Development and Validation of an Initial Electric Motor Rotor Vibration Model

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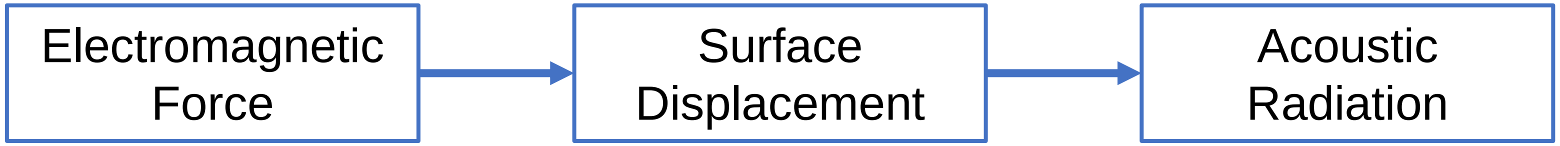
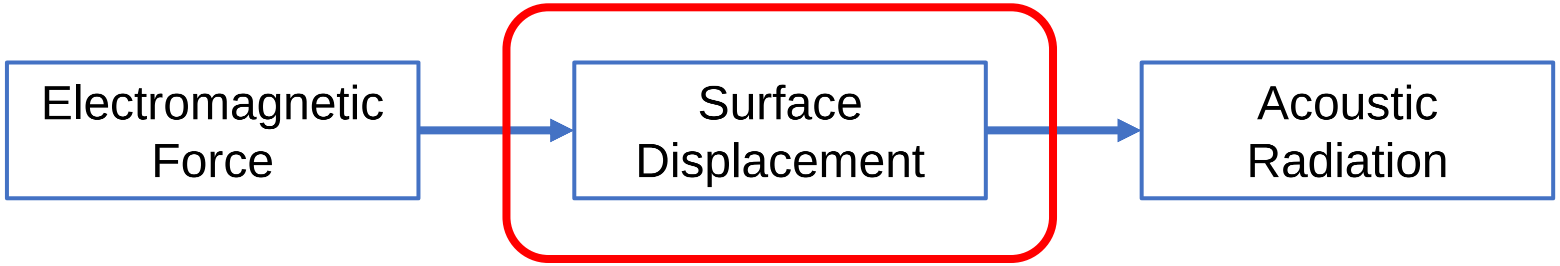
Motor Noise


