

LOWERING THE BARRIER TO AEROACOUSTIC PREDICTION

GPU-COMPUTED SBES FOR FAR-FIELD LANDING GEAR NOISE PREDICTION

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MOTIVATION

- Simulating broadband noise from bluff bodies is computationally demanding.
- Scale resolving simulations with long sampling times result in days to weeks on CPU based solvers.
- Native GPU solvers reduce this to be on the order of hours lowering the barrier to practical design iterations.
- **Purpose:** Demonstrate a workflow to predict landing gear aeroacoustics using a native GPU based solver using SBES coupled with a FW-H acoustics model.



WORKFLOW DIAGRAM

Geometry Preparation
Domain and acoustic surfaces

Watertight Meshing
BOIs and sizing

STEADY-STATE SOLVE

Steady RANS
k-ω SST baseline solution

LES Grid-Scale Evaluation
Compute integral length scale L_0 for LES grid

Mesh Refinement
LES + acoustic mesh requirements

RANS Restart
Refined mesh → converged initial field

Transient SBES
WALE subgrid, scale-resolving solve

Acoustic Sampling
FW-H capture once transients flush out

Acoustic propagation
FW-H integral to receiver locations

TRANSIENT SCALE-RESOLVING SOLVE

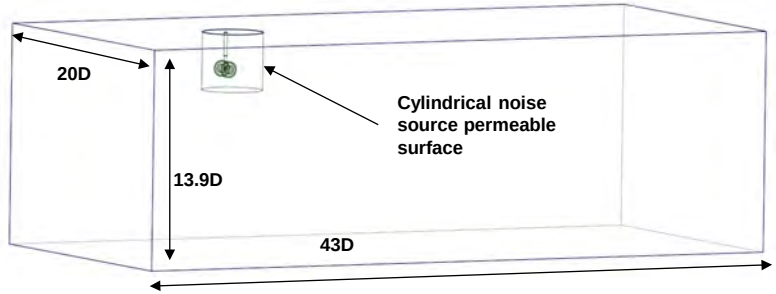
In this case, transient SBES is run for 0.1s followed by 0.1s of acoustic sampling

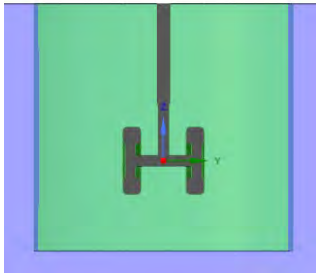
Ansys Fluent GPU solver used



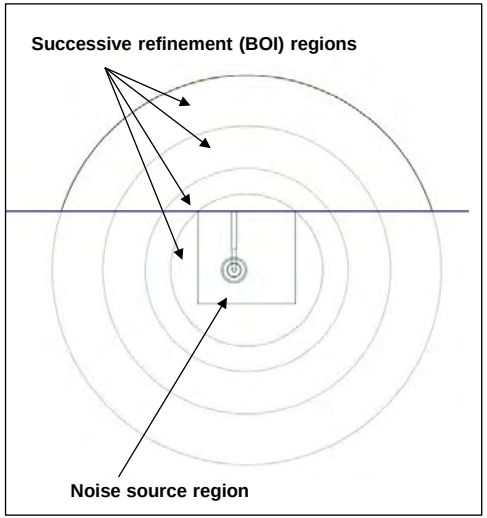
GEOMETRY

- Based on the LAGOON (1:2.5) nose landing gear – a standard aeroacoustics benchmark with published far field data.
- Domain sized to avoid boundary effects (reflections, blockage) contaminating solution.
- Domain is split into two regions
  - Localised noise source region (resolved gear, wake)
  - Coarser background region for the far field.
  - Refinements using BOI regions





