



Putting Confidence in
Ultrasound



Characterization of Acoustic Cavitation from a Megasonic Nozzle Transducer for Photomask Cleaning

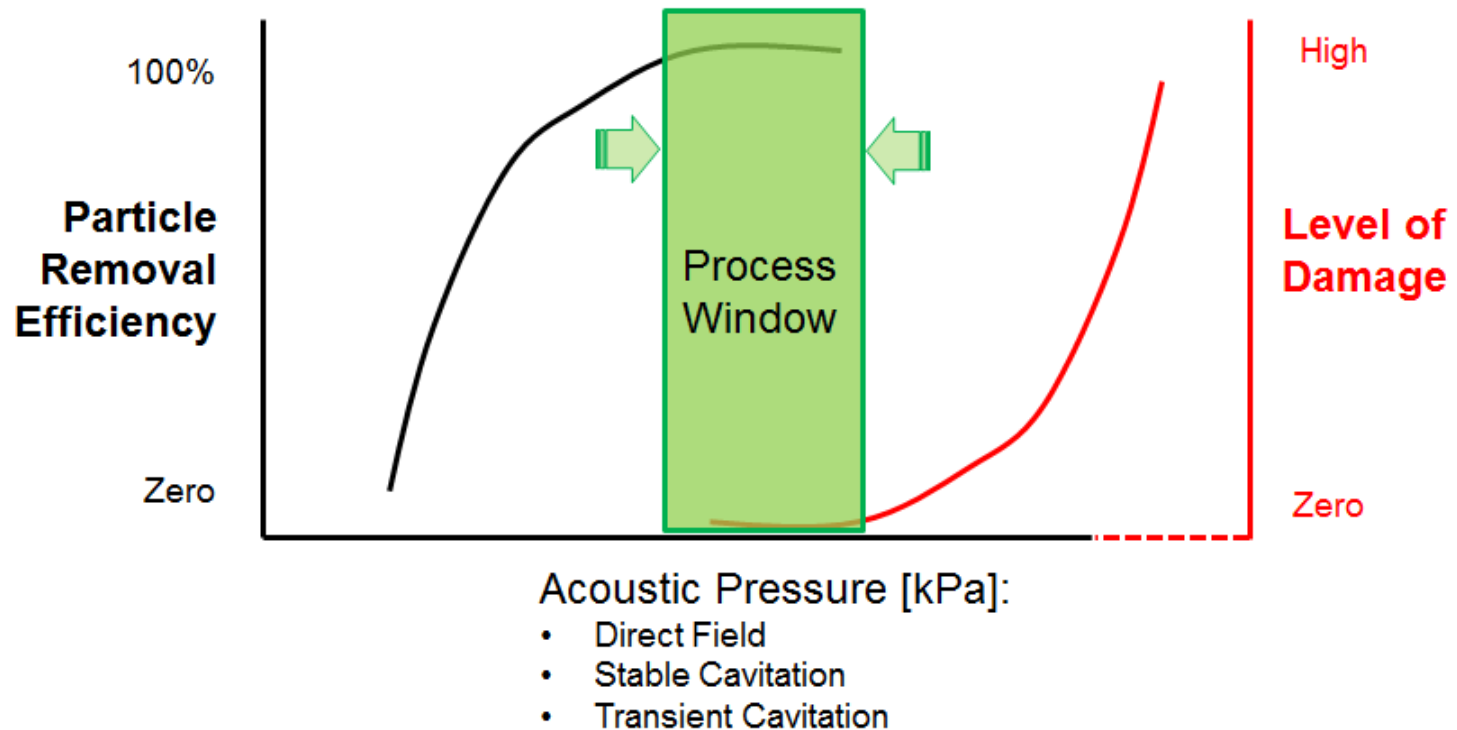
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SPIE BACUS 2017 – Monterey, CA

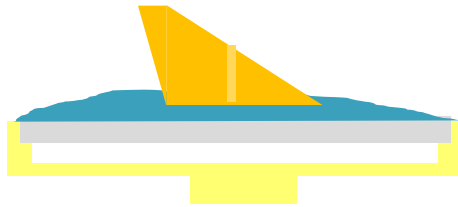
September 14, 2017

Mask Cleaning Trend: *Tighter Process Window*

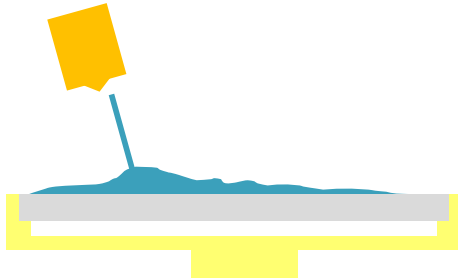


- Continued use of megasonics in 193i and EUV
- Shrinking feature dimensions and more complex patterns
- **Tighter process window !**

Photomask Cleaning Challenges



Skirt-Type
Transducer



Nozzle-Type
Transducer



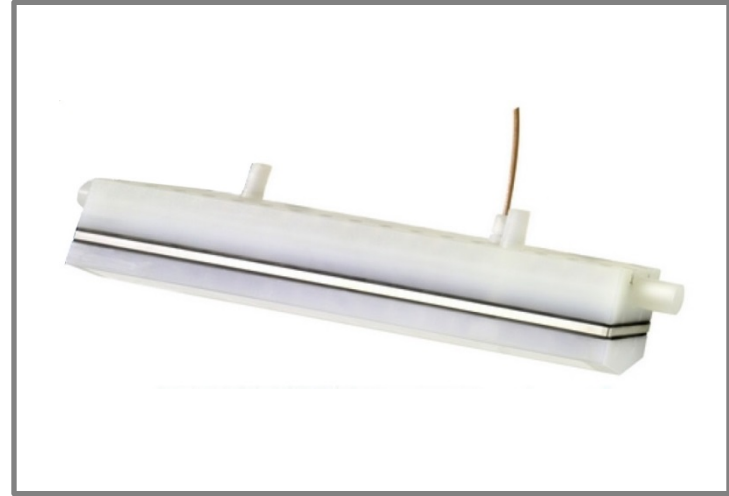
Plate-Type
Transducer

Dynamic Process:

- Transducer position
- *Acoustic uniformity*
- *Acoustic cavitation*
- Reflections
- *Flow rate*
- Water level
- Gas concentration
- Moving mask & transducer
- Temperature
- Chemistry
- *Frequency*
- *Generator power*
- Substrate material
- Process time
- And more...