Electromagnetic Force
Surface Displacement
Acoustic Radiation

Motor Noise


Electromagnetic Force
Surface Displacement
Acoustic Radiation

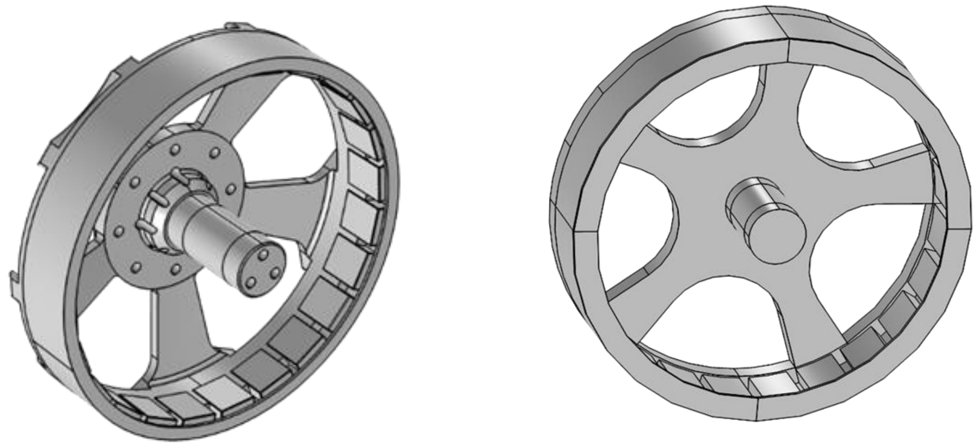
Objectives

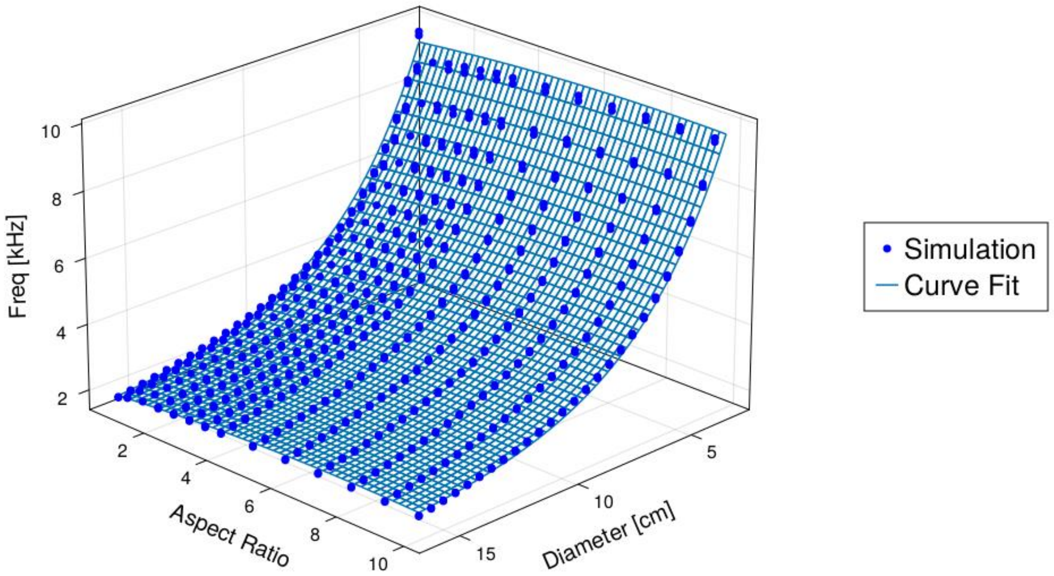
- Electric motors on UAM aircraft can generate tones
  - Tones caused by resonance of motor rotor
  - Acoustically relevant even with propellor noise

- Need a low fidelity noise prediction tool for system level studies
  - Aim to predict the frequency and mode shapes of resonances

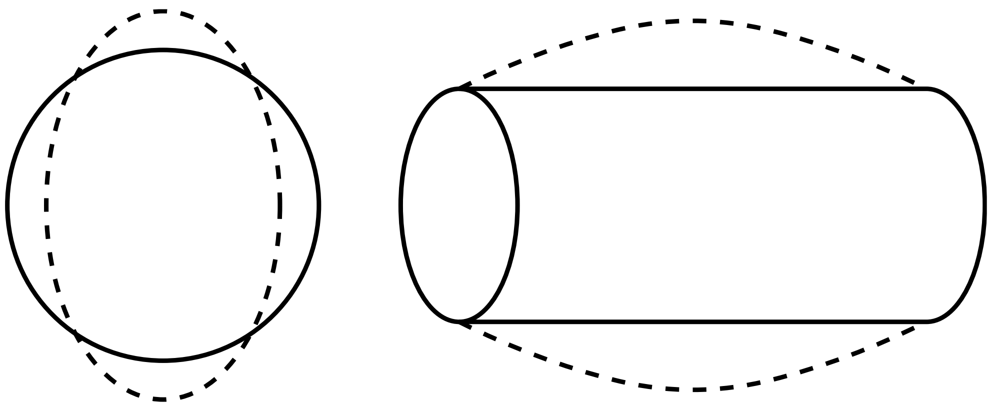
- Three stages of simulation and modeling
  1. High-fidelity geometry simulations
  2. Parameterized geometry simulations
  3. Parameter sweep and curve fit

