Particle Size Image Analysis of Explosive Formulations & Ingredients (Abstract #17289)

Dr. Jeremy Headrick
BAE Systems, Holston Army Ammunition Plant

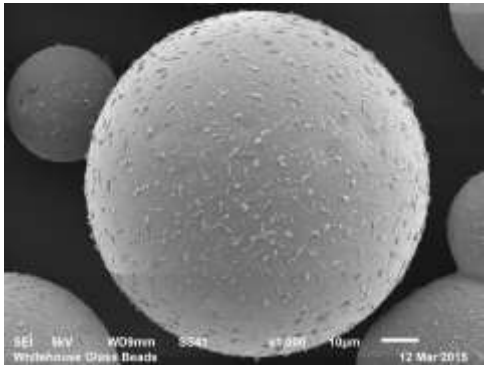
Presentation Outline

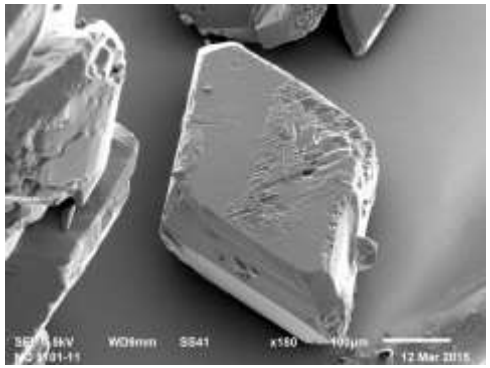
- Particle Size Image Analysis of Explosive Formulation & Ingredients
  - Particle Size Analysis
  - Image Analysis
  - Evaluation of Explosive Formulations
  - Evaluation of Explosive Ingredients
  - Shape Considerations
  - Summary

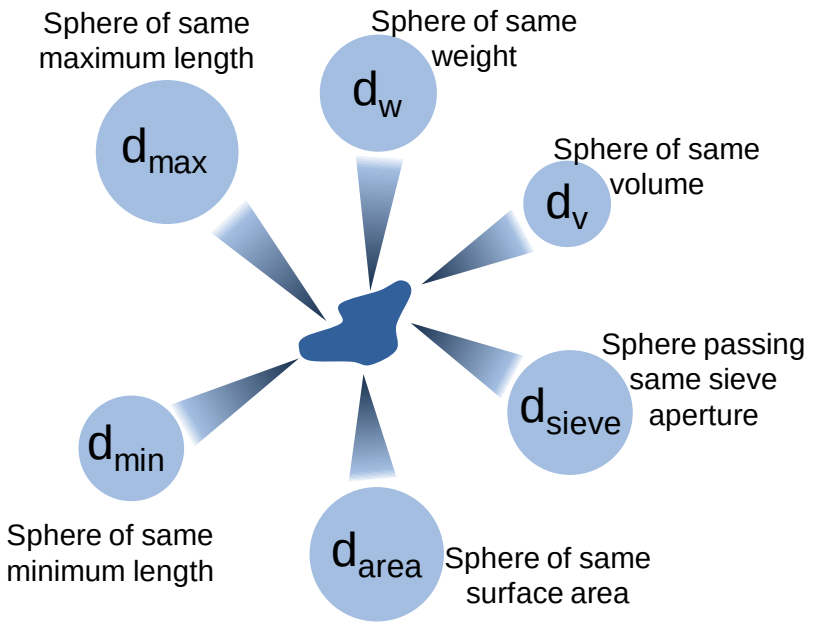
BAE SYSTEMS

Particle Size Analysis

- Particles are 3-dimensional objects.
- Unless the particles are perfect spheres, they cannot be described by a single dimension, such as radius or diameter.
- Most methods define the particle size as an equivalent sphere having a shared property with the actual particle, such as volume, area, or length.
- Different measurement techniques use different equivalent sphere models and therefore will not give exactly the same results for a given particle.







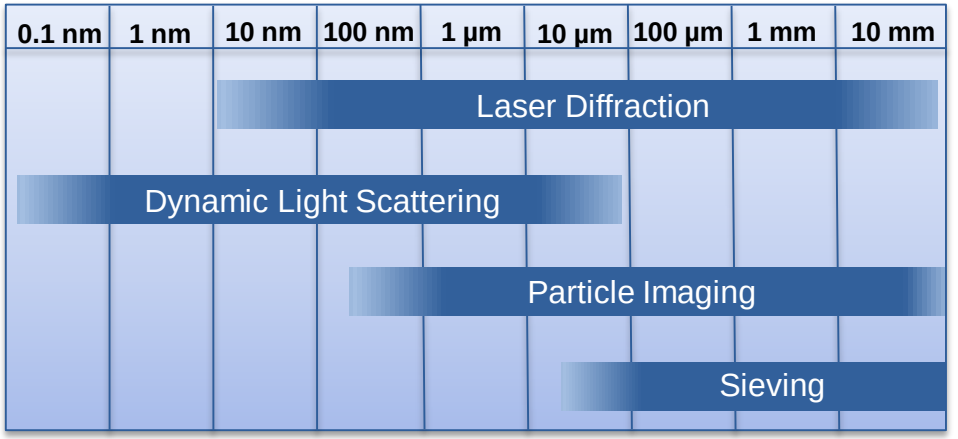
Particle Size Analysis Methods

- Currently most explosives ingredients and granular formulations have particle sizes ranging from approximately 1 micron to 10 millimeters.

- Historically particle size analysis of explosive formulations have been performed by sieving.

