

计算力学软件平台**SIPESC**

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数值仿真软件SiPESC

- 软件概况
- 优化设计
- 结构分析与数值模拟
- 软件定制与集成

概况

本单位自主软件研发坚持了几代人四十余年的，是引领本领域发展的一面旗帜

JIGFEX(1975, 多重多级子结构有限元)

- 国家力学一级学科
- 工业装备结构分析国家重点实验室
- 国际结构优化理论与应用联合研究中心
- 先进装备设计与CAE软件开发国家地方联合工程研究中心
- 院士：钱令希、钟万勰、程耿东、申长雨

DDDU(1980, 结构尺寸优化)

DDJ(1980,通用结构分析)

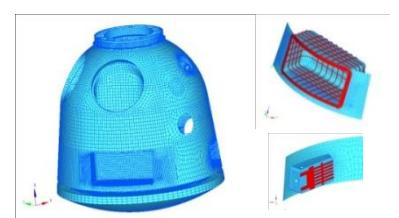
DASOS(1983, 海洋平台)

DASTAB(1985, 高层建筑)

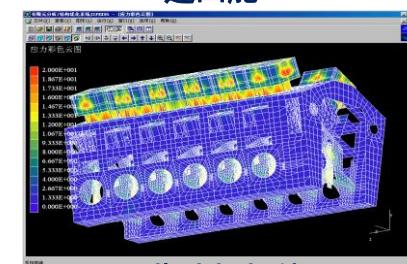
FEECA(1988, 饱和土与结构)

MCADS(1988, 结构集成优化)

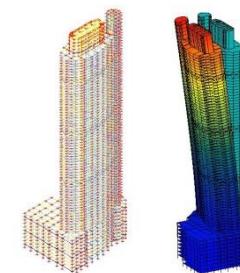
JIFEX(1995~2005, 结构分析集成系统)



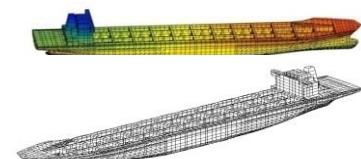
返回舱



柴油机机体

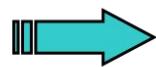
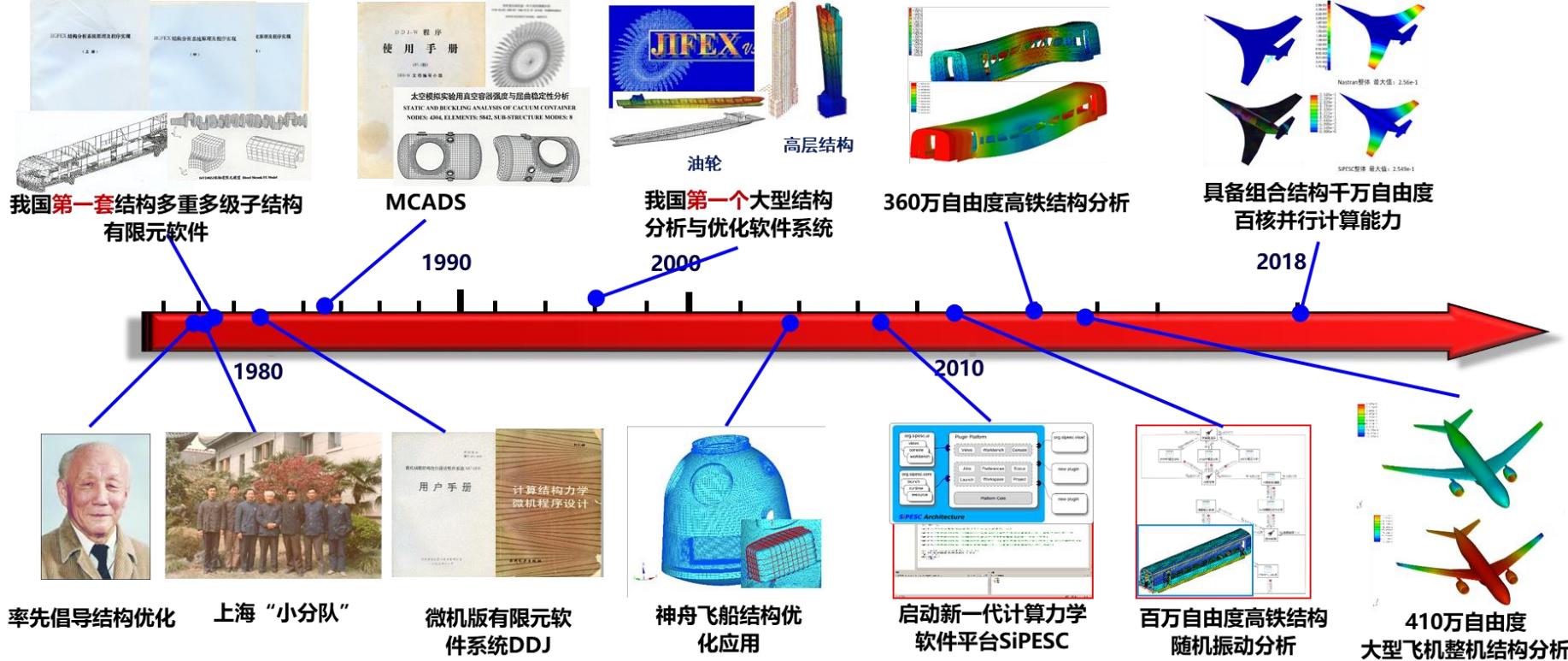


高层结构



油轮

概况



近四十年长期工作积淀、新老交替中不断传承

概况

- **重载列车**双层集装箱车体结构优化, 大连机车(重量降低12%, 刚度提升10%)
- **CD6140A/1000**卧式车床结构优化设计, 大连机床集团公司(实现减重8%)
- **大连国际贸易大厦**结构分析, 大连建筑设计院
- **8AS17活塞压缩机**机体结构分析, 大连冰山集团
- **天宫*号**相机支架结构设计(减重30%)
- **天宫*号**整体结构分析与优化
- **神舟*号**直属件结构分析与优化
- **空天飞行器**新概念结构设计
- **神舟*号飞船**返回舱结构减重优化设计(十余个部件优化, 实现减重45%)
- **神舟飞船**返回舱减速伞主伞包冲击强度分析(基于项目分析结果, 此后再无伞包强度问题发生)
- ****火箭结构**动力性能多重多级子结构高精度算法(计算精度完全超越国外商用软件)
- ****飞行器舵面**结构优化(实现减重19%)
- ****战略武器**复杂结构优化设计和可靠性评估,
- ****卫星中心承力筒**结构与整体结构优化设计(整星减重7%)
- **特种水下结构**强度设计优化设计
- **新一代高速列车**强度与自振分析, 南车四方机车
- **H418空分机**叶轮强度和振动分析与优化, 沈阳鼓风机集团
- **SVK160离心压缩机**结构整体强度分析, 沈阳鼓风机集团(实现减重15%, 经济效益超千万元)
- **离心压缩机**半开式叶轮轴孔变形分析与装配形式优化, 沈阳鼓风机集团
- **BDW285电除尘器**结构分析与优化设计, 鞍山除尘设备厂(实现减重20%, 年经济效益200万元)
- **Φ6000圆盘造球机**结构分析和优化, 鞍山亨通阀门集团(实现减重17%)
- **直升机桨叶接头**形状优化(最大应力降低15%, 产品寿命延长2倍)
-

数值仿真软件SiPESC-软件概况

SiPESC—Software Integration Platform for Engineering and Scientific Computation
工程与科学计算集成化软件平台

完成指标:

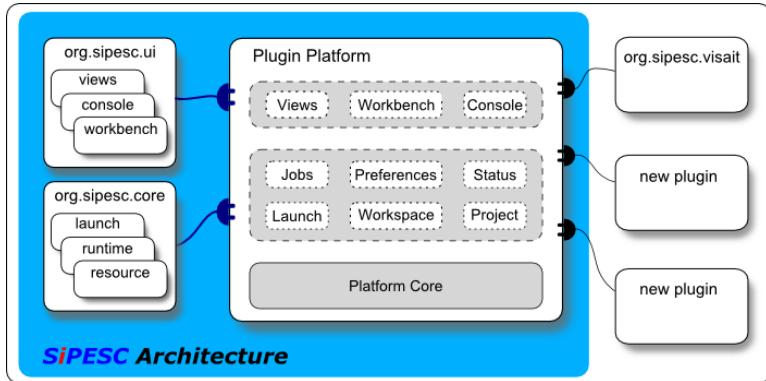
- 300万行以上源代码
 - 10个以上应用子系统
 - 1.6万套以上网上免费下载
 - 跨平台(Windows/Win64/Linux...)运行



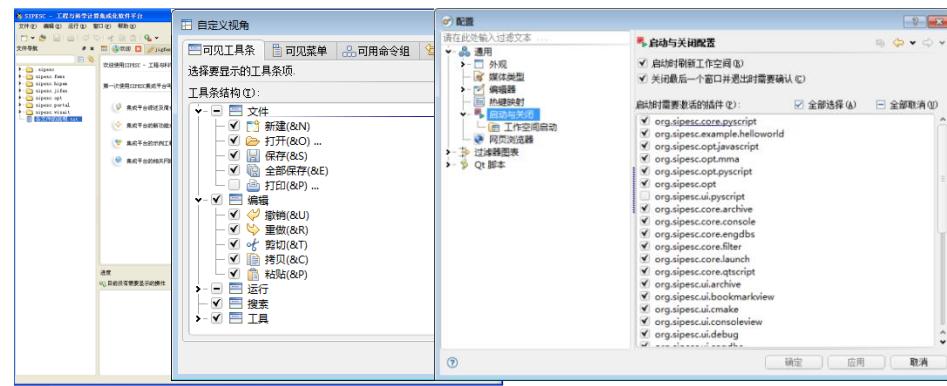
发展规划：

- 面向教育科研：免费共享，凝聚力量，协同发展；
 - 面向中小企业：工程师能用的定制软件，
 - 面向大型骨干企业：开发高端/特色/集成化的仿真软件，努力突破国外垄断局面；

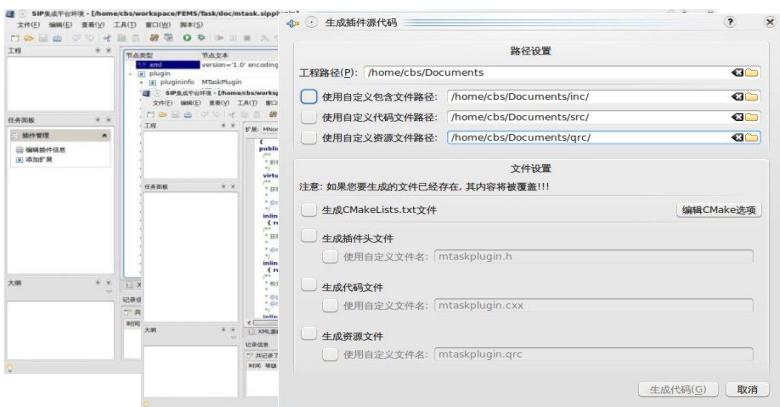
数值仿真软件SiPESC-软件概况



1.采用“平台+插件”体系结构



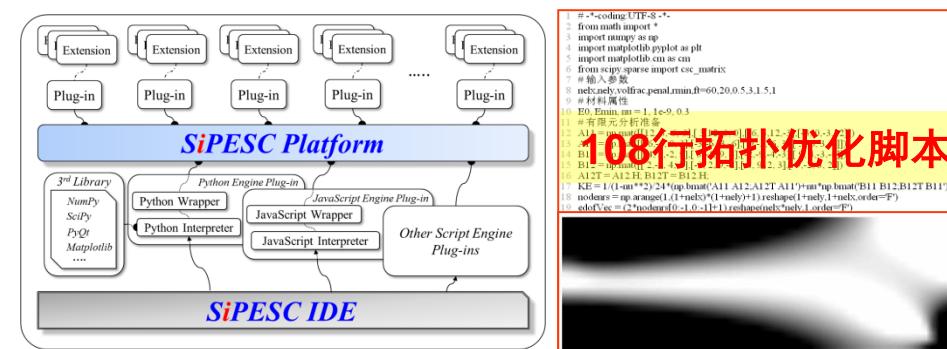
2.构建灵活界面环境：动态配置、定制开发



3.提供便捷的基于插件的二次开发工具

平台特色：

- 方便实现软件功能扩展；
- 快捷实施定制化开发

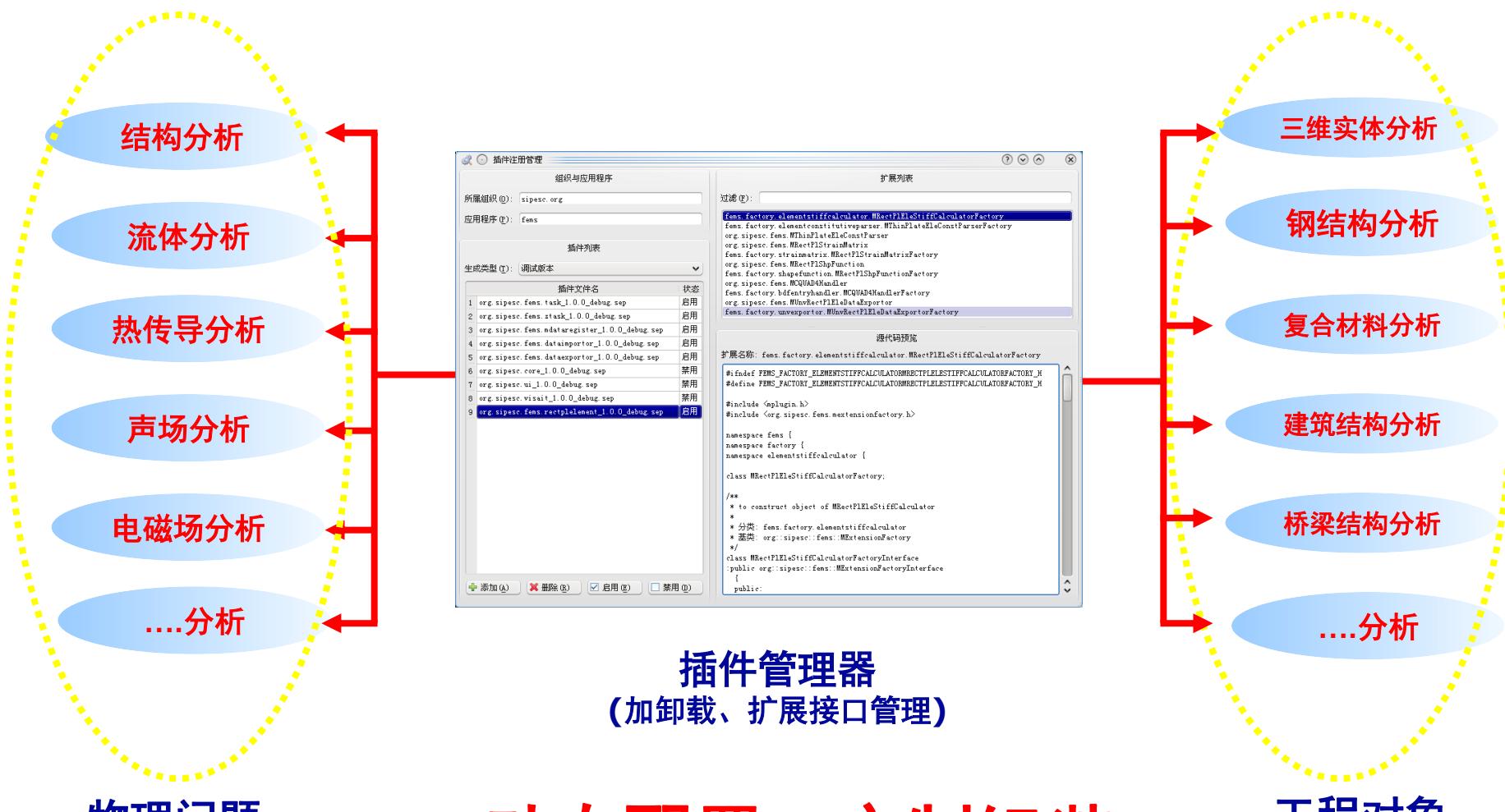


4.支持脚本语言(类似Matlab环境)

- 多种途径进行多类软件(商业/自主)集成；
- 支持多人/多组织协同开发与功能融合

```
1 # -*- coding: UTF-8 -*-
2 from math import *
3 import numpy as np
4 import mathplotlib as plt
5 import mathplotlib as cm
6 from scipy sparse import csc_matrix
7 # 输入参数
8 rho=1.0
9 trac.penalty=60.20.5.3.1.5.1
10 # 物理属性
11 E0,Emm,nn=1.1e-9,0.3
12 # 有限元分析准备
13 A1=A11*A12*A121
14 B1=B11*B12*B121
15 K1=K11*K12*K121
16 noders=(nn+nn1)*(nn+nn1)+1
17 noders=(nn+nn1)*(nn+nn1)+1
18 noders=(nn+nn1)*(nn+nn1)+1
19 edoVec=(2*nnoders*(nn+nn1)+1)*nnoders*nnoders*nnoders
20 edoVec=(2*nnoders*(nn+nn1)+1)*nnoders*nnoders*nnoders
```

数值仿真软件SiPESC-软件概况

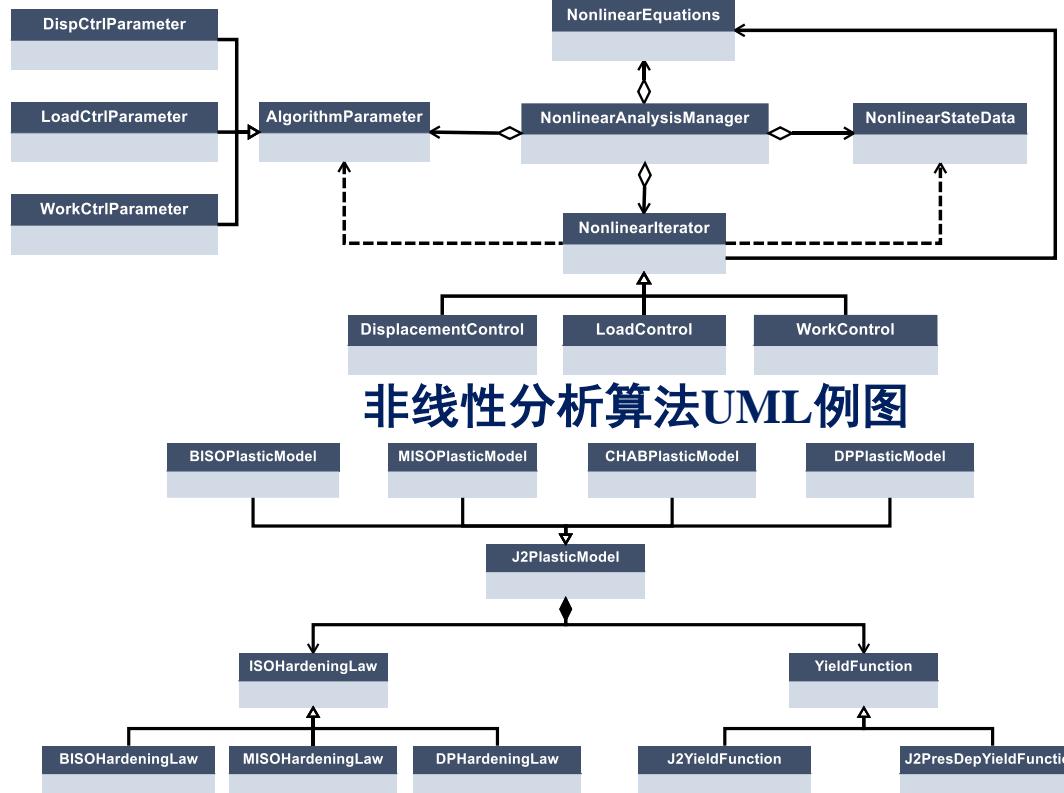


动态配置，定制组装

数值仿真软件SiPESC-算法设计模式

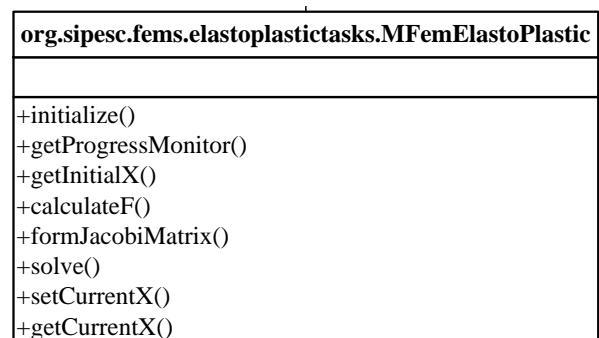
弹塑性分析的软件框架

- 抽象非线性分析同性数据为数据模型类，独立于算法
- 根据异性特征分别创建不同参数类、控制算法类，提高扩展性

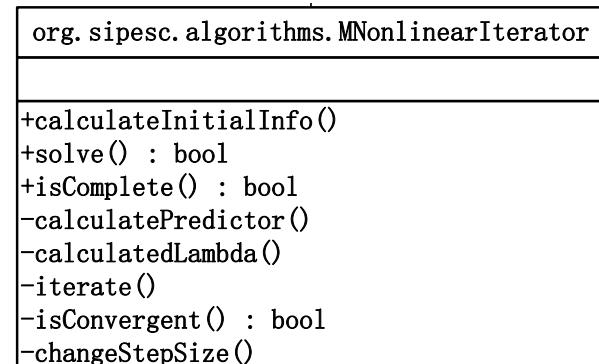


非线性分析算法UML例图

弹塑性本构模型UML例图



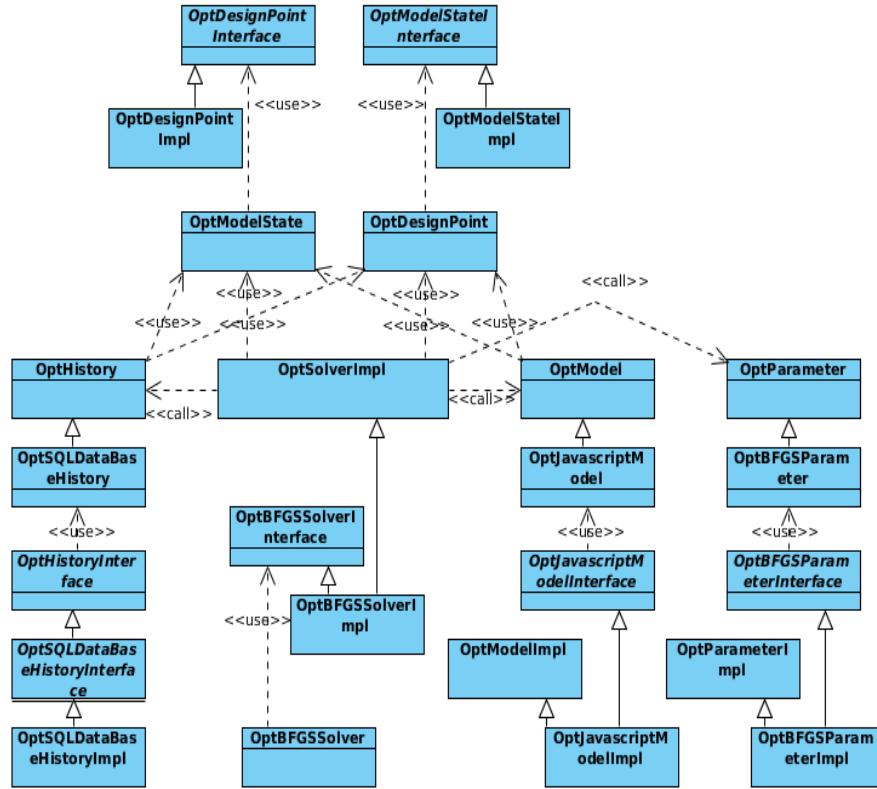
弹塑性模型类类图



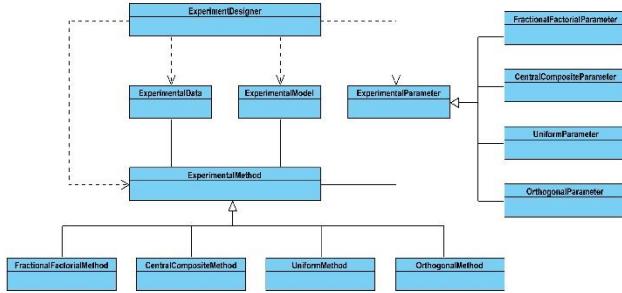
非线性迭代算法类类图

数值仿真软件SiPESC-算法设计模式

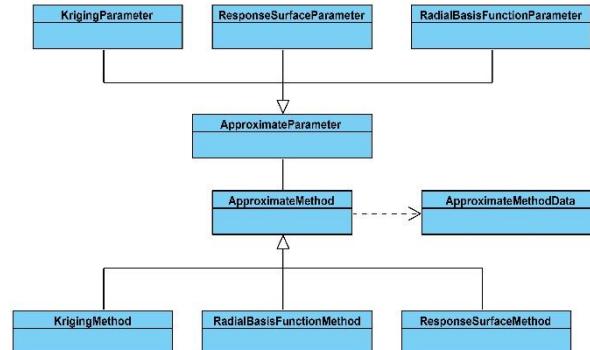
优化算法库/优化工具设计方案



优化算法库设计方案

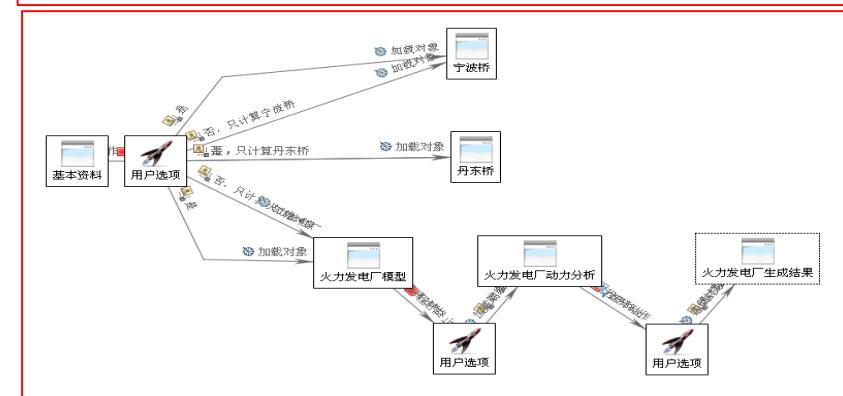
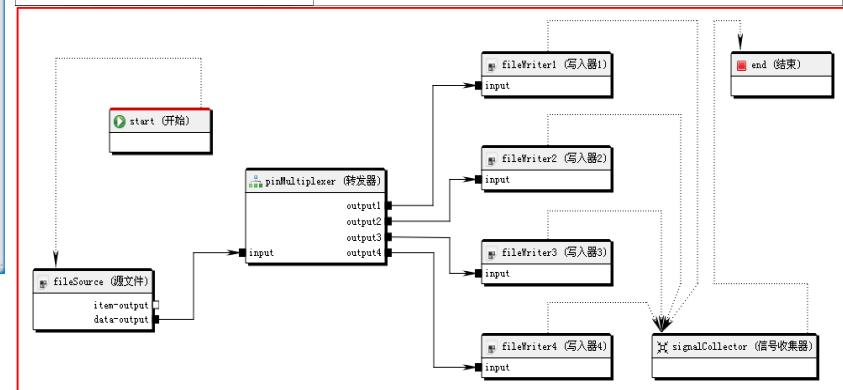
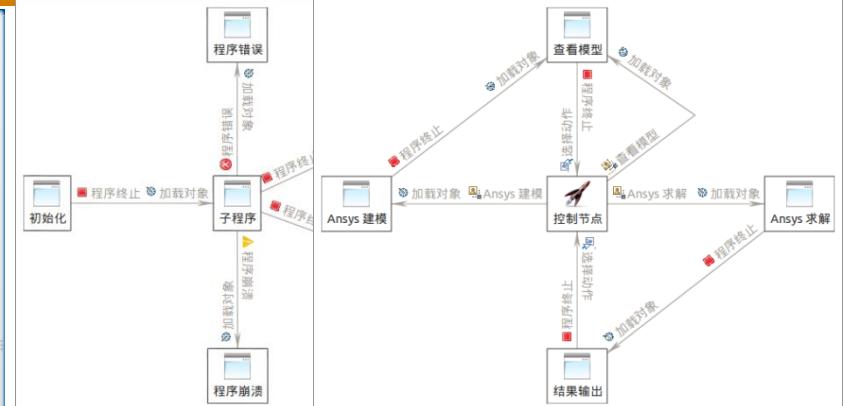


实验设计工具库类设计方案



近似模型工具库类设计方案

数值仿真软件SiPESC-软件概况



集成方案

活动流程图定制工具

运行程序集成的统一实现

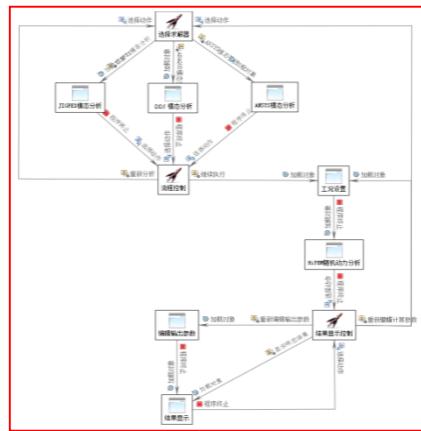
并发任务管理, 网格计算

复杂流程管理, 子流程嵌套

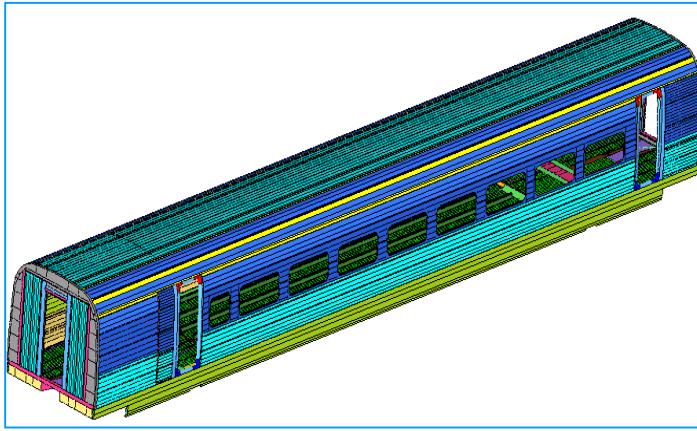
多学科/多场耦合/多尺度分析集成计算

数值仿真软件SiPESC-软件概况

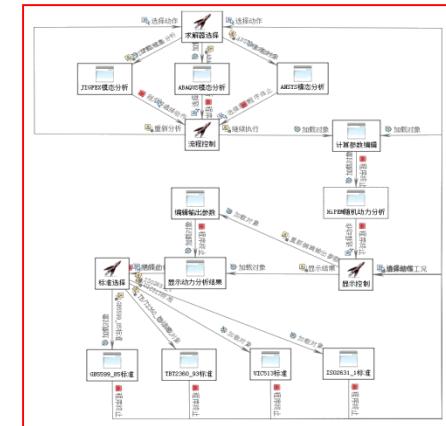
高速列车结构随机振动分析平台SiPESC.HiPEM



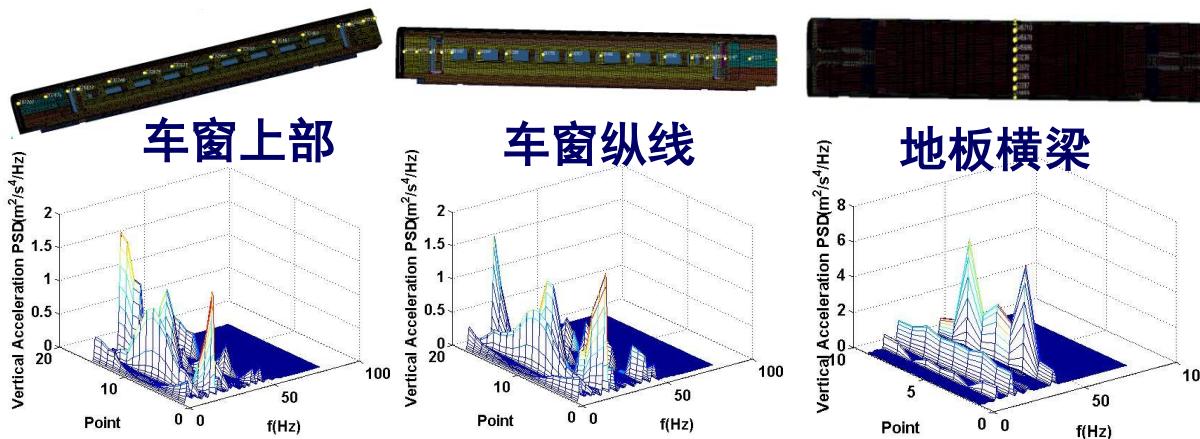
随机振动集成分析流程



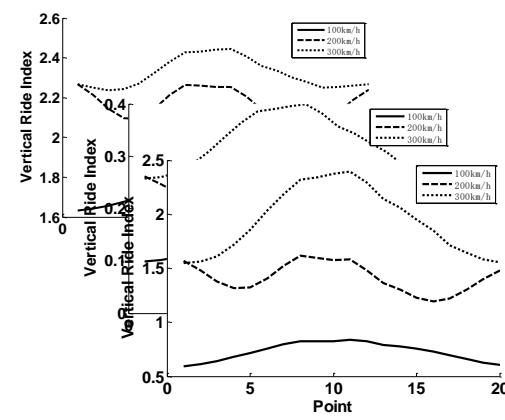
百万自由度规模随机振动分析



平顺性集成分析流程

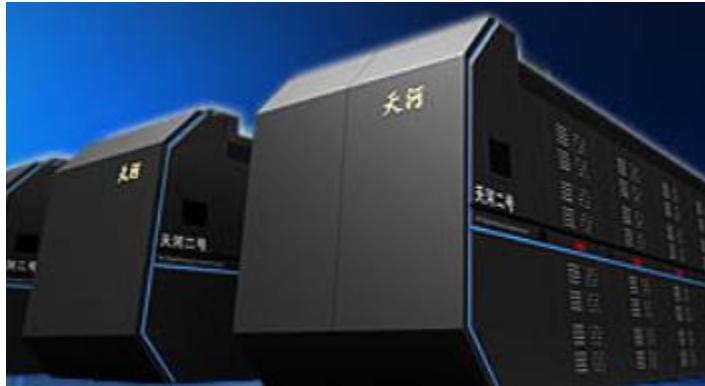


车速300km/h,功率谱分析



不同车速平顺性分析

SiPESC在超算环境的部署情况



部署8个超算环境

 国家超级计算广州中心 NATIONAL SUPERCOMPUTER CENTER IN GUANGZHOU	天河二号
 国家超级计算无锡中心 National Supercomputing Center in Wuxi	神威太湖之光
 国家超级计算深圳中心 National Supercomputing Center in Shenzhen 深圳云计算中心 Shenzhen Cloud Computing Center	深圳超算
 国家超级计算天津中心 National SuperComputer Center in Tianjin	天津超算
 空气动力发展中心 CARDC	空气动力发展中心
 上海超级计算中心 Shanghai Supercomputer Center Shanghai Supercomputing Center	上海超算
 上海航天技术研究院 中国航天 Shanghai Academy of Spaceflight Technology	航天8院
 大连理工大学 DALIAN UNIVERSITY OF TECHNOLOGY  云 LYING YUN	大连理工

数值仿真软件SiPESC

- 软件概况
- 优化设计
- 结构分析与数值模拟
- 软件定制与集成

数值仿真软件SiPESC-优化设计

◆ 仿真软件的数据备份和管理：

- 可以选择备份运行时输入、输出、项目配置等文件

◆ 优化算法：

- BFGS、SLP、SQP、MMA、GCMMA、GA、NLPQLP、CO等
- 自研SQP、GA、PSO等算法
- 多目标NSGAII、SPEA2等算法

◆ 试验设计算法：

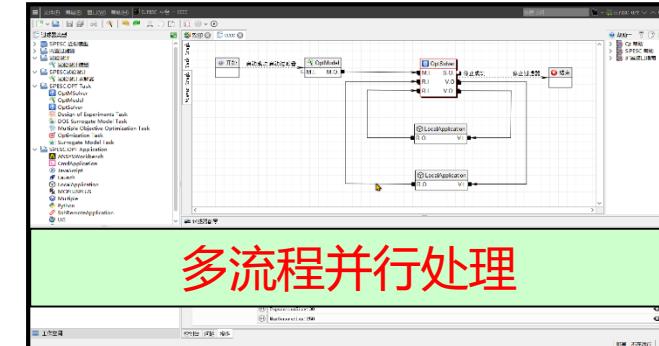
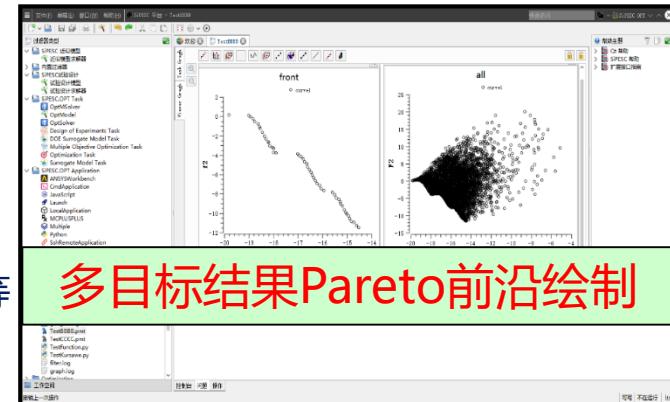
- 正交（170种）、均匀（1385种）、中心复合、析因、最优拉丁方、Sobol