Need *in-situ* measurement solution
to correlate with cleaning

Examples of Photomask Transducers

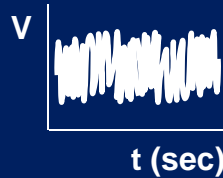


Quantification of Cavitation Pressure

Acquire data with Hydrophone



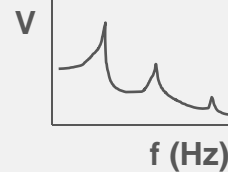
Voltage vs Time



Fourier Transform



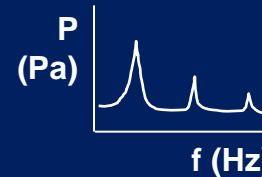
Voltage vs Frequency



Apply Hydrophone Calibration



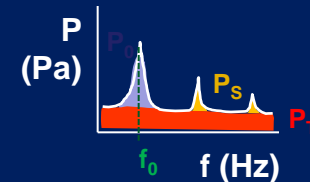
Pressure vs Frequency



Apply MCT-2000 Algorithms



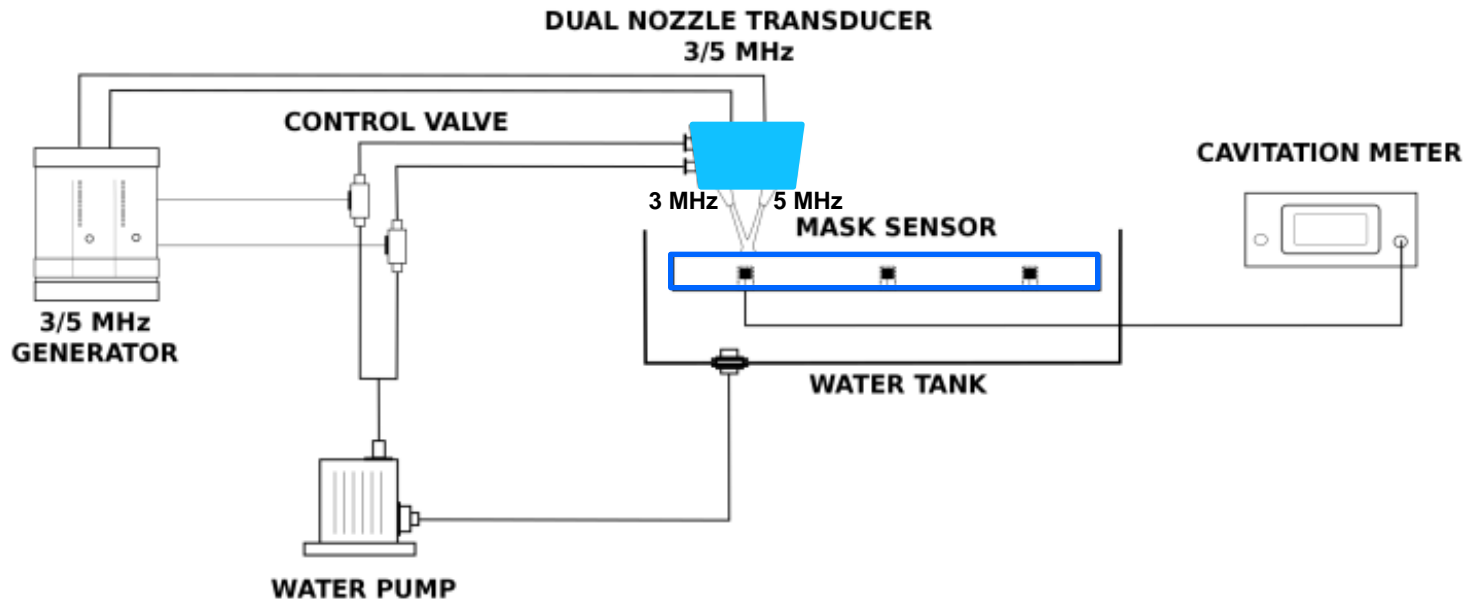
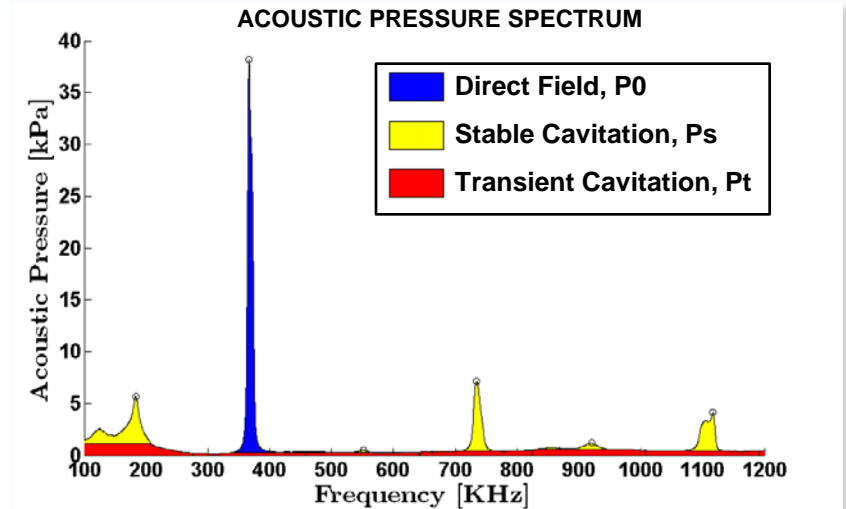
Calculation of P_0 , P_S , P_T , f_0



MCT-2000 Measures:

- V vs. t
- P vs. f
- P_0 , P_S , P_T , f_0

Cavitation Meter with Mask Sensor



Acoustic Test Plan

1. Gage Repeatability and Reproducibility (11 repeats)
2. Cavitation Pressure vs Frequency (3, 5, 3+5 MHz)
3. Cavitation Pressure vs Generator Power (10-100%, 35 W)
4. Cavitation Pressure vs Nozzle Distance (5-20 mm)
5. Cavitation Pressure vs Flow Rate (1-1.6 L/min)
6. Cavitation Pressure vs Sensor Position (A, B, C)