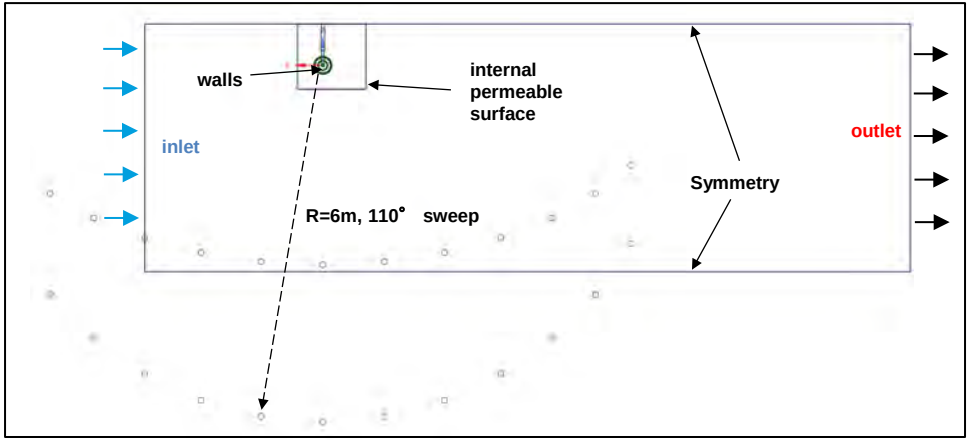


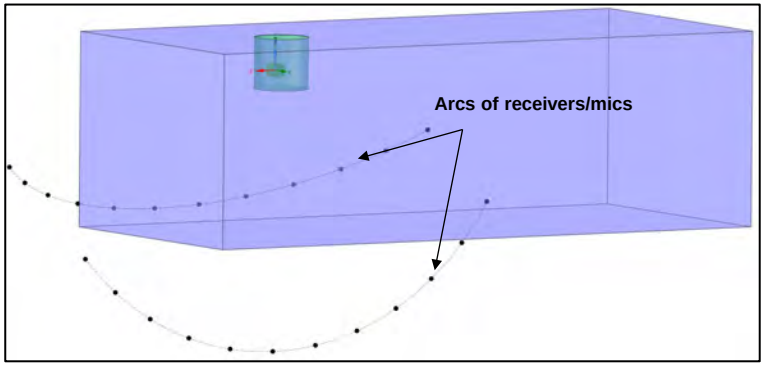


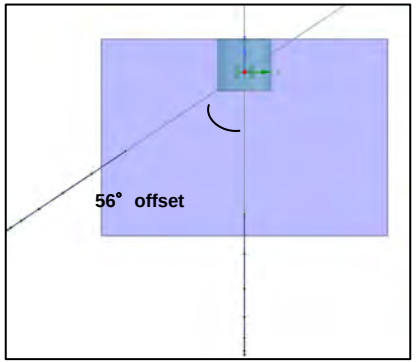


CASE CONDITIONS

- **Freestream & Inlet**
  - $U_\infty = 80m/s\ (M = 0.23)$
  - $P = 101325\ Pa,\ T = 22°C\ (Re_D \approx 1.6e6), Wheel\ D = 0.3m$
  - Turbulence intensity 1%, viscosity ratio 1.
- **Outlet**
  - Gauge pressure = 0
  - Non reflective acoustic boundary.
- **Walls**
  - Strut, wheels – smooth no slip.
  - All other domain faces – symmetry.
- **Farfield observers/receivers/mics**
  - Arc 1: R=6m, 110° sweep below wheel.
  - Arc 2: R=6m, 56° offset from Arc 1.









MESHING CRITERIA

- Mesh sizing governed by two factors:
  - LES scale resolution vs acoustic frequency capture.
  - For this flow condition and geometry, the frequency-based criteria is finer.
- Constant fine cell size held from wheel/strut walls to noise-source surface.
- Beyond the surfaces, octree transition of mesh sized by Body of Influence (BOI) regions.

$20\ cells\ across\ smallest\ wavelength$

$$\Delta x = \frac{C_0}{20 \cdot f_{max}}$$

$C_0 = Speed\ of\ sound$

$f_{max} = \max\ frequency\ resolved$

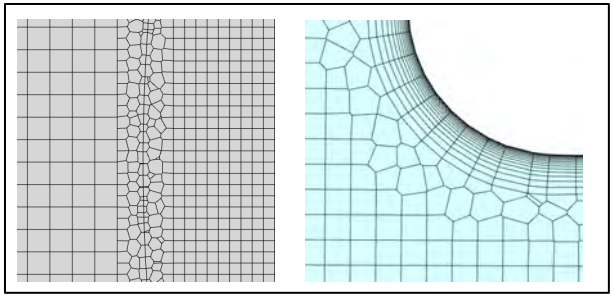
$$L_0 = \frac{k^{\frac{3}{2}}}{\beta^* k\omega} = \frac{\sqrt{k}}{0.09\omega}$$