◆ 代理模型方法：

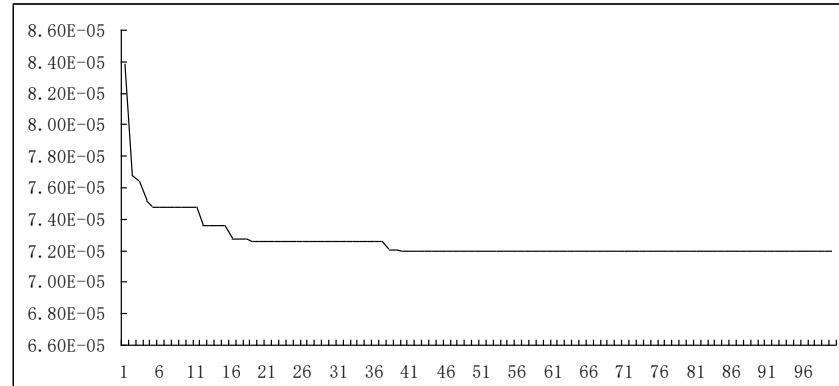
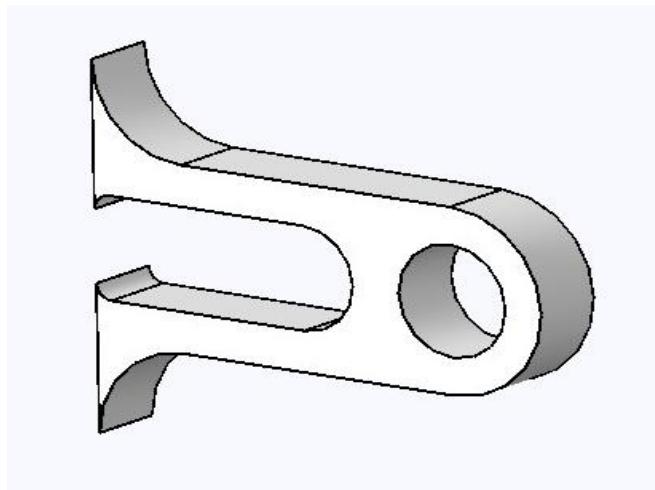
- 响应面、径向基函数、Kriging、Chebyshev张量积、稀疏回归
Chebyshev多项式

◆ 可靠性、不确定性估计：

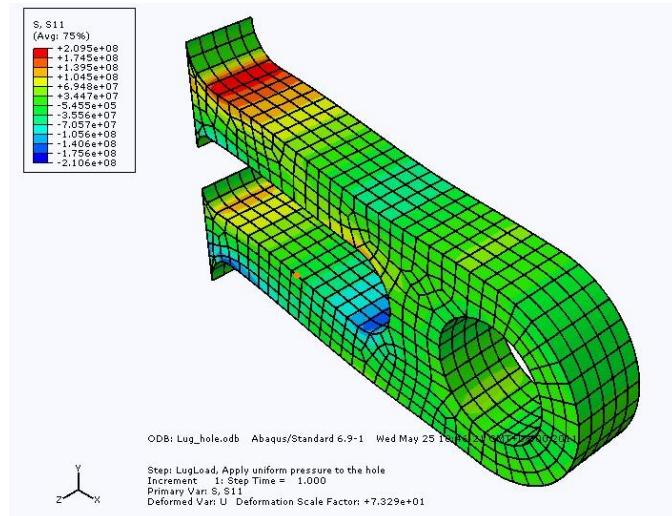
- 田口试验设计、MC、FORM、SORM、多项式区间估计、 6σ 鲁棒性优化设计



数值仿真软件SiPESC-优化设计



结构重量迭代历史



```
theModel.setVariable( "C" ,  
3.68574 ) ;  
theModel.setVariableLowerLimit( "  
C" , 0.001 ) ;  
  
var Solver = GA ;  
GA.setGENERATION( 100 );  
GA.setPOPULATIONSIZE( 20 );
```

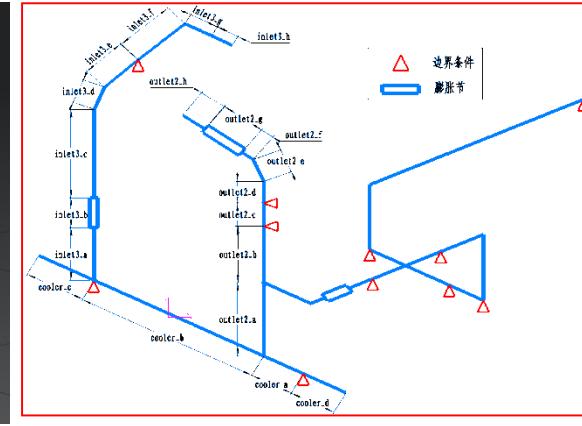
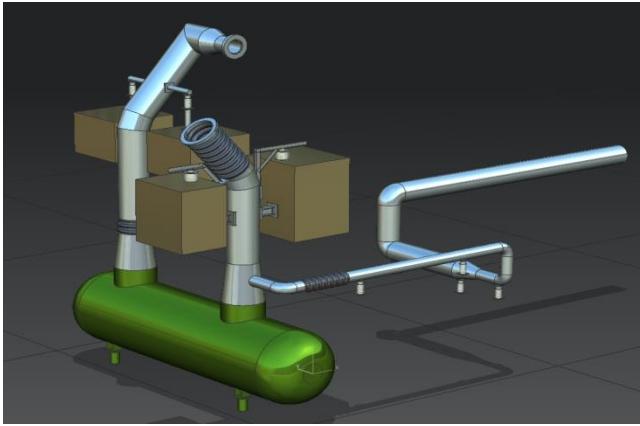
优化计算的JavaScript脚本

```
# define parameters  
d = 9.53  
t = 0.4.....  
s.Line(point1=(d/-2.0,  
t/2.0),  
point2=(d/2.0, t/2.0))
```

ABAQUS参数化Python脚本

集成ABAQUS的形状优化算例

数值仿真软件SiPESC-优化设计



PTA装置压缩机管路

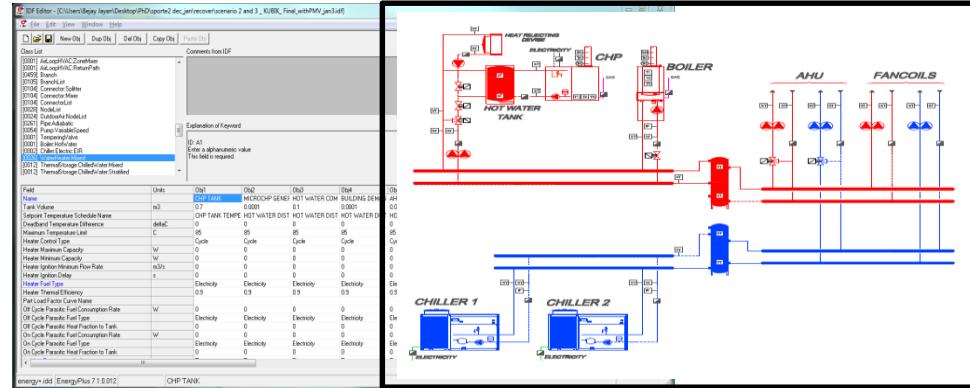
- 现场过大的管路振动导致管壁出现疲劳破坏。将复杂的减振设计提成机-管接口载荷及刚度识别和支撑刚度优化设计问题，两者均由SiPESC定制的脚本文件驱动分析器和优化算法库实现。
- 优化设计使管路振动峰值响应降低近20%，提高了抗疲劳可靠性；为大型压缩机管路的减振提供了更有效的手段和方法。

压缩机管路减振优化设计优化(沈鼓集团)

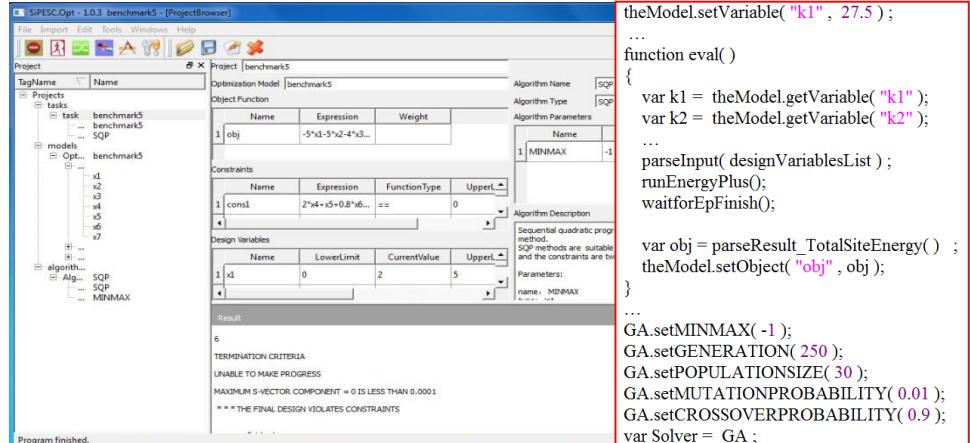
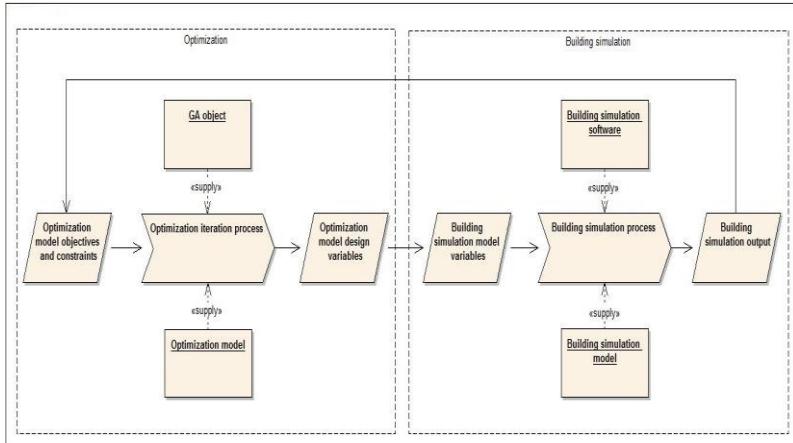
数值仿真软件SiPESC-优化设计



物理模型与计算模型



SportE²数值模拟



集成优化计算流程

SiPESC.OPT的优化计算(减耗5%~10%) 建筑节能优化(英国Cardiff大学)

```
theModel.setVariable("k1", 27.5);
...
function eval()
{
    var k1 = theModel.getVariable("k1");
    var k2 = theModel.getVariable("k2");
    ...
    parseInput(designVariablesList);
    runEnergyPlus();
    waitforEpFinish();

    var obj = parseResult_TotalSiteEnergy();
    theModel.setObject("obj", obj);
}

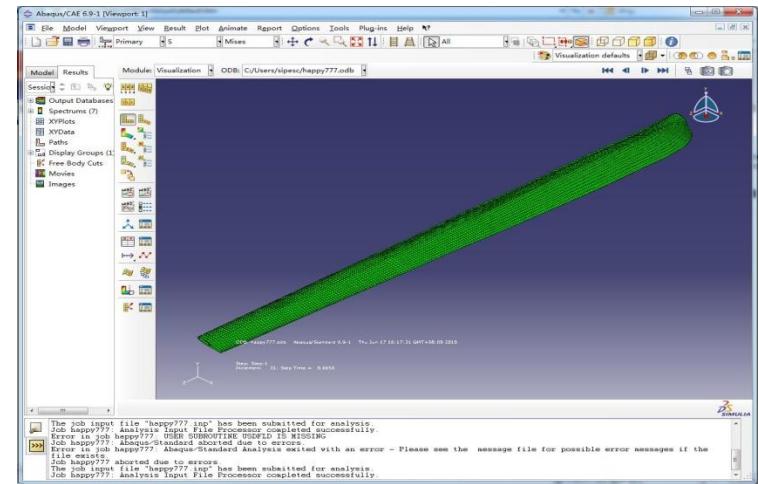
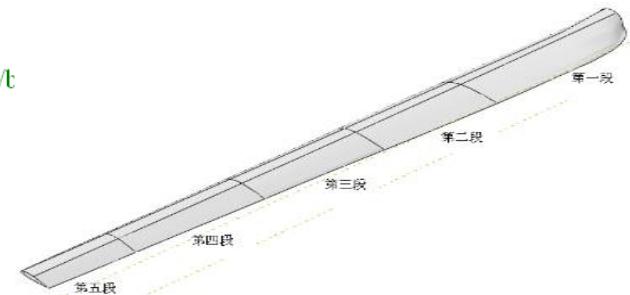
...
GA.setMINMAX(-1);
GA.setGENERATION(250);
GA.setPOPULATIONSIZE(30);
GA.setMUTATIONPROBABILITY(0.01);
GA.setCROSSOVERPROBABILITY(0.9);
var Solver = GA;
```

数值仿真软件SiPESC-优化设计



```
1 function runAbaqus()
2 {
3     //blade.bat:
4     // && C:/SIMULIA/Abaqus/6.9-1/exec/abq691.exe job=wing inp=e:/SIPOpt/t
5     // user=e:/SIPOpt/bin/pohuaizhunze.for cpus=8 mp_mode=threads
6     var args = new Array("/c", "e:/SIPOpt/bin/blade.bat");
7     abaqusProcess.execute("C:/Windows/System32/cmd.exe", args );
8     var jobName = "blade";
9     ...
10 }
11 ...
12 // setting design variables
13 theModel.setVariable("cl_1_0", 0.09);
14 //...
15 function eval()
16 {
17     //reading current design variables and renew FEA model...
18     runAbaqus();
19     //reading results and evaluate objective and constraints function
20 }
21 eval(); //start FEA analysis
22 DGA.setMINMAX(-1); //setting algorithmic parameters
23 //...
24 var Solver = DGA; //using GA optimization solver
25 Solver.initialize(theModel);
26 do{ // starting optimization computation
27     eval();
28     ModelSaver.save(theModel);
29     Solver.renewModel(theModel);
30 } while( ! Solver.isComplete() )
```

脚本语言驱动

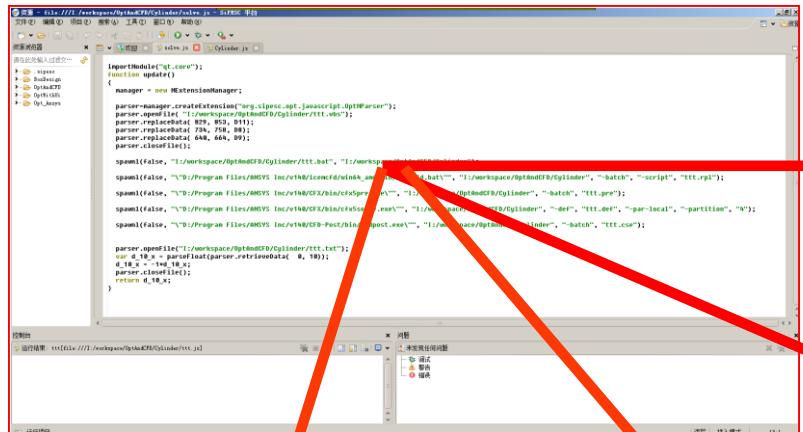


Abaqus集成

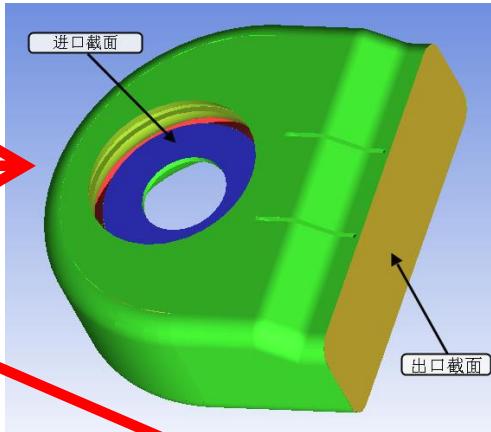
风力发电机叶片复合材料优化设计

重量降低4.7%,刚度提升10.9%

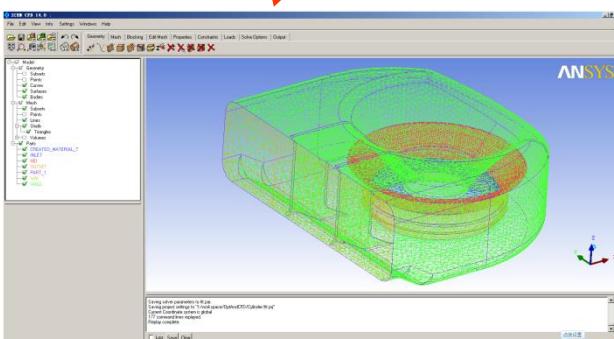
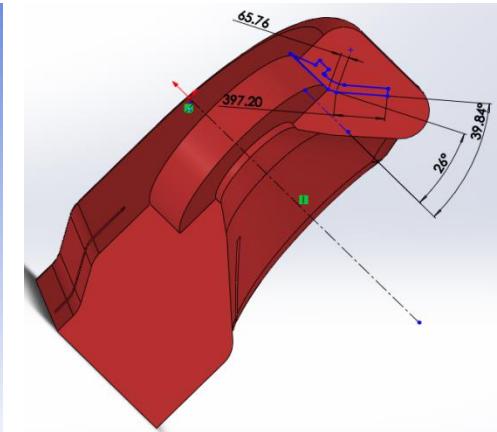
数值仿真软件SiPESC-优化设计



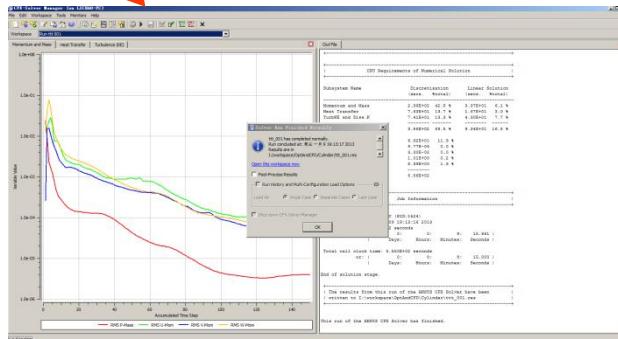
脚本语言



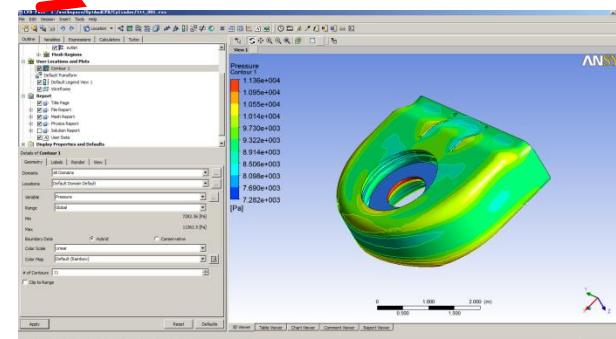
几何建模(SolidWorks)



网格剖分(ICEM)



计算(CFX5.solve)



计算(CFD.post)

汽轮机部件流场集成优化(杭州汽轮机)

数值仿真软件SiPESC-优化设计

Kriging 近似数学模型的片段

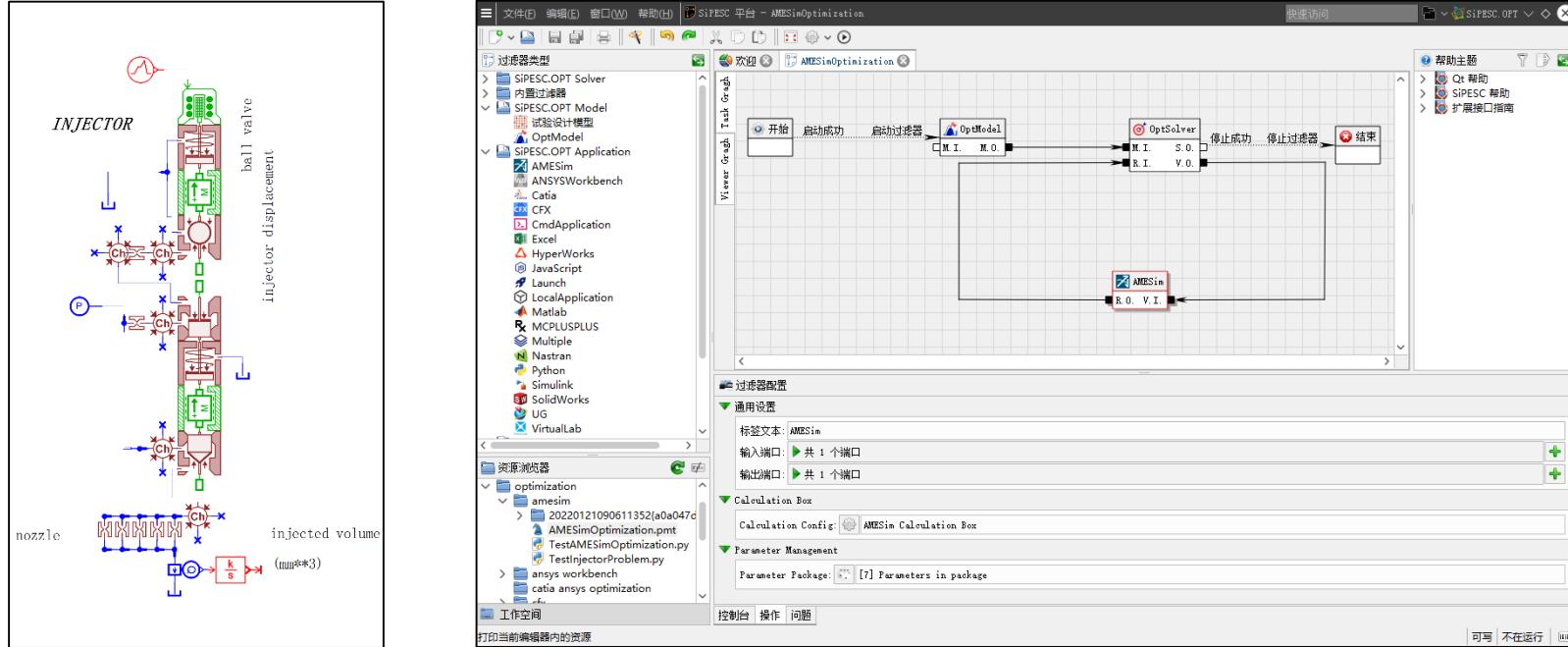
-0.0799099999999999*(3.799052876269879*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.349066-D8)*(0.349066-D8)+(0.072-D9)*(0.072-D9)+(0.785398-D10)*(0.785398-D10)+(0.37-D11)*(0.37-D11))))-1.368546342814545*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.436332-D8)*(0.436332-D8)+(0.096-D9)*(0.096-D9)+(1.0472-D10)*(1.0472-D10)+(0.31-D11)*(0.31-D11))))-1.82658349469517*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.523599-D8)*(0.523599-D8)+(0.12-D9)*(0.12-D9)+(0.698132-D10)*(0.698132-D10)+(0.25-D11)*(0.25-D11))))-0.6368026009005321*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.610865-D8)*(0.610865-D8)+(0.06-D9)*(0.06-D9)+(0.959931-D10)*(0.959931-D10)+(0.4-D11)*(0.4-D11))))-0.375532808940523*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.698132-D8)*(0.698132-D8)+(0.084-D9)*(0.084-D9)+(0.610865-D10)*(0.610865-D10)+(0.34-D11)*(0.34-D11))))+0.408412371080892*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.785398-D8)*(0.785398-D8)+(0.108-D9)*(0.108-D9)+(0.872664-D10)*(0.872664-D10)+(0.28-D11)*(0.28-D11))))+0.2129602205578495-0.1258*(-1.368546342814545*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.349066-D8)*(0.349066-D8)+(0.072-D9)*(0.072-D9)+(0.785398-D10)*(0.785398-D10)+(0.37-D11)*(0.37-D11)))))+3.713417086152318*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.436332-D8)*(0.436332-D8)+(0.096-D9)*(0.096-D9)+(1.0472-D10)*(1.0472-D10)+(0.31-D11)*(0.31-D11))))-0.3617208390907864*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.523599-D8)*(0.523599-D8)+(0.12-D9)*(0.12-D9)+(0.698132-D10)*(0.698132-D10)+(0.25-D11)*(0.25-D11))))-1.96429254835942*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.610865-D8)*(0.610865-D8)+(0.06-D9)*(0.06-D9)+(0.959931-D10)*(0.959931-D10)+(0.4-D11)*(0.4-D11))))+0.3566754530529567*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.698132-D8)*(0.698132-D8)+(0.084-D9)*(0.084-D9)+(0.610865-D10)*(0.610865-D10)+(0.34-D11)*(0.34-D11))))-0.3755328089405222*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.785398-D8)*(0.785398-D8)+(0.108-D9)*(0.108-D9)+(0.872664-D10)*(0.872664-D10)+(0.28-D11)*(0.28-D11))))+0.2604030142776222-0.06721000000000001*(-1.826583494695171*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.349066-D8)*(0.349066-D8)+(0.072-D9)*(0.072-D9)+(0.785398-D10)*(0.785398-D10)+(0.37-D11)*(0.37-D11)))))-0.3617208390907866*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.436332-D8)*(0.436332-D8)+(0.096-D9)*(0.096-D9)+(1.0472-D10)*(1.0472-D10)+(0.31-D11)*(0.31-D11))))+4.859270040536949*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.523599-D8)*(0.523599-D8)+(0.12-D9)*(0.12-D9)+(0.698132-D10)*(0.698132-D10)+(0.25-D11)*(0.25-D11))))-0.06987055749103974*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.610865-D8)*(0.610865-D8)+(0.06-D9)*(0.06-D9)+(0.959931-D10)*(0.959931-D10)+(0.4-D11)*(0.4-D11))))-1.96429254835942*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.698132-D8)*(0.698132-D8)+(0.084-D9)*(0.084-D9)+(0.610865-D10)*(0.610865-D10)+(0.34-D11)*(0.34-D11))))-0.6368026009005323*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.785398-D8)*(0.785398-D8)+(0.108-D9)*(0.108-D9)+(0.872664-D10)*(0.872664-D10)+(0.28-D11)*(0.28-D11))))+0.02663676516452819)-0.1343*(-0.6368026009005324*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.349066-D8)*(0.349066-D8)+(0.072-D9)*(0.072-D9)+(0.785398-D10)*(0.785398-D10)+(0.37-D11)*(0.37-D11)))))-1.964292548359421*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.436332-D8)*(0.436332-D8)+(0.096-D9)*(0.096-D9)+(1.0472-D10)*(1.0472-D10)+(0.31-D11)*(0.31-D11))))-0.06987055749104033*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.523599-D8)*(0.523599-D8)+(0.12-D9)*(0.12-D9)+(0.698132-D10)*(0.698132-D10)+(0.25-D11)*(0.25-D11))))+4.85927004053695*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.610865-D8)*(0.610865-D8)+(0.06-D9)*(0.06-D9)+(0.959931-D10)*(0.959931-D10)+(0.4-D11)*(0.4-D11))))-0.3617208390907867*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.698132-D8)*(0.698132-D8)+(0.084-D9)*(0.084-D9)+(0.610865-D10)*(0.610865-D10)+(0.34-D11)*(0.34-D11))))-1.826583494695171*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.785398-D8)*(0.785398-D8)+(0.108-D9)*(0.108-D9)+(0.872664-D10)*(0.872664-D10)+(0.28-D11)*(0.28-D11))))+0.02663676516452836)-0.006362*(-0.3755328089405227*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.349066-D8)*(0.349066-D8)+(0.072-D9)*(0.072-D9)+(0.785398-D10)*(0.785398-D10)+(0.37-D11)*(0.37-D11)))))+0.3566754530529567*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.436332-D8)*(0.436332-D8)+(0.096-D9)*(0.096-D9)+(1.0472-D10)*(1.0472-D10)+(0.31-D11)*(0.31-D11)))))-1.96429254835942*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.523599-D8)*(0.523599-D8)+(0.12-D9)*(0.12-D9)+(0.698132-D10)*(0.698132-D10)+(0.25-D11)*(0.25-D11)))))-0.3617208390907867*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.610865-D8)*(0.610865-D8)+(0.06-D9)*(0.06-D9)+(0.959931-D10)*(0.959931-D10)+(0.4-D11)*(0.4-D11))))+3.713417086152319*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.698132-D8)*(0.698132-D8)+(0.084-D9)*(0.084-D9)+(0.610865-D10)*(0.610865-D10)+(0.34-D11)*(0.34-D11))))-1.368546342814545*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.785398-D8)*(0.785398-D8)+(0.108-D9)*(0.108-D9)+(0.872664-D10)*(0.872664-D10)+(0.28-D11)*(0.28-D11))))+0.2604030142776224)-0.1417*(0.4084123710808923*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.349066-D8)*(0.349066-D8)+(0.072-D9)*(0.072-D9)+(0.785398-D10)*(0.785398-D10)+(0.37-D11)*(0.37-D11)))))-0.3755328089405222*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.436332-D8)*(0.436332-D8)+(0.096-D9)*(0.096-D9)+(1.0472-D10)*(1.0472-D10)+(0.31-D11)*(0.31-D11)))))-0.6368026009005319*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.523599-D8)*(0.523599-D8)+(0.12-D9)*(0.12-D9)+(0.698132-D10)*(0.698132-D10)+(0.25-D11)*(0.25-D11))))-1.826583494695171*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.610865-D8)*(0.610865-D8)+(0.06-D9)*(0.06-D9)+(0.959931-D10)*(0.959931-D10)+(0.4-D11)*(0.4-D11))))-1.368546342814546*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.698132-D8)*(0.698132-D8)+(0.084-D9)*(0.084-D9)+(0.610865-D10)*(0.610865-D10)+(0.34-D11)*(0.34-D11))))+3.799052876269879*(1-1*(1-Math.pow(Math.E, -0.9*Math.sqrt((0.785398-D8)*(0.785398-D8)+(0.108-D9)*(0.108-D9)+(0.872664-D10)*(0.872664-D10)+(0.28-D11)*(0.28-D11))))+0.2129602205578494;

SiPESC.OPT的GUI界面

SiPESC.OPT的GUI界面展示了以下功能：

- 菜单**：位于顶部，提供文件、编辑、窗口、帮助等选项。
- 快速访问、切换视角**：位于顶部，提供快速访问和切换视角的功能。
- 过滤器类型-视图**：优化拖拽模块，显示过滤器分类。
- 流程、结果-编辑器**：优化任务搭建、结果查看，显示任务图（Task Graph）。
- 帮助-视图**：查看扩展接口，显示帮助主题。
- 控制台、操作、问题-视图（叠加）**：配置拖拽模块属性、查看输出及问题，显示资源浏览器。
- 多个活动的流程搭建**：显示多个并行任务的流程搭建。
- 参数映射与数据传输**：显示参数映射与数据传输的配置。
- 拖拽配置搭建优化任务流程**：显示通过拖拽配置搭建优化任务流程。
- 信号连接**：显示信号连接操作，如连接信号、删除选择项。
- 数据连接**：显示数据连接操作，如输入Pin、输出Pin。

