



U.S. ARMY TANK AUTOMOTIVE RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

# A Users Perspective and Experience with Particle Counting in Liquid Fuels

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11 SEP 2017

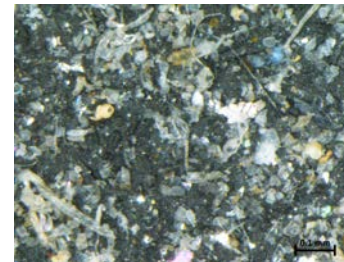
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# Concern over particulate contamination



- Wear within the fuel system and fuel injection equipment due to particle erosion
  - Particle hardness is more important than particle density
- Filter plugging
  - Reduced filter life, or engine fuel starvation
    - Particle size and quantity are more important than contaminant mass
- Fuel system passage blockage
  - Ultrafine particulate can restrict fuel passages and movement between fine tolerance components
    - Particulate size is more important than contaminant mass

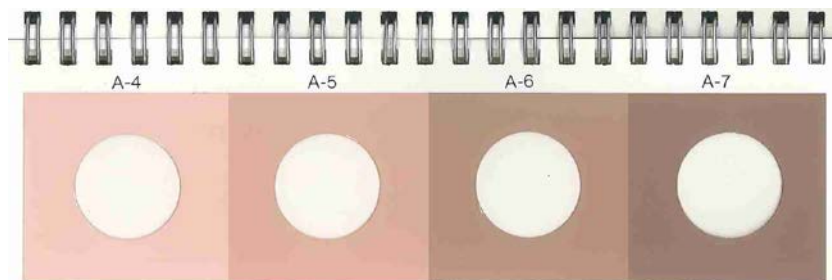




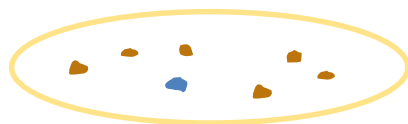
- ASTM D2276 – Particulate Contamination in Aviation Fuel by Line Sampling
  - gravimetric limit 1.0 mg/L (MIL-STD-3004, MIL-DTL-83133)
    - *Limit first appeared in MIL-T-5624G - 5 NOV 1965)*
- ASTM D5452 – Particulate Contamination in Aviation Fuels by Laboratory Filtration
  - gravimetric limit 1.0 mg/L (MIL-STD-3004)
- ASTM D3240 – Undissolved Water in Aviation Turbine Fuels
  - 10 PPM (MIL-STD-3004, ATP 4-43)
- ASTM D4176 – Free Water and Particulate Contamination in Distillate Fuels (Visual Inspection Procedures)
  - Clear and Bright

- Drawbacks:

- Operator subjectivity (ASTM D2276 color comparison)



- Lack of detail (ASTM D2276 gravimetric)



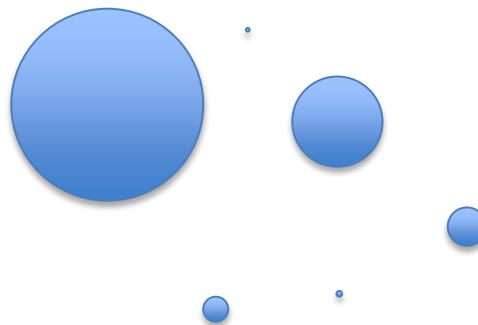
- Large sample volumes (500mL – 5 Liters)
- Potential contamination
- Time consuming
- Poor repeatability

# Particulate Hardness and size



common name	formula	Mohs hardness	density g/cm <sup>3</sup>	ISO 12103-1 A1 <sup>1</sup>	18 field samples median <sup>2</sup>
silica	SiO <sub>2</sub>	7	2.65	69-77%	36.60
aluminum oxide	Al <sub>2</sub> O <sub>3</sub>	9	3.95	8-14%	15.85
Hematite (iron (III) oxide)	Fe <sub>2</sub> O <sub>3</sub>	5-6	5.30	4-7%	3.4
Magnetite	Fe <sub>3</sub> O <sub>4</sub>	5.5-6.5	5.15		
Calcium oxide	CaO	3.5	3.34	2.5-5.5%	7.45
potassium chloride	KCl	2	1.98	2-5%	

Ø μm	μm <sup>3</sup>
0.8	0.27
1	0.52
4	33.51
6	113
14	1436
30	14137



<sup>1</sup> ISO 12103-1, A1 Ultrafine Test Dust - Powder Technology Inc.

<sup>2</sup> BFLRF No. 294 Characterization of CONUS and Saudi Arabian fine-grained soil samples

- DoD has published particle count limits in MIL-STD-3004 for aviation turbine fuel and in MIL-DTL-83133.
- MIL-DTL-5624 and DEF STAN 91-091 include a requirement to only report particle counting measurements.
- IP 564 – Parker ACM20
- IP 565/ASTM D7619 – Stanhope-Seta AvCount
- IP 577 – Pamas S40