$k, \omega\ field\ obtained\ from\ prev\ RANS\ run$

$LES\ filter\ size\ \Delta = \Delta x \leq \frac{L_0}{10}\ (or \frac{L_0}{20})$

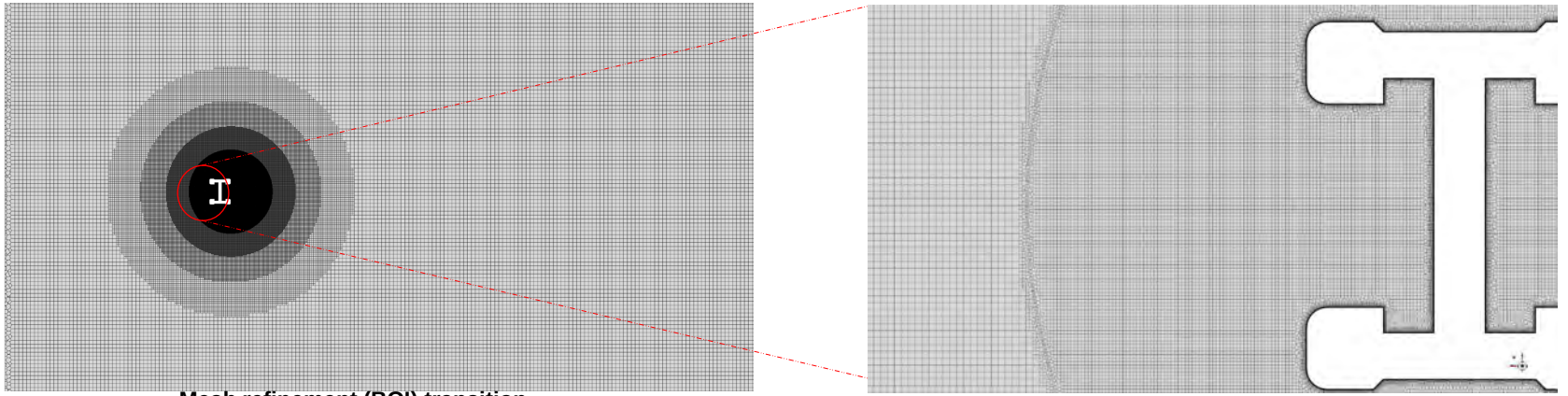
Poly-hexcore mesh
$\Delta x = 3.4mm$

42 million cells
6 min to mesh

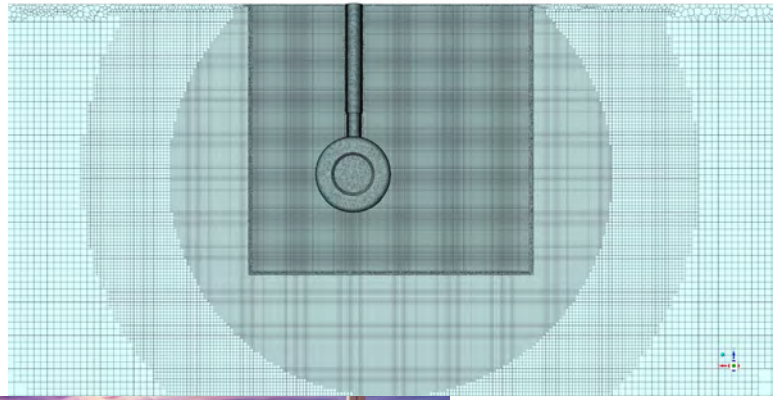


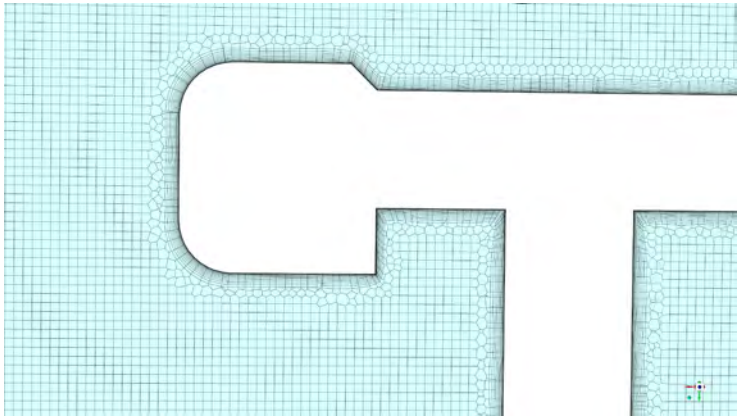


MESHING CRITERIA



Mesh refinement (BOI) transition





Inflation layer → Polyhedral → Hexcore transition



PHYSICS MODELS

- Ideal gas formulation is used
  - $U_\infty = 0.23\ Mach\ but\ U_{max} \sim 0.4\ Mach$
- Turbulence: Stress Blended Eddy Simulation.
  - Hybrid RANS-LES turbulence model, blending function from RANS to LES
  - RANS suitable aspect ratio grid at near wall with wall functions.
  - Wall-Adapting Local Eddy Viscosity model (WALE)
- Ffowcs Williams and Hawkings acoustic model.

