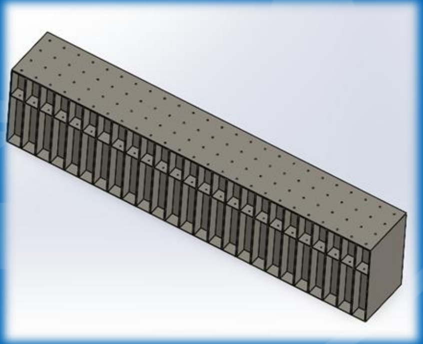
Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

Assignment 3: Research Proposal

4E3 Research Methods

Group 17:
K. Bakhet, B. Gaffney, B. Lee, E. McAleese, F. O’Connor, M. Sadlier.

Presented by: F. O’Connor and M. Sadlier



Acoustic Liner Solutions for Urban Air Mobility (UAM)

4/11/2025

Background and Motivation

Why UAM Noise Matters

- Rapidly growing industry.
  - eVTOL & drone transport, delivery.
  - Operates closely to built-up areas (vertiports).


[3]

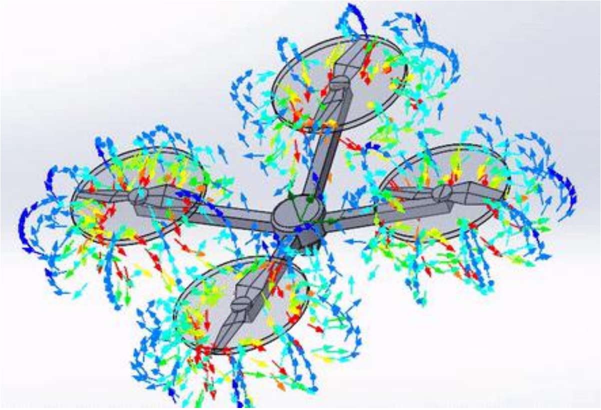
Background and Motivation

Why UAM Noise Matters

- Rapidly growing industry.
  - eVTOL & drone transport, delivery.
  - Operates closely to built-up areas (vertiports).

- Produces noise perceived to be of high annoyance.
  - Pure tones & high-frequency broadband sound[1].
  - Interrupted sleep, health risks, and physiological stress responses[2].

[4]



[5]

[2] W. Raza and R. S. Stansbury, 'Noise Prediction and Mitigation for UAS and eVTOL Aircraft: A Survey', *Drones*, vol. 9, no. 8, p. 577, Aug. 2025, doi: 10.3390/drones9080577.

[3] M. G. Smith, M. Cordoza, and M. Basner, 'Environmental Noise and Effects on Sleep: An Update to the WHO Systematic Review and Meta-Analysis', *Environ Health Perspect*, vol. 130, no. 7, p. 076001, July 2022, doi: 10.1289/EHP10197.

Research

Research

[6] Maa (1975) – Development of the first analytical model for micro-perforated panel (MPP) liners, relating absorption to porosity, thickness, cavity depth, and hole diameter.

[7] Rizzi et al. (2020) – Identified broadband aeroacoustic sources such as self-noise and vortex interactions in UAM propellor systems, pointing to the need for liners to be located in high-turbulence flow paths to mitigate noise.

[8] Gautam et al. (2022) – Showed that double-degree-of-freedom (DDOF) liners provide broadband and increased absorption by stacking two cavities of different depths.

[9] McKay et al. (2020) – Showed that MPP liners mixed with perforation sizes and cavity depths under grazing flow conditions can yield wider bandwidth absorption.

[10] Ciochon & Kennedy (2023) – Validated high-resolution MSLA 3D printing for acoustic materials, achieving accurate small-scale cavity construction.

Aim and Objectives

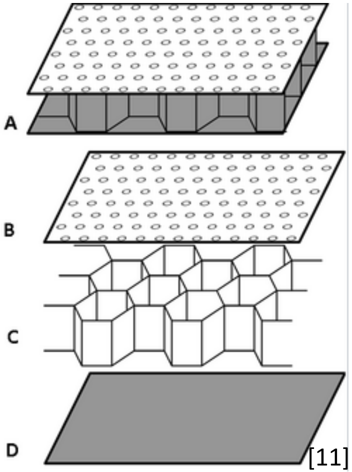
What We Aim to Achieve

Propose an acoustic liner for UAM that can achieve broadband attenuation with a high peak absorption coefficient, for a 500-1000 Hz range.