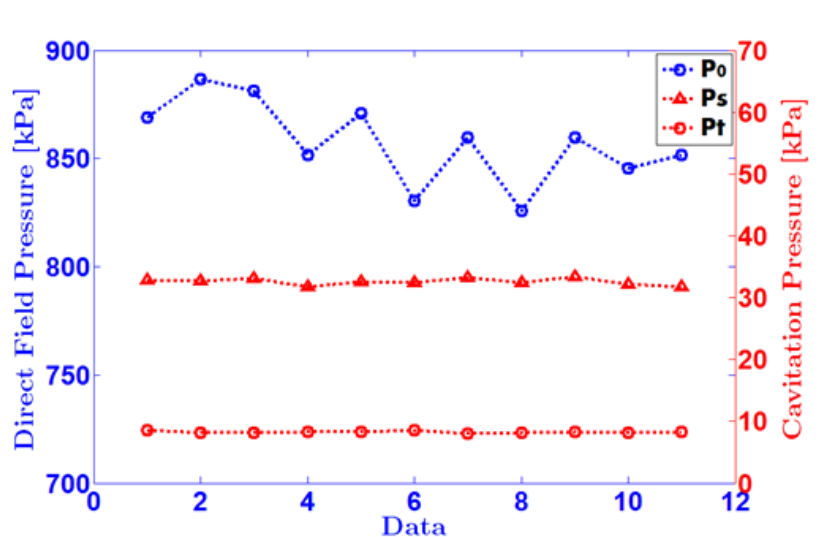
Gage R&R

Test Conditions:

- 3 MHz (50%), 5 MHz (50%)
- Nozzle Distance: 20 mm
- Medium: DIW
- Flow rate: 1.6 L/min

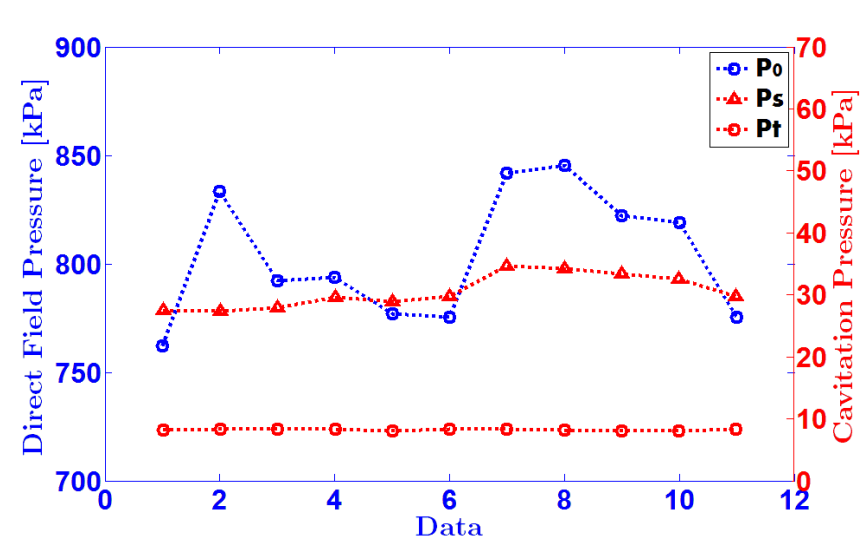
Static Repeatability (11X)

- Without Load/Unload of Mask Sensor



Reproducibility (11X)

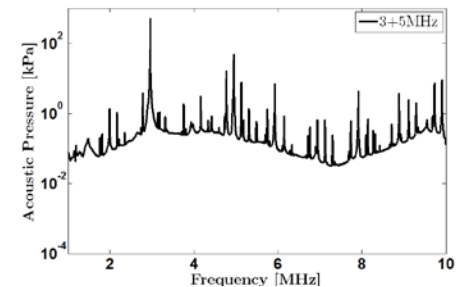
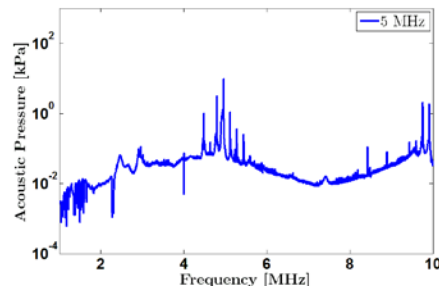
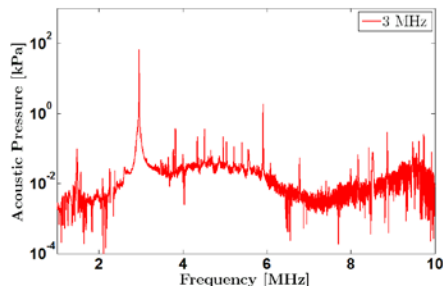
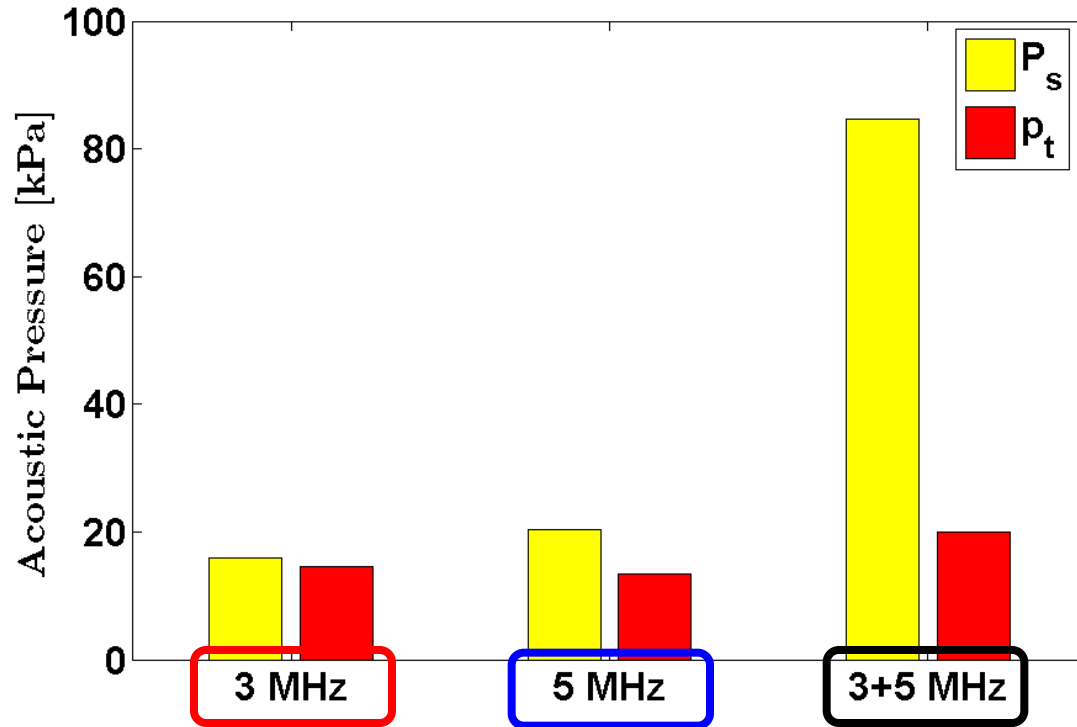
- With Load/Unload of Mask Sensor