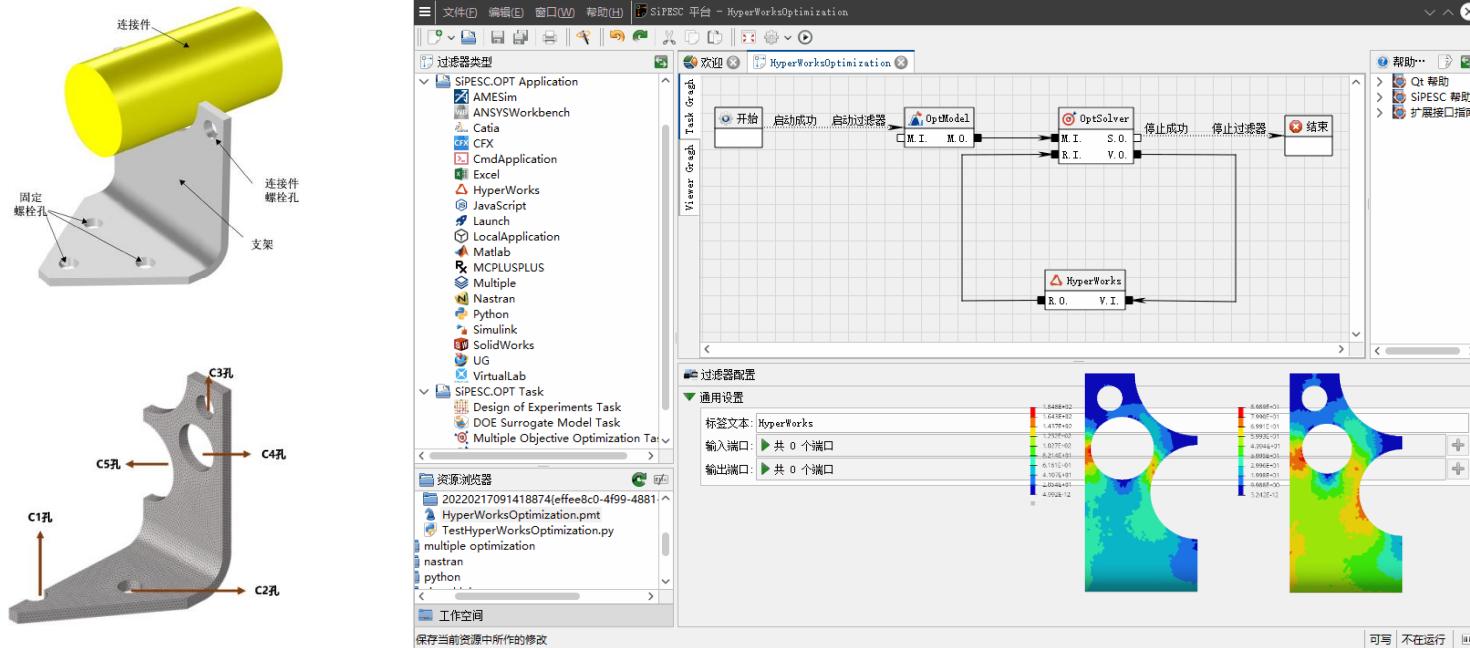
集成AMESim进行优化设计



需要找到一组合适的参数来达到指定的注入量，并保证约束限制约束

优化经过6次迭代，54次问题求解，获得最优结果。优化后注射输出精度得到了极大的提高，目标从6.327减少到0.0002，优化取得非常好的效果。

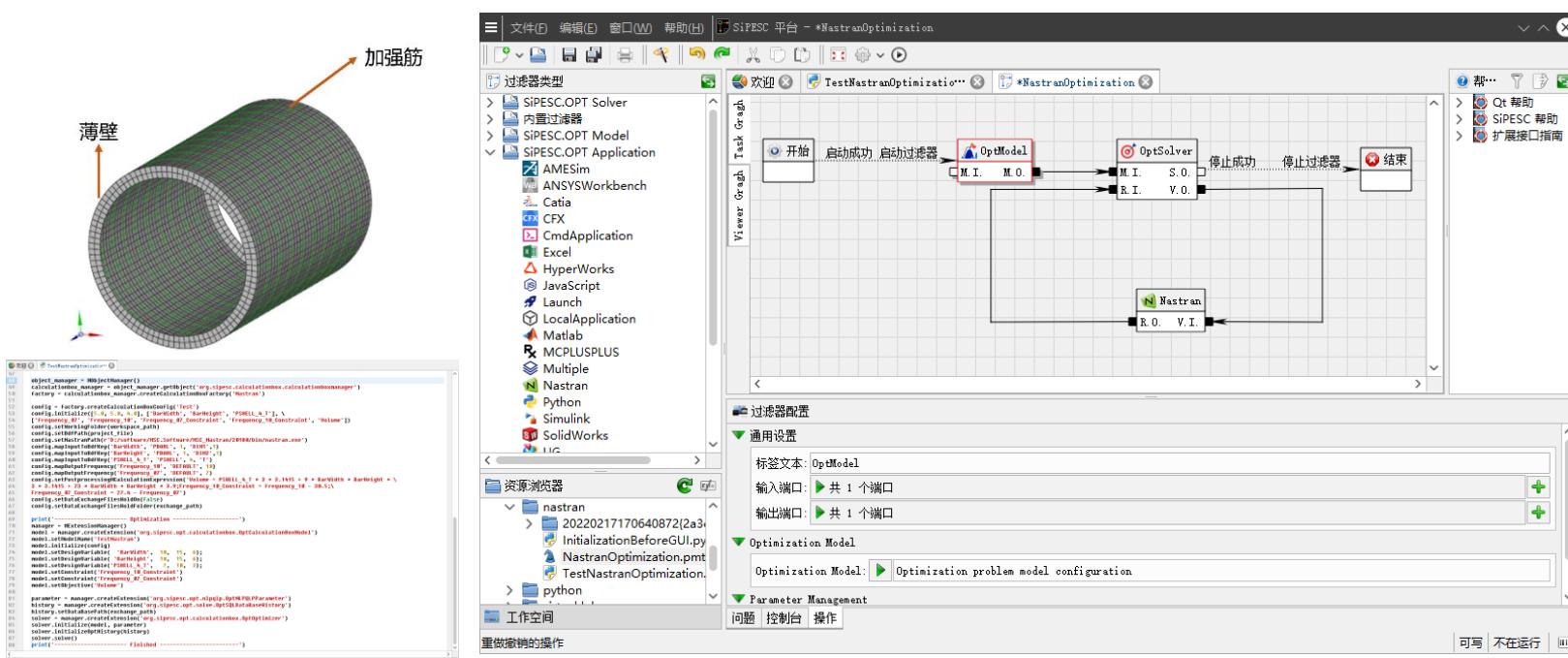
集成HyperWorks进行优化设计



工程支架底面由螺栓与整体连接固定，受过载压力，减轻支架重量

优化后，支架的VonMises应力从184.69MPa 降到89.8443Mpa，满足强度约束要求，优化取得非常好的效果

集成Nastran进行优化设计

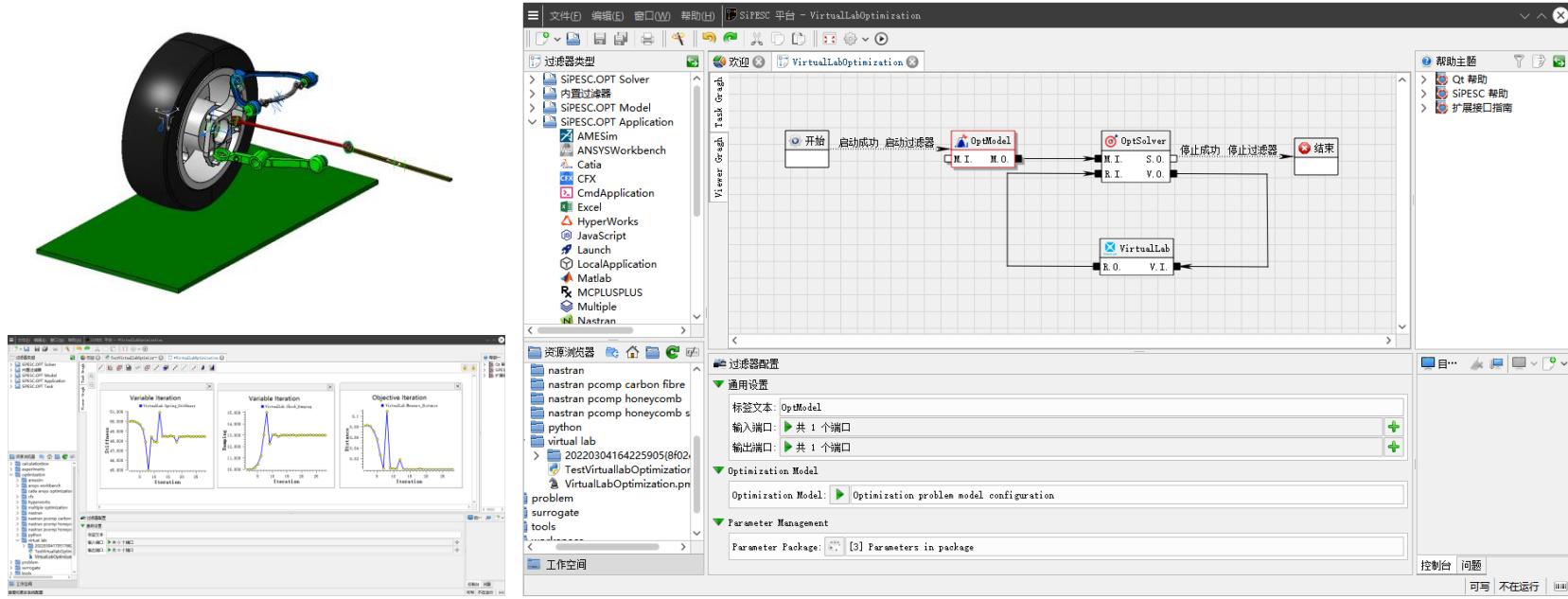


结构设计的固有频率要避开共振频率，飞行器重量越轻，成本费用越低

优化后舱段的体积得到明显的改善，**目标从17518mm³减少到9812.46mm³**，

优化结果满足约束要求，优化取得非常好的效果

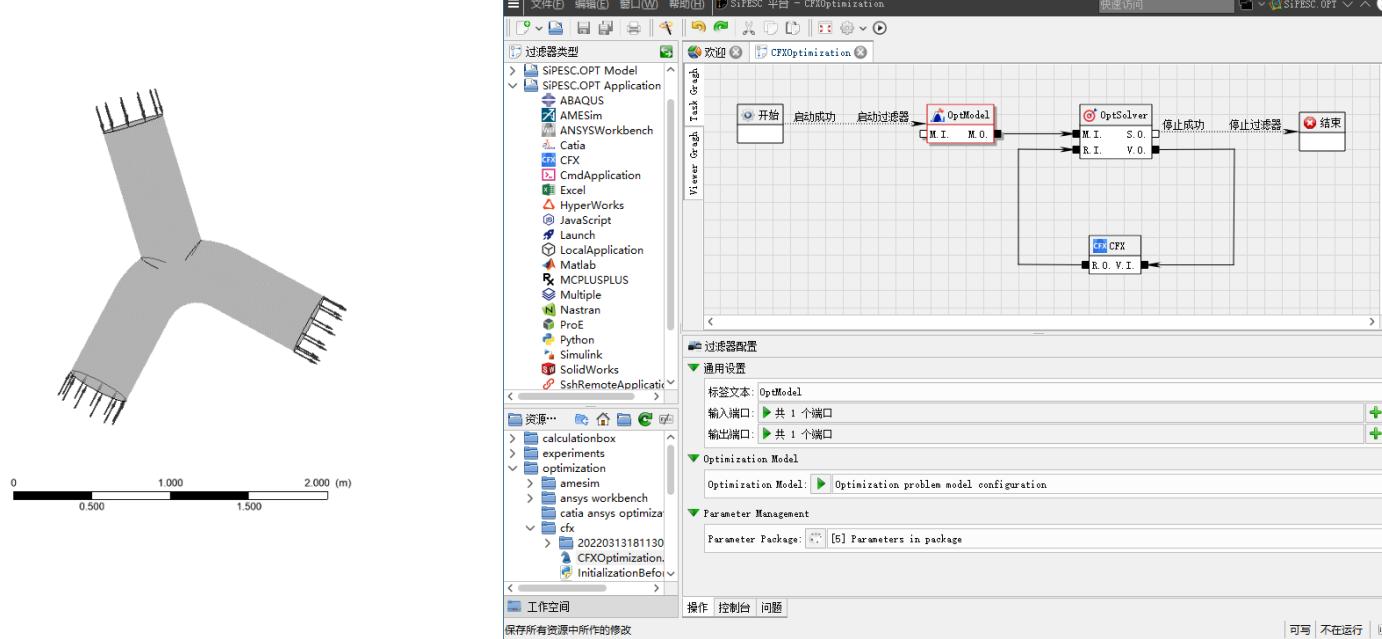
集成Virtual Lab进行优化设计



优化轮胎弹簧刚度系数，阻尼系数，实现精准控制传感器轴向距离

优化后轴间距得到精准调控，**目标从0.0813951减少到3.457E-09，优化取得非常好的效果**

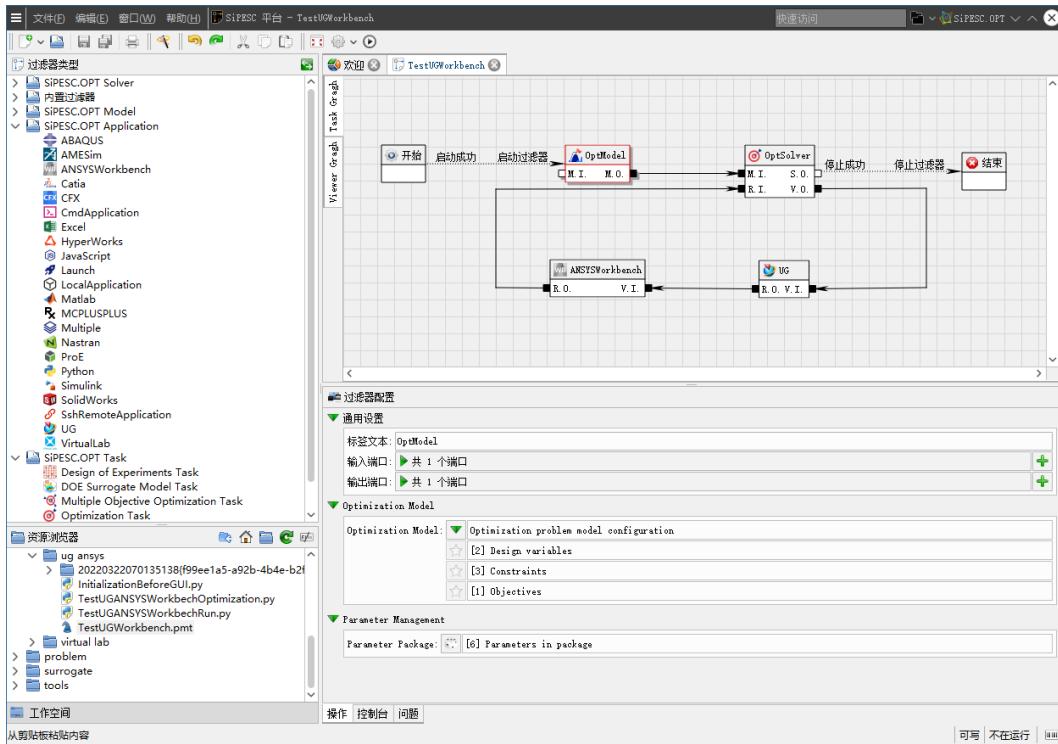
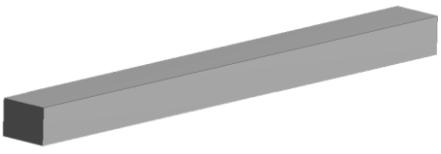
集成CFX进行优化设计



三通管流场设计，优化流场入口速度，满足出口压力要求和速度约束

优化后虽然目标值升高，但优化结果满足约束要求，其中压力约束从0.97782降低到-0.0004，出口压力从2.082218MPa提高到3.0004MPa，优化后速度约束从-8提升到-3.55271e-15，优化取得非常好的效果。

集成UG+ANSYS Workbench进行优化设计



梁结构重量最小化为目标，强度、刚度，几何尺寸为约束进行优化设计

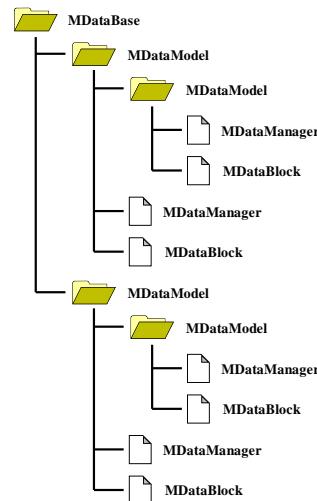
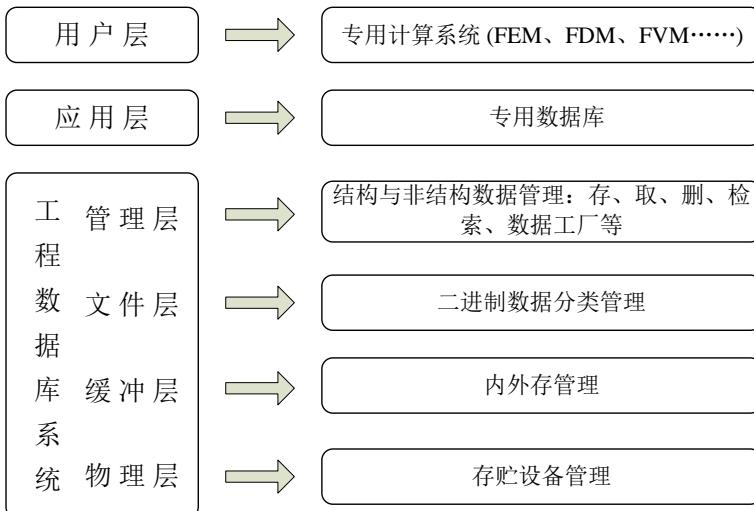
优化设计后，虽然目标体积比初始设计变大，但是所有约束满足要求，优化设计取得成功

数值仿真软件SiPESC

- 软件概况
- 优化设计
- **结构分析与数值模拟**
- 软件定制与集成

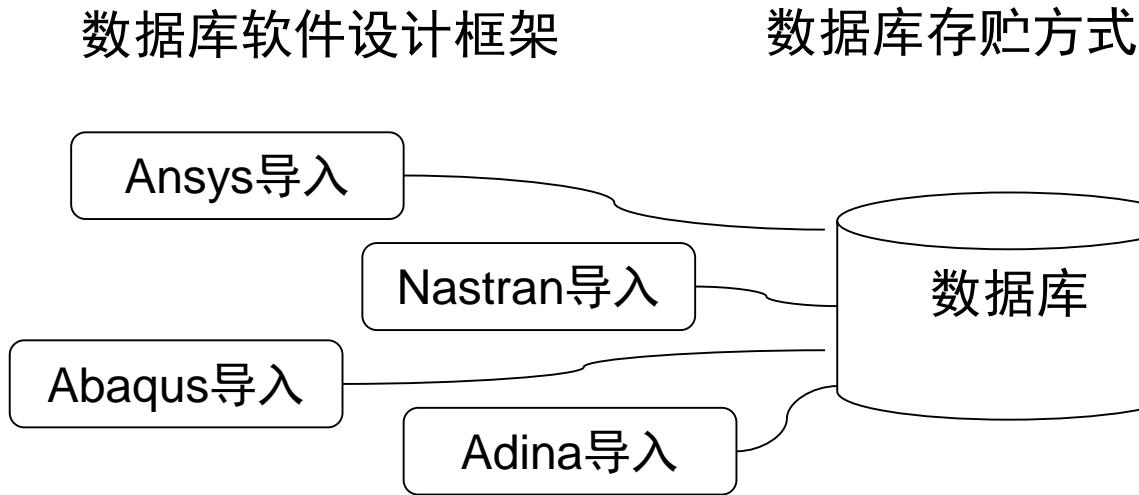
结构有限元分析系统

面向大规模计算的工程数据库管理系统



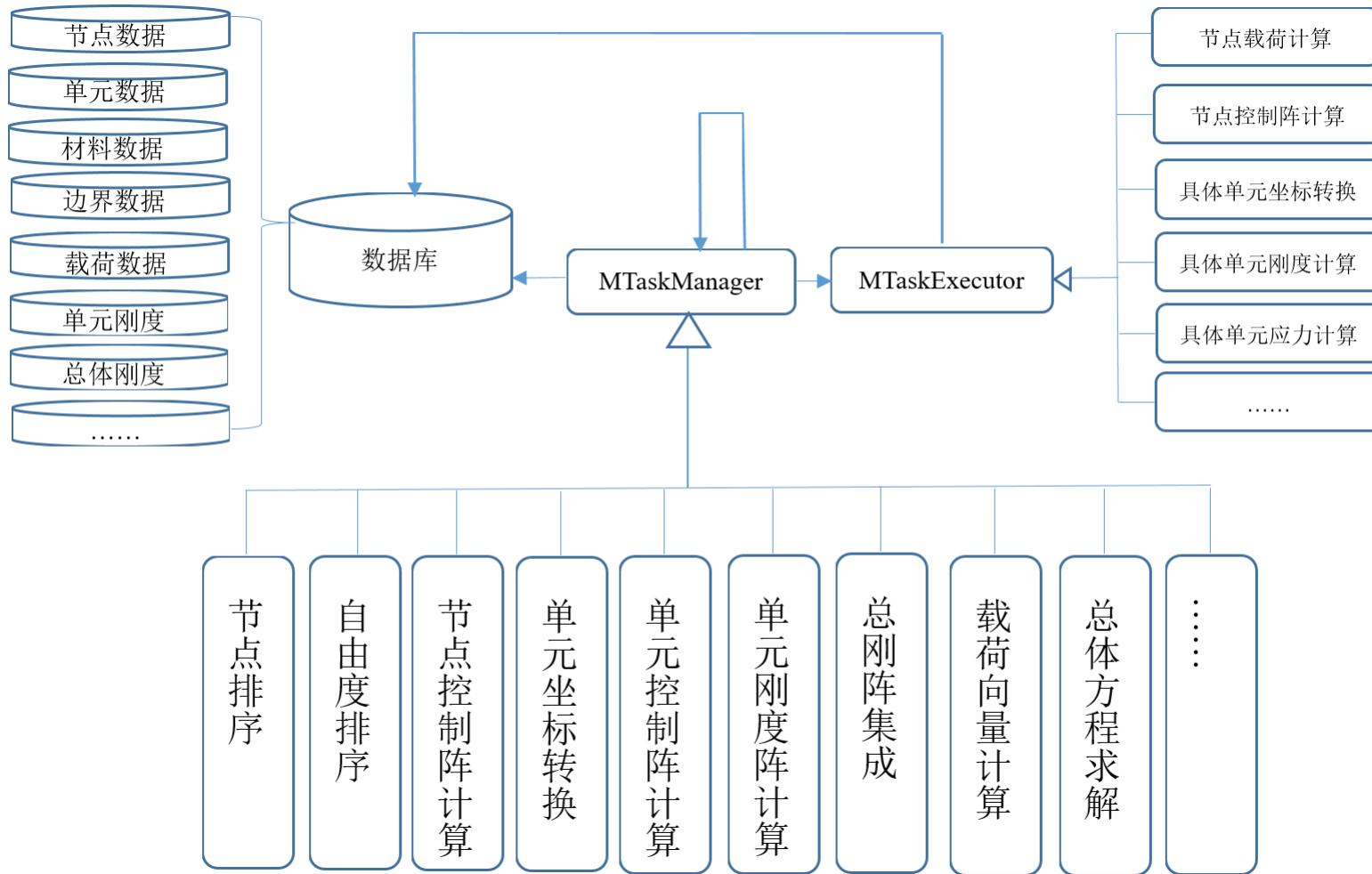
特性：

- 理论存贮量 10^6 TB
- 数据便捷管理
- 支持各类数据存贮
- 全级别开放
- 标准统一数据协议
- 多任务/耦合场



结构有限元分析系统

SiPESC.FEMS结构有限元设计框架



结构有限元分析系统

SiPESC.FEMS结构有限元系统代码示例

弹塑性分析流程

```
MElementGradMatrixManager;  
MElementElastoPlasticManager;  
MSolidEleStiffManager;  
MGivenValueLoadVectorManager;  
MLoadComponentManager;  
MLoadManager;  
MResultsManager;  
MMaterialNonlinearAnalysisManager;  
MSolidNodeStressManager;  
MJifexUnvExportor;
```

几何非线性分析流程 (小应变大变形)

```
MElementInterForceComponentManager;  
MInterForceVectorManager;  
MSolidElementStiffManager;  
MElementStressStiffMatrixManager;  
MNodeDataUpdateManager;  
MElementDeformGradManager;  
MElementGreenStrainManager;  
MSolidElementStressManager;  
MElementCauchyStressManager:
```

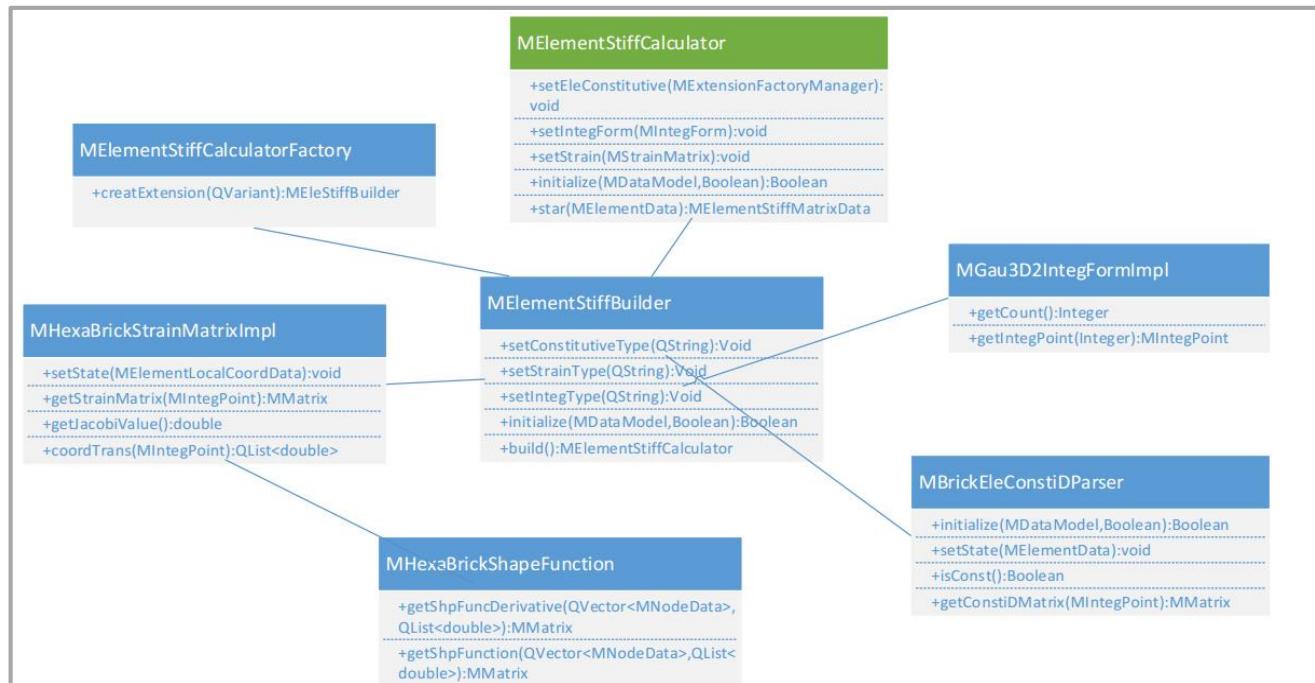
特性：

- 框架内的各模块可灵活组合，按需装配；
- 全级别开放，支持模块、数据、算法等的动态调用；
- 流程组合适用于多任务、耦合场等复杂问题计算；
- 支持外部数值算法库集成、混合语言编程；
- 支持脚本语言Python、JavaScript，支持数据灵活转换

结构有限元分析系统

SiPESC.FEMS结构有限元单元库设计模式

$$K_{(24 \times 24)}^e = \int_{-1}^1 \int_{-1}^1 \int_{-1}^1 \mathbf{B}^T \mathbf{D} \mathbf{B} |J| d\xi d\eta d\zeta = \sum_{j=1}^2 \sum_{k=1}^2 \sum_{w=1}^2 \left\{ A_j A_k A_w \left[\frac{\mathbf{B}^T}{(24 \times 6)} \frac{\mathbf{D}}{6 \times 6} \frac{\mathbf{B}}{6 \times 24} \right] \right\}_{(\xi_j, \eta_k, \zeta_w)} \cdot |J(\xi_j, \eta_k, \zeta_w)| \right\}$$

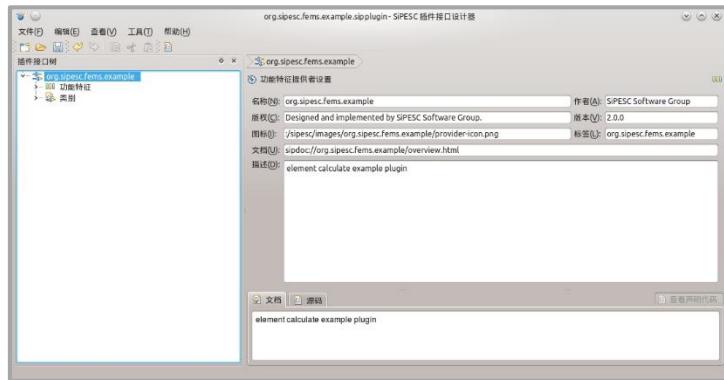


特性：

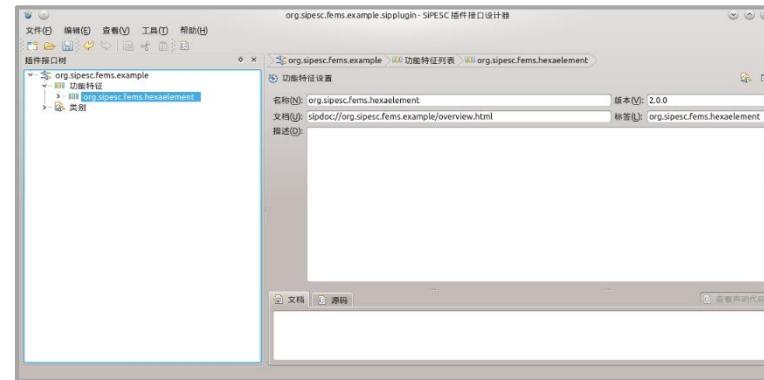
- 各类均有标准接口，按插件管理，支持动态替换；
- 单元计算框架的各类支持重用，支持多场耦合计算。

结构有限元分析系统

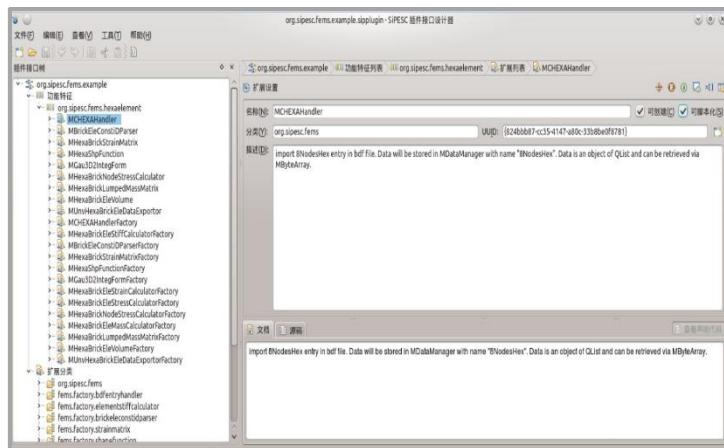
SiPESC.FEMS结构有限元单元库设计模式



1. 创建插件



2. 添加单元特性



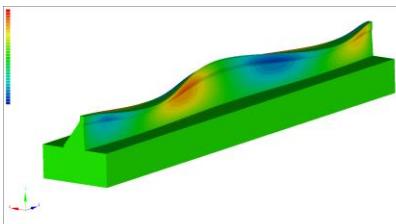
3. 添加扩展及设置继承关系



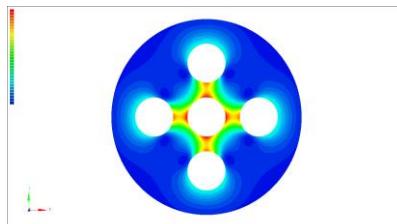
4. 生成插件接口代码

数值仿真软件SiPESC-有限元计算

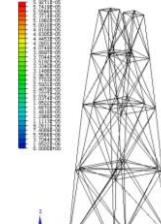
具备了复杂装备结构综合分析能力



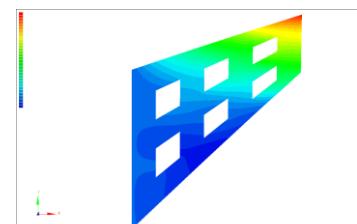
六面体单元



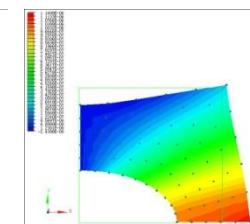
DKT板单元



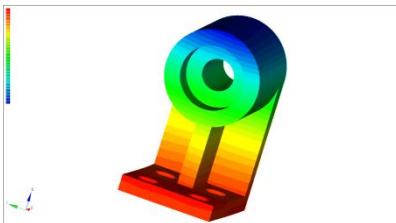
杆单元



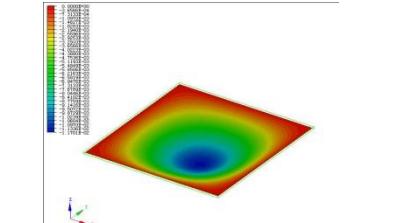
旋转膜单元



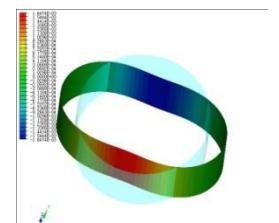
膜单元



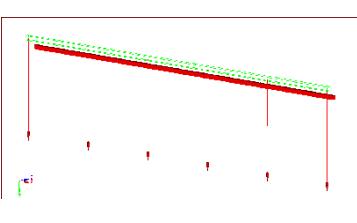
四面体单元



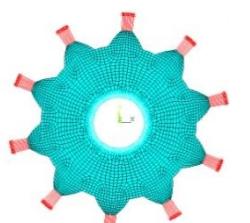
DKQ板单元



DKQ壳单元



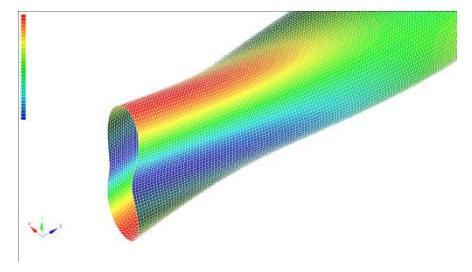
梁单元



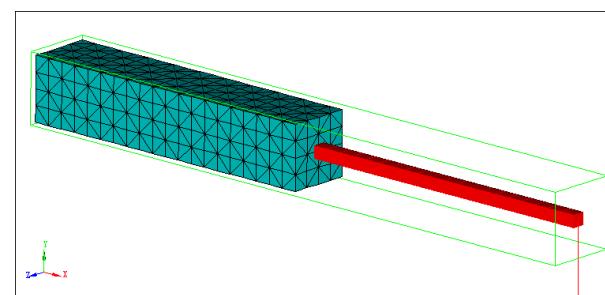
广义平面膜单元



棱柱单元



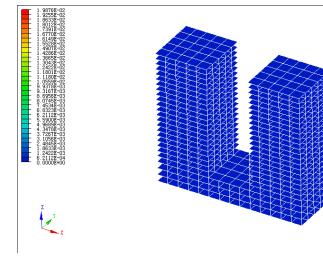
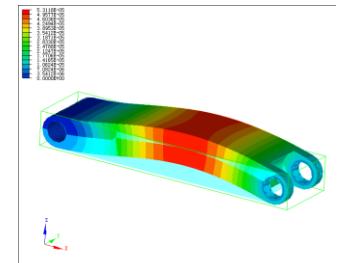
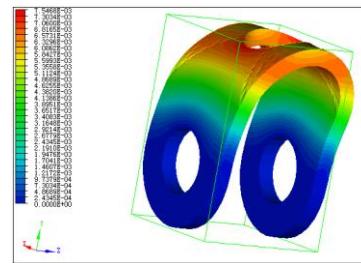
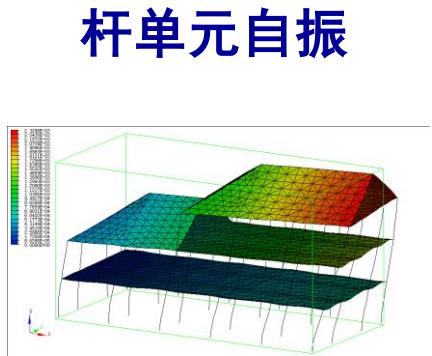
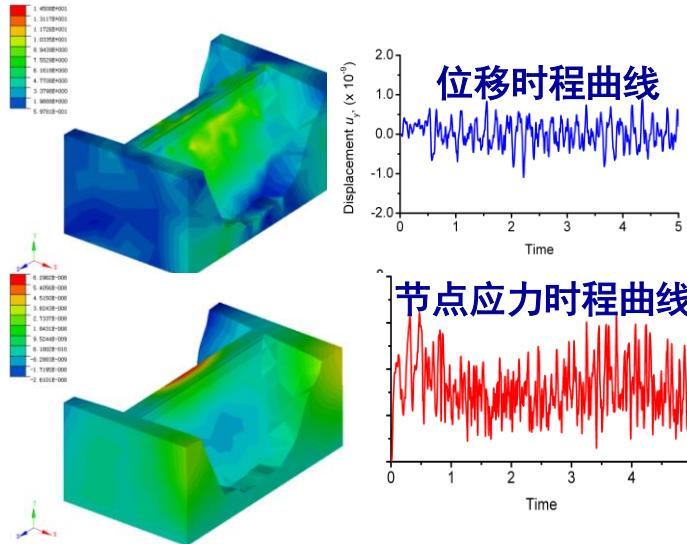
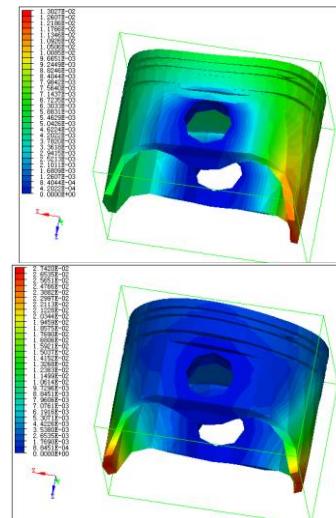
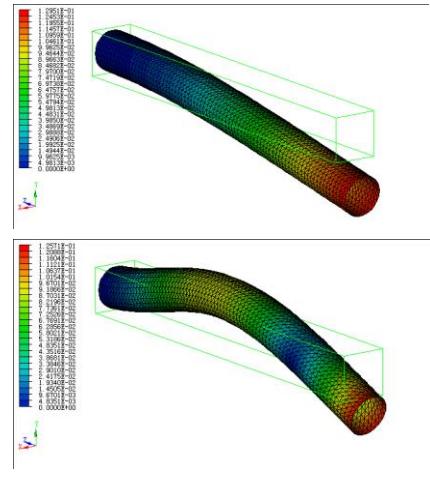
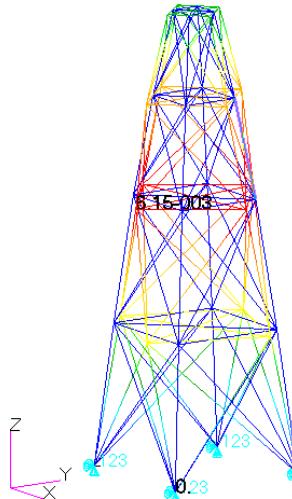
六自由度壳单元



多点约束考核算例

数值仿真软件SiPESC-有限元计算

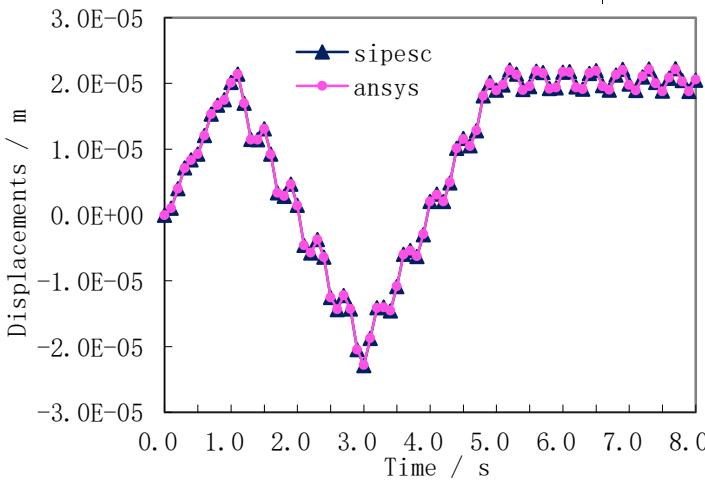
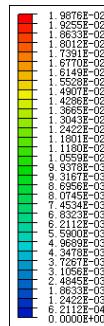
动力自振及响应分析



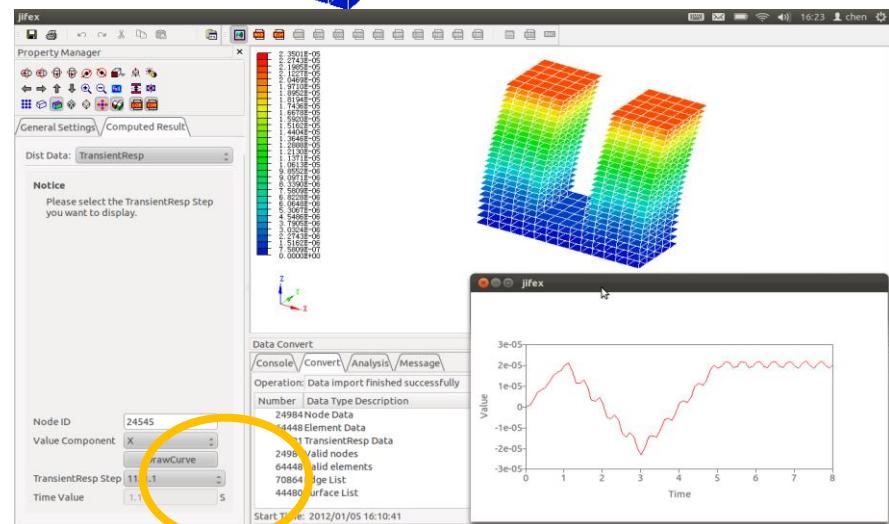
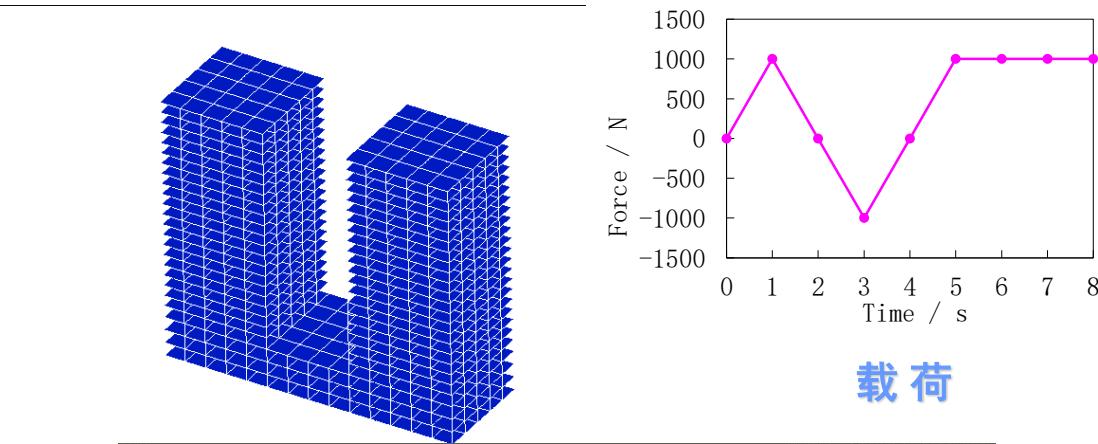
数值仿真软件SiPESC-有限元计算