- Particle size analysis of explosives ingredients have been done by sieving or laser diffraction methods.

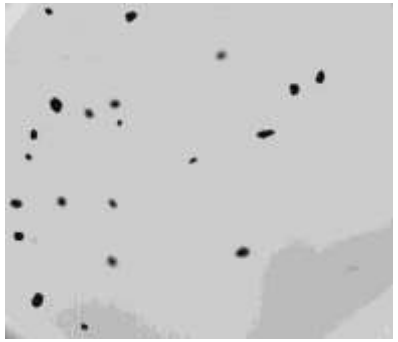
- Particle Imaging Analysis is an alternative technique that can also be used to measure particles in these size ranges



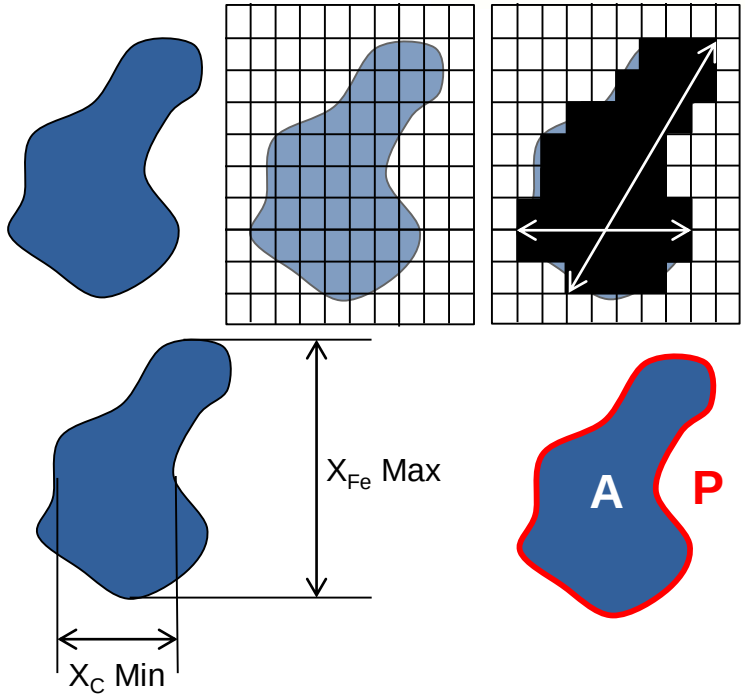
BAE SYSTEMS

Particle Imaging Analysis

- Samples are dispersed and passed in front of a digital camera where images are acquired.
  - Static
  - Dynamic



- The images are processed via software to segregate particles from background and to perform image analysis operations on each particle resulting in dimensional measurements.



- These particle measurements can be used to evaluate both size and shape.

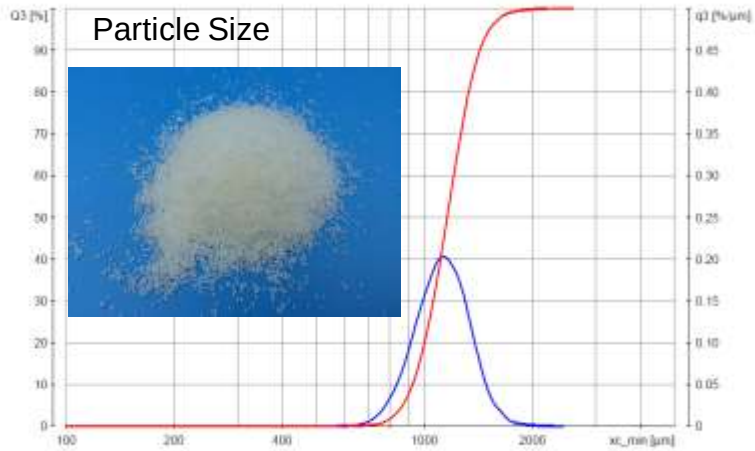
Aspect ratio = $\frac{X_{c\,min}}{X_{Fe\,max}}$ Sphericity = $\frac{4\pi A}{P^2}$

Explosive Formulations by Particle Image Analysis

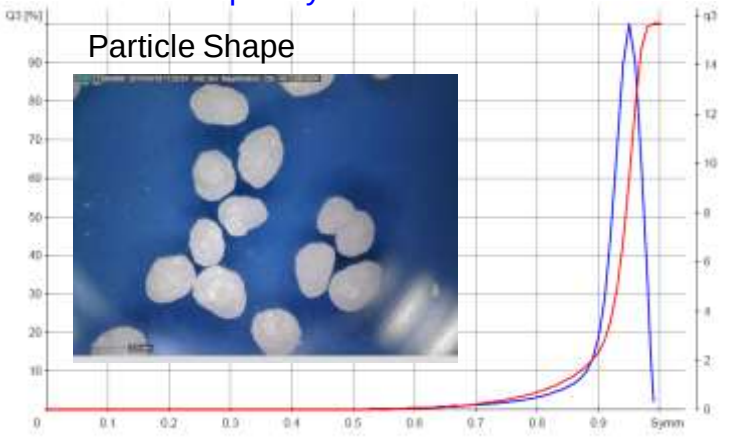
- Particles that are dry and free flowing can be analyzed by vibration feed table and gravity dispersion.

- Material simply falls past camera.

- There is no means of dispersing agglomerates of particles.

