Thermophone - Aero-Acoustic Tonal Noise Cancellation

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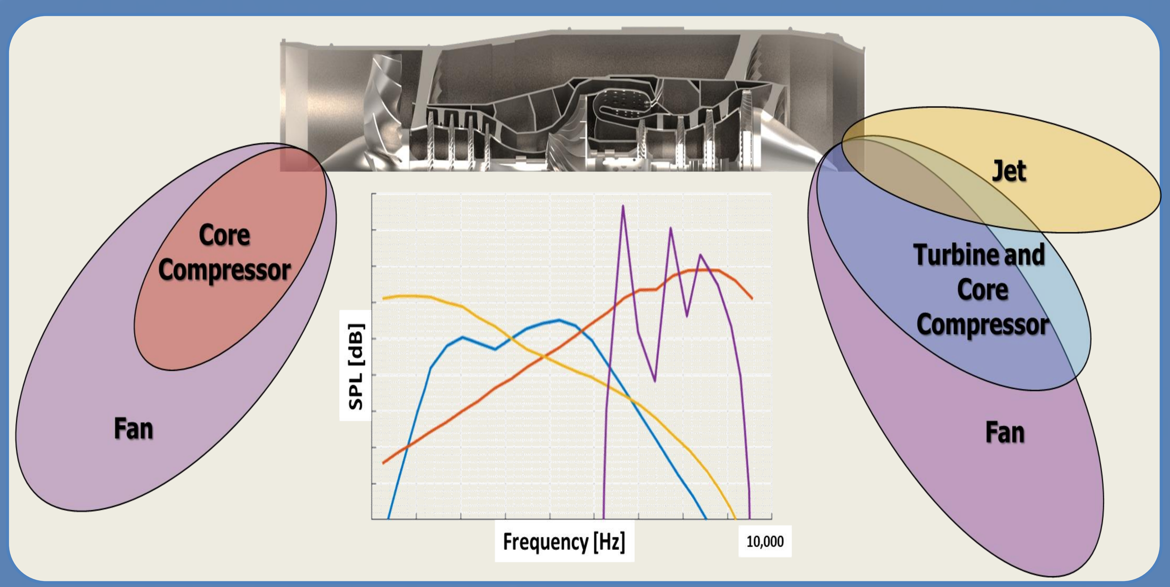
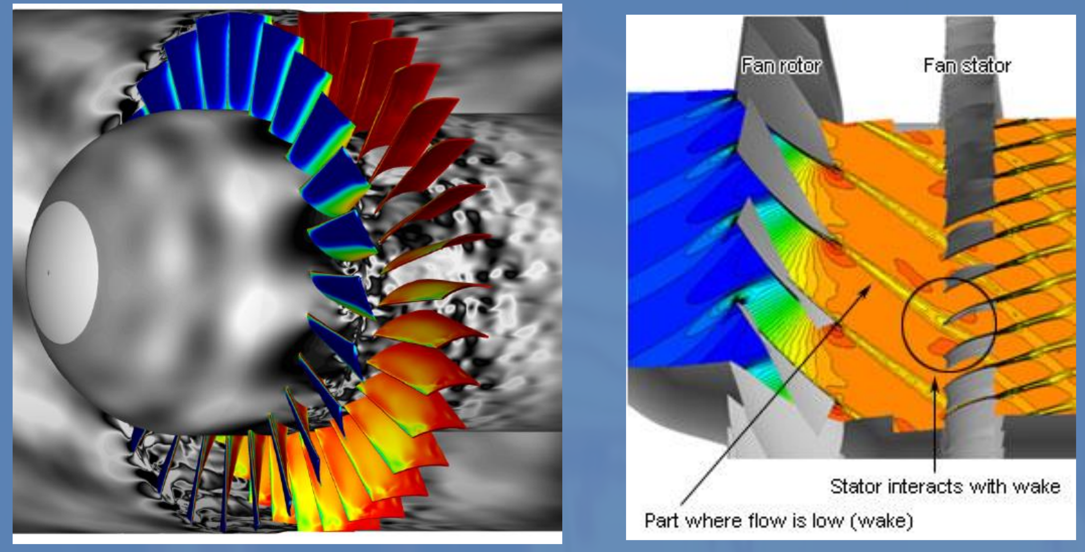


Top: *Noise sources and their relative level and direction in turbofan engine*
Bottom: *Examples of blade pass interaction noise*



MOTIVATION

Aircraft noise is significant consideration in both civil and military arenas. Tonal noise resulting from fan rotor-stator interactions is significant contributor to noise production.