瞬态响应分析-时程积分算法

- 3种瞬态算法: NewMark; Wilson-θ; 中心差分
- 求解器、算法封装; 动态选择



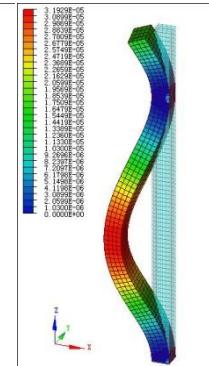
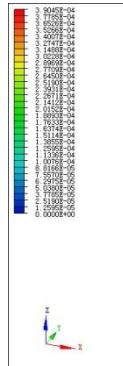
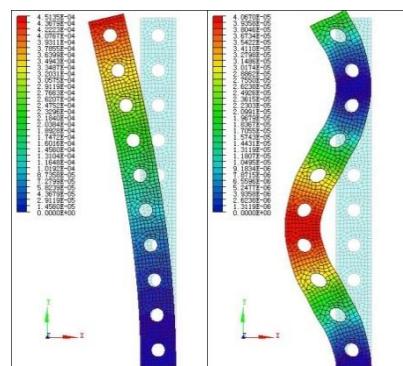
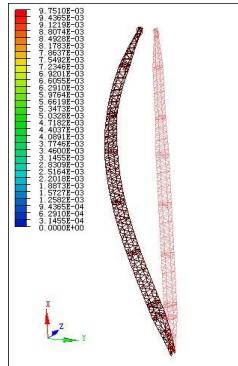
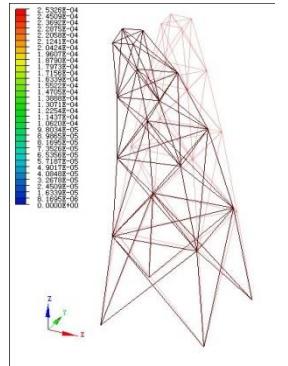
计算结果对比



自主研发的可视化和结果显示功能

数值仿真软件SiPESC-有限元计算

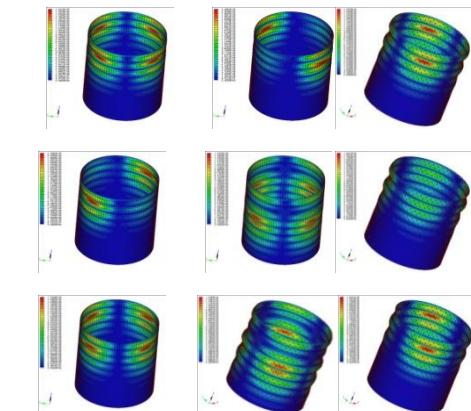
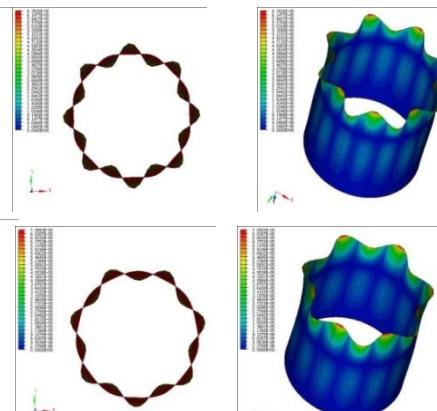
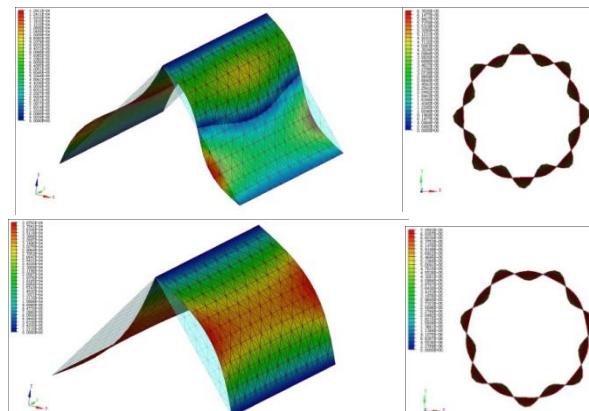
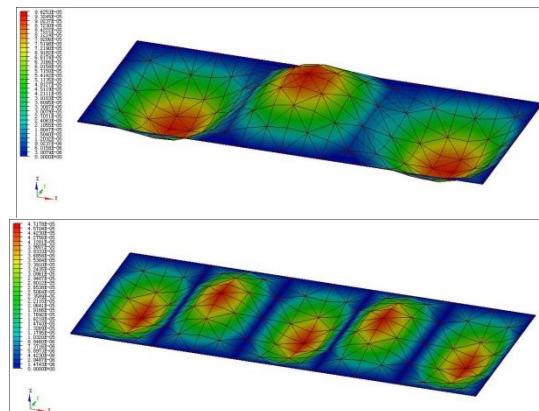
屈曲稳定性分析



杆单元

膜单元

实体单元



板单元

壳单元

壳单元

加筋壳结构

数值仿真软件SiPESC-有限元计算

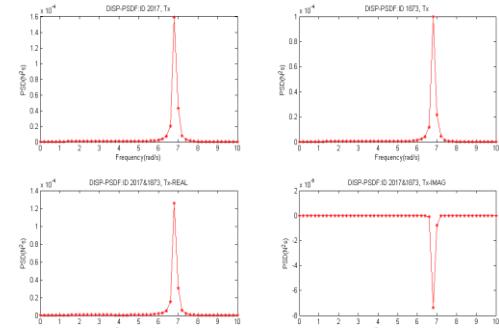
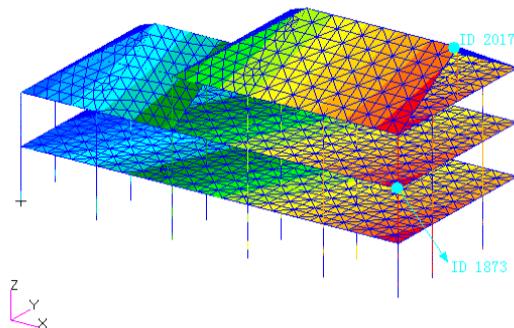
结构随机振动虚拟激励法

▶ 平稳随机响应

-单点

-多点完全相干

-多点部分相干



▶ 非平稳随机响应

-均匀调制

-非均匀调制



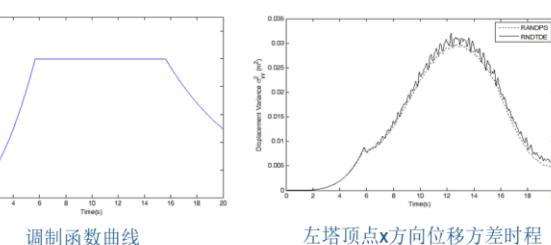
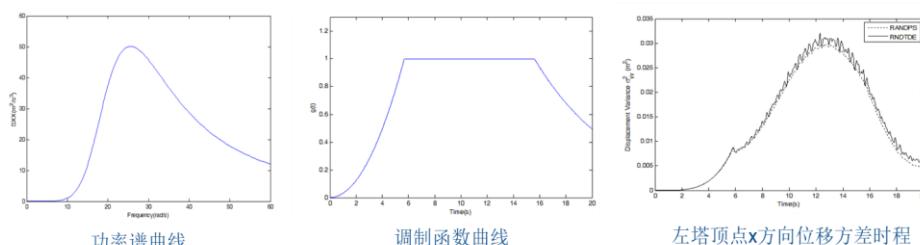
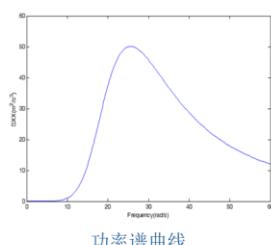
$$S(\omega) = \frac{1 + 4\zeta_g^2(\omega^2 / \omega_g^2)}{[1 - (\omega / \omega_g)]^2 + 4\zeta_g^2(\omega^2 / \omega_g^2)} \cdot \frac{\omega^6}{\omega^6 + \omega_c^6} \cdot S_0$$

$$S_0 = 36.6, \omega_g = 25.13, \zeta_g = 0.64, \omega_c = 18.84$$

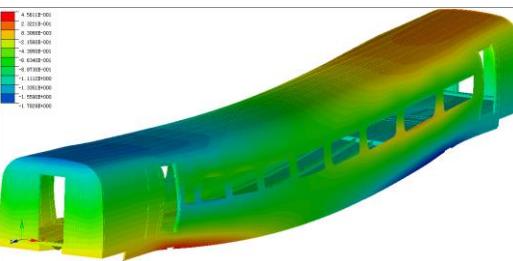
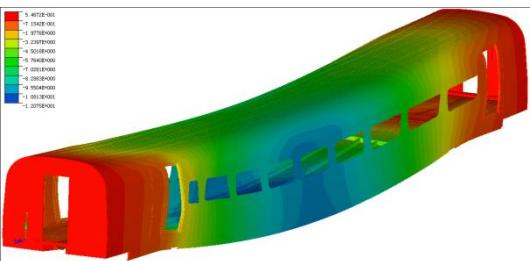
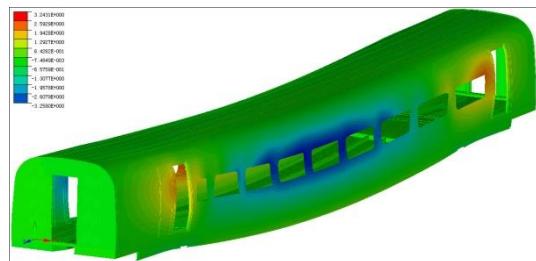
本桥采用梁单元、质量单元和杆单元模拟，有限元模型如图所示，共有5147个节点，5533个单元，桥墩和两端固支，功率谱采用胡聿贤-周锡元的改进模型，施加x方向一致地震激励

$$g(t) = \begin{cases} (t/t_1)^2, & t < t_1 \\ 1, & t_1 \leq t \leq t_2 \\ e^{-c(t-t_2)}, & t > t_2 \end{cases}$$

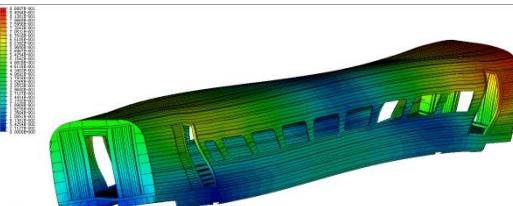
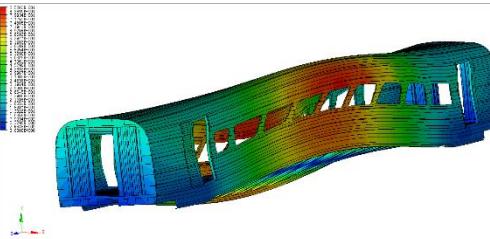
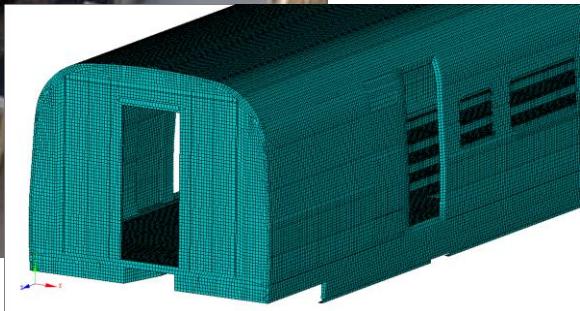
$$t_1 = 5.68, t_2 = 15.6, c = 0.16$$



数值仿真软件SiPESC-有限元计算



静力：
最大位移相差
0.2%



自振：
前30阶频率最大相差
0.94%

国内自主软件复杂结构最大规模算例
新一代300公里高速列车结构360万自由度有限元算例
609519节点、785867单元

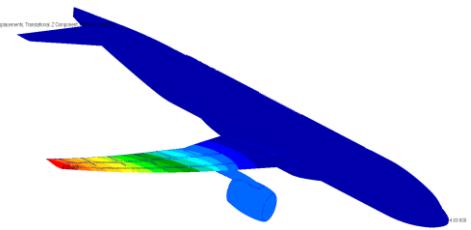
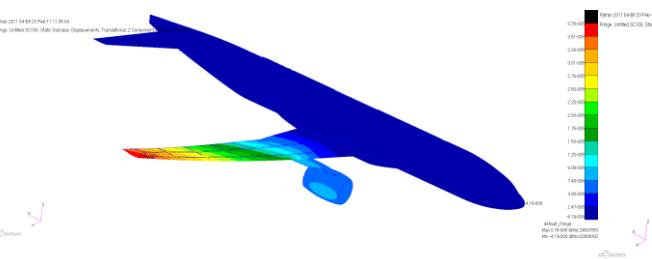
工程分析实例



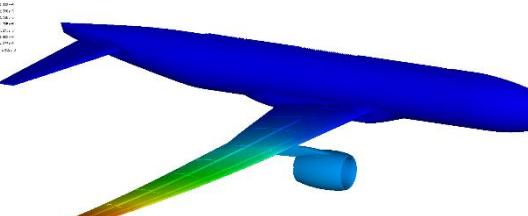
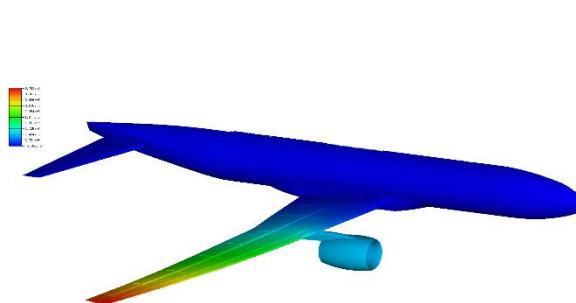
总节点数 706147

总单元数 3507309

总自由度 210 万自由度
多工况—307 个工况



LoadCase Number	Nastran	SiPESC.FEMS	Error
100	1.98	1.978	0.101%
101	1.74	1.744	0.230%
102	2.12	2.115	0.235%
103	1.56	1.558	0.128%
104	1.17	1.173	0.256%
105	1.18	1.182	0.169%
106	2.09	2.089	0.048%
107	0.405	0.4050	0.000%
108	0.376	0.3759	0.026%
109	0.0432	0.04321	0.002%

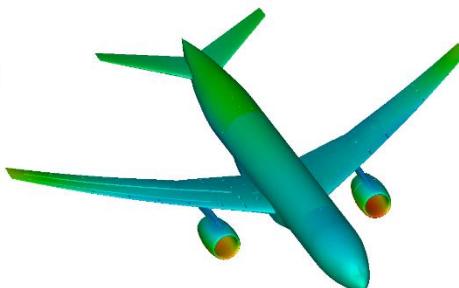


工程分析实例



静力分析测试
辅以bush单元和MPC连接
总节点数139万
总单元数691万
总自由度**410万**自由度

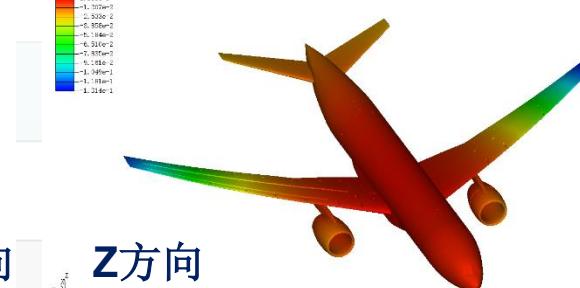
静力分析测试
辅以bush单元和MPC连接
总节点数139万
总单元数691万
总自由度**410万**自由度



Nastran
SiPESC.FEMS
Relative error



	X方向	Y方向
0.598	1.50	
0.5937	1.505	
0.719%	0.333%	

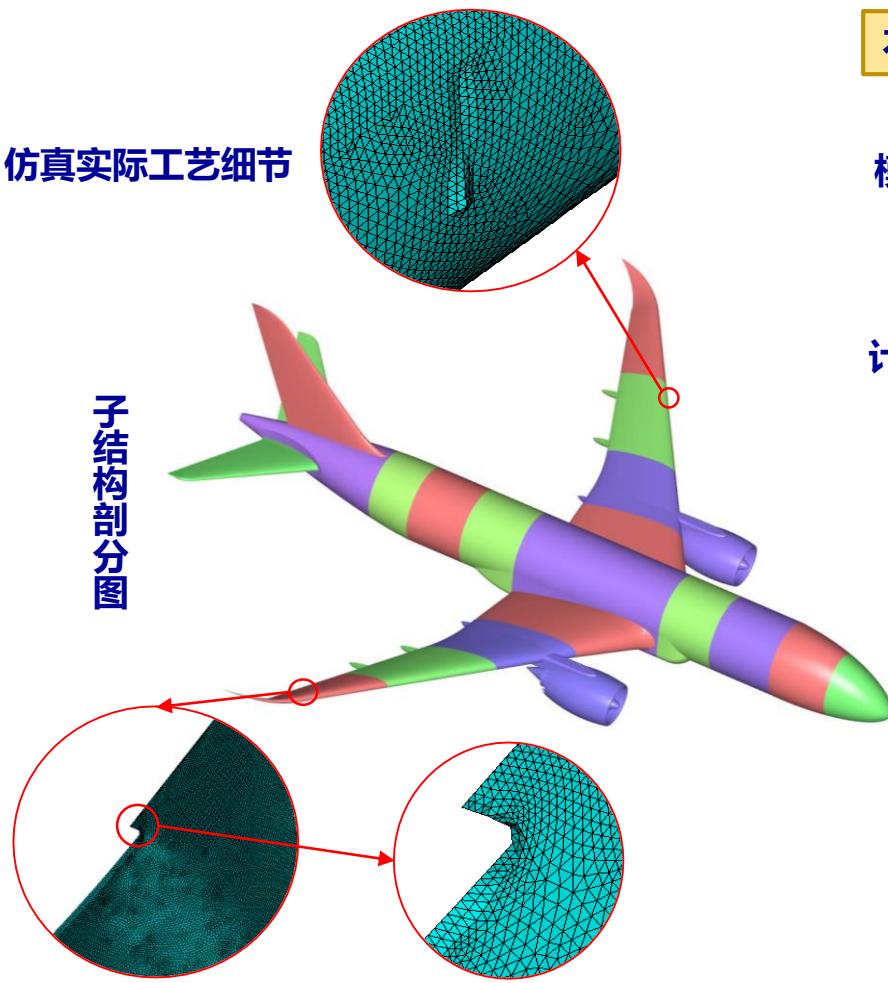


	Z方向
13.1	13.14
0.308%	

数值仿真软件SiPESC-有限元计算

- 大型客机整机精细网格-多重多级子结构静力分析算例
 - 1.07亿自由度

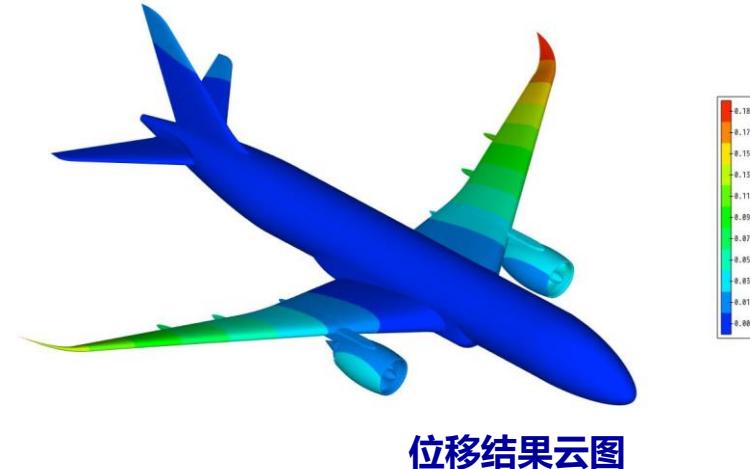
仿真实际工艺细节



高解析度匹配模型几何细节

本算例为：波音787实机模型

模型描述	自由度	子结构数	单元
	107m	20	CQUAD4
计算环境	处理器	内存大小	计算方式
	E5	128Gb	MPI并行计算

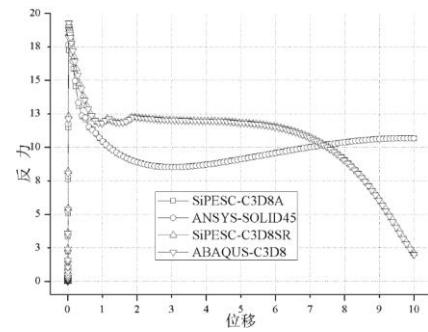
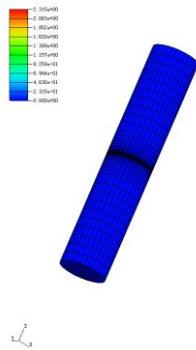


位移结果云图

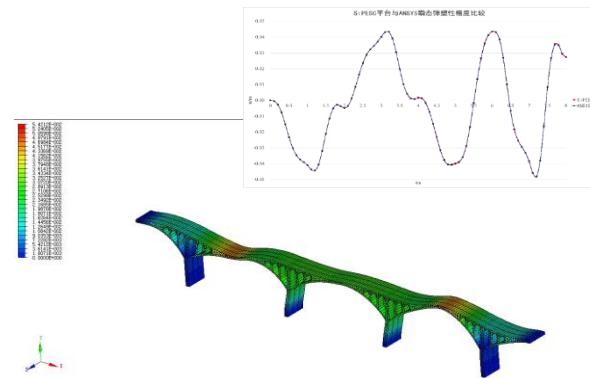
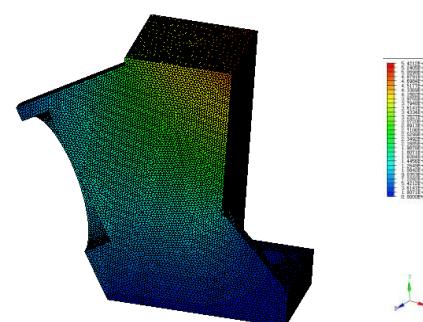
数值仿真软件SiPESC-有限元计算

□ 结构有限元非线性分析系统

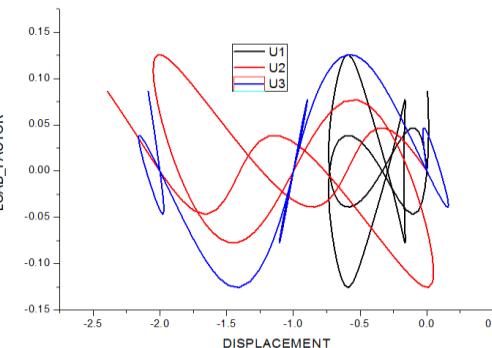
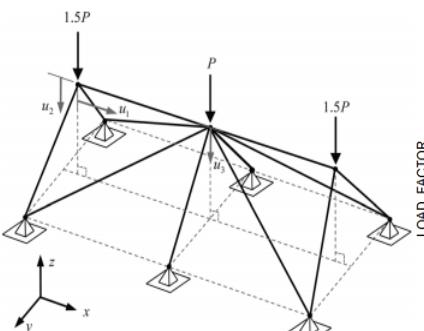
- 基于返回映射算法，提出了**材料本构更新**的软件架构
- 提出了结构非线性方程求解算法**迭代与控制**算法软件框架
- 实现了大规模**几何非线性**求解功能



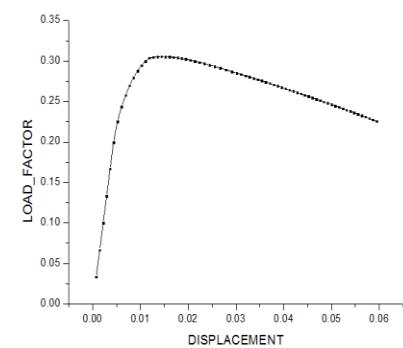
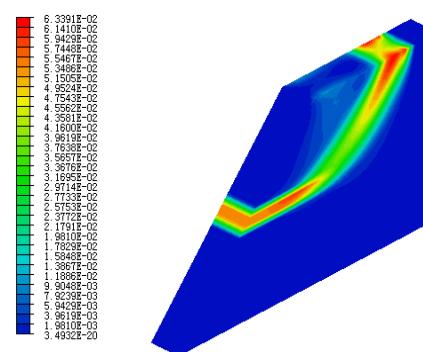
颈缩大应变问题分析



160万自由度弹塑性分析 桥梁非线性地震响应分析

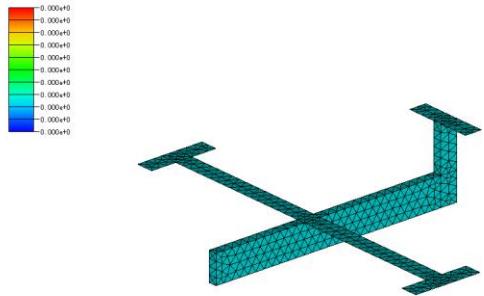


几何非线性路径跟踪算例

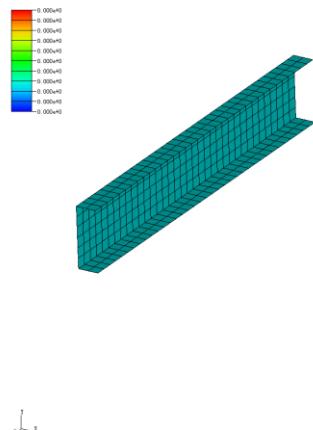


材料软化算例

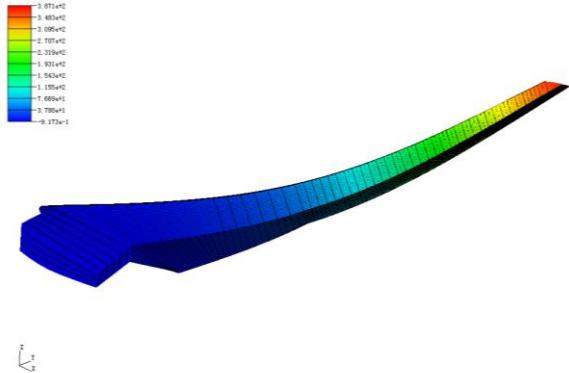
数值仿真软件SiPESC-有限元计算



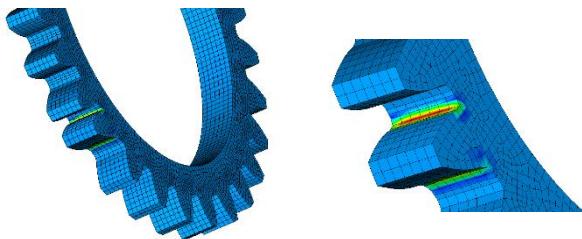
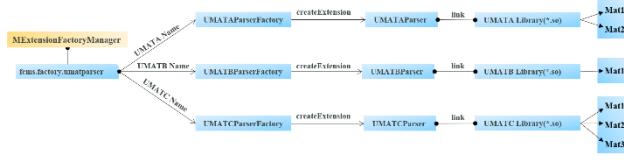
模型飞机刚柔耦合瞬态动力分析



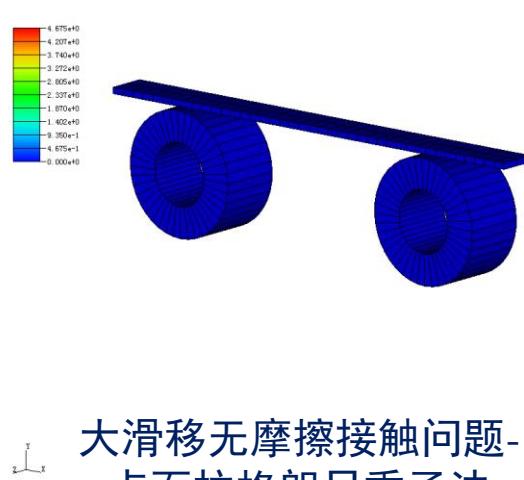
壳单元结构失稳



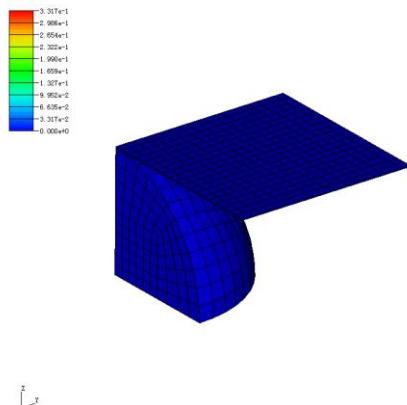
梁壳组合结构大变形分析



Abaqus非线性本构UMAT程序 动态集成

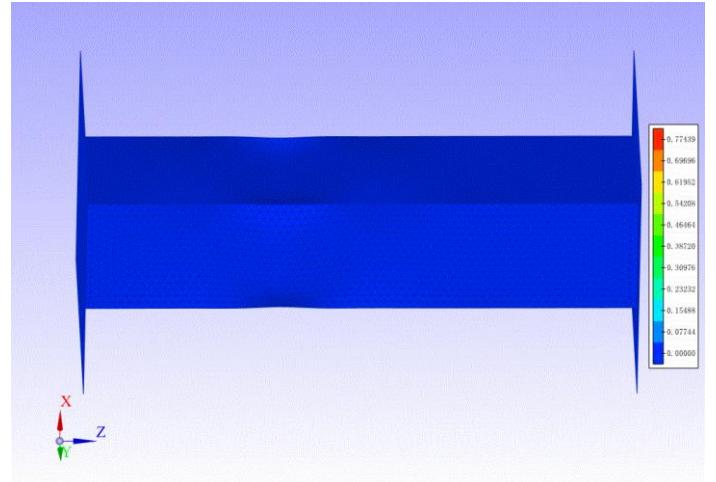
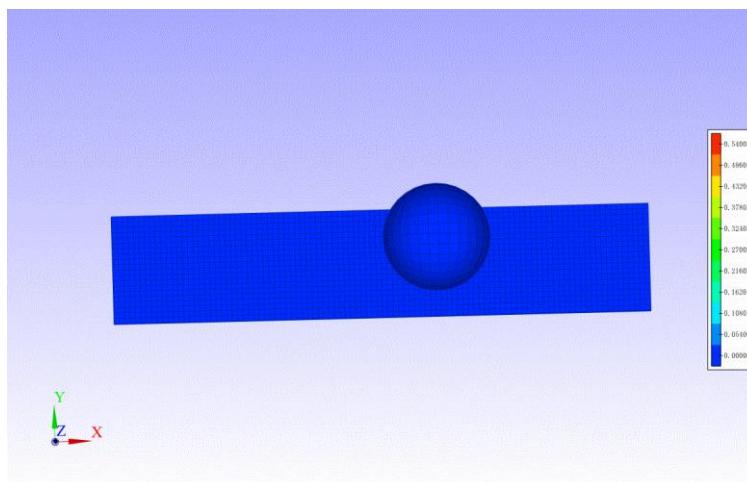
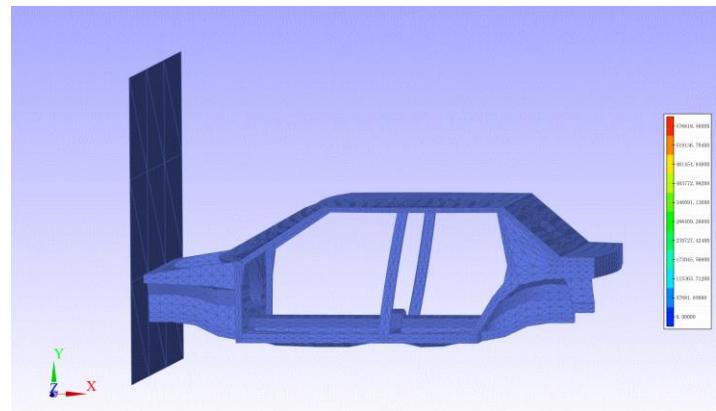
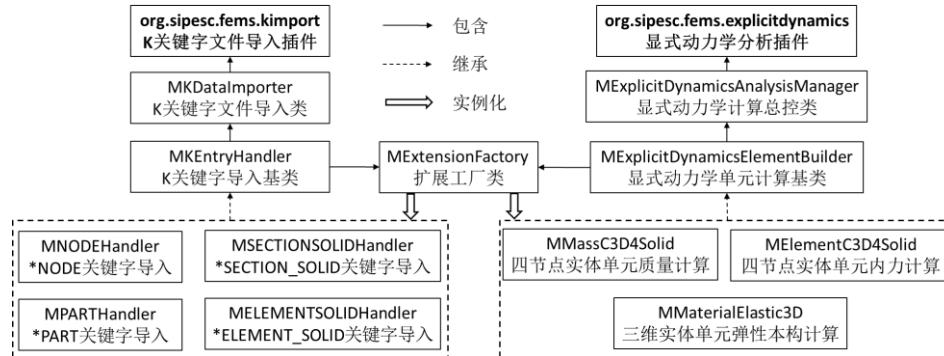


大滑移无摩擦接触问题- 点面拉格朗日乘子法



弹塑性摩擦成形问题- 点面罚函数法（等效塑形应变）

数值仿真软件SiPESC-显式有限元计算



数值仿真软件SIPESC-复合材料

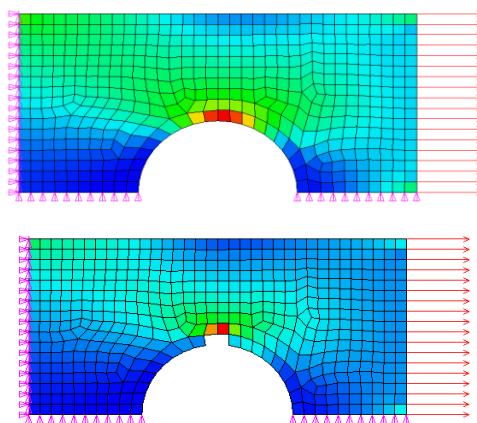
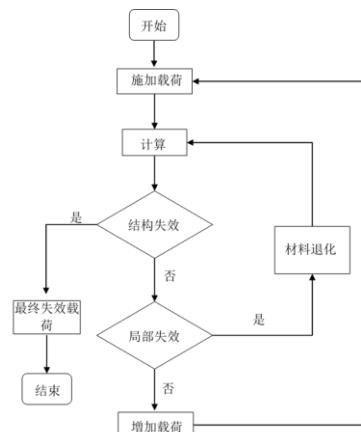
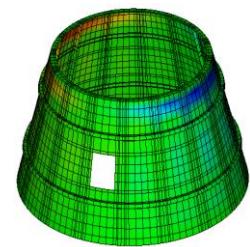
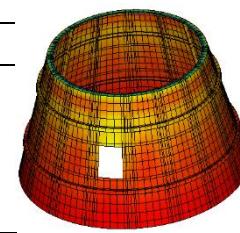
□ 复合材料结构系统

- 结构板壳单元、加筋结构、多点约束
- 复合材料层合板/夹层板，材料本构与单元的集成
- 静力、自振、谐响应、瞬态、屈曲、随机的计算功能融合

结构分析

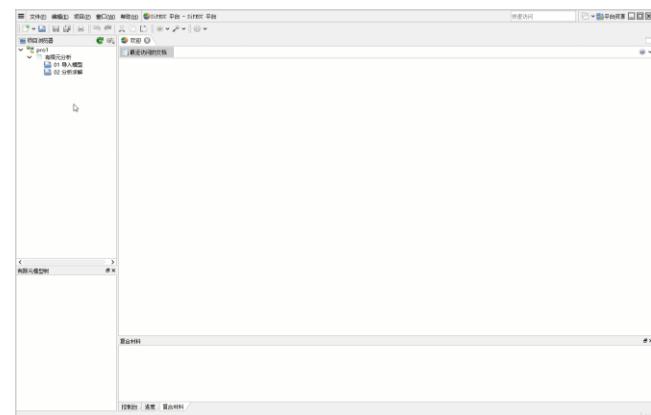


位移结果比较列表			
	X	Y	Z
ABAQUS	6.386e-5	-1.217e-4	5.827e-5
SIPESC	6.537e-5	-1.229e-4	5.851e-5
NASTRAN	6.86e-5	-1.29e-4	6.86e-5
与 Abaqus 相对误差	2.3%	0.98%	0.41%



