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

Justin M Gorham
Keana C. K. Scott, Sam Norris

National Institute of Standards and Technology
Gaithersburg, MD

QEEN II, October 9-10, 2018

Acknowledgments

- James Filliben, NIST
- Mitchell Slone, NIST

NIST Disclaimer

Certain commercial equipment, instruments, or materials are identified in this talk to foster understanding. Such identification does not imply recommendation or endorsement by NIST, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

CPSC Disclaimer

This project was funded by the U.S. Consumer Product Safety Commission (CPSC). The content of this publication has not been reviewed or approved by and does not necessarily reflect the views of the Commission, nor does mention of trade names, commercial products, or organizations imply endorsement by the Commission

Reason for interest in release during 3D printing

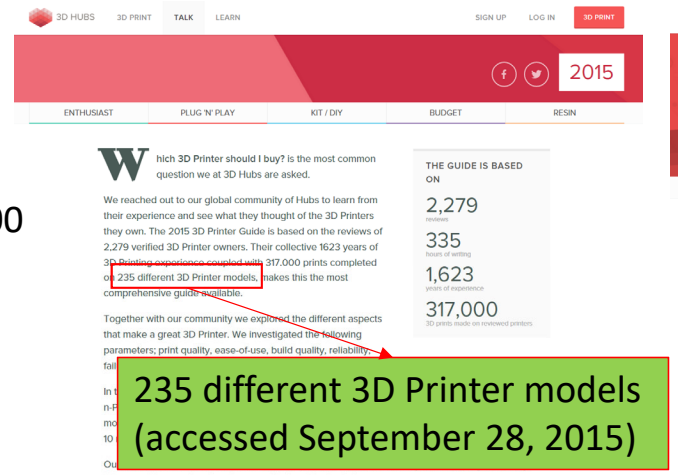
Global 3D printing market has grown from estimated $3.07B in 2013 to $7.34B in 2017 while *consumer 3D printing, a sub-segment of the global 3D printing market, is expected to grow from $75M in 2013 to >$500M in revenue by 2017.*

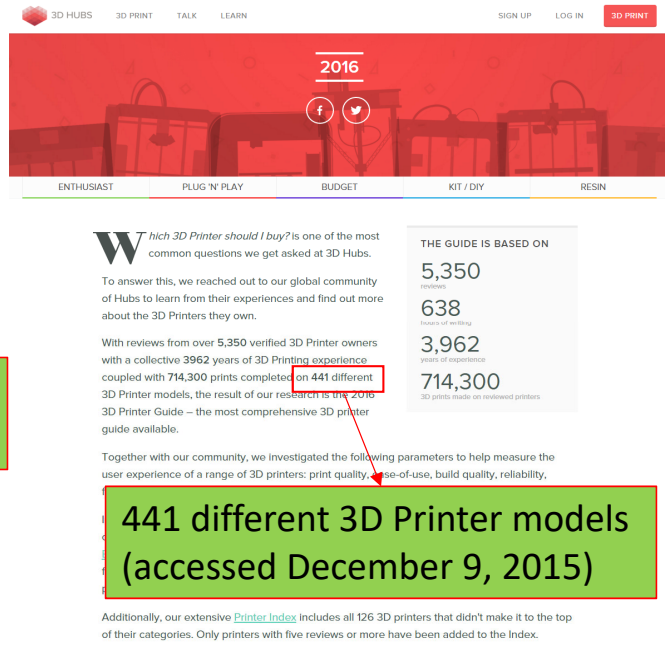
2007 – 1st 3D printing system under $10,000

2012 – few consumer level 3D printers

2015 – 400+ consumer level 3D printers

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

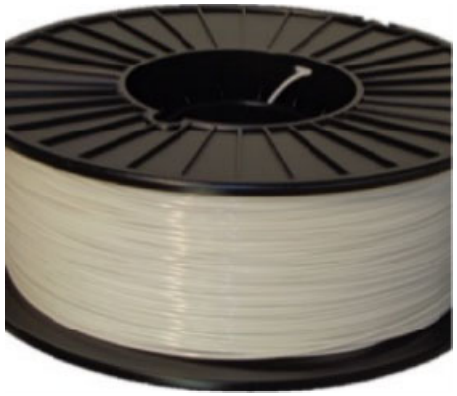




3D printing using composite filaments

MWCNT loaded ABS

VS



ABS only

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

Research questions

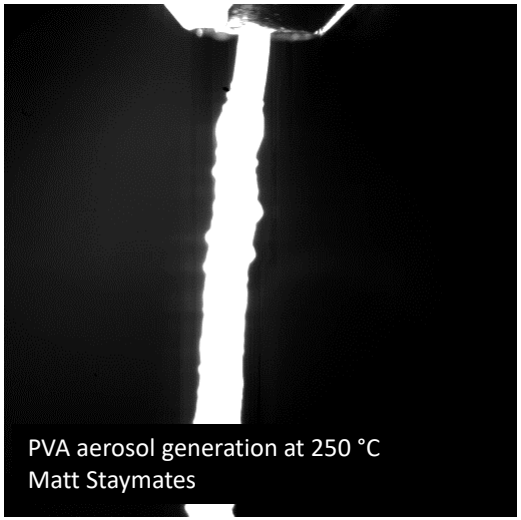
- Are particles being released from 3D printing with MWCNT-ABS filaments?
  - Are released particles of a respirable size fraction?