Physics and Design Concept

Physics of Acoustic Liners

- Acoustic liners work to **convert incident acoustic energy into heat**, reducing the amplitude of reflected sound waves.
- **Sound waves** forced into narrow holes, to **vibrate the air within cavities** of specific depths.
- **Good absorption** comes from a medium that closely **resembles the impedance** of the sound waves being directed at it.
  - $Z_{liner} = \rho_0 c_0$
- At the **Helmholtz Frequency**, the liner vibrates at a specific natural frequency, **dissipating energy**.
  - $f_H = \frac{c_0}{2\pi}\sqrt{\frac{A}{VL_{eff}}} = \frac{c_0}{2\pi}\sqrt{\frac{\phi}{LL_{eff}}}$
- **DDOF liner:** multiple frequency bands can be attenuated and absorption can be amplified.
- **Impedance chain:** $Z_{MPP} + Z_{cavity\ 1} + Z_{septum} + Z_{cavity\ 2} = Z_{liner}$



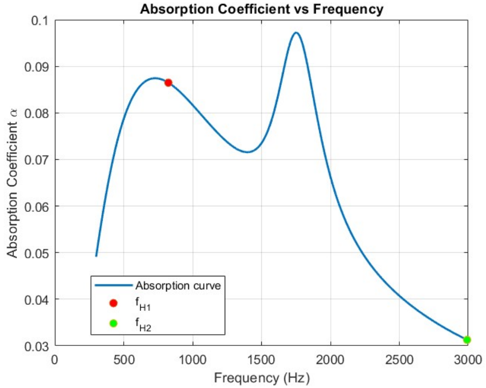
[11]

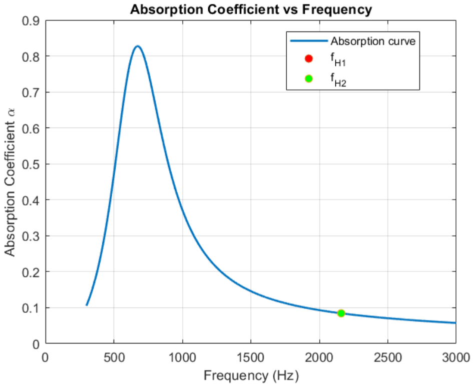
Predicted Performance and Benefits

MATLAB Simulation Results

- In order to create a design that works, an absorption chain was derived in **MATLAB** to model the liner's **absorption**.
- We **adjusted the liner dimension variables** until a we had a design that matched our desired performance.
- The model showed that for larger bandwidth models, overall absorption amplitude was compromised, indicating a **trade-off**.
- Solution yielded **average absorption** coefficients of:
  - **0.2267** for 300 – 3000 Hz.
  - **0.6364** for 500 – 1000 Hz.
- Compared to other researched liner designs and considering the 37 mm depth constraint, this **performance is very good**.

```
Total liner depth is 37.000 mm
Frequency band 1 (f_H1) = 2158.8 Hz
Frequency band 2 (f_H2) = 2160.3 Hz
Average absorption coefficient (300-3000 Hz): 0.2267
Average absorption coefficient (500-1000 Hz): 0.6364
```





