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LBM +GPU: CFD 流体仿真的超级加速器

LBM +GPU: CFD 流体仿真的超级加速器

ultraFluidX

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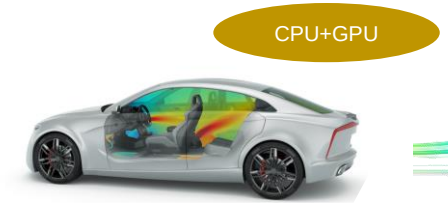
Altair CFD概述

适用于不同应用场景的CFD求解器

- AcuSolve：FEM算法，通用热-流体分析
- **ultraFluidX**：LBM算法，虚拟风洞、车辆空气动力学、气动噪声
- nanoFluidX：前后处理SimLab集成，SPH算法，传动系统润滑、液体晃动、涉水
- SimLab Electronics Thermal ： 前后处理SimLab集成， FVM算法，PCB板级，电子设备机箱散热仿真
- Flow Simulator：一维流动和热网络，系统级CFD仿真



通用热流体

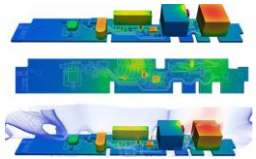
AcuSolve

空气动力学

ultraFluidX

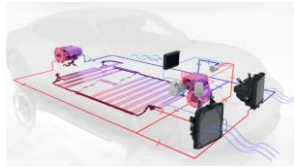
涉水和传动系统

nanoFluidX



电子散热

Electronics Thermal



一维流体系统

FlowSimulator

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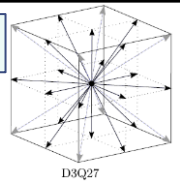
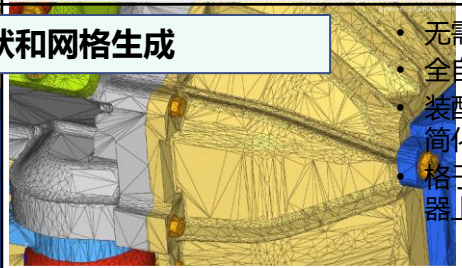
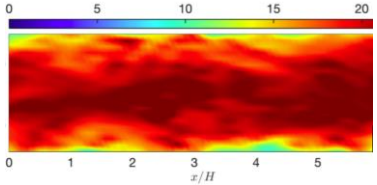
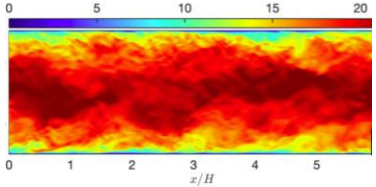
LBM算法与传统网格法CFD的优势

传统网格CFD (RANS Based)	数值方法	Lattice Boltzmann
• 被视为连续体的流体：纳维-斯托克斯方程 （PDE） • 离散计算网格上偏微分方程的数值求解 $\left(\frac{\partial}{\partial t}+u_j\frac{\partial}{\partial x_j}-\nu\frac{\partial^2}{\partial x_j\partial x_j}\right)u_i=-\frac{\partial w}{\partial x_i}+g_i$		 D3Q27 • 由在规则晶格网格上移动的离散粒子表示的流体 • 通过简单的粒子迁移和碰撞实现的数值解 • 高效的数值方案 • 在宏观尺度上完全恢复纳维-斯托克斯方程 $f_\alpha(t+\Delta t,\boldsymbol{x}+\boldsymbol{e_\alpha}\Delta t)=f_\alpha(t,\boldsymbol{x})+\Omega_\alpha$
• 流体体积网格从固体表面网格生长而来 • 必须简化复杂的几何形状 • 手动/半自动网格生成	**复杂几何形状和网格生成**  	• 无需简化的 CAD 几何形状 • 全自动流体体网格（格子）生成 • 装配体允许穿透和干涉，原始CAD无需简化 • 格子（Voxel）基于模板文件在GPU服务器上生成，设计变动仅需替换STL文件
• 模拟大多以稳态运行 • 非定常模拟代价较高 • 高质量体积网格 • 不保证数值收敛	**瞬态计算和稳健性**  	• 模拟本质上是瞬态的 • 求解非稳态Smagorinsky LES大涡模拟模型 • 低数值耗散 • 更好的 HPC 扩展性能 • 稳定性强 • 完全基于NVIDIA GPU加速

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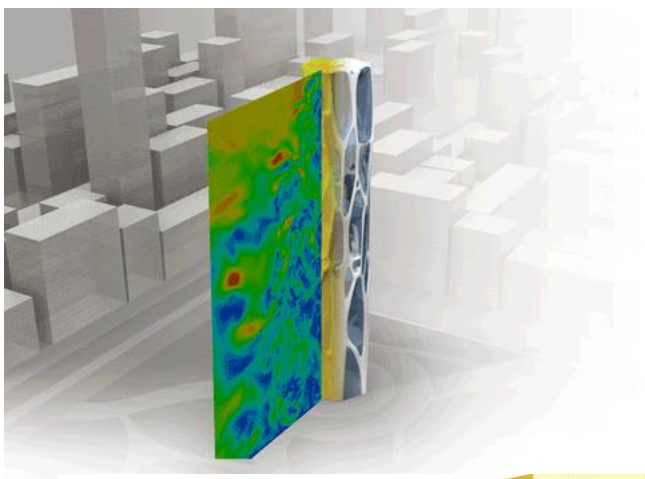
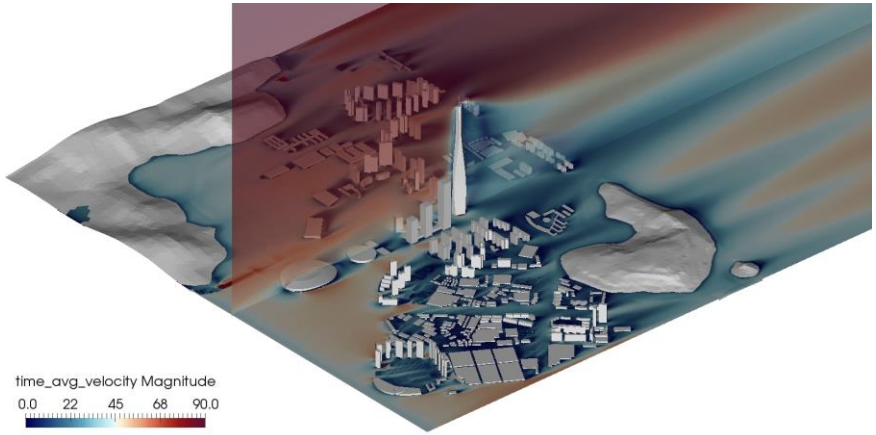
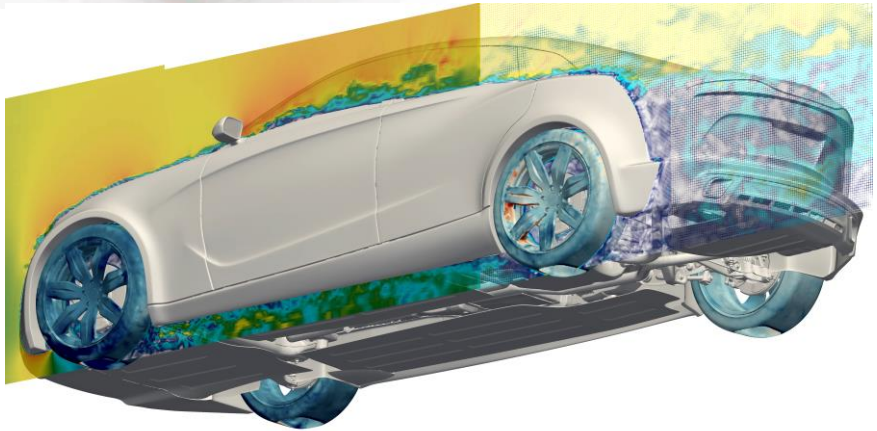
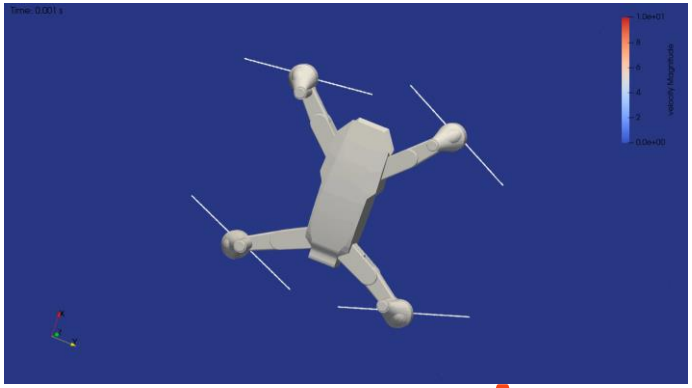
空气动力学

ultraFluidX的应用：低速空气动力学









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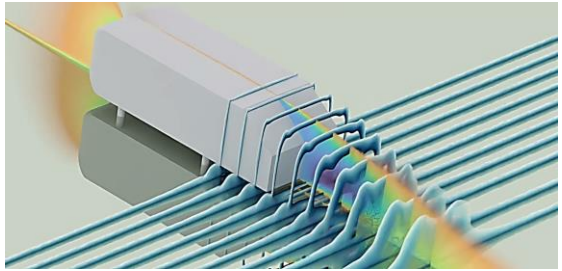
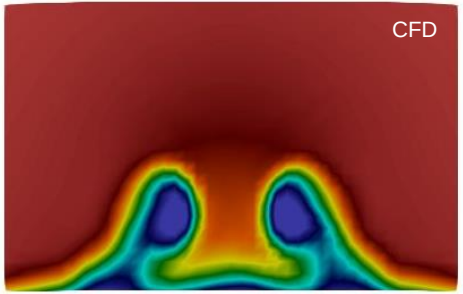
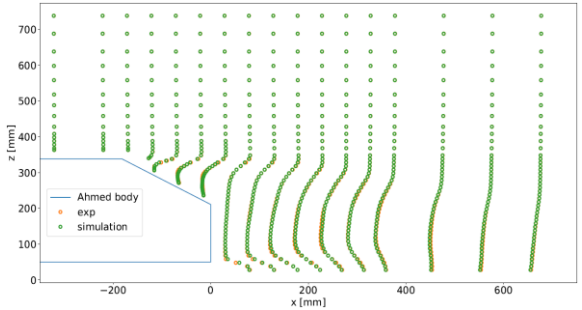
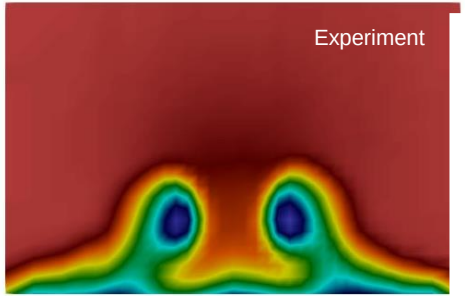
ultraFluidX的应用：低速空气动力学

