PLAYING WITH FIRE

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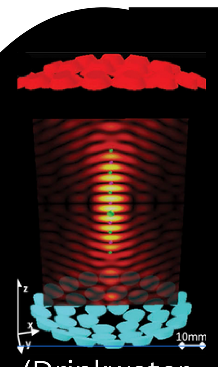
OBJECTIVES

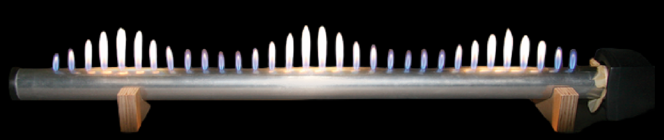
Build and test a focused ultrasound array and control algorithm for control of flames .

BACKGROUND

TinyLev, developed by the University of Bristol, is a single axis acoustic levitator and forms a basis for this project.


(Drinkwater, Barnes, and Marzo, 2017)

Acoustic waves impact flame formation as shown in experiments such as Ruben's Tube.


(https://www.flinnsci.com/sonic-flame-tube---demonstration-kit/ap7363/)

APPLICATIONS FOR FLAME CONTROL

Precise experimentation - Precision heating of specific regions of sample.

Increased thermodynamic efficiency - Enable the development of more precise, more efficient, thermodynamic machines.

Visual effects - Manipulate flames to create stunning visual displays .

ALGORITHMS

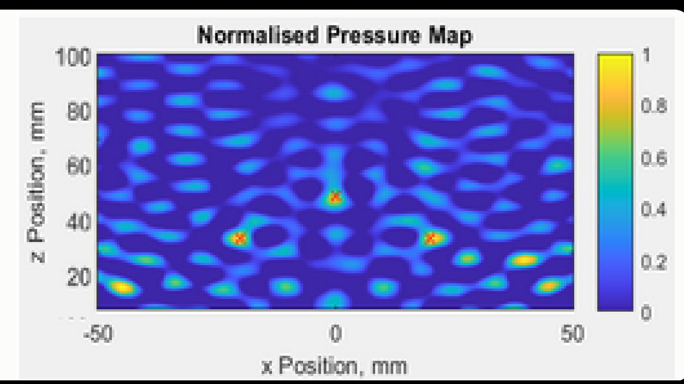
$$P(x,y,z) = \sum_{transducers} \frac{P_0 V D_f(\theta)}{d} e^{i(\phi+kd)},$$

$$D_f = sinc(kasin(\theta)).$$

Pressure field equation (Drinkwater, Barnes, and Marzo, 2017)

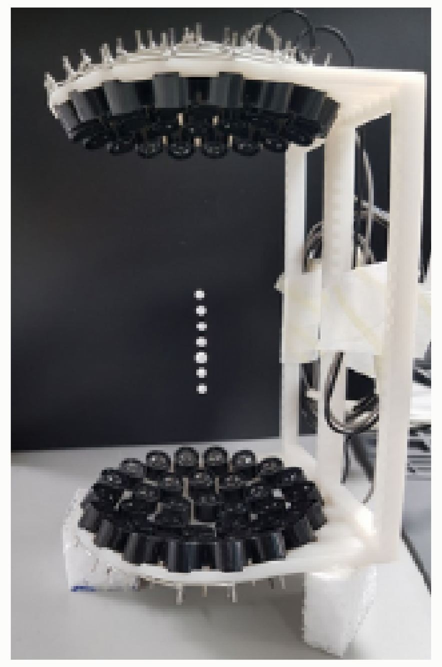
Simulation software was produced using MATLAB; takes any transducer specification and generates the pressure field mapping, in any plane specified, and force graphs (horizontal and vertical), along any axis specified. The simulations were used to test the above array geometry design proposals and to analyse experimental results.

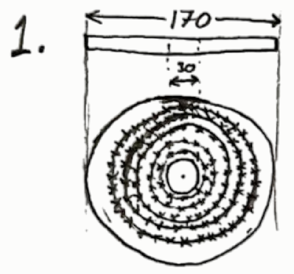
Optimisation algorithm took the desired antinode placement location, and optimised the transducer phases and voltages. Gradient ascent with a cost function that balanced the peak antinode pressure as well as the difference between all the antinode pressures was used.