$$\tau_{ij}^{SBES} = f_{SDES}\tau_{ij}^{RANS} + \left(1 - f_{SDES}\right)\tau_{ij}^{LES}$$

$$\nu_t^{SBES} = f_{SDES}\nu_t^{RANS} + \left(1 - f_{SDES}\right)\nu_t^{LES}$$

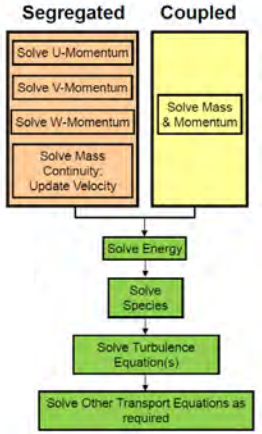
$$0 \le f_{SBES} \le 1$$

$$\begin{aligned}\frac{1}{a_0^2}\frac{\partial^2 p'}{\partial t^2} - \nabla^2 p' &= \frac{\partial^2}{\partial x_i \partial x_j}\{T_{ij}H(f)\} \\ &- \frac{\partial}{\partial x_i}\{[P_{ij}n_j + \rho u_i(u_n - v_n)]\,\delta(f)\} \\ &+ \frac{\partial}{\partial t}\{[\rho_0 v_n + \rho(u_n - v_n)]\,\delta(f)\}\end{aligned}$$



SOLVER METHODS AND FREQUENCY RESOLUTION

- SIMPLEC Segregated solver is used.
  - Better handling of skewed mesh cells.
- Second order spatial discretization for energy, turbulence equations.
- Low diffusion central differencing for momentum
  - Central scheme with a local upwinding scheme when the solution is unsmooth.
  - Linear Pressure discretization.
- SRS time-stepping dependent on maximum frequency to be resolved.
- Frequency resolution dependent on acoustic sampling duration.



$$\Delta t \leq \frac{1}{20 \cdot f_{max}}$$

$$\boldsymbol{f_{max} = 5kHz,\ \Delta t = 1e-5\ s}$$

$$\Delta f = \frac{1}{T_{sampling}}$$

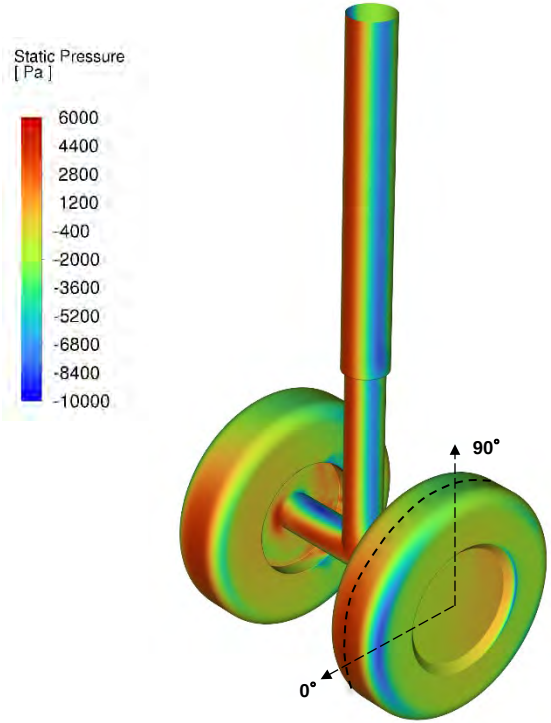
$$\boldsymbol{T_{sampling} = 0.1s, \Delta f = 10Hz}$$