This supported Milestone RVLT.23.21.L4104



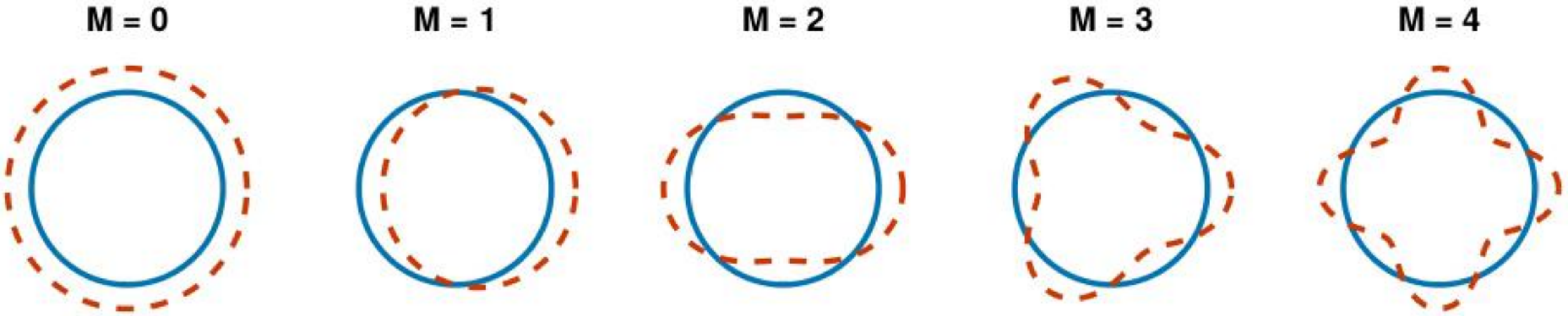


Mode Shapes



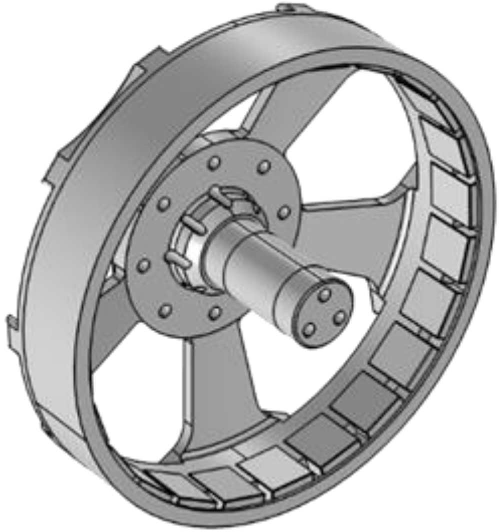
Azimuthal Mode
Number M

Axial Mode
Number N



High-Fidelity Geometry Simulations

- Accurate geometry created of the rotor for two motors
  - T-motor U13
  - Scorpion SII 4020
- FEA eigenfrequency/mode simulations performed in COMSOL
- Experimental comparisons good
  - Acoustic tones
  - Experimental modal analysis

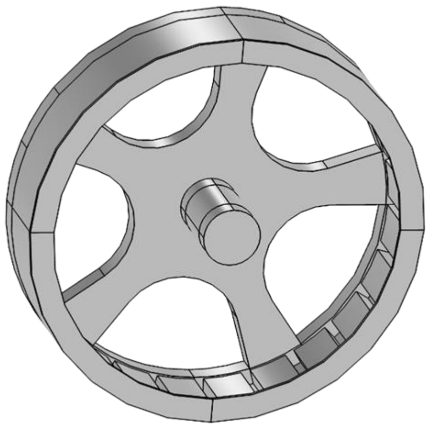


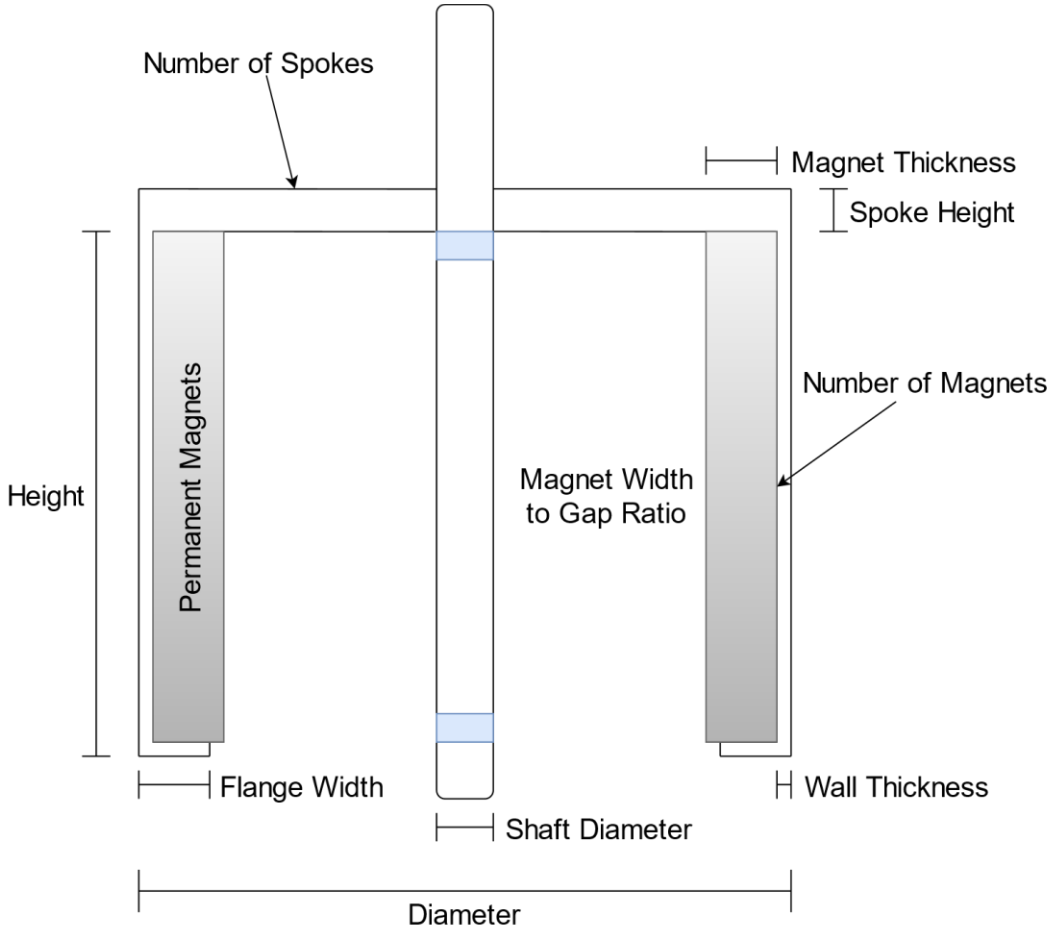
Parameterized Rotor Geometry

- Parameterized model defined by 10 key quantities
  - Most are non-dimensionalized by Diameter

