新能源汽车
整车外气动与热优化设计关键技术

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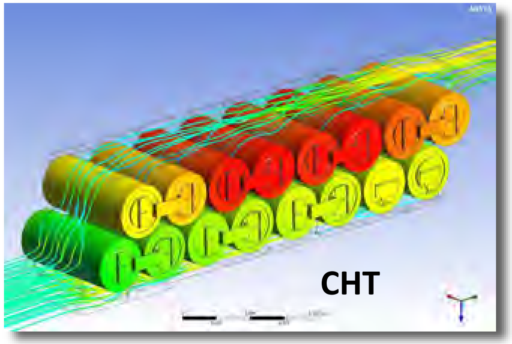
ANSYS

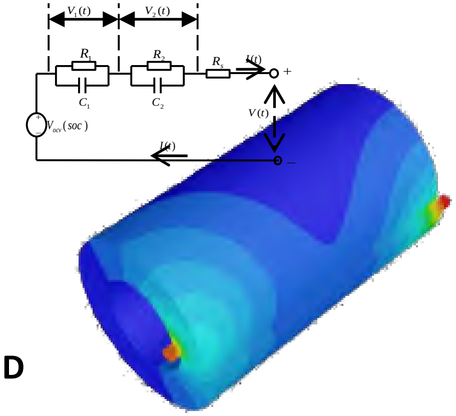
内容简介

- 电池热管理模拟方案
- 电机热管理模拟
- 驱动系统热模拟
- 整车外气动优化仿真技术

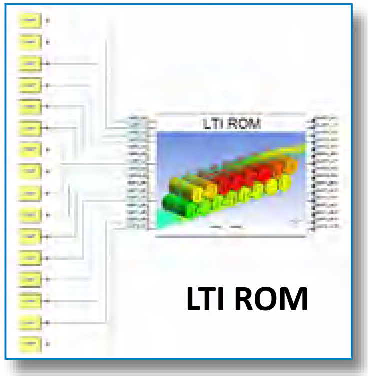
电池热管理模拟

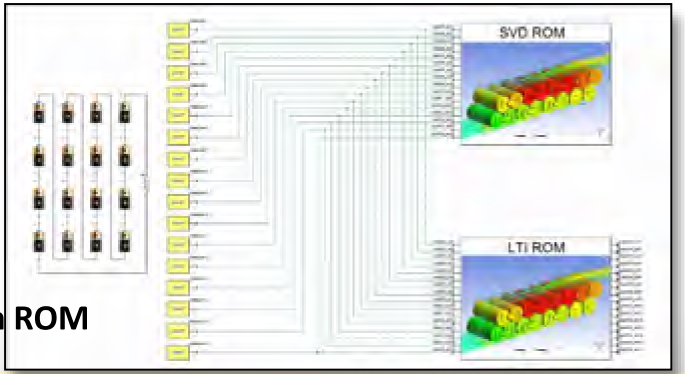


- 三维共轭换热
- 多维度多尺度（MSMD）热-电化学耦合模型
- 系统级热模型
  - LTI 降阶模型
  - SVD降阶模型
- 系统级热-电耦合模型



MSMD

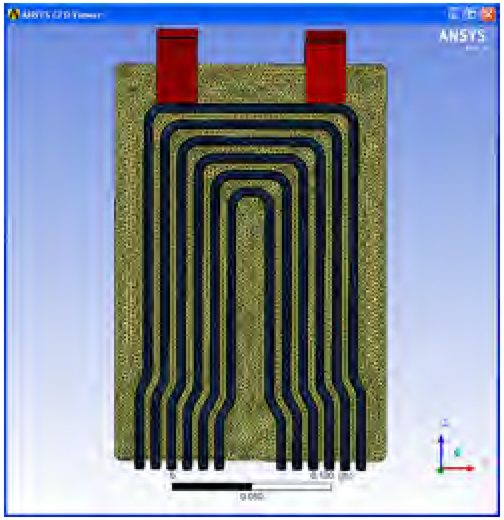


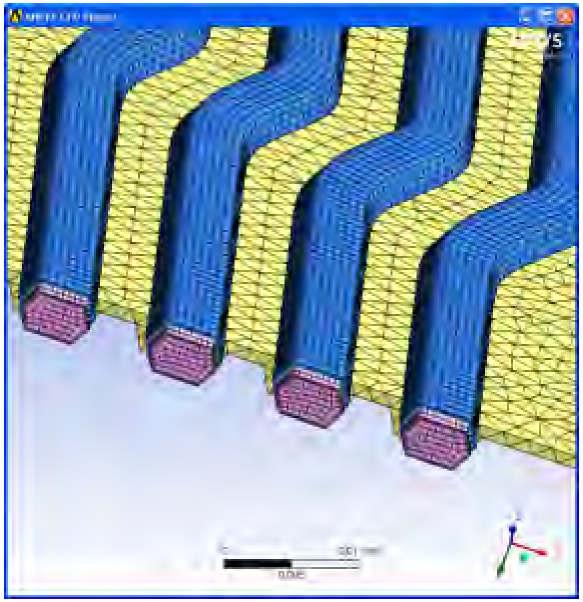


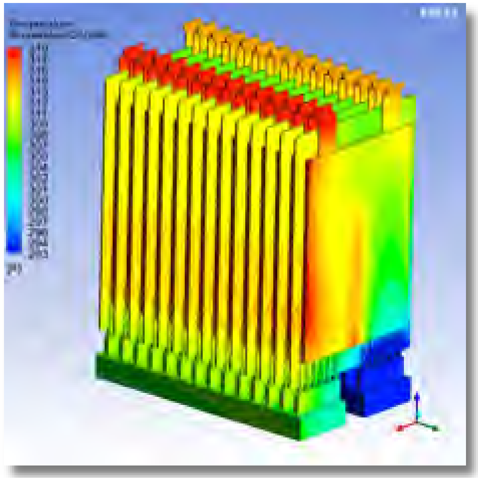
ECM Coupled with ROM

SVD ROM

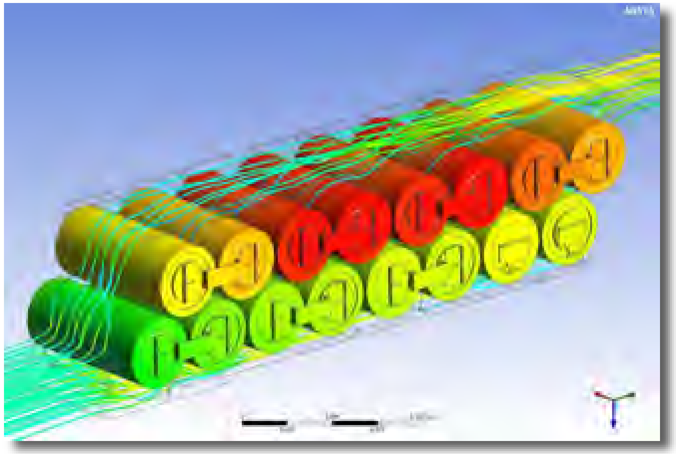
三维电池共轭换热分析



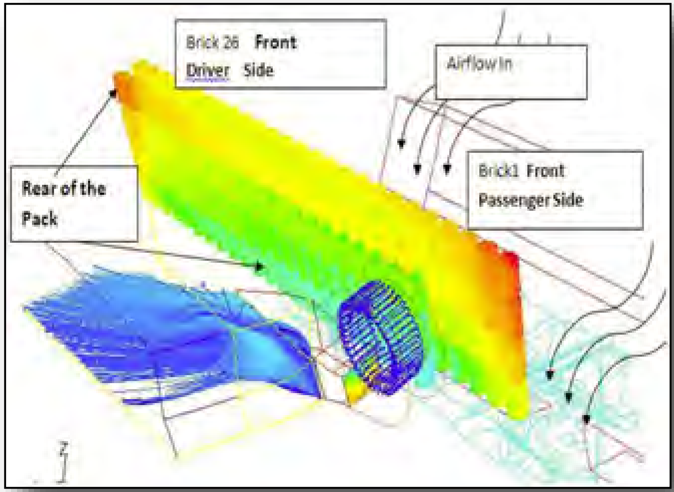




ANSYS **Example**



GM Example



Ford **Example**

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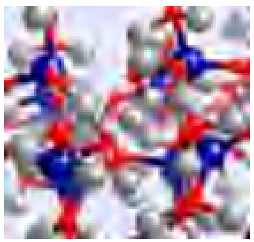
多尺度多维（MSMD）电池电-热耦合仿真

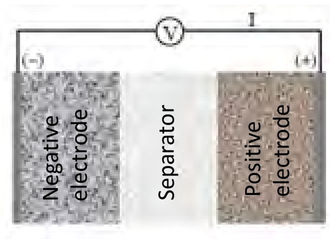
- Li$^+$ 电池的尺度

material



10^{-9}~10^{-8}

electrode pair



10^{-6}~10^{-4}

cell, pack

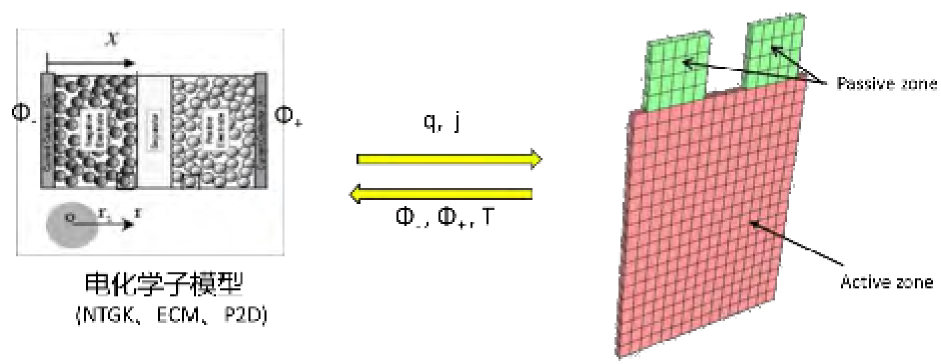
10^{-2}~10^{0}

- 多尺度多维(MSMD) 模型
  - 并不求解极片结构

$$\frac{\partial \rho C_p T}{\partial t} + \nabla \cdot \left(\rho \vec{V} C_p T\right) = \nabla \cdot \left(k \nabla T\right) + \dot{q}$$