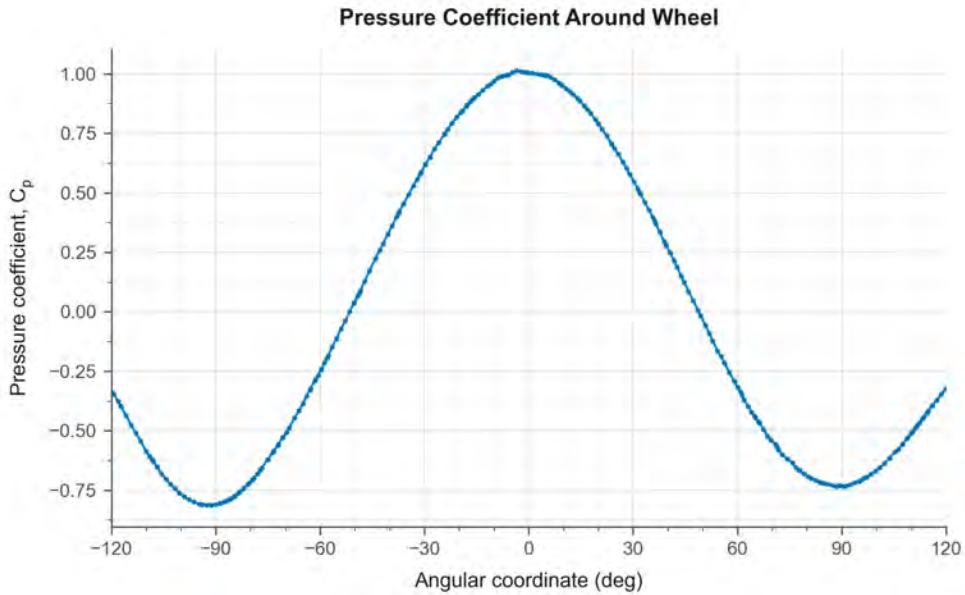
FLOW RESULTS



PRESSURE DATA

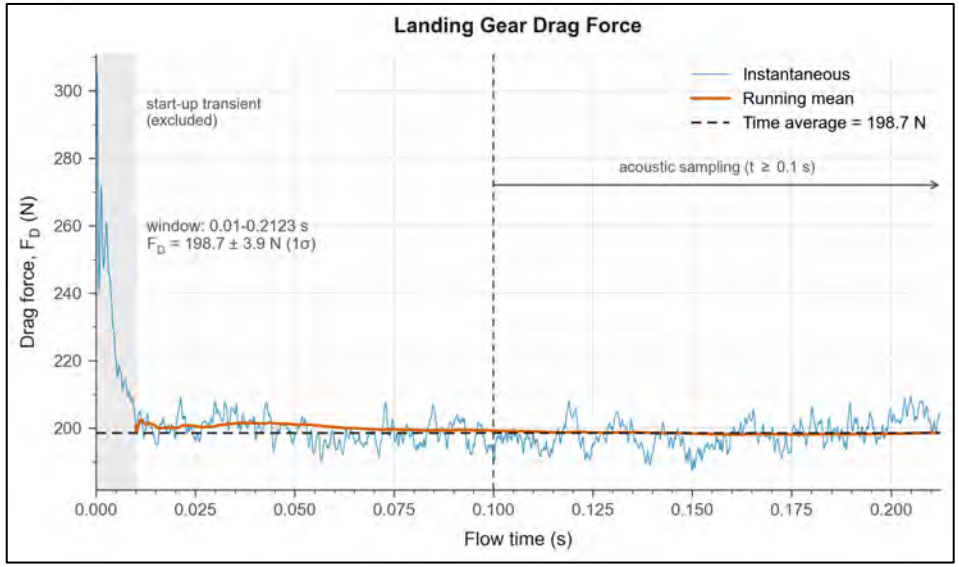


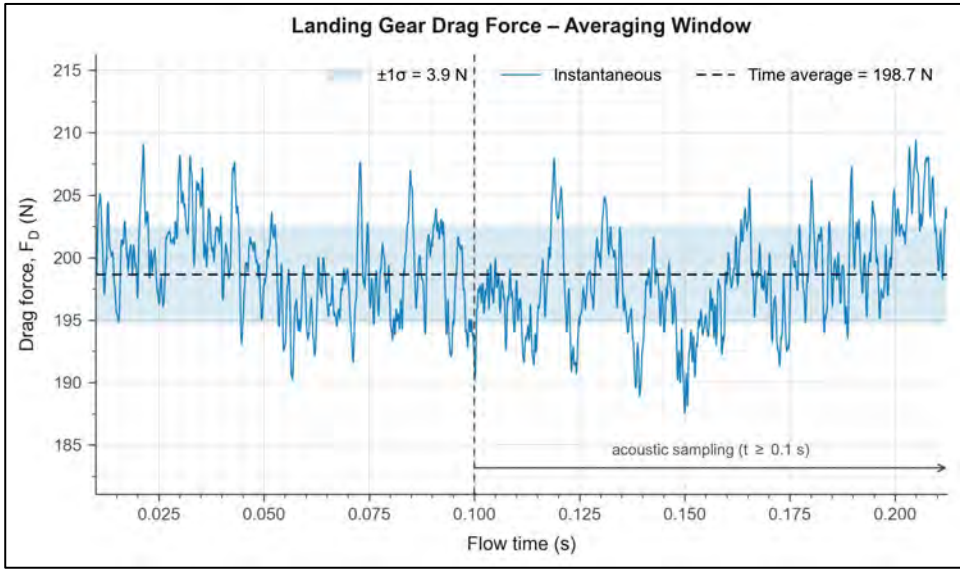
Pressure Contour (Gauge Static Pressure)





