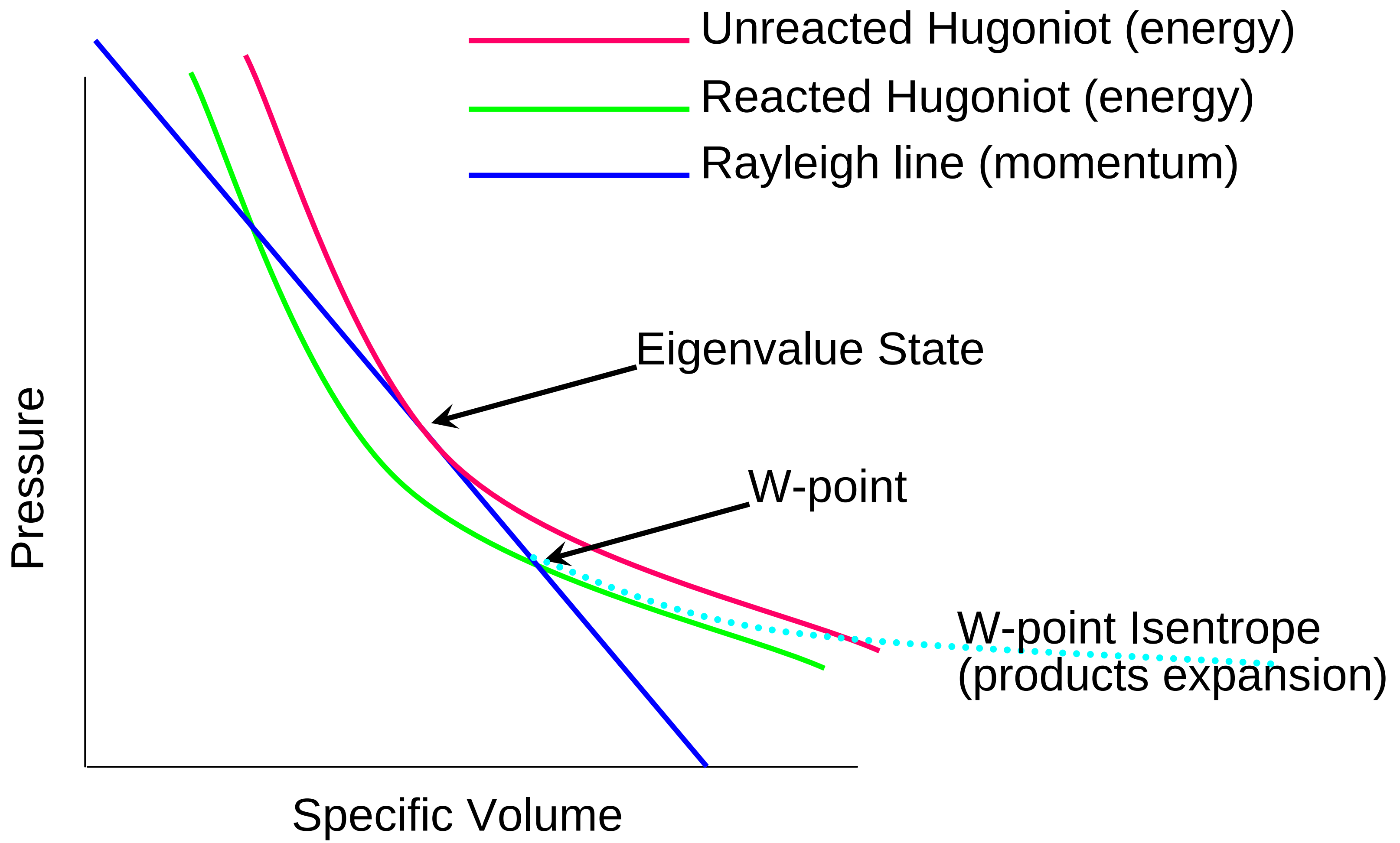
What if the reacted Hugoniot lay below the unreacted Hugoniot? (opposite of normal)