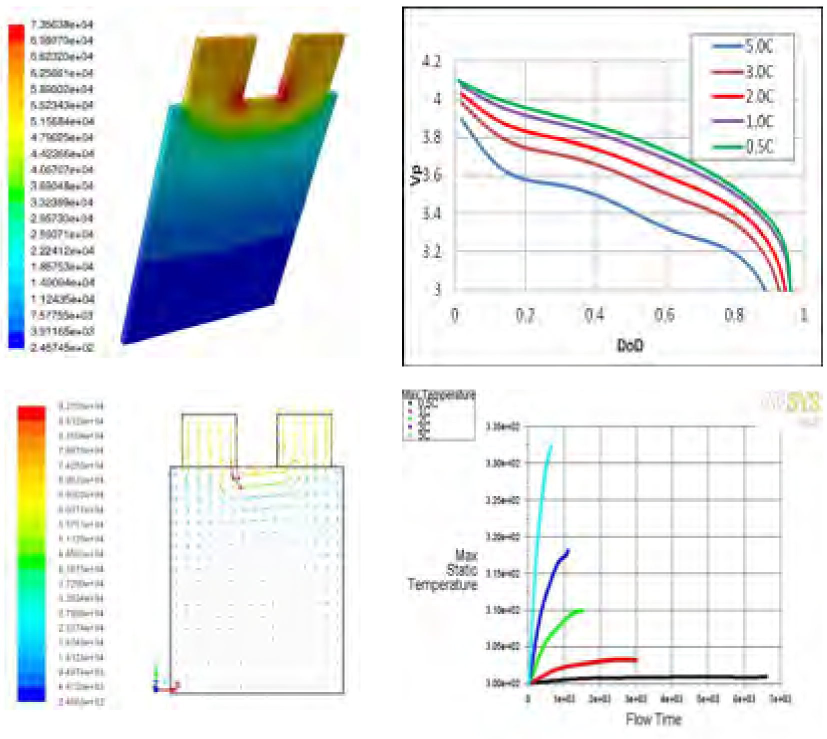
$$\nabla \cdot \left(\sigma_+ \nabla \phi_+\right) - j = 0$$

