构建Digital Twin的基石：高保真的系统仿真平台

侯东/ Senior AE

ANSYS

主要内容

- Digital Twin技术要素
- ANSYS高保真系统仿真解决方案
- 总结

Digital Twin技术要素

数字模型与实物之间的关系

Digital Twin的定义

Digital Twin：

某个特定实体产品的数字表示，用于更深入地洞察该产品的状态、性能和行为。

Digital Twin的关键技术

智能机械　　智能制造　　无人驾驶

智能终端

传感器数据
异常情况

应用
校正动作

IoT 平台

试验
校正动作

仿真结果

高保真的系统仿真技术是基础！

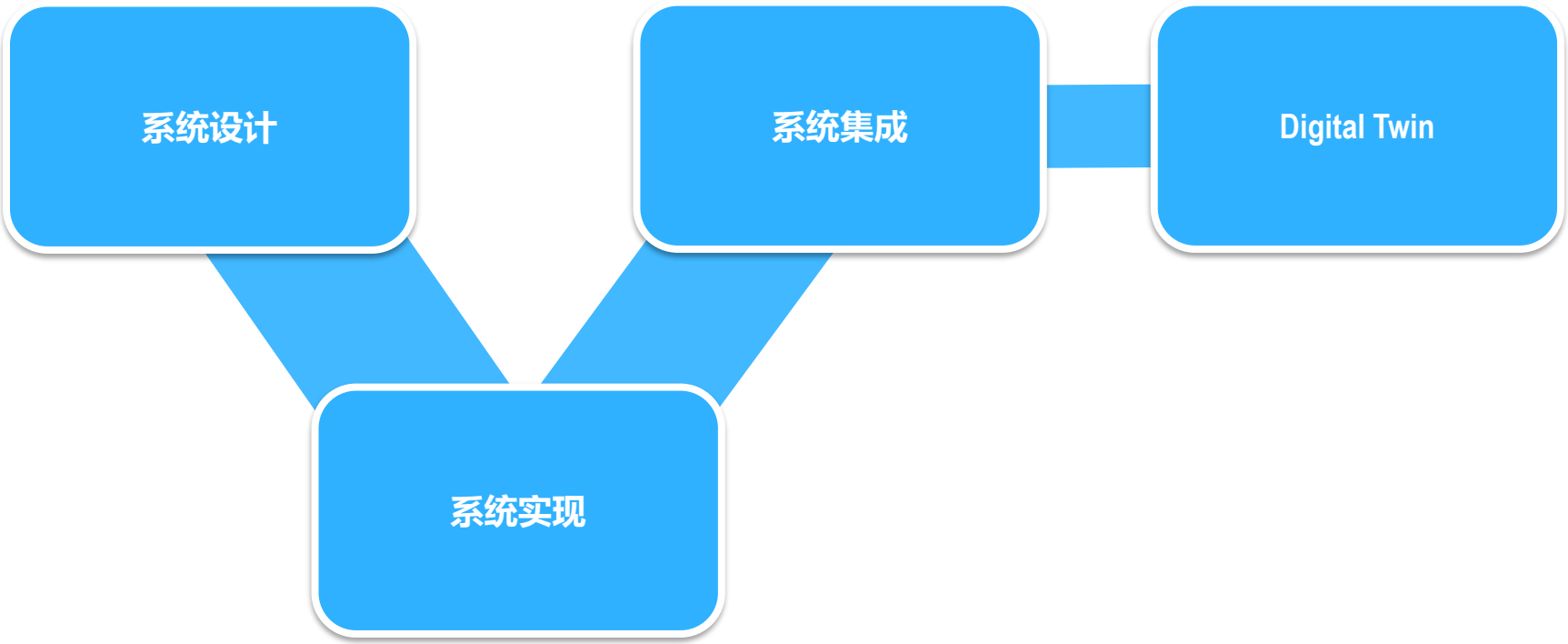
数字孪生

ANSYS云计算平台

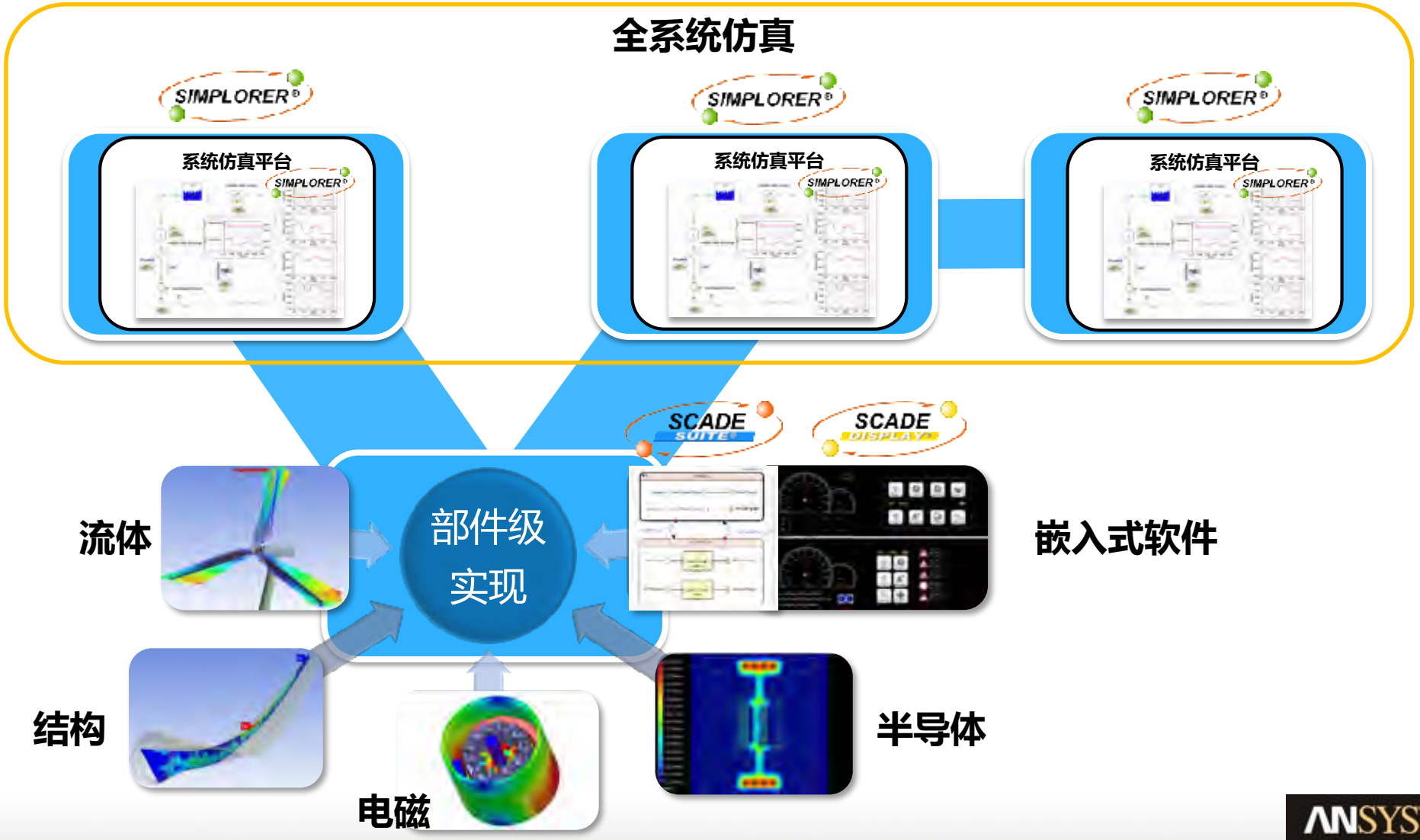
ANSYS高保真系统仿真解决方案

- 方案总览
- 强大的建模能力