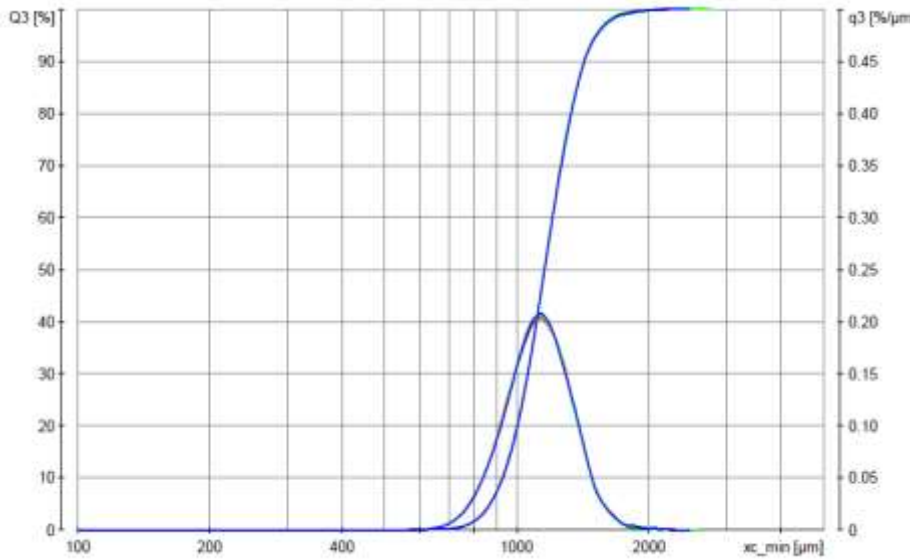


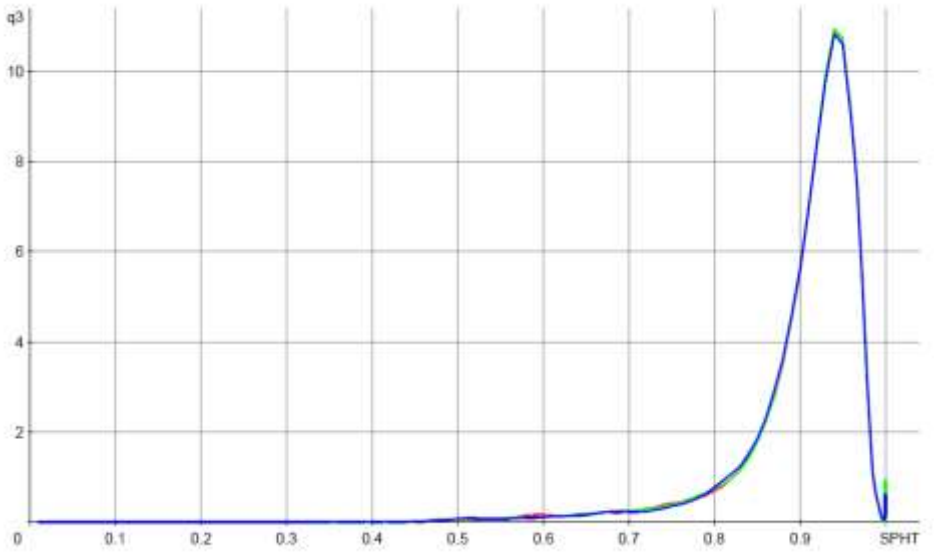
Red – Cumulative Distribution (% passing)
Blue – Frequency Distribution



Red – Cumulative Distribution
Blue – Frequency Distribution

Explosive Formulations by Particle Image Analysis





Replicate	D10 (µm)	D50 (µm)	D90 (µm)
1	926.1	1156.3	1425.7
2	928.3	1154.8	1422.8
3	928.9	1156.7	1425.7

Replicate	Sphericity	Symmetry	Aspect Ratio
1	0.908	0.928	0.765
2	0.908	0.929	0.766
3	0.908	0.928	0.766

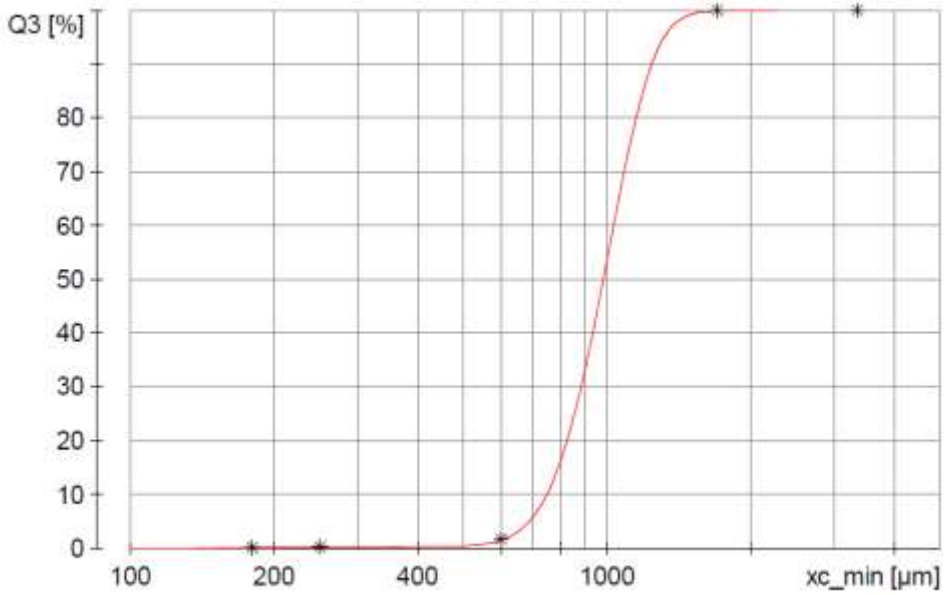
- Replicate analysis of materials shows good repeatability for both size and shape analysis

BAE SYSTEMS

Comparison of Particle Image Analysis vs Sieving

- Sample was analyzed by Image Analysis and then by sieving using sieve sizes from product specifications.

