IPS 2024

IPS 24-5.2

Explosive Capacity of Perforating Guns

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Explosive Capacity

Evaluation of Perforating Gun Systems

Introduce a simplified engineering approach

- Survival Testing Observations
- Establish the Explosive Capacity of a gun system
- Limitations
- Further developments

Explosive Capacity

How much is too much?

I got this 4-5/8" 14 spf gun that you run with a 28gram charge.

We like the performance data of the 30gram charge.

Increasing the explosive load… we should test

Can you make this 16 spf? I NEED MORE FLOW AREA!

Higher shot density… we should test

A competitor says they have a gun with big charges & lots of shots!

Explosive Capacity

So now what ?

…. Survival Test

Survival Test:

- Load a gun & shoot it
- Pass or Fail

API 19PT Validation Testing

Validation Grade	Dynamic Survivability
V4	Supplier/ manufacturer- defined
V3	Single test with nominally loaded charges
V2	Single test with over-loaded charges defined by supplier/manufacturer
V1	Single test with 3% min. over loaded charges
V0	Single test with 5% min. over loaded charges

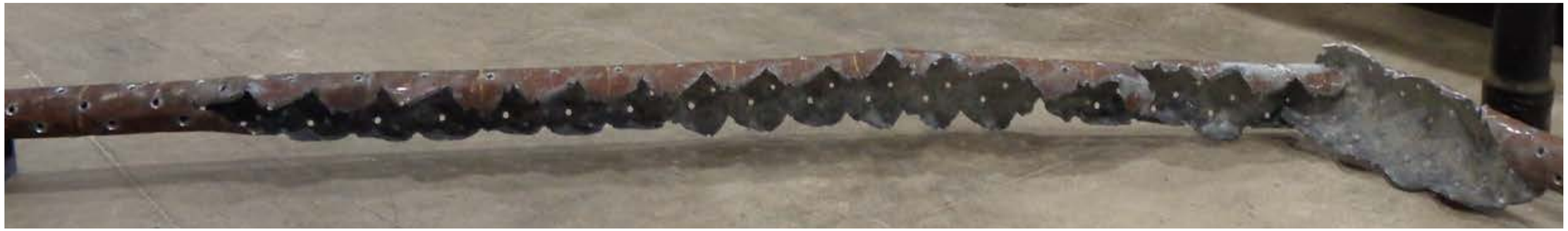
Considering Survival Tests

PASS

Considering Survival Tests

PASS

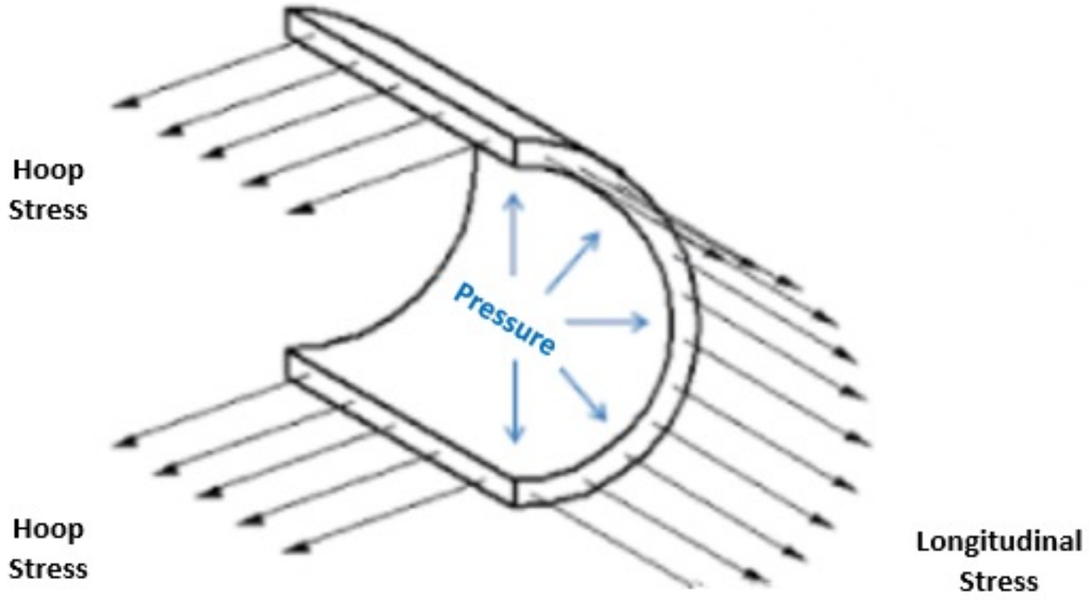
FAILED



Failure of Burst Gun

Gun Failure:

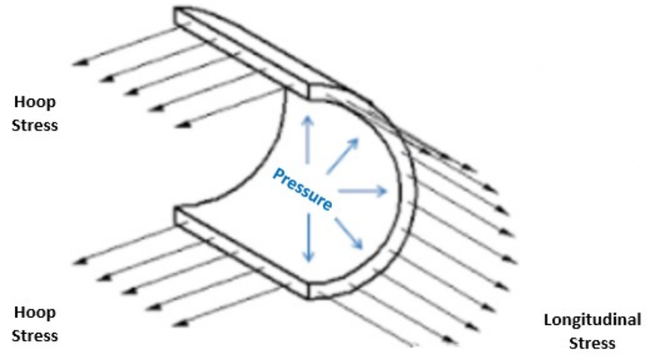
- Longitudinal split
- Initiated at ID of carrier



Conclusion

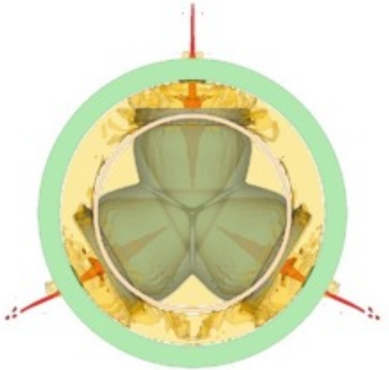
- Internal Pressure Exceeds Material Strength
  - Burst pressure (hoop Stress)

Burst Pressure of Gun

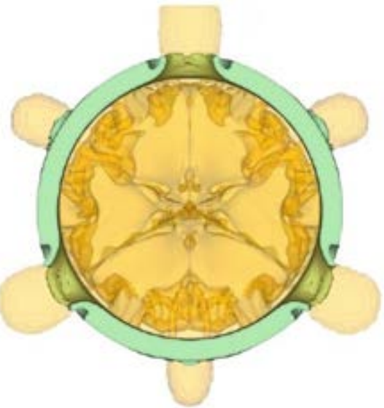


Hoop stress
- observed as the primary cause of failure

Actual hoop stress:
- remains an uncertain value
- energy dynamics and
- high-speed transients of pressures, volumes, and temperatures.



The energy within a perforating gun system
- distributed by the transfer of energy
- charge liners,
- charge cases,
- other internal components,
- and a relatively small amount of heat transfer.

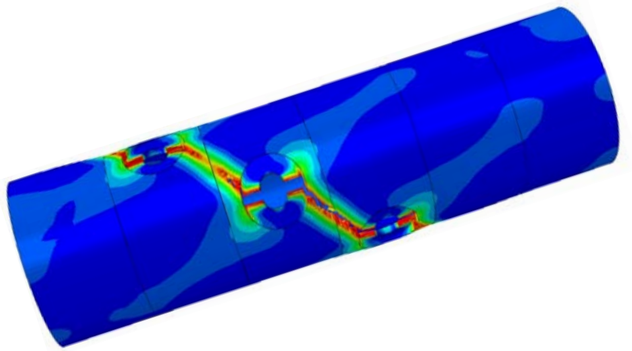


Leaving a remainder of energy as the pressure exerted on to the carrier tube.

Burst Pressure of Gun

Physical Properties of Material

- Yield strength
- wall variation of carrier tube



A study of survival test is used to demonstrate the effects of material strength variations.