更新了湍流壁面函数



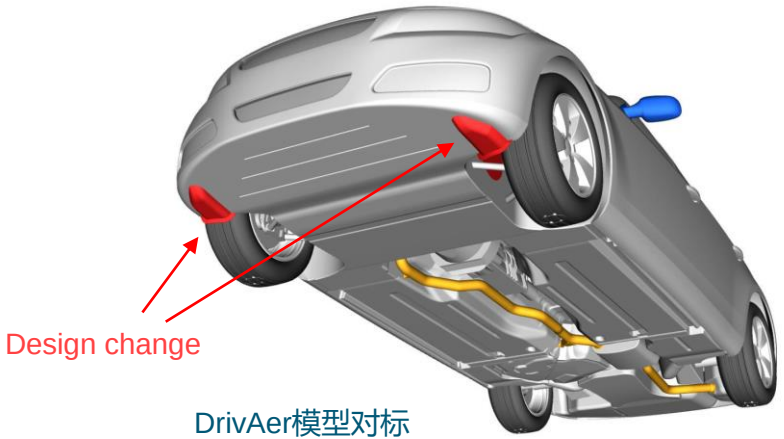




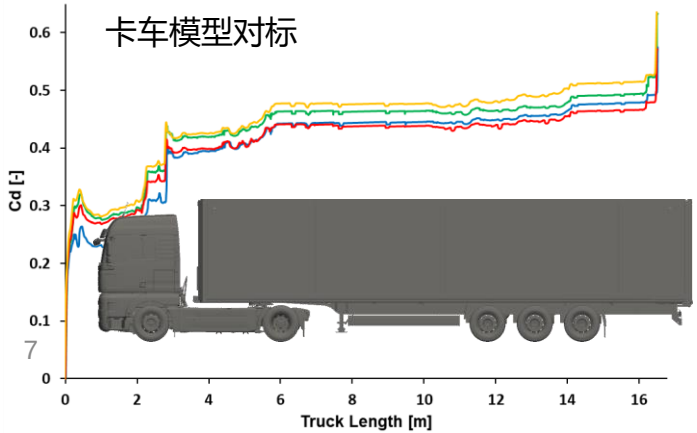


Ahmed Body对标

尾迹区预测



DrivAer模型对标



空气动力学设计优化流程

造型和仿真深度融合，借助高性能GPU计算服务器，1天以内完成1轮设计迭代

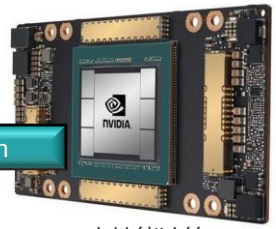
初版设计数据

Inspire Studio

HyperMesh CFD前处理

Preparation

Simulation



GPU高性能计算

1天内完成1轮设计迭代

Design

Inspire Studio造型

Investigation

HyperMesh CFD后处理

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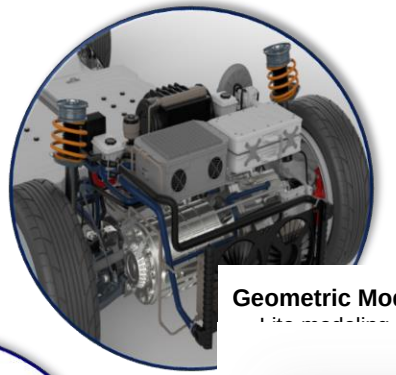
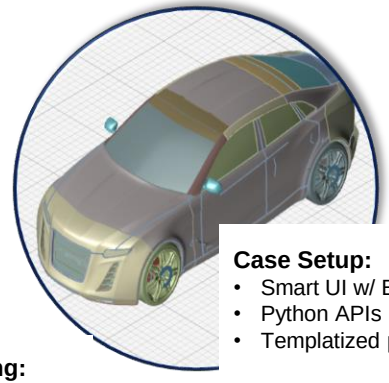
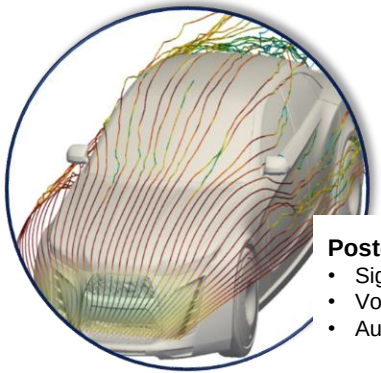
Hypermesh CFD 快速的前后处理工具



Geometric Modeling:

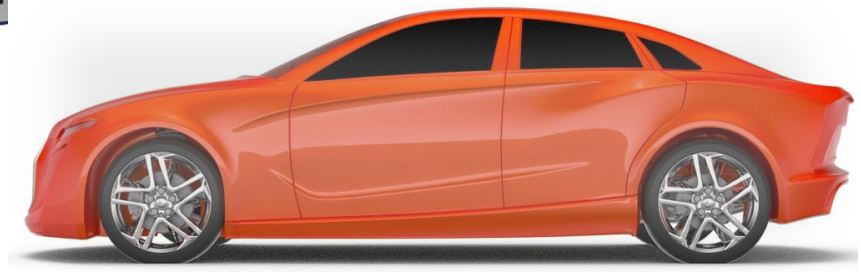


Case Setup:
- Smart UI w/ Best Practices
- Python APIs
- Templatized process



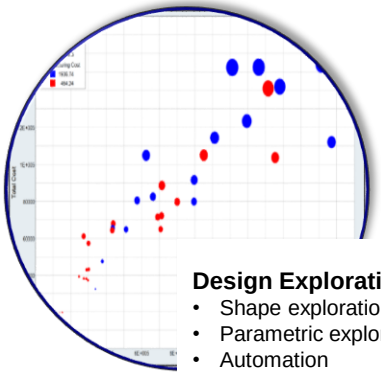
Post-processing:
- Signal processing
- Volume rendering
- Auto reporting tool

Solution Layer:
- Single UI integration
- Solution centric workflows
- Efficient Data handling



HyperMesh CFD 2024

整车建模，CFD参数设置，CFD后处理



Design Exploration:
- Shape exploration
- Parametric exploration
- Automation

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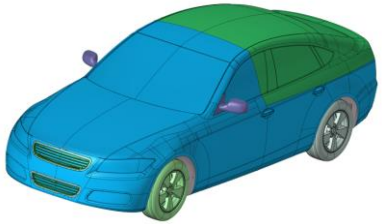
Hypermesh CFD 前处理