- Good Agreement to sieving data however data only describes the extremes.



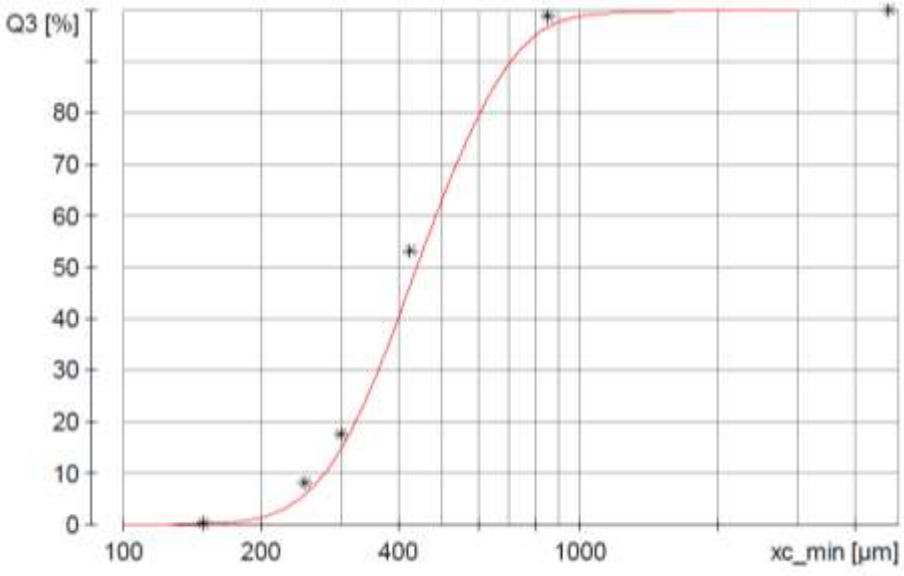
Red – Cumulative Distribution (% passing)
✕ - Sieving Data

Sieve #	Sieving (% passing)	PIA (% passing)
#6	0.0	0.0
#12	0.0	0.1
#30	98.5	98.4
#60	1.4	1.4
#80	0.0	0.0
PAN	0.1	0.1

BAE SYSTEMS

Comparison of Particle Image Analysis vs Sieving

- Another sample was analyzed by Image Analysis and sieve sizes were selected based upon these results to better described the sample by sieving.
- Generally good agreement to sieving data.
- Slight differences based upon orientation of particle when image acquired.



Red – Cumulative Distribution (% passing)

Ⱦ - Sieving Data

Sieve #	Sieving (% passing)	PIA (% passing)
#4	0.0	0.0
#20	1.2	3.3
#40	45.5	50.3
#50	35.7	31.7
#60	9.4	8.8
#100	7.9	5.7
PAN	0.3	0.2

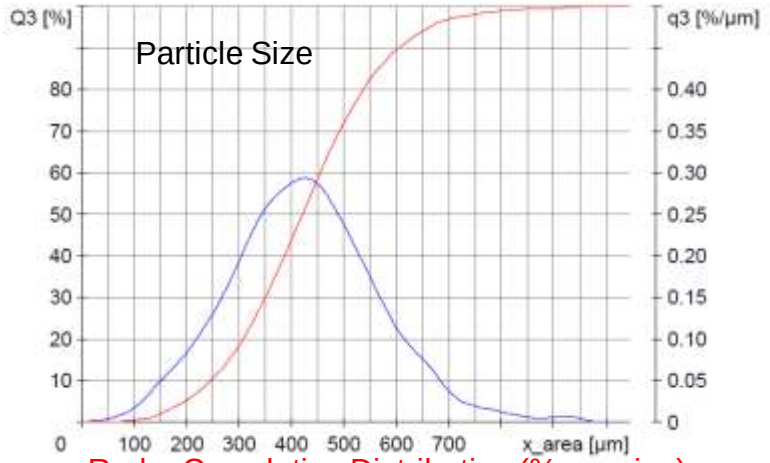
BAE SYSTEMS

Explosive Ingredients by Particle Image Analysis

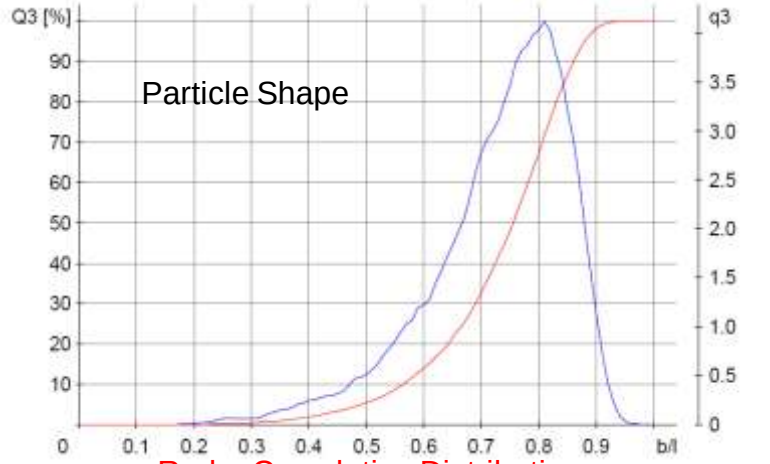
- Dry fine particles that agglomerate can be analyzed by vibration feed table and air pressure dispersion.