Eigenvalue Detonation

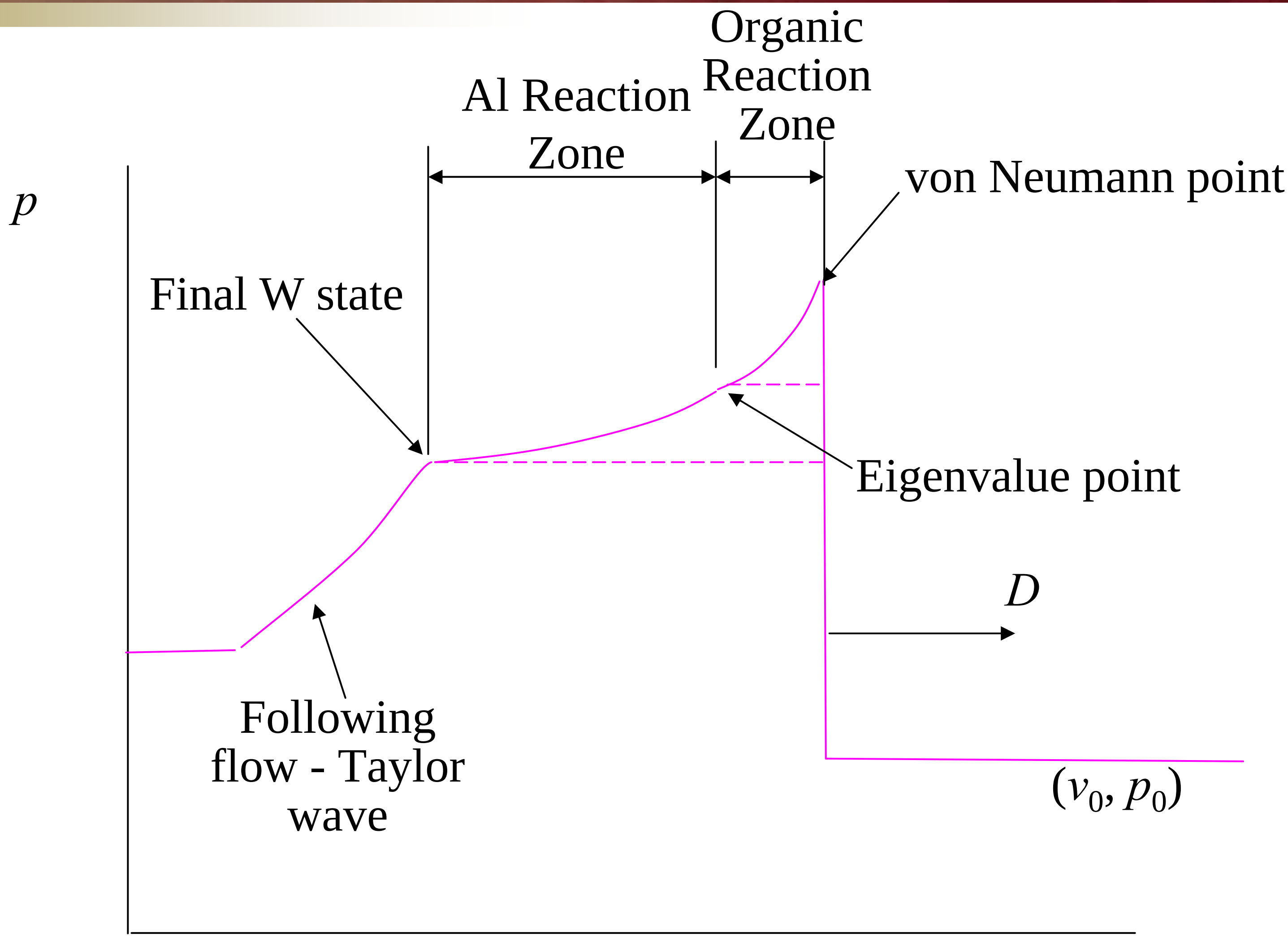


Fickett 1979
Tarver 2003

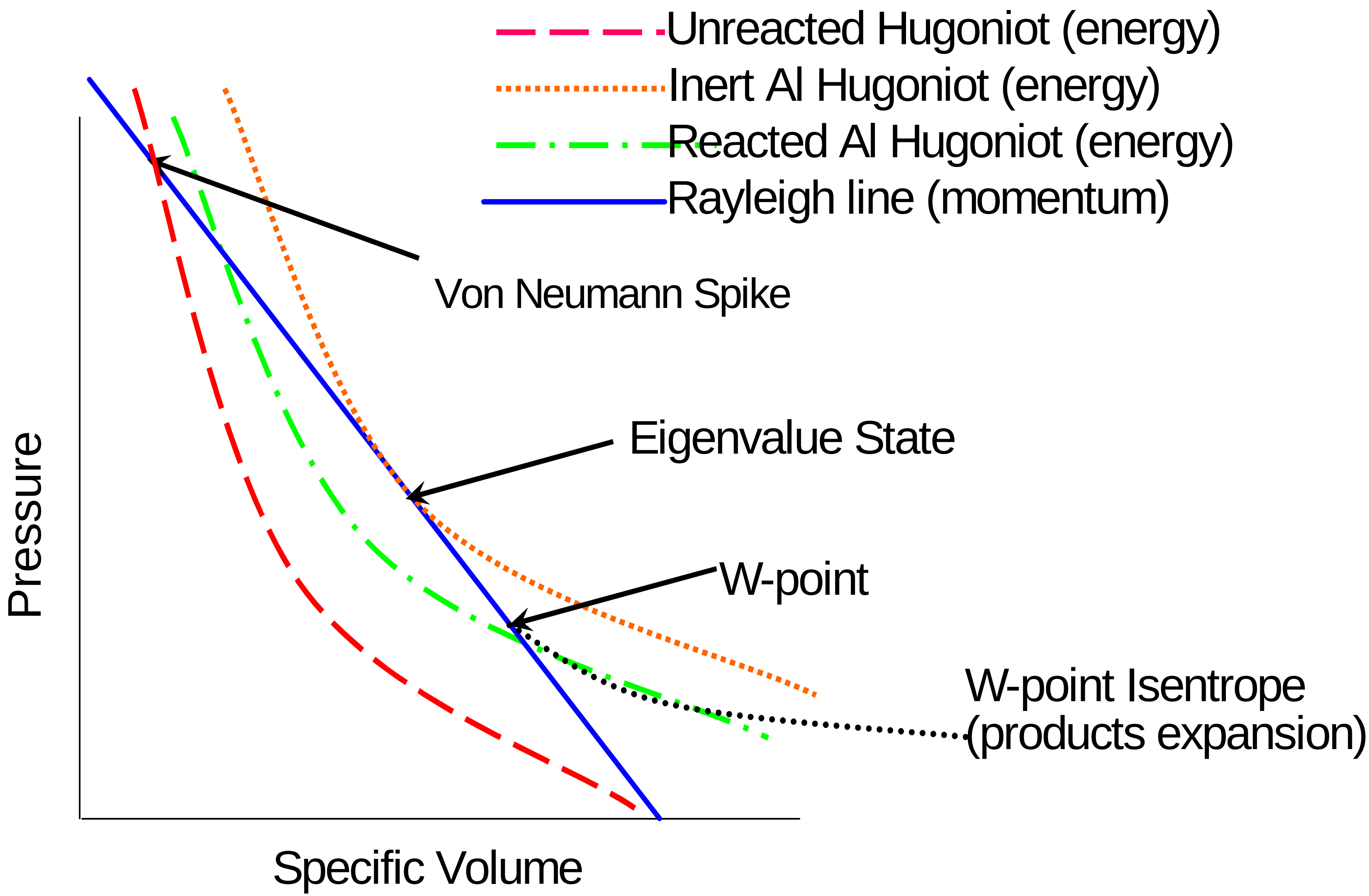