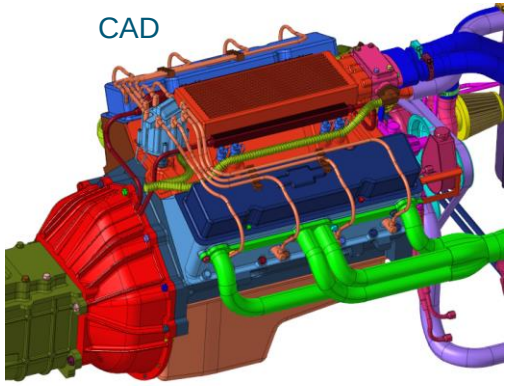
STL



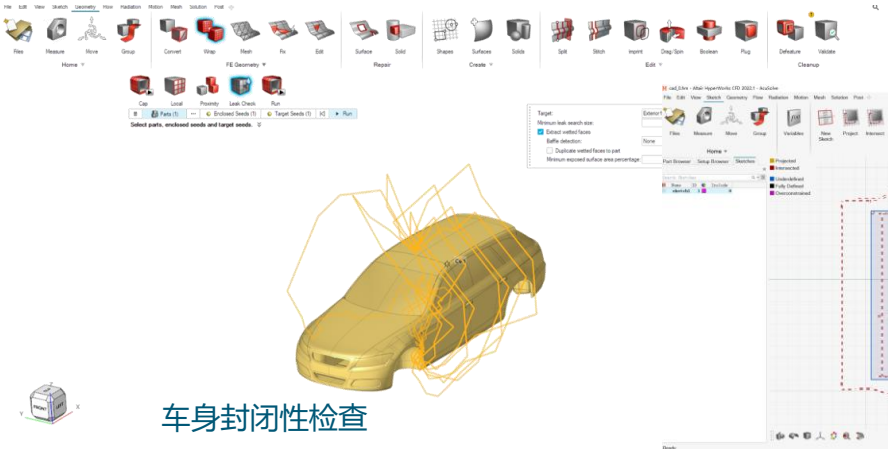
offset

projected

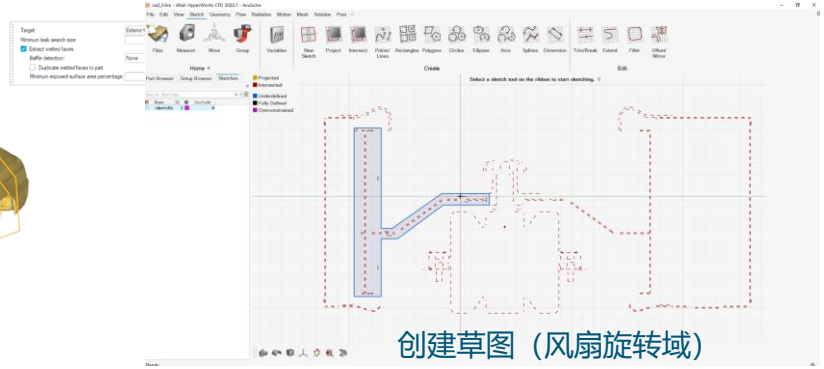
CAD



网格包面

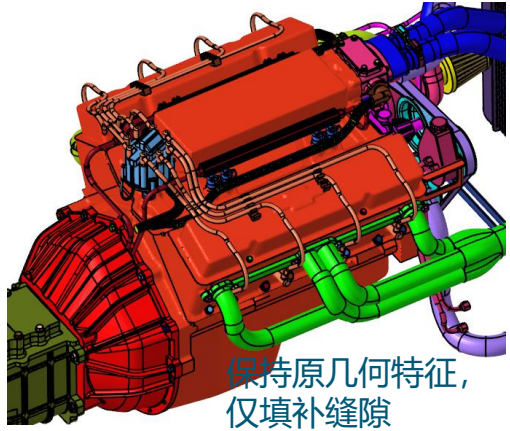


车身封闭性检查



创建草图（风扇旋转域）

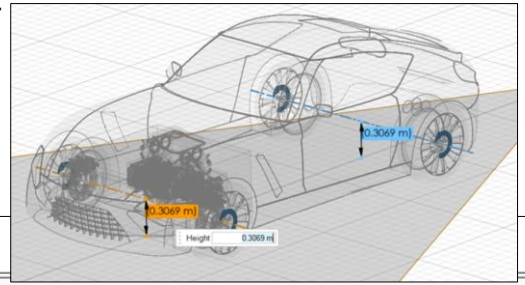
STL

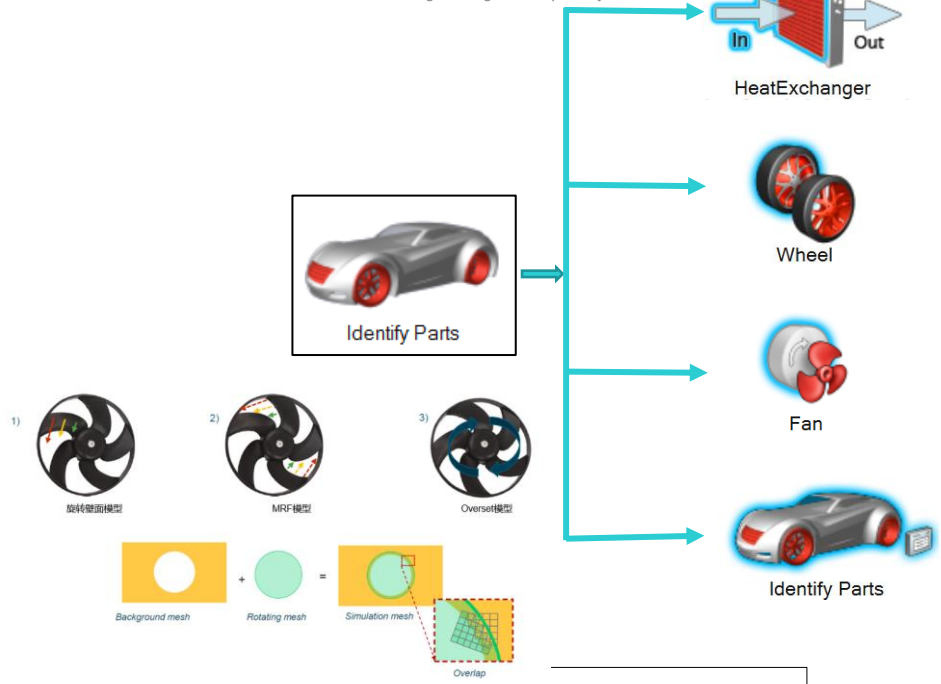


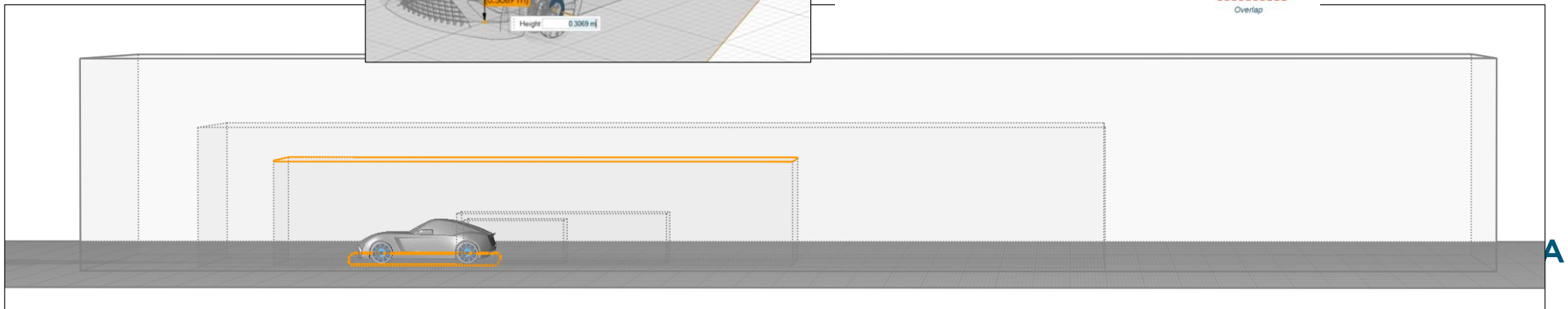
保持原几何特征，
仅填补缝隙

Hypermesh CFD求解设置

- 多孔介质（换热器）
- 地面移动系统（5带，单带），边界层抽吸
- 旋转体识别（风扇，轮胎）
- 格子加密
- 悬架高度调整
- 监测点，监测面，切面定义等输出选项
- 悬架高度调节

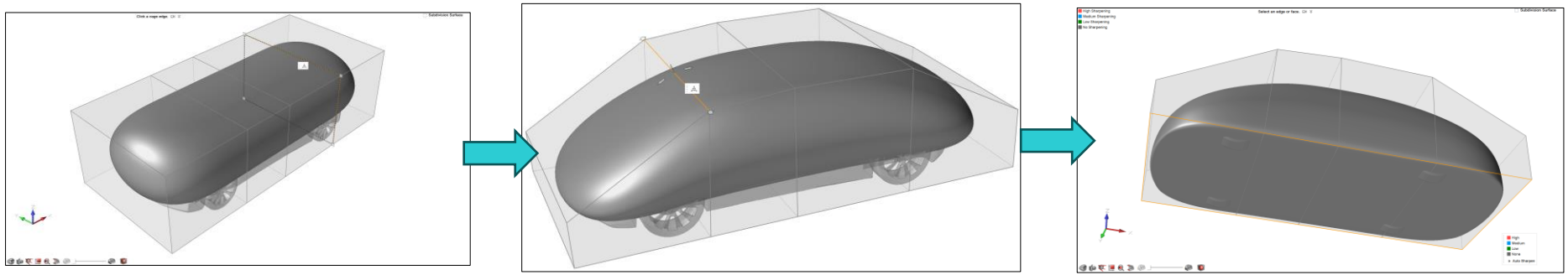


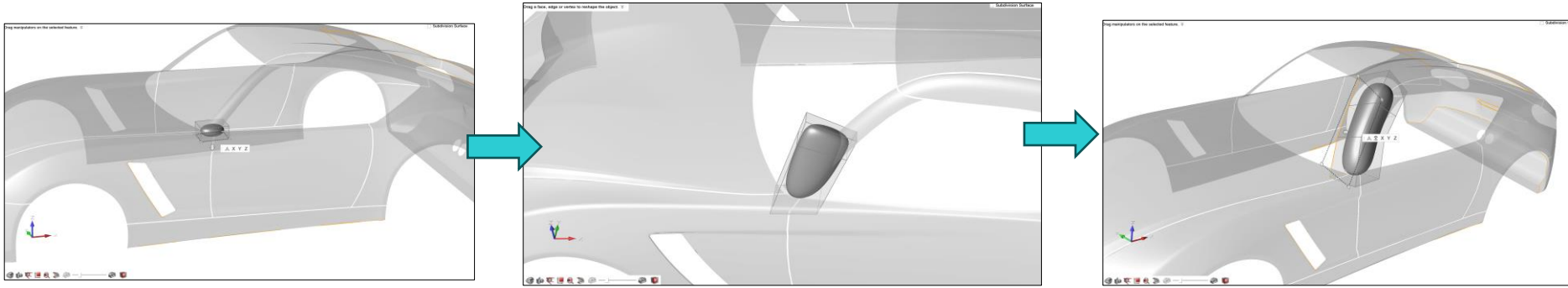




Hypermesh CFD快速造型设计

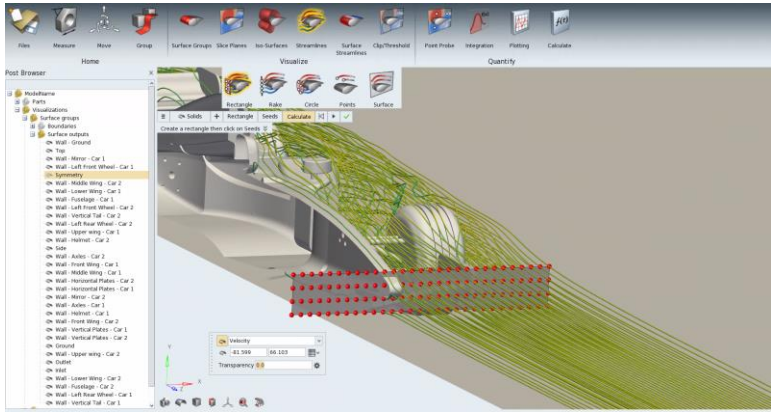
快速调整造型或加密区域形状

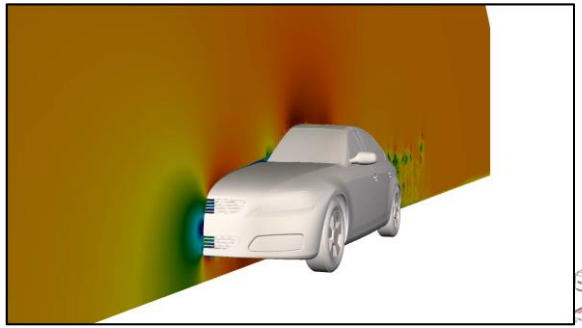


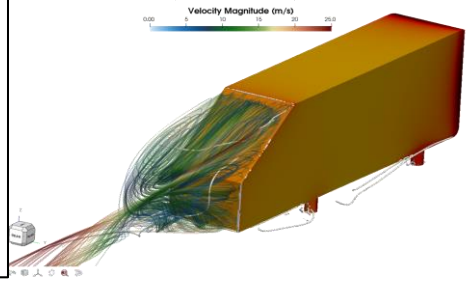


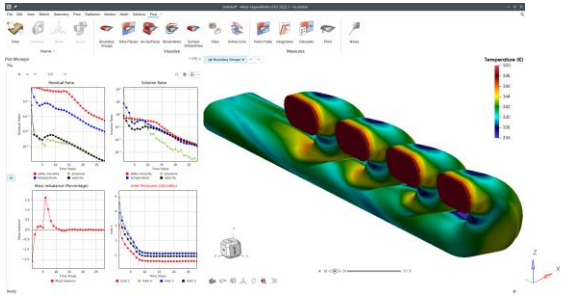
Hypermesh CFD后处理

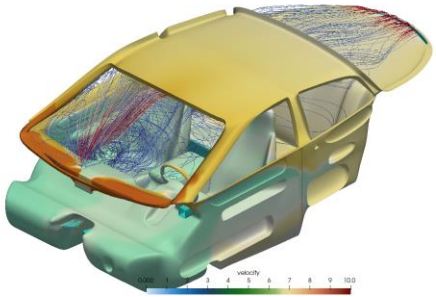
- 通用CFD后处理：
  - 支持格式：LBM、传统网格法CFD结果，Ensight，h3d结果
  - 云图、矢量图，动画、流线、积分、XY Plot等等