- Particles mixed with stream of compressed gas to break up agglomerates.

- Particles & gas stream exit out of a nozzle past the camera for measurement.



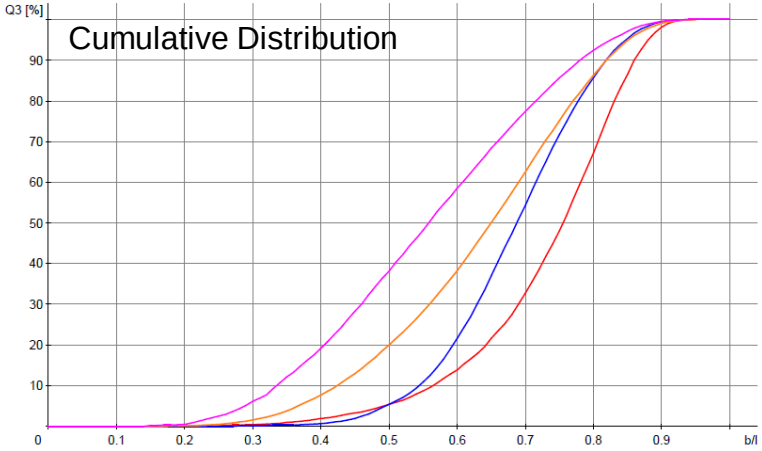
Red – Cumulative Distribution (% passing)
Blue – Frequency Distribution

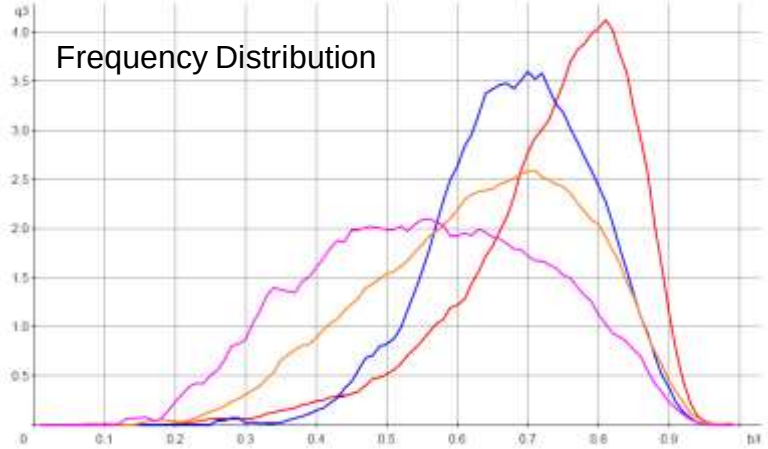


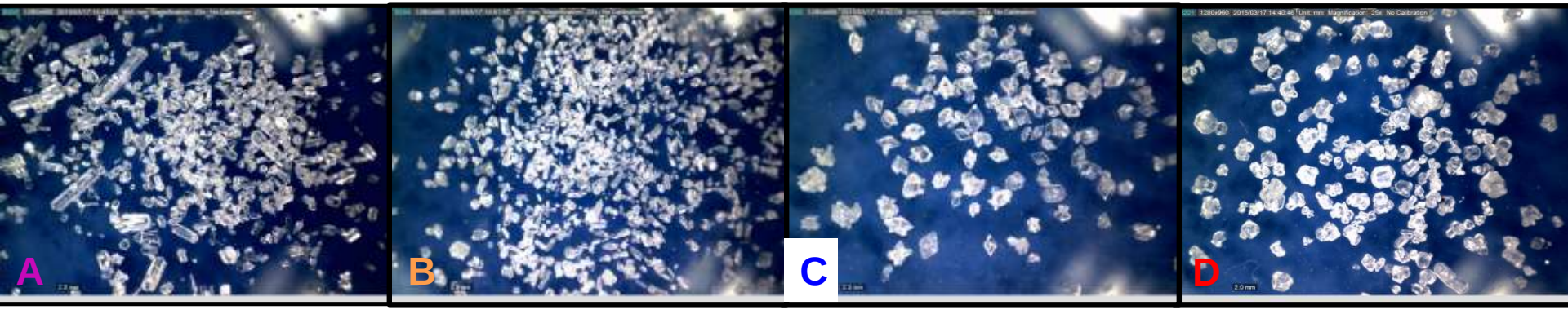
Red – Cumulative Distribution
Blue – Frequency Distribution

Explosive Ingredients - Shape Analysis by Particle Imaging

- Analysis of ingredients for differences in aspect ratio.