DRAG TIME HISTORY

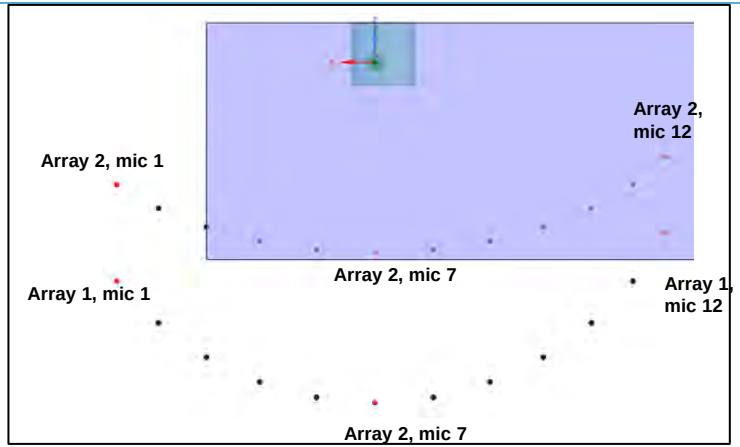


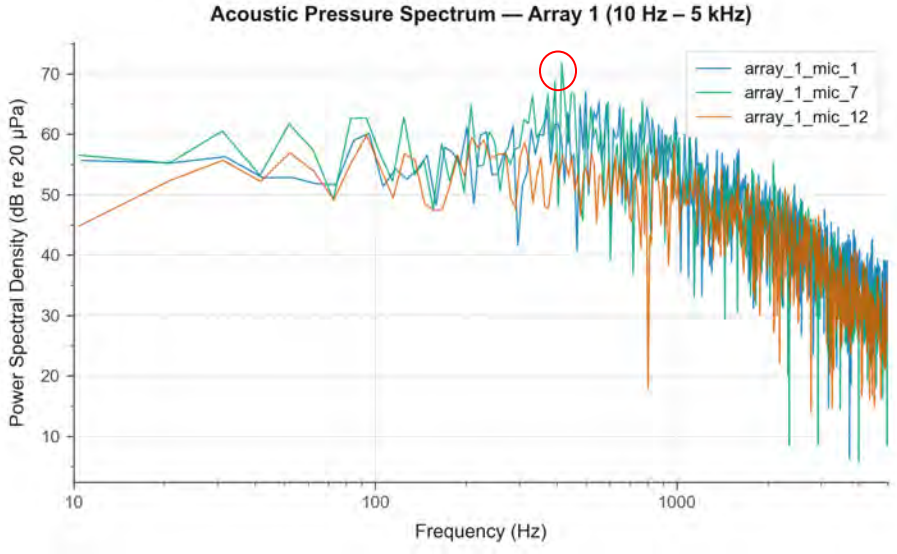




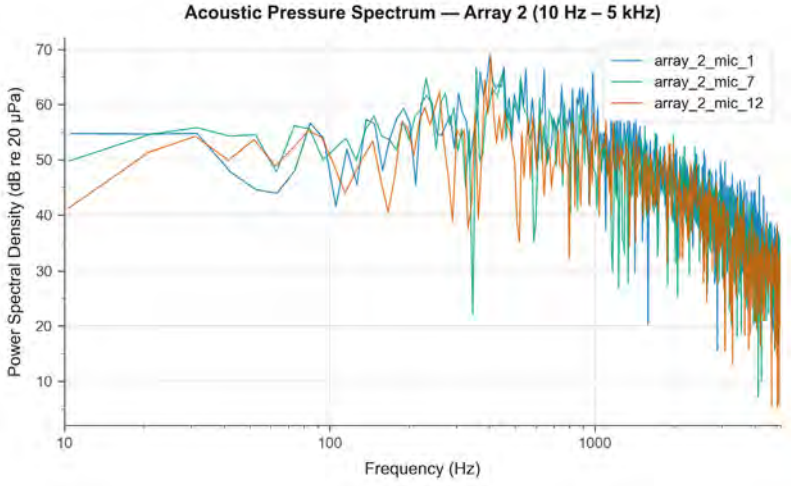
FARFIELD NOISE SPECTRUM

- Three mics in each array are considered for this analysis.