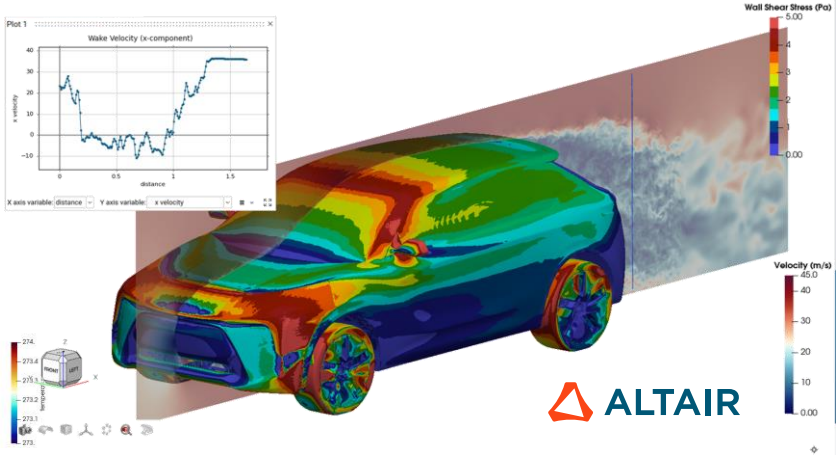












Hypermesh CFD自动出具报告

External Aerodynamics Results
Report Template

HWCFD | Altair

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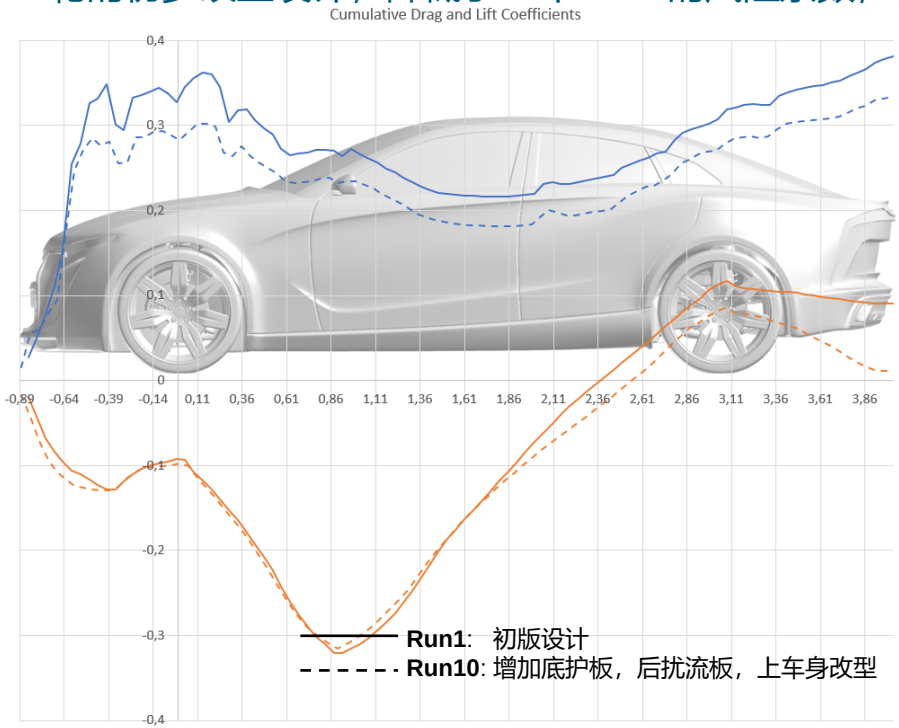
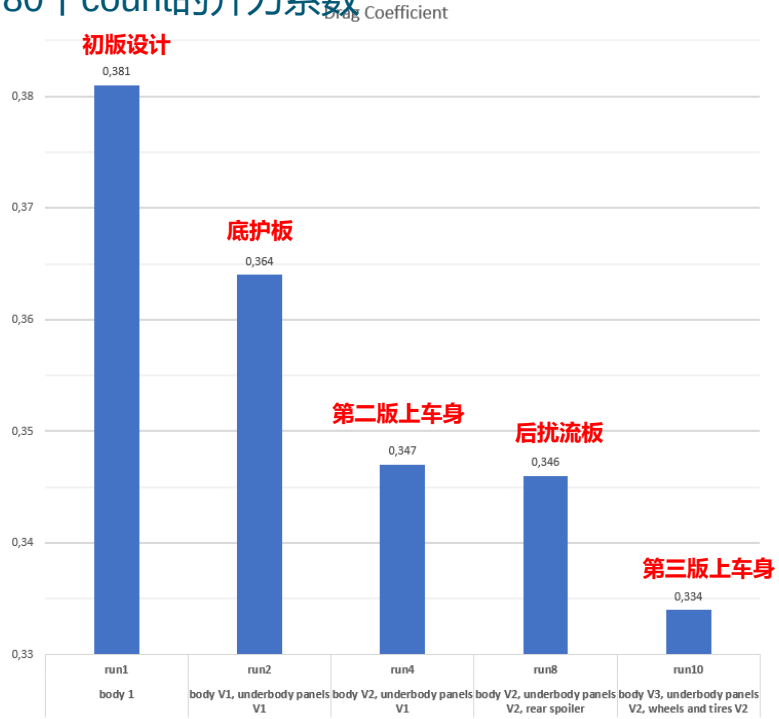
空气动力学设计快速迭代

10轮的初步改型设计，降低了47个count的风阻系数，和80个count的升力系数



风阻发展曲线对比



风阻系数的迭代

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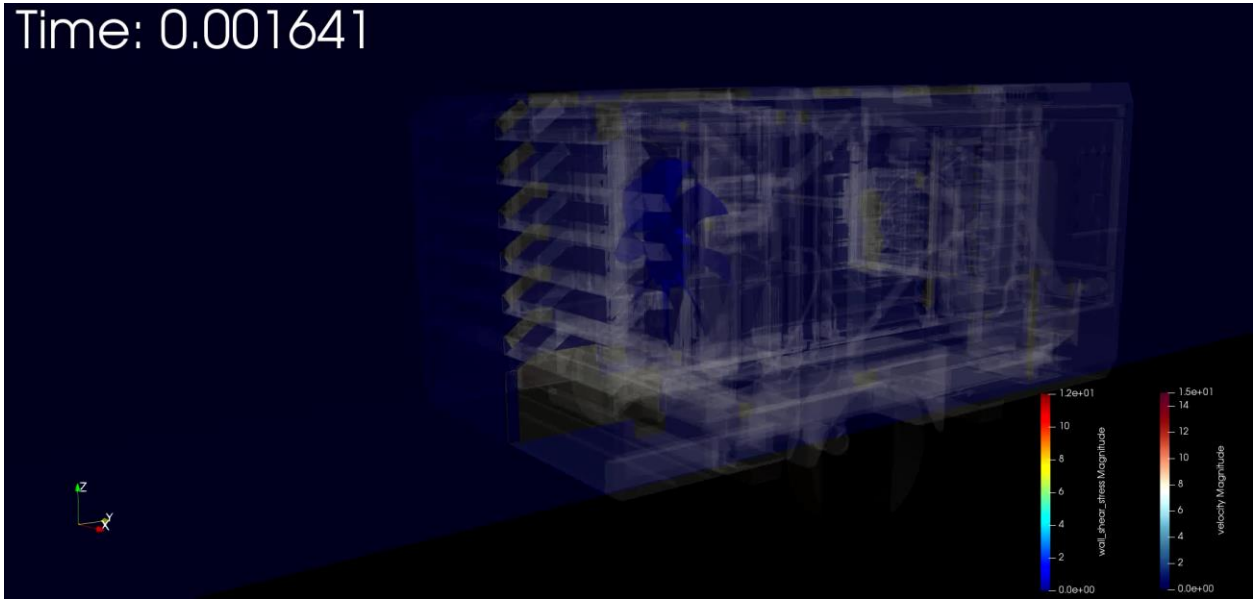
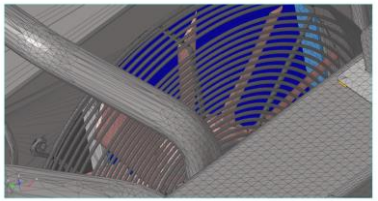
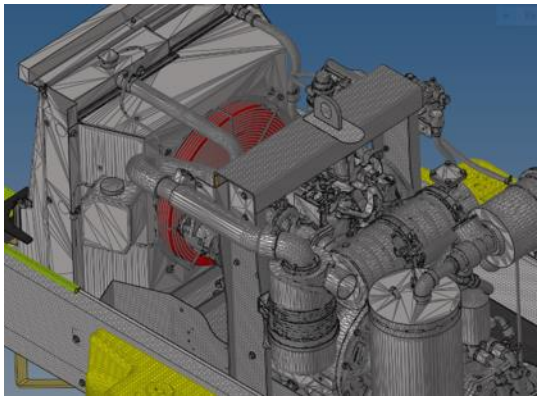
风扇噪声

ultraFluidX: 近场噪声







包含全细节的机舱模型，总格子数6亿
8张A100 GPU计算2天

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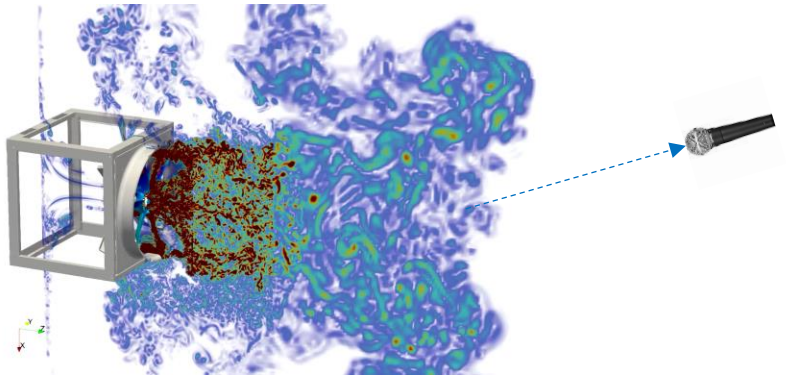
ultraFluidX: FW-H模型

噪声远场传播

- ultraFluidX可以直接模拟从噪声源到接收端的声传播现象。如果传播距离较长，格子总数会增加
- FW-H模型基于声学类比法，单独求解波动方程模拟噪声的传播
  - 适合接收端距离声源较远的情况，减少了格子总数
  - 声波是自由传播的，可以考虑XYZ方向的反射和吸收
  - 在前处理建模中需要创建一个包裹住声源的监测面，记录监测表面上的压力脉动



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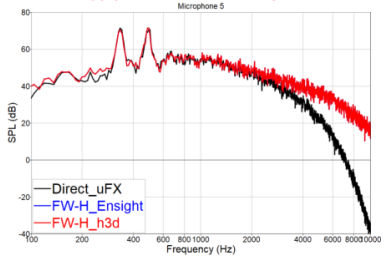
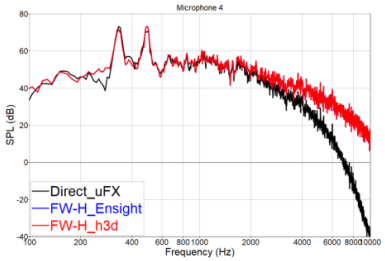
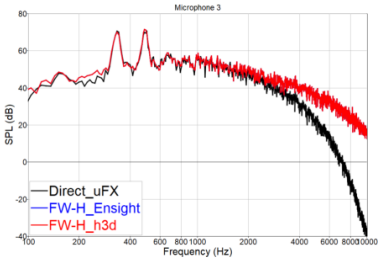
ultraFluidX: FW-H模型