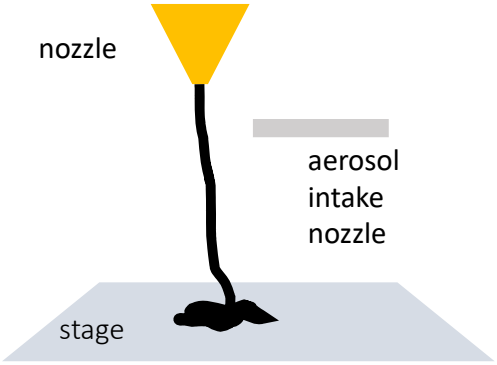
- Can we detect MWCNT release during 3D printing with MWCNT-ABS filaments?
  - If so, how are they released? (bound in polymer vs. free)

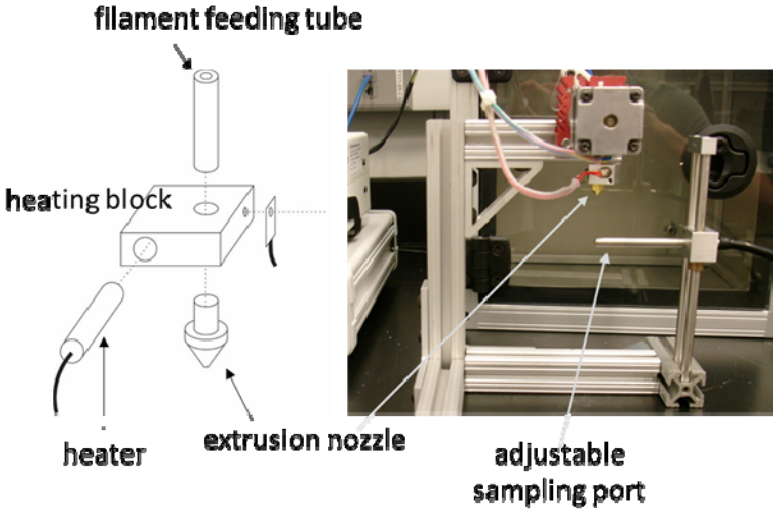
- What are the important factors related to particle release?
  - Distance from extruder
  - Filament storage
  - Extruder temperature

