

# Important factors in characterizing particle release during 3D printing of MWCNT enabled filaments

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Gaithersburg, MD

QEEN II, October 9-10, 2018

# Acknowledgments

- James Filliben, NIST
- Mitchell Slone, NIST

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# Reason for interest in release during 3D printing

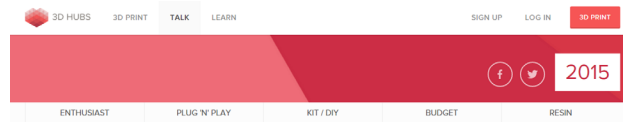
Global 3D printing market **has grown** from estimated \$3.07B in 2013 to \$7.34B in 2017 while *consumer 3D printing, a sub-segment of the global 3D printing market, is expected to grow from \$75M in 2013 to >\$500M in revenue by 2017.*

2007 – 1<sup>st</sup> 3D printing system under \$10,000

2012 – few consumer level 3D printers

2015 – 400+ consumer level 3D printers

2016-2017 – Est. 528,952 desktop 3D printers sold



Which 3D Printer should I buy? is the most common question we at 3D Hubs are asked.

We reached out to our global community of Hubs to learn from their experience and see what they thought of the 3D Printers they own. The 2015 3D Printer Guide is based on the reviews of 2,279 verified 3D Printer owners. Their collective 1623 years of 3D printing experience coupled with 317,000 prints completed on 235 different 3D Printer models, makes this the most comprehensive guide available.

Together with our community we explored the different aspects that make a great 3D Printer. We investigated the following parameters: print quality, ease-of-use, build quality, reliability.

Printers with more than 5 reviews are displayed in the Index. A big thank you to our community. Without you, the 2015 3D Printer Guide would not be possible.

THE GUIDE IS BASED ON

2,279

reviews

335

hours of writing

1,623

years of experience

317,000

3D prints made on reviewed printers

235 different 3D Printer models (accessed September 28, 2015)



Which 3D Printer should I buy? is one of the most common questions we get asked at 3D Hubs.

To answer this, we reached out to our global community of Hubs to learn from their experiences and find out more about the 3D Printers they own.

With reviews from over 5,350 verified 3D Printer owners with a collective 3962 years of 3D Printing experience coupled with 714,300 prints completed on 441 different 3D Printer models, the result of our research is the 2016 3D Printer Guide – the most comprehensive 3D printer guide available.

Together with our community, we investigated the following parameters to help measure the user experience of a range of 3D printers: print quality, ease-of-use, build quality, reliability.

THE GUIDE IS BASED ON

5,350

reviews

638

hours of writing

3,962

years of experience

714,300

3D prints made on reviewed printers

441 different 3D Printer models (accessed December 9, 2015)

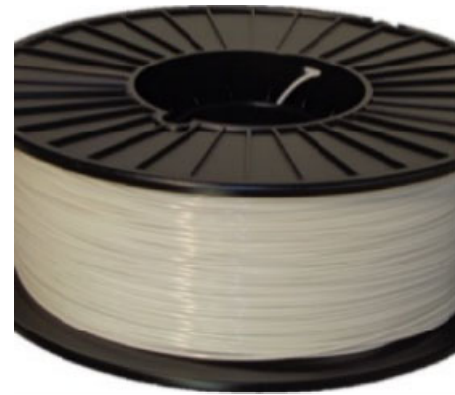
Additionally, our extensive [Printer Index](#) includes all 126 3D printers that didn't make it to the top of their categories. Only printers with five reviews or more have been added to the Index.