Peak frequency in mic 7 ~400Hz

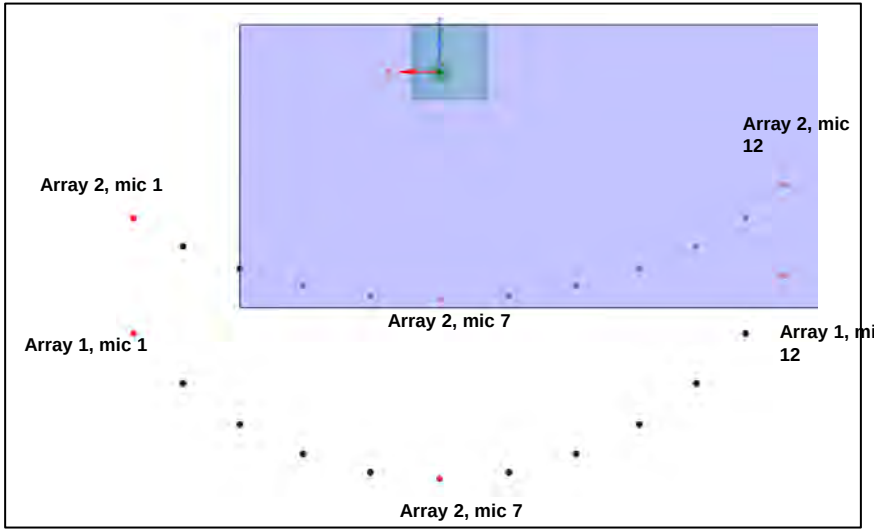




FARFIELD SOUND PRESSURE LEVEL

- Three mics in each array are considered for this analysis.
- The overall sound pressure level can be calculated as follows.

$$\mathrm{OASPL} = 10\log_{10}\left(\frac{1}{p_{\mathrm{ref}}^2}\int_{f_1}^{f_2} S_{pp}(f)\,\mathrm{d}f\right)$$



Discretized form of equation

$$\mathrm{OASPL} = 10\log_{10}\left(\frac{1}{p_{\mathrm{ref}}^2}\sum_{i=1}^{N-1}\frac{S_{pp,i}+S_{pp,i+1}}{2}(f_{i+1}-f_i)\right)$$

Microphone	OASPL (dB re 20 µPa)
Array_1_mic_1	90.2
Array_1_mic_7	91.2
Array_1_mic_12	85.3
Array_2_mic_1	90.8
Array_2_mic_7	88.5
Array_2_mic_12	86.7



TIMING AND BENCHMARKING

Steady state	CPU baseline	GPU
Hardware	64 cores AMD EPYC 9534	2 × NVIDIA RTX 6000 Ada
Time per iteration	7.4s	2.0 s

Transient	CPU baseline	GPU
Hardware	64 cores AMD EPYC 9534	2 × NVIDIA RTX 6000 Ada
Time per iteration	5.8 s	0.98 s
Wall clock time	4.3 days*	17.4 hours

6X speedup

Runs that take a week are reduced to a day

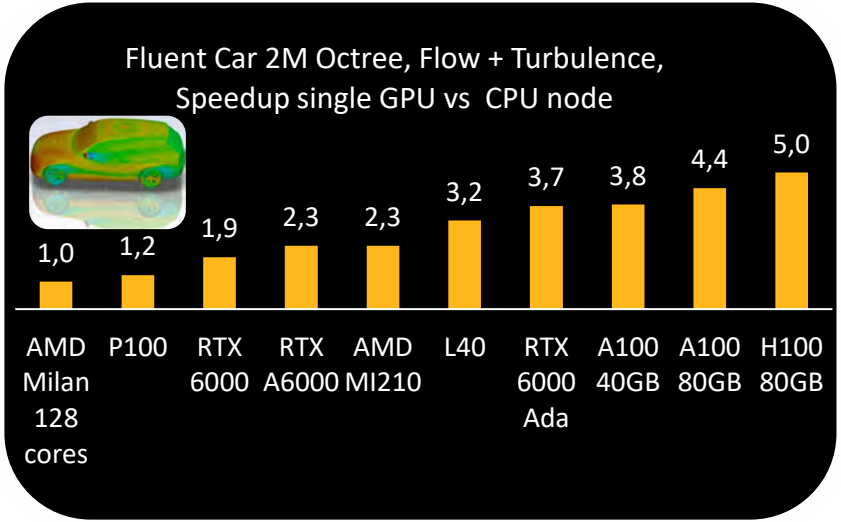
- **Steady state solve time - 15 - 30 min**
  - 500 iterations to pseudo-steady state
  - Extended a further 500 iterations to confirm convergence
- **Transient solve time - 17.4 hr**
  - 0.1 s startup transient
  - 0.1 s acoustic sampling