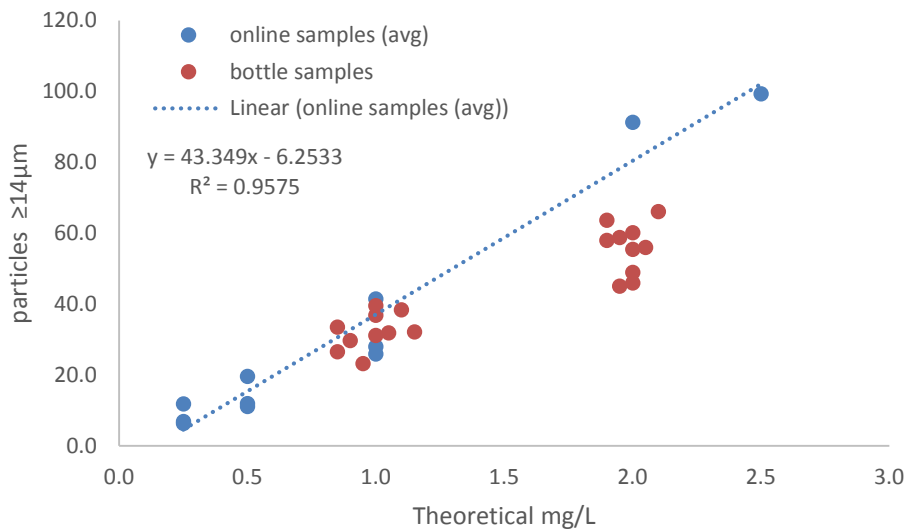
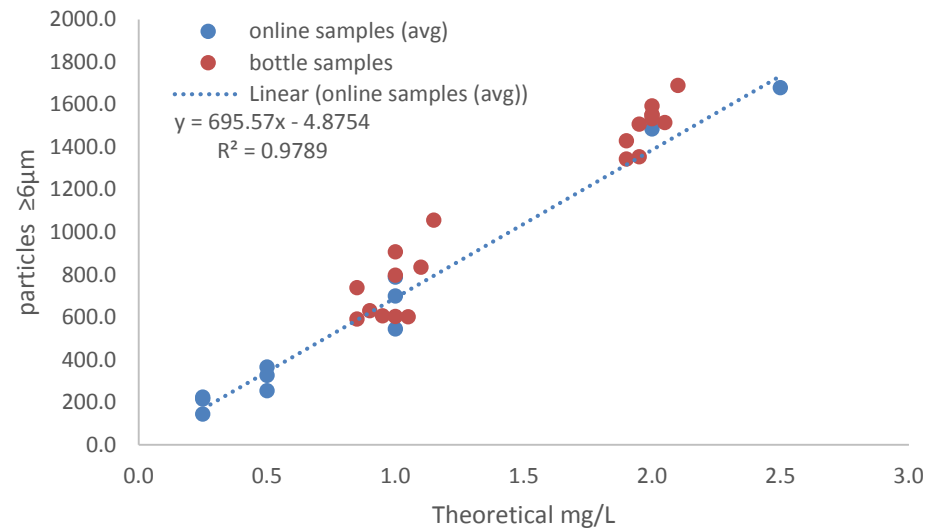
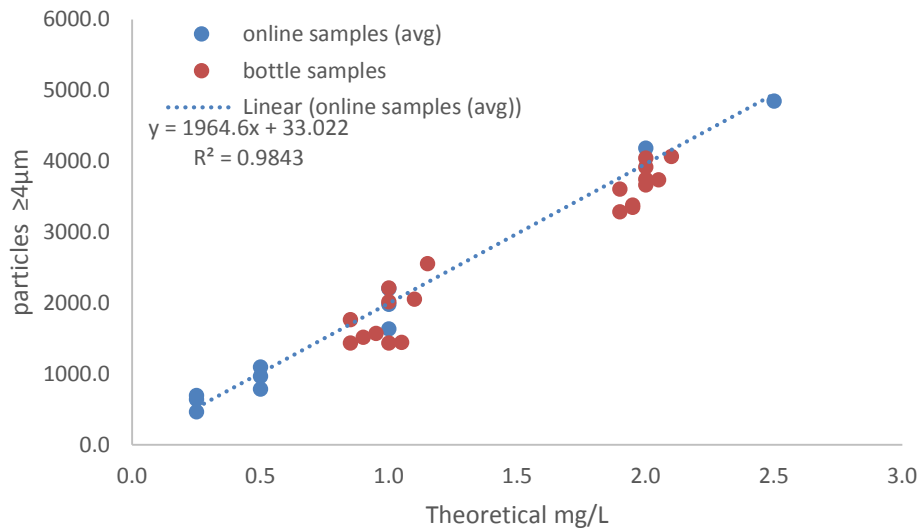
# Particle Counter Methodology



- Particle counts are taken utilizing calibration methodologies and standardized cleanliness code ratings
  - ISO 11171
  - ISO 4406
- Particle Count ISO 4406 code 19/17/14/13 limits of 4 $\mu$ m (c) /6 $\mu$ m (c)/14 $\mu$ m (c)/30 $\mu$ m (c) corresponding to 1.0 mg/L
- Limit can be applied directly to instruments reporting  $\mu$ m (b) if available

Number of particles per millilitre		Scale number
More than	Up to and including	
2 500 000		>28
1 300 000	2 500 000	28
640 000	1 300 000	27
320 000	640 000	26
160 000	320 000	25
80 000	160 000	24
40 000	80 000	23
20 000	40 000	22
10 000	20 000	21
5 000	10 000	20
2 500	5 000	19
1 300	2 500	18
640	1 300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2,5	5	9
1,3	2,5	8
0,64	1,3	7
0,32	0,64	6
0,16	0,32	5
0,08	0,16	4
0,04	0,08	3
0,02	0,04	2
0,01	0,02	1
0,00	0,01	0