	Static Repeatability (% Std Dev)	Reproducibility (% Std Dev)
P0	2.2	3.7
Ps	1.6	9.4
Pt	1.9	1.4

Cavitation vs. Frequency

- Test Conditions:**
- 3 MHz (50%), 5 MHz (50%)
 - Nozzle Distance: 20 mm
 - Medium: DIW
 - Flow rate: 1.6 L/min

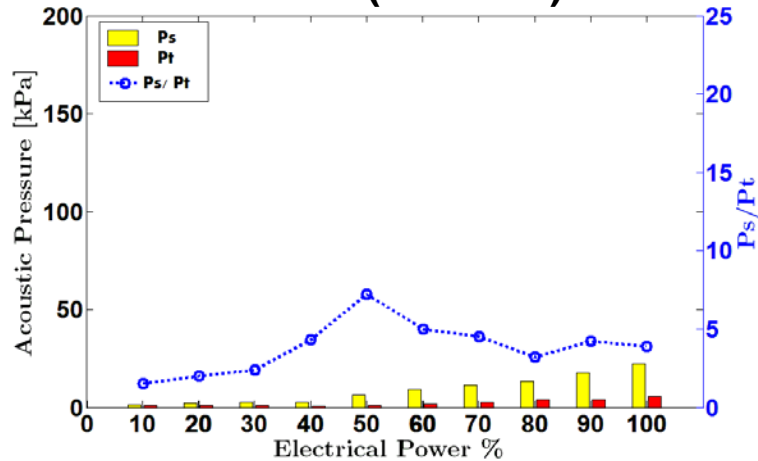


Cavitation vs. Generator Power

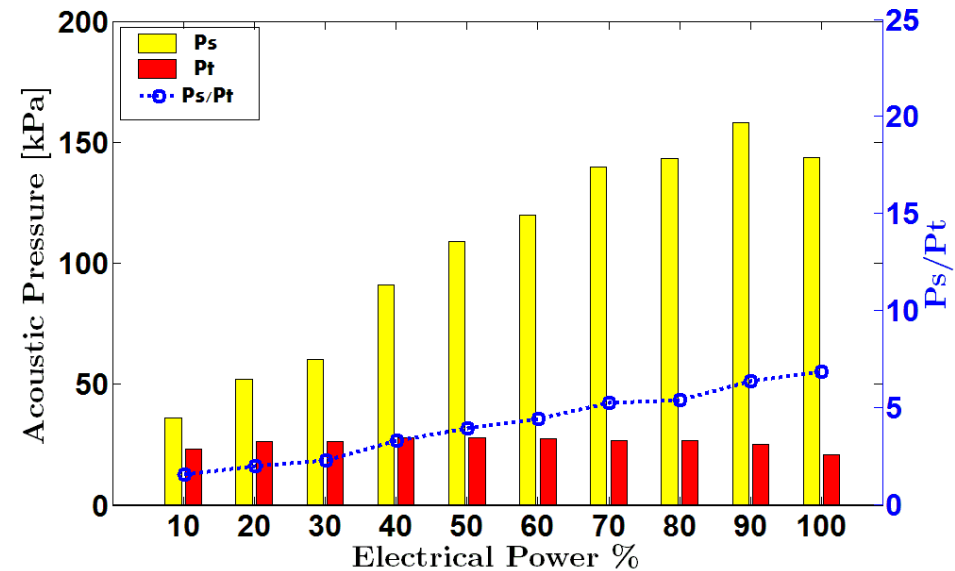
Test Conditions:

- Nozzle Distance: 20 mm
- Medium: DIW
- Flow rate: 1.6 L/min

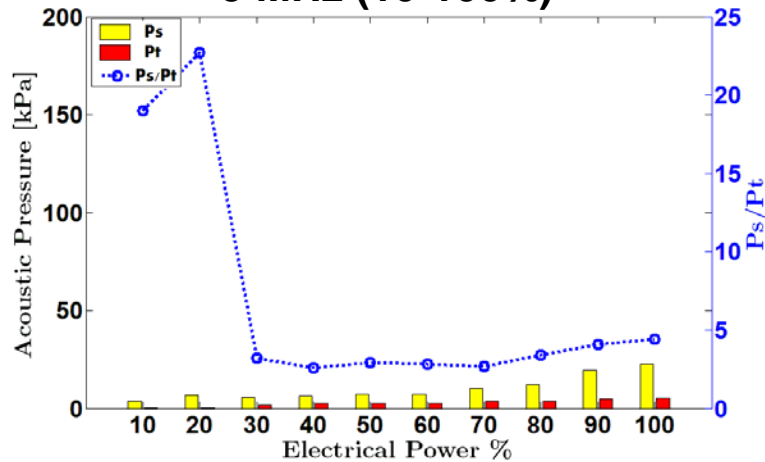
3 MHz (10-100%)