Strides towards higher bypass ratio engines has further accentuated contribution of fan rotor interactions to overall noise.

Elimination of rotor-stator tonal noise has only seen limited success due to complex mechanical environment and variable operating conditions.

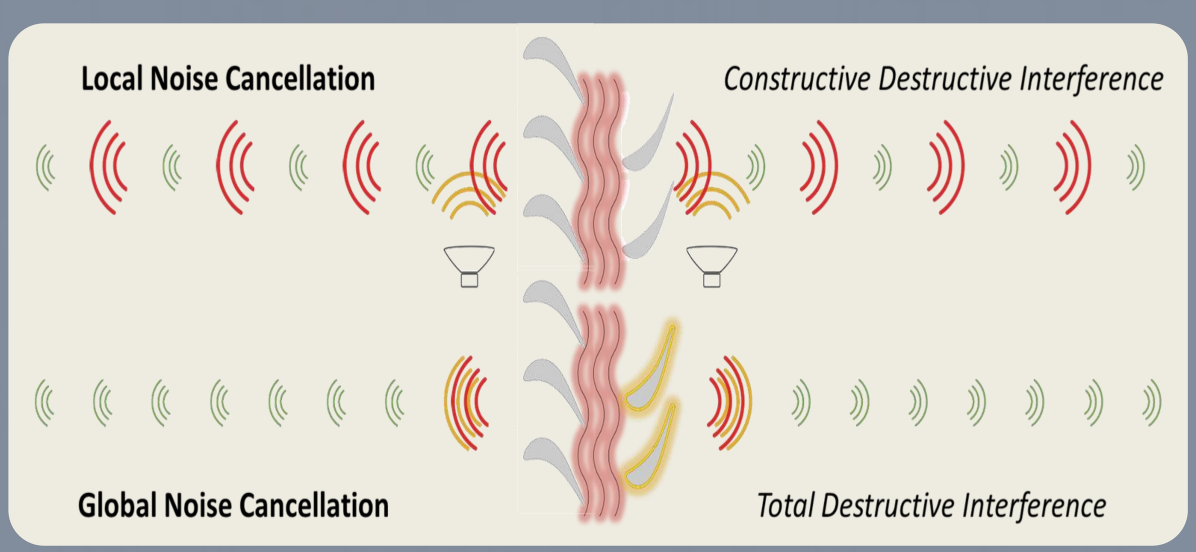
METHODOLOGY

Thermophones are thin electrical resistors that generate sound waves via periodic heat flux fluctuation at fluid boundary, upon application of oscillating electrical current.