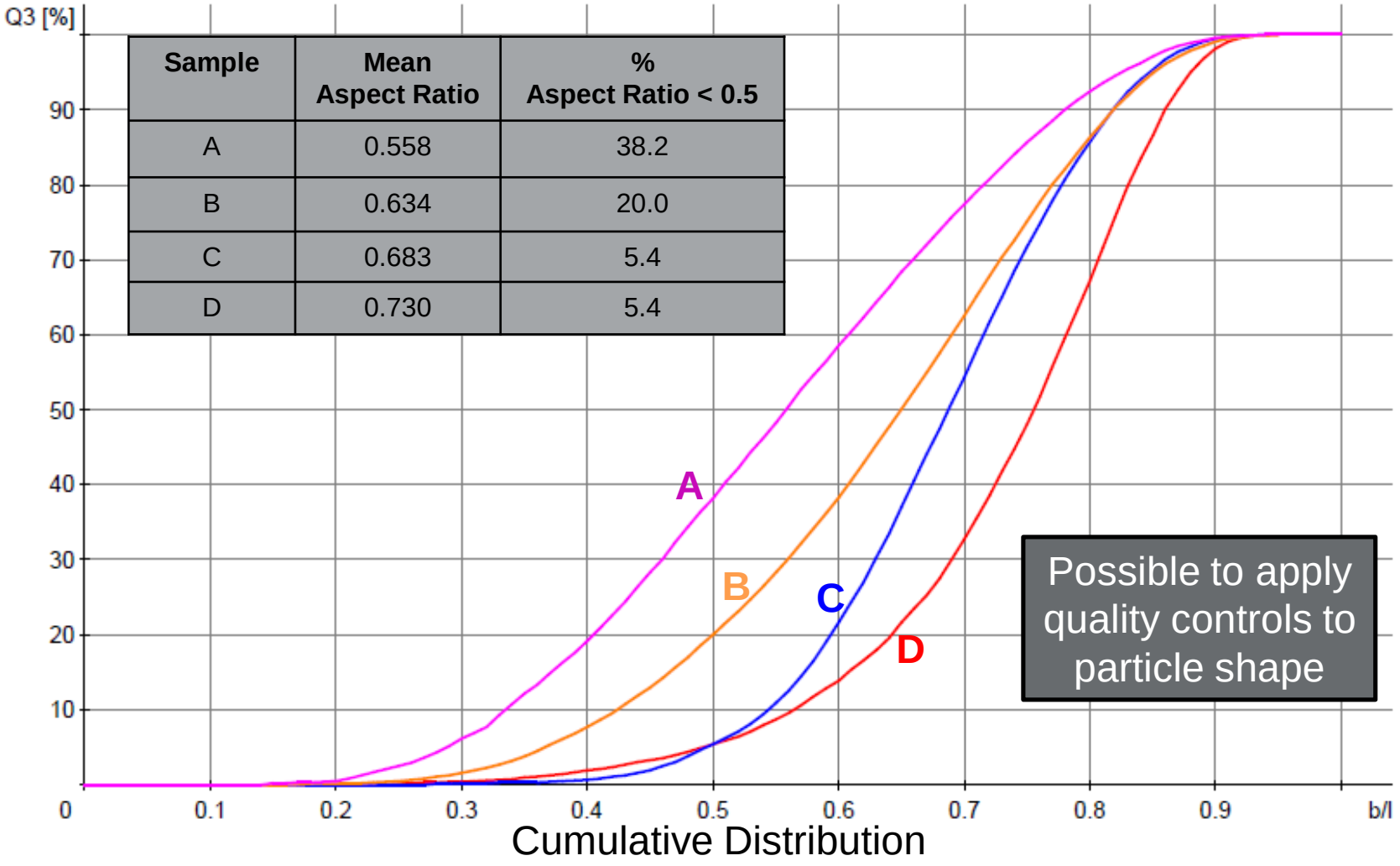




- Differences in Aspect Ratio from Image Analysis consistent with optical microscope images.

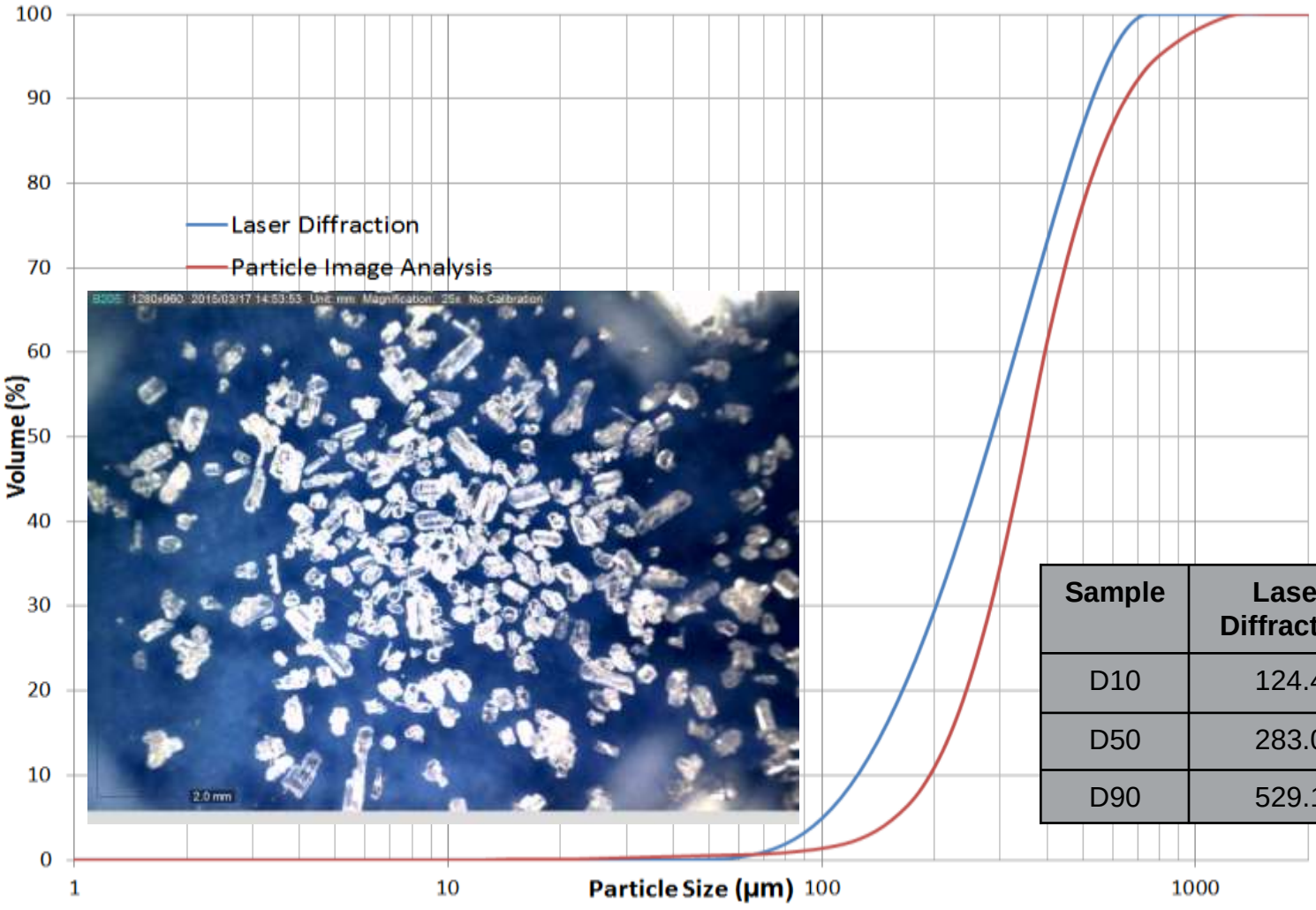
Explosive Ingredients - Shape Analysis by Particle Imaging