Eigenvalue Detonation



Eigenvalue Detonation
Aluminized Explosive



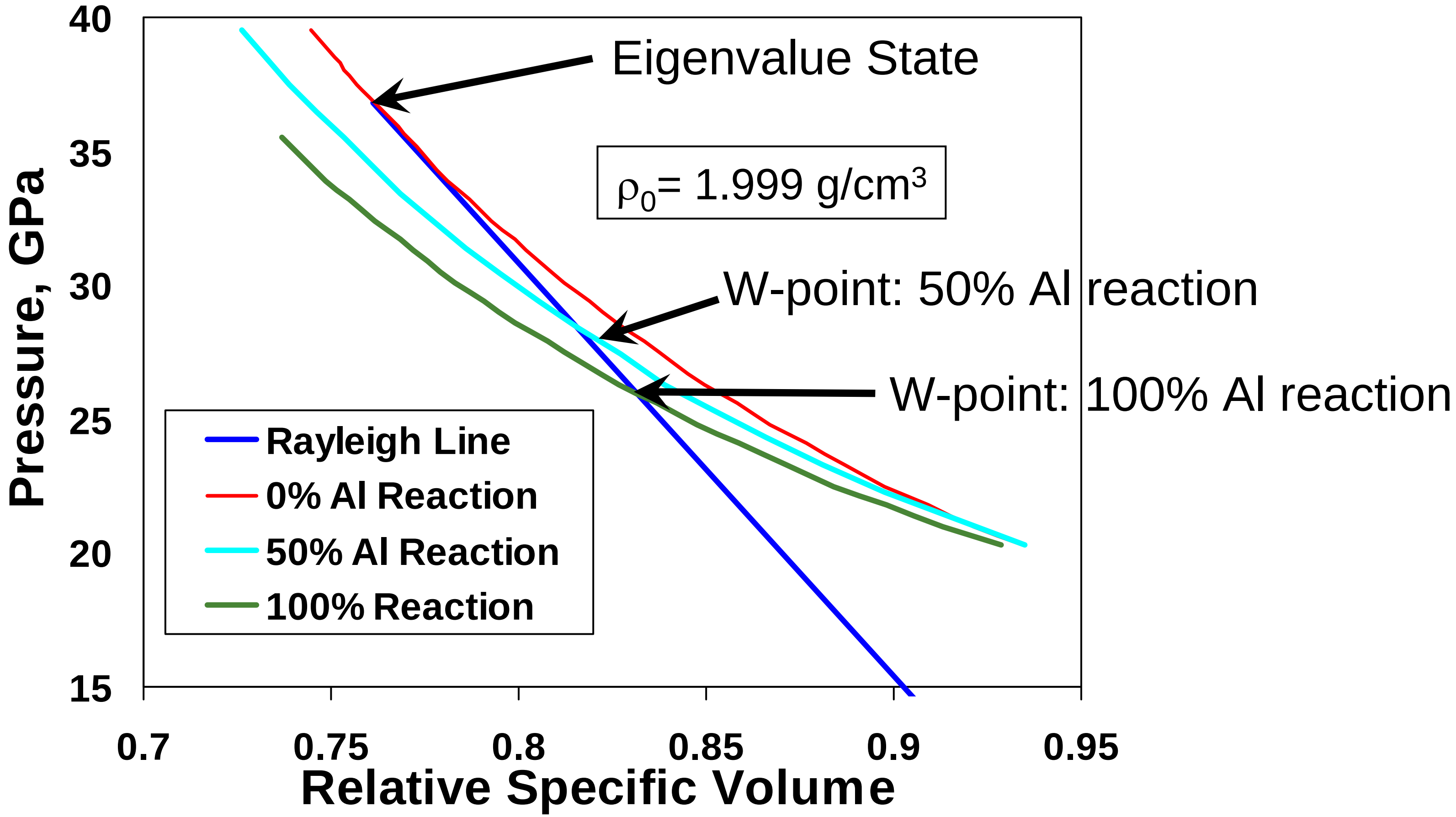
Eigenvalue Detonation
Aluminized Explosive