- ROM的支持
- FMI的支持
- 案例

产品生命周期

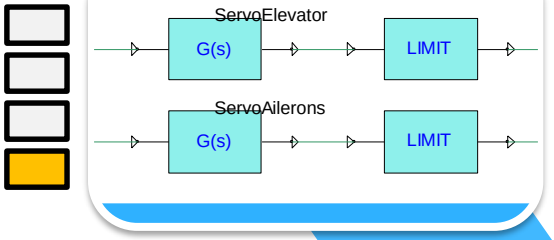


ANSYS的全生命周期仿真支持

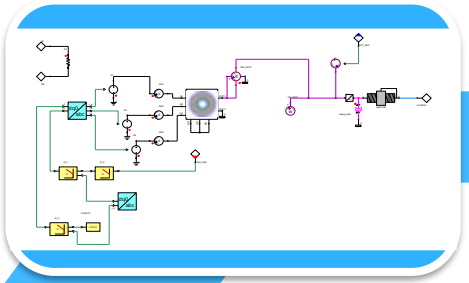


「系统仿真」贯穿整个产品生命周期

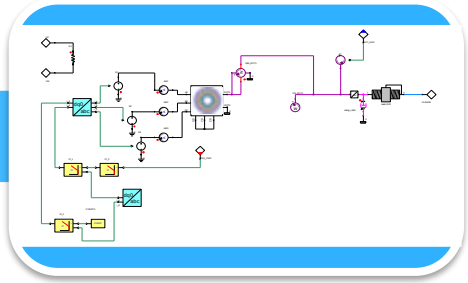
原型探索：理想简化模型



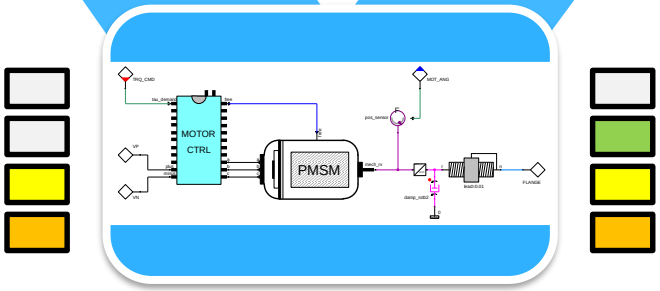
系统虚拟集成：基于ROM的极高保真模型



产品服役：基于ROM的极高保真模型



低保真度



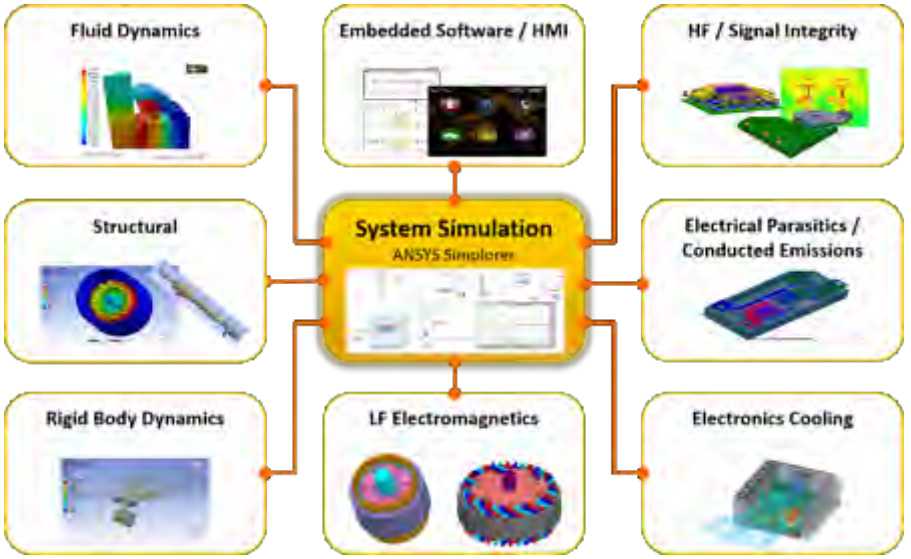
部件开发与测试：行为级中/高保真模型

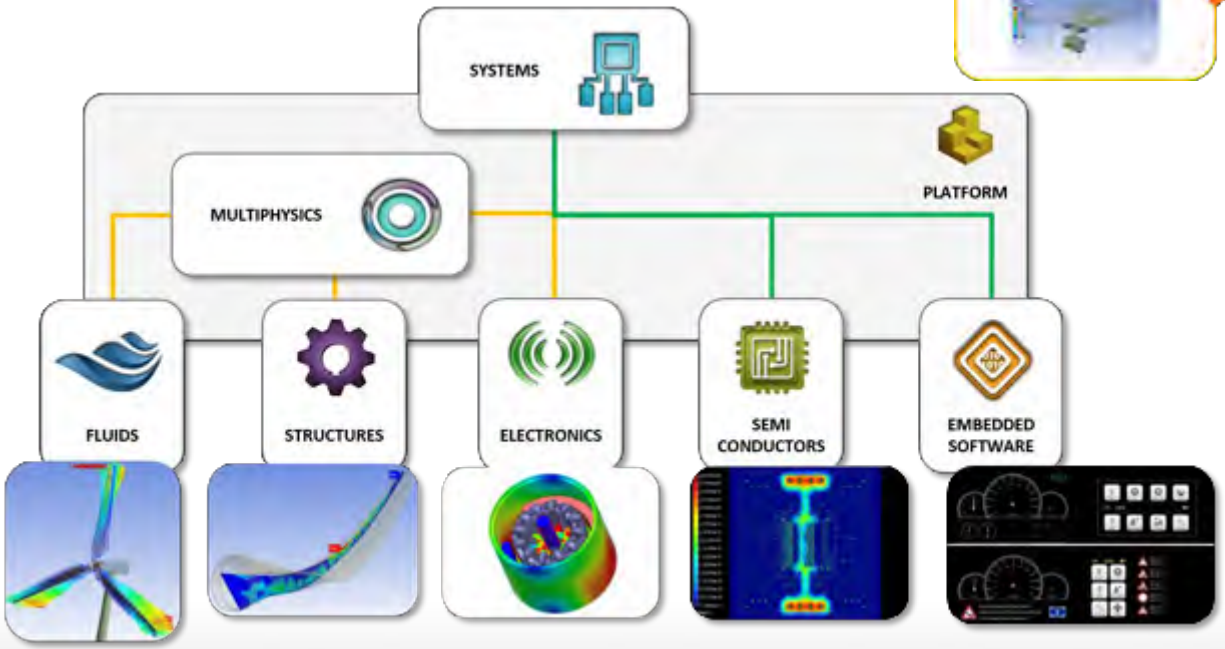
实测数据

实物系统

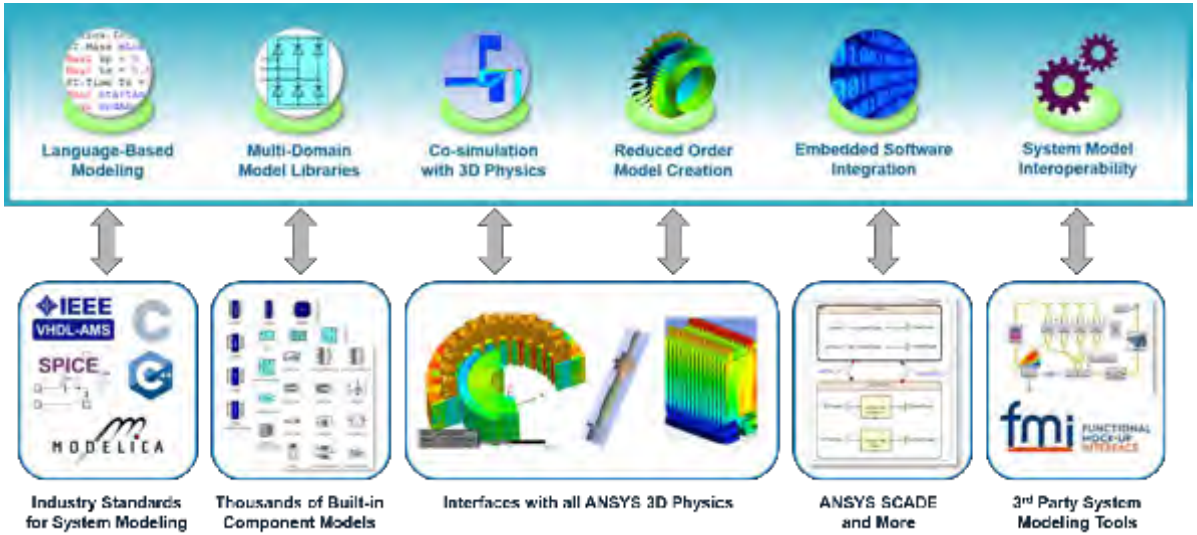