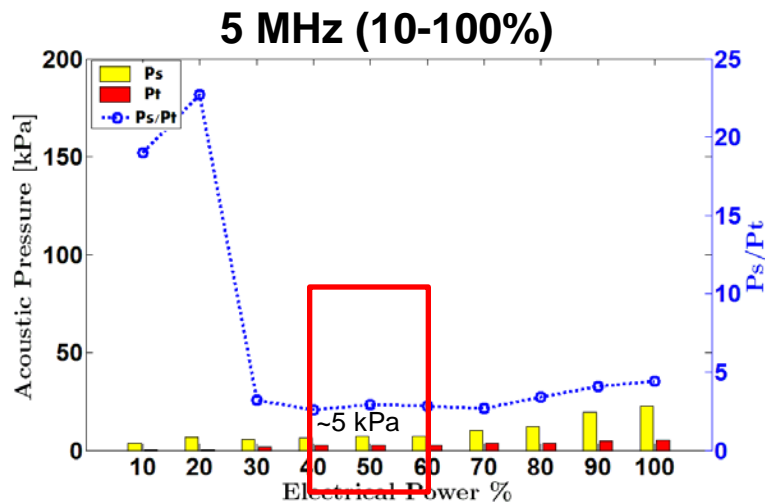
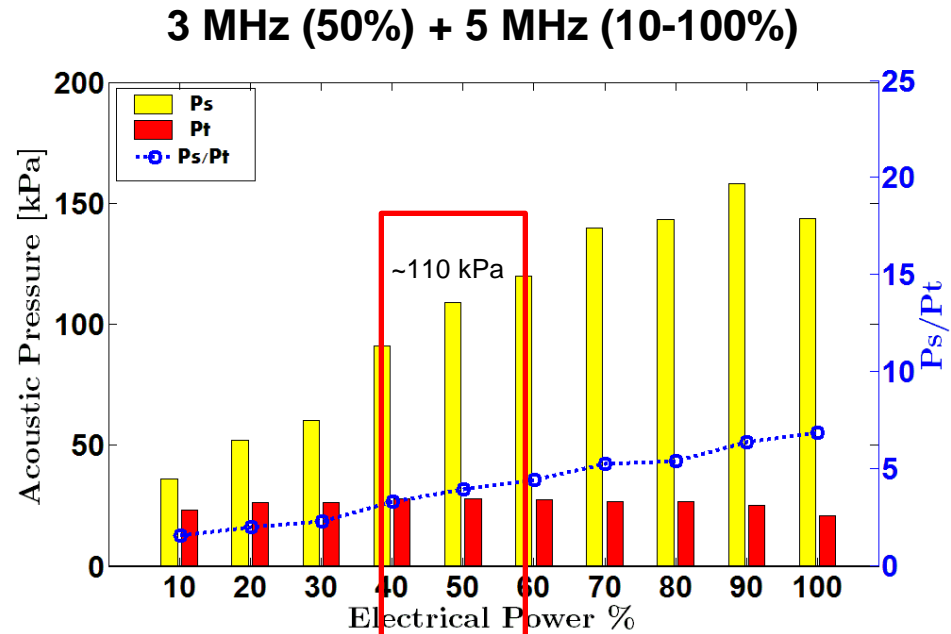
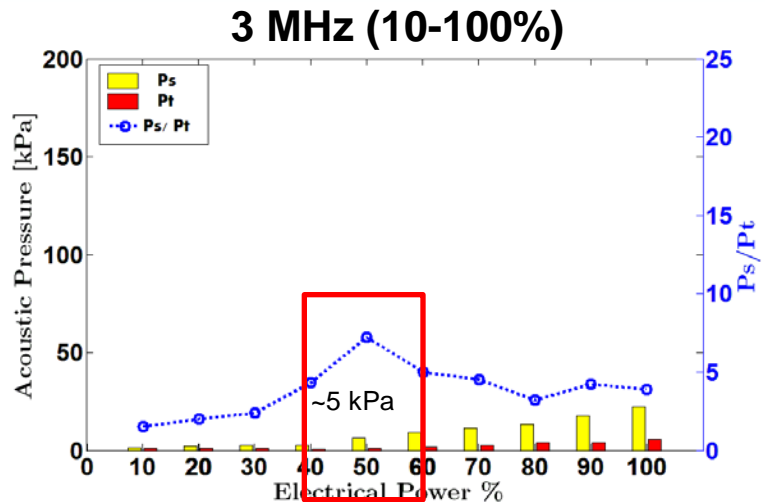
3 MHz (50%) + 5 MHz (10-100%)



5 MHz (10-100%)



Cavitation vs. Generator Power

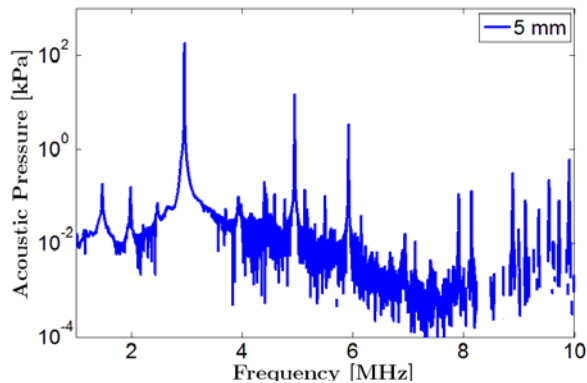
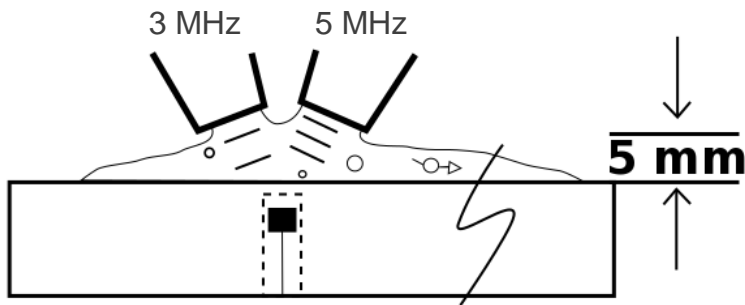


5 + 5 ≠ 110!

Cavitation vs. Nozzle Distance

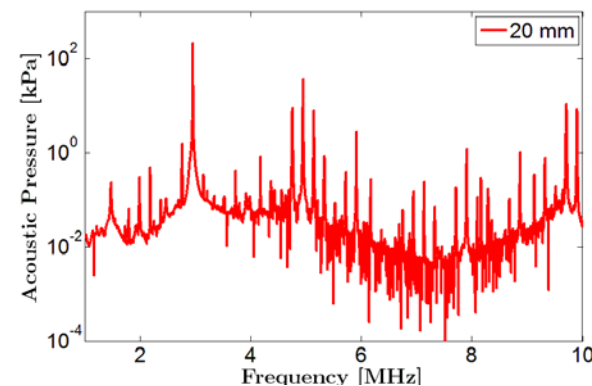
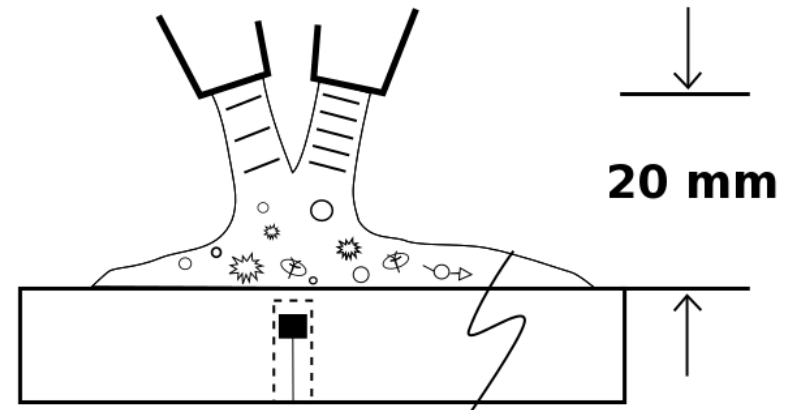
At 5 mm:

Lower presence of static bubbles which yields less stable cavitation



At 20 mm:

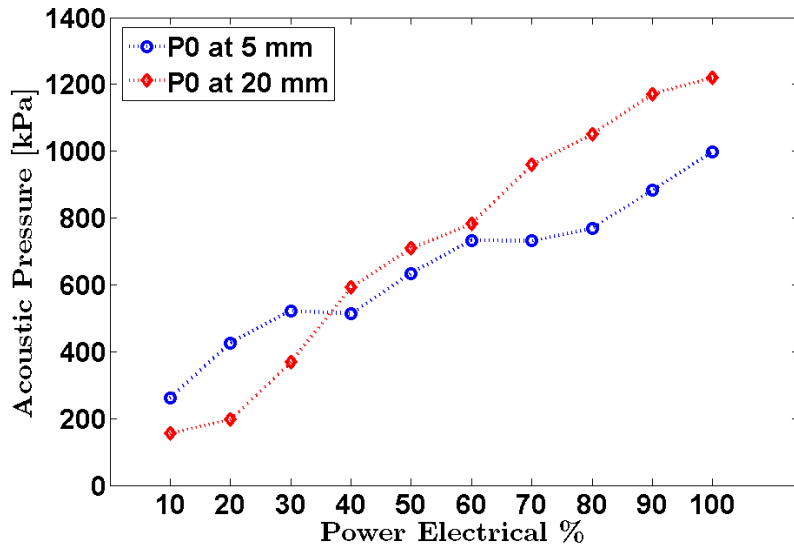
More static bubbles which promote generation of stable cavitation.



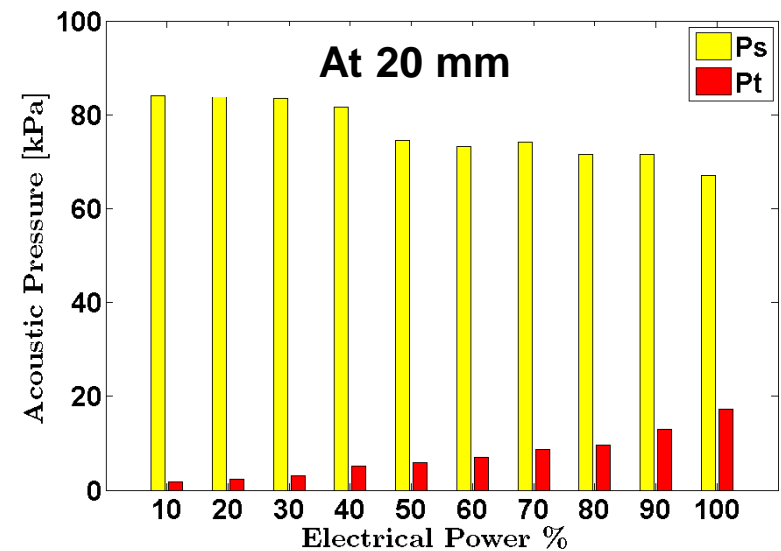
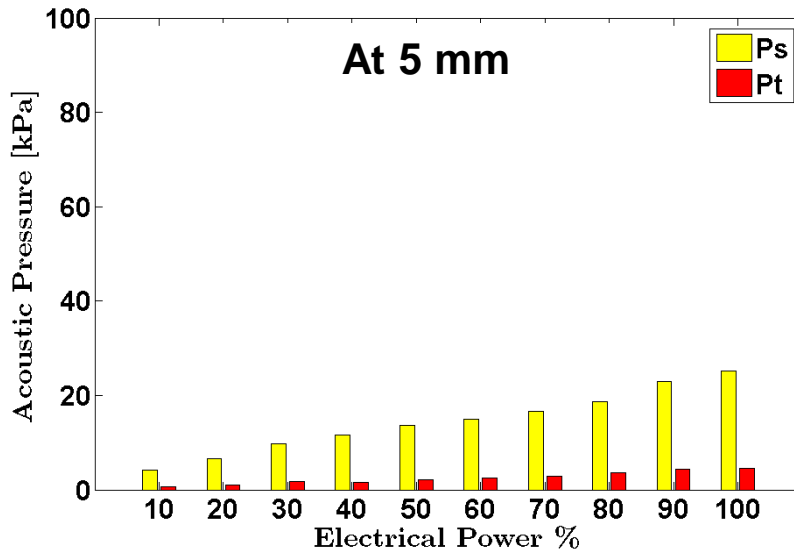
Cavitation vs. Nozzle Distance

Test Conditions:

- 3 MHz (10-100%), 5 MHz (50%)
- Nozzle Distance: 5, 20 mm
- Medium: DIW
- Flow rate: 1.6 L/min



At 20 mm, Ps/Pt is maximized at low power.



Cavitation vs. Flow Rate

Low Flow (1.0 L/min):

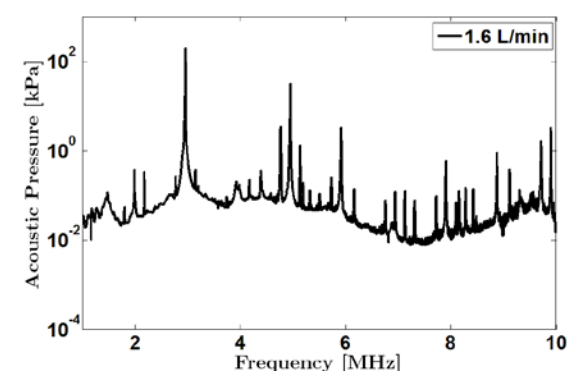
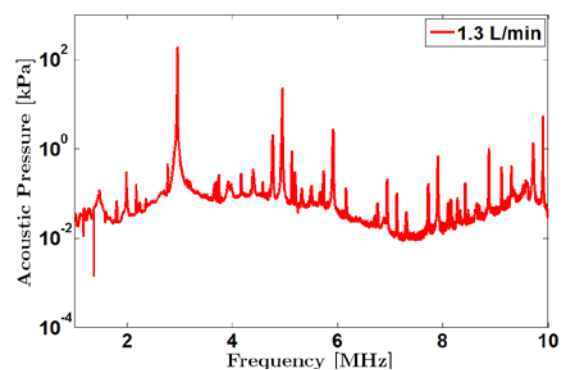
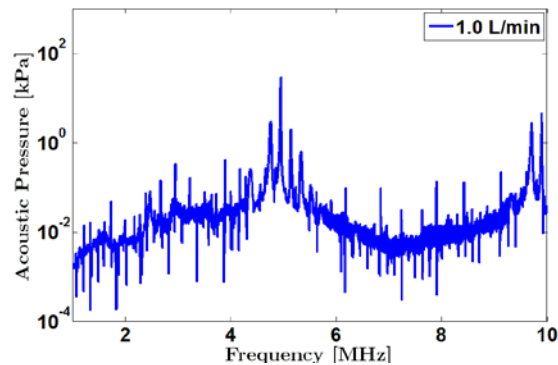
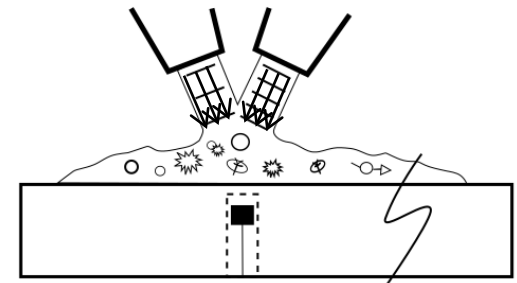
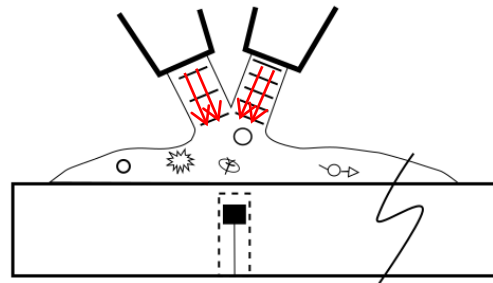
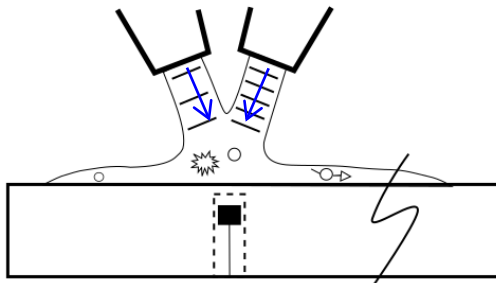
Generation of static bubbles from liquid flow