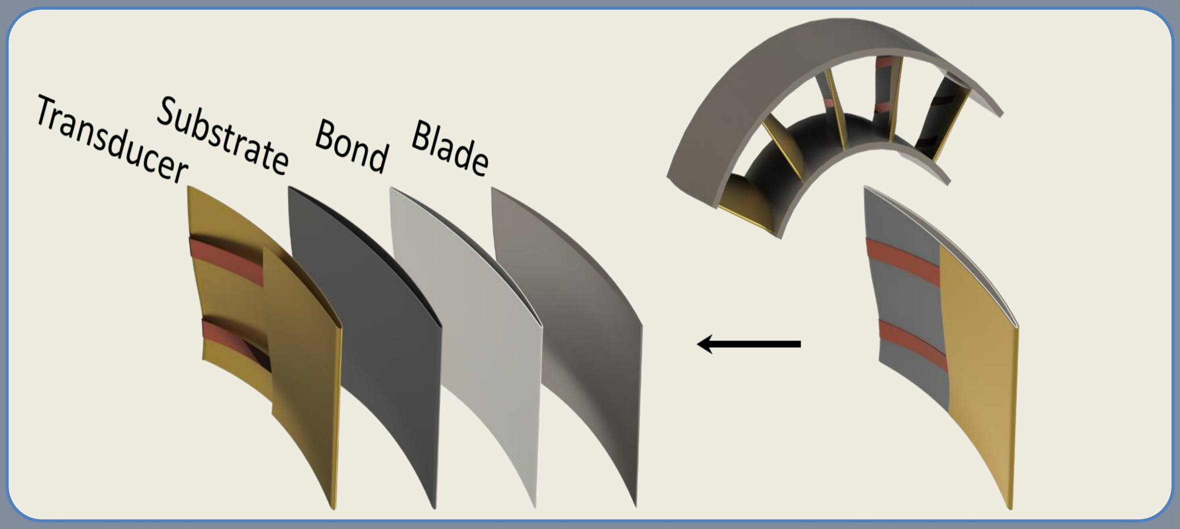
Potential advantages of thermophone loudspeakers include:

- Simplicity
- Sound purity
- Flexibility
- Scalability
- Broad frequency range
- Absence of resonances

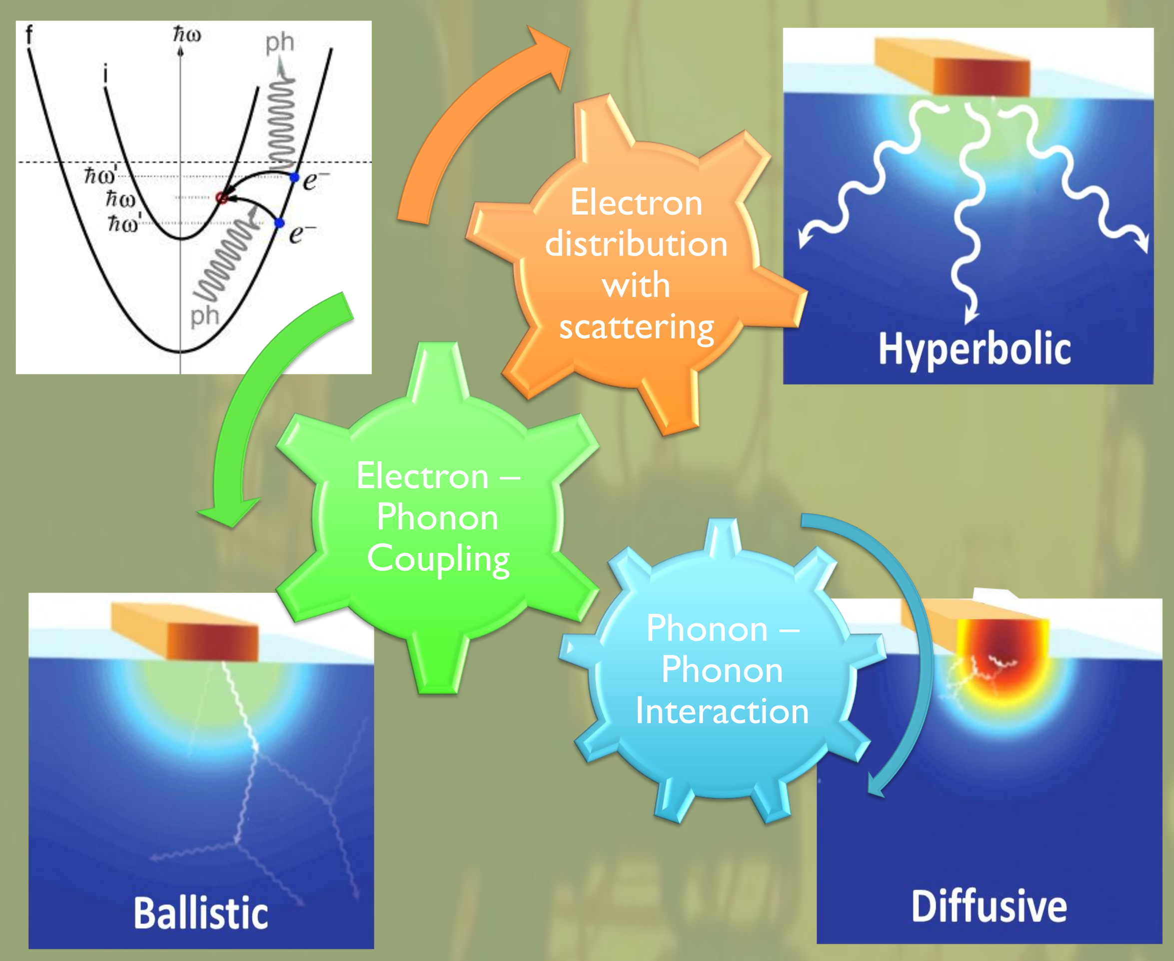
These heat-flux sound transducers offer unique potential of total active noise cancellation from any vibrating surface or acoustic source. They can be placed at locations of rotor interactions and destructively interfere with generated soundwaves at their source.