$$\nabla \cdot \left(\sigma_- \nabla \phi_-\right) + j = 0$$

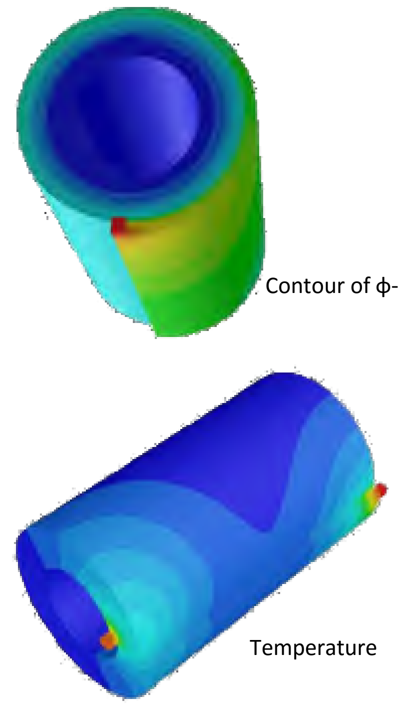


- 不同区域构建独立的网格
- 每个网格作为一个“小”电池来处理

基于NTGK模型的计算结果

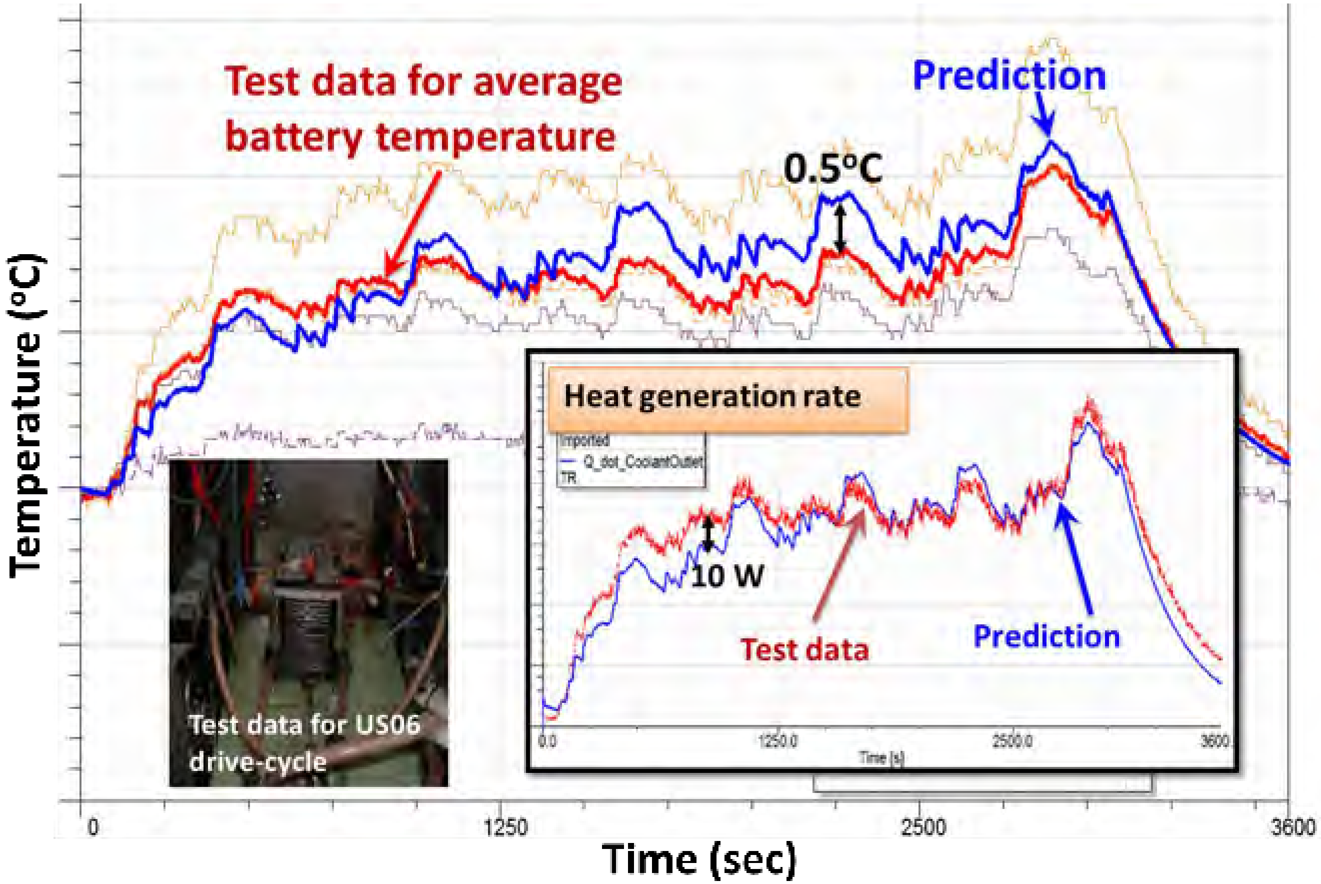


Prismatic cell

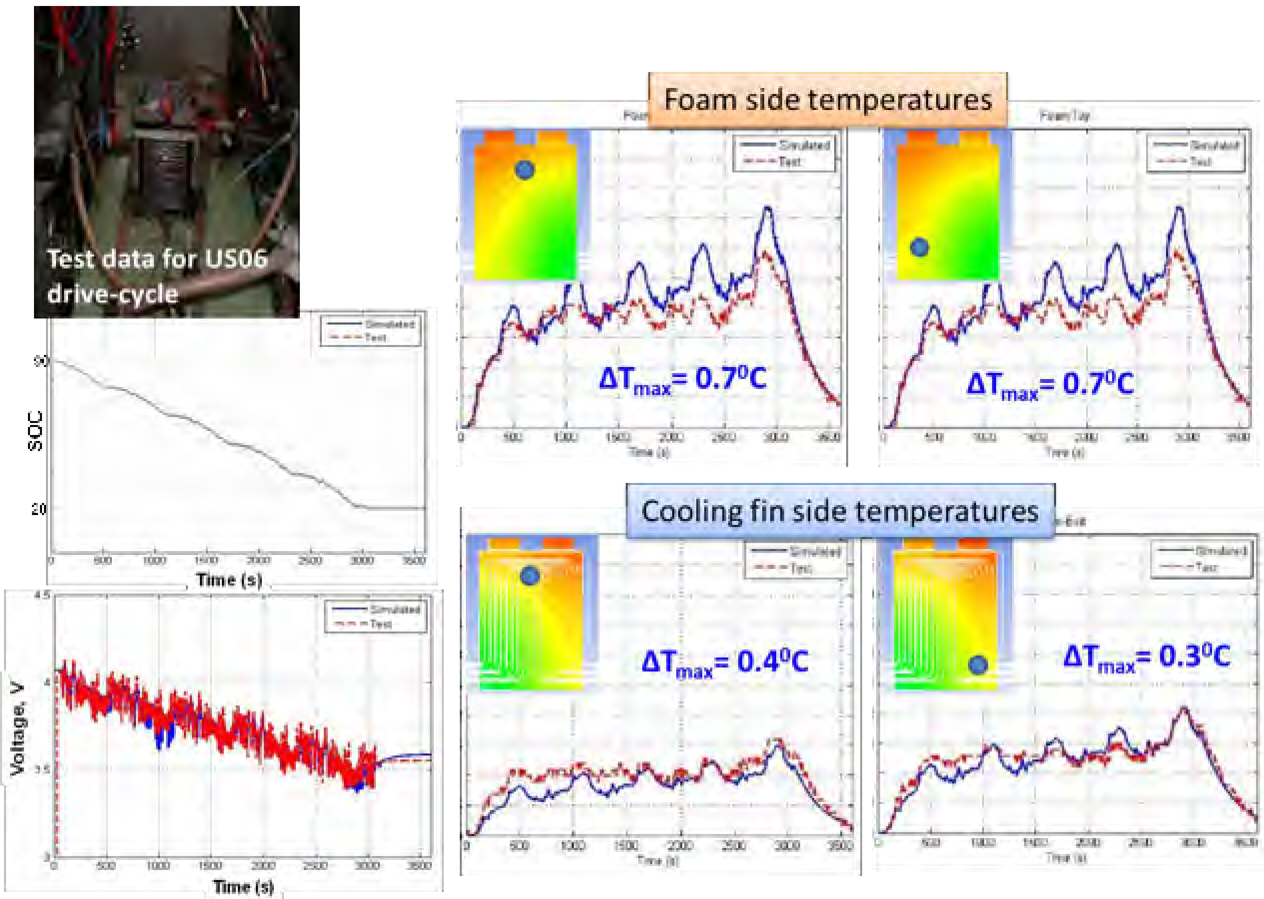


Cylindrical cell with discrete tabs

系统级模型的验证 - US06循环试验



系统级模型的验证 - US06循环试验



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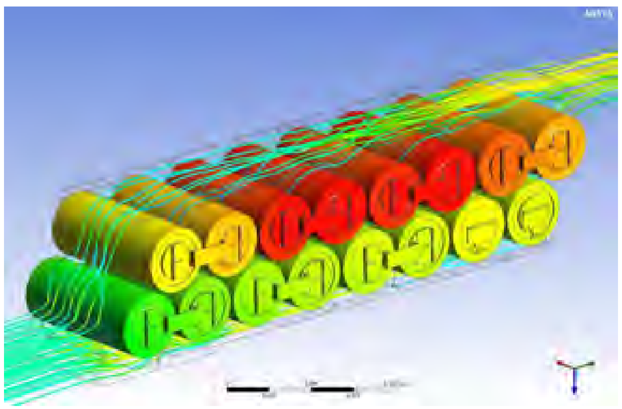
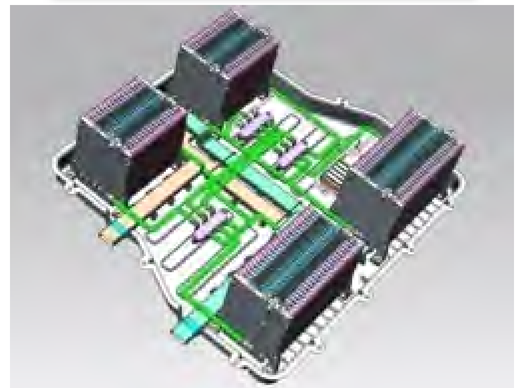
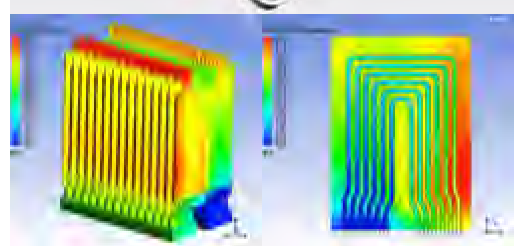
降阶模型(ROM)的目的

- **CFD 可以提供准确的结果.**
  - 但系统级的计算则颇为耗时
- **ROM 可以显著降低模型的运算规模和缩短时间.**







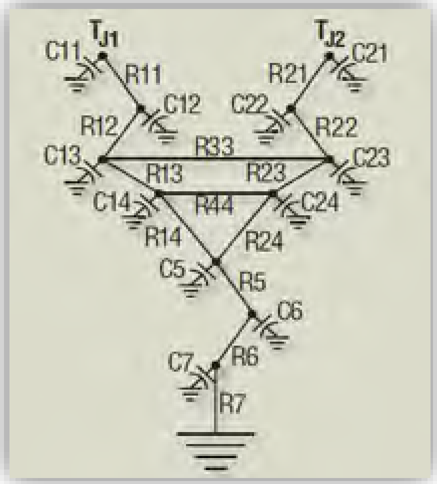
降阶模型

➢热网络模型

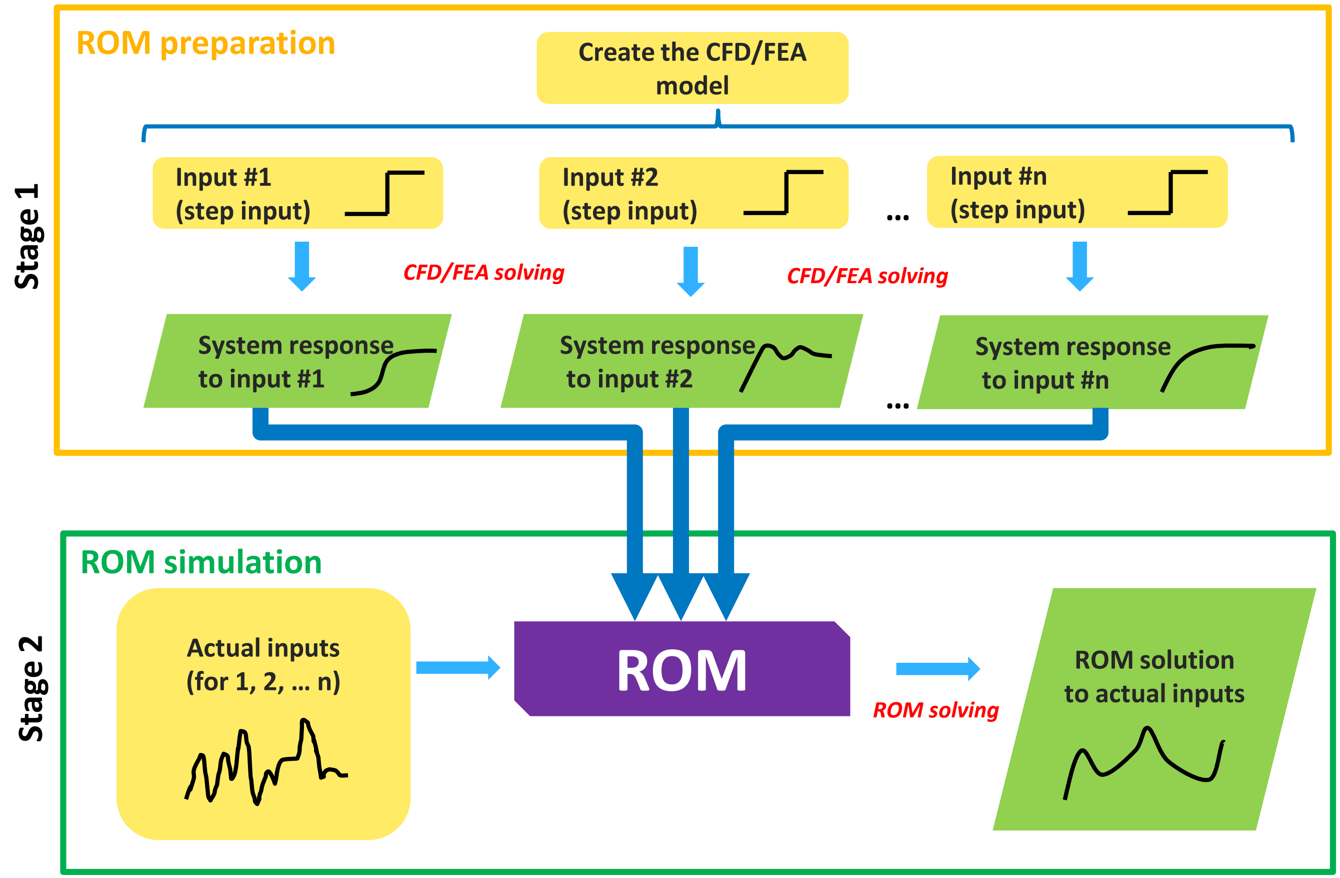
- 需要计算和测试数据
- 准确性存疑

➢ANSYS降阶模型

- 需要CFD计算数据
- 无需测试
- 和CFD一样准确



ROM生成过程



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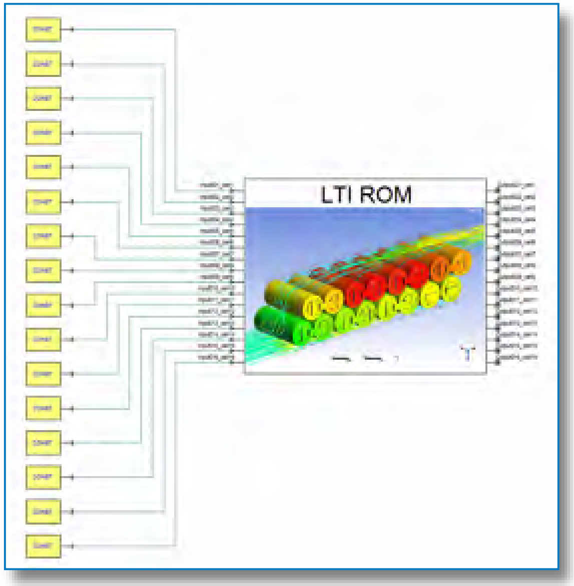
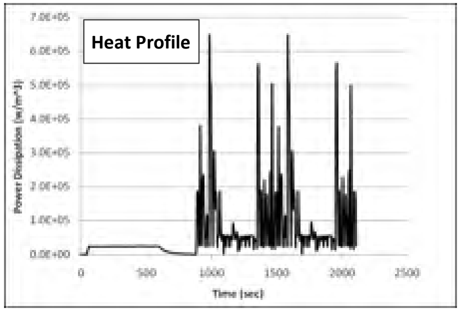
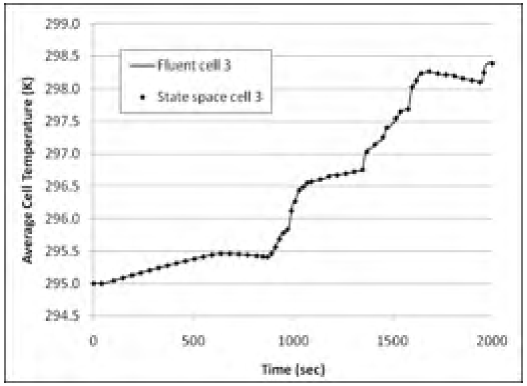
GM电池模组的ROM模型



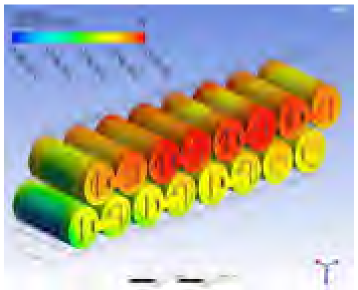
LTI ROM 计算时长2s，CFD计算时长2小时



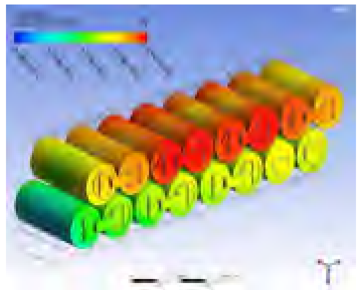


X. Hu, S. Lin, S. Stanton, W. Lian, “A Foster Network Thermal Model for HEV/EV Battery Modeling,” IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 47, NO. 4, JULY/AUGUST 2011
X. Hu, S. Lin, S. Stanton, W. Lian, “A State Space Thermal Model for HEV/EV Battery Modeling", SAE 2011-01-1364