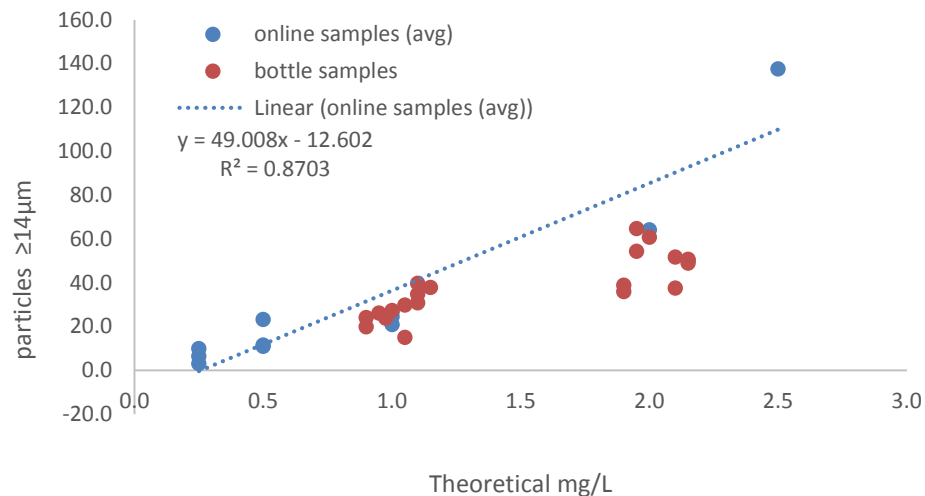
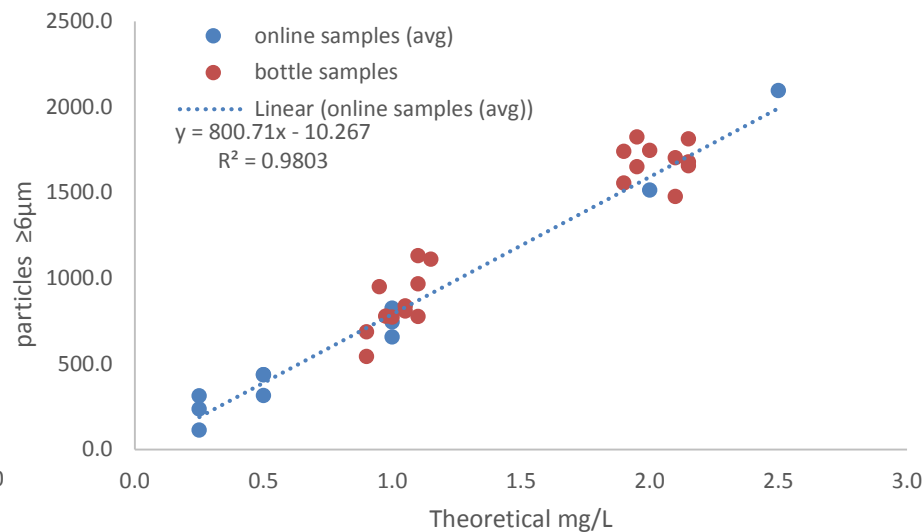
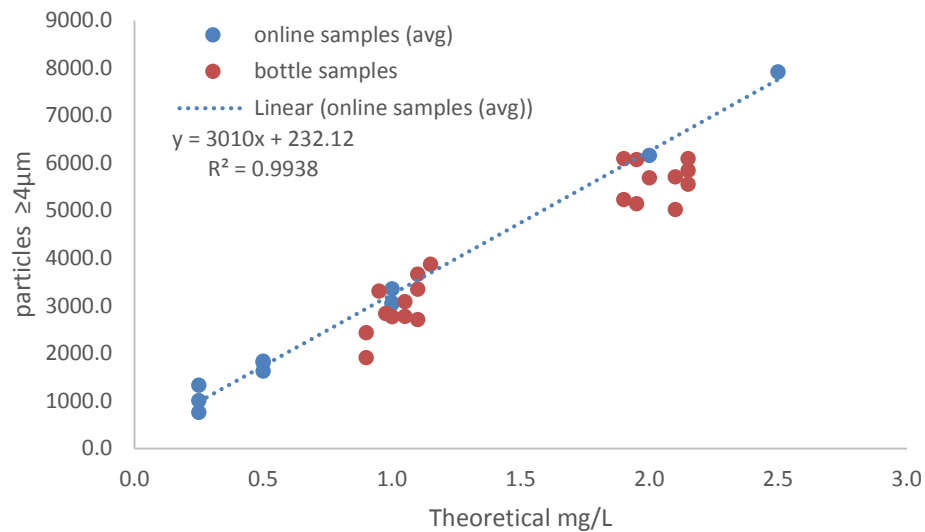
# ISO 12103-1 A3 medium test dust evaluation



1.0 mg/L ~ 18/17/12  
 0.5 mg/L ~ 17/16/11

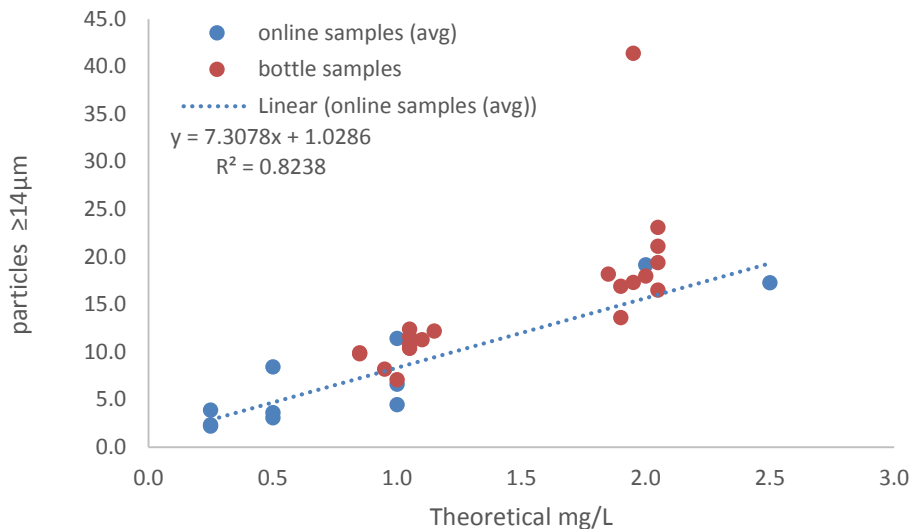
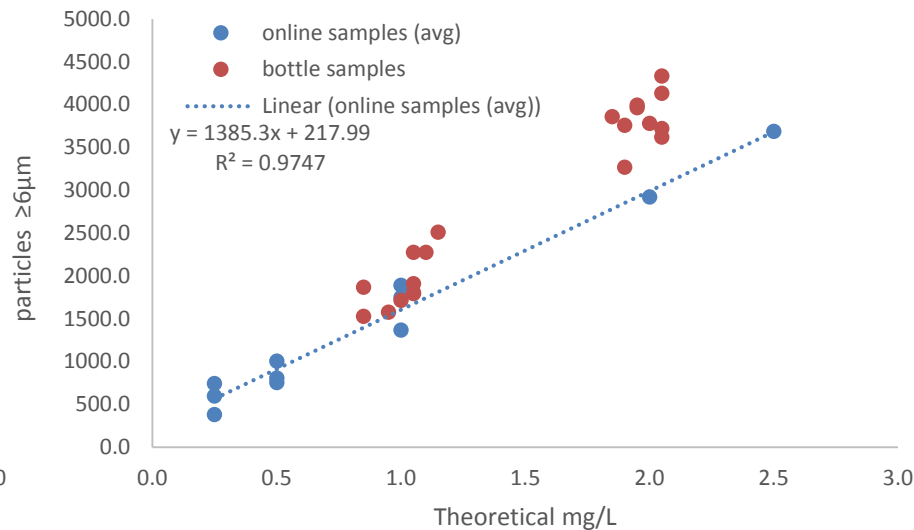
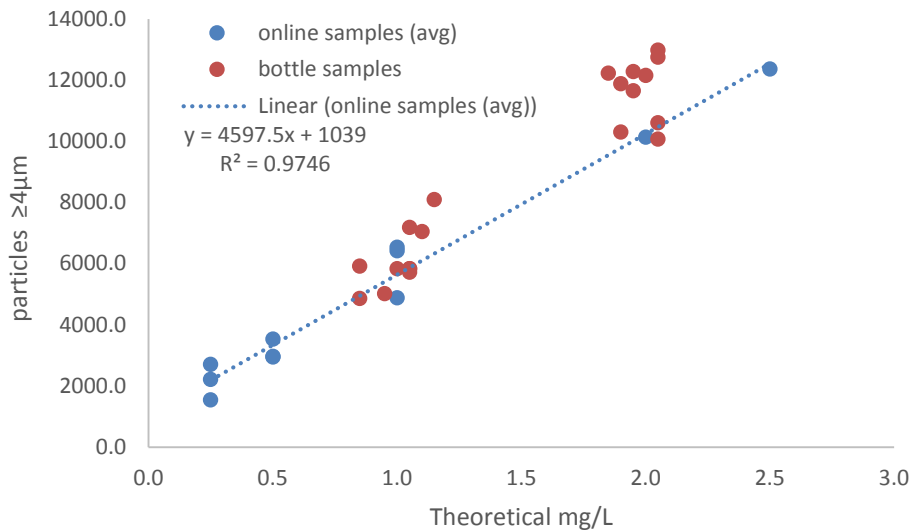