Top: *Global and local noise cancellation*
Bottom: *Thermophone manufacturing methodology*



THERMO-ACOUSTIC TRANSDUCTION MECHANISM



Top left: *Schematic of electron-phonon scattering process*
Top right: *Illustration of hyperbolic heat conduction process dynamics*
Bottom left: *Illustration of ballistic heat conduction process dynamics*
Bottom right: *Illustration of diffusive heat conduction process dynamics*

Energy input undergoes two transduction processes:

1. Electrical energy undergoes thermalization
2. Portion of interface heat flux generates pressure wave

Second process is well understood and modelled with existing techniques, such as linearized Navier-Stokes-Fourier equations.

Thermalization process is complicated, due to presence of multiple energy carriers (electrons and phonons), as well as multiple thermalization mechanisms stemming from small spatial and temporal scales associated with thermophone sound production.

This processes include scattering effects, ballistic (quasi-collisionless) transport, classical diffusive processes and hyperbolic (wavelike) heat propagation.

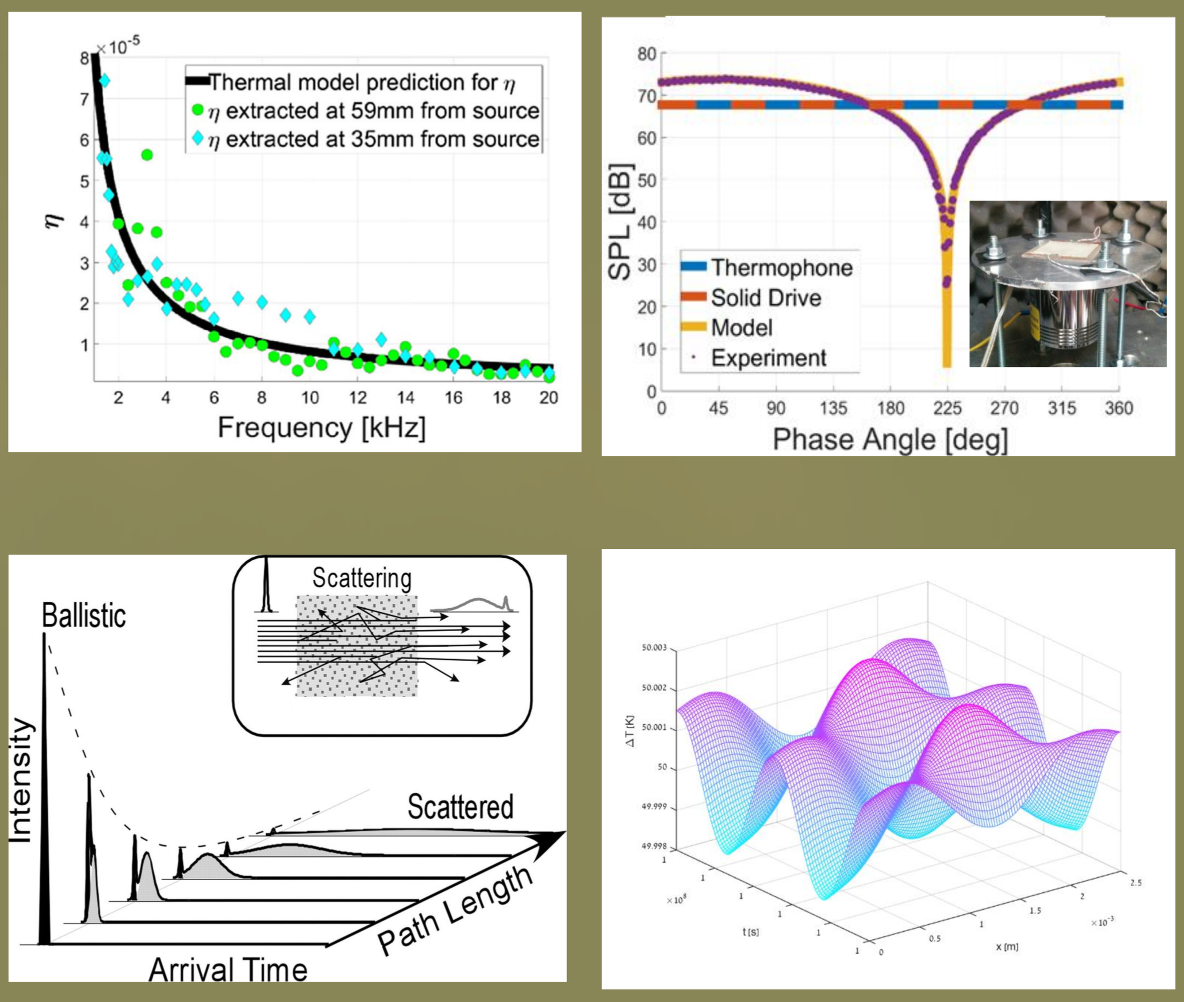
PRELIMINARY MODELLING AND EXPERIMENTAL RESULTS

First ever demonstration of total active noise cancelation from co-axial mechanical source using heat-flux transducer resulted in maximum sound pressure amplitude reduction of $> 10^5$ times.

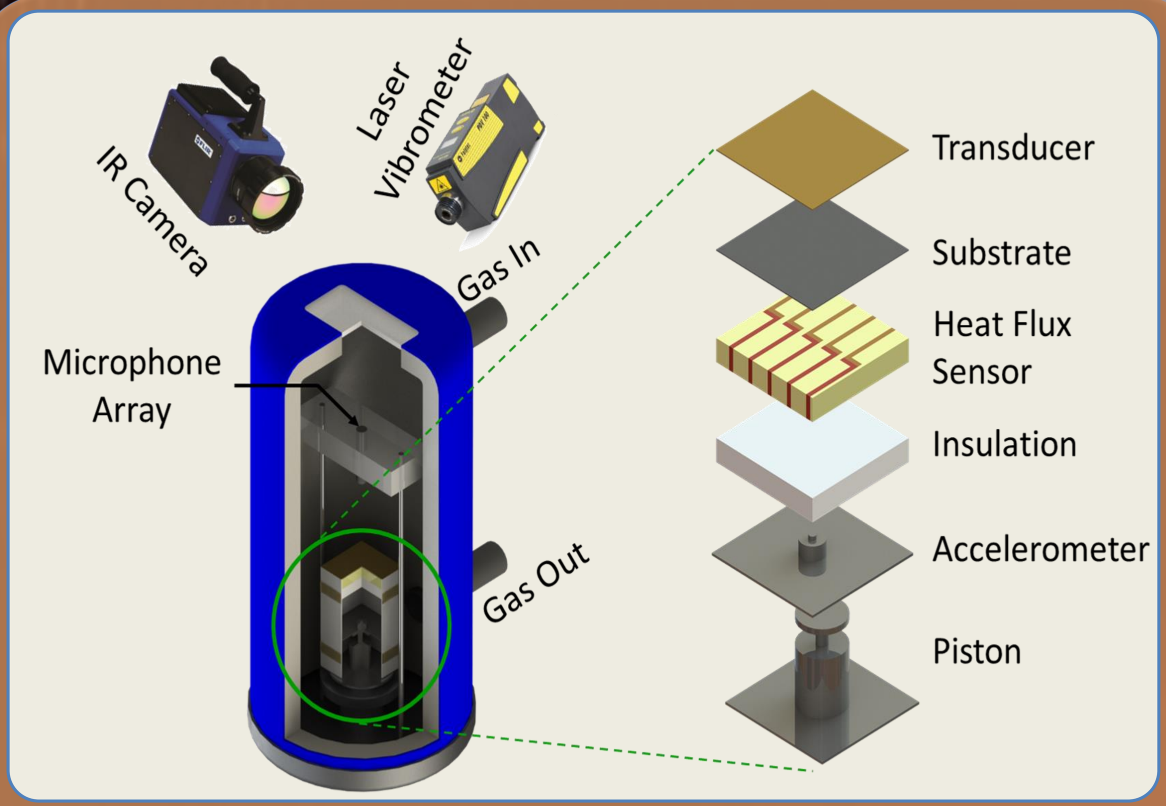
Device thermalization transduction efficiency was characterized and predictions as to extent of ballistic transport processes were made.