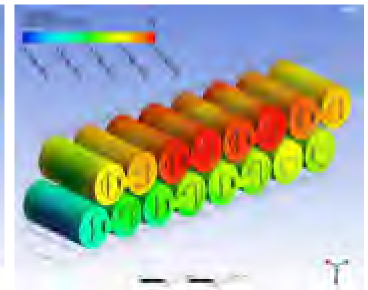
SVD ROM模型



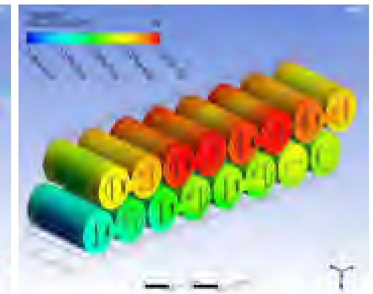
CFD (200 sec)



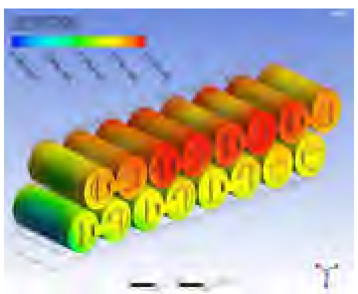
CFD (400 sec)



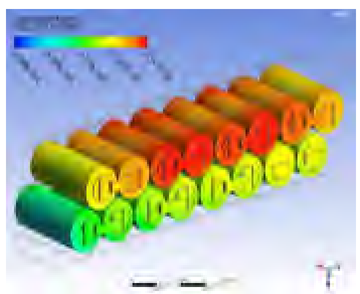
CFD (600 sec)



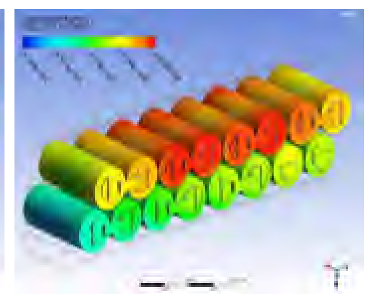
CFD (800 sec)



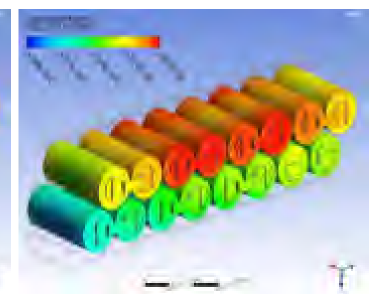
SVD ROM
(200 sec)



SVD ROM
(400 sec)



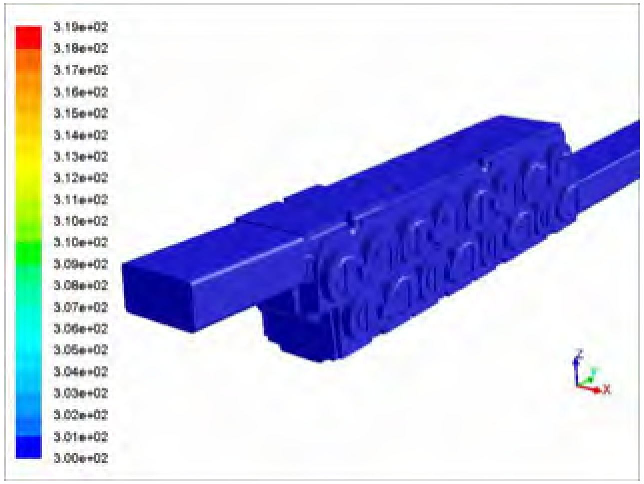
SVD ROM
(600 sec)

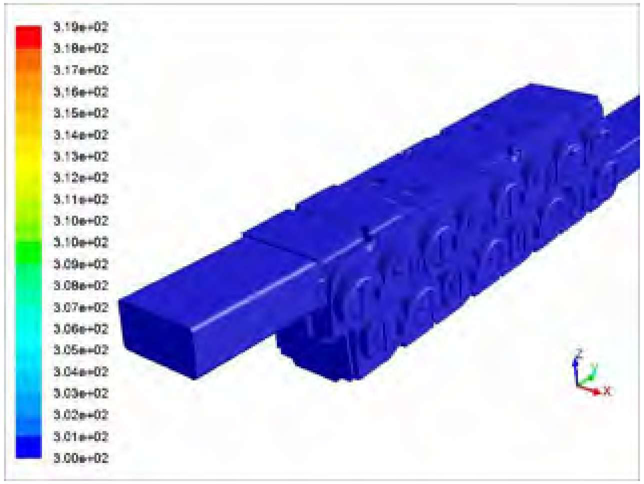


SVD ROM
(800 sec)

X. Hu, S. Asgari, I. Yavuz, S. Stanton, C-C Hsu, Z. Shi, B. Wang, H-K Chu, “A Transient Reduced Order Model for Battery Thermal Management Based on Singular Value Decomposition,“ ECCE 2014.

SVD ROM模型

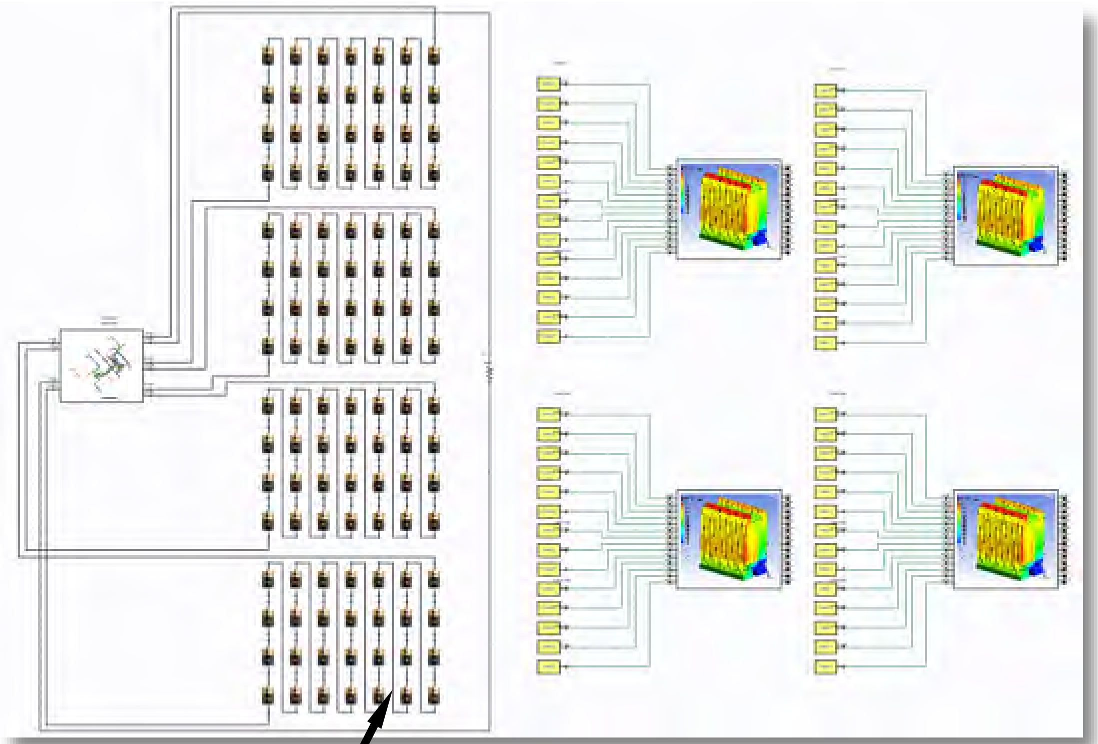




CFD计算的温度。
计算资源6CPU，时长7小时

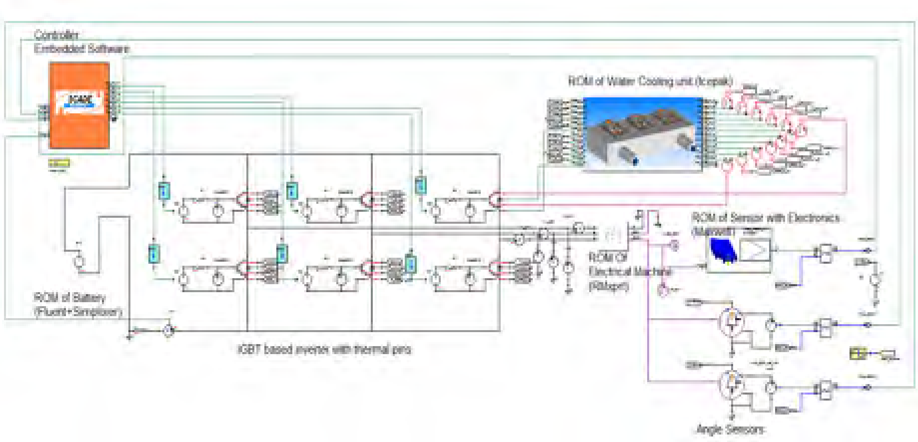
SVD ROM模型的计算结果
计算资源1CPU，时长0.5小时

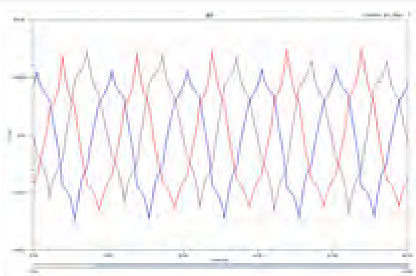
系统级的电热耦合 – ECM与ROM

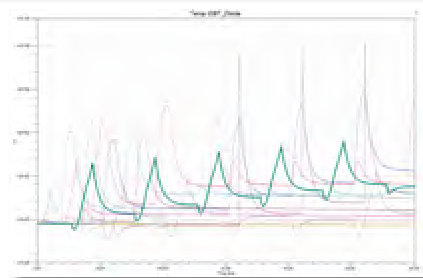


Voc = -1.031*exp(-35*(abs(IBatt.V/Vinit))) + 3.685 + 0.2156*(abs(IBatt.V/Vinit)) - 0.1178*(abs(IBatt.V/Vinit))^2 + 0.3201*(abs(IBatt.V/Vinit))^3 + 0.3/30.0*(U1.Temp_block_1-273)