- Parameters anticipated to be most critical
  - Diameter
  - Height (or Aspect Ratio)
  - Spoke Height
  - Wall Thickness

- Model tuned to experiments and high-fidelity models





Parametric Simulation Sweep

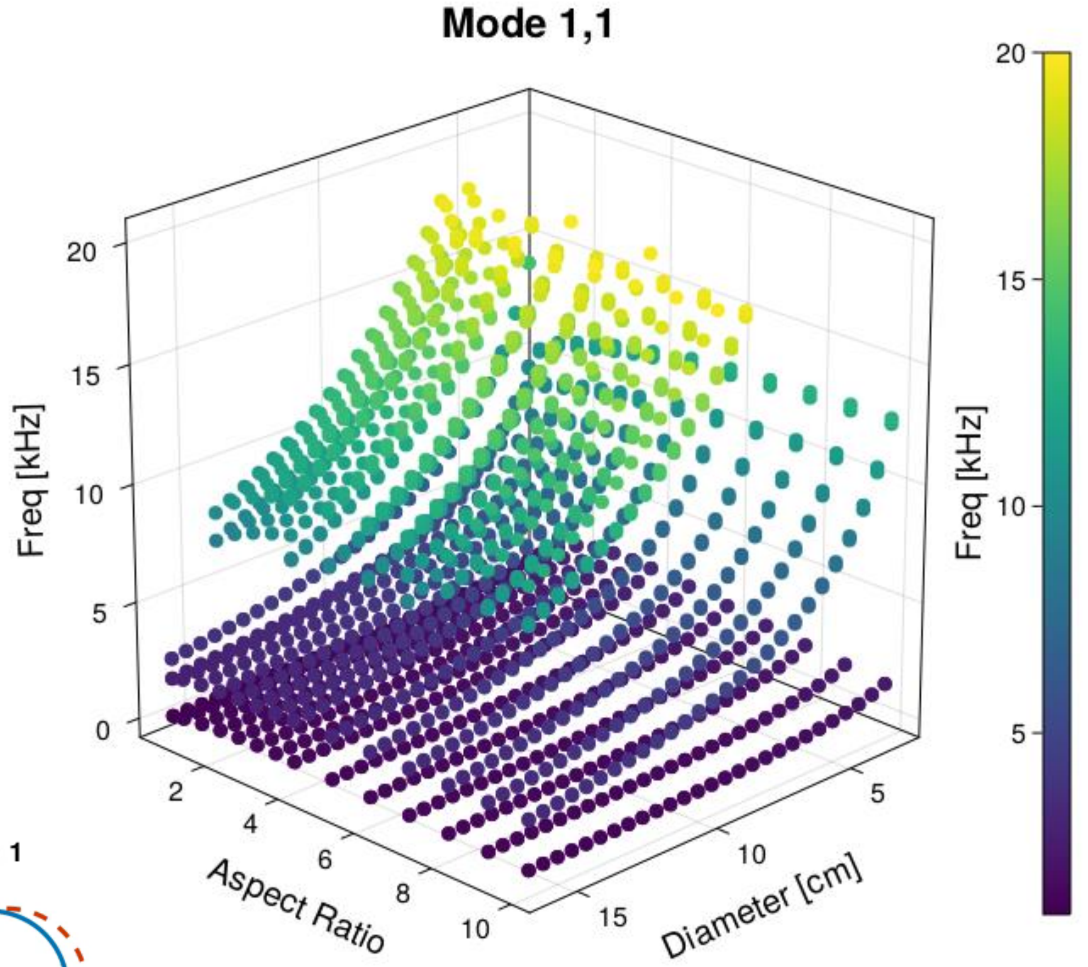
- 35 eigenfrequencies/eigenmodes calculated for each simulation
- Four most important dimensions iterated over
  - Diameter: 30mm – 160mm
  - Aspect Ratio (Diameter/Height): 0.7 – 10
  - Spoke Height Ratio: 0.1 – 0.3
  - Wall Thickness Ratio: 0.02 – 0.04
- Other dimensions were given fixed values corresponding to off the shelf motors
- ~3400 total combinations
- Moderate computer requirements
  - Intel Xeon E5-2637 v4
    - 8 cores (7 threads used)
    - Used less than 64GB RAM
  - Less than 24 hours compute time

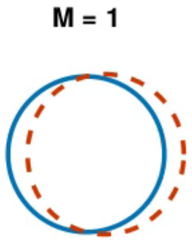
Simulation Sweep Results

- 3400+ simulations
  - 35 results per simulation
  - Each result has M,N and frequency