# 3D printing using composite filaments



MWCNT loaded ABS

VS



ABS only

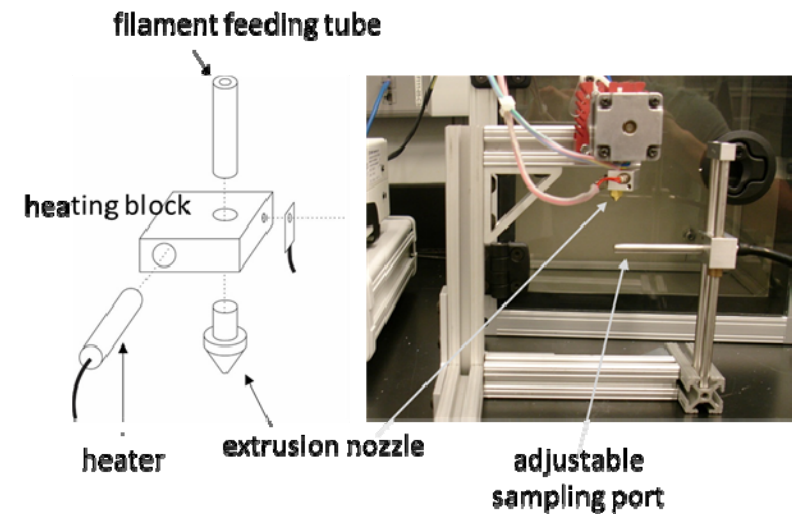
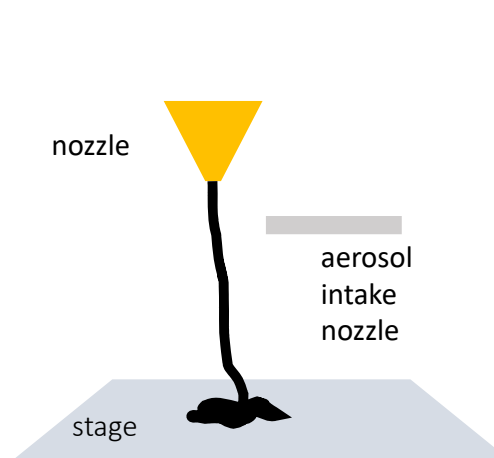
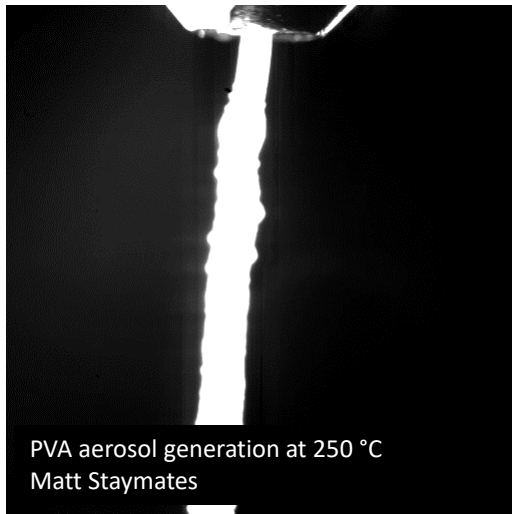
- In ABS, MWCNTs are employed largely to impart their electrical properties
- In-house testing revealed  $\approx 5\%$  by mass MWCNT loading
- Prints under comparable conditions to pristine ABS feedstock