整个驱动系统的模拟







三相电流（左图）与IGBT结温（右图）

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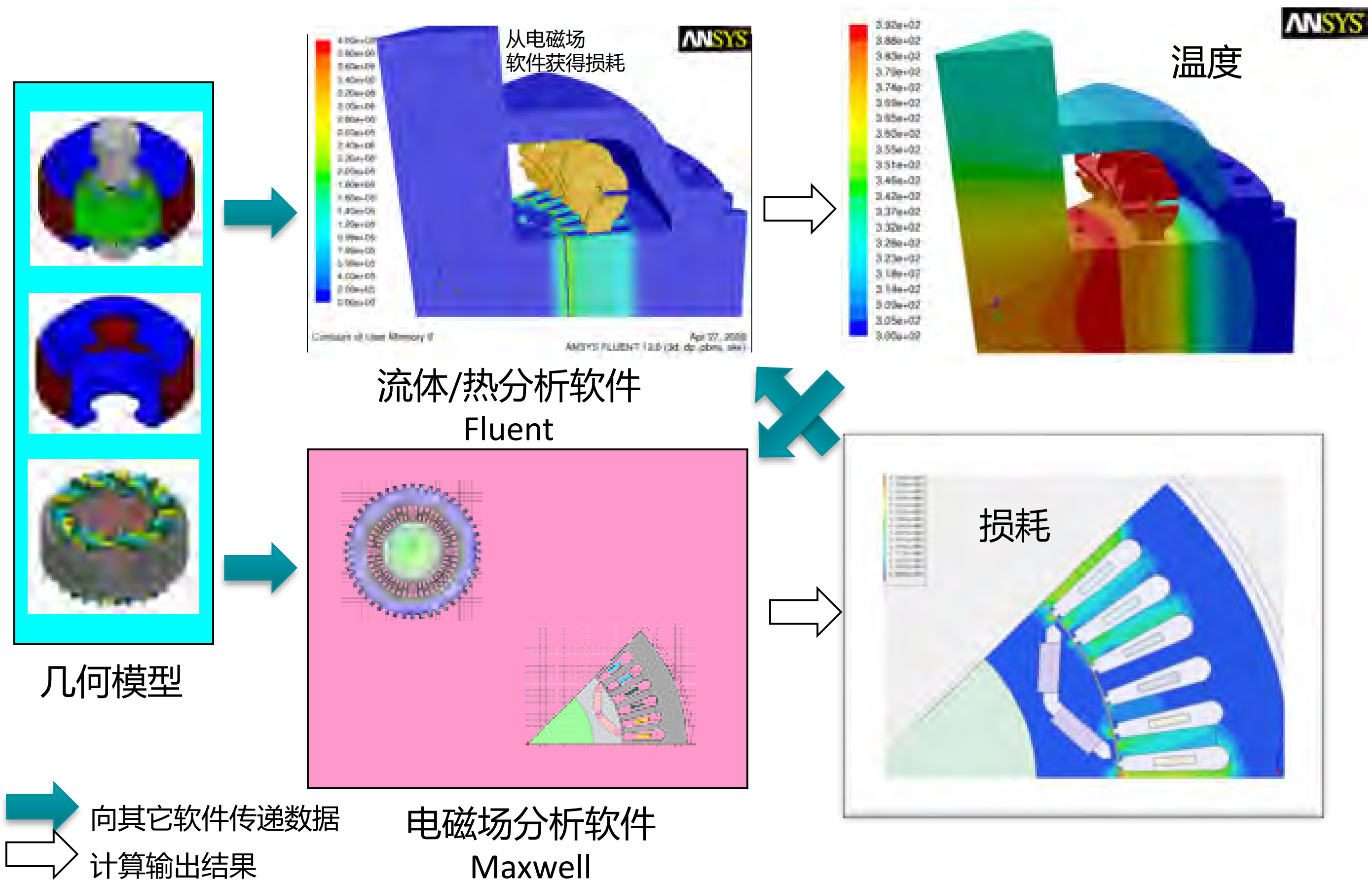
背景

- **电机运行时，绕组损耗、铁心损耗、机械损耗转变为热量，使电机各部件的温度升高，当温度超过绝缘允许的温度时，将导致绝缘乃至电机的损坏**
- **新能源电机主要为永磁电机。当永磁体温度上升时，其退磁特性发生偏移，进而导致电机特性变差，控制性能恶化，并可能导致更加严重的温升和特性偏移**
- **要将电机各部件的温度控制在允许范围内，一方面要降低损耗，减少电机的发热量，另一方面要提高电机的冷却散热能力**

ANSYS电磁、流体、温度场耦合分析



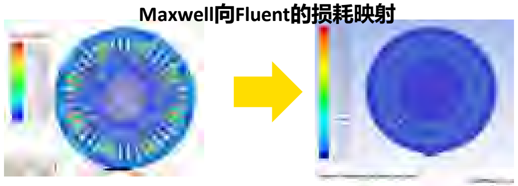
水冷电机案例

Parameter	Value
Type	PMSM
Speed	2500RPM
Voltage	300voltage

损耗映射

水冷电机分析结果

Maxwell向Fluent的损耗映射



水冷电机分析结果

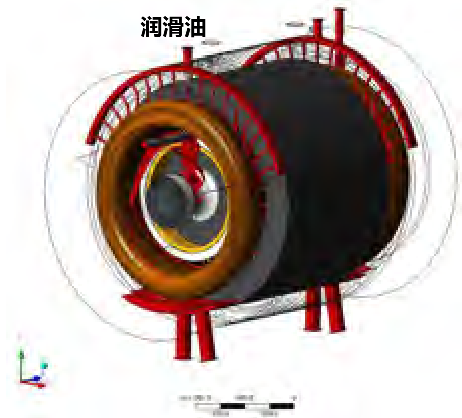
冷却设计

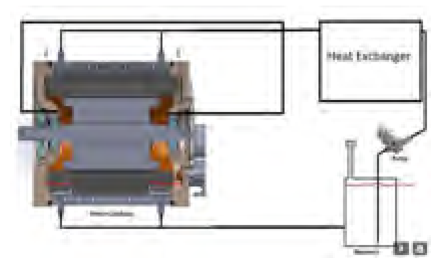
LUCID

ANSYS

乙二醇溶液

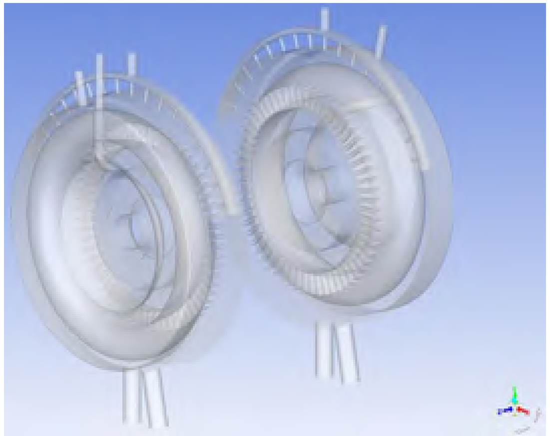
润滑油





油冷共轭换热的分析

润滑油流动模型（瞬态）



壁面温度

壁面换热系数和当地流体温度

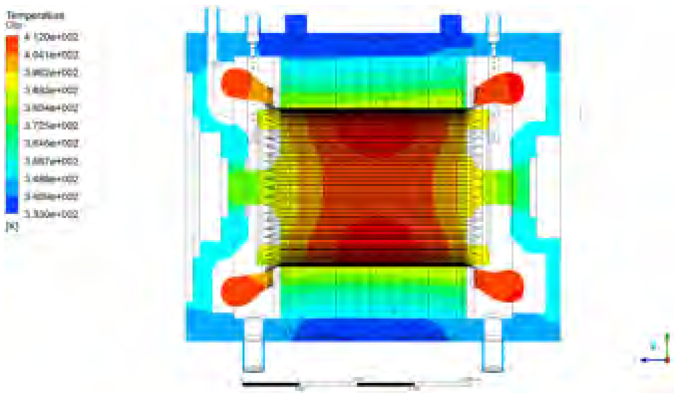
共轭换热模型（稳态）

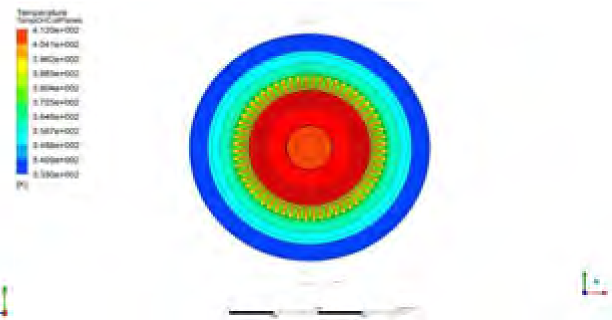
- 步骤1：假定初始壁面温度，进行润滑油流动计算
- 步骤2：将计算获得的换热系数进行周向平均，并将换热系数和当地流体温度传递给共轭换热模型
- 步骤3：对共轭换热模型进行计算，再将壁面温度传输回润滑油流动模型

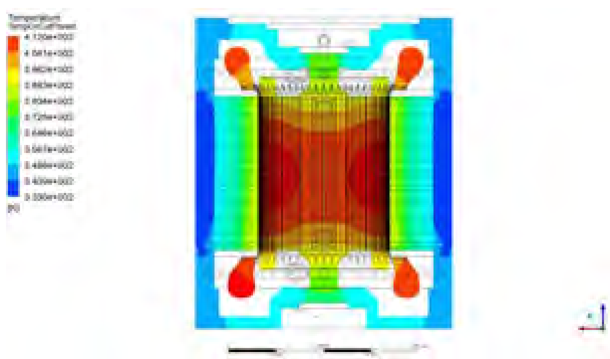
迭代直至壁面温度不再发生变化

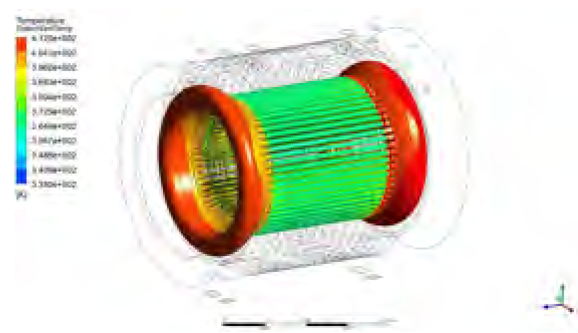
油冷共轭换热的分析结果

Wall Temperature	Test (Deg C)	CFD Model UDF EW (Deg C)	CFD Model UDF EW Error %
Steady state winding temp	144	148	2.78
Steady state rotor temp	106	109	2.83