Model system

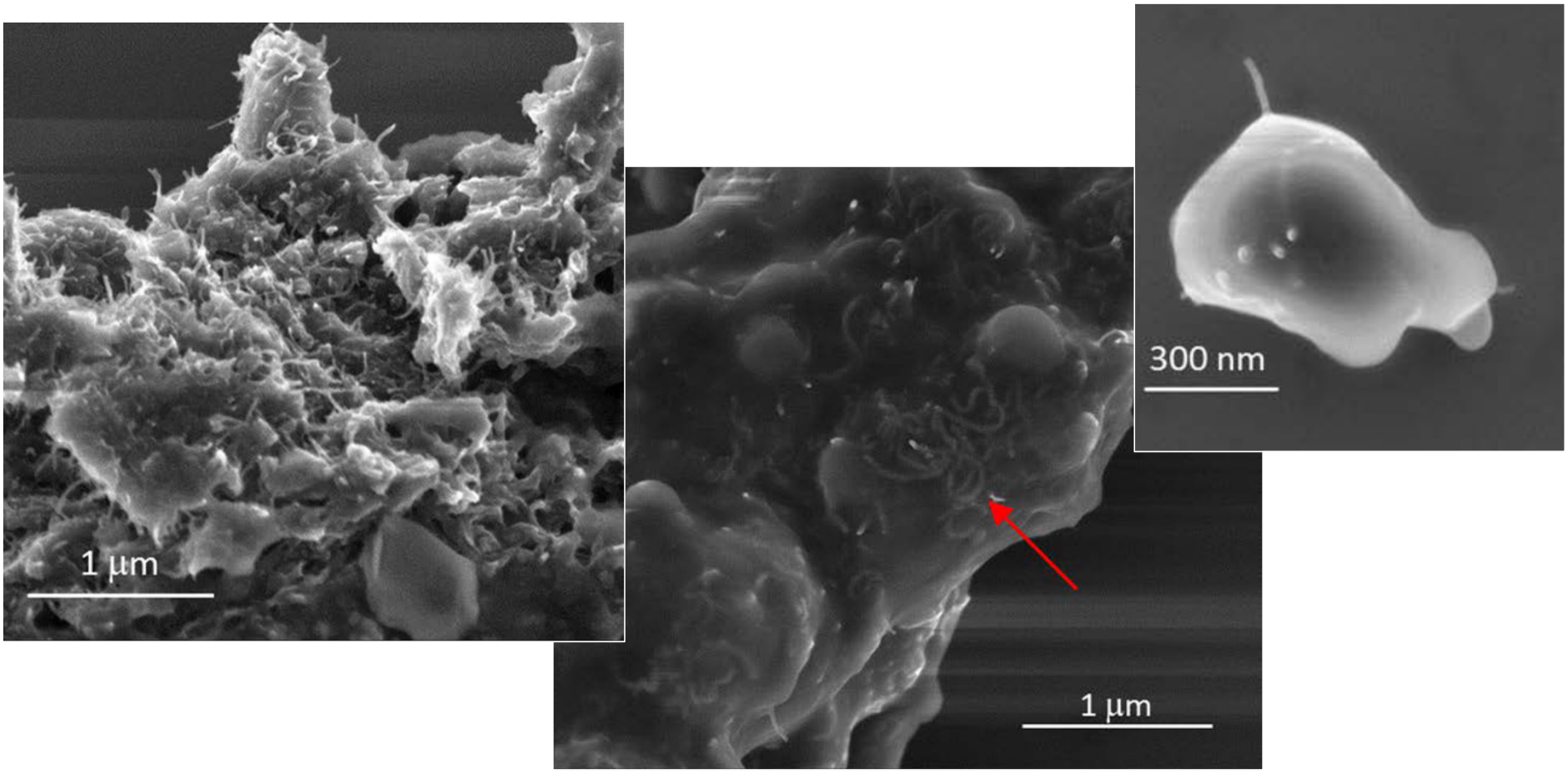
- Aerosol measurement from 3D printing process
  - Filaments with and without MWCNTs
  - Model system to examine aerosol generation as a function of temperature and intake parameters such as a nozzle location, velocity, size, etc.
  - Analyze released material with SEM


PVA aerosol generation at 250 °C
Matt Staymates





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

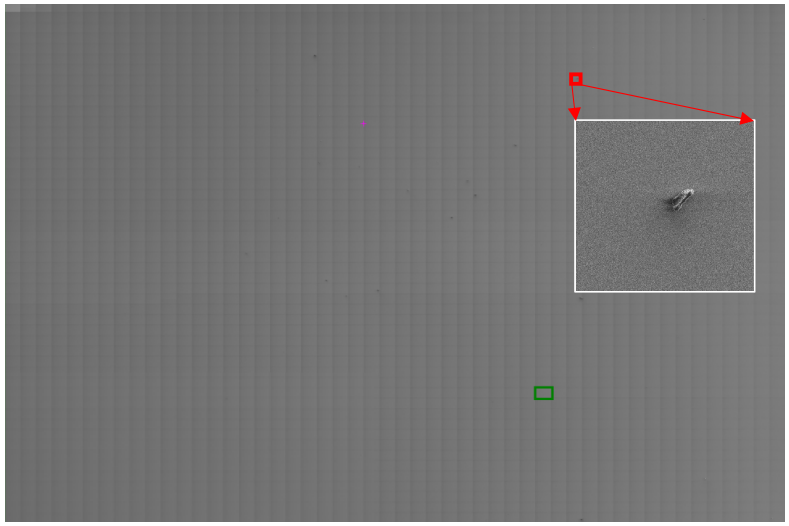
- Two-part SEM analysis
  - Evaluation of respirable fraction using low resolution automated protocol
  - Evaluation of free-MWCNT release by limited sampling

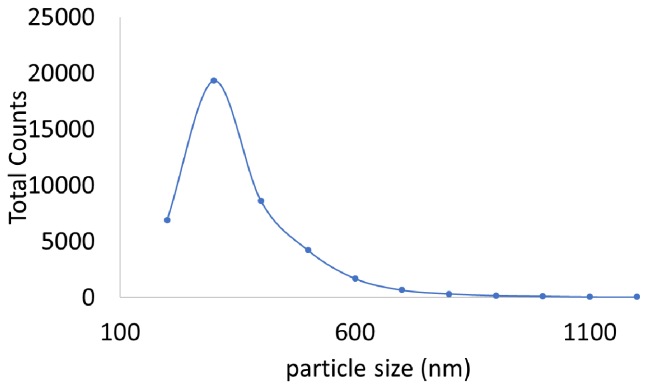
Important experimental considerations

- 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)***