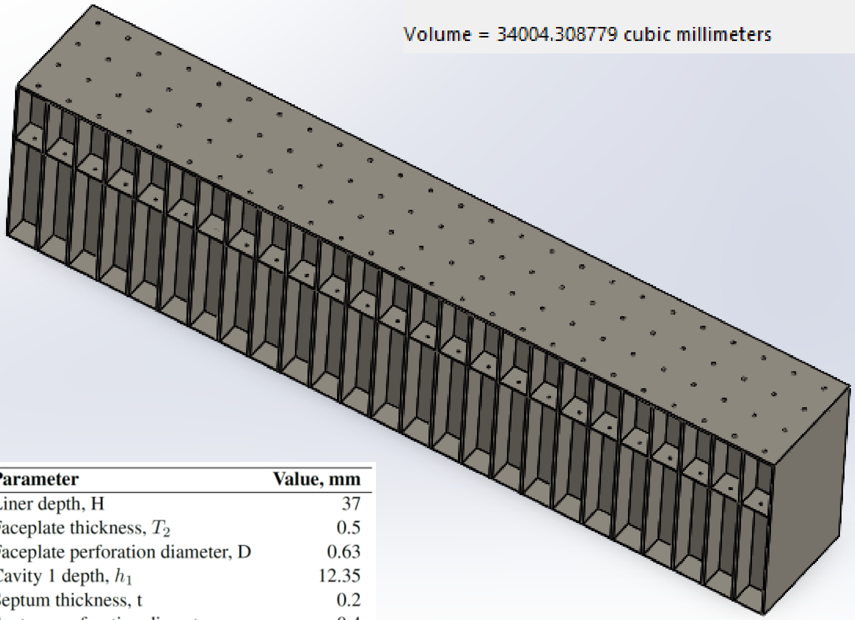
Final Design

Liner CAD Model

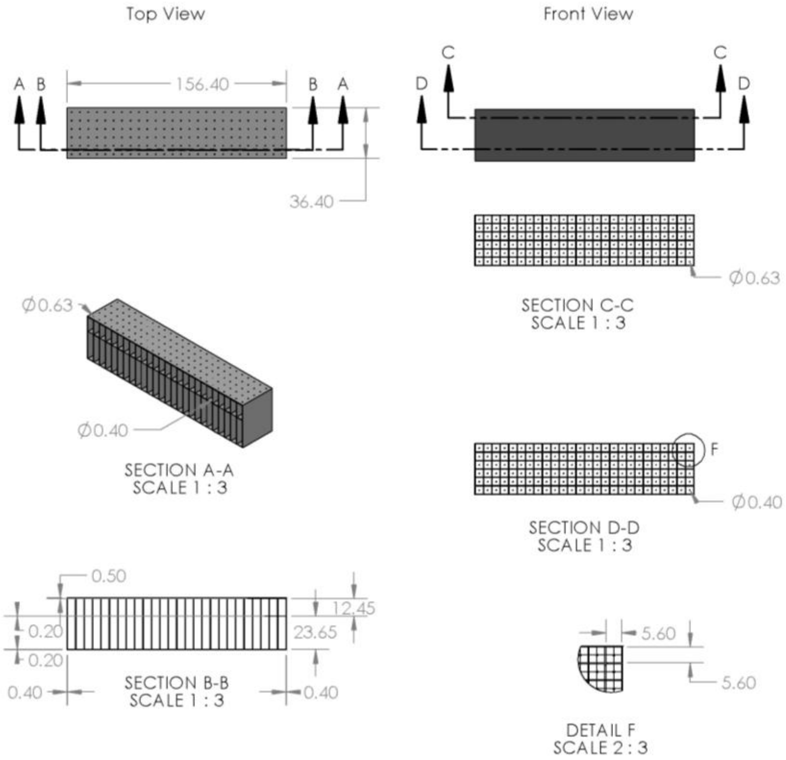
Density = 0.001150 grams per cubic millimeter

Mass = 39.104955 grams

Volume = 34004.308779 cubic millimeters



Parameter	Value, mm
Liner depth, H	37
Faceplate thickness, T_2	0.5
Faceplate perforation diameter, D	0.63
Cavity 1 depth, h_1	12.35
Septum thickness, t	0.2
Septum perforation diameter	0.4
Cavity 2 depth, h_2	23.65
Backplate thickness, T_2	0.5



Manufacturing Strategy

How the Liner Will be Made

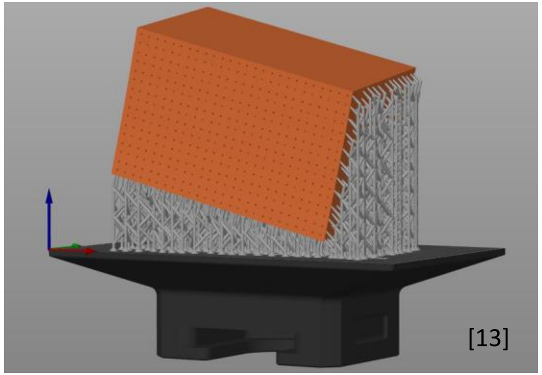
Manufacturing Method – MSLA (Masked Stereolithography)