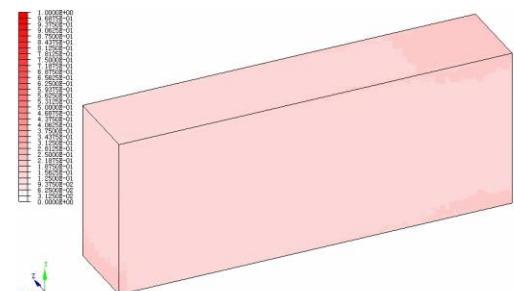
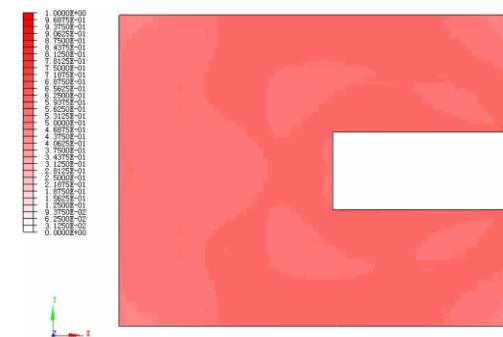
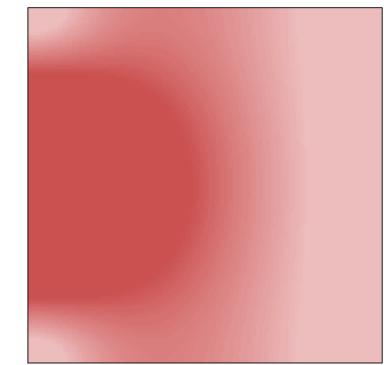
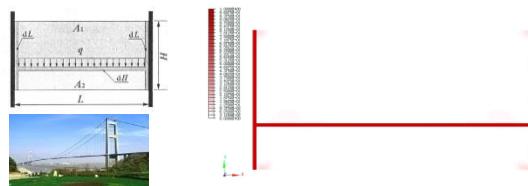
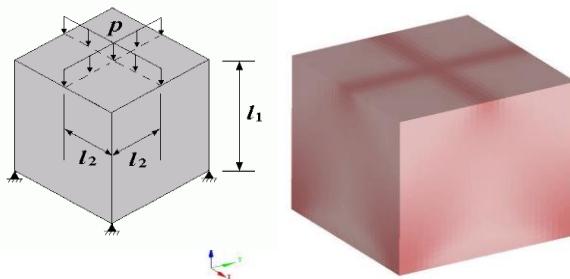
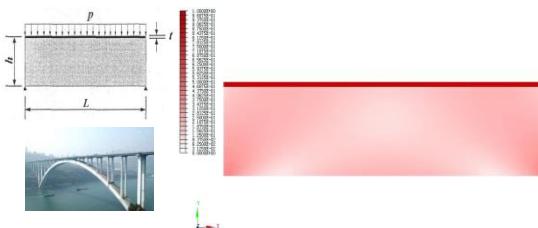
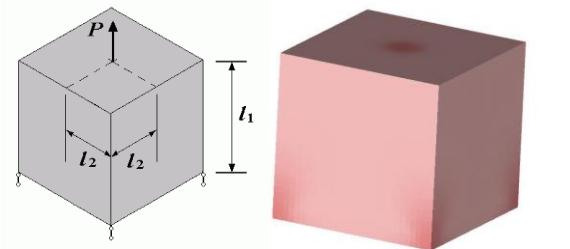
渐进破坏

专用可视化



数值仿真软件SiPESC-有限元计算

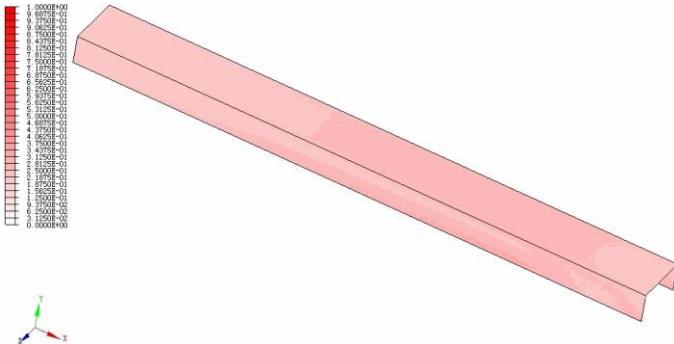
结构拓扑优化功能拓展，实现基础研究与应用结合



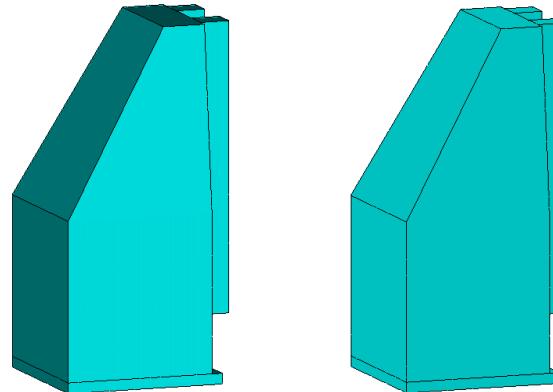
集成了大工多类优化特色算法

数值仿真软件SiPESC-有限元计算

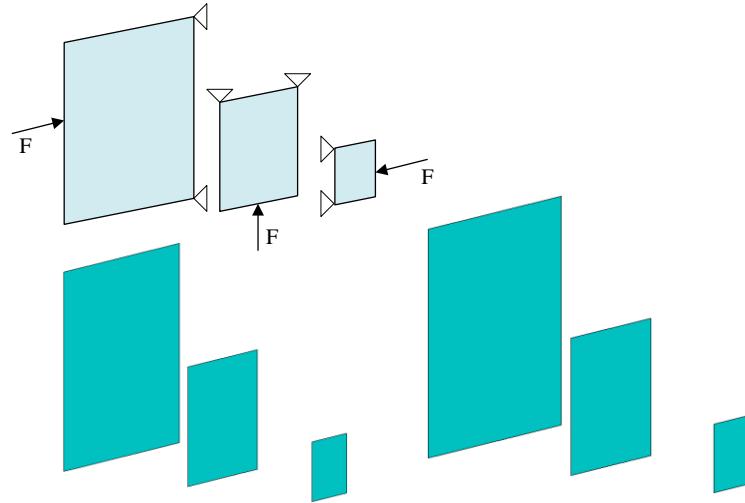
集成了多种插值、密度过滤/灵敏度过滤、自主特色算法、与SiPESC.OPT集成



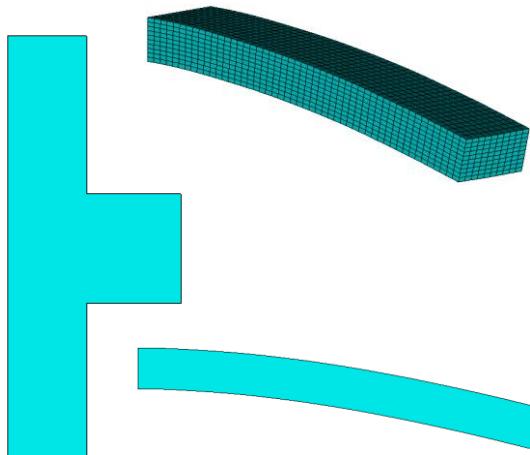
起重机吊臂壳体结构优化算例



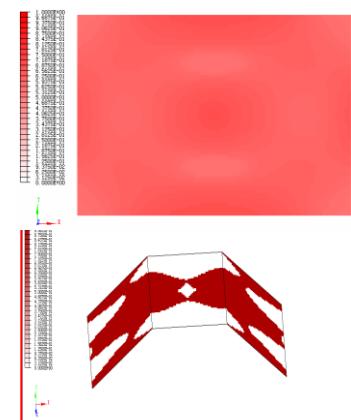
考虑对称性机床结构优化



考虑模式重复的结构优化



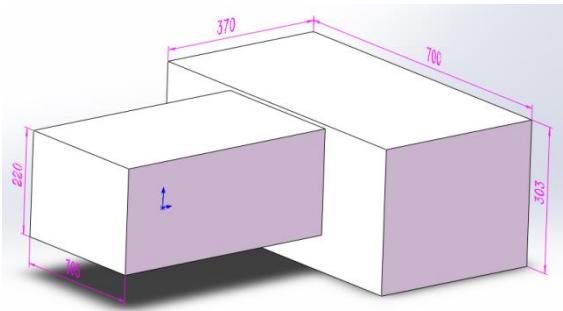
应力/屈曲约束的结构优化



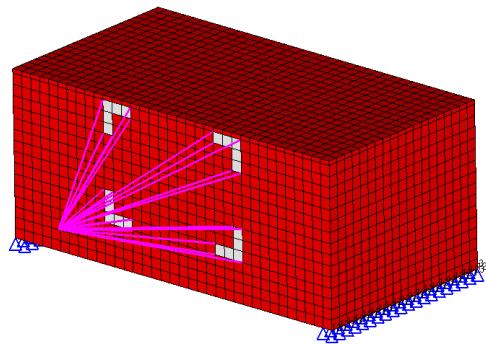
板基频最大
质量/刚度不同插值算法

数值仿真软件SiPESC-有限元计算

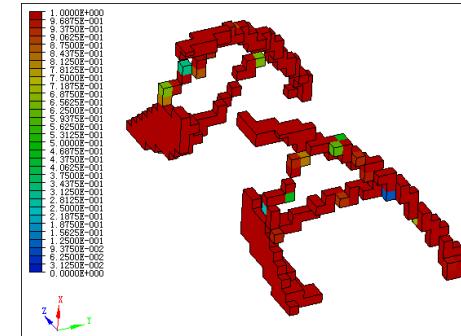
工程师方案15kg, 优化设计后5.4Kg



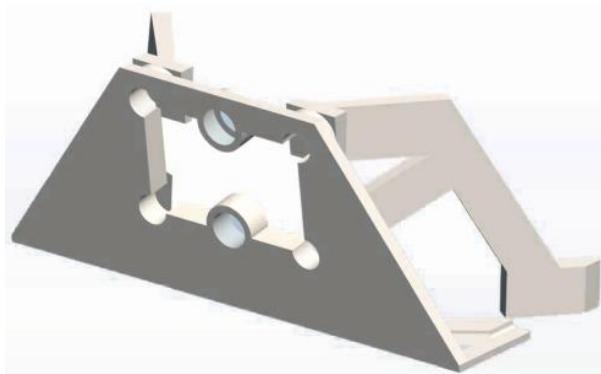
1) 结构设计区域



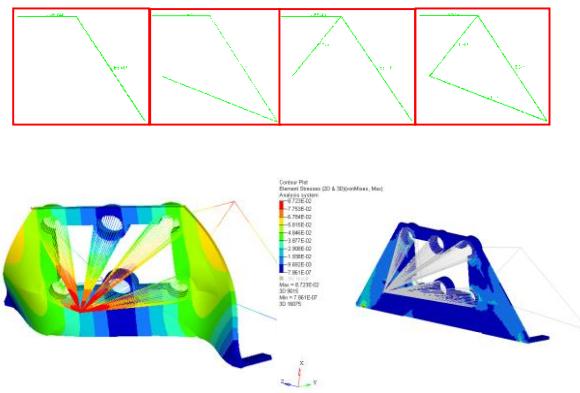
2) 拓扑优化初始设计模型



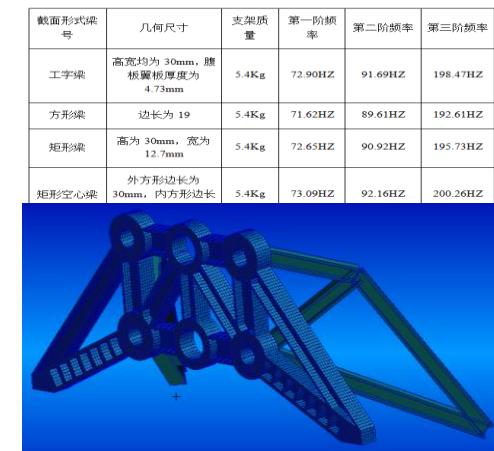
3) 拓扑优化计算结果



4) 初步设计构思



5) 支撑杆多案对比

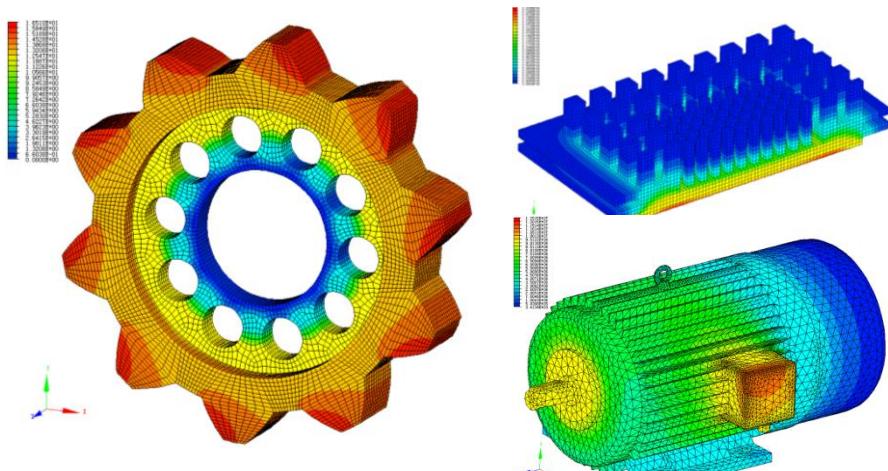
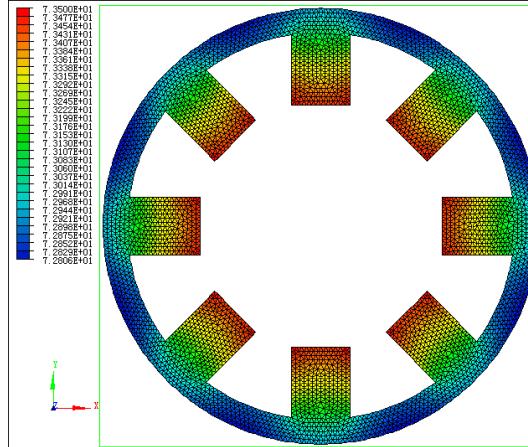
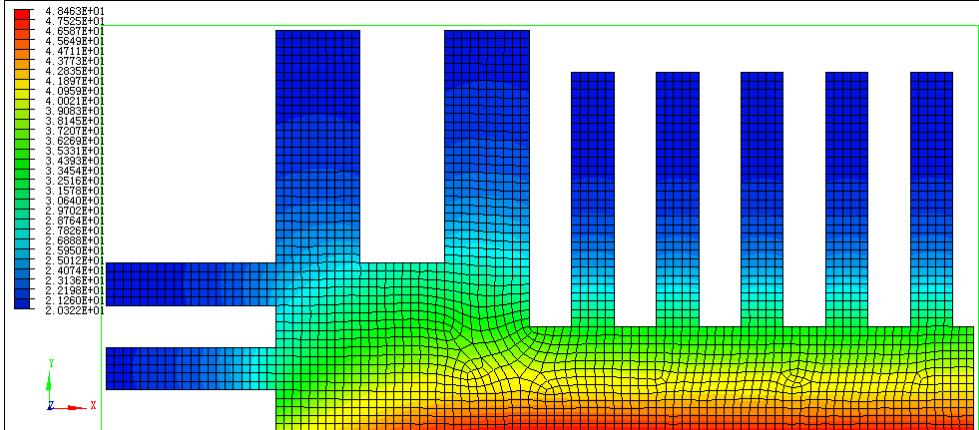


6) 详细设计及定型

截面形式及梁号	几何尺寸	支架质量	第一阶频率	第二阶频率	第三阶频率
工字梁	高宽均为 30mm, 腹板翼板厚度为 4.73mm	5.4Kg	72.90HZ	91.69HZ	198.47HZ
方形梁	边长为 19	5.4Kg	71.62HZ	89.61HZ	192.61HZ
矩形梁	高为 30mm, 宽为 12.7mm	5.4Kg	72.65HZ	90.92HZ	195.73HZ
矩形空心梁	外方形边长为 30mm, 内方形边长为 12.7mm	5.4Kg	73.09HZ	92.16HZ	200.26HZ

数值仿真软件SiPESC-有限元计算

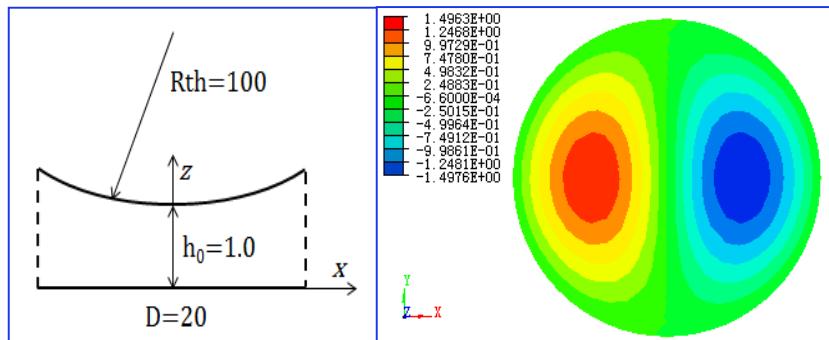
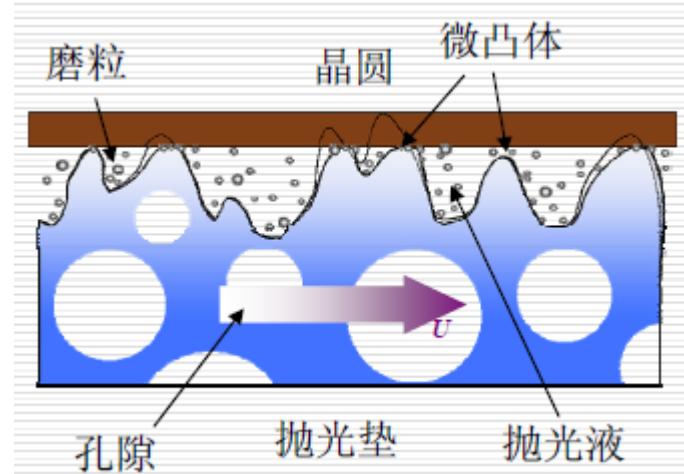
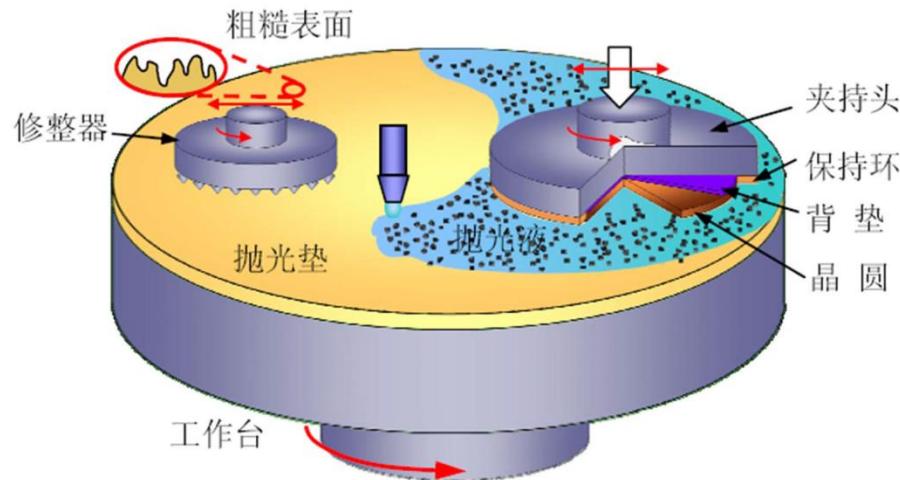
工业装备多领域仿真应用实例：热传导分析



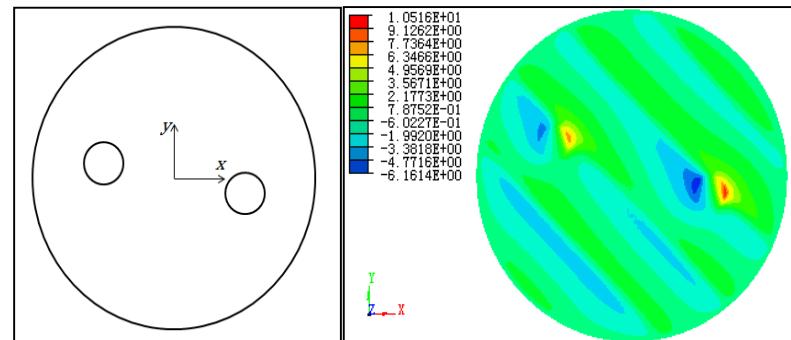
功能：

- 一维、二维、三维
- 指定温度、对流、热流
- 热应力
- 稳态、瞬态
- 非傅立叶热传导(热波)

数值仿真软件SiPESC-有限元计算



圆形液面球形厚度分布油膜压力分析



含孔圆形液面正弦厚度分布油膜压力分析

Intel晶圆/芯片制造加工设计的关键工具(首家研发)

数值仿真软件SiPESC-有限元计算

多领域仿真应用实例：多孔介质耦合场有限元分析(土木/环保)



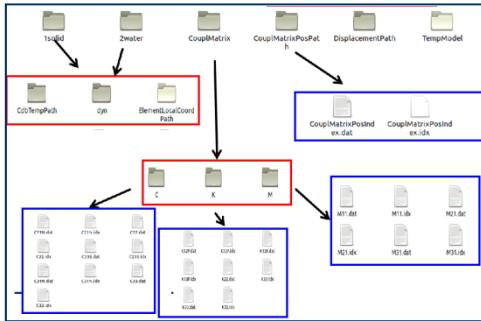
四川汶川山体滑坡



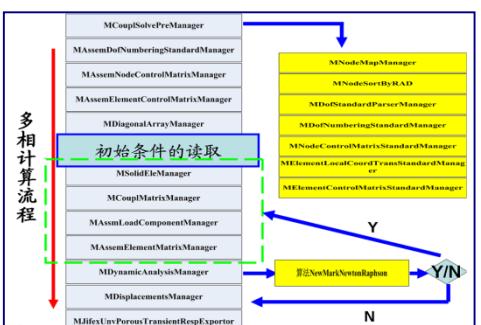
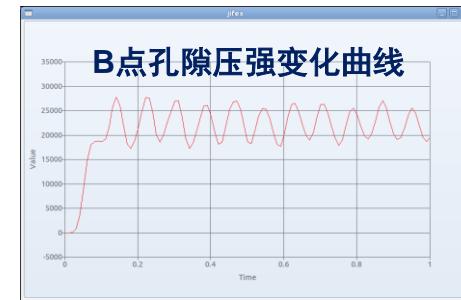
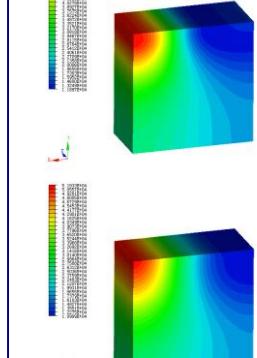
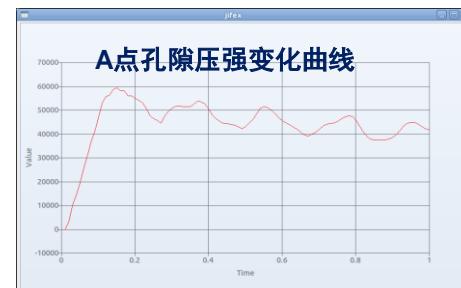
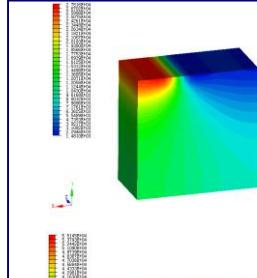
地震引起地基液化



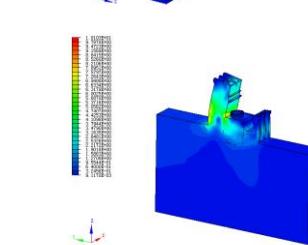
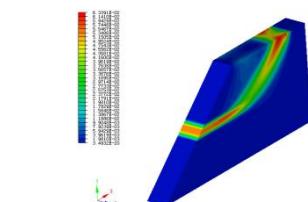
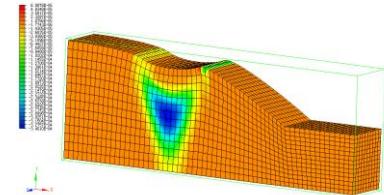
土体强度降低



数据管理



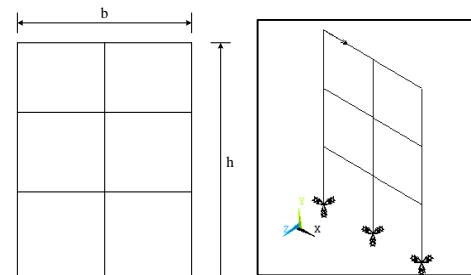
流程管理



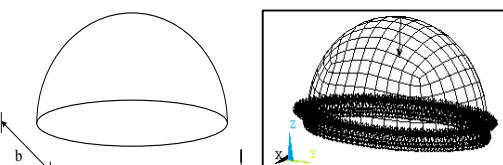
三维饱和动力分析算例

特色算法研究-半解析灵敏度分析改进算法

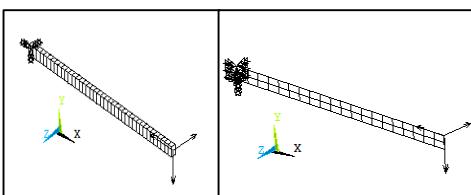
- 难点：原半解析方法精度受限、刚体位移引发误差大
- 目标：提升精度、提高效率；发展适用性的敏感度分析算法
- 成果：改进算法精度提升、稳定性超越全局差分；具有普适性



钢架结构算例

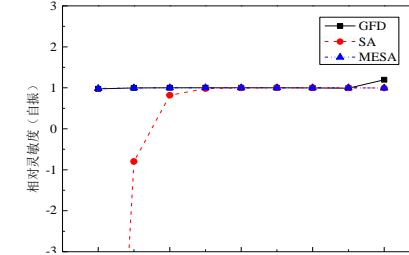
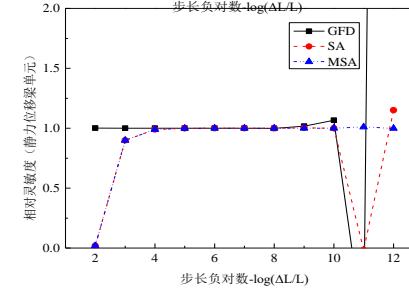
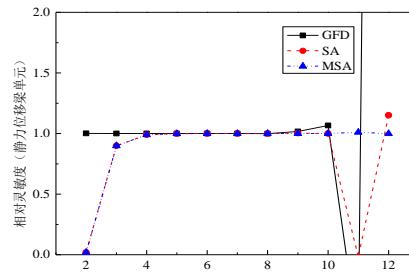


球壳结构算例

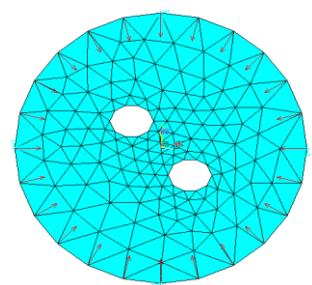


悬臂梁

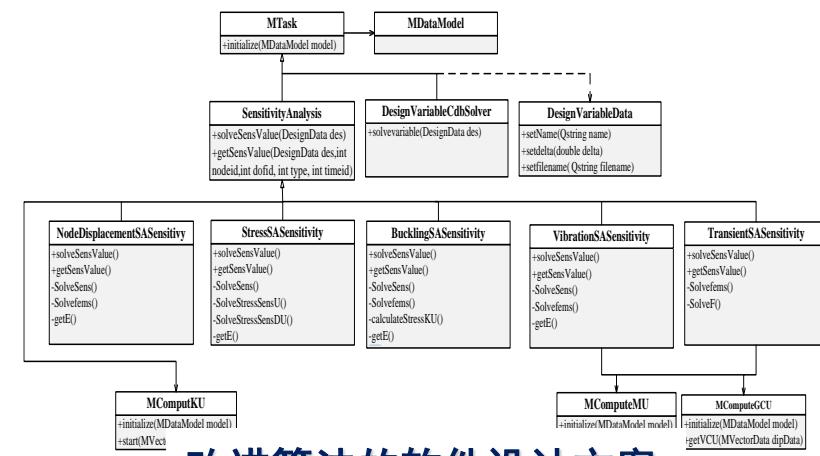
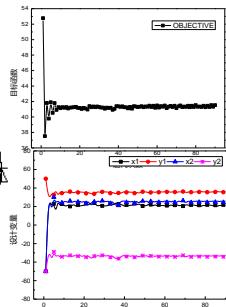
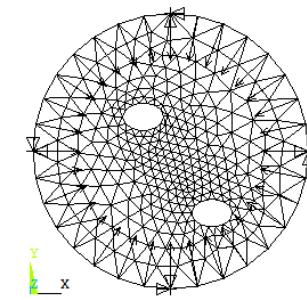
(梁单元、壳单元) 算例



改进算法稳定性最佳



形状设计优化实例 (支持网格自由重构)

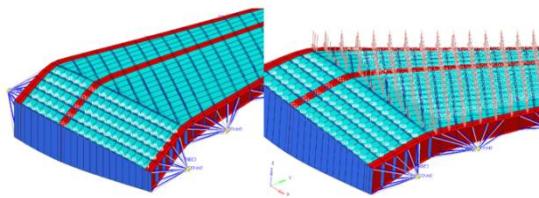


SiPESC针对商用飞机结构算例测试

表1 结构静强度分析采用的 NASTRAN 卡片

类别	NASTRAN 卡片				
	GRID	CBEAM	CBUSH	CELAS1	CFAST
单元	CBAR	CBEAM	CBUSH	CELAS1	CFAST
	CHEXA	CONM2	CPENTA	CQUAD4	CROD
CSHEAR	CTRIA3	CWELD			
MPC	RBAR	RBE2	RBE3	RSPLINE	
坐标系	CONROD	CORD2C	CORD2R		
材料	MAT1	MAT2	MAT8	MAT9	
属性	PBAR	PBARL	PBEAM	PBEAML	PBUSH
	PCOMP	PCOMPG	PELAS	PFAST	PROD
	PSHEAR	PSHELL	PSOLID	PWELD	
约束	SPC	SPCADD			
载荷	FORCE	MOMENT	PLOAD	PLOAD4	

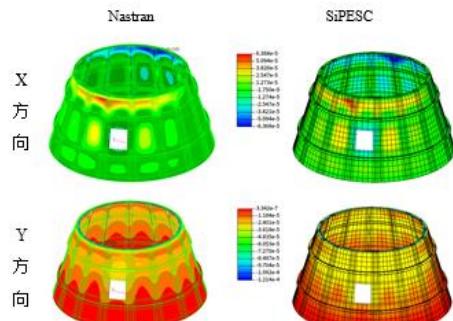
第1章	词条相应功能及理论	1
1.1	词条解释及对应算例总述	1
1.2	节点与坐标系	4
1.2.1	GRID	4
1.2.2	CORD1C	4
1.2.3	CORD1F	4
1.2.4	CORD2C	4
1.3	一般单元及	
1.3.1	CROD	
1.3.2	CBEAM	
1.3.3	CBAR/P	
1.3.4	CHEXA	
1.3.5	CTRIA3	
1.3.6	CPENTA	
1.3.7	CSHEAR	
1.4	连接单元	
1.5	Rigid 单元及	
1.6	标量单元	
1.6.1	CELAS1	
1.6.2	CFAST	
1.6.3	CONM2	
1.7	约束条件	
1.7.1	SPC, SPCADD	
1.8	静力载荷	
1.8.1	FORCE	
1.8.2	FORCE1	
1.8.3	PLOAD	
第2章	算例对比说明	13
2.1	算例介绍	13
2.2	坐标系测试	14
2.2.1	桁架结构斜支撑约束	14
2.2.2	梁组合弯曲	15
2.3	梁单元性能测试	16
2.3.1	短粗梁剪切测试	16
2.4	实体单元	17
2.4.1	非协调单元测试	17
2.5	板壳单元	18
2.5.1	膜性能测试	18
2.5.2	CRM 机翼静力分析	19
2.5.3	正交各向异性材料变厚度机翼问题	21
2.6	复合材料模型	22
2.6.1	SiPESC 的 Composite 模块	22
2.6.2	某火箭结构畸形网格测试	24
2.7	大型机翼模型	25
第3章	结论	29



表格 2-8 CRM 算例结果列表

	SiPESC	Nastran	相对偏差
位移 X	32.2	31.8	1.3%
位移 Y	177.2	177.4	0.11%
位移 Z	-1502	-1503	0.1%
总位移	1513	1513	0.0%

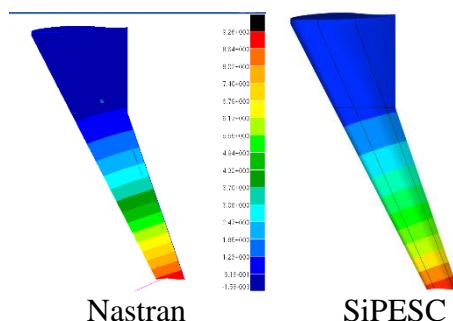
CRM机翼静力分析



表格 2-11 复合材料算例结果列表

	X	Y	Z
ABAQUS	6.39e-5	-1.22e-4	5.83e-5
SiPESC	6.38e-5	-1.21e-4	5.83e-5
NASTRAN	6.86e-5	-1.29e-4	6.86e-5
Abaqus 相对偏差	0.15%	0.82%	0.0%

复合材料结构畸形网格测试



表格 2-12 SiPESC 与 Nastran 计算的节点 10557 位移对比

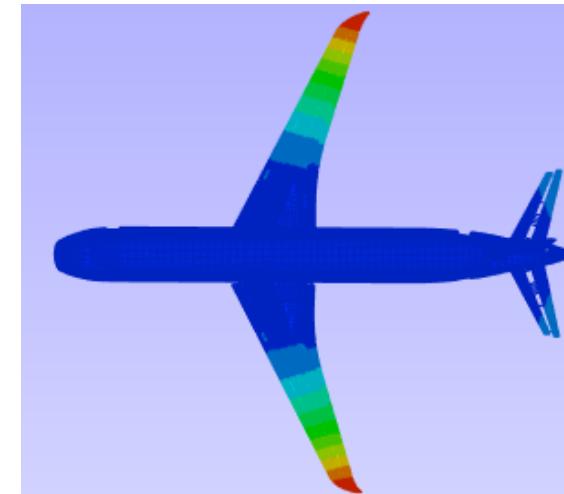
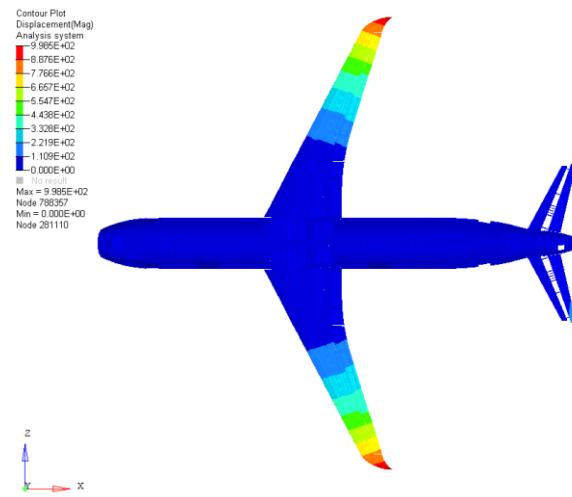
	SiPESC	Nastran	相对偏差
位移 X	0.163032	0.1667939	-2.25%
位移 Y	1.01577	1.024241	-0.85%
位移 Z	9.17636	9.256304	-0.86%

大型复杂机翼结构算例测试

SiPESC针对商用飞机结构算例测试

919全机自然网格模型模型总自由度：417151

卡片类型		
CBAR	CORD2R	PBARL
CBEAM	CPENTA	PBEAML
CBUSH	CQUAD4	PBUSH
CELAS1	CROD	PCOMP
CHEXA	CSHEAR	PELAS
CONM2	CTRIA3	PROD
CORD2C	FORCE	PSHEAR
GRID	MOMENT	PSHELL
LOAD	RBAR	PSOLID
MAT1	RBE2	
MAT2	RBE3	
MAT8	RSPLINE	
MAT9	PBAR	



标准化后的位移结果对比：

Nastran：
998.5mm

SiPESC：
993.4mm

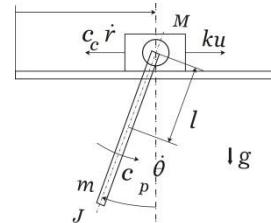
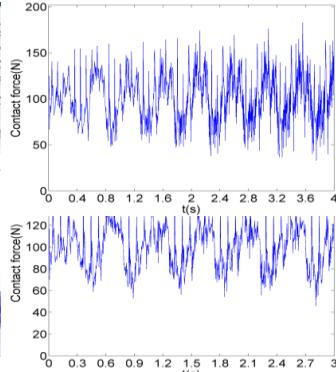
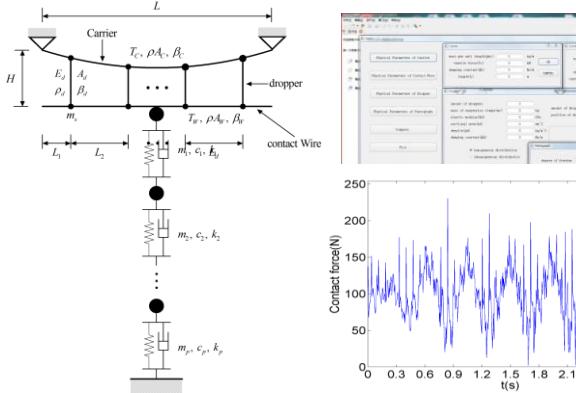
偏差：0.5%