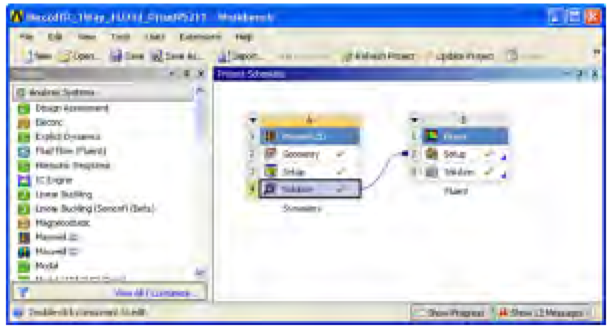


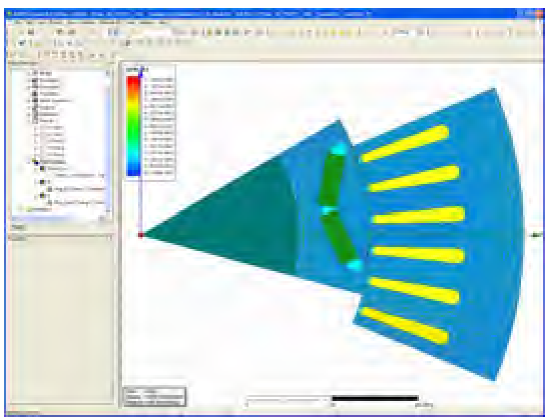




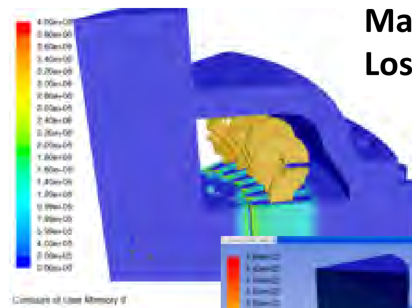


Prius电机算例
FLUENT – Maxwell双向耦合

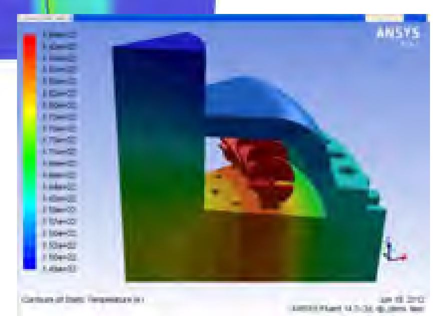




Electromagnetics

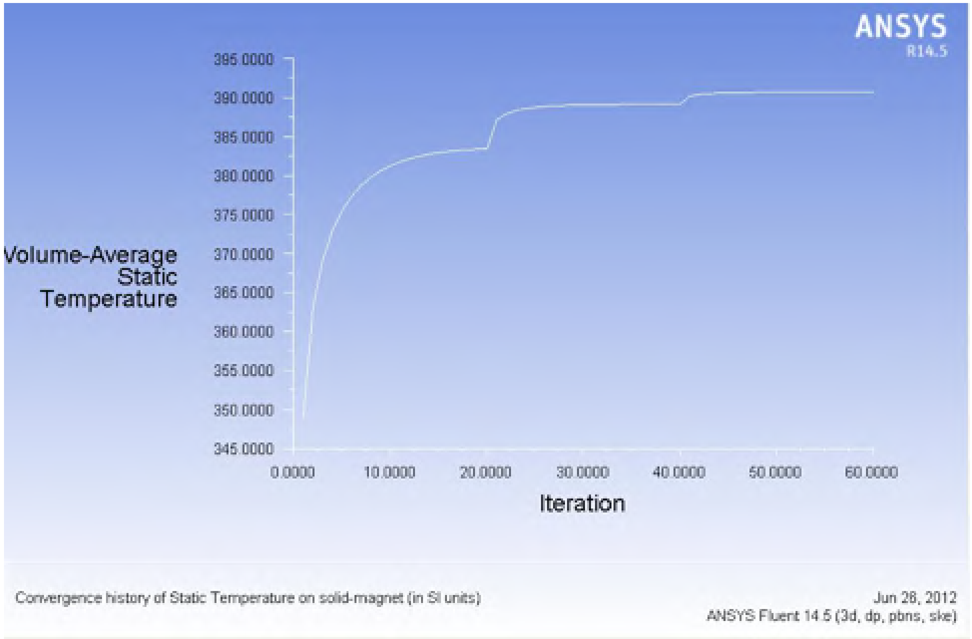


Mapped Loss



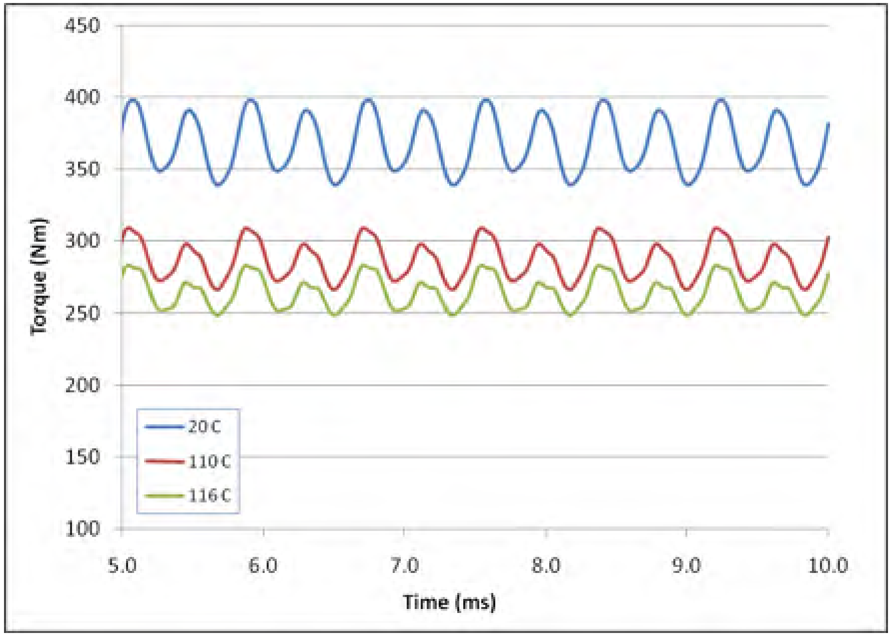
Temperature

温度收敛过程



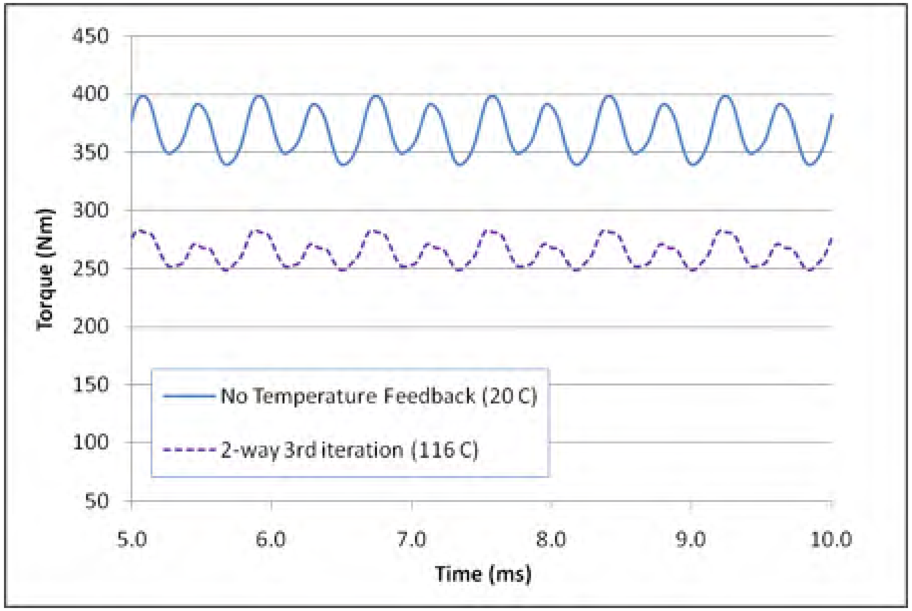
经过三次耦合获得了收敛值

扭矩收敛过程



需要三次迭代步方可获得收敛解

单向耦合与双向耦合的比较



- 双向耦合颇有必要
- 扭矩对温度非常敏感

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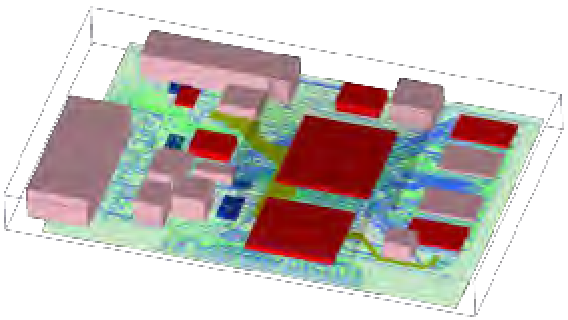
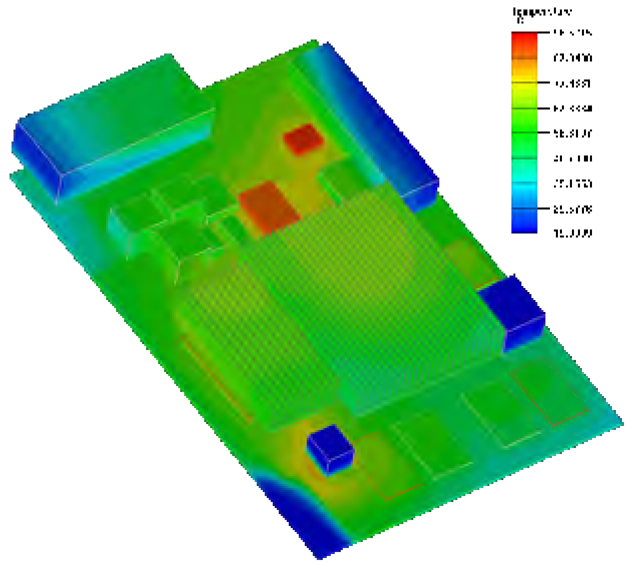
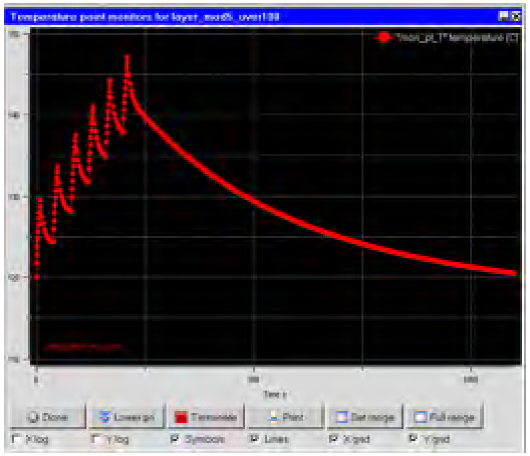
- 整车外气动优化仿真技术