Survey of Survival Tests

		30g	30g
Identification (Heat)	**Mill**	**Heat 1**	**Heat 2**
Working Practice	A519 Seamless	A519 Seamless	A519 Seamless
Material Type	Low Alloy Steel	Low Alloy Steel	Low Alloy Steel
Yield Strength (psi)	140 – 170 k	153,800	150,700
Charpy V-Notch (ft-lb)	38	56	59

Passed

Explosive Capacity

		30g	30g	30g	30g
Identification (Heat)	**Mill**	**Heat 1**	**Heat 2**	**Heat 3**	**Heat 3**
Working Practice	A519 Seamless	A519 Seamless	A519 Seamless	A519 Seamless	A519 Seamless
Material Type	Low Alloy Steel	Low Alloy Steel	Low Alloy Steel	Low Alloy Steel	Low Alloy Steel
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Passed

Failed

Explosive Capacity

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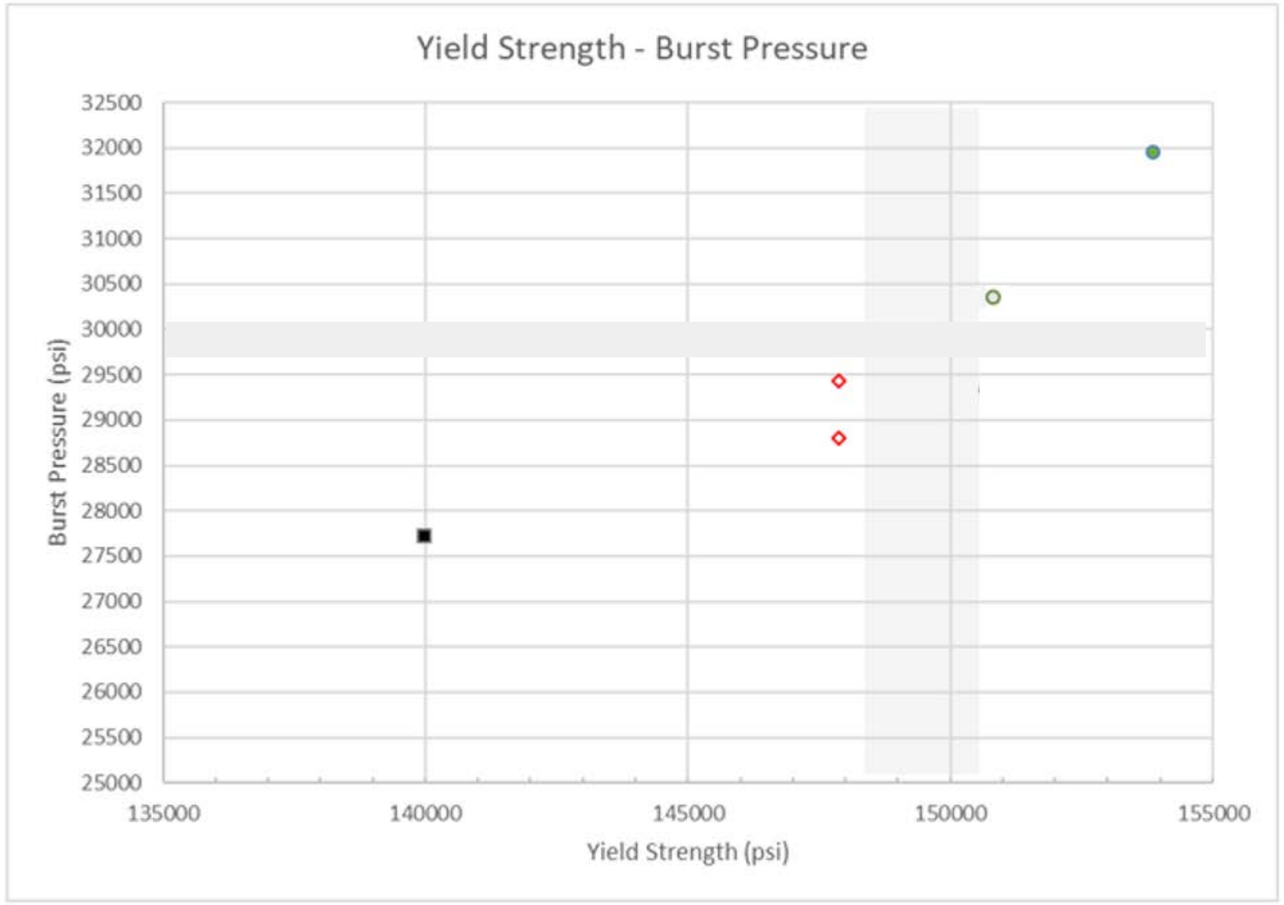
Passed