# Research questions

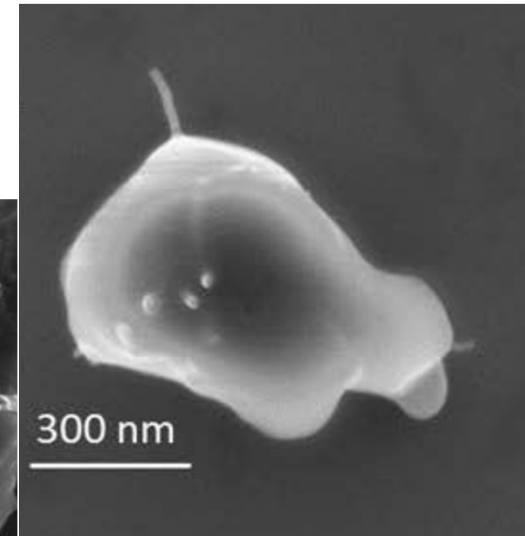
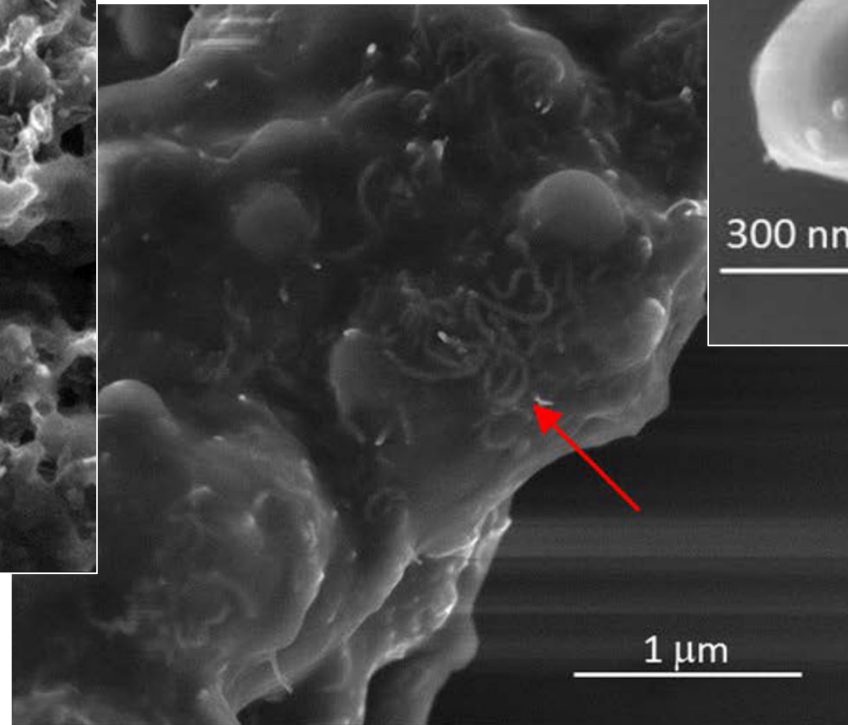
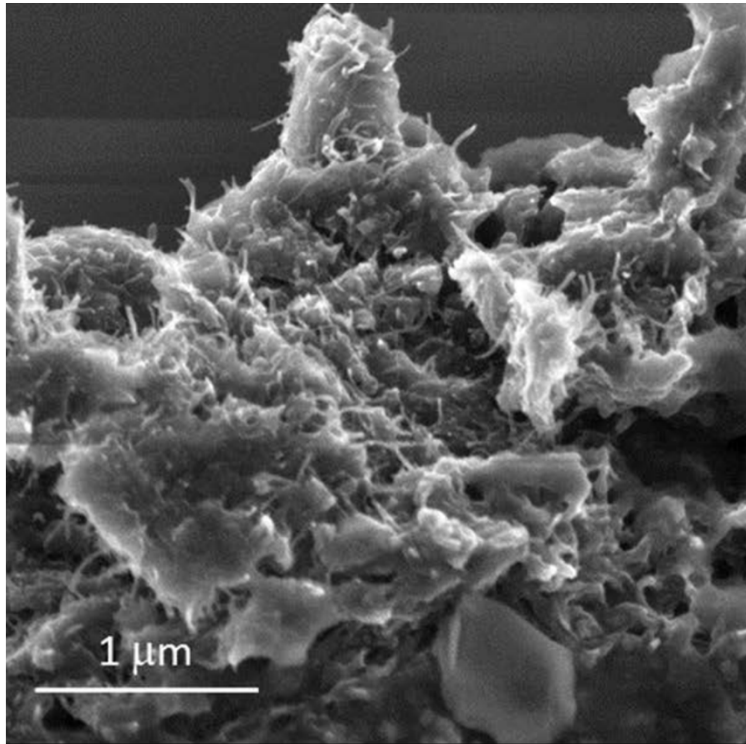
- Are particles being released from 3D printing with MWCNT-ABS filaments?
  - Are released particles of a respirable size fraction?
- Can we detect MWCNT release during 3D printing with MWCNT-ABS filaments?
  - If so, how are they released? (bound in polymer vs. free)
- What are the important factors related to particle release?
  - Distance from extruder
  - Filament storage
  - Extruder temperature