ANSYS系统仿真平台总览

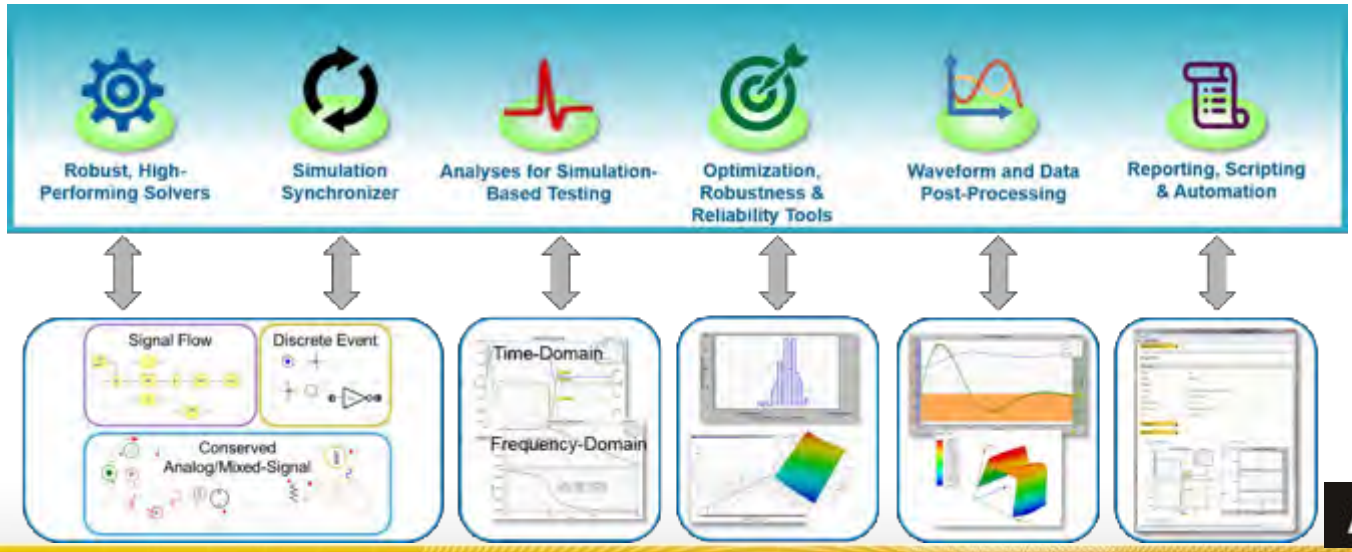
SIMPLORER®





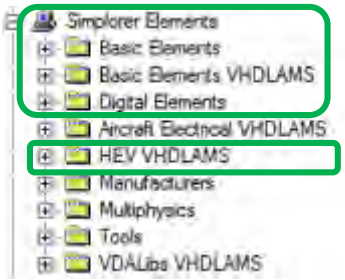
强大的系统建模能力

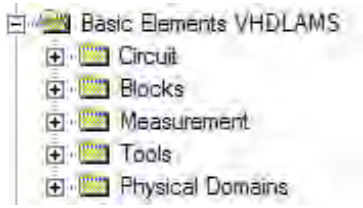

Language-Based Modeling
Multi-Domain Model Libraries
Co-simulation with 3D Physics
Reduced Order Model Creation
Embedded Software Integration
System Model Interoperability
IEEE
VHDL-AMS
SPICE
MODELICA
fmi
Industry Standards for System Modeling
Thousands of Built-in Component Models
Interfaces with all ANSYS 3D Physics
ANSYS SCADE and More
3rd Party System Modeling Tools

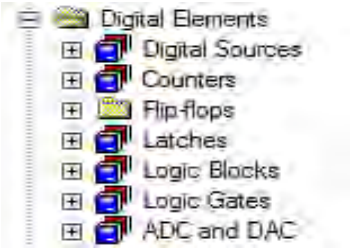

Robust, High-Performing Solvers
Simulation Synchronizer
Analyses for Simulation-Based Testing
Optimization, Robustness & Reliability Tools
Waveform and Data Post-Processing
Reporting, Scripting & Automation
Signal Flow
Discrete Event
Conserved Analog/Mixed-Signal
Time-Domain
Frequency-Domain