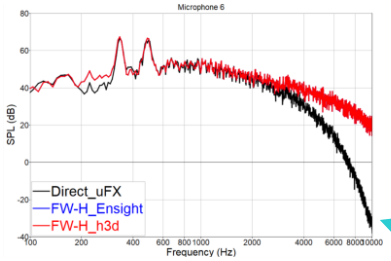
风扇噪声传播，直接模拟和FW-H对比

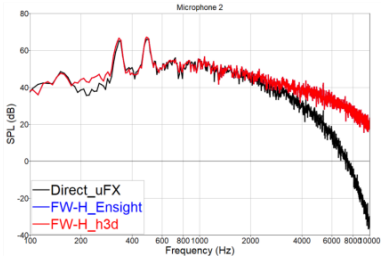
如果声波传播路径上的格子尺寸太粗，在高频部分会造成信号衰减，FW-H模型可以避免这种情况

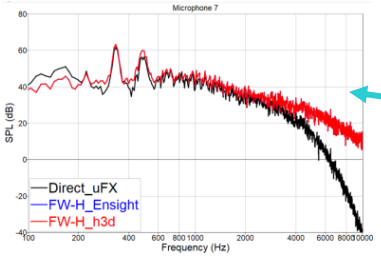


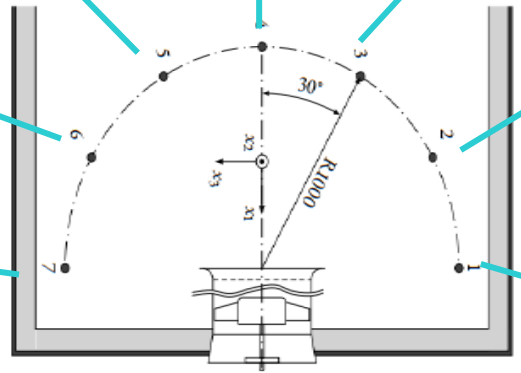


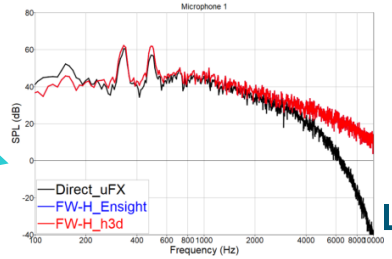












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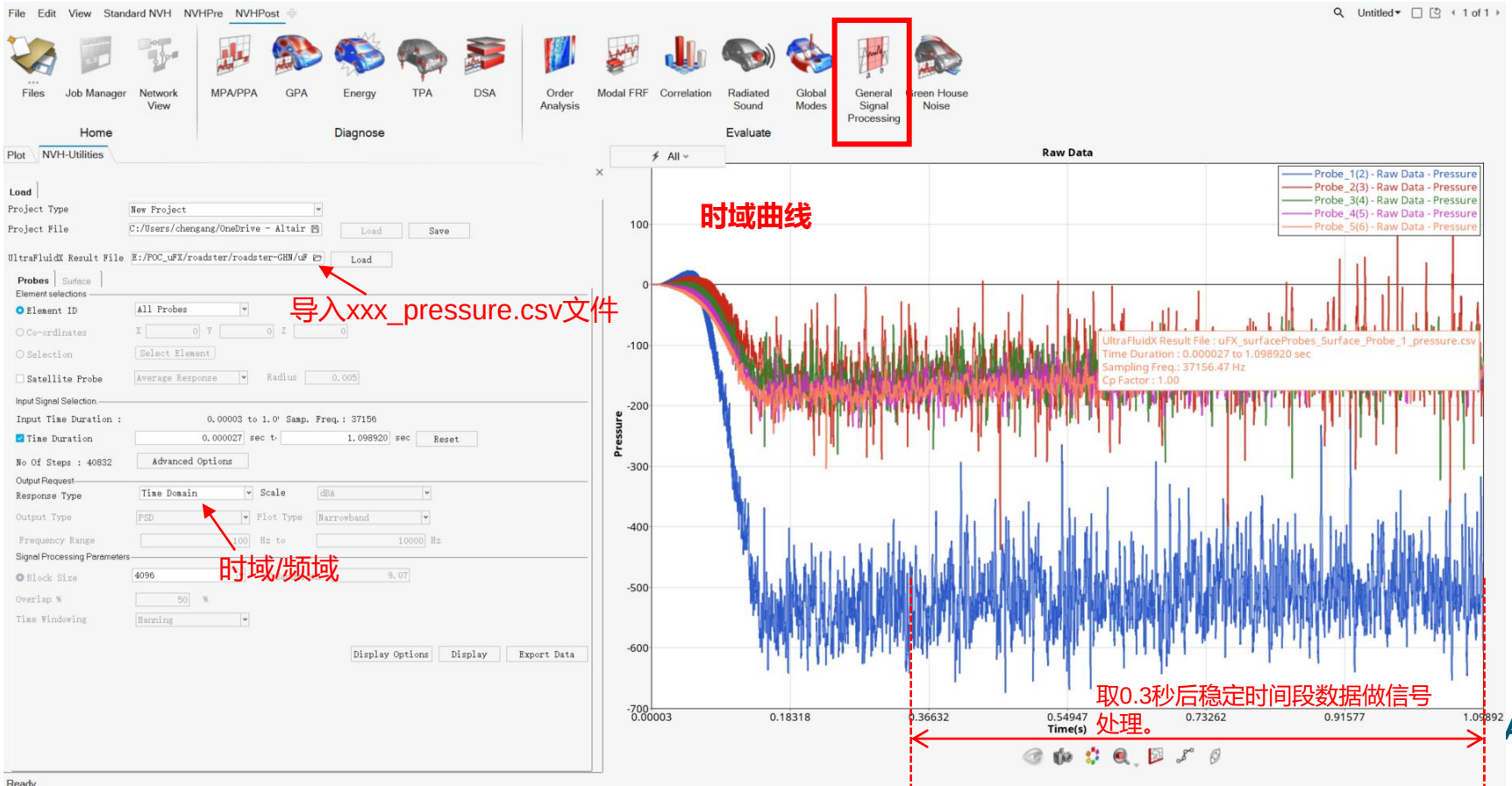
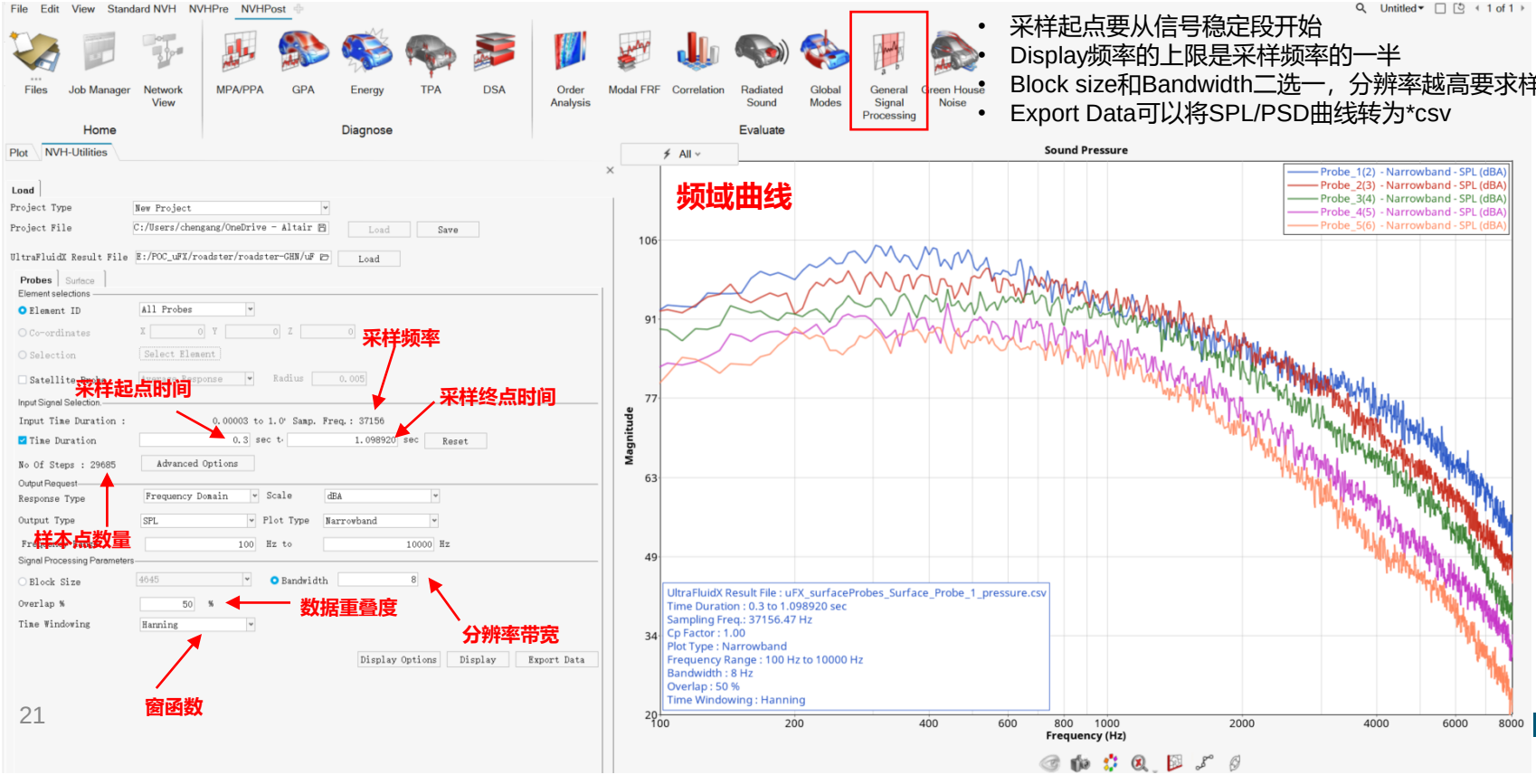
Hypermesh NVH噪声信号处理-监测点的信号