- Chosen for its **high resolution**, **surface quality** and **quick printing times**.
- Uses **UV cured resin** and an **LCD screen** to form each layer.
- **LED array cures resin layer by layer** as the platform lifts.
- Produces accurate **high quality parts** suitable for acoustic liner testing.

[12]

Build Strategy

- Part requires **structural supports** during printing.
- **Angled build orientation** to minimize supports.
- Angle reduces unsupported horizontal elements vulnerable to sagging.



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Risk Assessment & Mitigation

How We Would Address Potential Issues

#	Risk	Likelihood (1-5)	Impact (1-5)	Risk	Mitigation
R1	**Undersized Print**	4	4	16	Slightly oversize grooves/bores to add manufacturing margin (reduces hole closure).
R2	**Reprints Leading to Delays**	4	3	12	Oversize features to cut rework; add lowest-point drains to improve cleaning; seal after.
R3	**Geometry Distortion**	3	4	12	Careful IPA cleaning and adequate UV post-cure to limit shrinkage-induced warping.
R4	**Trapped Resin Causing Peel**	3	3	9	Add drain holes at the lowest point on a non-acoustic face, then seal them during finishing.

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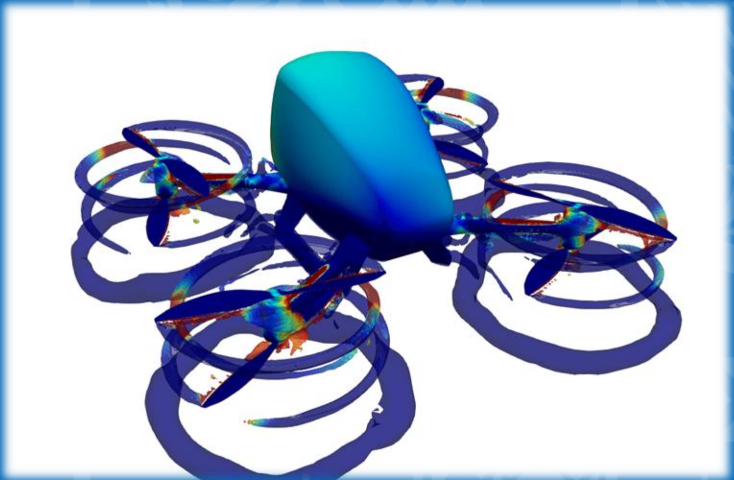
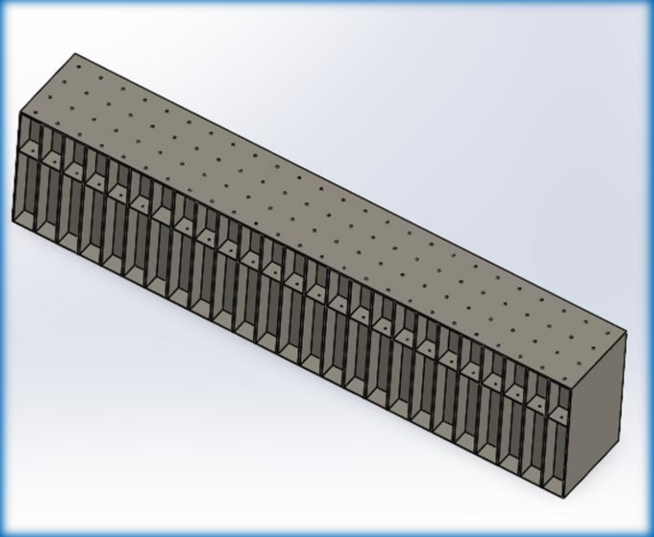
Thank You!