建模语言的支持

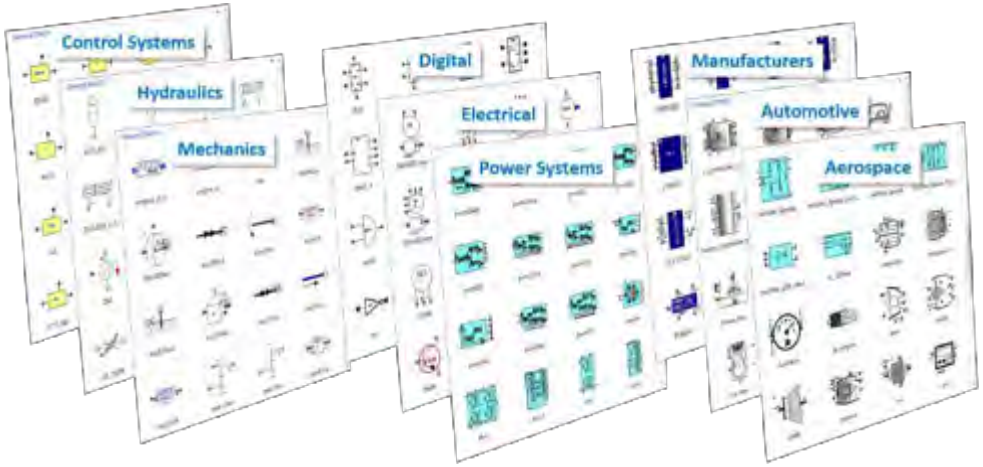
VHDL-AMS模型库





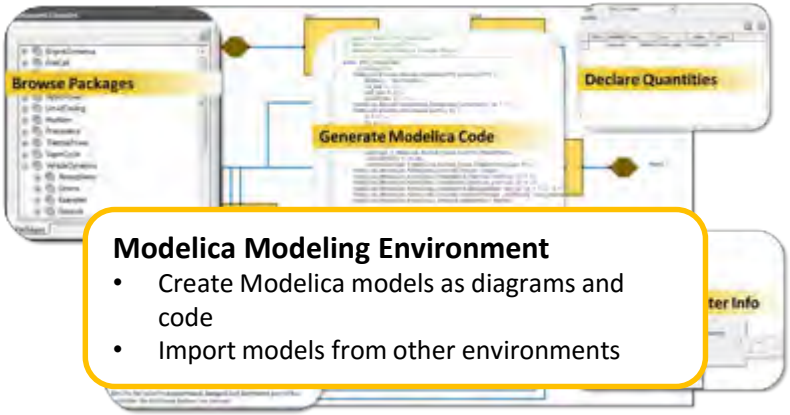


- Totally 9 libraries with 1700+ models.
- 700+ VHDL-AMS models
- Nearly 1000 demonstrative examples, with daily regression test.
- Nearly 150 basic components
  - Circuit & Physical Domains (like mechanical, thermal, fluidic and magnetic).
  - Blocks (continuous, discrete, sources, signal processing, math blocks)
  - Measurement, all the meters cover all the physical domains include circuits.
  - Tools, time function sources.
- Nearly 50 digital components
  - Digital sources, counters, logic blocks, logic gates and so on.



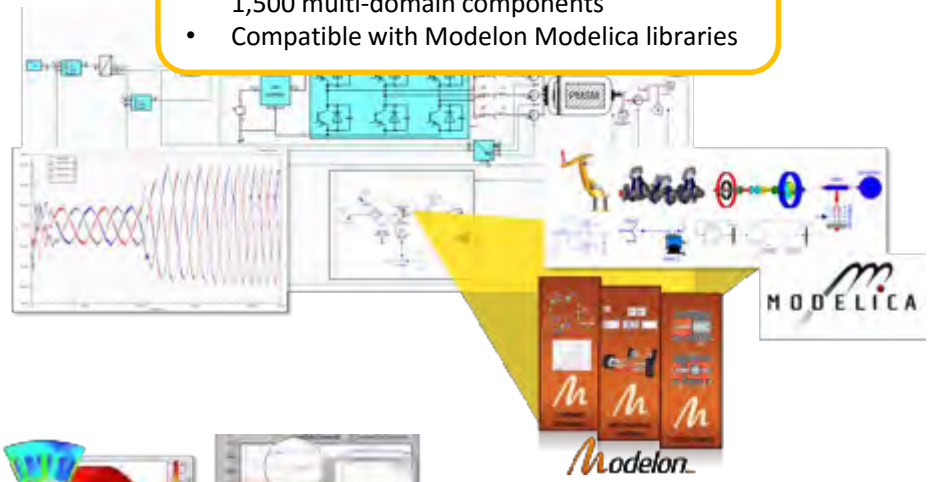
VHDL-AMS Model Libraries for Multi-Domain Systems

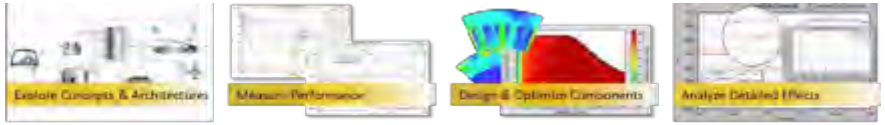
Simplorer对Modelica的支持



Modelica Modeling Environment
- Create Modelica models as diagrams and code
- Import models from other environments

Access to Modelica Libraries
- Modelica Standard Library built in – over 1,500 multi-domain components
- Compatible with Modelon Modelica libraries