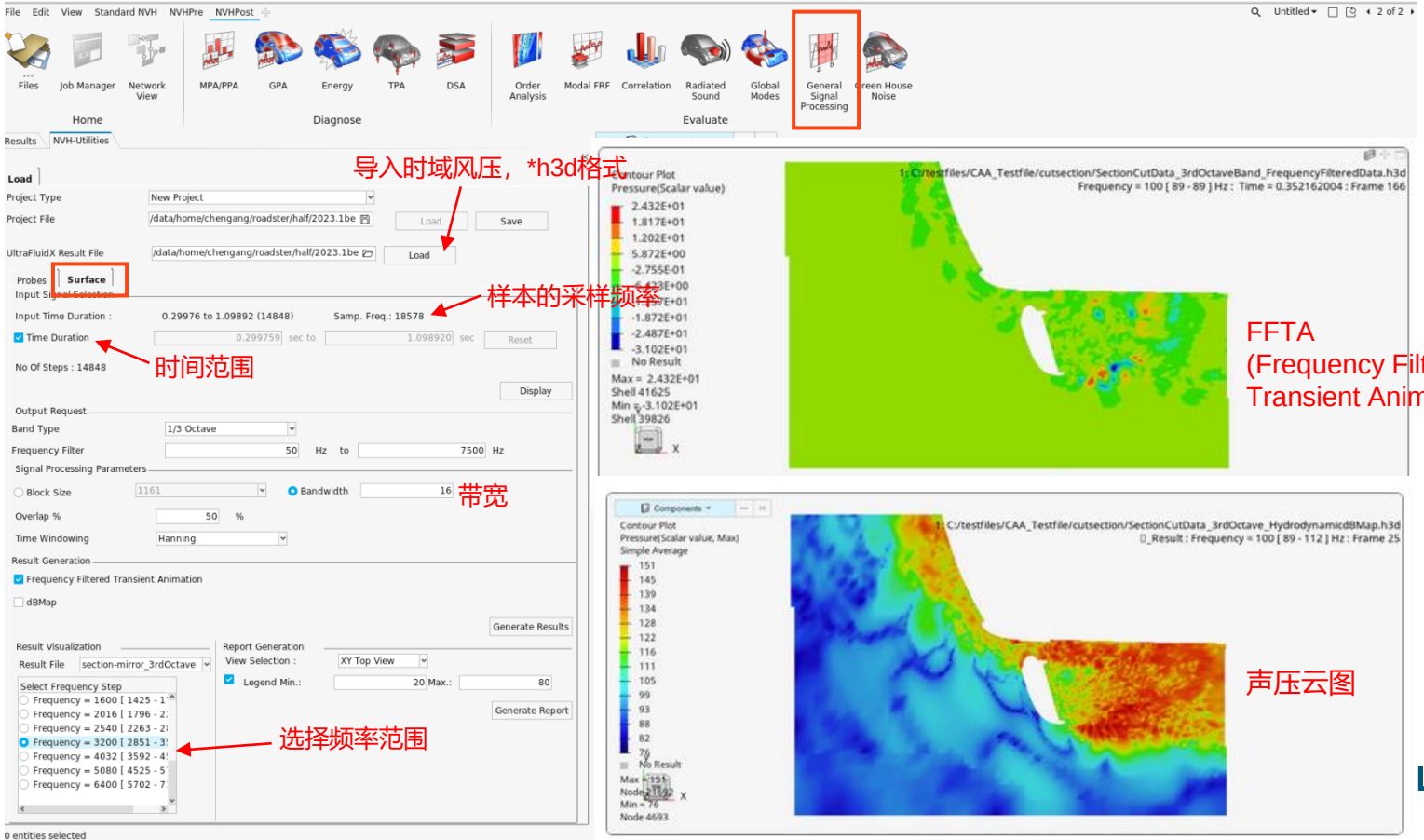


Hypermesh NVH 噪声信号处理-监测点的信号



- 采样起点要从信号稳定段开始
- Display频率的上限是采样频率的一半
- Block size和Bandwidth二选一，分辨率越高要求样本量越大
- Export Data可以将SPL/PSD曲线转为*csv

Hypermesh NVH 噪声信号处理-流场的FFT



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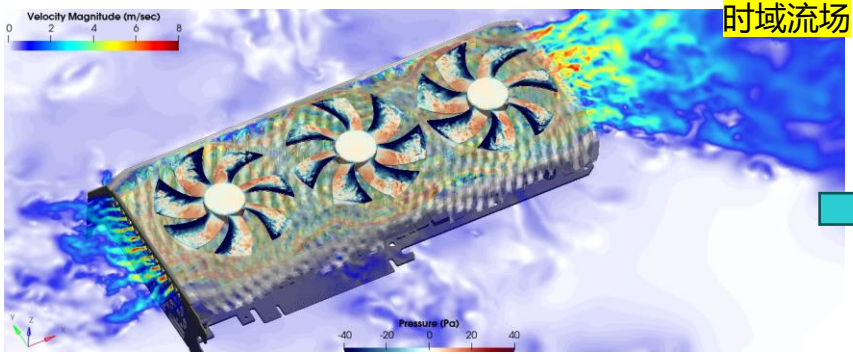
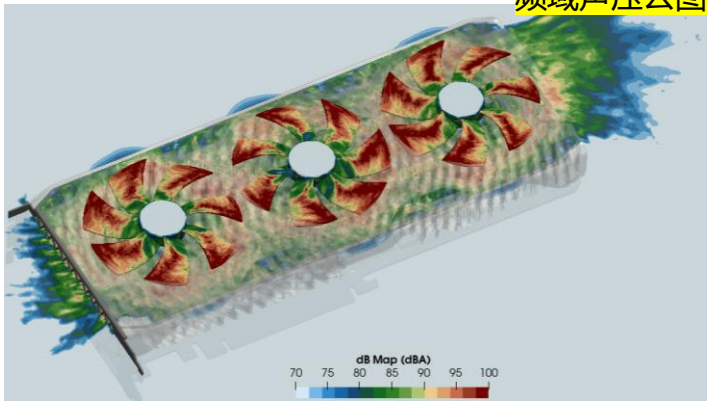
Hypermesh NVH 噪声信号处理-流场的FFT