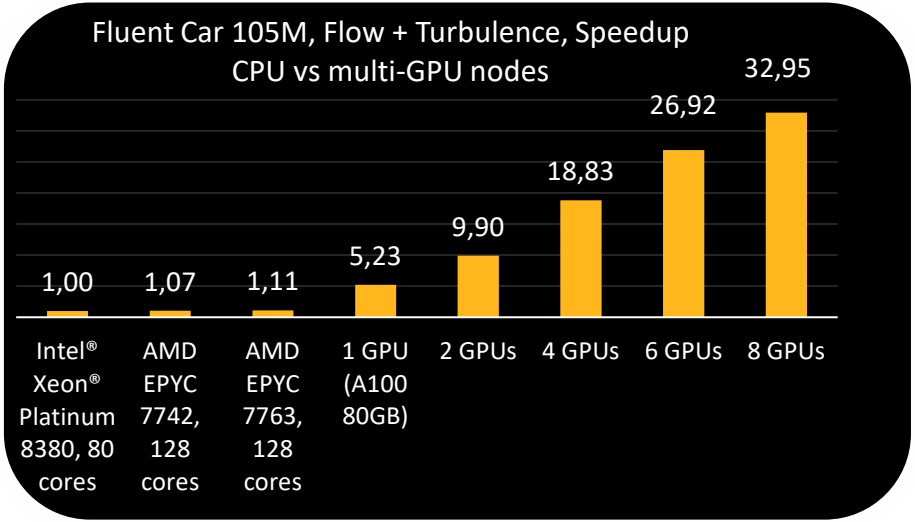


*CPU wall clock time is estimated based on time per iter. Roughly 2-3 iterations per timestep.

LOOKING AHEAD

- Scaling is very parallel even across multiple GPUs





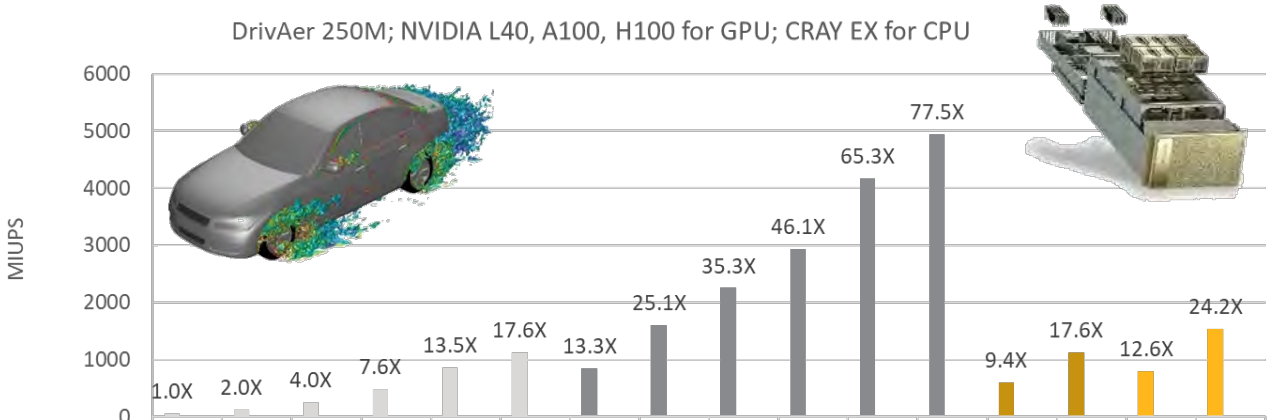
Parallel efficiency of 80% with 8 GPU cards!



LOOKING AHEAD CONTD.

Ansys / FLUENT NVIDIA

- **CPU**
  - **CRAY EX**
  - **AMD EPYC 7763 64-Core**
  - **128 cores per node**
- **GPU**
  - **Cluster 1**
    - **NVIDIA L40, 4 GPUs per node, Infiniband**
  - **Cluster 2**
    - **NVIDIA A100 80GB, 8 GPUs per node**
  - **Cluster 3**
    - **NVIDIA H100 80GB, 8 GPUs per node**
- **With 64 L40 GPUs**
  - **0.05 seconds per iteration**
  - **5 iterations per step**
  - **10000 steps in 40 minutes with**



	512	1024	2048	4096	8192	12288	8 L40 GPUs	16 L40 GPUs	24 L40 GPUs	32 L40 GPUs	48 L40 GPUs	64 L40 GPUs	4 A100 GPUs	8 A100 GPUs	4 H100 GPUs	8 H100 GPUs
MIUPS	64	125	252	483	863	1124	848	1598	2254	2939	4164	4943	602	1124	802	1541
Parallel efficiency	100%	98%	99%	95%	85%	73%	100%	94%	89%	87%	82%	73%	100%	93%	100%	96%
Time per iteration	3.92	2.00	0.99	0.52	0.29	0.22	0.29	0.16	0.11	0.09	0.06	0.05	0.41	0.22	0.31	0.16

A single H100 GPU ≈ 1,500 CPU cores