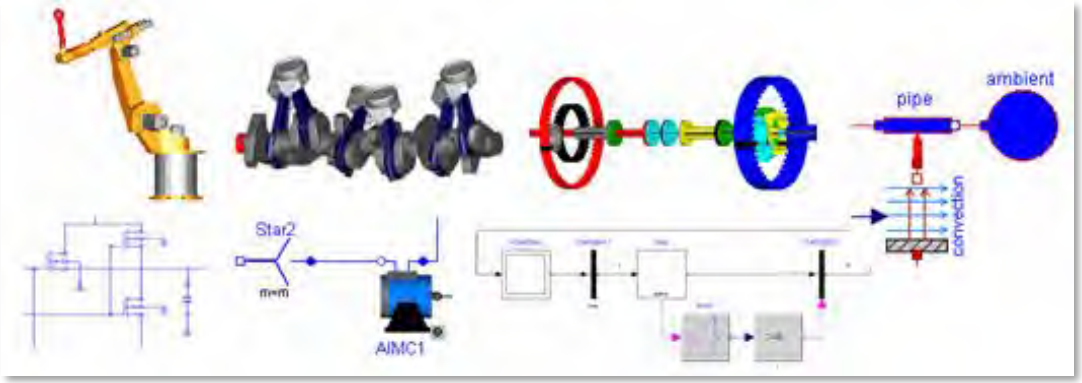


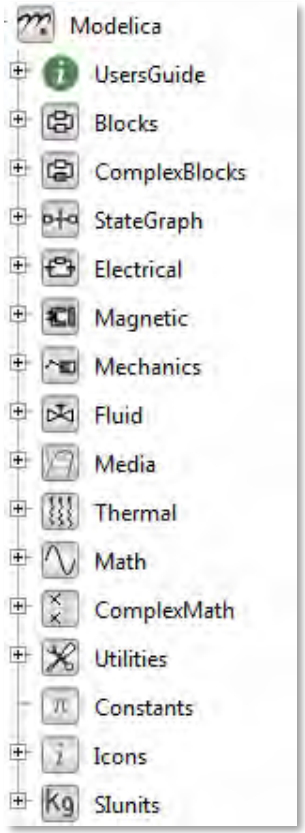


Simulate & Analyze Modelica with Simplorer

Access to Simplorer's Powerful Simulation Environment
- Time-domain studies through sophisticated statistical and optimization experiments

Modelica标准库



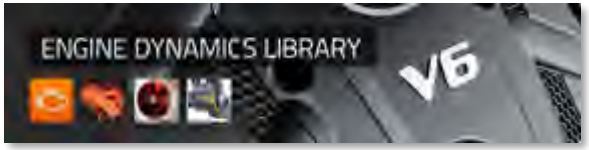


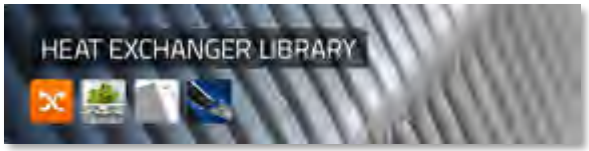
The **Modelica Standard Library (MSL)** is a **free library** from the Modelica Association with **over 1,500 components** for modeling mechanical, electrical, thermal, fluid, and control systems.

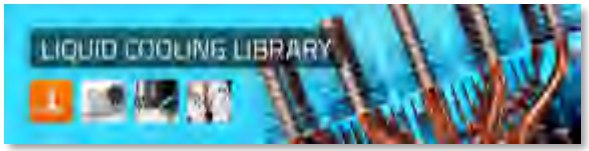
In Simplorer:

- MSL included with installation
- Create diagrams from MSL models
- Import subsystems built with MSL models

Modelon库







In Simplorer:

- Create diagrams from supported Modelon libraries
- Import subsystems built with Modelon models

* Modelon libraries are provided by Modelon AB / Inc.

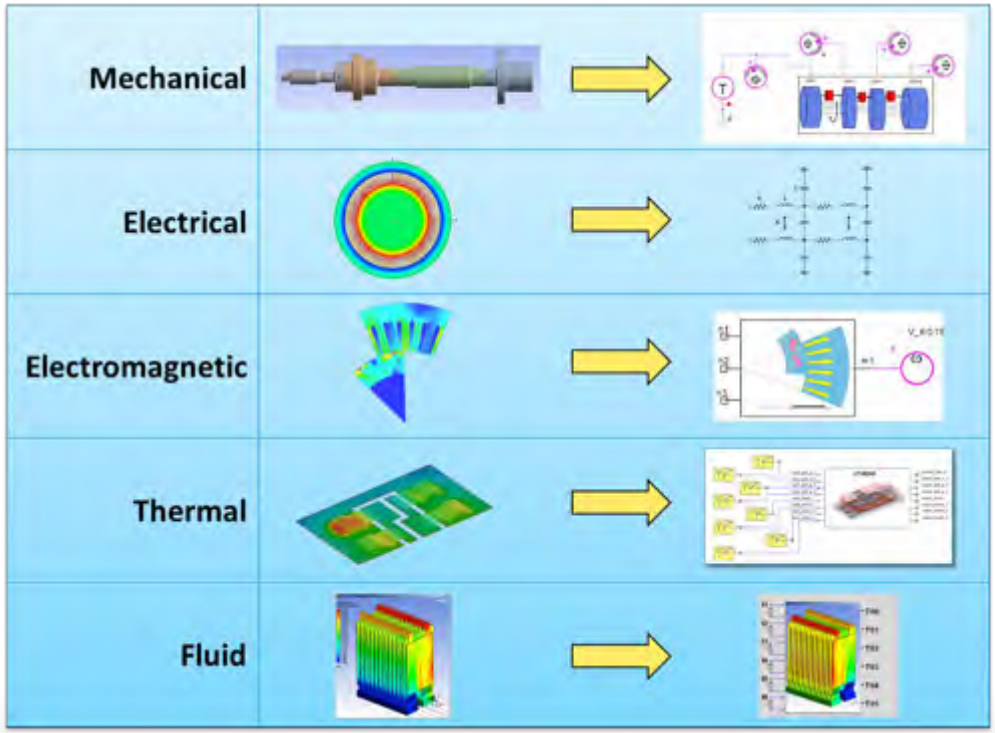
ROM——降阶模型

A Reduced Order Model (ROM) is a simplification of a high-fidelity dynamical model that preserves essential behavior and dominant effects, for the purpose of reducing solution time or storage capacity required for the more complex model.