Medium Flow (1.3 L/min):

Generation of higher level of static bubbles with increasing flow rate

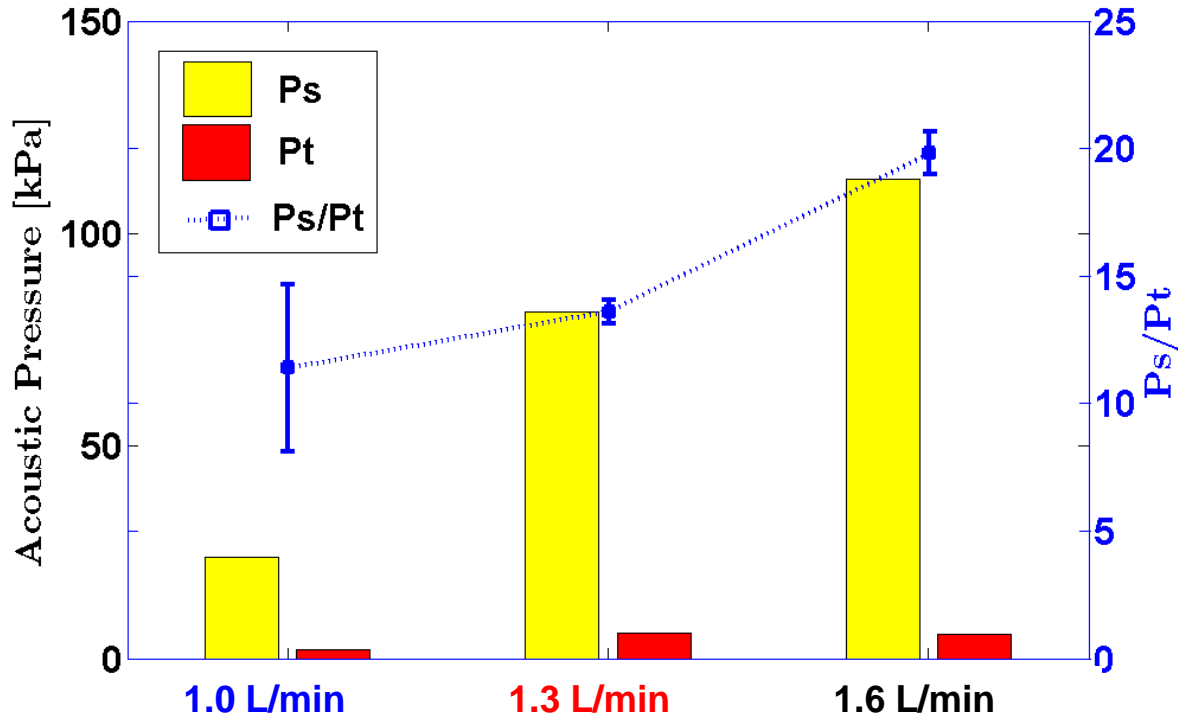
High Flow (1.6 L/min):

Static bubbles assist the generation of acoustic cavitation from direct field pressure