Failed

Explosive Capacity

Gun Carrier Material Review of Testing



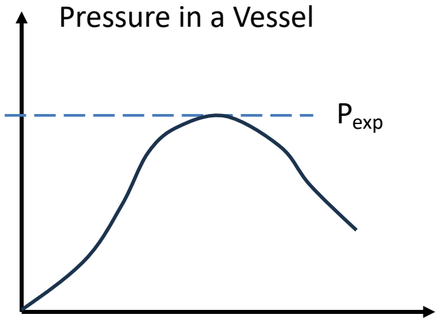
mill specification Failed Tests Passed Tests

- Calculated burst pressure (*Hoop Stress*):
  - Yield strength, OD, wall thickness
  - Actual test material

What is the pressure generated by the explosives?

Reaction Pressure in a Closed Volume		
Pressure (PSI)	4.625-16spf	API Grade
103,013	22 ft. w/ 5% overload	V0

Explosive Pressure



Explosive Pressure ~ $f(explosive\ density, composition)$

- Explosive Density (ρ) : (explosive load / FAV)
  - Explosive load: total mass of explosive
  - Free Air Volume (FAV): unoccupied volume inside the gun carrier

- CHEETAH: thermochemical code
  - Explosive reaction in a constant volume

Reaction Pressure in a Closed Volume		
Pressure (PSI)	4.625-16spf Gun length & explosive load	API Grade
103,013	22 ft. w/ 5% overload	V0

Handbook of Non-Ferrous Metal Powders (Second Edition)