Eigenvalue Detonation
Combined Effects Explosive

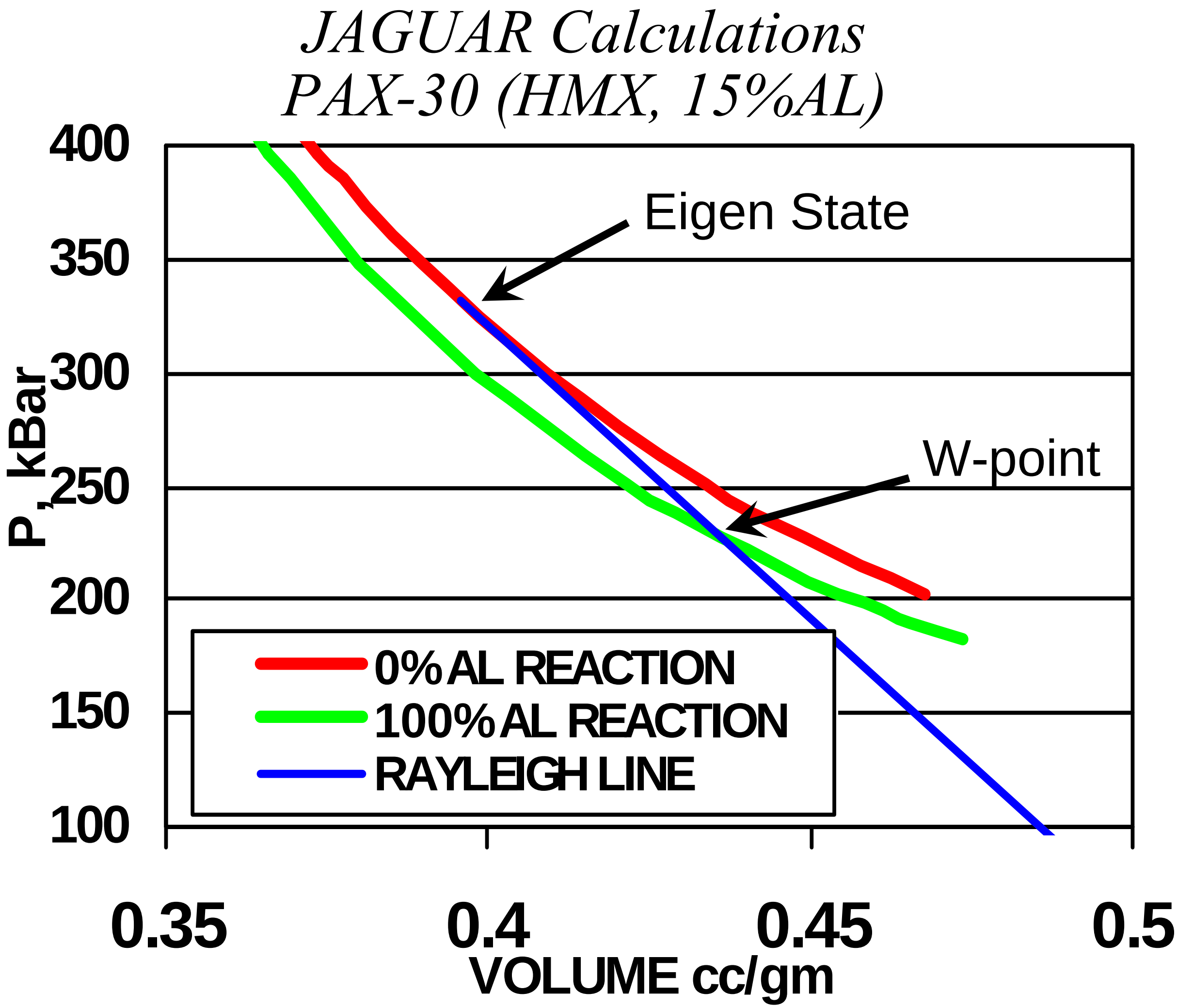
JAGUAR Calculations

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



Aluminum reaction produces lower Hugoniots

Eigenvalue Detonation
Combined Effects Explosive



Detonation velocity controlled by 0% AL reaction Hugoniot!

Detonation Velocity
Aluminized Explosives Data