# ISO 12103-1 A2 fine test dust evaluation



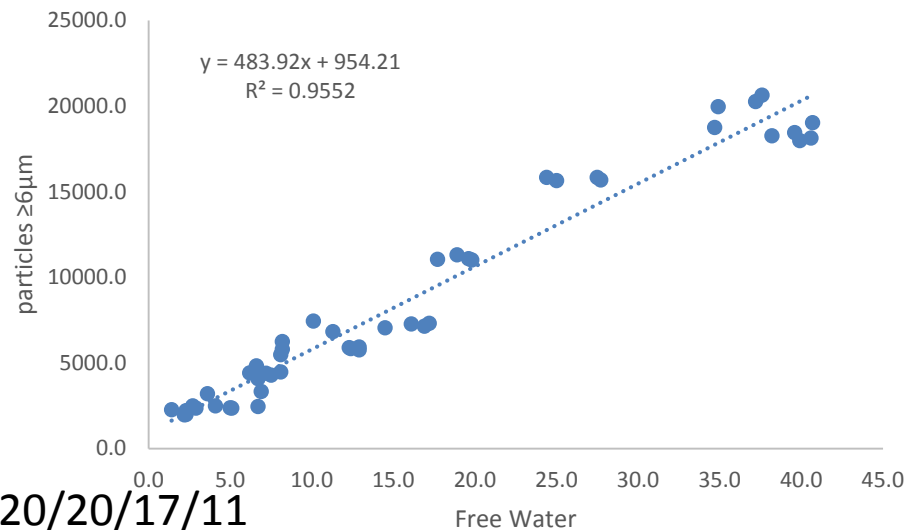
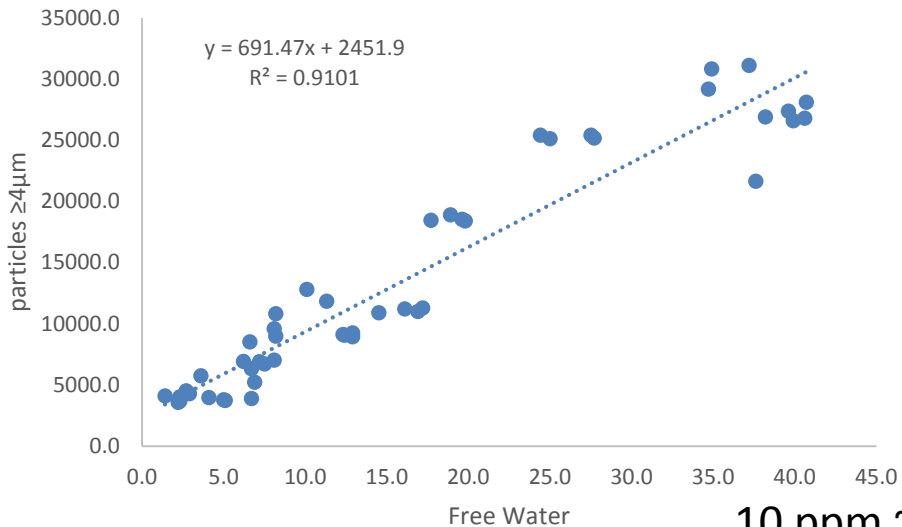
1.0 mg/L ~ 19/17/12  
 0.5 mg/L ~ 18/16/11