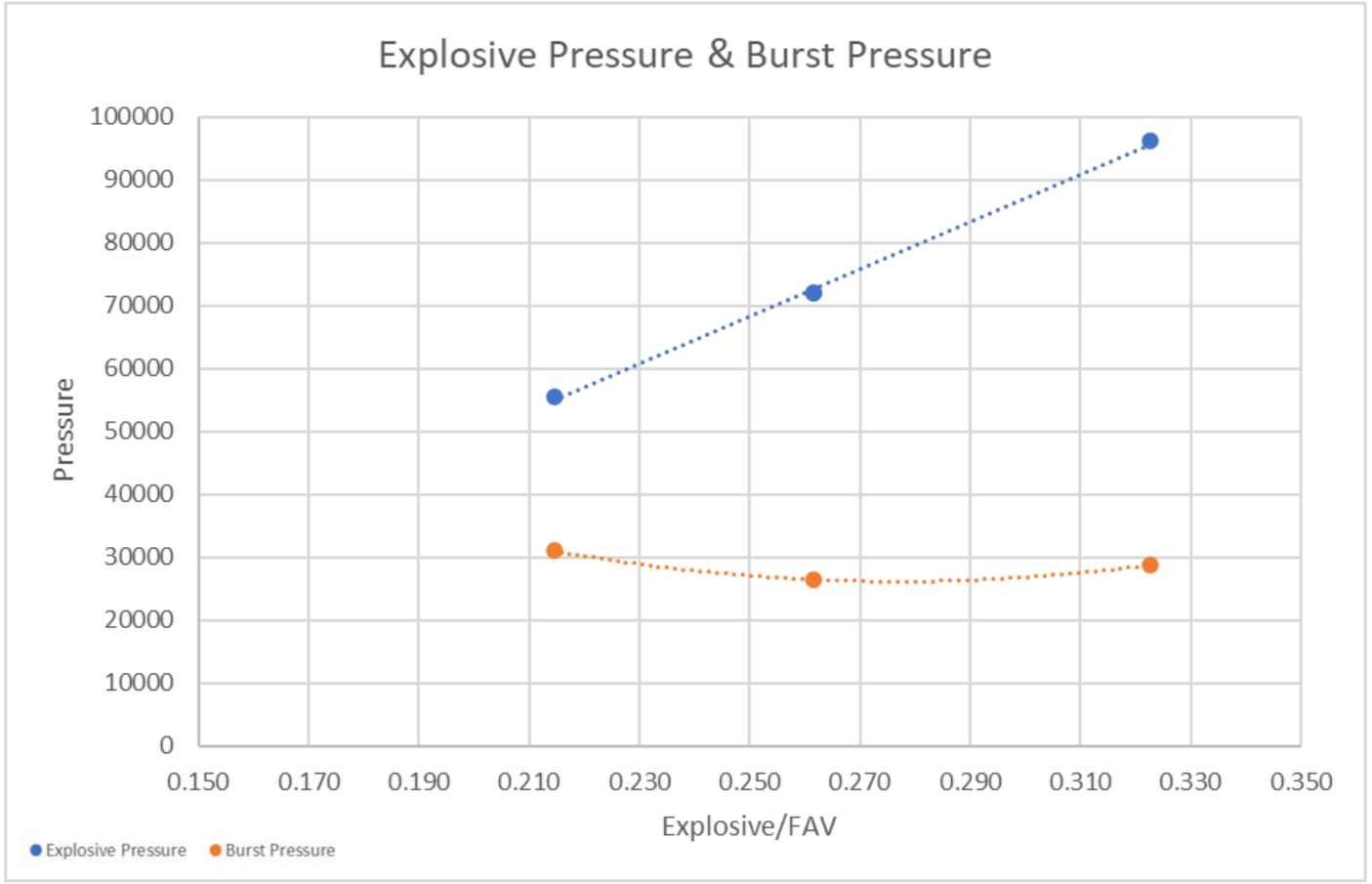
Explosive Pressure & Burst Pressure

Compared to Historical Systems:

- 12 SPF – 28 gram
- 14 SPF – 28 gram
- 16 SPF – 30 gram

- Burst calculated based on actual test articles.

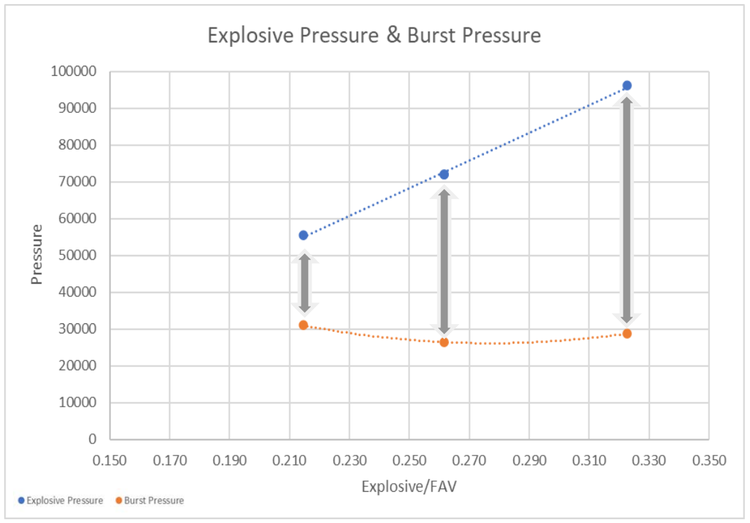
- Explosive pressure theoretical detonation in constant volume.