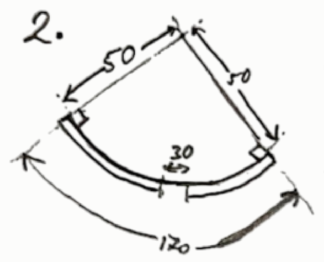
Simulated P map for array (5) with target antinodes marked by red crosses

DESIGN PROGRESSION

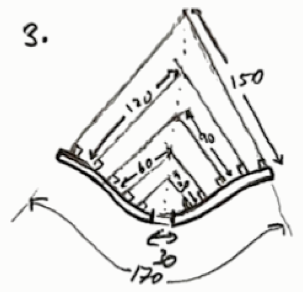

TinyLev array, built for some initial testing
+ Good resolution, produced large forces
- Could only produce one, simple pressure field, too small to be safely used with fire



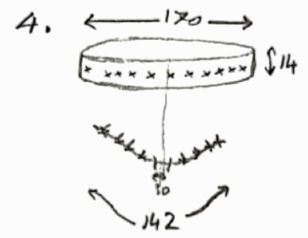
Concentric rings of transducers on a planar disk
+ Simple to manufacture
- Small peak pressure, terrible vertical resolution



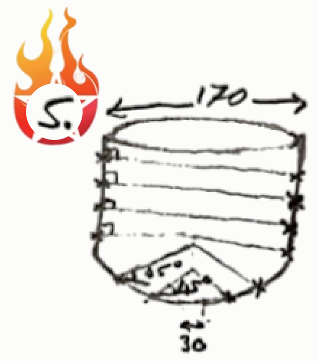
Concentric rings on a sperical cap
+ Better resolutions than (1), high peak pressure
- Bad horizontal and vertical range



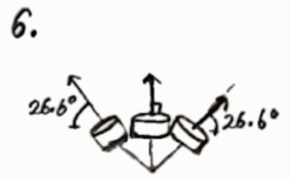
Concentric rings on a spherical surface with increasing radius
+ Better resolution, slightly better vertical range
- More residuals (unwanted high pressure regions)



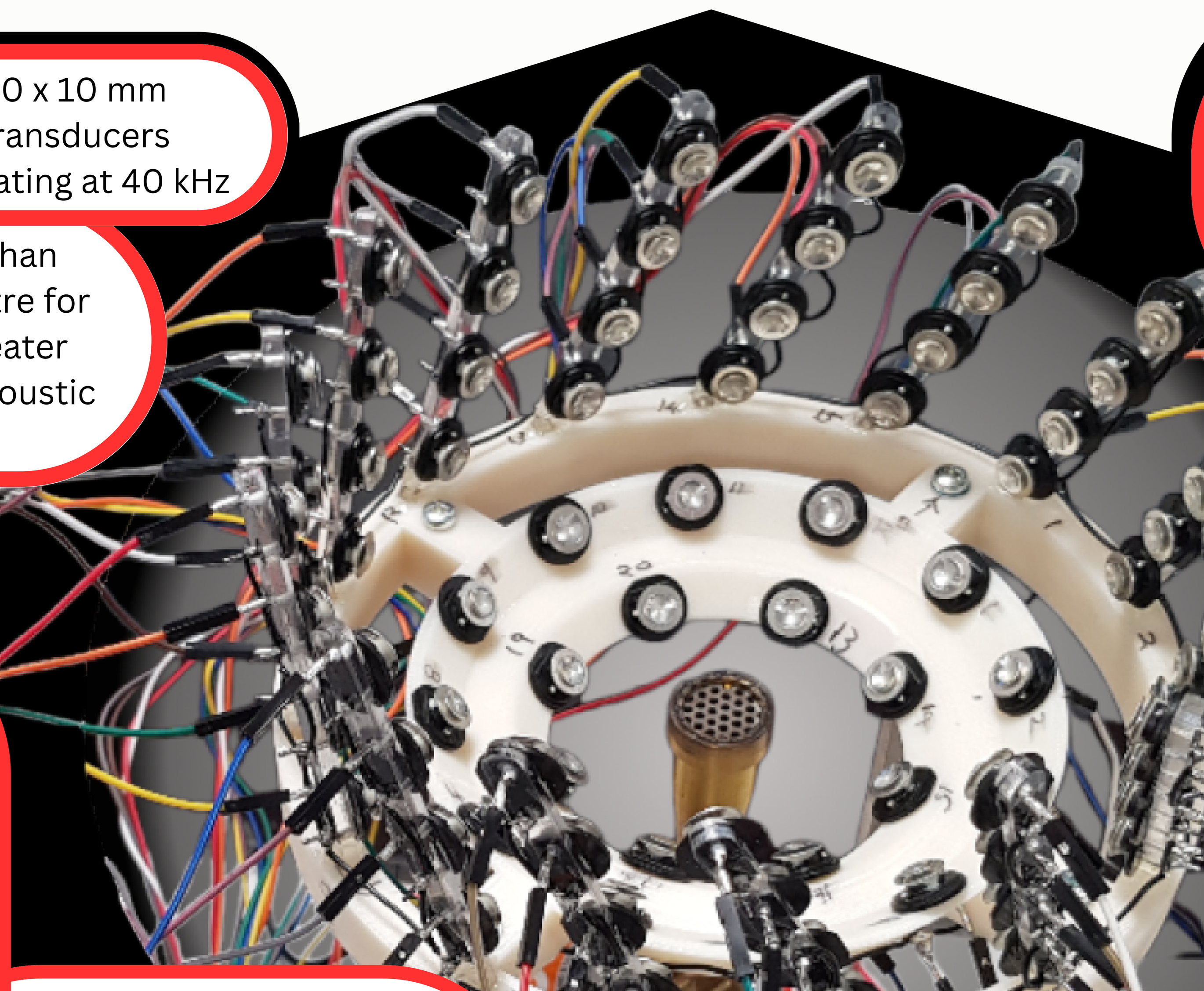
Lower rings are identical to (3). Top ring is raised and directed horizontally inwards
+ Better range, fewer residuals in complex P fields
- Worse resolution than (2) and (3)