Sample	Mean Aspect Ratio	% Aspect Ratio < 0.5
A	0.558	38.2
B	0.634	20.0
C	0.683	5.4
D	0.730	5.4



BAE SYSTEMS

Explosive Ingredients - Size Analysis of Mixed Shapes

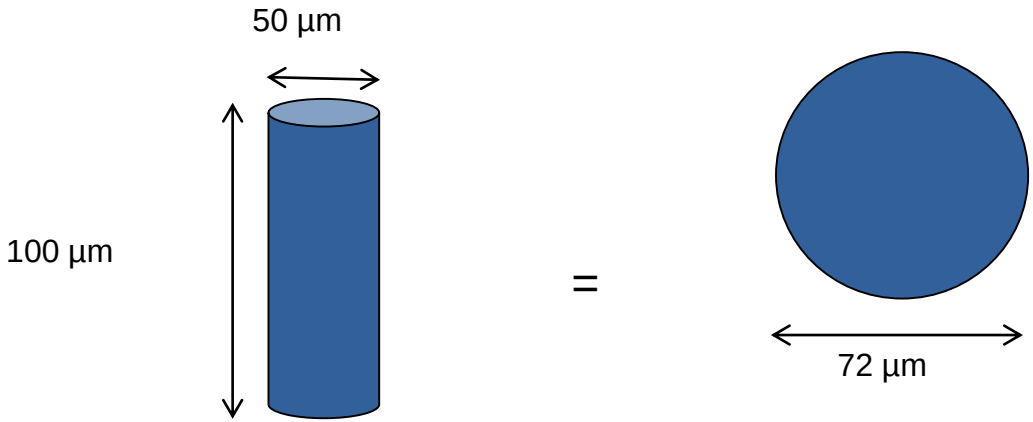


Sample	Laser Diffraction	Image Analysis
D10	124.4	194
D50	283.0	356
D90	529.1	644

Explosive Ingredients - Size Analysis of Mixed Shapes

- Comparison of Laser Diffraction and Particle Image Analysis for materials containing “rods”.

- Laser diffraction predicts smaller size for “rods” than image analysis.