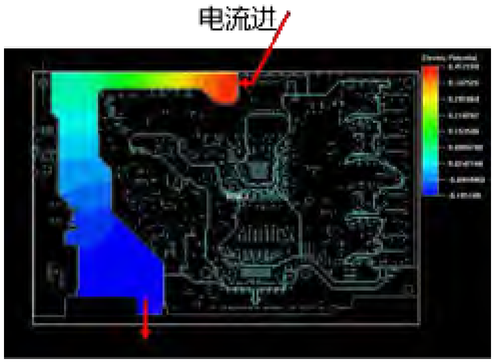
PCB电热耦合分析







电流进

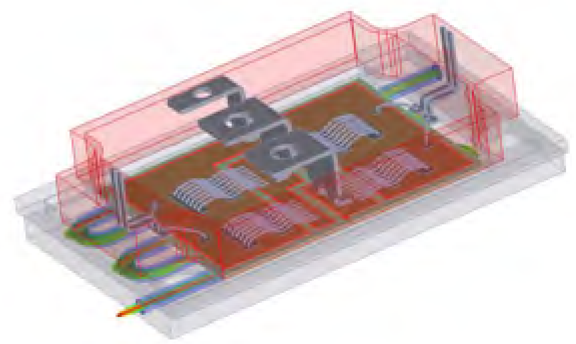


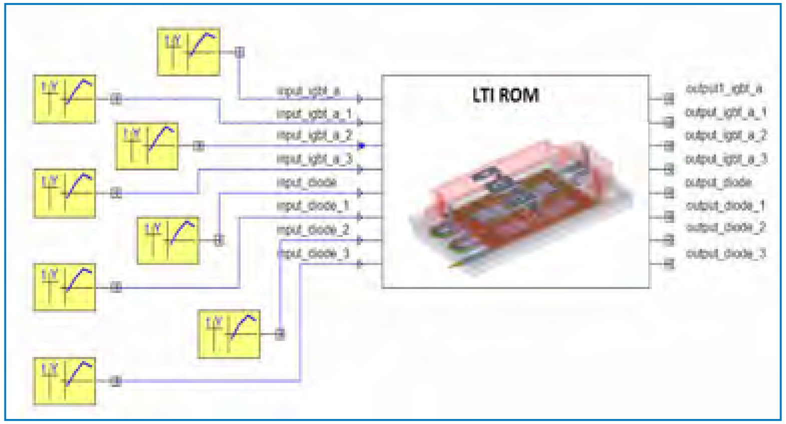
电流出

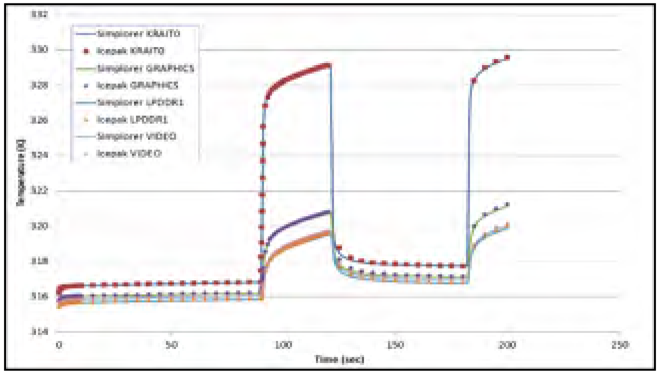
- 大电流通过PCB板时，PCB本身成为一个重要的发热部件
- 焦耳热成为热分析不可忽略的因素

IGBT热模型

- CFD三维仿真可提供精确的结果
  - 进行瞬态仿真时，运算量成为阻碍其工程应用最重要的因素
- LTI ROM可以获得和CFD相似的结果，但运算时间却仅以秒计