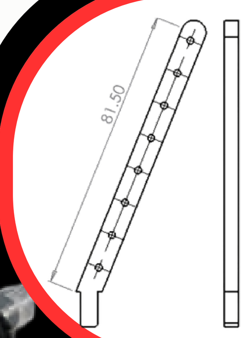
Lowest 2 rings identical to (3). Top 4 rings raised, spread evenly over the control volume
+ Far better vertical resolution, far better range
- Small peak pressure, even more residuals

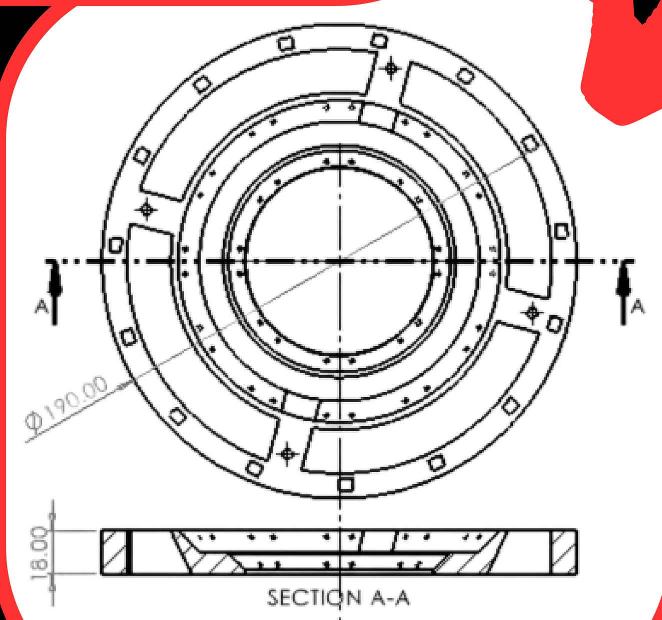


Same structure as (5) but transducers are grouped into threes and orientated as shown
+ Good vertical resolution, best vertical range
- Very small peak pressure, terrible residuals

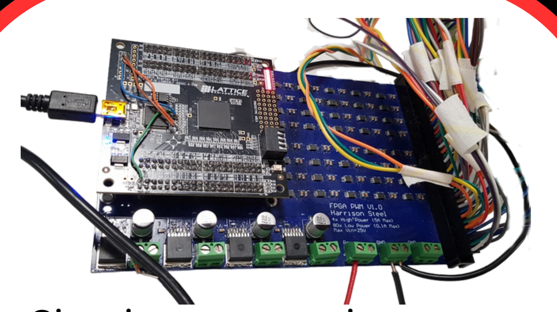

80 x 10 mm transducers operating at 40 kHz

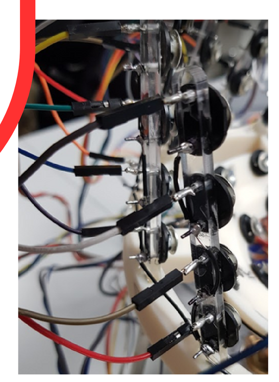
Transducers are not less than 190mm from the flame centre for safety reasons, but not greater than 190mm to maximise acoustic power at focus


Vertical struts are planar and machined separately so can be laser cut



Base is 3D printed


Circuitry connecting power supply, transducers, and controller. Independent 8-bit control of phase/amplitude for each transducer channel


A common ground wire and individual live wires for separate control

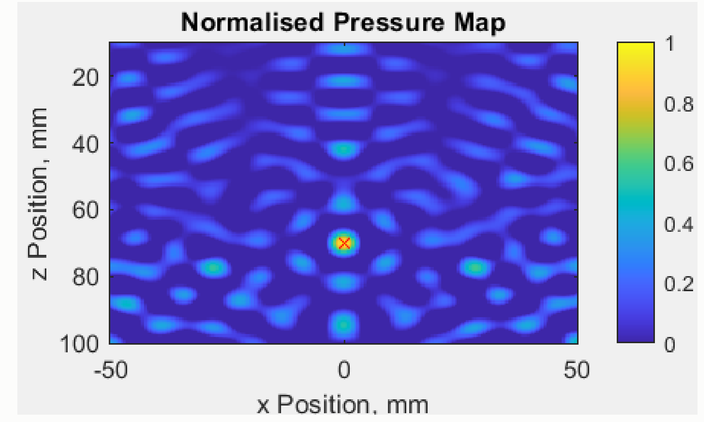
Bunsen positions flame at centre of ultrasound field