# ISO 12103-1 A1 ultrafine test dust evaluation



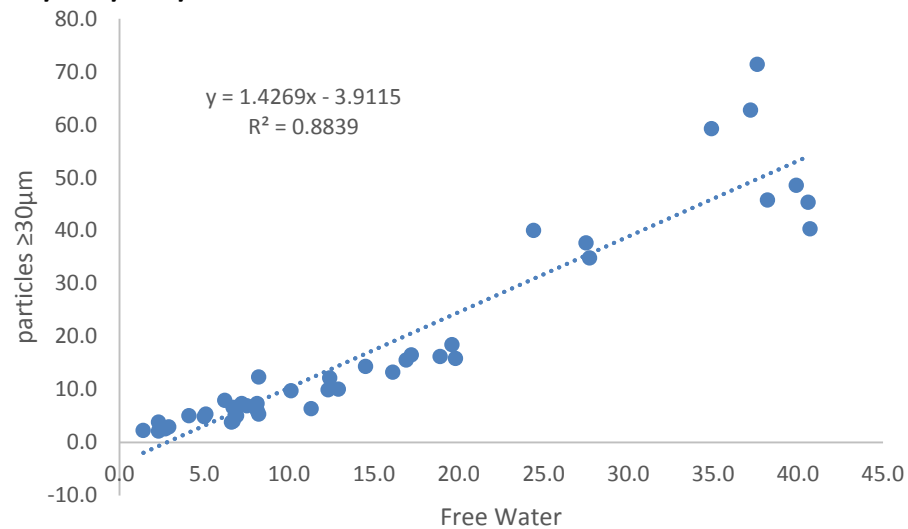
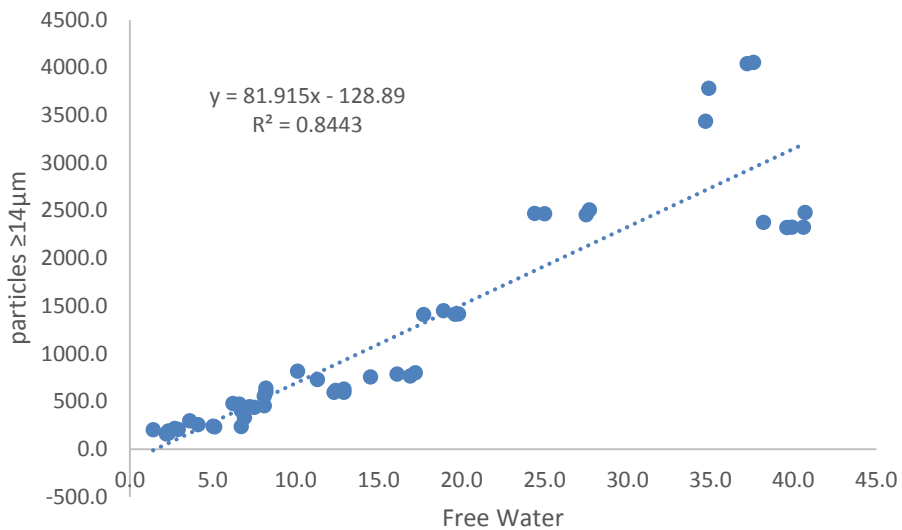
1.0 mg/L ~ 20/18/10  
 0.5 mg/L ~ 19/17/9

# Free water EI 1581 test loop full flow 100 gpm

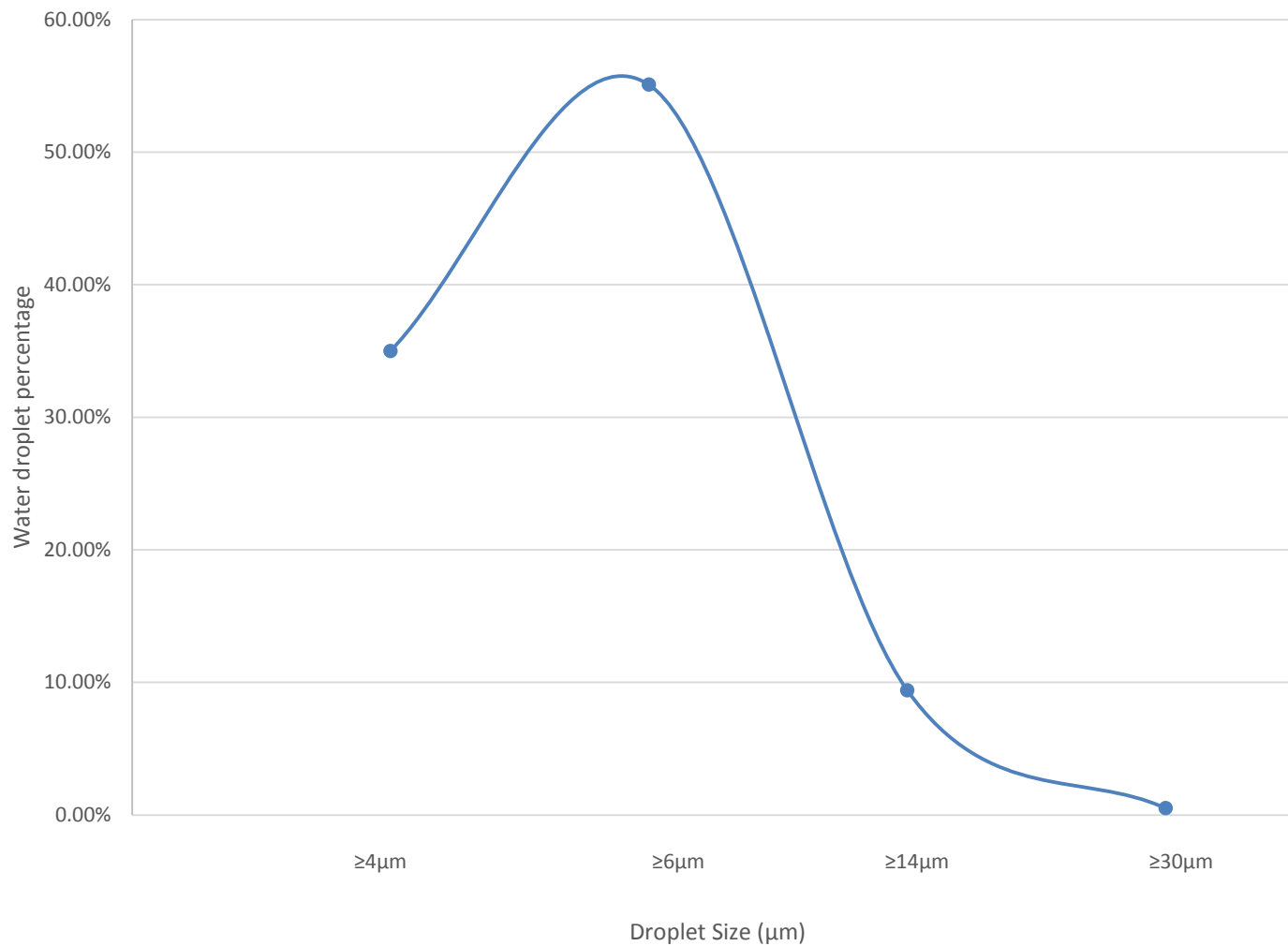


10 ppm ~ 20/20/17/11

5 ppm ~ 20/19/15/9



# Free water EI 1581 test loop full flow 100 gpm



# Recommended Limits



	Receipt	Vehicle Fuel Tank	Fuel Injector
<b>Aviation Fuel</b>			
DEF (AUST) 5695B		18/16/13	
Parker	18/16/13	14/10/7	
Pamas / Parker / Particle Solutions	19/17/12		
U.S. DOD	19/17/14/13*		
USAF into plane#		18/16/14	
<b>Diesel Fuel</b>			
World Wide Fuel Charter 5th		18/16/13	
Truck & Engine Manufacturers Association		18/16/13	
DEF (AUST) 5695B		18/16/13	
Caterpillar		18/16/13	
Detroit Diesel		18/16/13	
MTU		18/17/14	
Bosch/Cummins		18/16/13	
Donaldson	22/21/18	14/13/11	12/9/6
Pall	17/15/12	15/14/11	12/9/6 11/8/7