# Model system

- Aerosol measurement from 3D printing process
  - Filaments with and without MWCNTs
  - Model system to examine aerosol generation as a function of temperature and intake parameters such as a nozzle location, velocity, size, etc.
  - Analyze released material with SEM



# Observations from the model system



# Fractional factorial experimental design

Factor	Level	Value
X1: Printer Model	1	Model 1
	2	Model 2
X2: MWCNT Concentration	1	Neat
	2	MWCNT containing
X3: Sampling Distance	1	Near
	2	Far
X4: Printing Temperature	1	Low
	2	High
X5: Filament Storage Humidity	1	Dry box
	2	Lab humidity

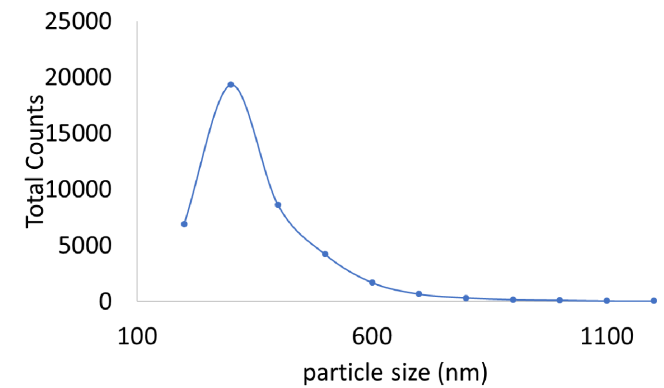
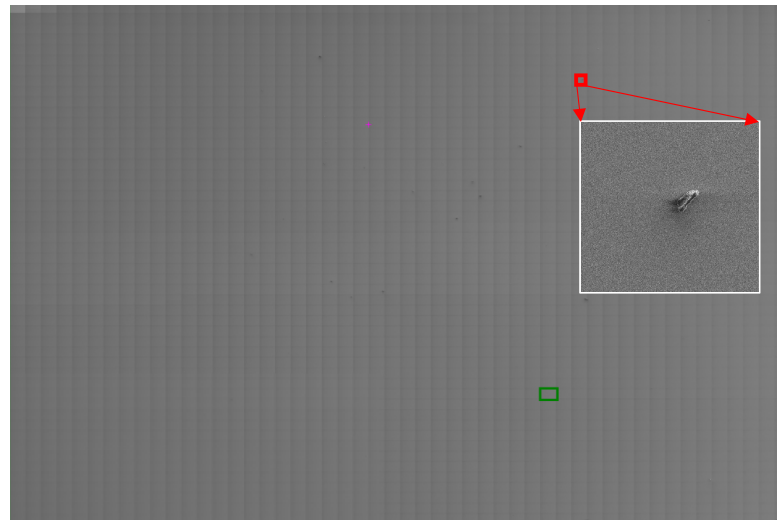
- Two-part SEM analysis
  - Evaluation of respirable fraction using low resolution automated protocol
  - Evaluation of free-MWCNT release by limited sampling



# Important experimental considerations

- Choice of printed object:
  - Should take sufficient time to print
  - Should not cause too much movement to impact sampling air flow
- Sampling nozzle placement
  - Mounted on printing nozzle to reduce distance variation
- Institute between run cleaning procedure and allow sufficient time for the testing chamber condition to settle
- Focus on detecting particles in the respirable size range

# Evaluation of respirable fraction



- SEM analysis of a 50 image x 50 image (12 mm x 18 mm) area
- Particles were counted and evaluated for size (equivalent spherical diameter)
- Size distributions and counts were compared based on different factors.

# Summary from 3D printing study

- **Proximity to the extruder has the greatest effect on the total particle counts.**
- Neat ABS filament produced more particles of respirable size than MWCNT ABS filament during 3D printing.
- Sampled particles using MWCNT ABS filament printing contained MWCNTs.
- High resolution imaging necessary to detect individual MWCNTs was prohibitively resource intensive.
- Additional replicates necessary for better statistics
- Quantitative analysis of MWCNT release requires understanding of total material release, total sampling volume, and sampling efficiency.
- ***We do not have the sampling efficiency number (Focus of future studies)***