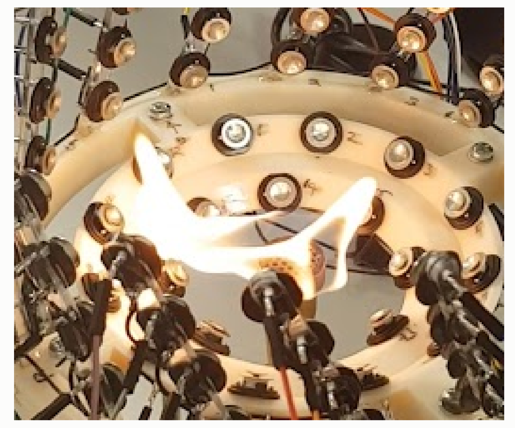
Transducers orientated in different directions to improve resolution

EXPERIMENTATION

METHOD 1 - ANTINODE PLACEMENT

Antinodes produce large, rapid pressure variation that is hypothesised to either 'blow' the flame away, or to increase the gas flow causing a 'fanning' effect - increase the flame intensity at these points. These effects were used to attempt to shape the flame.

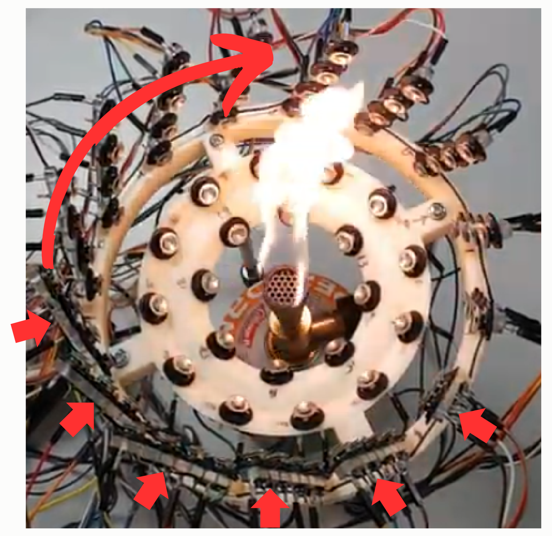



Simulated and experimental results for a single, central antinode

After experimentation, it was found that large, inconsistent temperature differences vary the speed of sound inside the flame, causing dispersion that breaks down the pressure field, so complex shapes can not be formed.

METHOD 2 - COLLECTIVE PUSHING

A more direct approach; simultaneously activate all transducers opposite the desired flame direction, creating a 'pushing' effect that dynamically controls the flame.


Stationary, 'pushed' flame. Active columns marked with small red arrows, rotation of active transducers marked with large red arrow.

CONCLUSION

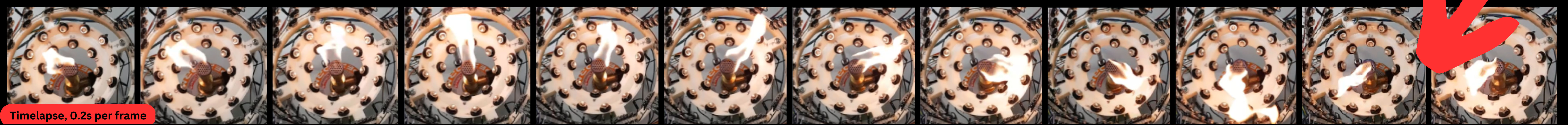
Temperature differences in the flame cause too much dispersion to allow complex flame shapes, but using the 'pushing' method, the flame position in the xy plane of the control volume can be entirely controlled.

ACHIEVEMENTS : An array and control system, capable of controlling a flame to some extent was created, along with a simulation algorithm. Experiments were completed to determine the extent of control.

LIMITATIONS : Flame behaviour in a pressure field was not known before the array design process meaning that the array designed didn't focus on the most critical features. Further developments could better utilise the 'push' method and produce a more effective outcome.

REFERENCES

- A Marzo, A Barnes, and B Drinkwater. "TinyLev:A multi-emitter single-axis acoustic levitator". In:Review of Scientific Instruments 88.8 (2017),p. 085105
- https://www.flinnsci.com/sonic-flame-tube---demonstration-kit/ap7363/
- Pierce, A. Acoustics - An Introduction to Its Physical Principles and Applications. 3rd ed. ASA Press (2019)


Timelapse, 0.2s per frame