\* 4µm (c)/ 6µm (c)/ 14µm (c)/ 30µm (c)

# proposed



- September 2012 – July 2017
- ASTM D5452 Laboratory filtration (aviation)
- ASTM D6217 Laboratory filtration (diesel)
- IP 564 – Parker ACM20 (59 samples only)
- IP 565/ASTM D7619 – Stanhope-Seta AvCount
- 2509 samples analyzed



- 2509 samples analyzed
- 2137 samples passed both gravimetric and particle count
- 372 samples failed particle count or gravimetric
  - 294 out of 372 samples failed particle count
  - 246 out of 372 samples failed gravimetric
  - 168 out of 372 samples failed both particle count and gravimetric
- 78 False negatives (fails gravimetric, passes particle count)
- 126 False positives (fails particle count, passes gravimetric)

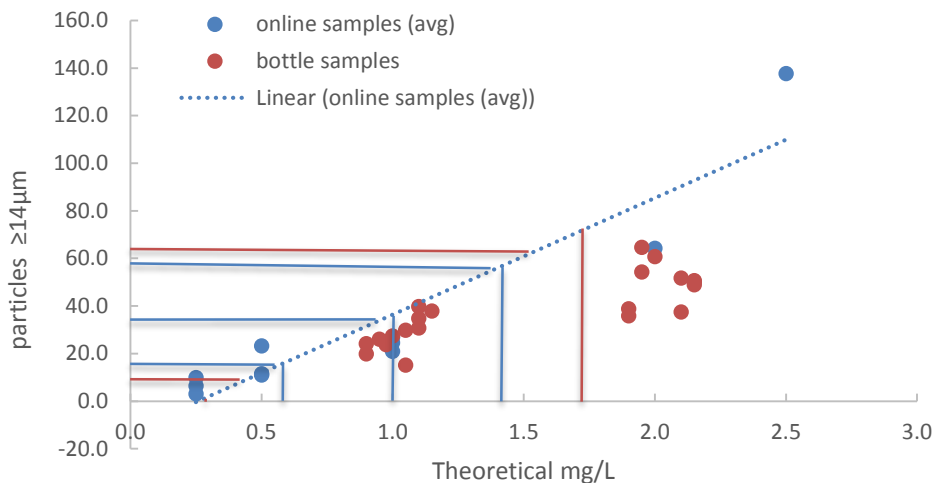
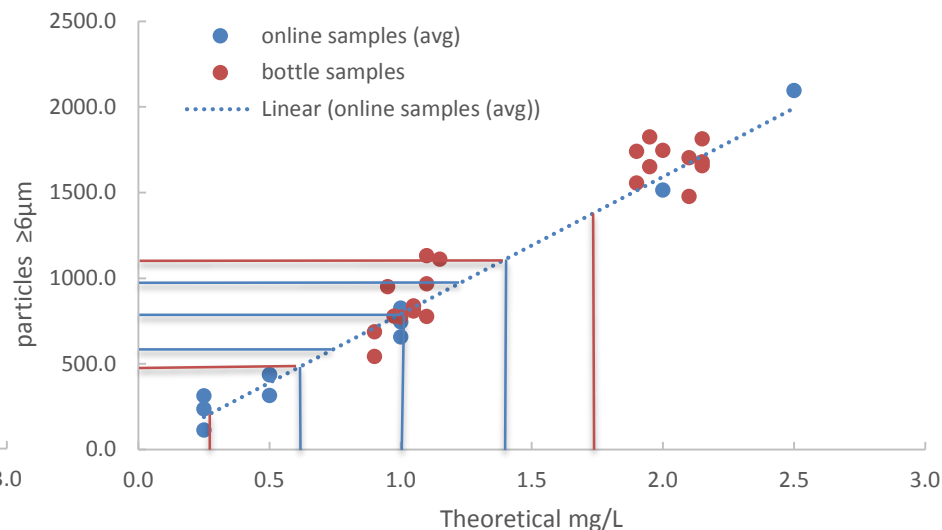
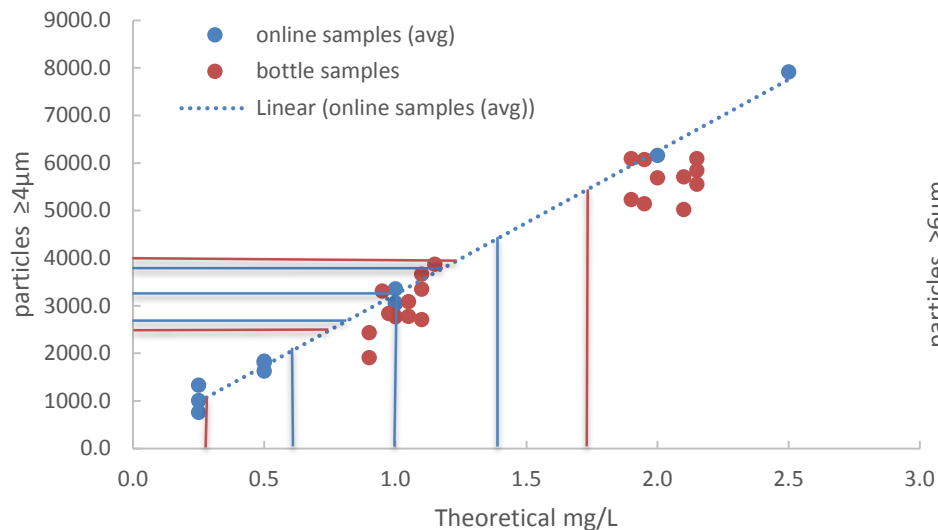
**91.9% agreement**



- 78 False negatives (fails gravimetric, passes particle count)
- ASTM D5452 repeatability (r) 0.0-0.6 mg/L
  - $r = 0.415x^{0.5}$
  - $r$  at 1.0 mg/L = 0.415 mg/L
    - repeatability formula based on 5 liter sample
- 58 samples may be lower than 1.0 mg/L based on repeatability calculations.
- 20 samples have high gravimetric reading that is not accounted for by particle count data.
- Particles not seen by particle counter
  - Particle greater than 70 $\mu$ m (c) (Stanhope Seta) - 200 $\mu$ m (c) (Parker)
  - Particles less than 4 $\mu$ m (c)