数值仿真软件SiPESC

- 软件概况
- 优化设计
- 结构分析与数值模拟
- 软件定制与集成

数值仿真软件SiPESC-定制与集成

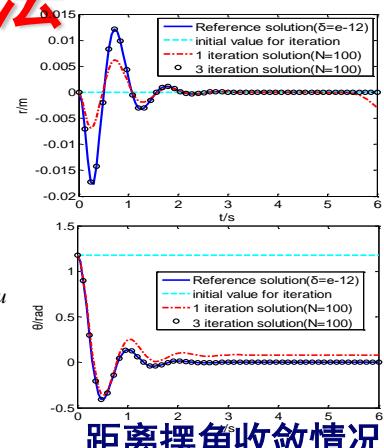
平台算法扩展：多体动力学保辛算法



$$\begin{cases} (M+m)\ddot{r} - ml\ddot{\theta} \cos \theta = -c_c \dot{r} - ml\dot{\theta} \sin \theta + ku \\ -ml\ddot{r} \cos \theta + (J+ml^2)\ddot{\theta} = -c_p \dot{\theta} - mgl \sin \theta \end{cases}$$

$$J = \frac{1}{2} \int_0^6 [100r_1^2 + \theta_2^2 + \dot{r}_3^2 + 0.1\dot{\theta}_4^2 + 0.02u^2] d\tau$$

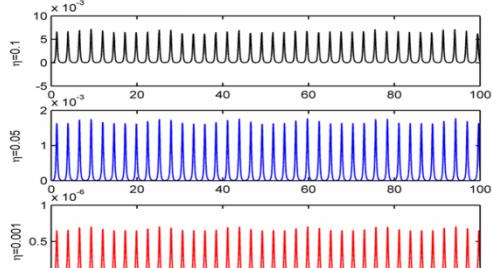
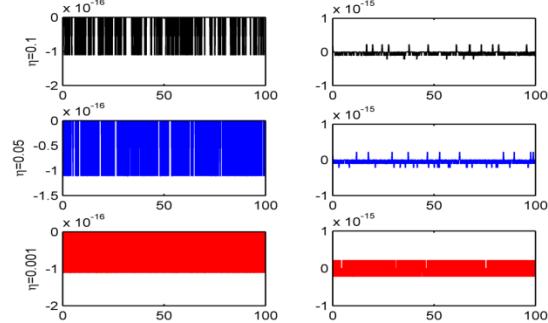
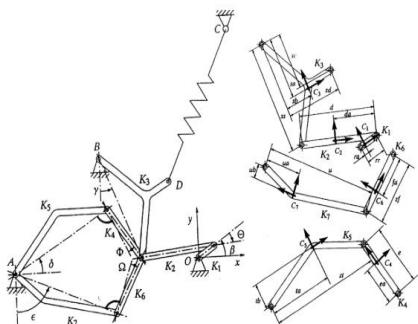
吊重控制系统



距离摆角收敛情况

高铁弓网动力学系统分析(拉压非线性)

非线性系统闭环反馈控制保辛算法



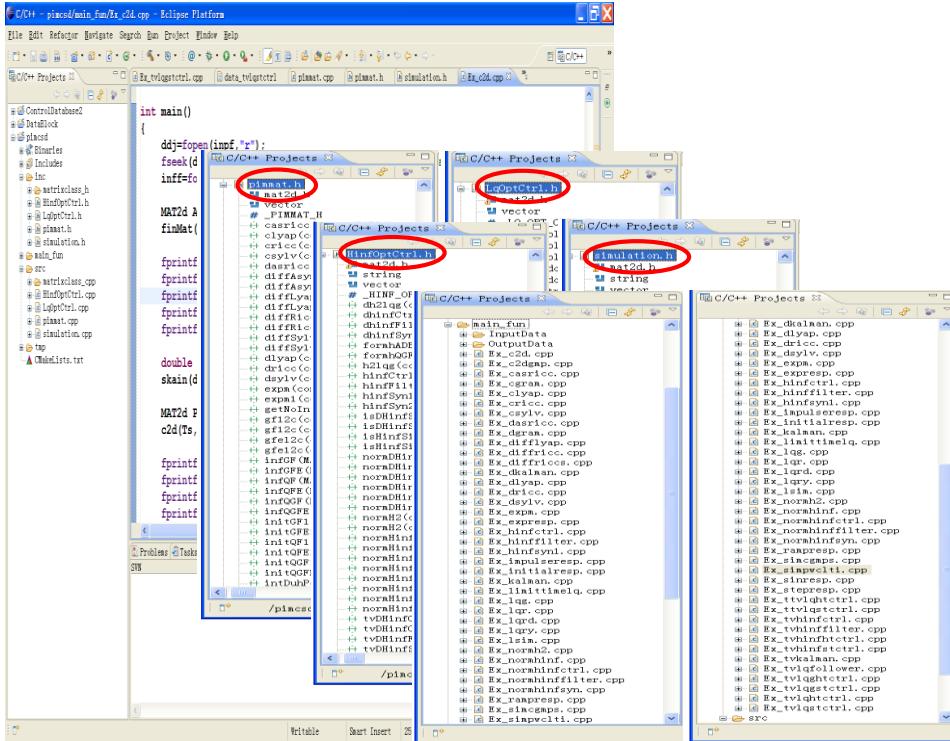
安德鲁压榨系统动力学仿真

精确满足运动副约束

保守系统能量长时间守恒

数值仿真软件SiPESC-定制与集成

平台算法扩展：最优控制算法



84个底层函数：精细积分与基本矩阵方程求解

75个LQ部分函数：控制系统设计、滤波器设计及综合

46个H_{oo}部分函数：控制系统设计、滤波器设计及综合

32个仿真函数：控制系统设计、滤波器及综合仿真

52个测试函数：基本涵盖常用控制系统设计与仿真功能

LINEAR-QUADRATIC (LQ) OPTIMAL CONTROL SYNTHESIS	
Controller	
<u>pim c2d</u>	- Conversion of continuous-time models, including discretization of DGMFs for
<u>pim c2dgmf</u>	- Converting 离散化
<u>pim care</u>	- Solve continuous Algebraic Riccati 方程
<u>pim dare</u>	- Solve discrete Algebraic Riccati 方程
<u>pim cran</u>	- Controllability and Observability
<u>pim deran</u>	- Controllability and Observability
<u>pim lqr</u>	- Linear-quadratic regulator design
<u>pim lard</u>	- Discrete Linear-quadratic regulator
<u>pim lqry</u>	- Linear-quadratic regulator design
<u>pim dlqr</u>	- Linear-quadratic regulator design
<u>pim dlgy</u>	- Linear-quadratic regulator design
<u>pim tlfqfl</u>	- TV LQ Follower/Disturbance-Reject
<u>pim tlfqfl</u>	- TV LQ Follower/Disturbance-Reject
<u>pim tlhtc</u>	- TV LQ Hard Terminal Controller
<u>pim tigetc</u>	- TV LQ Soft Terminal Controller
<u>pim tdigetc</u>	- TV LQ Hard Terminal Controller
<u>pim tldgetc</u>	- TV LQ Soft Terminal Controller
<u>pim ttlhtc</u>	- TV LQ Hard Terminal Controller
<u>pim ttlastc</u>	- TV 时变系统终端控制
<u>pim tlhtc opn</u>	- TV 变性能指标终端控制
<u>pim ttlastc opn</u>	- TV 时变系统终端控制

ROBUST H_{INF} CONTROL OPTIMAL SYNTHESIS
 Norms/Controller/Filter/Synthesis

pin norm2 - Continuous H₂-norm.
pin norminf - Continuous H-Infinity norm of INFINITE/FIR
pin normhc - Continuous Hinf-norm of state-feedback controller
pin normhf - Continuous Hinf-norm of optimal filtering controller
pin normhcif - Continuous Hinf-norm of state-feedback controller with integral filtering controller
pin normhcif - Continuous Hinf-norm of state-feedback controller with integral filtering controller
pin normhfif - Discrete Hinf-norm of state-feedback controller with integral filtering controller
pin normhfif - Discrete Hinf-norm of optimal filtering controller with integral filtering controller
pin normhcf - Discrete Hinf-norm of output feedback controller
pin hinf - TI Hinf state feedback controller for continuous system.
pin hinf - TI Hinf optimal filter for continuous system.
pin dhinf - TI Hinf state feedback controller for discrete system.
pin dhinf - TI Hinf optimal filter for discrete system.
pin thinf - TV Hinf state feedback controller for continuous system.
pin thinf - TV Hinf state feedback controller for continuous system.
pin thinf - TV Hinf optimal filter for continuous system.
pin thinf - TV Hinf state feedback Controller for discrete system.
pin thdhinf - TV Hinf optimal Filter for discrete system.

pin h2lqr - TI H₂ control synthesis for continuous system.
pin dh2lqr - TI H₂ control synthesis for discrete system.
pin hinf1 - TI Hinf output feedback controller for continuous system.
pin hinf2 - TI Hinf output feedback controller for continuous system.
pin dhinf2 - TI Hinf output feedback controller for discrete system.
pin thinf2 - TI Hinf output feedback controller for continuous system.
pin thinf2 - TI Hinf output feedback controller for discrete system.
pin thinf2 - TI Hinf output feedback controller for discrete system.
pin thinf2 - TI Hinf output feedback controller for discrete system.
pin thinf2 - TI Hinf Hard Terminal Controller for continuous system.
pin thinf2 - TI Hinf Soft Terminal Controller for continuous system.

pin h2, H_{inf}综合 - H₂, H_{inf}综合控制器 for discrete system.
pin thinf2 - TI Hinf output feedback controller for discrete system.
pin thinf2 - TI Hinf Hard Terminal Controller for continuous system.
pin thinf2 - TI Hinf Soft Terminal Controller for continuous system.

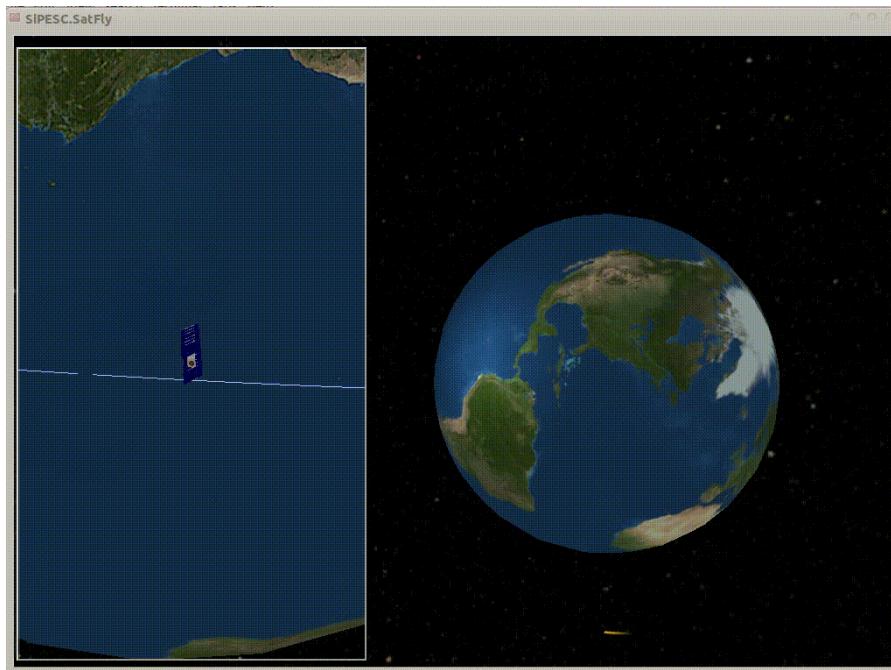
Filter	
<u>pin_kalman</u>	- TV Kalman-Bucy filter for continuous
<u>pin_dkalman</u>	- TV Kalman-Bucy filter for discrete system.
<u>pin_kalmd</u>	- TV Discrete Kalman filter for continu
<u>pin_lkalm</u>	- TV Kalman-Bucy Filters.
<u>pin_fifilt</u>	- TV Forward Information Filter for
<u>pin_tbclft</u>	- TV Backward Covariance Filter for
<u>pin_tbiflt</u>	- TV Backward Information Filter for
<u>pin_tbiflt</u>	- TV Backward Information Filter-Sm
<u>pin_tbiflt</u>	- TV Forward Smoothing Information F
<u>pin_tdkalm</u>	- TV Kalman-Bucy filter for discrete sys
<u>pin_tdbeflt</u>	- TV Backward Covariance Filter for
<u>pin_tdbiflt</u>	- TV Backward Information Filter for
<u>pin_tdfiflt</u>	- TV Forward Information Filter for
<u>pin_tdbiflt</u>	- TV Backward Information Filter-Sm
<u>pin_tdbiflt</u>	- TV Forward-Backward Information F
<u>pin_tdfcbiflt</u>	- TV Forward Covariance and Backwar
Synthesis	
<u>pin_log</u>	- TV LQG Gaussian controller
<u>pin_lqgste</u>	- TV LQG Soft terminal controller f
<u>pin_lgghte</u>	- TV LQG Hard terminal controller f
<u>pin_tdlogste</u>	- TV LQG Soft terminal controller f
<u>pin_tdglgste</u>	- TV LQG Hard terminal controller f
<u>pin_lqgfll</u>	- TV LQG Follower synthesis (New Met
<u>pin_tdglgfil</u>	- TV LQG Follower synthesis for dis

SIMULATION OF CONTROL SYSTEM	
<u>pia_step</u>	- Step response of continuous LTI state-space
<u>pia_initial</u>	- Initial response of continuous LTI state-space
<u>pia_impulse</u>	- Impulse response of continuous LTI state-space
<u>pia_lsim</u>	- Simulate time response of continuous LTI to arbitrary input
	系统仿真
<u>pia_sinesres</u>	- Sine response of continuous LTI state-space
<u>pia_express</u>	- Exponential response of continuous LTI state-space
<u>pia_rampresp</u>	- Ramp response of continuous LTI state-space
<u>pia_ltisim</u>	- Simulation of the LTI/PWC (Piece-Wise
	常数)
<u>pia_siskalman</u>	- Simulation for TI Kalman-Bucy Filter
<u>pia_sindkalman</u>	- Simulation for TI Kalman filter of discrete time
<u>pia_sintkal</u>	- Simulation for TV Kalman-Bucy Filter
<u>pia_sintkaln</u>	- Simulation for TV Kalman filter of discrete time
<u>pia_sintlgqetc</u>	- Simulation for TV LQG SFC of continuous time
<u>pia_sintlgqetc</u>	- Simulation for TV LQG HWC of continuous time
<u>pia_sintdlogetc</u>	- Simulation for TV LQG HWC of discrete time
<u>pia_sintdlogetc</u>	- Simulation for TV LQG HWC of discrete time
<u>pia_sintlgqff</u>	- Simulation for TV LQG Fowler of continuous time
<u>pia_sintlgqff</u>	- Simulation for TV LQG Fowler of discrete time
<u>pia_sinthinf</u>	- Simulation for TV Hinff state-feedback
<u>pia_sinthinf2</u>	- Simulation for TV Hinff output-feedback
<u>pia_sintdhinf</u>	- Simulation for TV Hinff state-feedback
<u>pia_sintdhinf2</u>	- Simulation for TV Hinff output-feedback

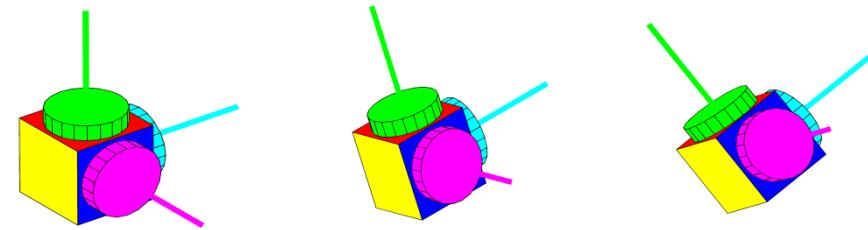
数值仿真软件SiPESC-动力学与控制

平台算法扩展：最优控制算法

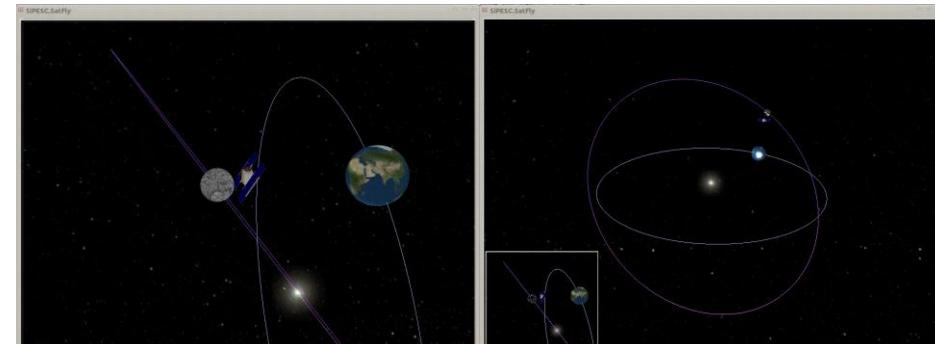
- 钟万勰院士等研发了PIMCSD控制算法工具箱, LQG和 H_∞ 控制系统设计与仿真;特色算法: 时变控制器/滤波器设计功能、非线性最优控制的保辛/多层次/自适应数值求解算法



近地轨道航天器编队重构过程



航天器姿态机动过程



航天器探测小行星过程

数值仿真软件SiPESC-保辛控制算法

控制力矩受限情况下国际空间站姿态机动轨迹规划问题



NASA采用勒让德伪谱法对国际空间站在2h45min内进行180度姿态调整

保辛方法

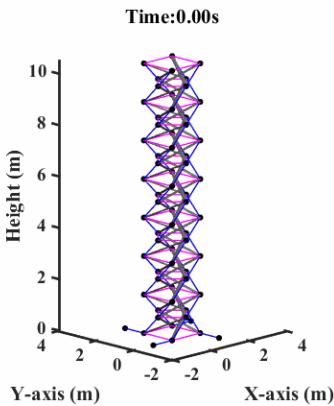
UIUC大学伪谱软件BMIP

Case No.	Description	t_f / s	u_{\max} / (N·m)	Cost functional		$\frac{J_2 - J_1}{J_2} \times 100\%$
				SPM, J_1	DTPM, J_2	
1	Rotate 180° around X	2h45min	0.6	2.892667779276549e+02	3.090105399212052e+02	6.3893490489304%
2	Rotate 180° around Y	2h45min	0.6	3.121937959210609e+02	3.375201544222824e+02	7.5036581280817%
3	Rotate 180° around Z	2h45min	0.6	2.942277191827744e+02	3.197401339811511e+02	7.9791093100251%
4	Rotate 180° around X	1h	0.6	8.382109457191971e+02	8.491219700281501e+02	1.2849772699429%
5	Rotate 180° around Y	1h	0.6	1.629468588962380e+03	1.691789888901058e+03	3.6837494033707%
6	Rotate 180° around Z	1h	0.6	8.585450742233979e+02	8.751520183713437e+02	1.8976067928006%

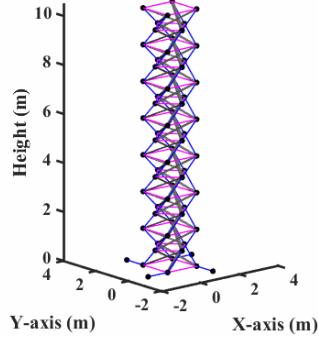
辛方法相对伪谱方法可进一步最多节省近八万美元的燃料

数值仿真软件SiPESC-保辛控制算法

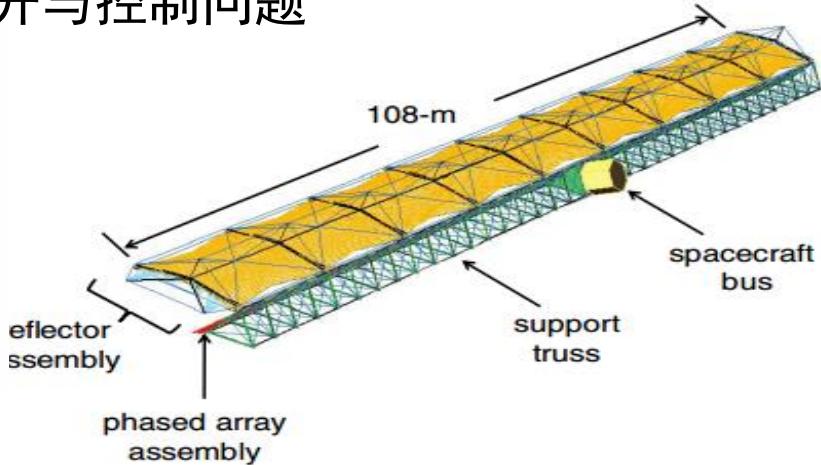
□ 大型索网天线展开与控制问题



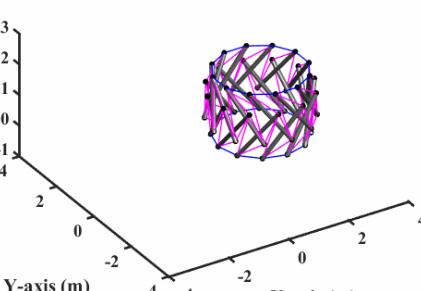
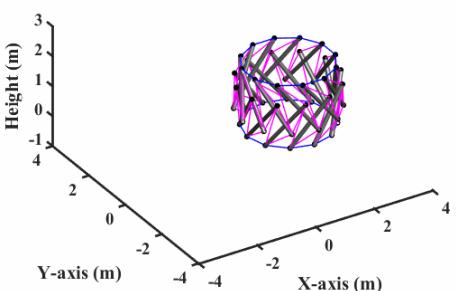
基于最优控制压缩过程



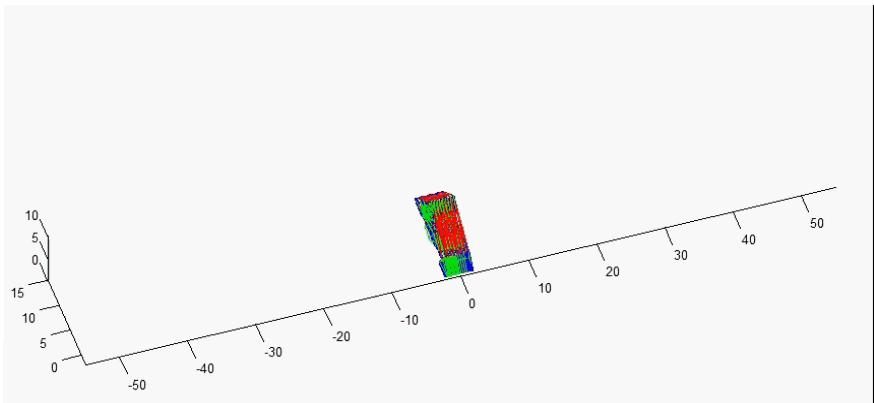
常速率压缩过程



相控阵雷达反射天线



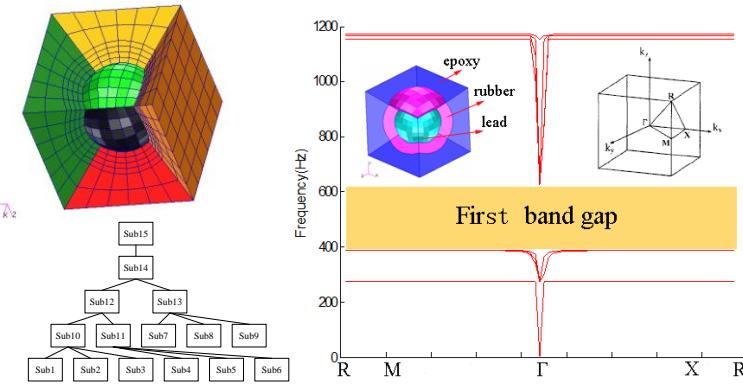
□ 不仅可以将结构快速地折叠/展开至目标位置，且同时可使得结构到达目标形态后残余振动最小。



多体动力学数值模拟展开过程

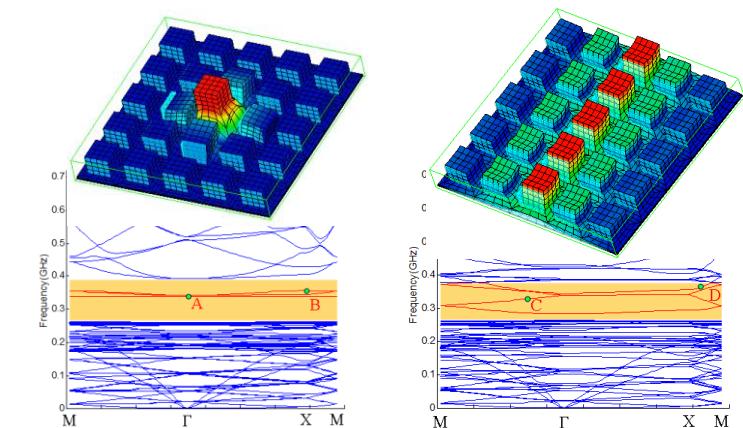
数值仿真软件SiPESC-定制与集成

- **自主特色的多重多级子结构算法**
- **算法思路：多类周期性边界条件在顶层子结构统一施加**
- **保证精度同时内存用量、耗时大幅度降低，提升计算效率**

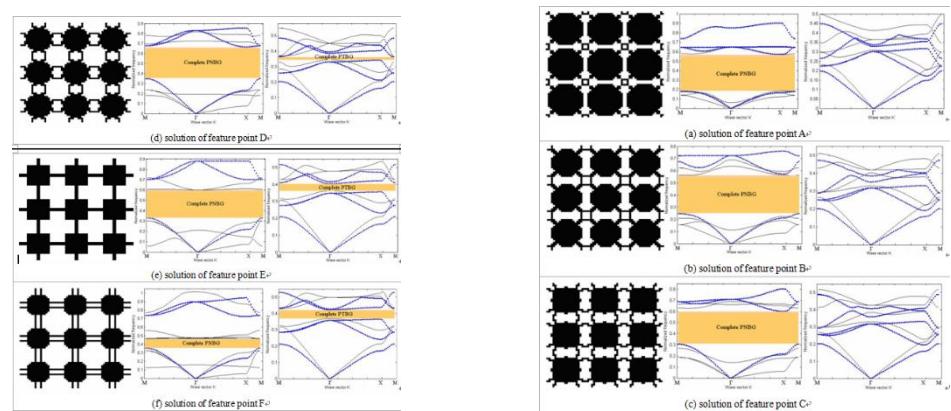


	用时(分钟)	存贮量(GB)
传统方法	544.6	5.43
传统方法+改进迭代	219.7	5.43
多重多级子结构方法	96.6	0.42
多重多级子结构方法+改进迭代	8.7	0.42

经典局域共振算例



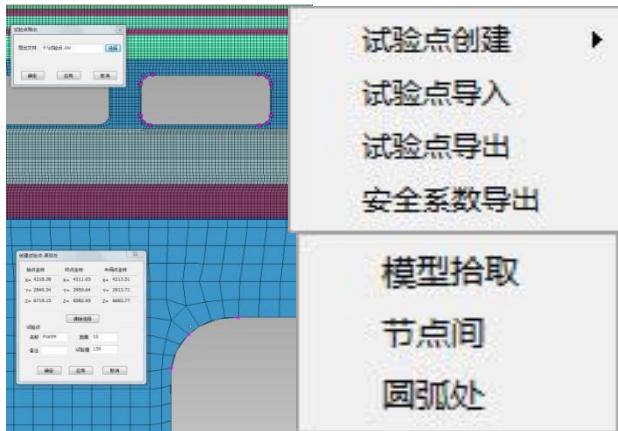
Lamb波缺陷态分析



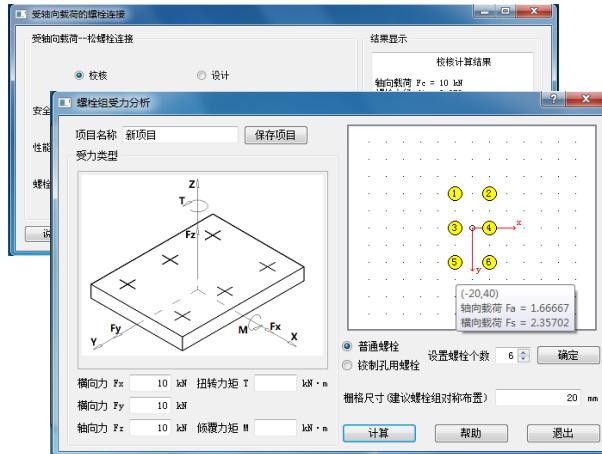
声子光子晶体多目标拓扑优化

数值仿真软件SiPESC-定制与集成

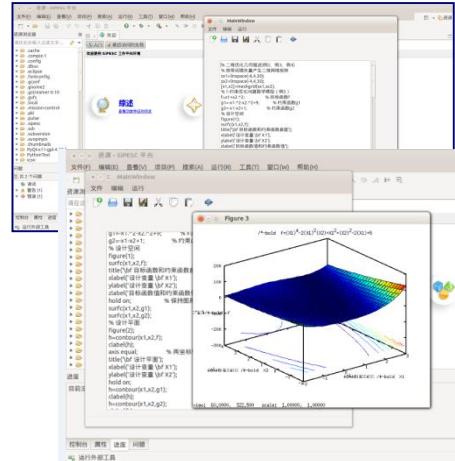
平台灵活扩展实例：工程定制软件



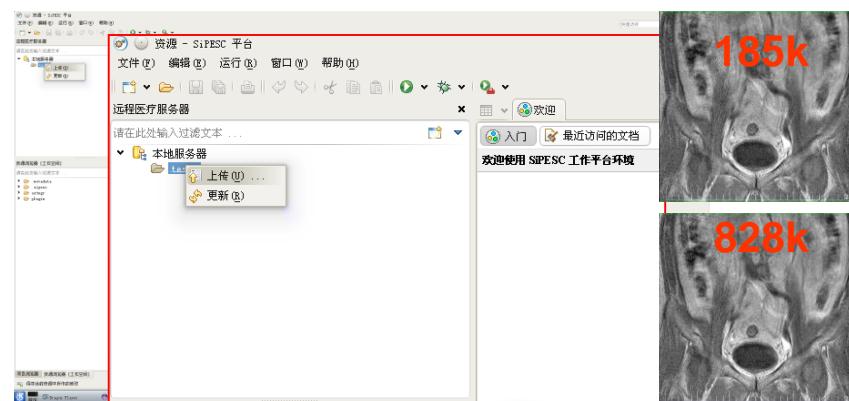
实验与有限元分析结果可视化对比系统



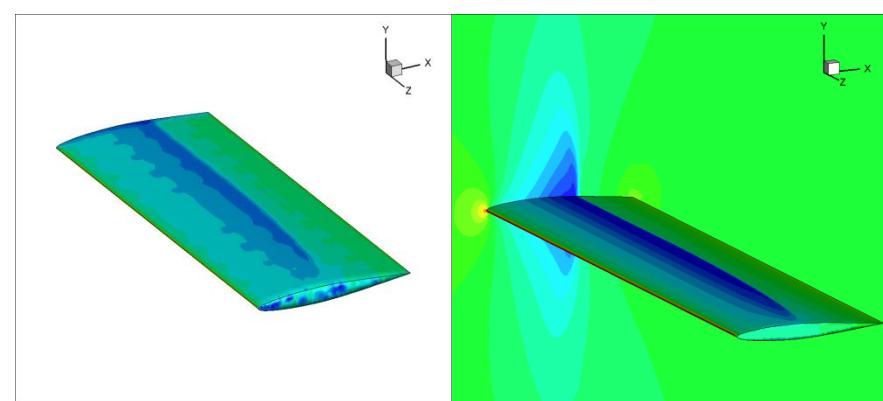
螺栓构件校核系统



Matlab运行环境

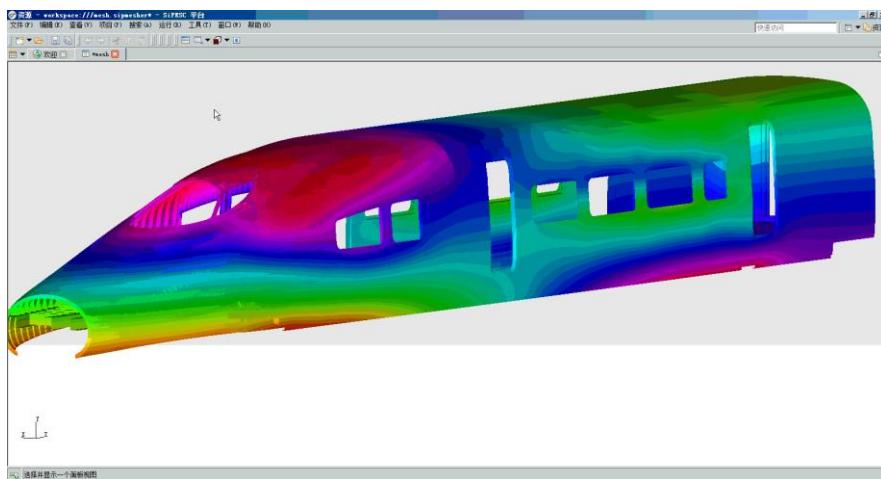


医用图像传输系统(上：压缩图；下：原图)