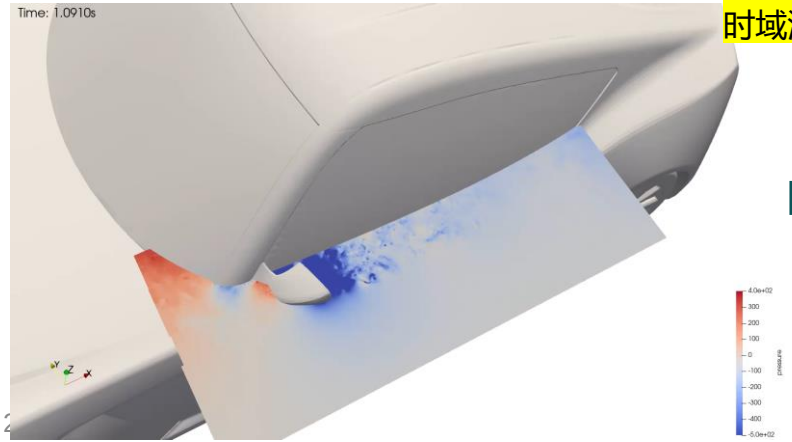
时域流场



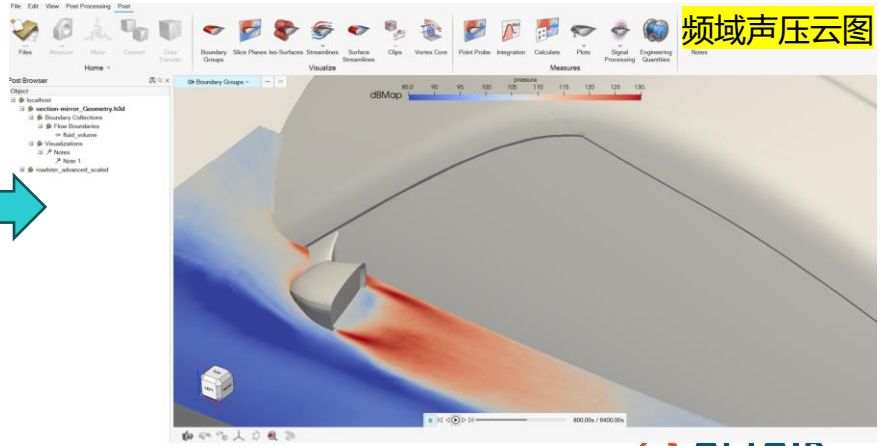
频域声压云图



时域流场

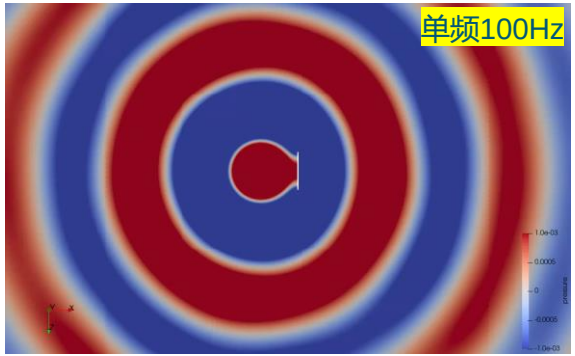


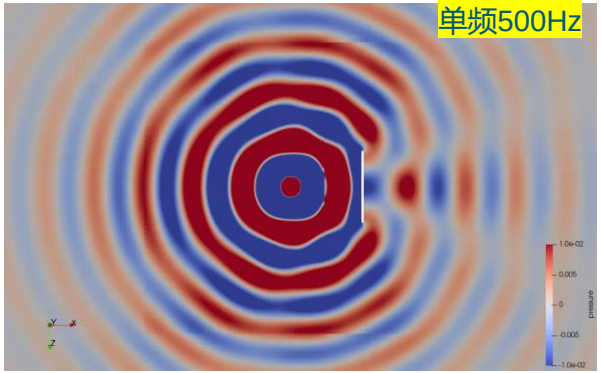
频域声压云图

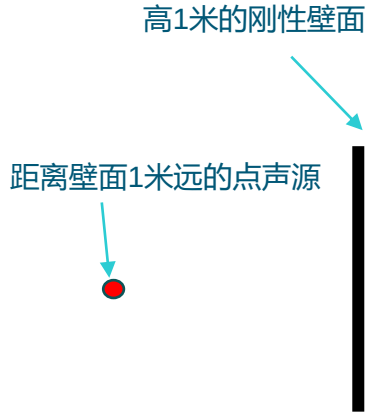


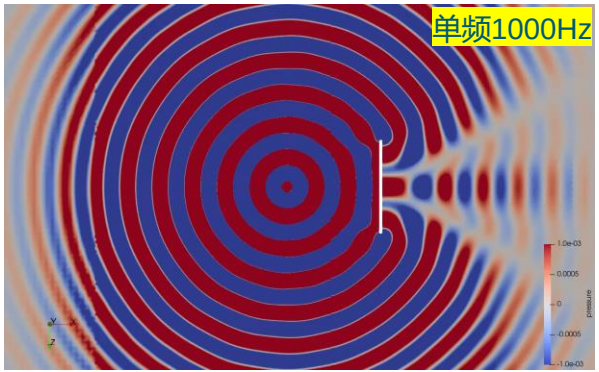
ultraFluidX:模拟点声源

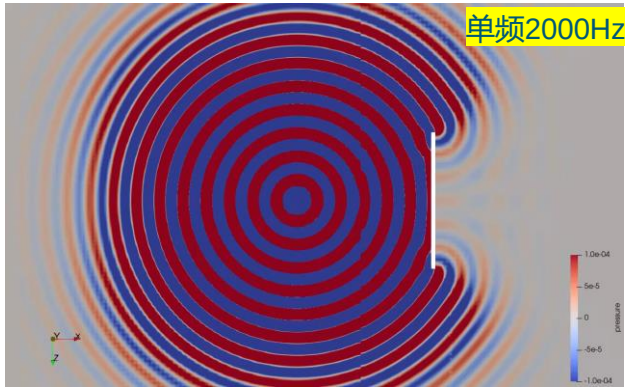
模拟声波的反射和衍射现象

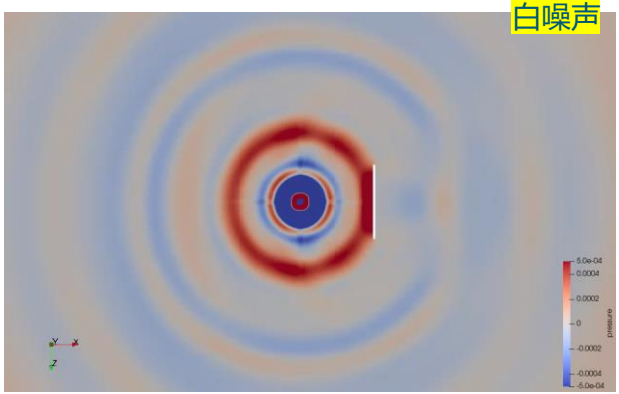












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乘员舱噪声

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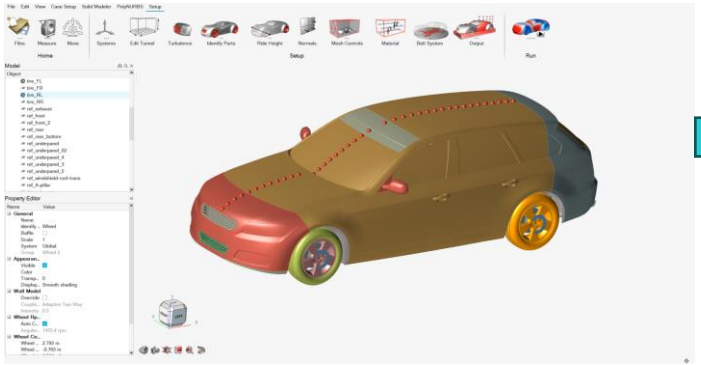
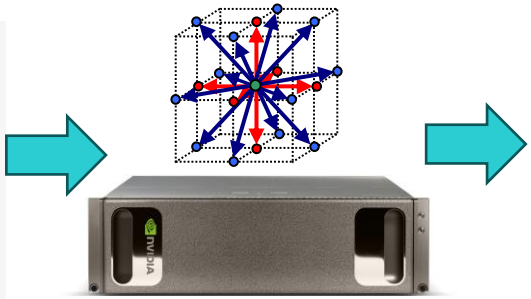
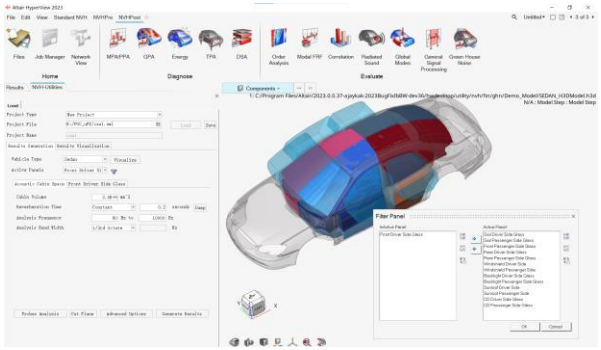
汽车乘员舱风噪仿真流程



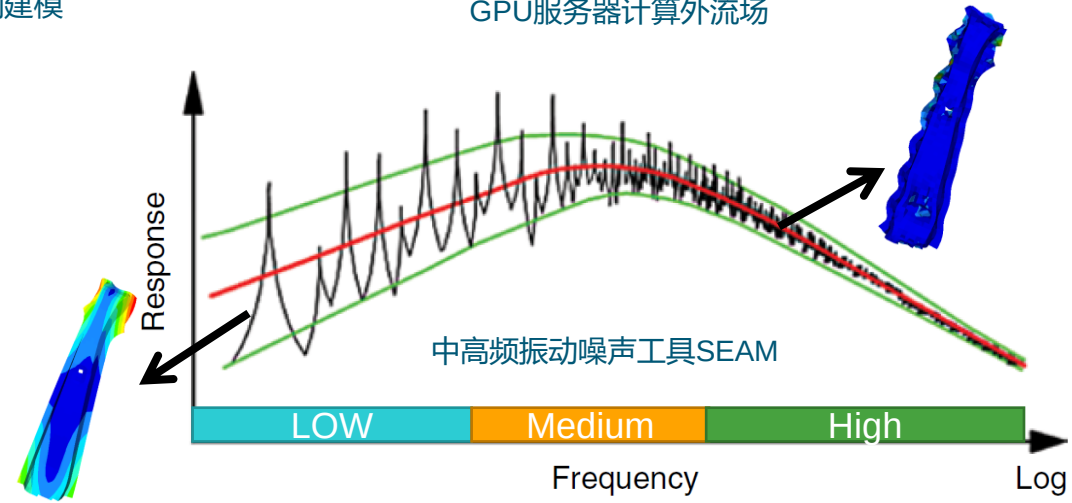
HyperMesh CFD
虚拟风洞建模



ultraFluidX
GPU服务器计算外流场



HyperMesh NVH
风噪分析专用工具



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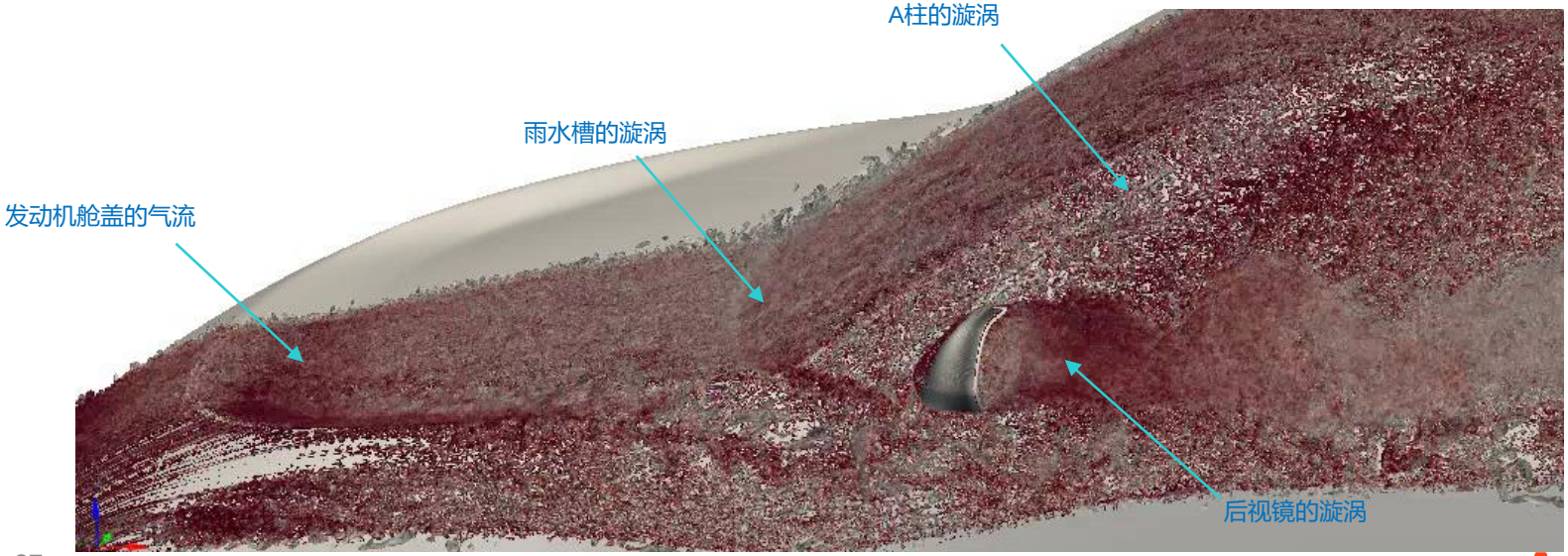
汽车乘员舱风噪仿真

- 风噪控制是细节决定成败，关键部位的微小变动都会对噪声产生显著影响，因此CFD仿真需要高保真度的瞬态解，车窗附近的空间分辨率约在0.5mm，信号采集频率约在20kHz，捕捉不同空间/时间尺度的精细湍流结构。
- 外流场噪声向舱内的噪声传播采用统计能量法工具SEAM计算，得到车内的声压级和语音清晰度