EXPLOSIVE	Al%	ρ_0(gm/cc)	Experiment D (Km/s)	JAGUAR Calculations Inert Al D (Km/s)	JAGUAR Calculations 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

Cylinder Velocity
Analytic Cylinder Model

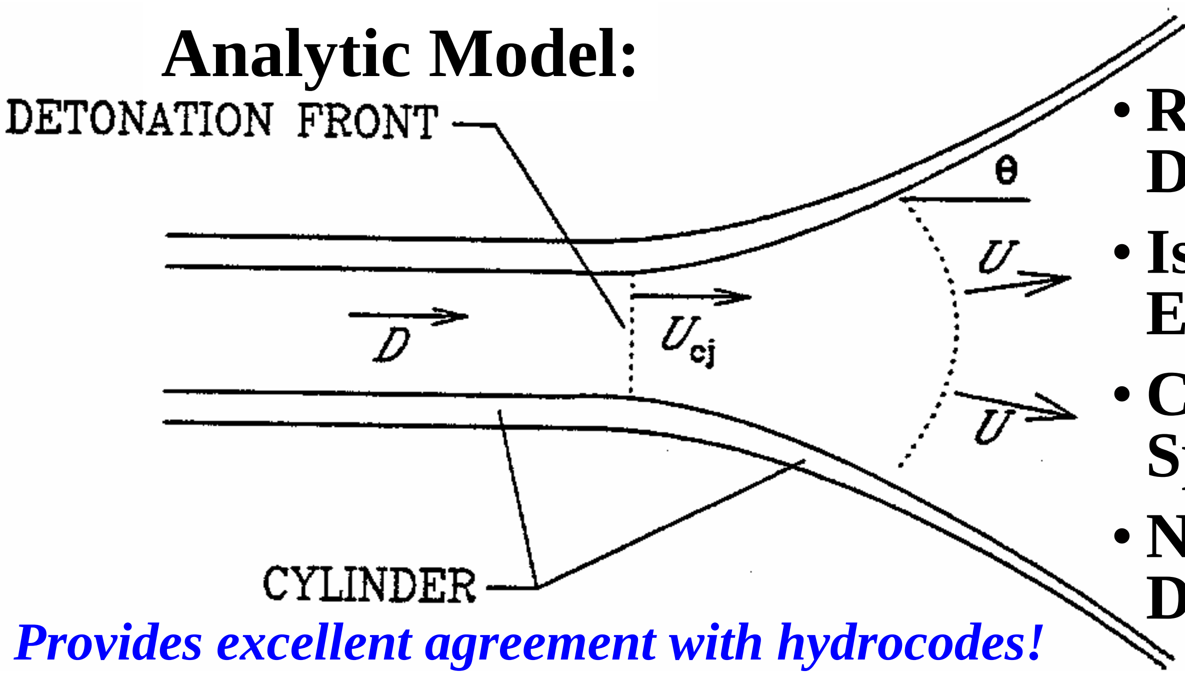
JWLB Equation of State:

$$P = \sum_i \mathrm{A}i\left(1-\frac{\lambda}{\mathrm{R}iV*}\right)e^{-\mathrm{R}iV*} + \frac{\lambda E}{V*} + \mathrm{C}\left(1-\frac{\lambda}{\omega}\right)V*^{-(\omega+1)}$$