Implications of hyperbolic heat conduction in thermophone sound production were studied (resonances).

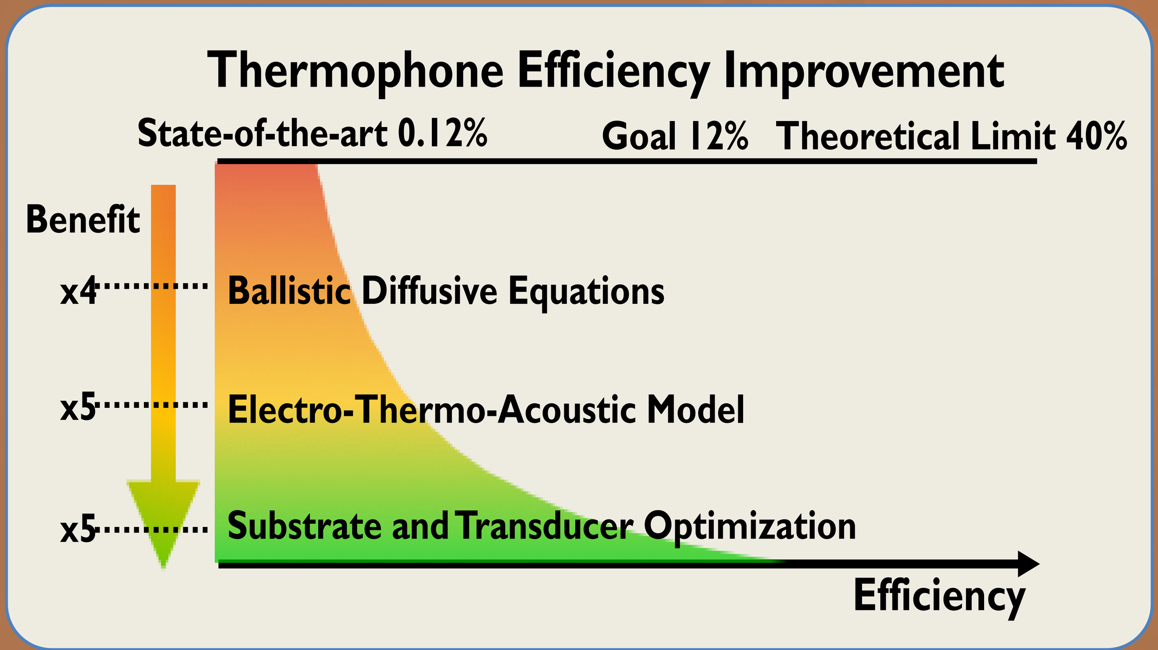
Julius, Simon, et al. "Modeling and experimental demonstration of heat flux driven noise cancellation on source boundary." *Journal of Sound and Vibration* 434 (2018): 442-455