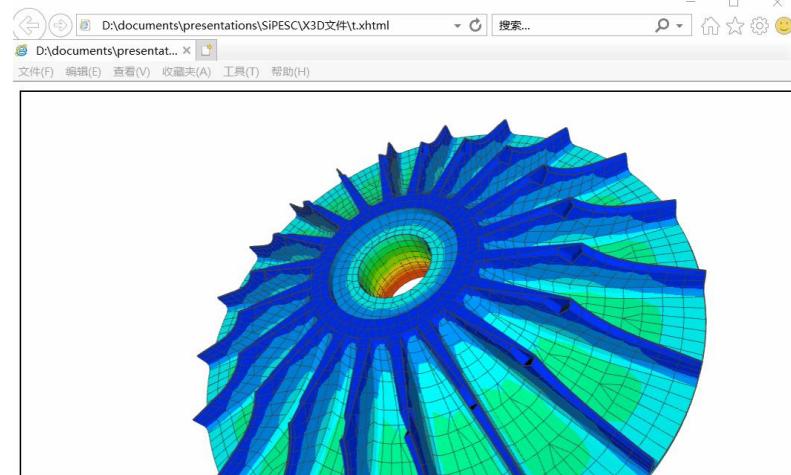


流体-固体载荷映射模块

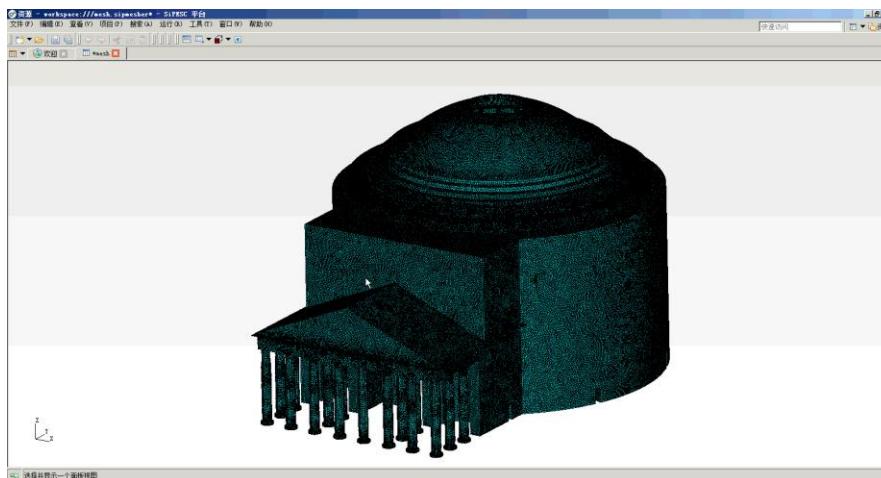
数值仿真软件SiPESC-定制与集成



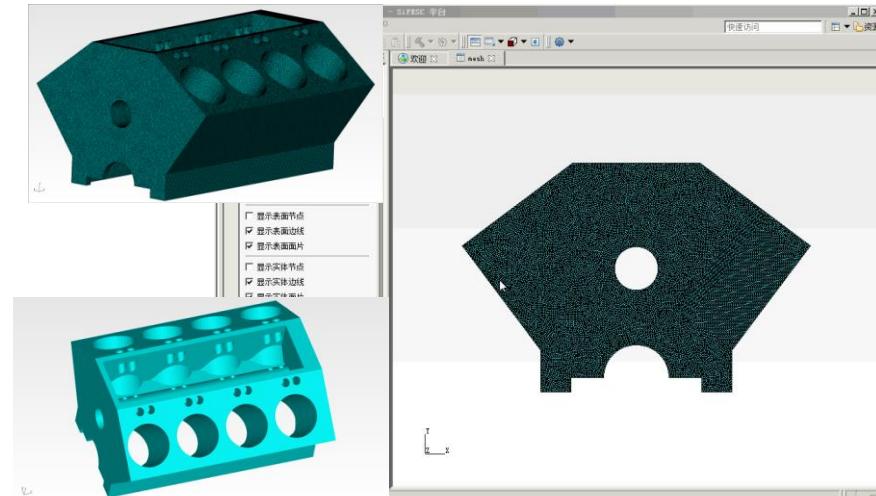
53万节点, 67万单元



有限元X3D文件生成/IE浏览

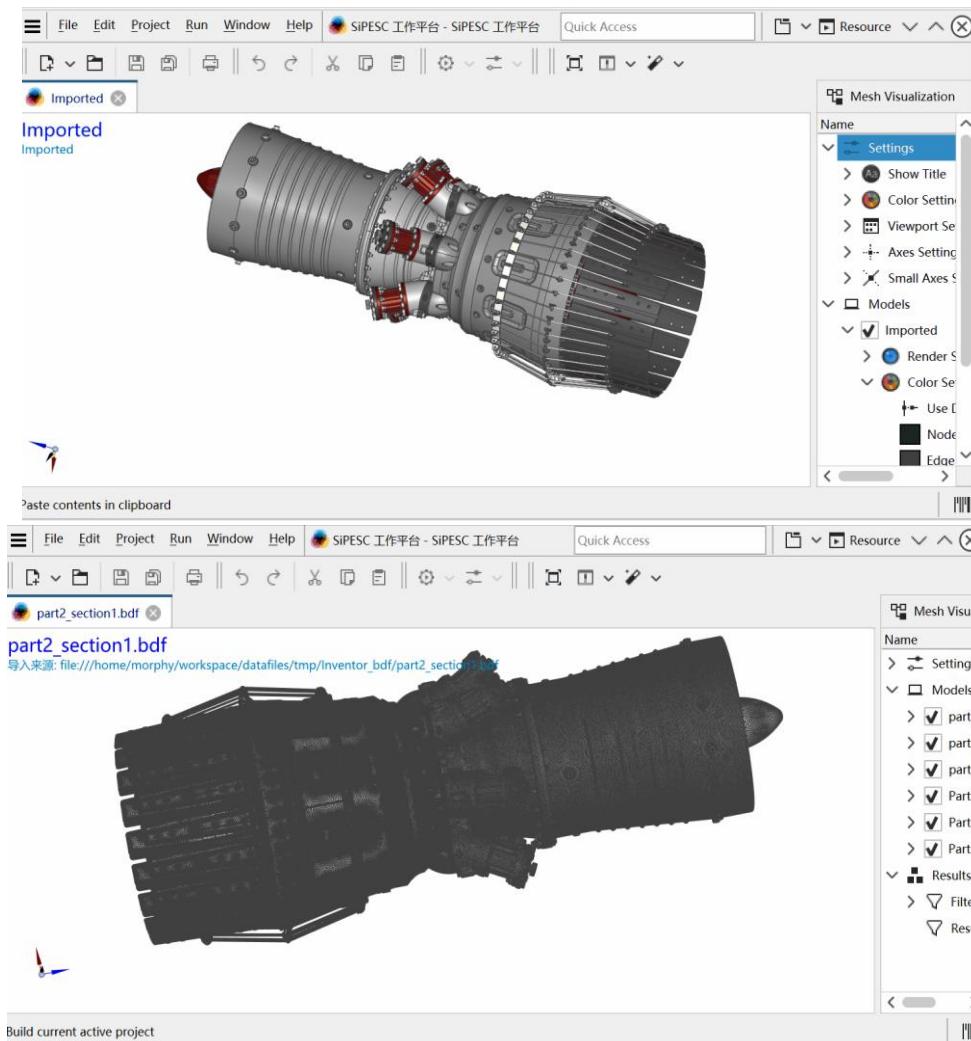


128万节点, 617万单元



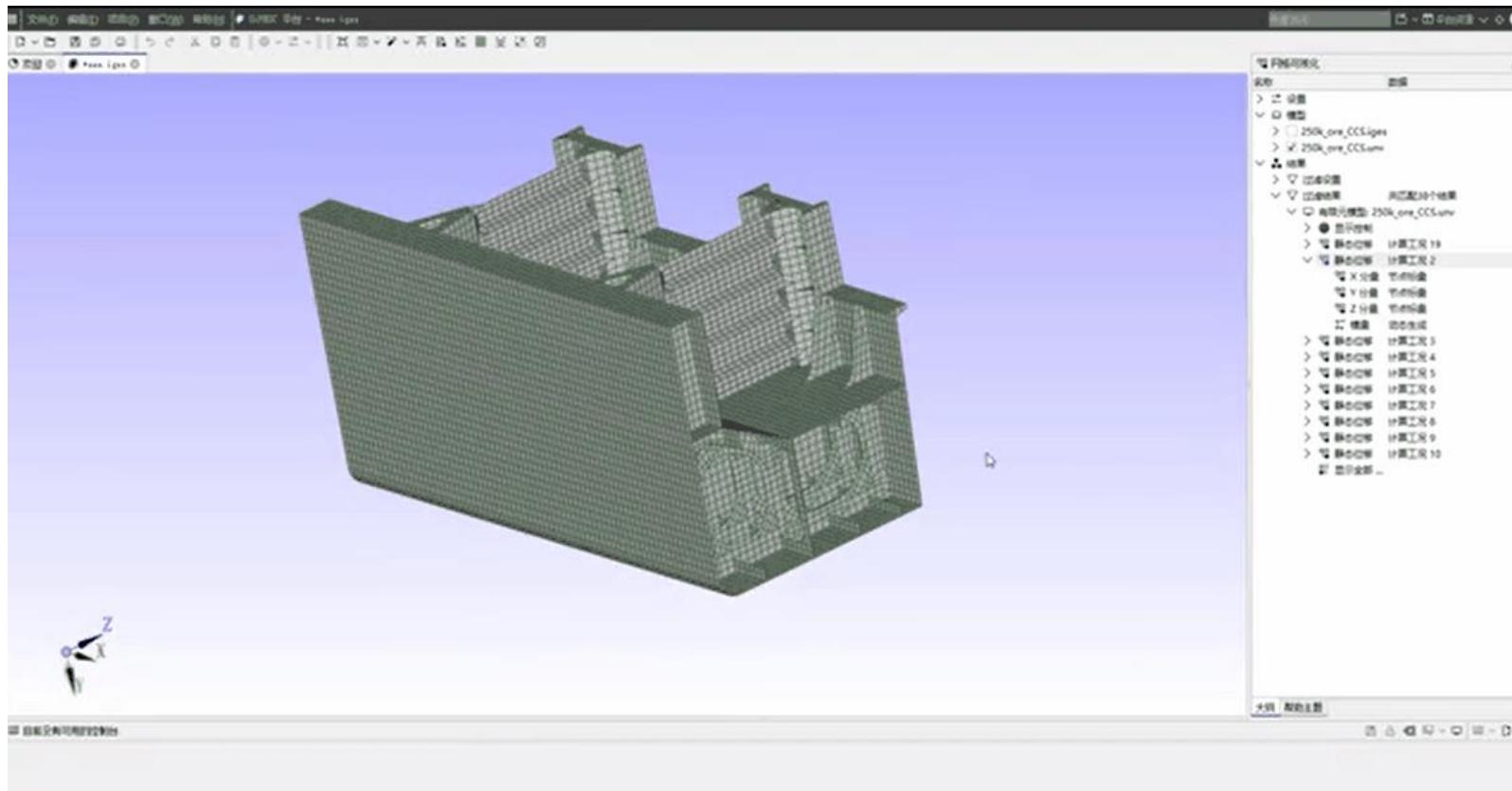
1300万节点有限元模型

数值仿真软件SiPESC-CAD集成



自主的CAD可视化引擎、CAD/CAE融合可视化

数值仿真软件SiPESC-CAD集成



自主的CAD可视化引擎、CAD/CAE融合可视化

数值仿真软件SiPESC-定制与集成

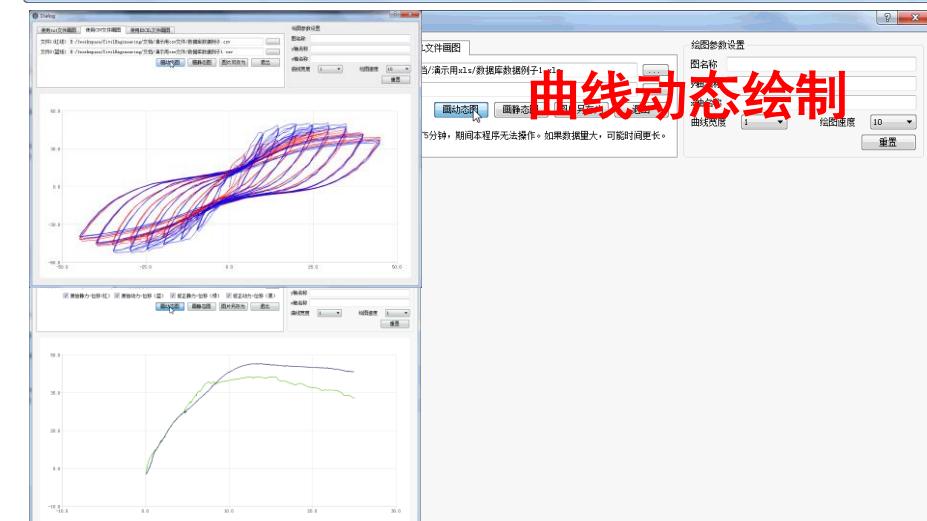
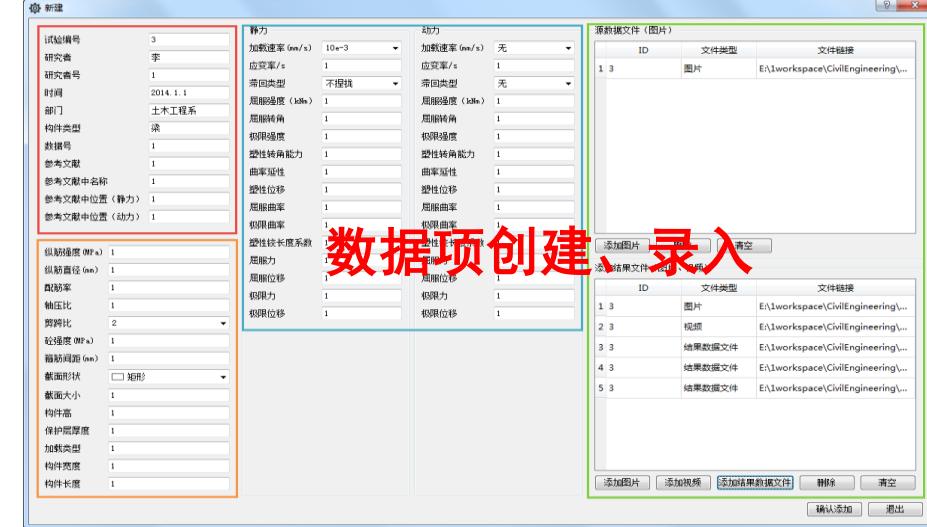
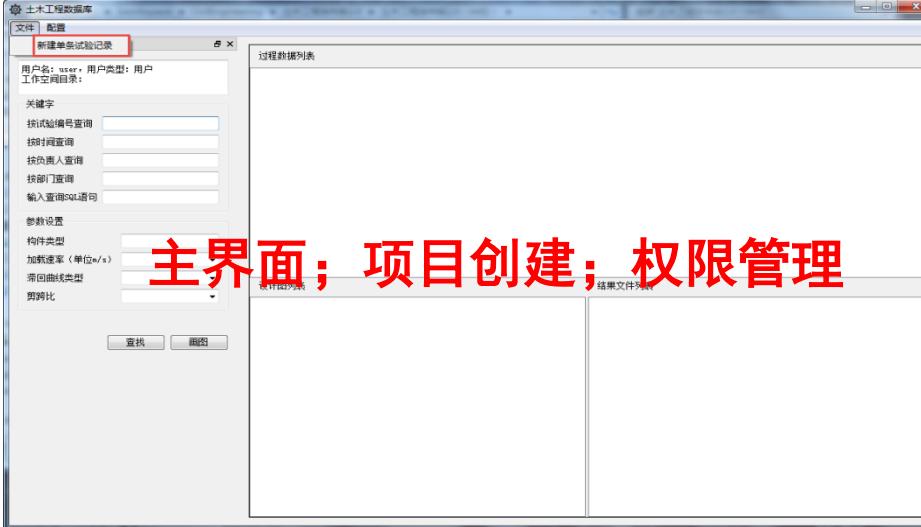
混凝土试验数据管理系统

主界面；项目创建；权限管理

数据项创建、录入

支持多类型文件管理

曲线动态绘制



数值仿真软件SiPESC-定制与集成

汽轮机安全评估系统

汽轮机安全评估系统

基本强度评估 | 结构寿命评估 | 其他

Select ODB
ODB File Name: D:/abaqus6.12/TestPython.odb | Load ODB

Select Component & Material
选择部件: Casing etc | 选择材料: 10315AP

Select Step/Frame
Step-1-weight
Step-1-weight_Frame 0
Step-1-weight_Frame 1
Step-2-pressure
Step-2-pressure_Frame 0
Step-2-pressure_Frame 1
Step-3-vwo
Step-4-creep_20WH
Step-6-ShutDown

Select Output
Select | Deselect
Completed

100% | CALCULATE | CLEAR

Si, Mises (Avg: 75%)

+8.526e+02	+7.617e+02	+7.108e+02	+6.398e+02	+5.689e+02	+4.980e+02	+4.271e+02	+3.561e+02	+2.852e+02	+2.143e+02	+1.433e+02	+7.241e+01	+1.477e+00
------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------

Si, Mises (Avg: 75%)

+8.526e+02	+7.817e+02	+7.108e+02	+6.398e+02	+5.689e+02	+4.980e+02	+4.271e+02	+3.561e+02	+2.852e+02	+2.143e+02	+1.433e+02	+7.241e+01	+1.477e+00
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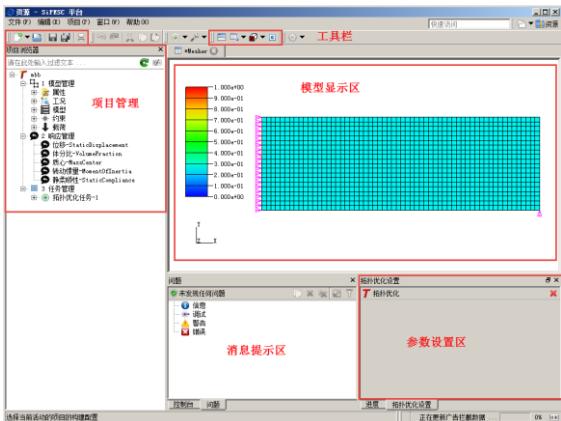
OBB: TestPython.odb Abaqus/Standard 6.12-2015 08 15:05:20 08:00 2015
Step: Step-3-vwo
Increment 1: Step Time = 1.000
Primary Var: S, Mises
Deformed Var: U Deformation Scale Factor: +2.424e+01

OBB: TestPython.odb Abaqus/Standard 6.12-2015 08 15:05:20 08:00 2015
Step: Step-3-vwo
Increment 1: Step Time = 1.000
Primary Var: S, Mises
Deformed Var: U Deformation Scale Factor: +2.424e+01

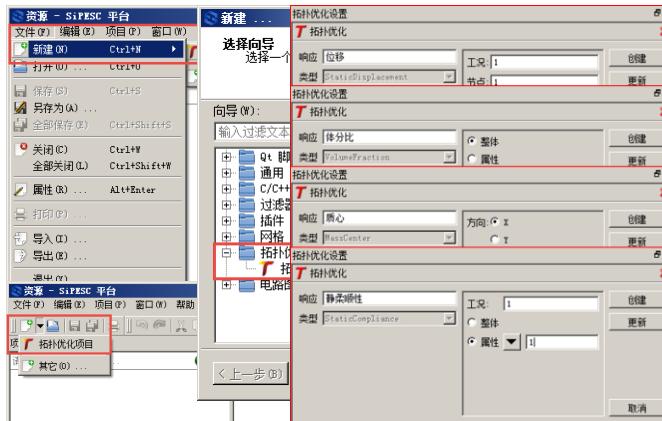
上海电气电站设备有限公司汽轮机厂
SHANGHAI ELECTRIC POWER GENERATION EQUIPMENT CO.LTD

数值仿真软件SiPESC-定制与集成

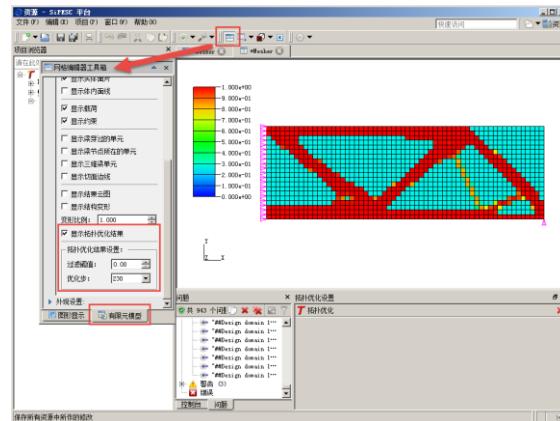
- 结构拓扑优化软件SiPESC.TOPO;
- 具备工程组合结构拓扑优化计算功能;
- 集成了主流算法与大工多项特色算法;



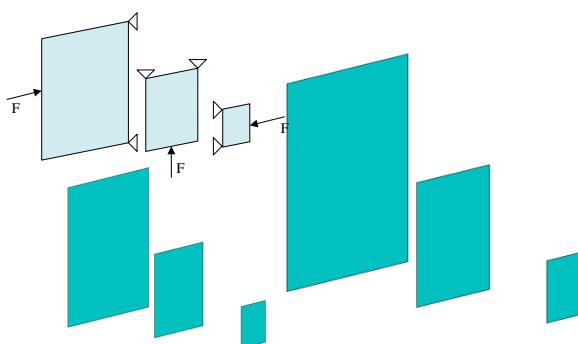
集成化界面环境



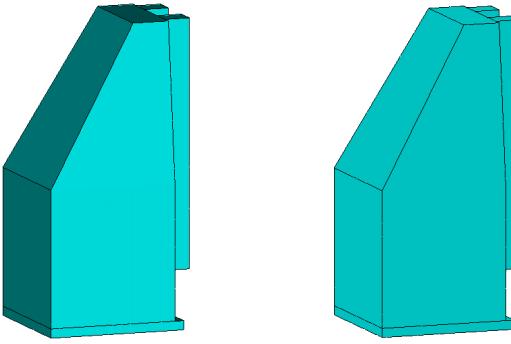
创建工程项目



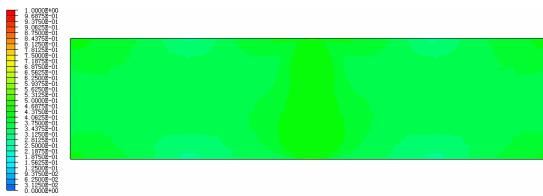
计算可视化



考虑模式重复的结构优化



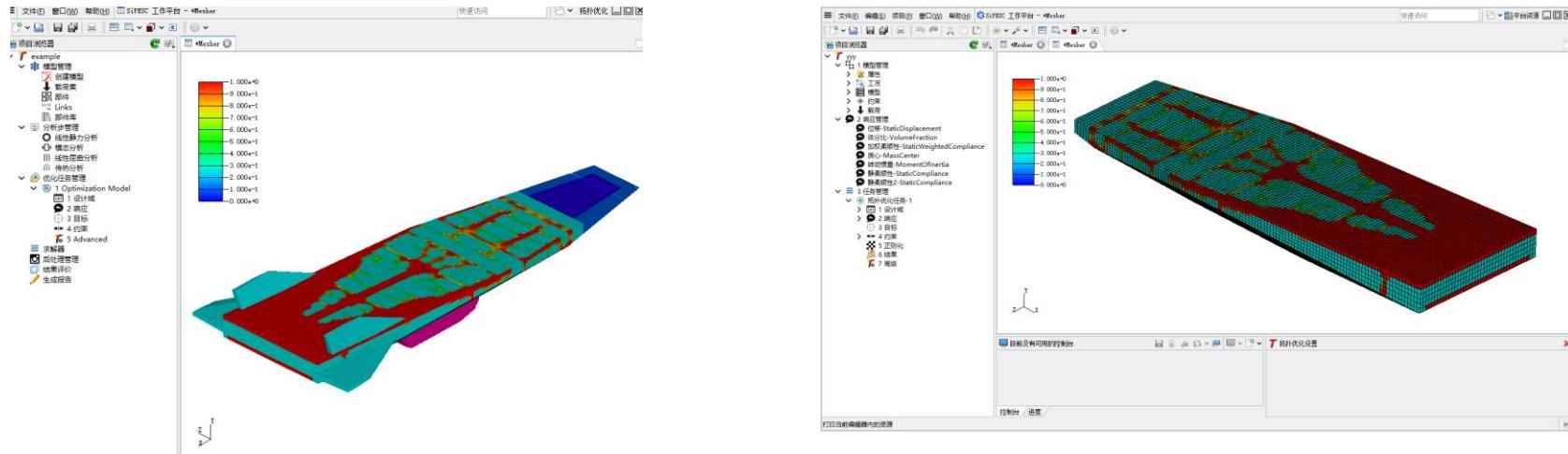
考虑对称性机床结构优化



典型结构拓扑优化实例

数值仿真软件SiPESC-定制与集成

- 结构拓扑优化工程通过Project模式管理
- 支持多种拓扑插值方案，能有效解决局部模态等复杂问题
- 支持通过Project管理多拓扑优化任务并发计算
- 支持梁、板、壳、实体、组合结构等的拓扑优化



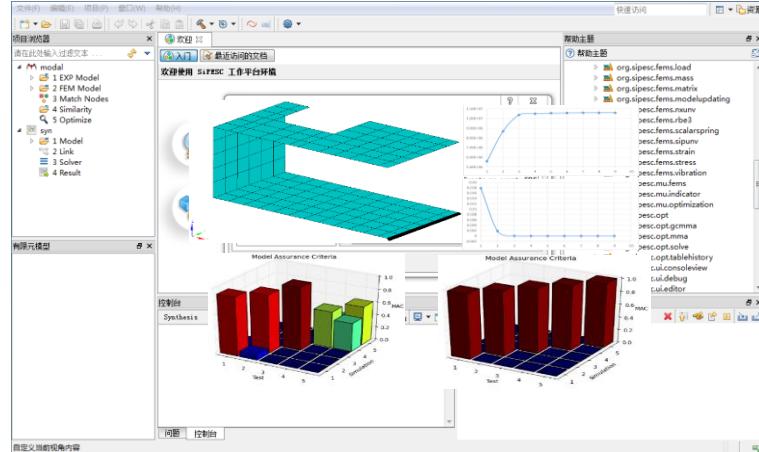
高超声速飞行器X43机身承载结构模型

数值仿真软件SiPESC-定制与集成

结构动力模型修正

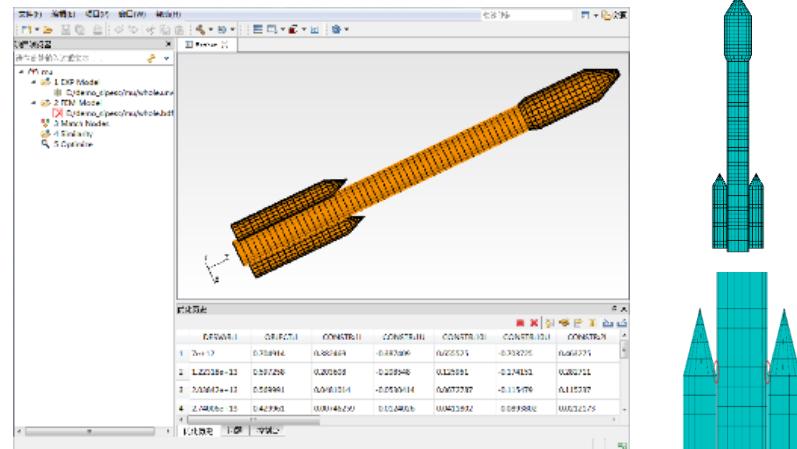
● 模型修正结构

- 仿真分析 - 基础
- 相关性分析 - 建立优化模型
- 灵敏度分析 - 优化
- ◆ 多种优化算法集成
- ◆ 同时可实现载荷识别、损伤诊断等
- ◆ 可扩展模型确认、响应预报等



● 扩展功能

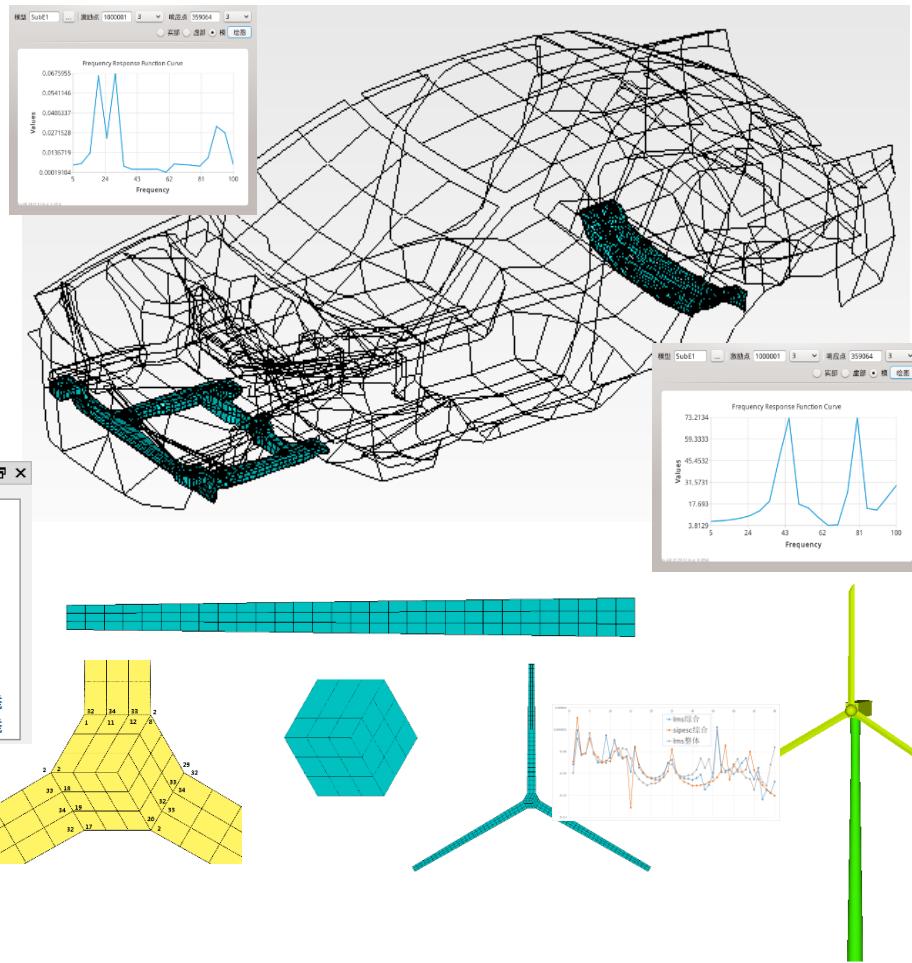
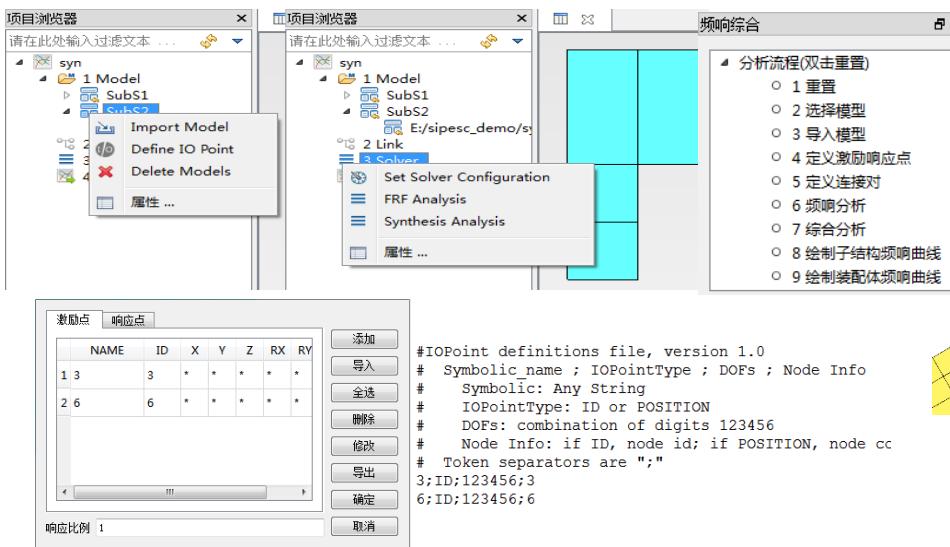
- 相关性分析 - MAC MSF CSF CSAC DAC DSF
- 指标: MACMEAN、FREQLS
- 灵敏度分析 - 差分法、半解析法



数值仿真软件SiPESC-定制与集成

频响综合

- 直接使用试验频响函数
- 对中、高频段依然适用；
- 具有子结构法本身的优点。
- 支持几何坐标变换
- 支持多种连接(刚性、柔性)
- 支持多种数据格式

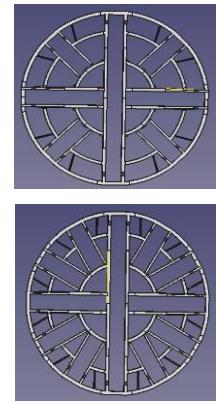
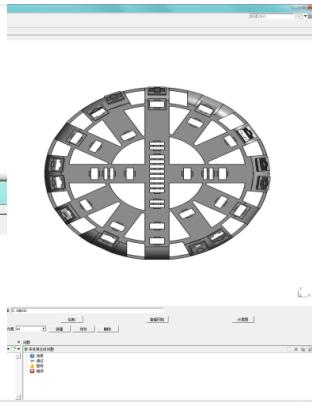
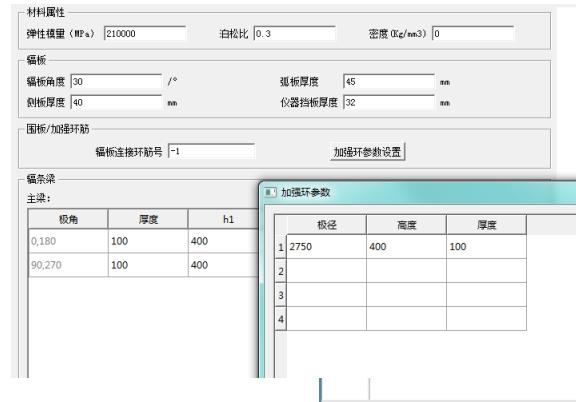
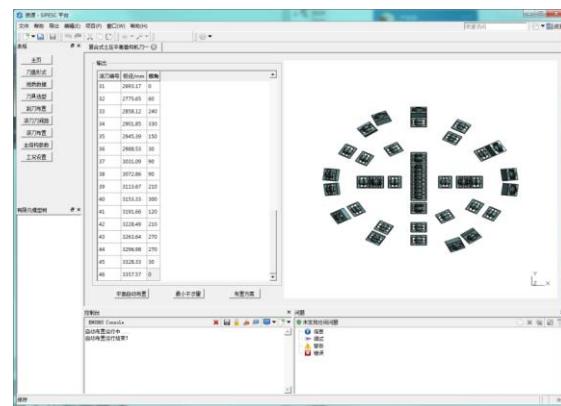
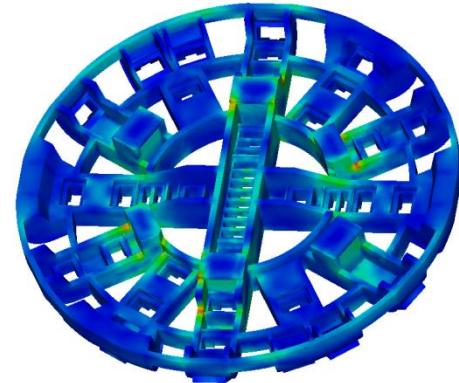
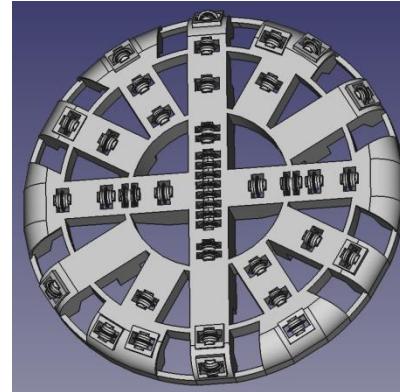
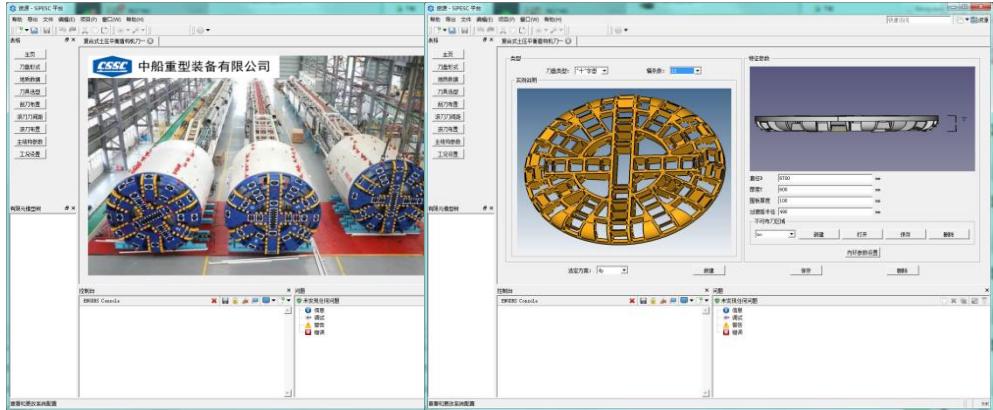