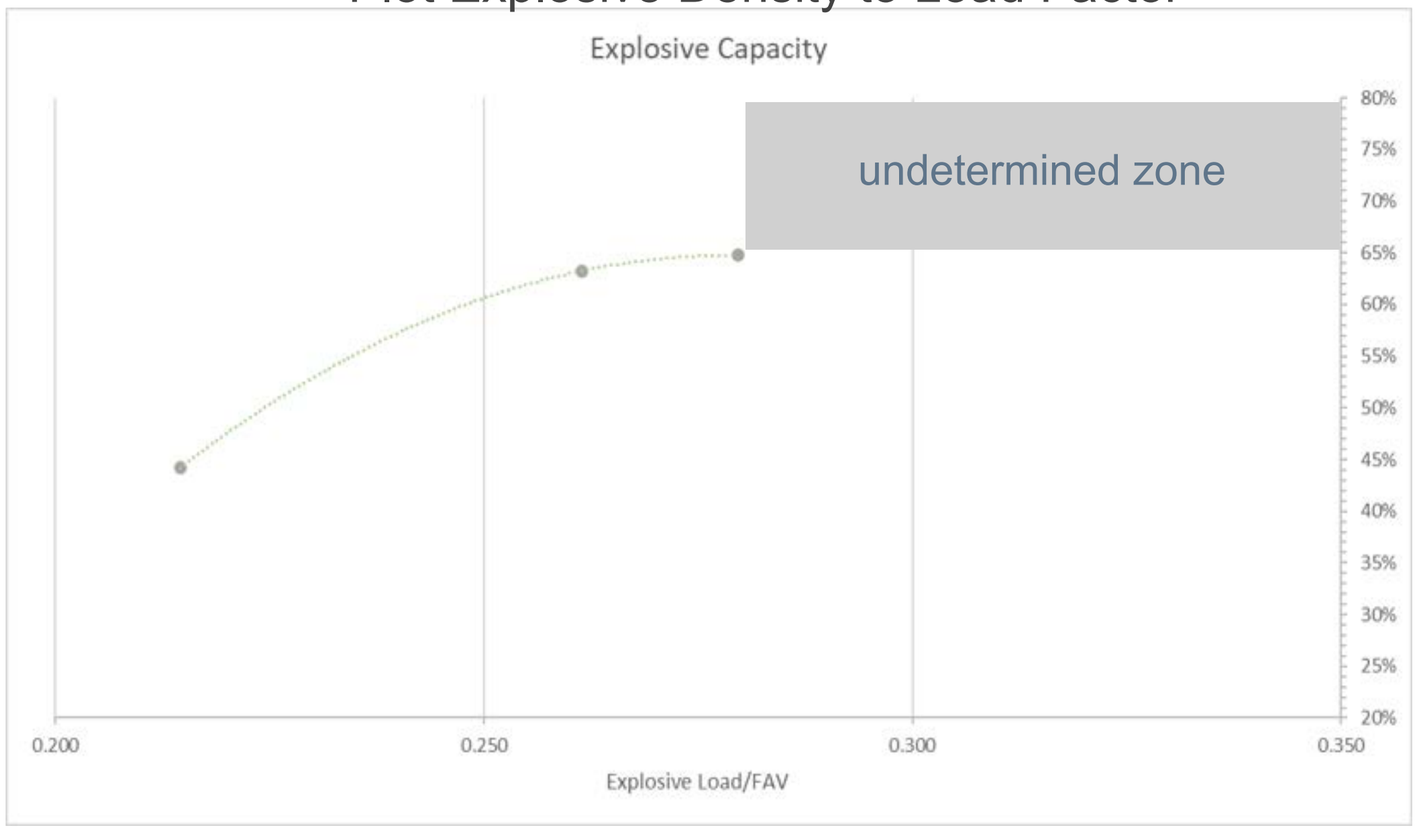
Explosive Capacity of a System

Load Factor:

- Relative difference of explosive pressure to burst pressure



Plot Explosive Density to Load Factor

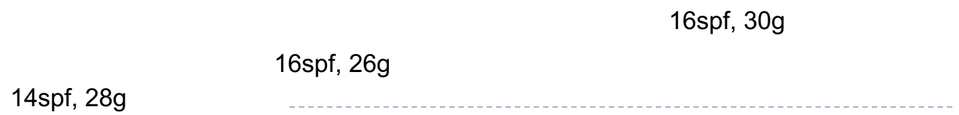


System Evaluation

Compared 4 5/8” Systems:

- 12 SPF – 28 gram *passed*
- 14 SPF – 28 gram *passed*
- 16 SPF – 26 gram *passed*
- 16 SPF – 30 gram *failed*

Explosive Density – Load Factor



Explosive Capacity of System:

- Burst limit : Explosive pressure
  - Material strength
  - Explosive load
  - FAV

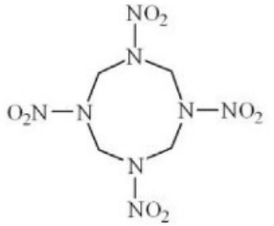
Explosive Capacity

Explosive Capacity ~ $f(explosive\ pressure, yield\ strength, OD, wall\ )$

Explosive Pressure ~ $f(explosive\ density\ )$

- Explosive Density (ρ) : (explosive load / FAV)
  - Explosive load: total mass of explosive
  - Free Air Volume (FAV): unoccupied volume inside the gun carrier
- CHEETAH: thermochemical code