[14]



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References

Key Sources of Information

Citations:

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[6] Y. Maa. Theory and design of microperforated panel sound-absorbing constructions. Scientia Sinica,1975. English translation available via SciEngine. https://www.sciengine.com/Math%20A0/articleIndex?doi=10.1360/ya1975-18-1-55&scroll=

[7] Stephen A Rizzi. Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations. 2020. https://ntrs.nasa.gov/api/citations/20205007433/downloads/NASA-TP-2020-5007433.pdf

[8] A. Gautam, A. Celik, and M. Azarpeyvand. On the acoustic performance of double degree of freedom Helmholtz resonator based acoustic liners. Applied Acoustics, 191:108661, 2022. https://www.sciencedirect.com/science/article/pii/S0003682X22000354

[9] A. McKay, I. Davis, J. Killeen, and G. J. Bennett. Semsa: A compact super absorber optimised for broadband, low-frequency noise attenuation. Scientific Reports, 10(1):17967, 2020. https://pubmed.ncbi.nlm.nih.gov/33087735/

[10] A. Ciochon, J. Kennedy, R. Leiba, L. Flanagan, and M. Culleton. The impact of surface roughness onan additively manufactured acoustic material: An experimental and numerical investigation. Journal of Sound and Vibration, 546:117434, 2023. https://www.sciencedirect.com/science/article/pii/S0022460X22006174

Images:

[1] https://yelzkizi.org/how-do-i-simulate-a-drone-camera-in-blender/

[4] https://www.portofrotterdam.com/en/news-and-press-releases/first-drone-vertiport-in-the-netherlands-now-operational

[5] https://www.linkedin.com/pulse/cfd-simulation-drone-yong-kw/

[11] https://en.wikipedia.org/wiki/Acoustic_liner

[12] https://www.3dnatives.com/en/difference-between-sla-and-msla-020820224/

[13] https://arc.aiaa.org/doi/full/10.2514/1.J063384

[14] https://aantc.ust.hk/

MATLAB Code

Slide 1

```matlab
close all; clear; clc;

%% ------------------------ Initial Conditions ------------------------
% Constants
c0   = 343;                  % Speed of sound in air at 20 °C [m/s]
rho0 = 1.225;                % Air density [kg/m^3]
Z0   = rho0 * c0;            % Characteristic impedance of air [Pa·s/m]
v0   = 1.506e-5;             % Kinematic viscosity of air [m^2/s]

% Frequency range
f     = 300:1:3000;          % [Hz]
omega = 2*pi*f;
k     = omega / c0;

% Geometry constraints
max_liner_depth = 0.037;     % [m] (37 mm maximum)

% Faceplate (micro-perforated panel)
faceplate_thk      = 0.0005;   % [m]
faceplate_d        = 0.00063;   % Hole diameter [m]
faceplate_phi      = 0.02;    % Open area ratio [-]
L_eff_faceplate    = faceplate_thk + 0.85*faceplate_d;

% Cavity 1
cavity1_depth = 0.01235;      % [m]

% Septum (perforated)
septum_thk    = 0.0002;      % [m]
septum_d      = 0.0004;      % Hole diameter [m]
septum_phi    = 0.02;        % Open area ratio [-]
L_eff_septum  = septum_thk + 0.85*septum_d;

% Cavity 2
cavity2_depth = 0.02365;      % [m]

% Backplate thickness (rigid)
rigid_backplate_thk = max_liner_depth - (faceplate_thk + cavity1_depth + ...
                                         septum_thk     + cavity2_depth);

% Sanity check on total depth
sum_of_depths_m = faceplate_thk + cavity1_depth + septum_thk + ...
                  cavity2_depth + rigid_backplate_thk;

disp(['Total liner depth is ', num2str(sum_of_depths_m*1e3, '%.3f'), ' mm']);
if sum_of_depths_m > max_liner_depth + 1e-9
    warning('Liner thickness too large.');
end

%% ---------------- Helmholtz frequency band estimation ----------------
% MPP facesheet + cavity 1
f_H1 = (c0/(2*pi)) * sqrt(faceplate_phi/(cavity1_depth * L_eff_faceplate));

% Septum + cavity 2
f_H2 = (c0/(2*pi)) * sqrt(septum_phi/(cavity2_depth * L_eff_septum));

disp(['Frequency band 1 (f_H1) = ', num2str(f_H1, '%.1f'), ' Hz']);
disp(['Frequency band 2 (f_H2) = ', num2str(f_H2, '%.1f'), ' Hz']);

%% ----------------------- Impedance Calculations ---------------------
% Complex unit
j = 1i;

% --- Micro-perforated faceplate impedance (Bessel formulation) ---
x_faceplate          = (faceplate_d/2) * sqrt((-j*omega)/v0);
J0_faceplate         = besselj(0, x_faceplate);
J2_faceplate         = besselj(2, x_faceplate);
Z_MPP                = ((-j*k)./faceplate_phi) .* (J0_faceplate ./ J2_faceplate);

% --- Cavity 1 input impedance (standalone) ---
Z_cavity1 = -j*Z0 .* cot(k*cavity1_depth);

% --- Perforated septum impedance (Bessel formulation) ---
x_septum   = (septum_d/2) * sqrt((-j*omega)/v0);
J0_septum  = besselj(0, x_septum);
J2_septum  = besselj(2, x_septum);
Z_septum   = ((-j*k)./septum_phi) .* (J0_septum ./ J2_septum);
```