风力发电整机装配与频响综合

数值仿真软件SiPESC-定制与集成

盾构机结构设计软件

- 几何与数值模型参数化建模；
- 载荷/边界自动施加
- 集成刮刀/滚刀布置算法；
- 载荷/边界自动施加

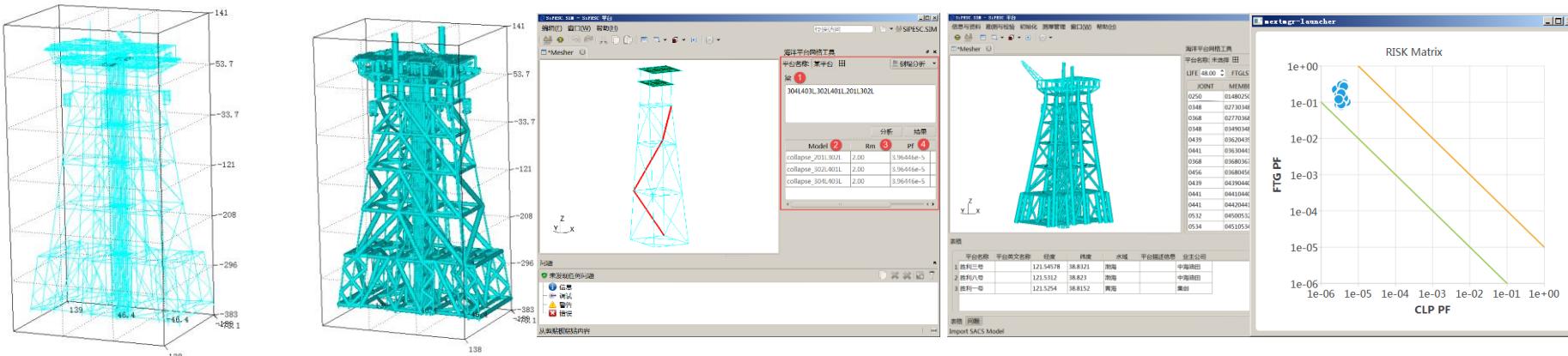


数值仿真软件SiPESC-定制与集成

海洋平台结构完整性分析软件



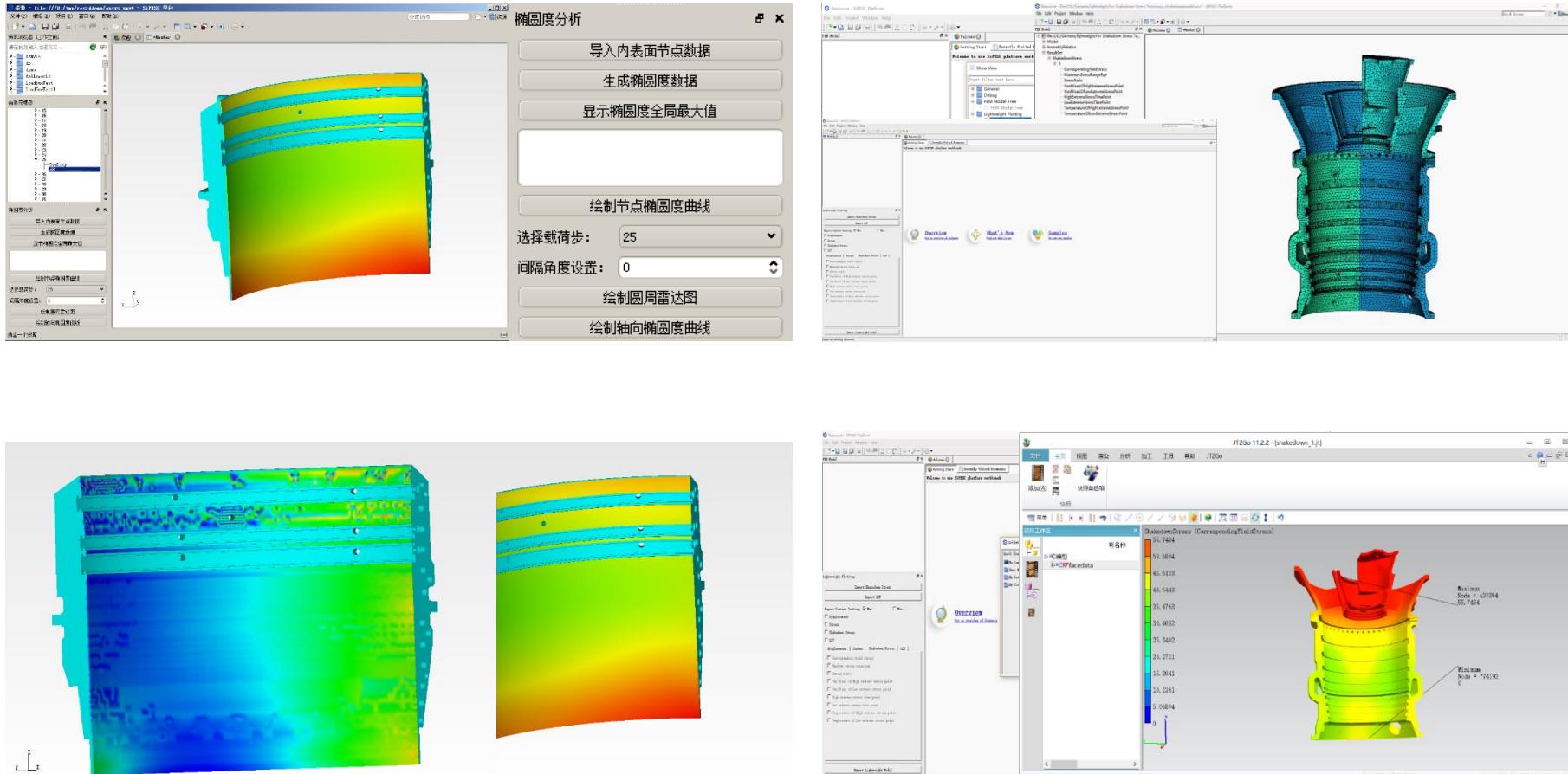
海洋平台结构信息管理子系统



海洋平台结构分析与可靠性分析子系统

数值仿真软件SiPESC-定制与集成

■ 西门子/上海汽轮机燃气机可视化应用系统研发：

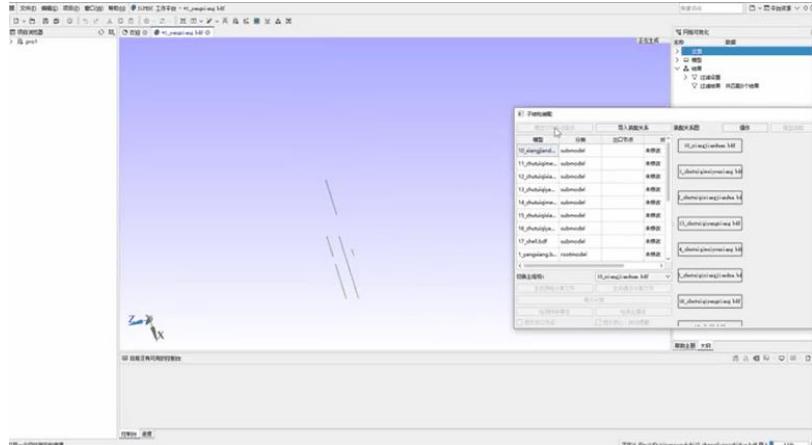


燃气机定子结构热变形椭圆度计算

大规模结构轻量级可视化功能

数值仿真软件SiPESC-定制与集成

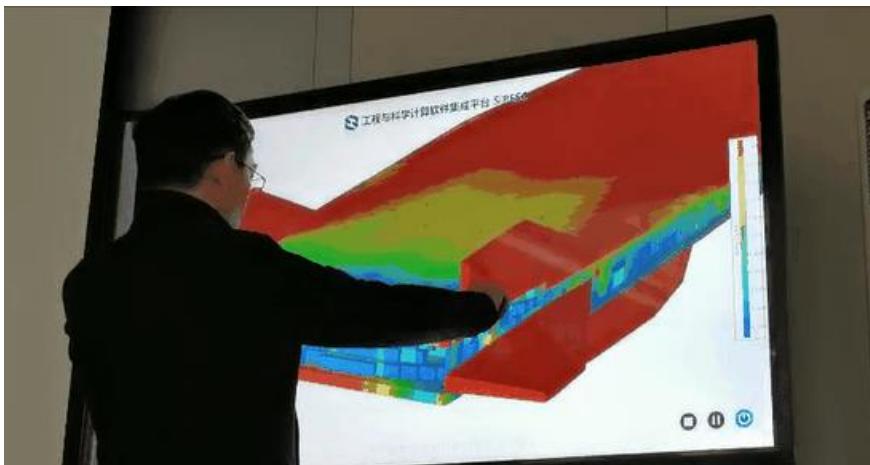
- 平台开放性机制支持功能扩展及定制软件开发；
- 支持多类行业定制软件、面向智能装备嵌入式开发；



火箭组合结构可视化拼装



汽车虚拟驾驶器研发



计算可视化触摸屏功能

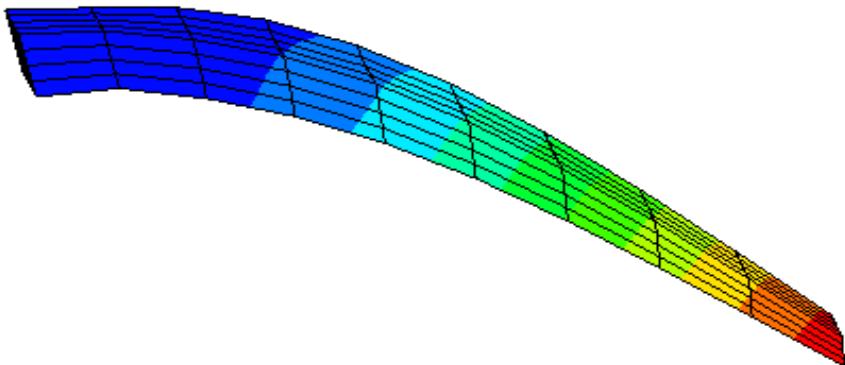
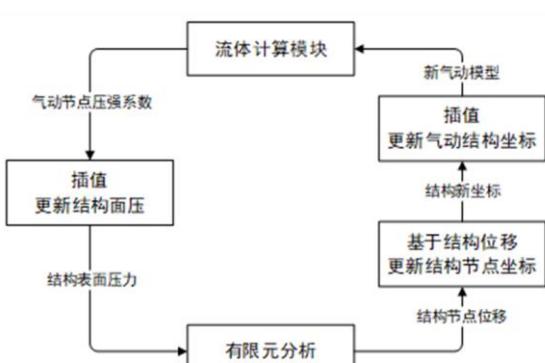
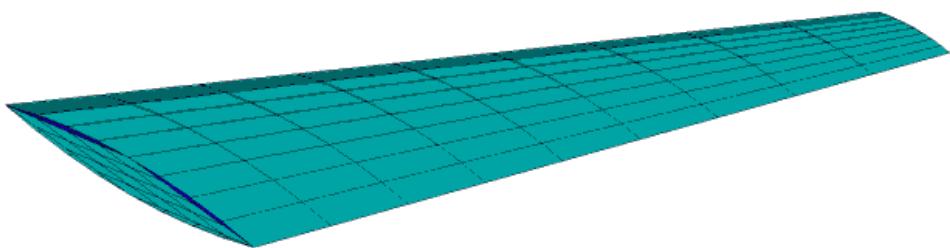
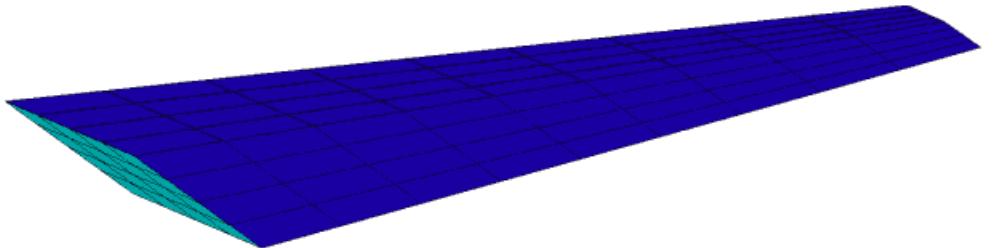
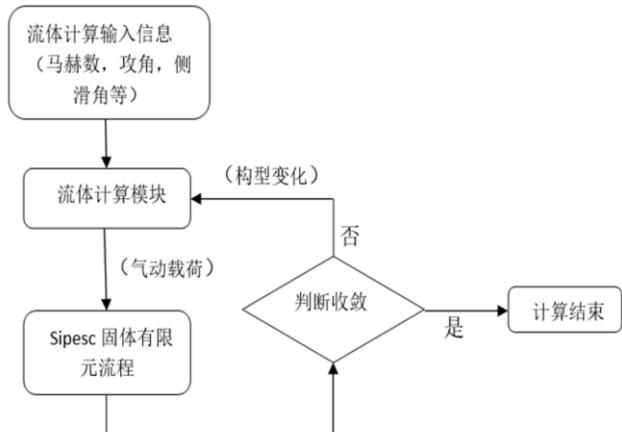


无人机数字孪生软件平台

数值仿真软件SiPESC-定制与集成

- PanAir高阶面元法计算程序的集成
- 面元与结构载荷的计算结果映射

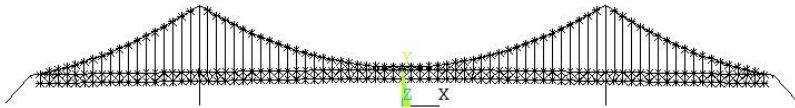
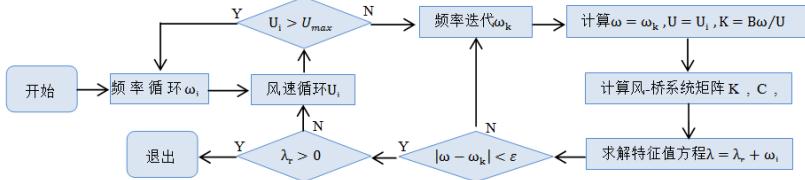
SiPESC与PanAir的耦合分析过程



数值仿真软件SiPESC-定制与集成

- 桥梁结构气动耦合分析
- 非对称矩阵特征值分析

- 结构湿模态分析
- 边界积分计算模块



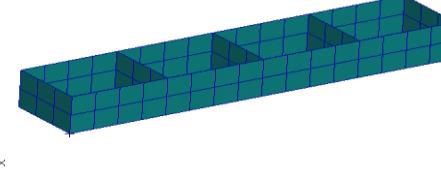
风速	迭代频率阶	SiPESC结果		Ansys结果	
		实部符号	频率	实部符号	频率
57	7	-	0.269	-	0.26978
60	7	-	0.269	-	0.26982
63	7	-	0.269	-	0.26987
66	7	+	0.269	-	0.26991
69	7	+	0.269002	+	0.26996
72	7	+	0.269001	+	0.27001
75	7	+	0.269001	+	0.27007
78	7	+	0.269	+	0.270107
时间		74.6s (单线程)		40s左右 (双线程)	

$$\begin{aligned}\nabla^2 \phi &= 0 & \forall x \in V \\ \frac{\partial \phi}{\partial n} &= \vec{u} \cdot \vec{n} & \forall x \in S \\ \nabla \phi &= 0 & \text{in } \infty\end{aligned}$$

$$T_f = \frac{1}{2} \rho \iiint_V u \cdot u dV = \frac{1}{2} \rho \iiint_V (\nabla \phi \cdot \nabla \phi) dV$$

$$T_f = \frac{1}{2} \rho \iint_S \phi \frac{\partial \phi}{\partial n} dS$$

关键速度势和速度势梯度计算

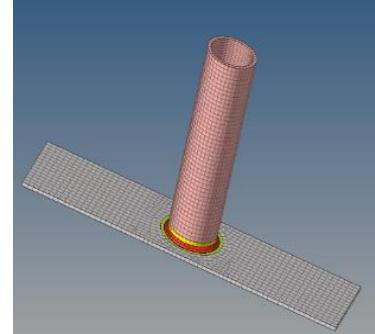
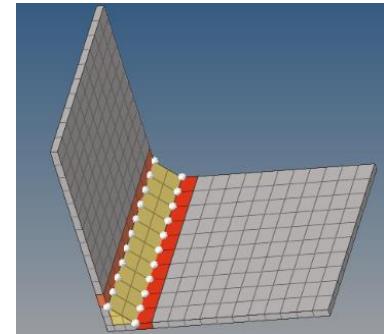
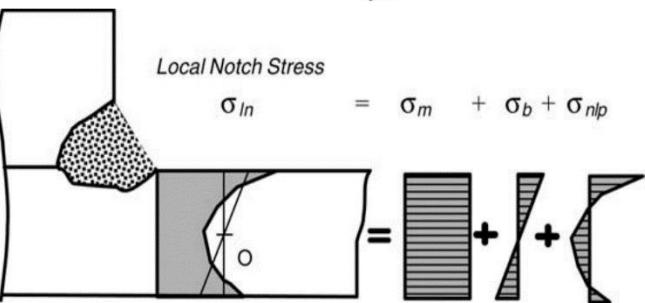
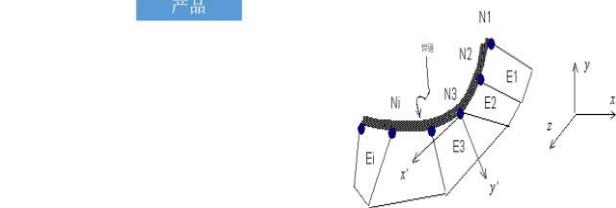
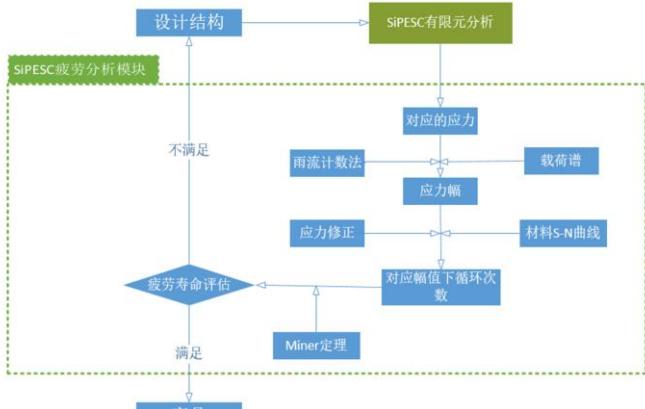


阶数	Natranc			SiPESC		
	干模态	湿模态	频率降低 %	干模态	湿模态	频率降低 %
1	0.239	0.178	25.5	0.238	0.184	22.6
2	1.388	0.832	40	1.382	0.823	40.5
3	1.458	0.842	42.2	1.448	0.848	41.5
4	1.572	1.26	19.8	1.544	1.159	24.9
5	1.615	1.335	17.3	1.592	1.263	20.7
6	1.65	1.362	17.4	1.615	1.316	18.6
7	1.822	1.382	24.1	1.775	1.33	25
8	1.976	1.423	28	1.93	1.367	29.2
9	2.207	1.49	32.5	2.138	1.389	35
10	2.296	1.631	29	2.187	1.535	29.8

数值仿真软件SiPESC-定制与集成

- 结构疲劳分析功能集成
- 焊接结构的结构应力方法

- 与材料疲劳分析方法的集成
- 疲劳分析与结构有限元的集成



节点号	Normal-结构应力			Normal-疲劳寿命		
	SiPESC	FE-SAFE	相对误差	SiPESC	FE-SAFE	相对误差
1384	52.7317	52.7317	0.0000%	4.9413	4.9413	0.0000%
1383	30.5889	30.5889	0.0000%	5.7426	5.7426	0.0000%
1382	27.0987	27.0987	0.0000%	5.9863	5.9863	0.0000%
1381	1.81935	1.81935	0.0000%	8	8	0.0000%
1380	31.2658	31.2658	0.0000%	5.7802	5.7802	0.0000%
1379	66.5424	66.5424	0.0000%	4.7323	4.7323	0.0000%
1378	107.706	107.706	0.0000%	4.0742	4.0742	0.0000%
1377	154.513	154.513	0.0000%	3.5852	3.5852	0.0000%
1376	208.164	208.164	0.0000%	3.1755	3.1755	0.0000%
1375	272.359	272.359	0.0000%	2.8109	2.8109	0.0000%
1374	377.003	377.003	0.0000%	2.3595	2.3595	0.0000%

节点号	Shear-结构应力			Shear-疲劳寿命		
	SiPESC	FE-SAFE	相对误差	SiPESC	FE-SAFE	相对误差
1384	200.209	205.209	0.0000%	5.3292	5.3292	0.0000%
1383	57.52	57.52	0.0000%	8	8	0.0000%
1382	46.137	46.137	0.0000%	5.8693	5.8693	0.0000%
1381	34.0136	34.0136	0.0000%	6.285	6.285	0.0000%
1380	42.7587	42.7587	0.0000%	6.3895	6.3895	0.0000%
1379	44.0437	44.0437	0.0000%	6.5956	6.5956	0.0000%
1378	45.1087	45.1087	0.0000%	6.9248	6.9248	0.0000%
1377	43.1901	43.1901	0.0000%	7.5014	7.5014	0.0000%
1376	39.9986	39.9986	0.0000%	8	8	0.0000%
1375	29.6875	29.6875	0.0000%	8	8	0.0000%
1374	24.3159	24.3159	0.0000%	8	8	0.0000%

注: (1)此疲劳寿命以10的对数结果表示(即1e0)。
 (2)材料类型为Steel, 取置信度为3-曲线参数。
 (3)剪切对比结果为fe-safe verify结果, 法向与切向结构应力对疲劳寿命的影响不同, 采用的s-N曲线算法不同。

节点号	Normal-结构应力			Shear-结构应力		
	SiPESC	FE-SAFE	相对误差	SiPESC	FE-SAFE	相对误差
33	200.2487	200.2491	0.0002%	23.59653	23.59648	-0.0004%
32	155.071	155.0707	-0.0002%	45.46363	45.46364	0.0000%
31	82.54615	82.54629	0.0002%	65.33908	65.33901	-0.0001%
30	5.682361	5.682366	0.0043%	74.00738	74.00728	-0.0001%
29	105.4133	105.413	-0.0003%	77.83203	77.83218	0.0002%
28	210.9785	210.9782	-0.0001%	66.79602	66.79591	-0.0002%
27	286.7476	286.748	0.0001%	49.15542	49.1553	-0.0002%
26	343.6764	343.6761	-0.0001%	22.60599	22.6062	0.0000%
25	362.296	362.2956	-0.0001%	9.297657	9.297797	0.0015%
24	342.1603	342.16	-0.0001%	32.44569	32.4456	-0.0003%
23	275.9373	275.9359	-0.0001%	50.95314	50.95319	0.0001%
22	198.7562	198.7565	0.0002%	53.74669	53.74675	0.0001%
21	104.5697	104.5693	-0.0004%	56.52647	56.52647	0.0000%
20	44.02501	44.02491	-0.0002%	31.43146	31.43163	0.0005%
19	13.9904	13.99911	0.0004%	12.24289	12.24278	-0.0010%
18	32.50671	32.50674	0.0001%	31.45851	31.45553	0.0000%
17	90.24676	90.24672	0.0000%	59.68652	59.68649	-0.001%
16	196.8182	196.8183	0.0000%	67.9719	67.97189	0.0000%
15	285.6201	285.6201	0.0000%	55.2423	53.24237	0.0001%
14	347.6012	347.6000	-0.0001%	37.30014	37.30003	-0.0003%
13	353.4369	353.4371	0.0001%	12.3575	12.35758	0.0006%
12	365.1507	365.1511	0.0001%	21.41242	21.41235	0.0006%
11	313.5168	313.5167	0.0000%	50.52825	50.52761	-0.0013%
10	122.7969	122.7968	-0.0002%	78.52651	78.52603	-0.0006%
9	14.45617	14.45609	-0.0006%	80.00967	80.00984	0.0002%
8	68.20935	68.20939	0.0000%	68.50116	68.50108	-0.0001%
7	169.9298	169.9293	-0.0003%	49.14882	49.14894	0.0000%

结构应力结果对比

数值仿真软件SiPESC-定制与集成

桥梁监测数据管理模块

- 监测数据云端管理
- 传感器数据分类管理/可视化

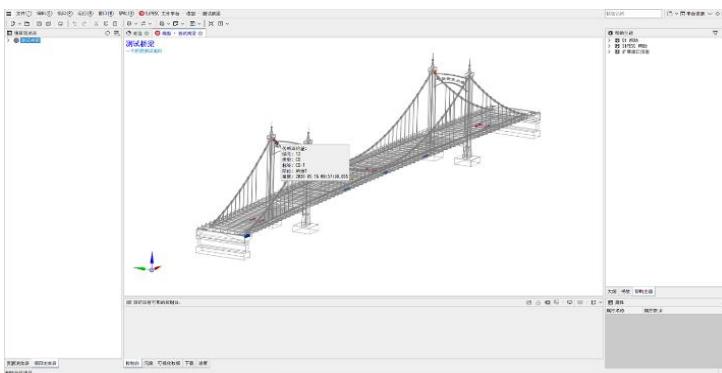
- 桥梁几何模型与监测数据融合 (BIM)
- 桥梁群监测数据管理



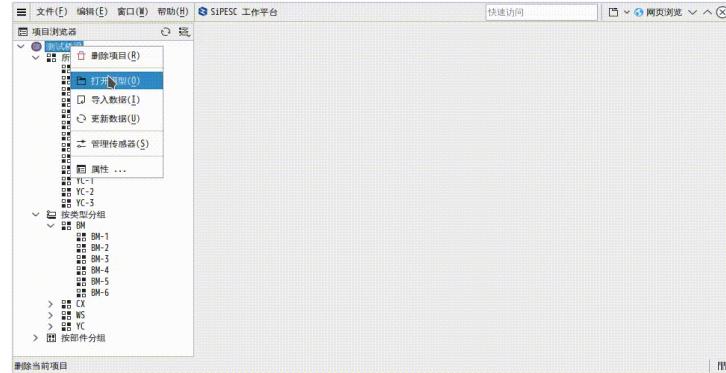
桥梁健康监测软件主界面



桥梁监测数据显示

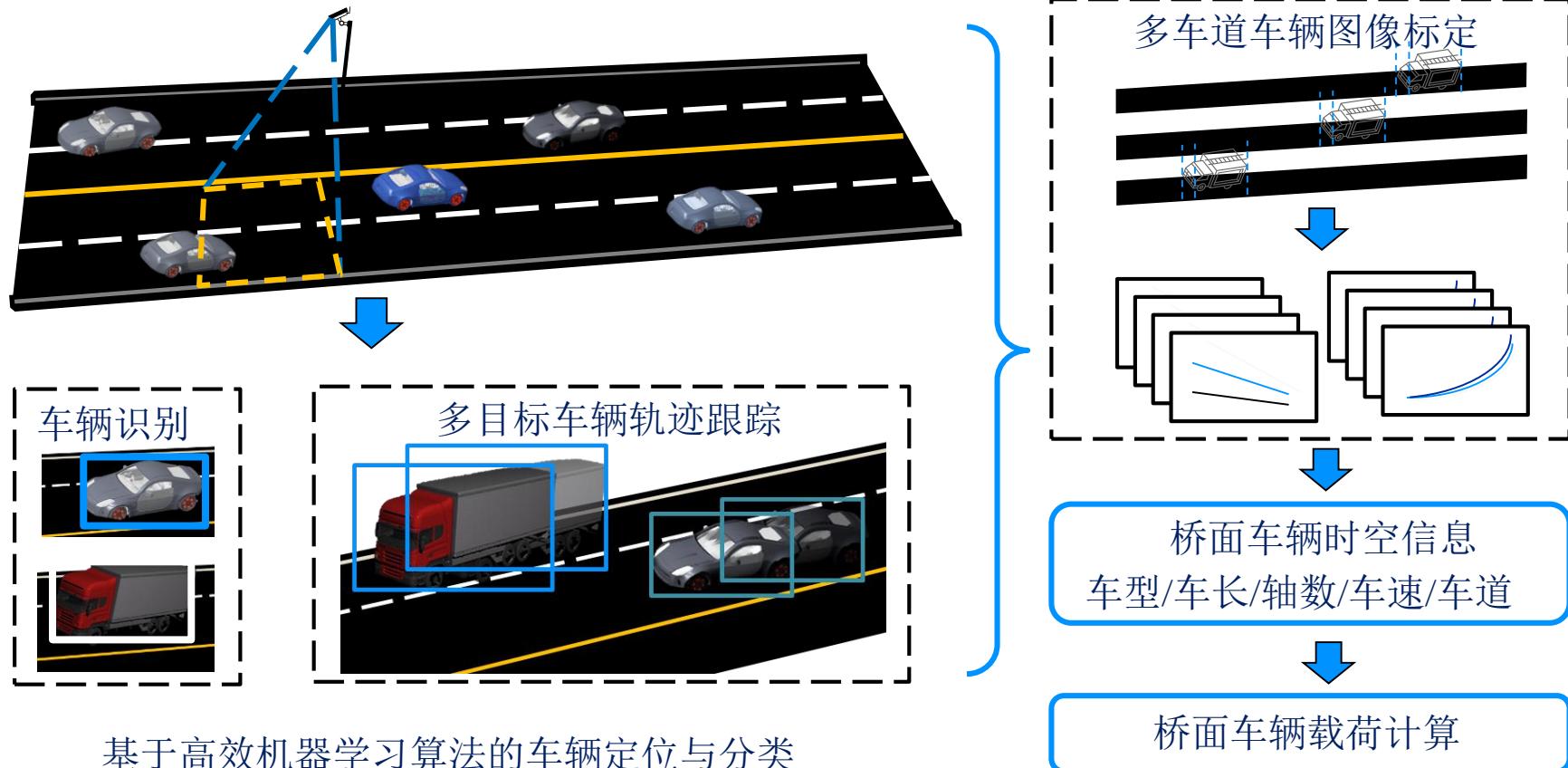


桥梁CAD模型与传感器关联显示



桥梁监测软件操作演示

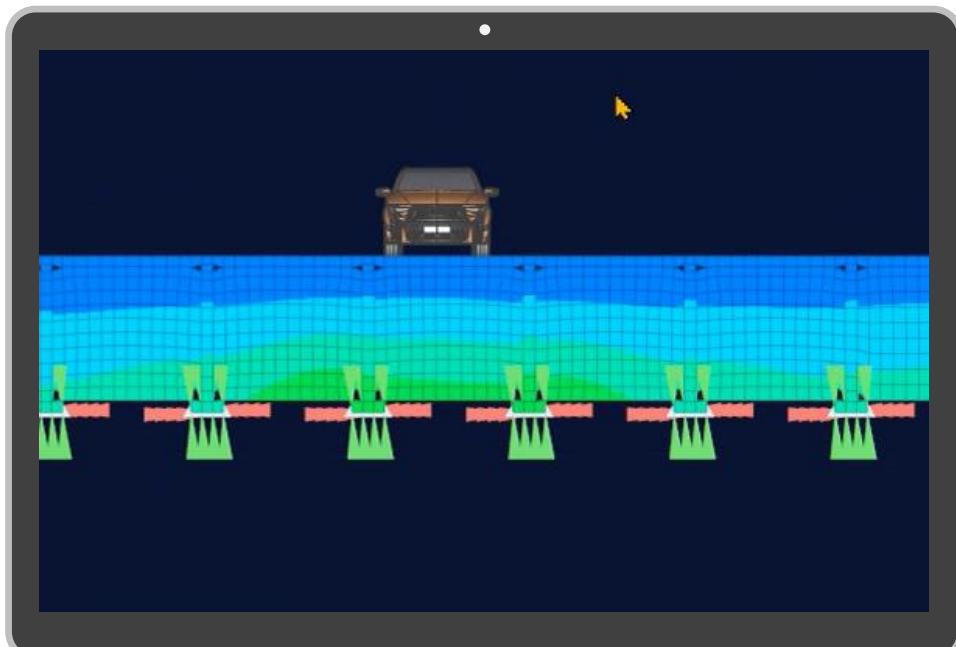
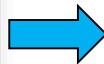
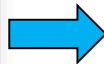
- 基于视频技术与机器学习的载荷识别技术



• SiPESC数字孪生 案例

• 桥梁健康监测系 统

基于视频技术与机器学习的载荷识别技术



车辆识别

有限元实时
计算



动画物体：
门嵌板 50-70 双嵌板铝门 50系列无横档 [272063]:
是否可见: 是
防火门-双扇5 1200 x 2200 mm [266630]:
透明系数: 1

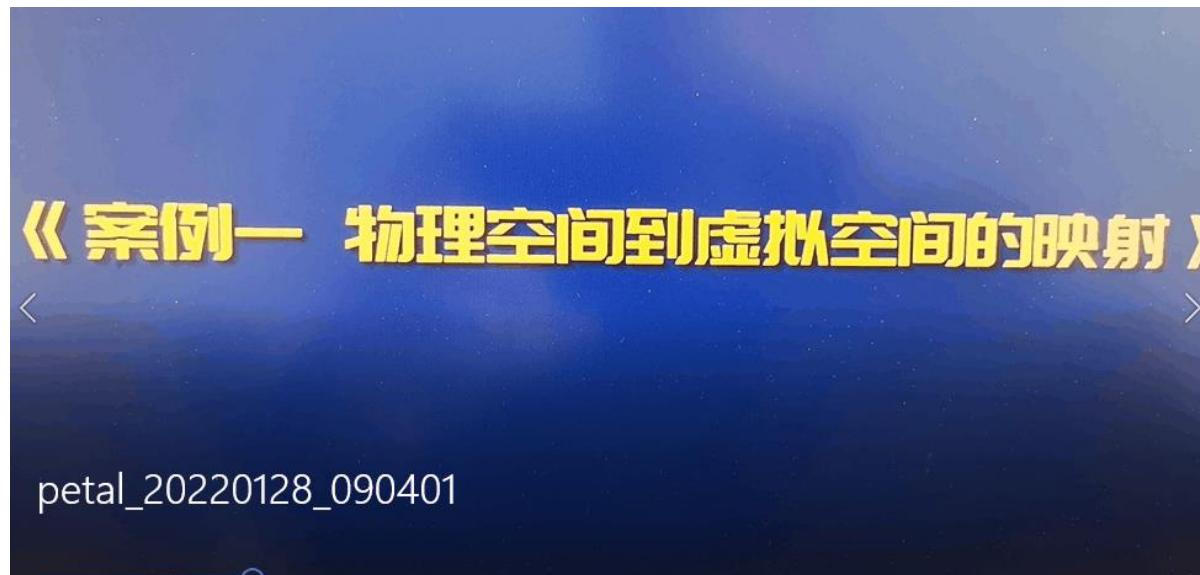




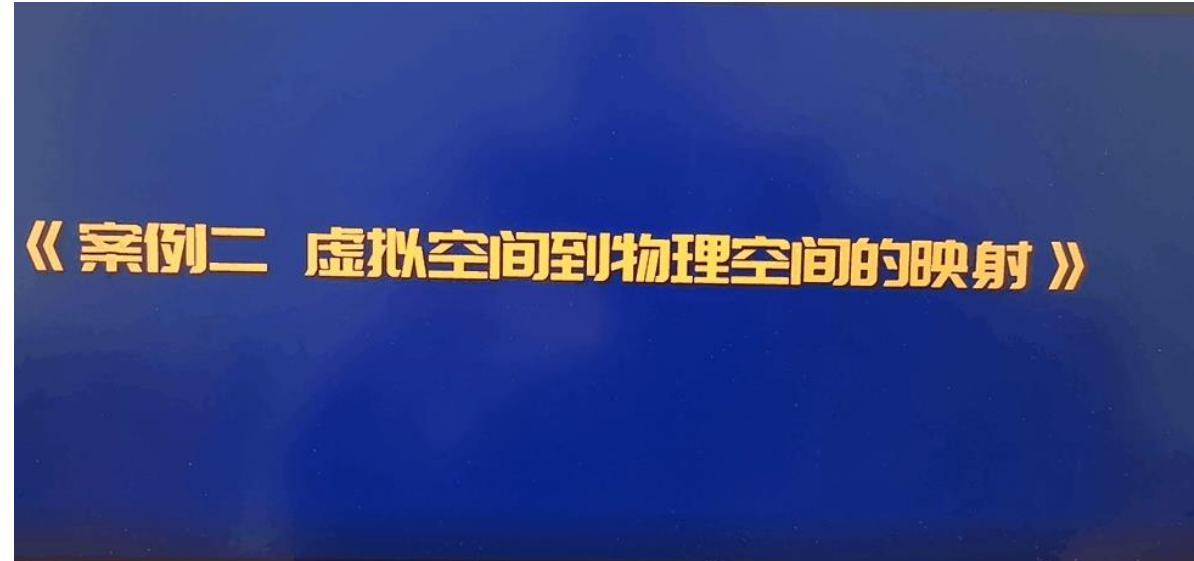
■ 合作方: 核工业工程研究
设计有限公司
www.sipesc.com

■ 溶解液管路吊装

• 柔性臂运动

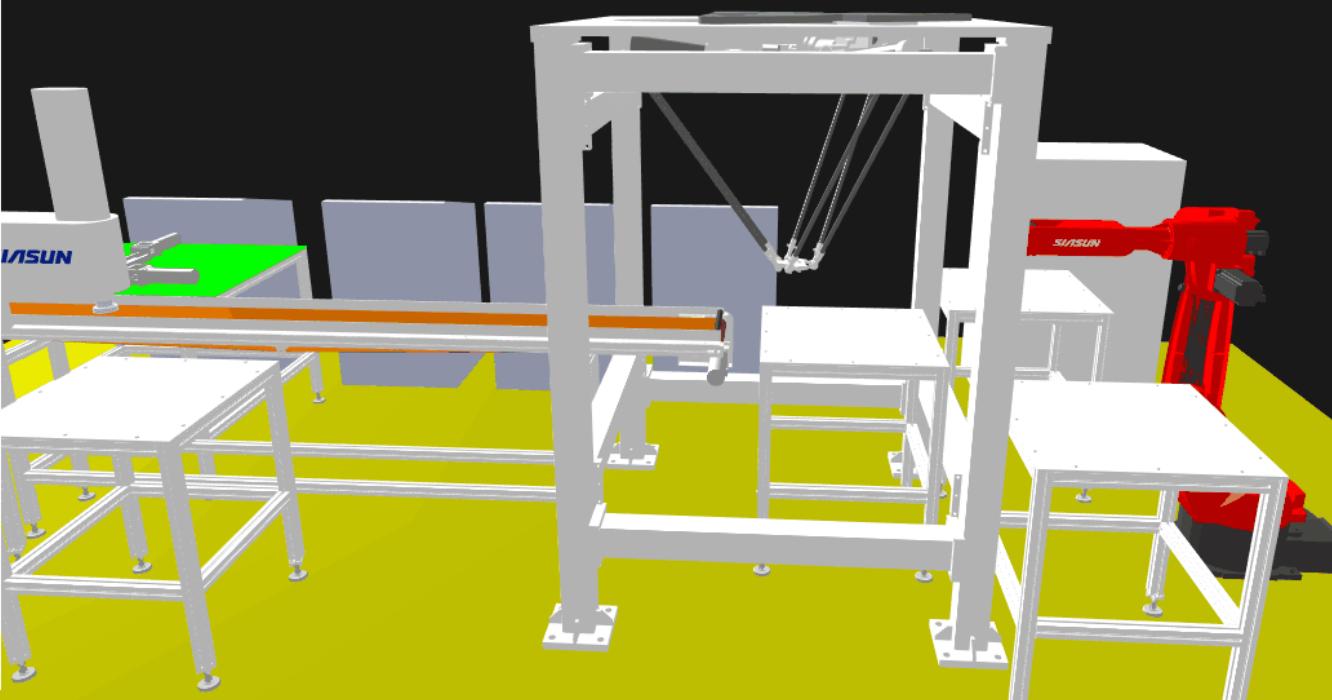


■ 虚拟→物理





动画物体:
Solid:
 旋转角度: 0
 旋转轴向: 0,0,0
SRBT10A-AS1000T-63: 法兰_20:
 中心位置: 129, 63.8, -62.5
吸盘竖臂臂:
 中心位置: 244, -22.5, -94.3
A1:
 旋转角度: 0
 旋转轴向: 0,0,0
大:
 旋转角度: 0
 旋转轴向: 0,0,0
外伸臂:
 旋转角度: 0
 旋转轴向: 0,0,0
12:
 旋转角度: 0
 旋转轴向: 0,0,0
吸盘体:
 中心位置: -64.1, -16.7, -87.8
头部:
 旋转角度: 0
 旋转轴向: 0,0,0
1:
 中心位置: 221, -41.7, -96.7
弯管:
 旋转角度: 0
 旋转轴向: 0,0,0
A3:
 旋转角度: 0
 旋转轴向: 0,0,0
2a:
 旋转角度: 0
 旋转轴向: 0,0,0
A2:
 旋转角度: 0
 旋转轴向: 0,0,0
2:
 中心位置: 244, -31.5, -77.4
a1:
 旋转角度: 0
 旋转轴向: 0,0,0
中:
 旋转角度: 0
 旋转轴向: 0,0,0
3a:
 旋转角度: 0
 旋转轴向: 0,0,0



■数字孪生工厂



汇报结束

谢谢！

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