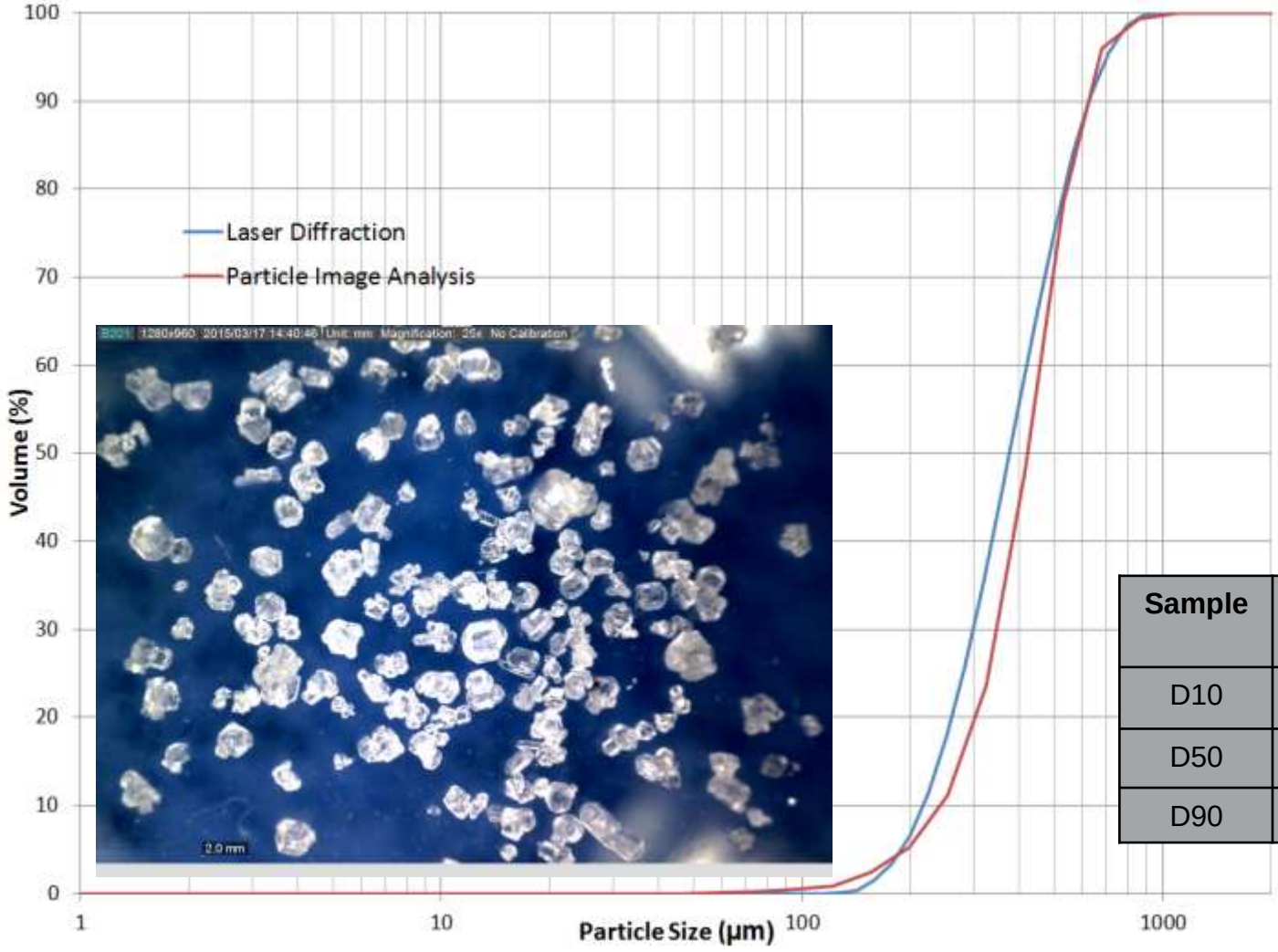
$$V = \pi r^2 \mathrm{h}$$

$$V = \frac{4}{3}\pi r^3$$

- As rod length grows this difference increases.

BAE SYSTEMS

Explosive Ingredients - Size Analysis of Mixed Shapes



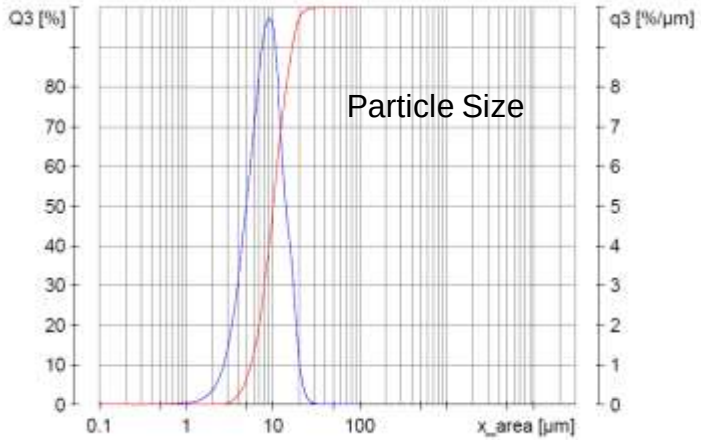
Sample	Laser Diffraction	Image Analysis
D10	217.5	245.5
D50	375.1	420.7
D90	625.8	605.1

Explosive Ingredients by Particle Image Analysis

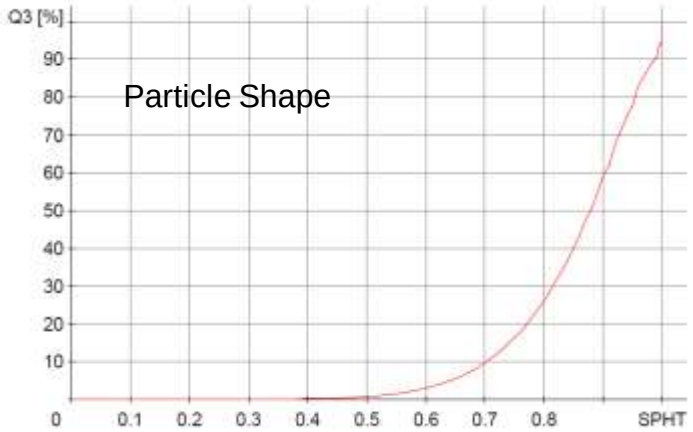
- Fine particles that agglomerate can also be analyzed using a wet mode.

- Particles are slurried in water. Agglomerates are broken up by sonication.

- The slurry is pumped through a liquid cell past the camera for measurement.



Red – Cumulative Distribution (% passing)
Blue – Frequency Distribution



Summary

- Particle Imaging has been used to evaluate a variety of explosive formulations and ingredients.
- Imaging analysis has shown good agreement with sieving data for explosive formulations. Method is faster, less hands on, and easier to clean-up.
- Particle imaging analysis has shown the ability to distinguish differences in particle shape that other methods cannot detect.
- Image analysis has a limited dynamic range of analysis compared to other methods.

Acknowledgments

BAE Systems / HSAAP

Mr. Matt Hathaway

Dr. Tess Kirchner

Ms. Kelly Guntrum

Dr. Jacob Morris

RDECOM-ARDEC

Ms. Florence Delacruz

Mr. Paul Vinh