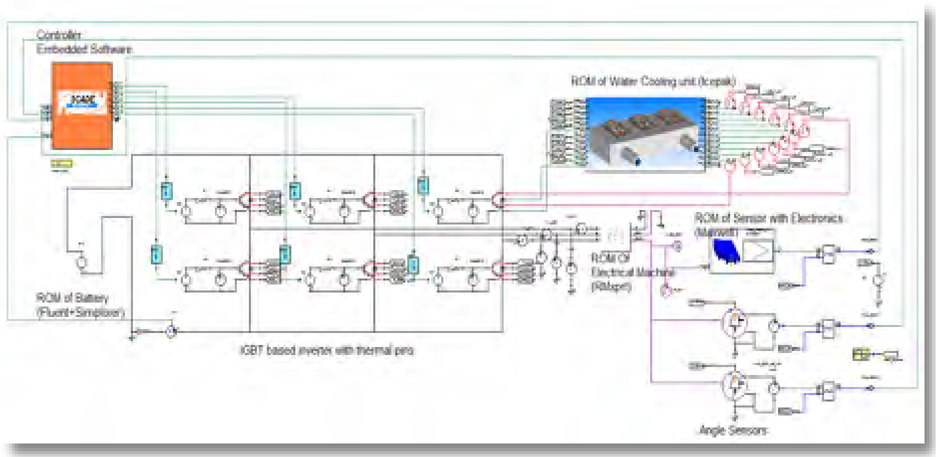


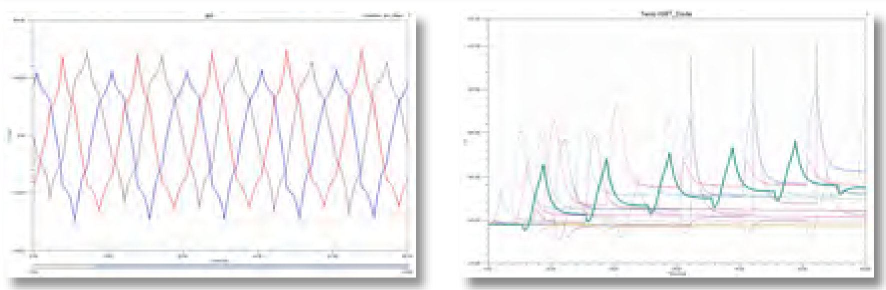




计算只需数秒钟，而CFD需要数个小时

系统级模型



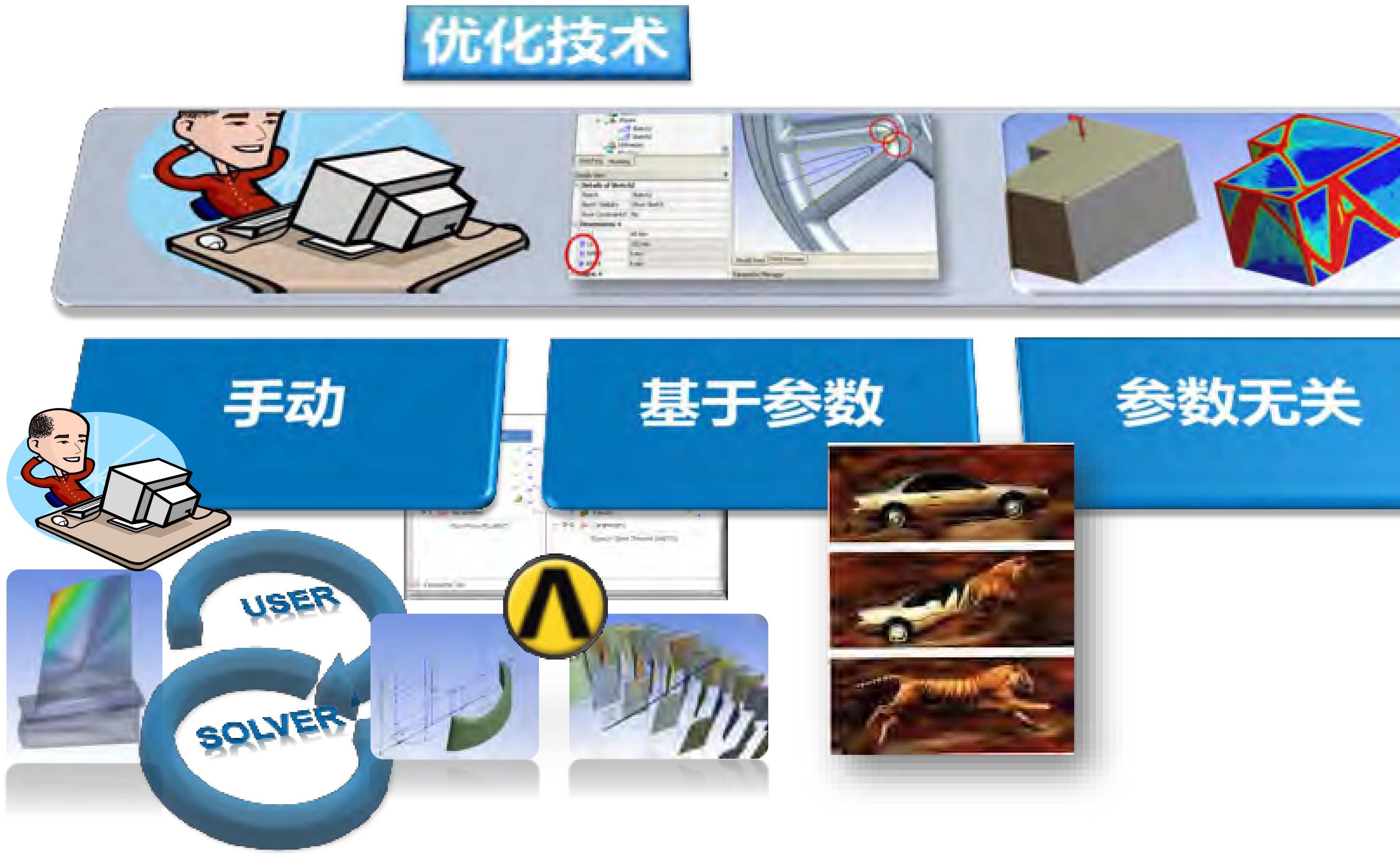


3相交流电和IGBT的结温

内容简介

- 电池热管理模拟方案
- 电机热管理模拟
- 驱动系统热模拟
- 整车外气动优化仿真技术

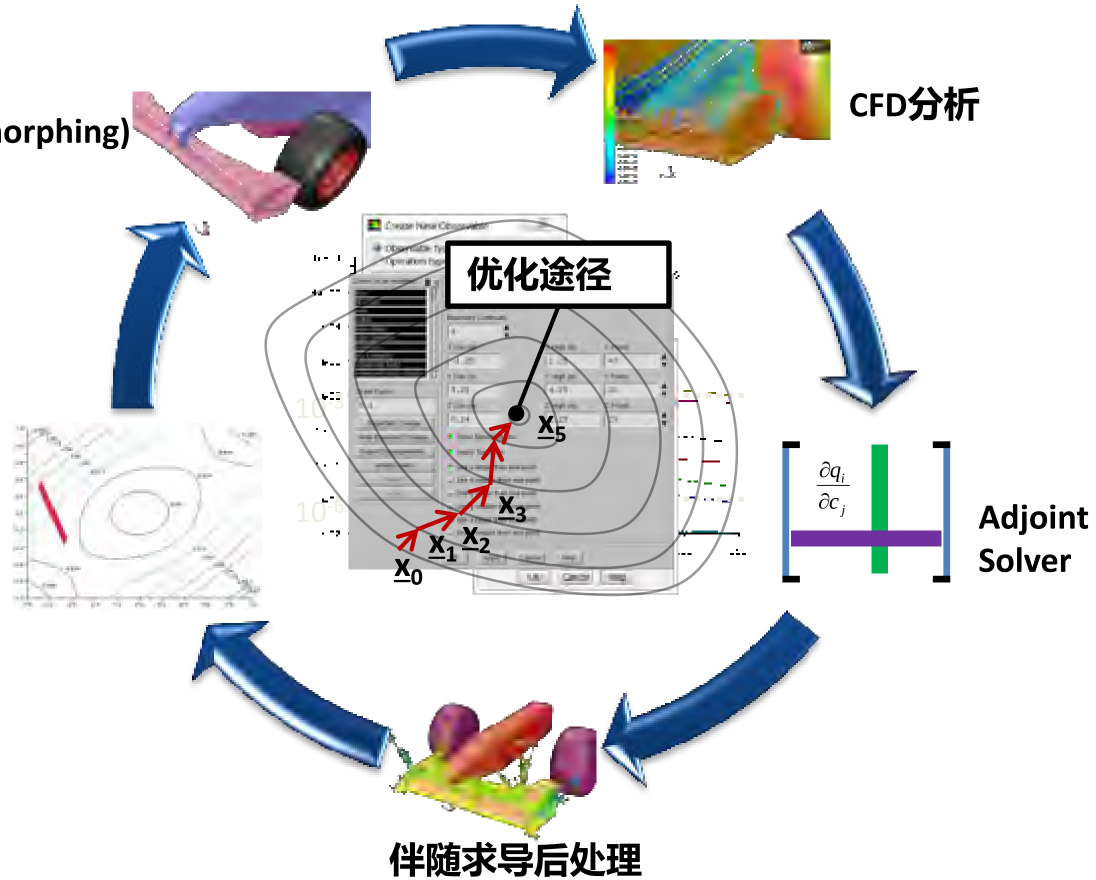
优化方法



Adjoint Solver简介

- Adjoint Solver基于流动分析的结果，进行敏感度分析
- Adjoint Solver可以分析任意系统输入参数和工程目标之间的依赖关系
- 一旦完成计算，软件可基于该结果进行智能化的设计调整。辅以优化算法，可自动完成流动系统的优化。

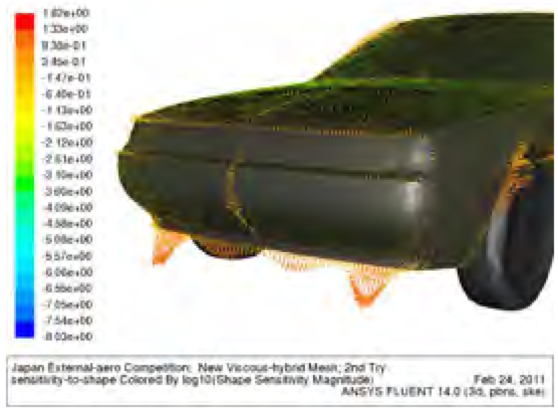
工作流程

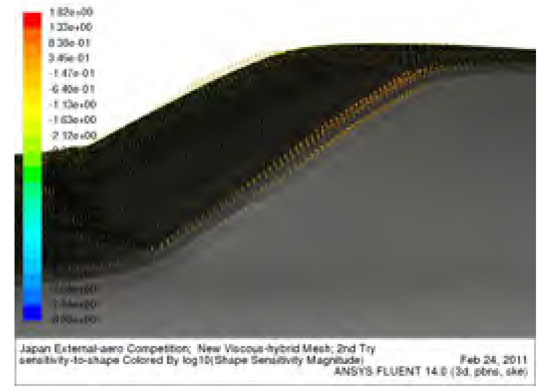


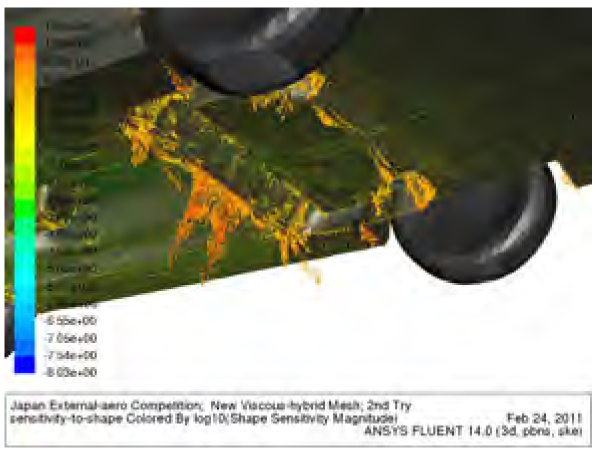
CFD分析
Adjoint
Solver
伴随求导后处理
当地优化
优化设计(morphing)
优化途径
$\frac{\partial q_i}{\partial c_j}$
$\underline{x}_0$
$\underline{x}_1$
$\underline{x}_2$
$\underline{x}_3$
$\underline{x}_5$

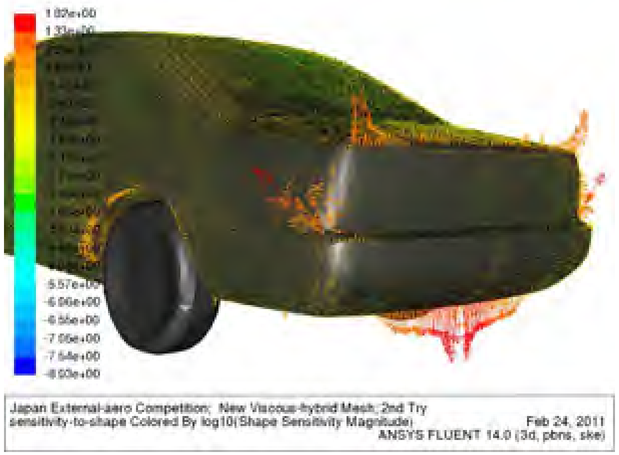
外气动优化- Sedan

阻力系数相对于外形的敏感度

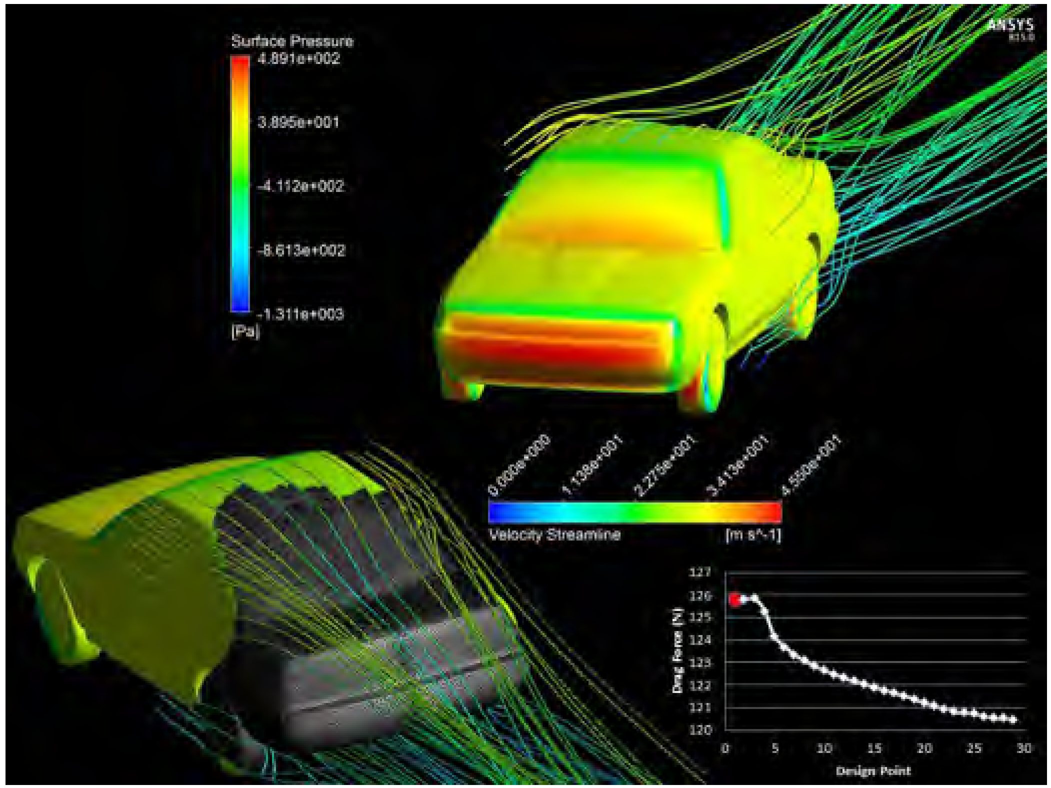




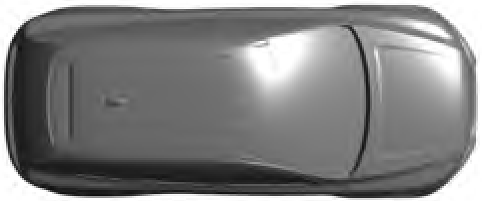


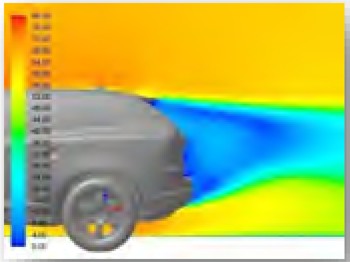


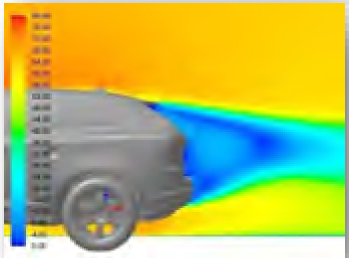
外气动优化- Sedan


ANSYS
Surface Pressure
4.891e+002
3.895e+001
-4.112e+002
-8.613e+002
-1.311e+003
[Pa]
0.000e+000
1.138e+001
2.275e+001
3.413e+001
4.550e+001
Velocity Streamline
[m s^-1]
Drag Force [N]
127
126
125
124
123
122
121
120
0
5
10
15
20
25
30
Design Point

VOLVO XC60 50:50:50







总结

- **ANSYS提供了完善的电池热解决方案**
  - 从三维到零维
  - 从极片->单体->整个系统
  - 从单纯热到电热耦合
- **ANSYS仿真分析可以涵盖目前所见的电机/驱动器热问题**
  - 电/磁/热耦合
  - 水冷/油冷
- **ANSYS提供的伴随求导器为气动优化提供了方向**

感谢聆听

ANSYS-China