ultraFluidX捕捉车身表面的湍流结构

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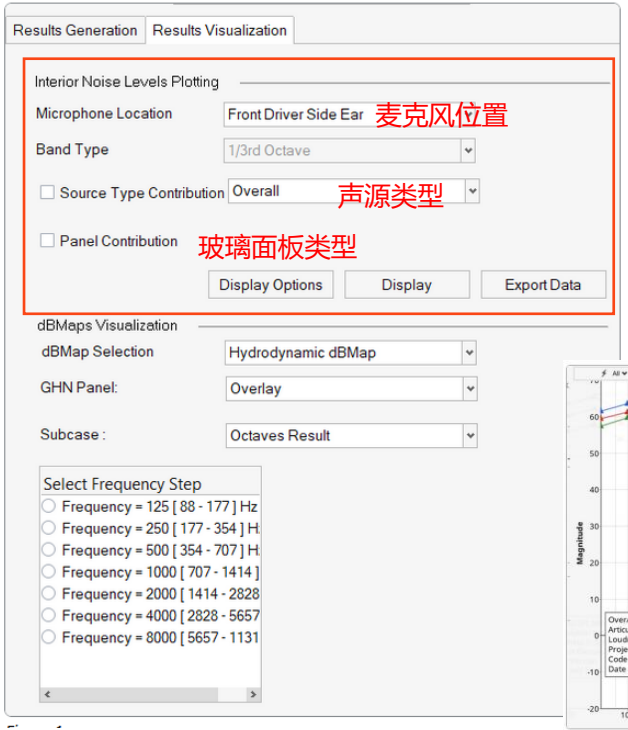
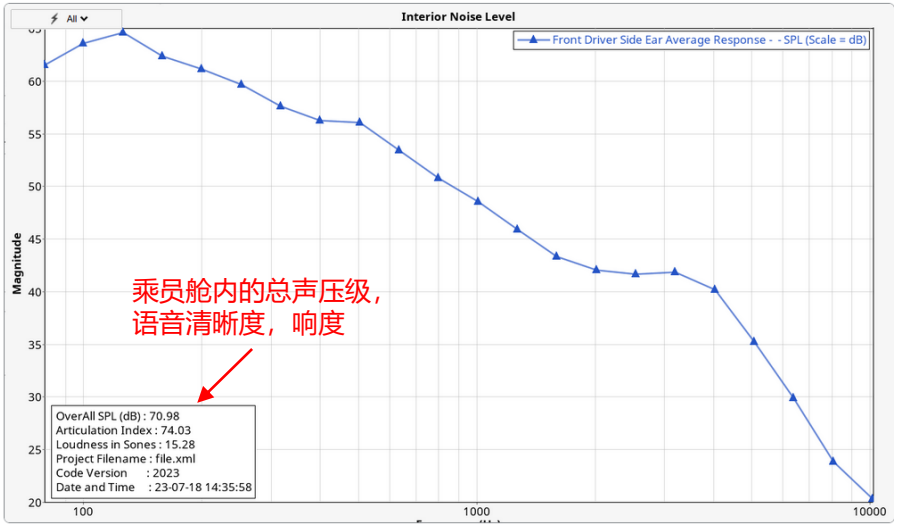
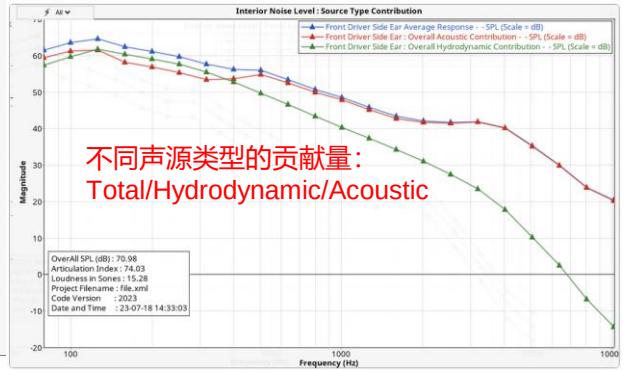
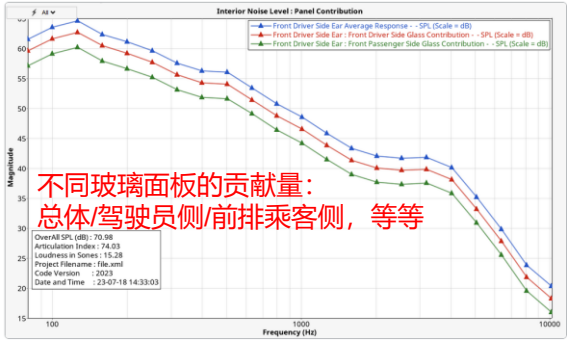
Hypermesh NVH 噪声信号处理

汽车乘员舱内的噪声曲线









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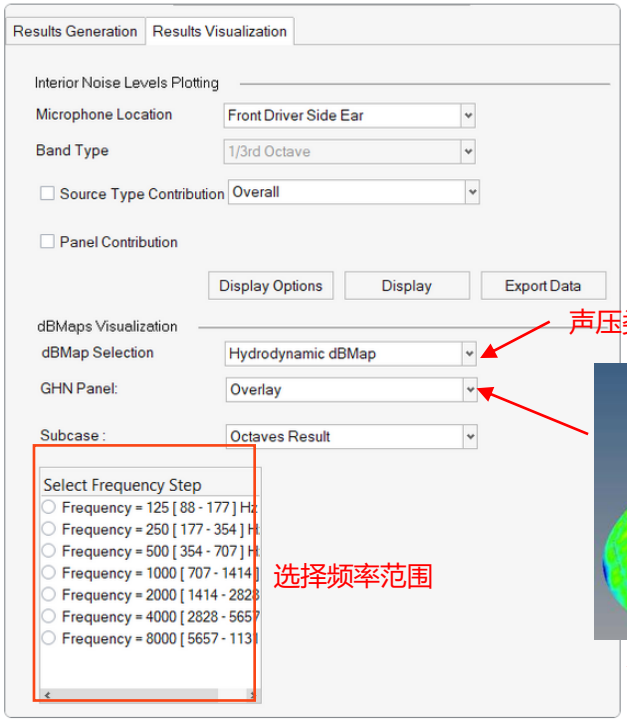
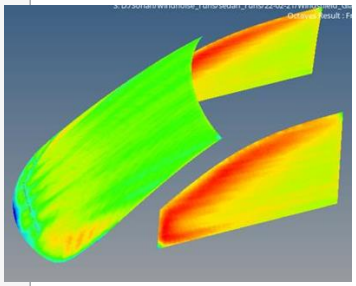
Hypermesh NVH 噪声信号处理

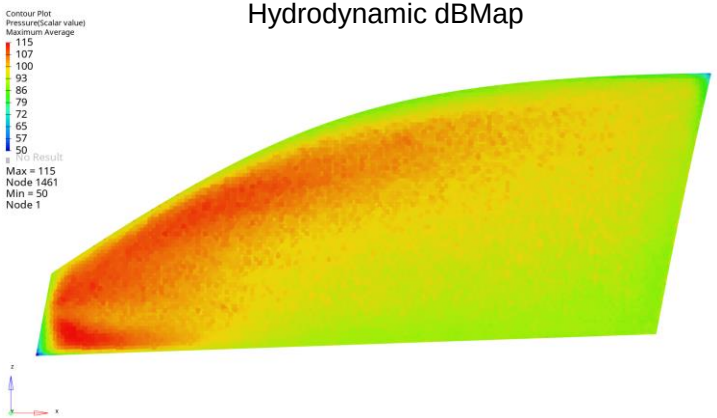
车窗玻璃表面的声压云图



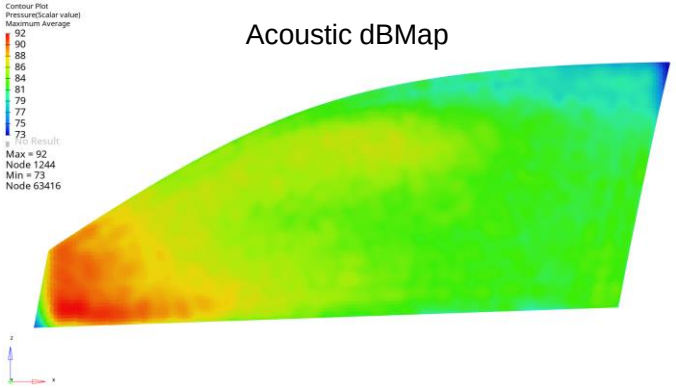


多个玻璃的单个/重叠显示

Hydrodynamic dBMap



Acoustic dBMap



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GPU高性能计算

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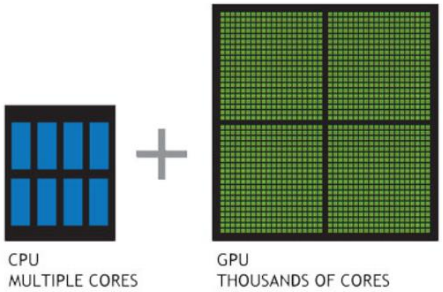
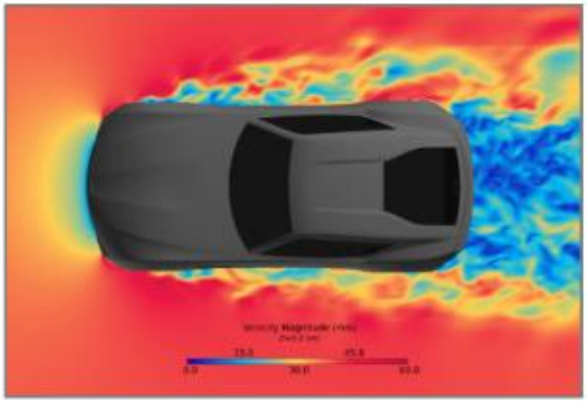
GPU高性能计算

相比传统CFD求解器，GPU求解效率极大提高

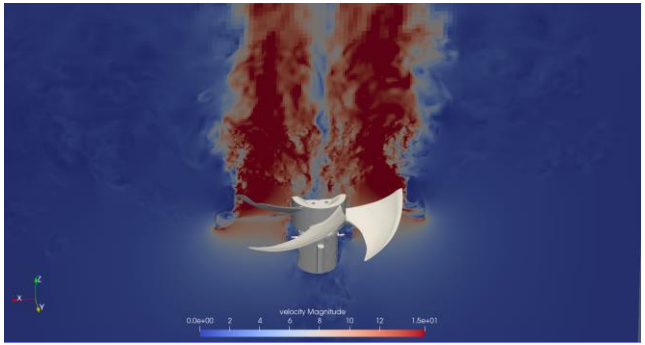
- 求解器基于NVIDIA GPU优化
- 更少的硬件投资和更短的仿真周期



CPU与GPU架构比较



整车外流场模型
1亿4千万格子，2*A100计算7~12小时



轴流风扇噪声模型
3亿格子，2*A100计算1~2天

8*A100计算服务器

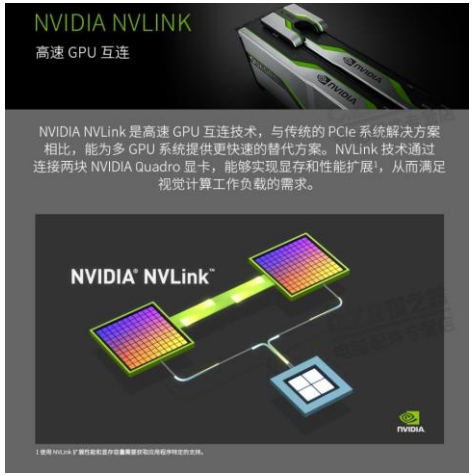
GPU高性能计算

- **GPU主要参数**
  - 显存大小：影响模型计算规模
  - NVLink/PCIE ： 多GPU通讯效率
  - GPU显存带宽：通讯效率
  - 浮点计算TFLOPS：解方程效率
  - CUDA核心数：解方程效率
  - 功耗：发热量和电力消耗
- **CFD大模型推荐GPU类型**
  - 英伟达H100/A100/A6000/L40/L20
  - 主流计算卡显存>48G

相同的LBM模型，A100 NVLink
比PCIE快2.8倍

GPU Configuration	A100-PCIe-80GB	A100-SXM4-40GB
# of GPU's	02	02
# of Fluid Voxels (Mn)	104	104
Physical Time (s)	2	2
# of Coarse Iterations	1522	1522
Pre-processing Time (s)	**3956**	**3485**
Initialization Time (s)	**248**	**227**
Run & Data Export Time (s)	**70722**	**22881**
Total Wall Time (s)	**74926**	**26593**
Per GPU Performance (MNUPS)	**125**	**375**

NVLink显著提高了多
GPU并行效率



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THANK YOU

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