MATLAB Code

Slide 2

```matlab

% --- Cavity 2 impedance (rigid termination) ---
Z_cavity2 = -j*Z0 .* cot(k*cavity2_depth);

% --- DDOF combination via transfer (input) impedance ---
% Load at the end of cavity 1 (septum in series with cavity 2)
Z_load = Z_septum + Z_cavity2;

% Input impedance looking into cavity 1 terminated by Z_load:
% Z_in1 = Z0 * (Z_load*cos(kL1) - j*Z0*sin(kL1)) / (Z0*cos(kL1) - j*Z_load*sin(kL1))
ck1  = cos(k*cavity1_depth);
sk1  = sin(k*cavity1_depth);
Z_in1 = Z0 .* (Z_load.*ck1 - j*Z0.*sk1) ./ (Z0.*ck1 - j*Z_load.*sk1);

% ------------------------- Total Impedance ---------------------------
Z_total = Z_MPP + Z_in1;

%% ---------------------- Acoustic Absorption -------------------------
Gamma = (Z_total - Z0) ./ (Z_total + Z0);      % Reflection coefficient
alpha = 1 - abs(Gamma).^2;                      % Absorption coefficient

avg_alpha = trapz(omega, alpha) / (omega(end) - omega(1));
disp(['Average absorption coefficient (300-3000 Hz): ', num2str(avg_alpha, '%.4f')]);

%% ----------------- Average Absorption: 500-1000 Hz -------------------
f_lower = 500;
f_upper = 1000;

% Logical indices for frequencies within 500-1000 Hz
idx_band = (f >= f_lower) & (f <= f_upper);

% Average absorption coefficient in this range
avg_alpha_500_1000 = trapz(f(idx_band), alpha(idx_band)) / ...
                     (f_upper - f_lower);

disp(['Average absorption coefficient (500-1000 Hz): ', ...
      num2str(avg_alpha_500_1000, '%.4f')]);

```

```matlab
%% ---------------------------- Plotting ----------------------------
figure('Color','w');
plot(f, alpha, 'LineWidth', 1.6); hold on;

% Mark estimated Helmholtz peaks (interpolate alpha at f_H1, f_H2 if in range)
if f_H1 >= f(1) && f_H1 <= f(end)
    plot(f_H1, interp1(f, alpha, f_H1), 'o', 'MarkerFaceColor', 'r', 'DisplayName', 'f_{H1}');
end
if f_H2 >= f(1) && f_H2 <= f(end)
    plot(f_H2, interp1(f, alpha, f_H2), 'o', 'MarkerFaceColor', 'g', 'DisplayName', 'f_{H2}');
end

xlabel('Frequency (Hz)', 'Interpreter','tex');
ylabel('Absorption Coefficient \alpha', 'Interpreter','tex');
title('Absorption Coefficient vs Frequency');
legend('Absorption curve','f_{H1}','f_{H2}', 'Location','best');
grid on; box on;
```