Top left: *Simplified model efficiency prediction vs. experimental data*
Top right: *Cancellation of coplanar sources (SPL vs Phase)*
Bottom left: *Statistical distribution of ballistic heat conduction and scattering processes*
Bottom right: *Simulation showing existence of thermal resonances*



Top: *Model validation experimental set-up*
Bottom: *Foreseen potential thermophone efficiency improvements*



MODEL VALIDATION AND OPTIMIZATION

Low efficiency of state-of the art thermophone transduction is most critical risk to project success. Reliable model is therefore of paramount importance to ensure that device can be optimized.

Macro-scale mathematical description of micro and nanoscale heat transfer processes is very challenging and requires extensive experimental validation.

Correct capturing of ballistic and wavelike thermalization processes is necessary to model thermophones. Therefore, mathematical model must reflect physics of scattering, electron-phonon and phonon-phonon coupling.

Once correct macro-scale description is obtained, thermophone design will undergo an optimization procedure.

APPLICATION-DRIVEN CONSIDERATIONS AND SET-UP

Final thermophone design must be suitable to survive harsh operating environment of fan stage. This requires appropriate material selection for transducer itself, as well as for substrate.

To actively reduce tonal noise, control circuit is required to establish feedback loop between transducer and 'error'-reading microphone.

Active tonal rotor-stator noise cancellation can then be demonstrated in miniature electric ducted fan setup.

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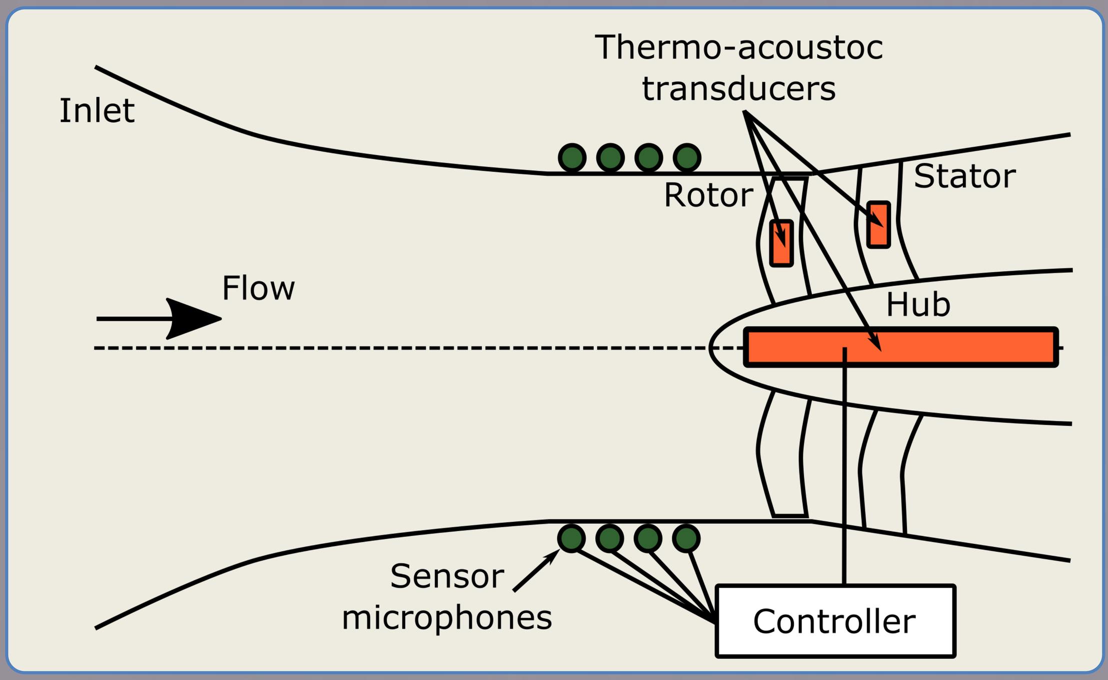

Top: *Illustration of anticipated control mechanism*
Bottom: *Illustration of set-up and material selection considerations*