Gruneisen Parameter:

$$\lambda \equiv \sum\left(\mathrm{A}_{\lambda}\mathrm{i}V*+\mathrm{B}_{\lambda}\mathrm{i}\right)e^{-\mathrm{R}_{\lambda i}V*} + \omega$$

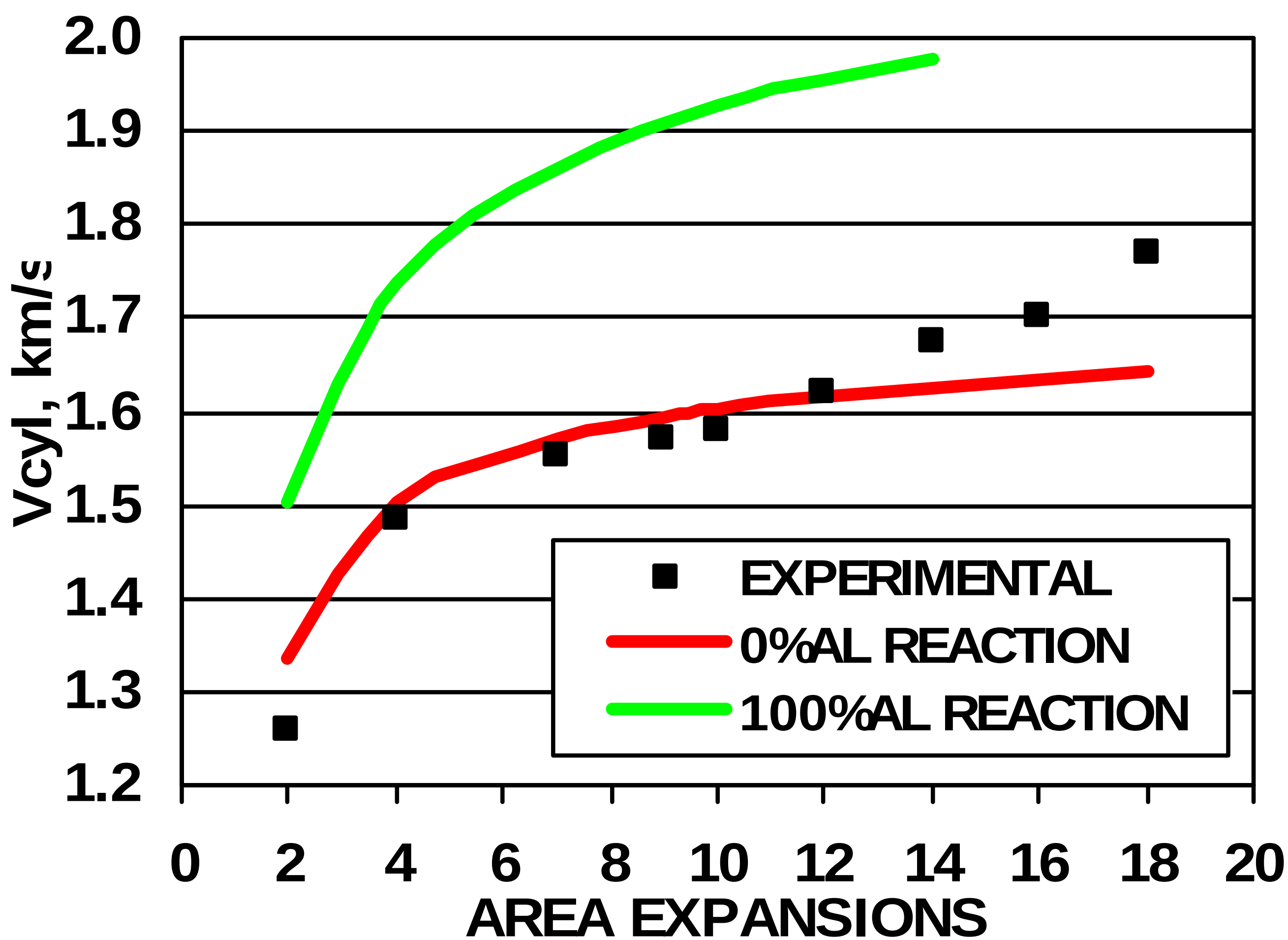
Analytic Model:



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

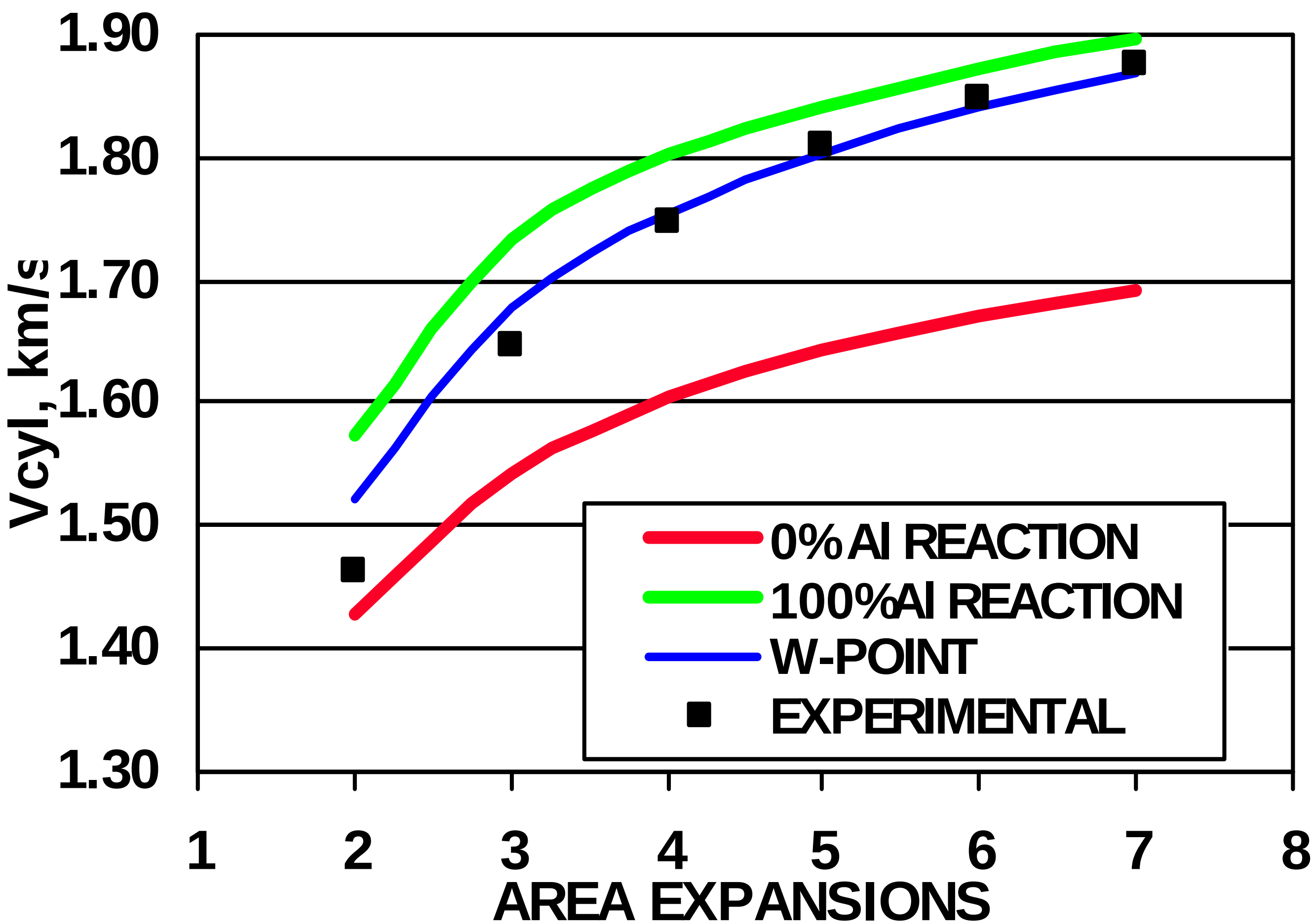
Provides excellent agreement with hydrocodes!