- Dimensions not shown
  - Spoke Height
  - Wall Thickness
  - Other modes

- Three distinct groups are visible
  - Each group same mode shape
  - Differences in details of vibration

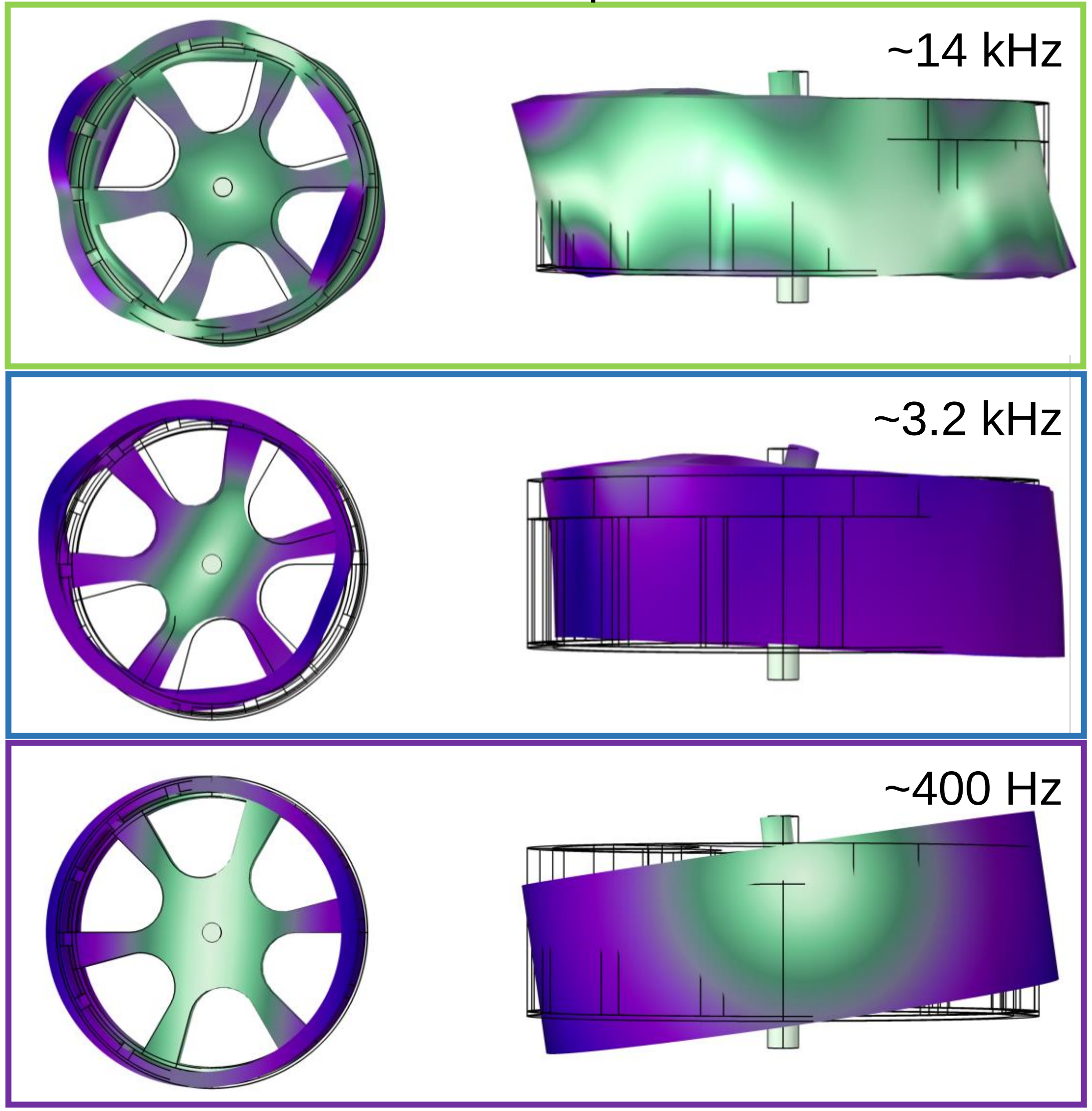


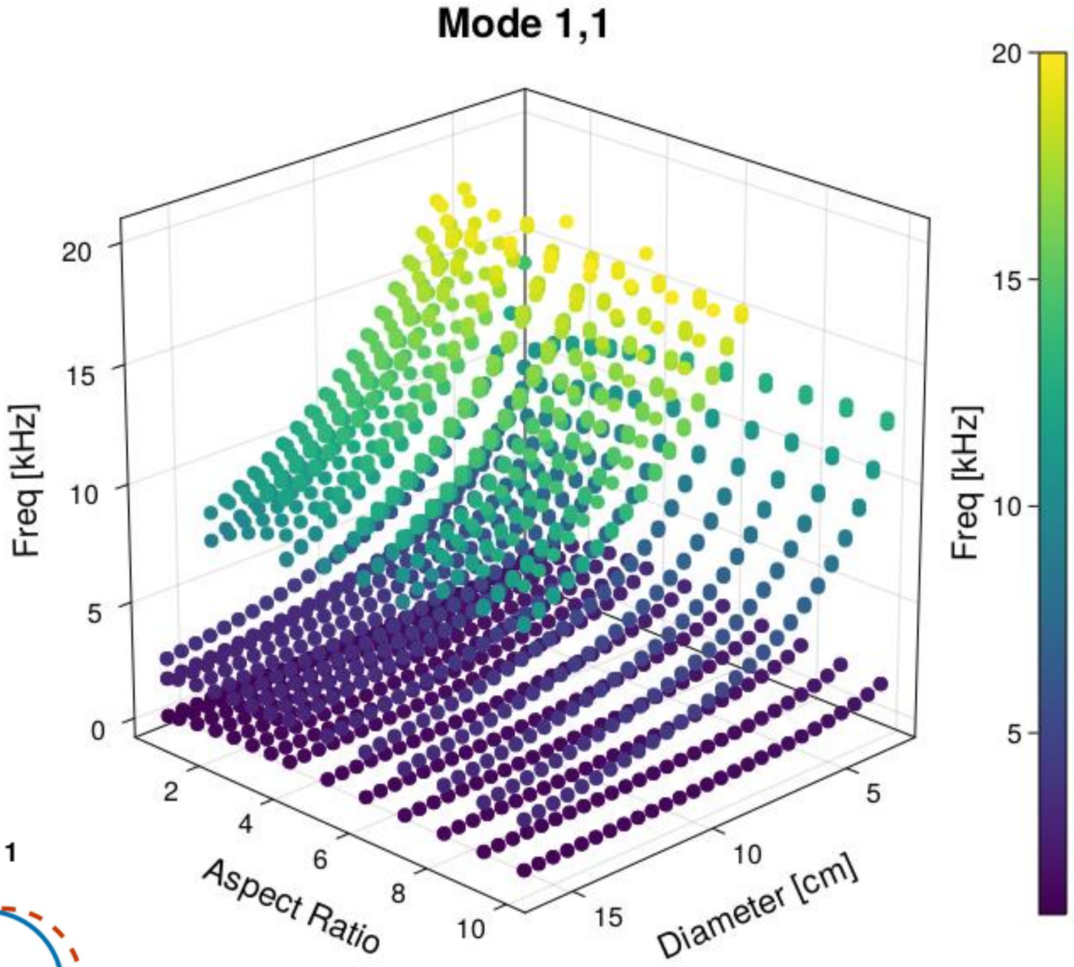


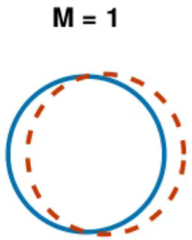
3D slice of 6D result space

Simulation Sweep Results

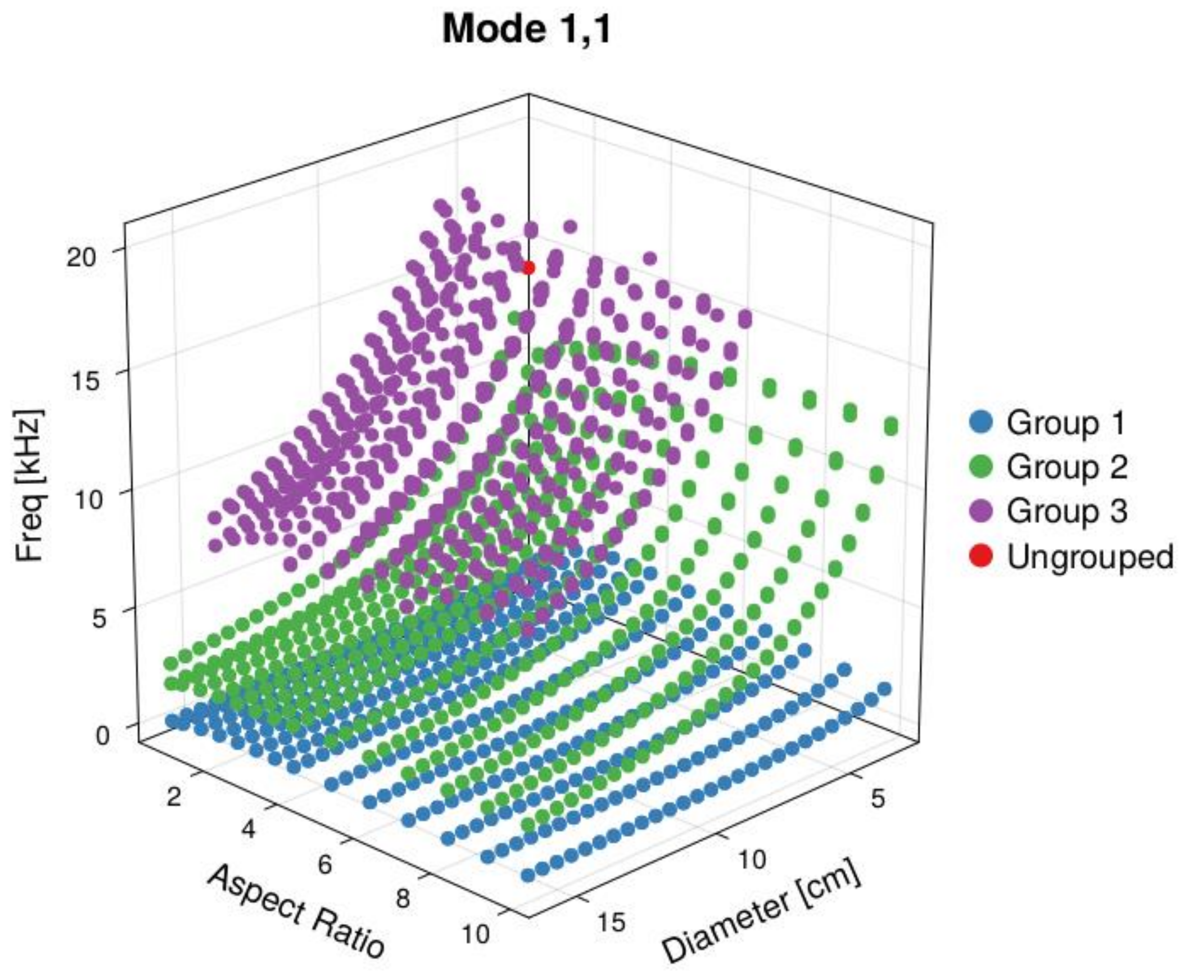
Diameter 10cm, Aspect Ratio 4