# ISO 12103-1 A2 repeatability and reproducibility



ASTM D5452\* extrapolated  
IP 564  
repeatability  
Reproducibility



- 126 False positives (fails particle count, passes gravimetric)
  - 56 samples gravimetric data may be greater than 1.0 mg/L based on repeatability calculations.
  - 118 fuels high in 6 $\mu$ m (c), 14 $\mu$ m (c), and/or 30 $\mu$ m (c) channels indicating free water contamination
  - Analyzed to determine if free water contributed to the high particle counts
    - 16 of 118 fuel samples confirmed >5 ppm free water contamination
    - 15 of 118 fuel samples with 1-5 ppm free water
    - 41 of 118 fuel samples confirmed to be absent of free water
    - 46 of 118 fuel samples untested

- 475 samples analyzed
- 435 samples passed both gravimetric and particle count
- 40 samples failed particle count or gravimetric
  - 27 out of 40 samples failed particle count
  - 18 out of 40 samples failed gravimetric
  - 5 out of 40 samples failed both particle count and gravimetric
- 13 False negatives (fails gravimetric, passes particle count)
- 22 False positives (fails particle count, passes gravimetric)

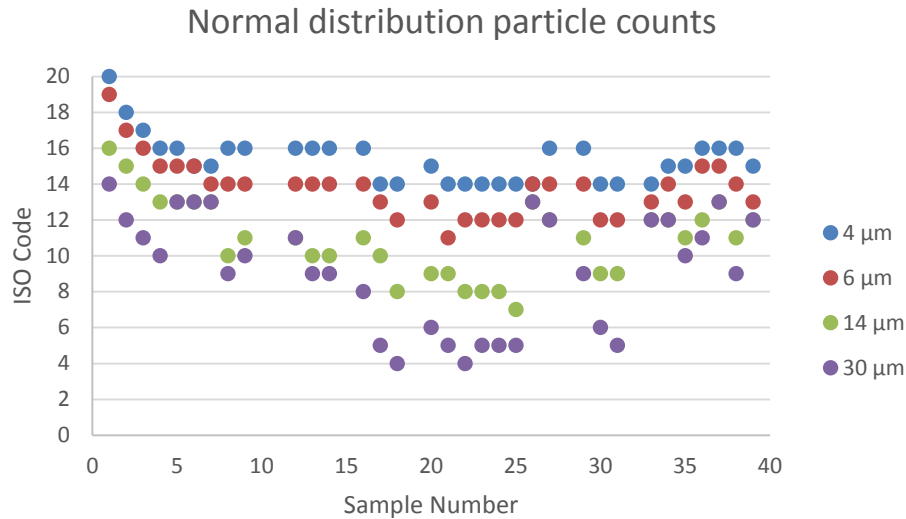


## 92.6% agreement

- 2509 samples analyzed
- 1603 samples passed both gravimetric and particle count
- 906 samples failed particle count or gravimetric
  - 559 out of 906 samples failed particle count
  - 695 out of 906 samples failed gravimetric
  - 348 out of 906 samples failed both particle count and gravimetric
- 347 False negatives (fails gravimetric, passes particle count)
- 211 False positives (fails particle count, passes gravimetric)

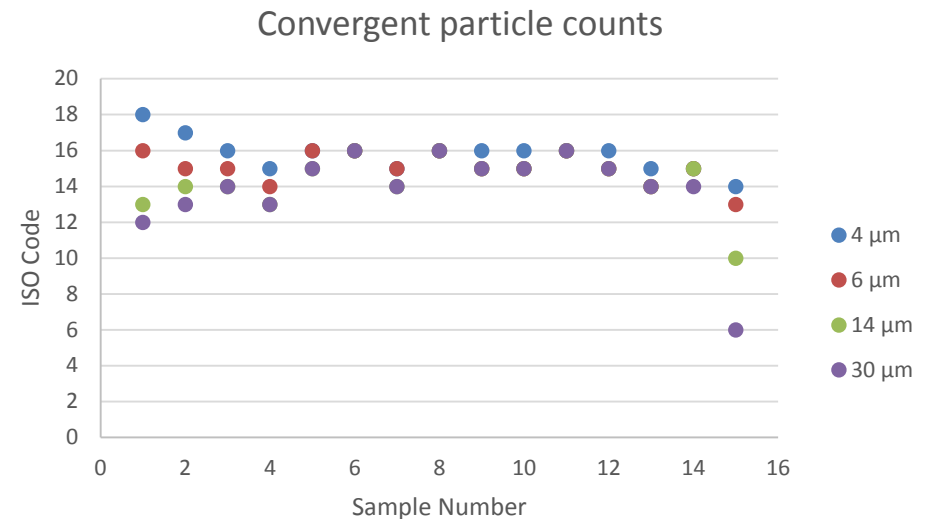
**77.8% agreement**

- Non Aviation Brigade Support Battalion



- Normal distribution of particle counts indicative of minimal sediment contamination

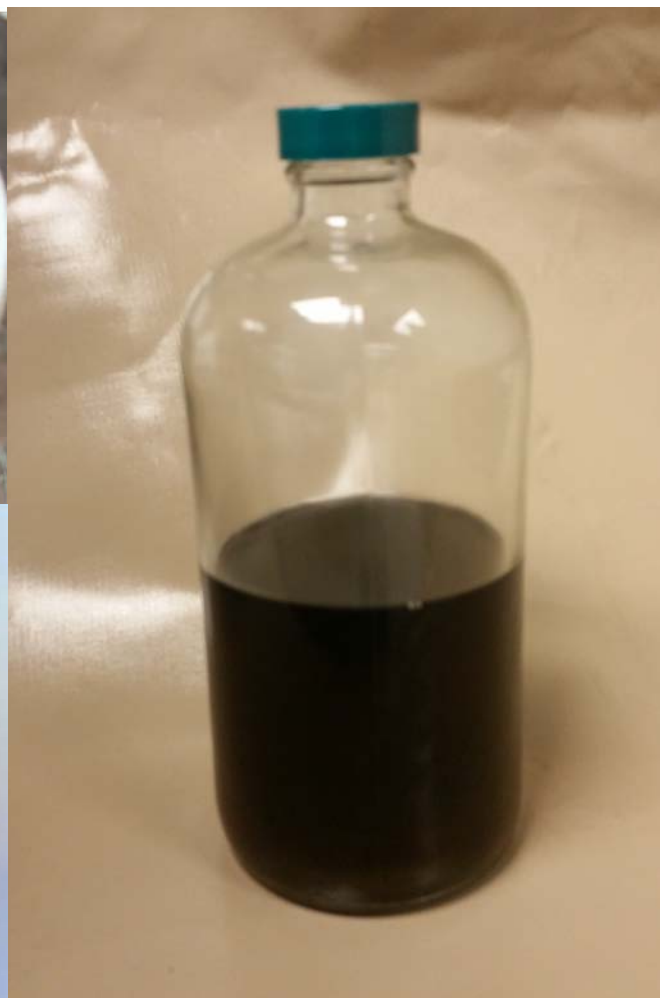
- Convergent particle counts where all channels read close together indications large water droplets present in the fuel.