HMX + (*energy*) ⟶ gases + heat



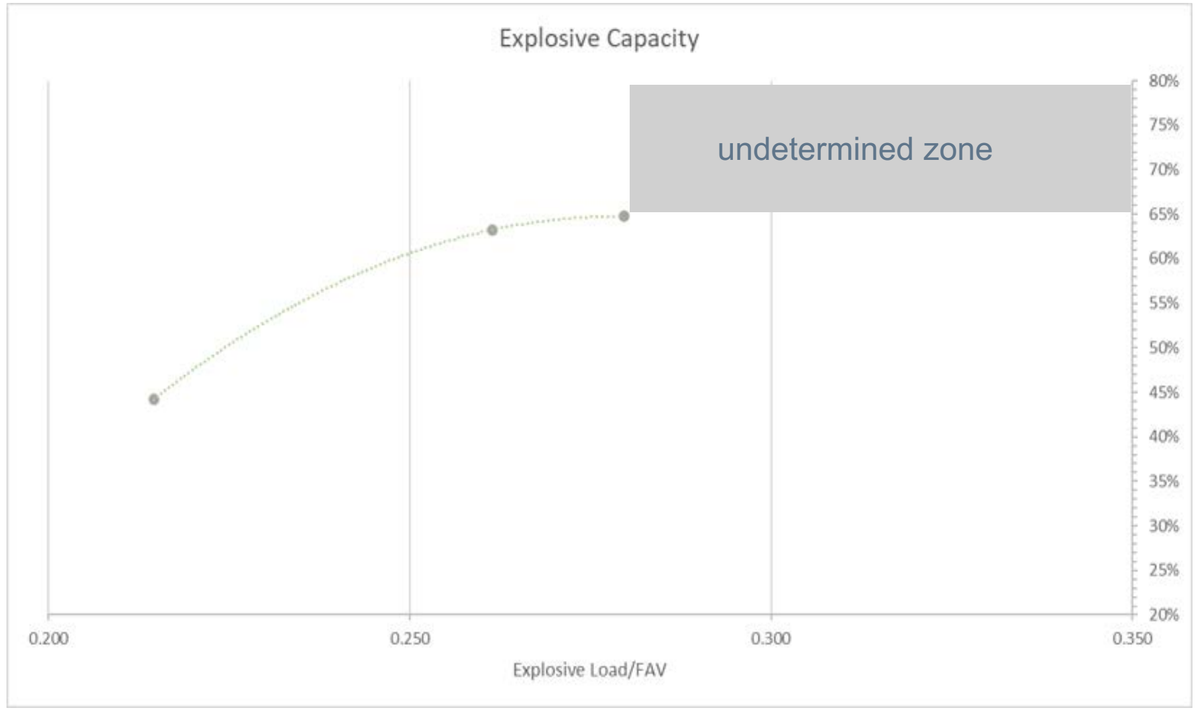
HMX Image source: Computational Design of High Energy RDX-Based Derivatives: Property Prediction, Intermolecular Interactions, and Decomposition Mechanisms

Survival Assessment of Systems

Rethinking Survival Philosophy

Capacity Limit based on analysis of the data

- Materials properties
- Explosive load density



Actual properties from testing

- yield strength,
- outside diameter,
- wall thickness of the carrier,
- explosive density