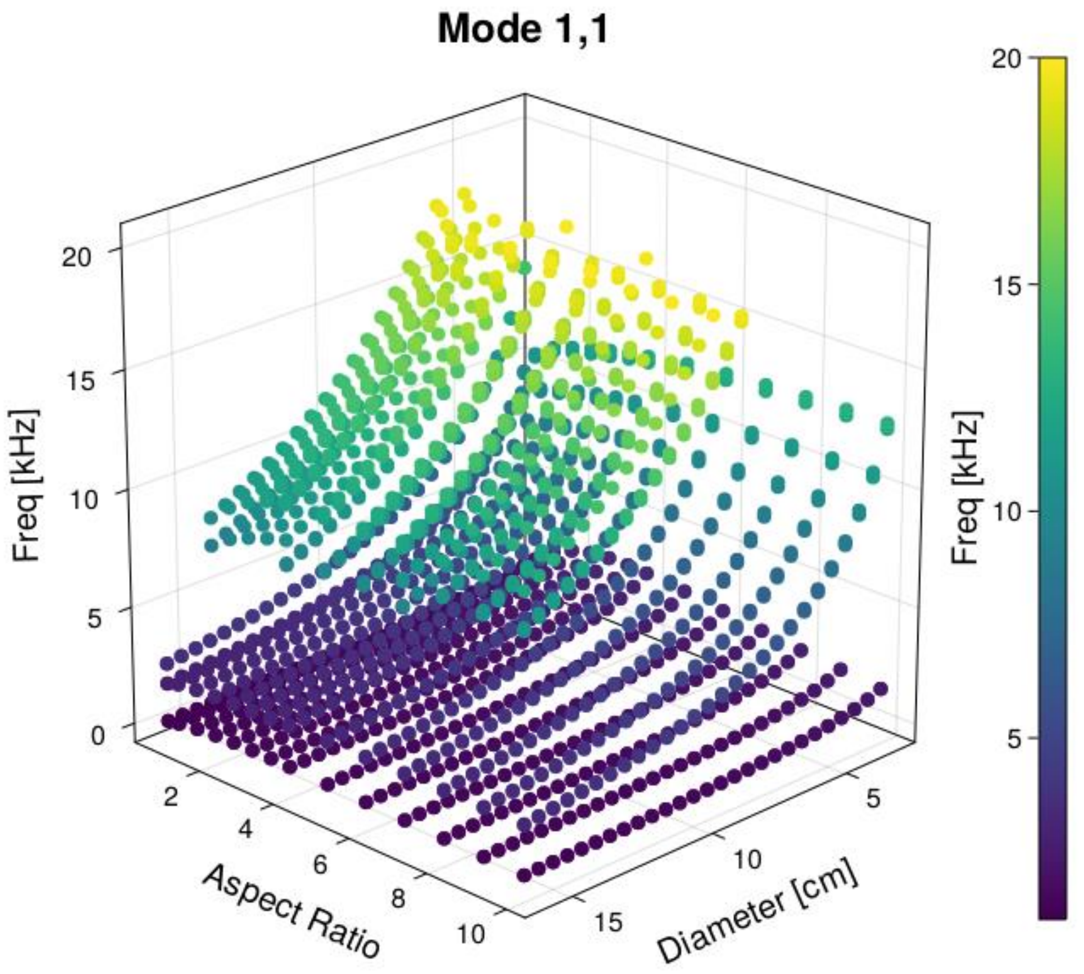




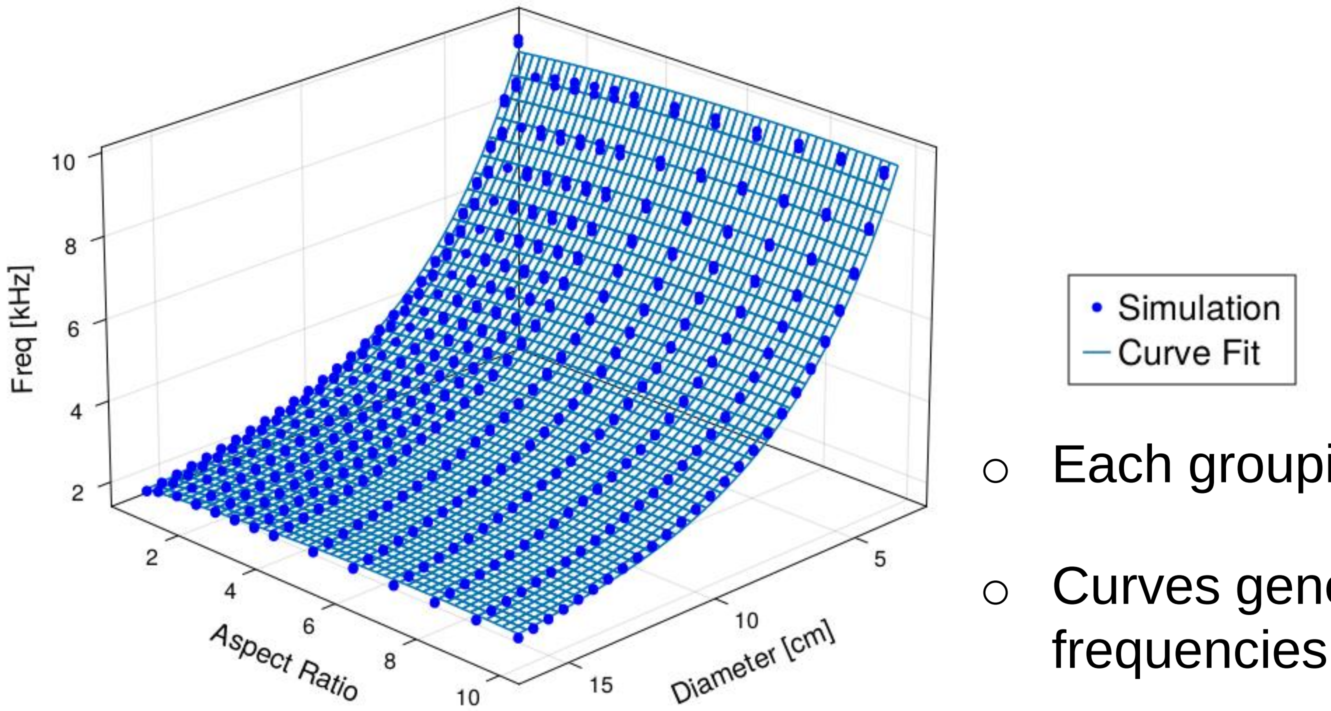


Simulation Sweep Results





Validation



Mode Shape	Predicted Freq [Hz]	Experimentally Measured Freq [Hz]
1,1	935	
2,1	3515	2971
1,1	6411	5942
3,1	6676	6919
0,1	7023	
0,1	8382	
4,1	8841	

- Each grouping can have a curve-fit applied
- Curves generate a list of mode shapes and frequencies at which resonance is predicted
- These predictions match what has been experimentally measured

Conclusions

- A small parameter simulation can capture the relevant physics of the resonant modes of outrunner brushless motors in the 1-5kW range.

- This model can be used to create a simple set of fitted functions that do not require even the FEA simulation to be performed.

Future Work

- Find method to quantify important and unimportant parameters and modify the model accordingly
  - Run simulations to see impact of each parameter
  - Approximate some parameters as functions of others
- Improve mode shape categorization and omit modes that won’t radiate acoustically
- Improve curve-fit equations
- Add amplitude predictions
- Continue experimental validation

- Integrate with the larger prediction tool (electro-magnetic forcing predictions and acoustic propagation calculations)

Questions?

Thank you!