# Field success stories



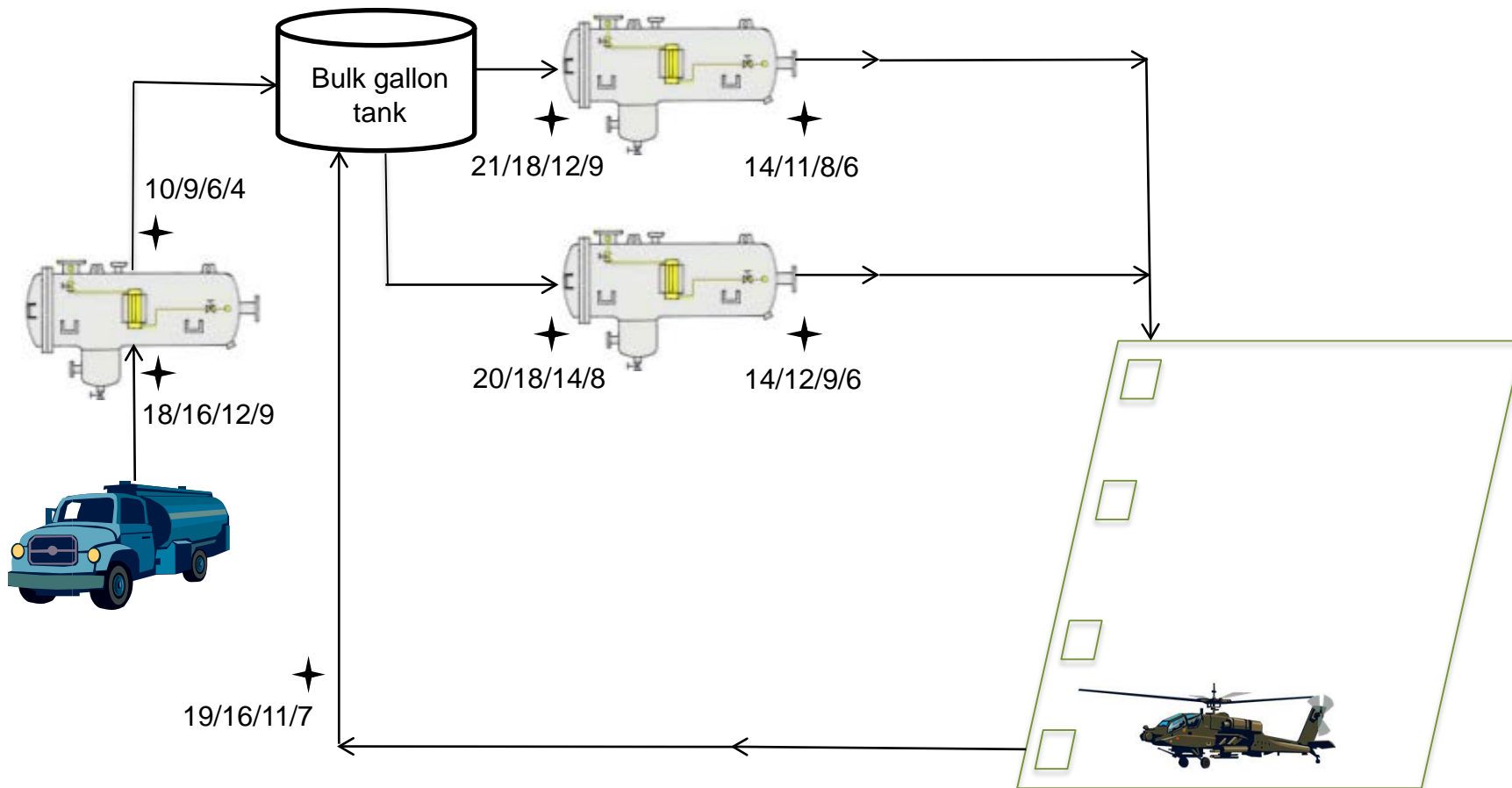
- Non Aviation Brigade Support Battalion
- Water contamination confirmed! Led to microbial infestation outbreak.



# Field success stories



- Airfield Hydrant return line contamination
- Filters required replacement after 3 months of service
- Gravimetric measurements at fuel receipt and retail normal



- Low levels of free water can have a large impact in particle count readings, this may account for an unknown number of the false positive readings.
  - Recommend following the procedure to utilize chemical treatment to eliminate the interference of free water droplets from particle counts found in Annex B of IP 564, IP 565, IP 577 and proposed for inclusion into ASTM D7619.
- The published particle count limit of 19/17/14/13 for the 4 $\mu$ m (c)/ 6 $\mu$ m (c)/ 14 $\mu$ m (c)/ 30 $\mu$ m (c) size channels in MIL-STD-3004 for aviation turbine fuel and MIL-DTL-83133 have shown to be in agreement 92% of the time.



- Intent of the DoD is to gain push of particle counting technology down to the skin of the aircraft.
- A particle count limit of 18/16/14 for into plane samples has a high correlation to 0.5 mg/L sediment.
  - 92.6% agreement for USAF samples ranging from 0.0 – 0.5 mg/L
  - 77.8% of the time for USA samples ranging from 0.0 – 1.0 mg/L.
    - 38% of these samples not in agreement are false positives samples
    - 62% false negatives



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Questions?