System Evaluation

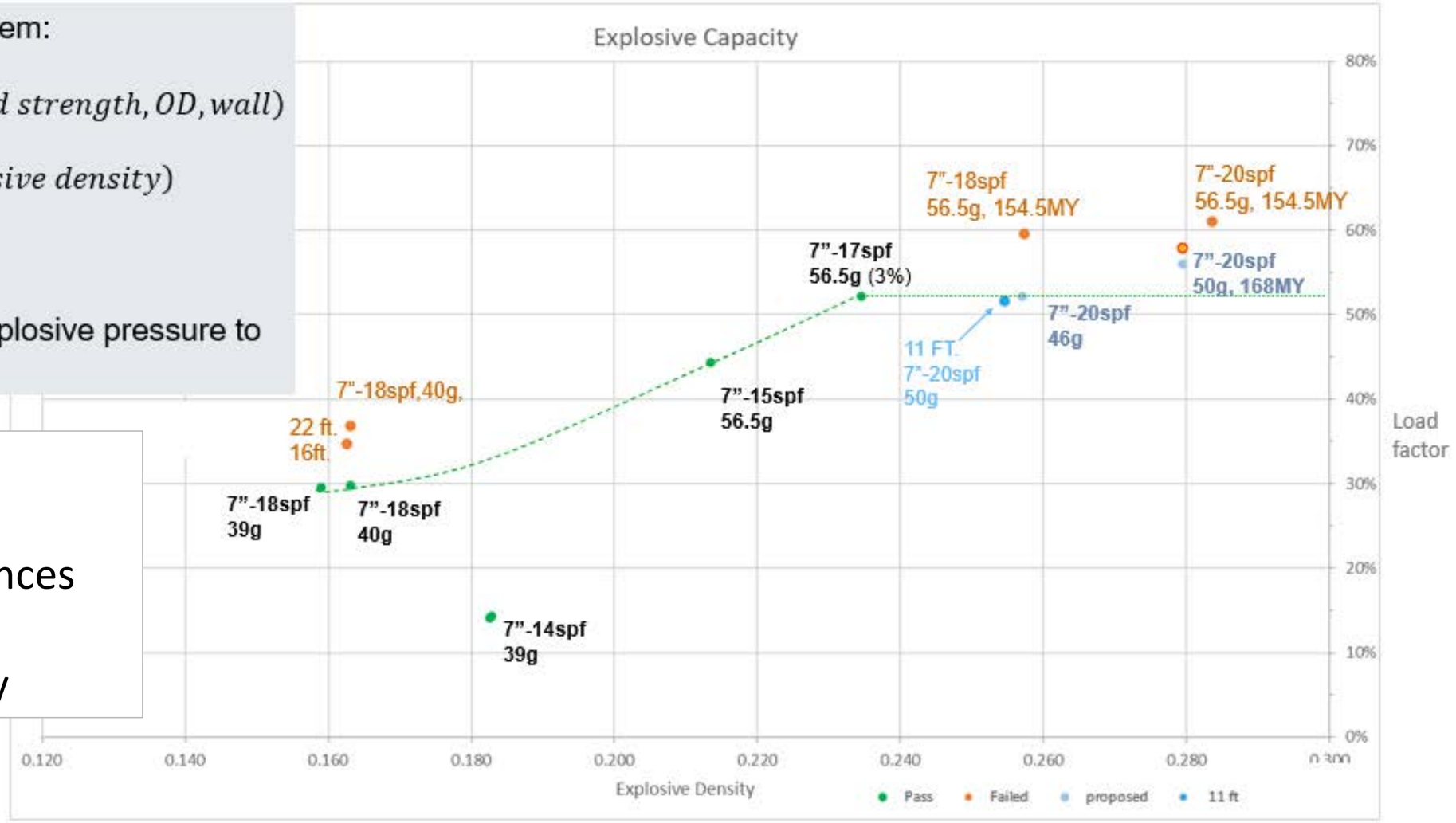
Explosive Capacity of System:

$f(explosive\ pressure, yield\ strength, OD, wall)$

Explosive pressure: $f(explosive\ density)$

Load factor:

- relative difference of explosive pressure to burst pressure



- Material differences
- Explosive load differences
- Length & Shot Density

Calculations based on actual test & product data.

Charge explosive weights shown as nominal but calculated as 5% overloaded unless indicated otherwise.

Explosive Capacity

Limits & Further Developments

- Shot Phasing is not evaluated
  - Hoop Stress
- Scallops are neglected
- Impacts from fragments from explosion
- Dynamic Fracture Toughness
  - Crack / flaw size acceptance
- Standardize Gun Materials for the industry?

QUESTIONS?

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UNHOLSTER WELL POTENTIAL USING CONVERGING SHOCKWAVES

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