3D详细模型

计算时间：小时级别

计算资源：HPC集群

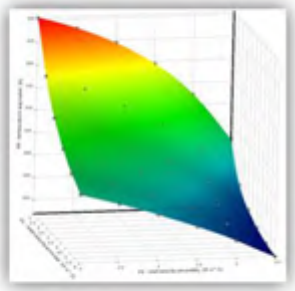
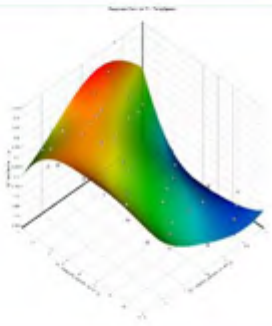
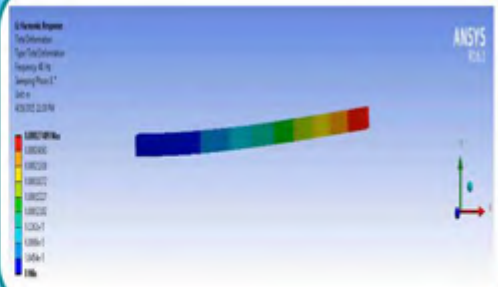
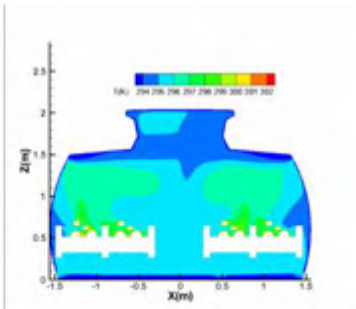