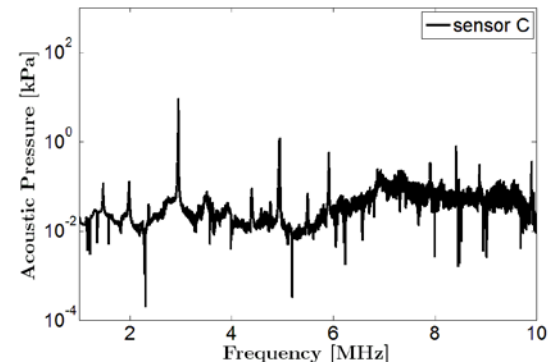
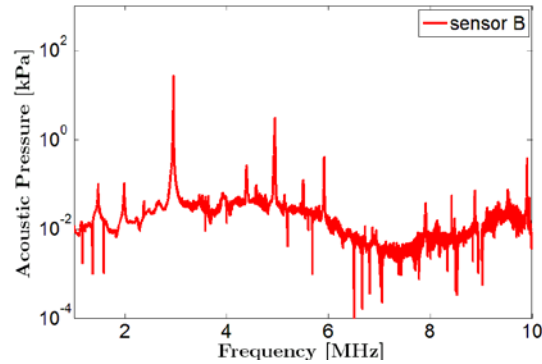
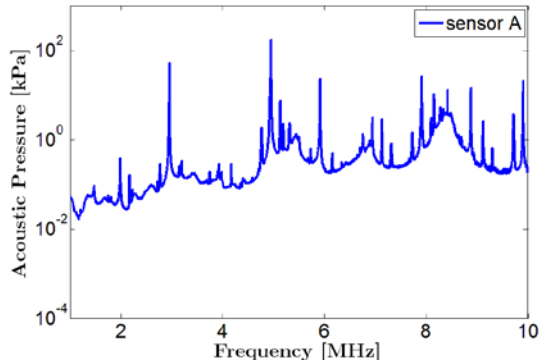
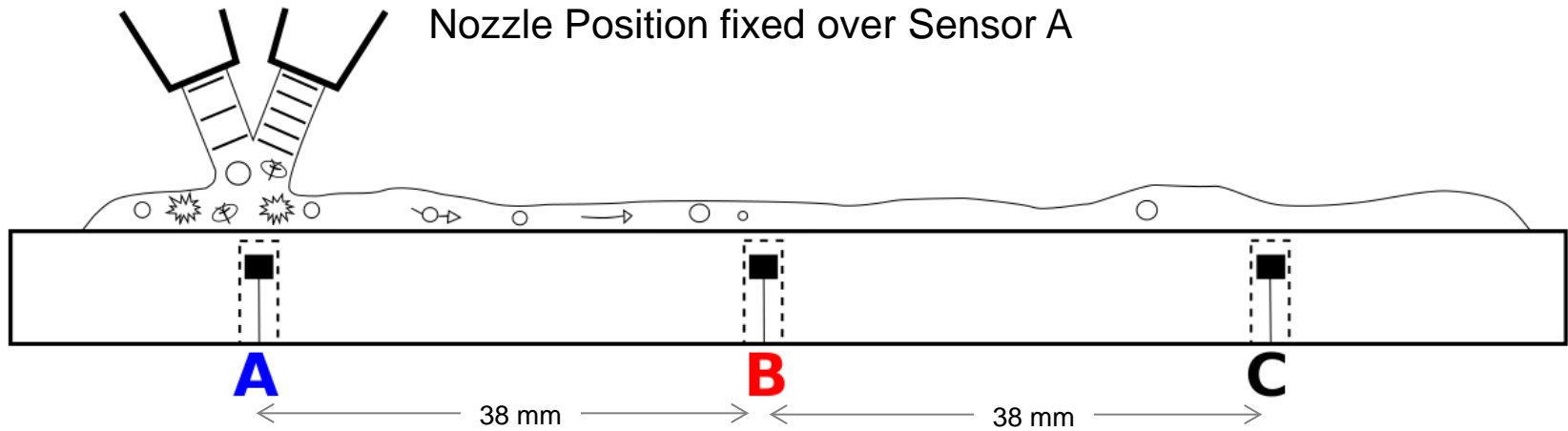
Cavitation vs. Flow Rate

- Test Conditions:**
- 3 MHz (10-100%), 5 MHz (50%)
 - Nozzle Distance: 5, 20 mm
 - Medium: DIW
 - Flow rate: 1.0, 1.3, 1.6 L/min

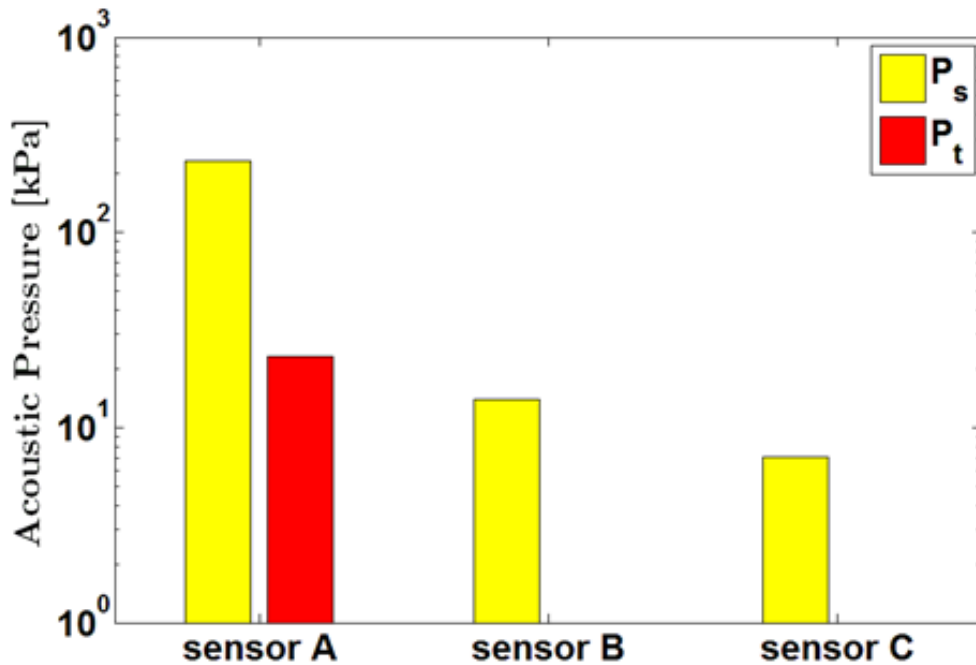
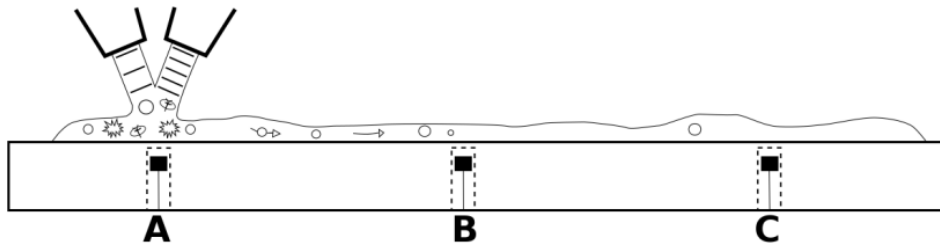


Higher flow rates yield higher levels of static cavitation relative to transient cavitation

Cavitation vs. Sensor Location



Cavitation vs. Sensor Location



At sensor B:

- P_s reduced more than 10X
- P_t is negligible

At sensor C:

- Modest level of P_s detected
- P_t is negligible

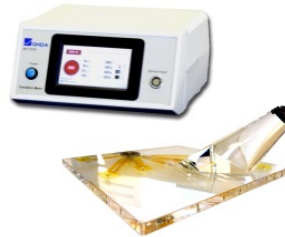
Conclusions

- The *in-situ* mask sensor enables one to define cavitation limits that correlate to PRE and pattern damage
- Differentiating between stable and transient cavitation is integral to control this process window.
- This solution allows measurement of cavitation as a function of:
 - Drive frequencies
 - Electrical power
 - Nozzle distance
 - Flow rate
 - Acoustic pressure distribution
- Future work: acoustically characterize variables such as gas concentration, chemistries, temperature and complex patterns, and understand their **correlation to cleaning and damage**.

Thank you

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