Cylinder Test Results
PAX-3 (HMX, 18%AL - large)



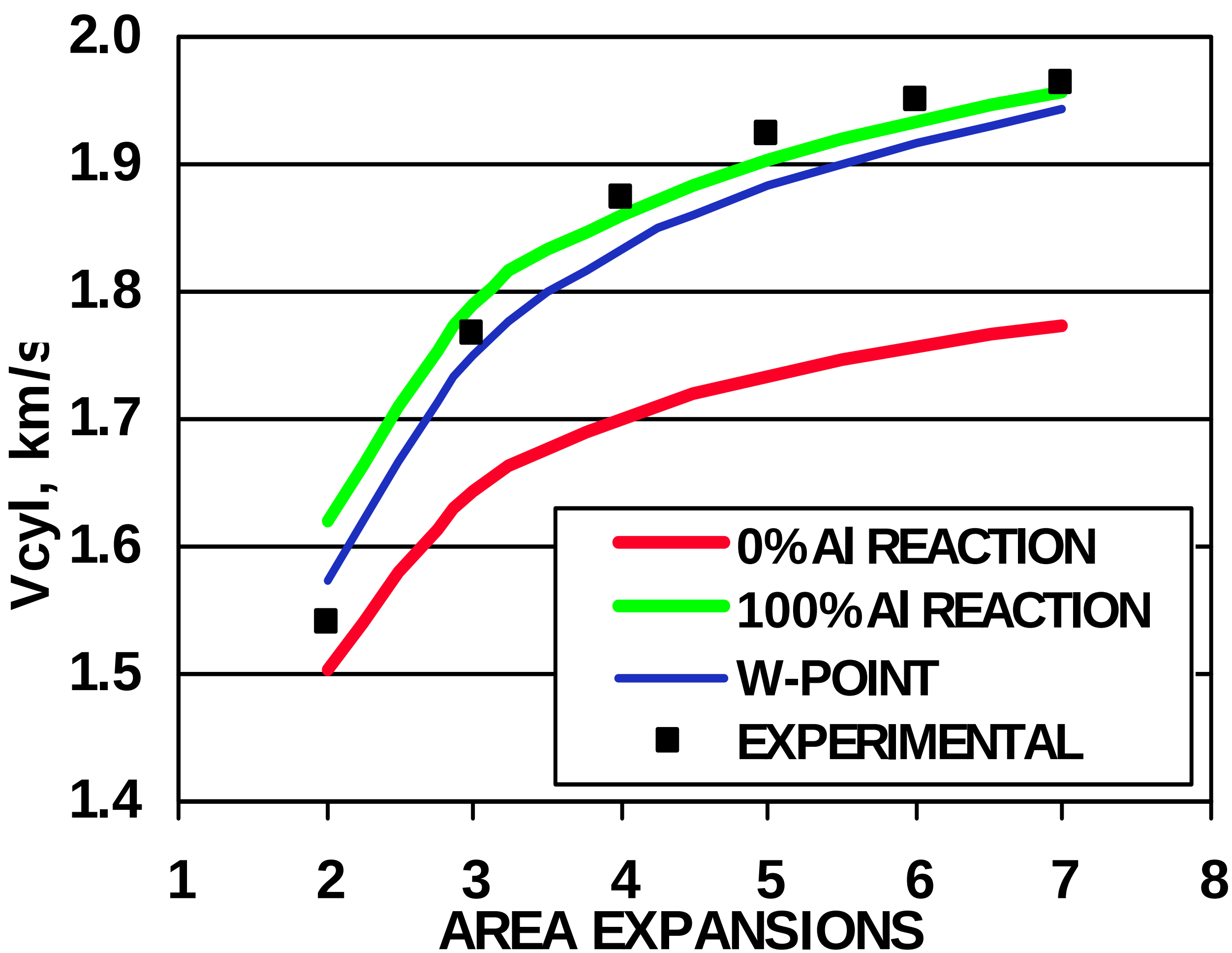
HMX with large particle size Aluminum: AL reacts late!

Cylinder Test Results
PAX-30 (HMX, 15%AL - small)



HMX with small particle size aluminum: AL reacts early!

Cylinder Test Results
PAX-29 (CL-20, 15%AL - small)



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

JWLB Equations of State

	PAX-3 (Al INERT)	PAX-29	PAX-30	PAX-42
ρ0 (g/cc)	1.866	1.999	1.885	1.827
E0 (Mbar)	0.08223	0.14611	0.13568	0.13109
D (cm/μs)	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)

JWL Equations of State

	LX14	PAX-2A	PAX-29	PAX-30	PAX-42
ρ0 (g/cc)	1.819	1.770	1.999	1.885	1.827
E0 (Mbar)	0.10213	0.09953	**0.14714**	**0.135755**	**0.12994**
D (cm/μs)	0.8630	0.8391	0.8784	0.8342	0.8137
P (Mbar)	0.3349	0.3124	0.2599	0.2419	0.2339
A1 (Mbar)	26.1406	27.0134	8.58373	7.19151	13.8484
A2 (Mbar)	.763619	.762675	0.168261	0.097112	0.145102
R1	6.93245	7.22237	4.7726	4.59098	5.74864
R2	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!

Conclusions

- 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