降阶模型

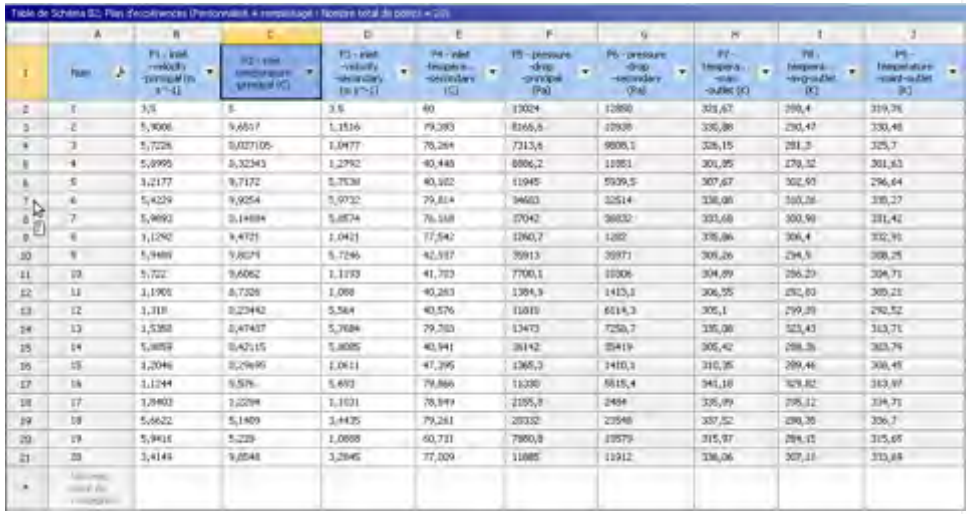
计算时间：秒级别

计算资源：PC机

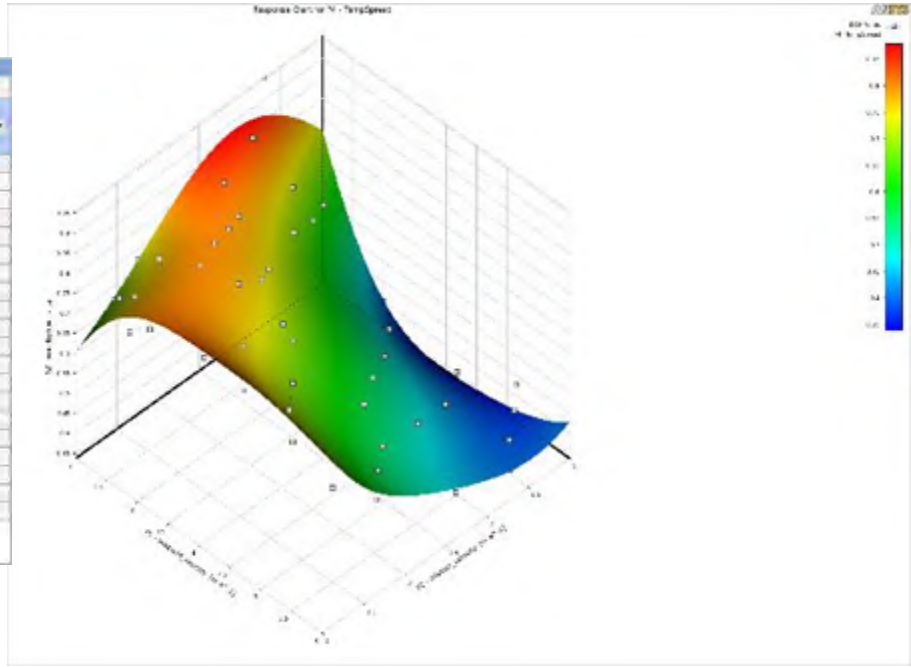
ROM类型

	Linear	Nonlinear
Static		
Transient		

静态ROM——响应面法

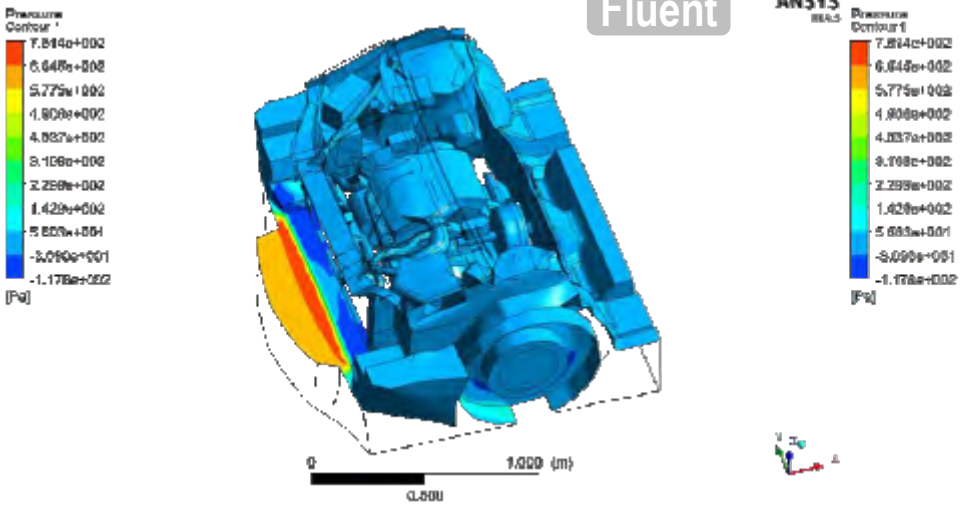


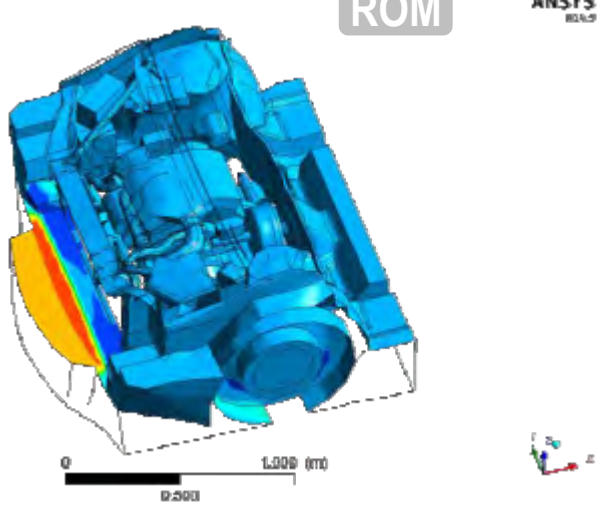
	A	B	C	D	E	F	G	H	I	J
1	Nom	P1 - inlet velocity - principal (m s^-1)	P2 - inlet temperature - principal (C)	P3 - inlet velocity - secondary (m s^-1)	P4 - inlet temperature - secondary (C)	P5 - pressure drop - principal (Pa)	P6 - pressure drop - secondary (Pa)	P7 - temperature - max - outlet (K)	P8 - temperature - avg - outlet (K)	P9 - temperature - coeff - outlet (K)
2	1	3,5	5	3,5	40	13024	12880	321,67	299,4	319,76
3	2	5,3006	9,6517	1,1516	79,283	8166,6	10939	335,88	290,47	330,48
4	3	5,7226	0,027105	1,0477	78,264	7313,6	9808,1	326,15	281,3	325,7
5	4	5,0995	0,32343	1,2792	40,448	8806,2	11051	301,85	279,32	301,63
6	5	3,2177	9,7172	5,7538	40,102	11945	5939,5	307,67	302,93	296,64
7	6	5,4229	9,9054	5,9732	79,814	34603	32514	338,08	310,26	330,27
8	7	5,9692	0,14884	5,8574	76,168	37042	36832	333,68	300,99	331,42
9	8	3,1292	9,4721	1,0421	77,542	1260,7	1282	335,86	306,4	332,91
10	9	5,9488	9,8079	5,7246	42,337	35913	35971	309,26	294,5	308,25
11	10	5,722	9,6062	1,1193	41,703	7700,1	10306	304,89	286,23	304,71
12	11	3,1901	0,7326	1,088	40,263	1384,9	1415,1	306,55	292,83	305,23
13	12	3,318	0,23442	5,584	40,576	11819	6114,3	305,1	299,39	292,52
14	13	3,5358	0,47437	5,7684	79,503	13473	7258,7	335,08	323,43	313,71
15	14	5,9859	0,42115	5,8085	40,941	36142	35419	305,42	288,36	303,74
16	15	3,2046	0,29699	1,0411	47,295	1365,3	1410,1	310,35	289,46	308,45
17	16	3,1244	9,576	5,693	79,866	11330	6815,4	341,18	329,82	313,97
18	17	3,2403	3,2298	1,1031	78,349	2185,8	2484	335,09	295,12	334,71
19	18	5,6622	5,1409	3,4435	79,261	28332	23548	337,52	298,36	336,7
20	19	5,9416	5,229	1,0898	60,731	7860,8	10579	315,97	284,15	315,65
21	20	3,4144	9,8548	3,2845	77,009	11685	11912	336,06	307,11	333,88
*										



- The values of output parameters as a function of input parameters are obtained on the design points defined in the design of experiments
- Interpolation methods are essential to the model

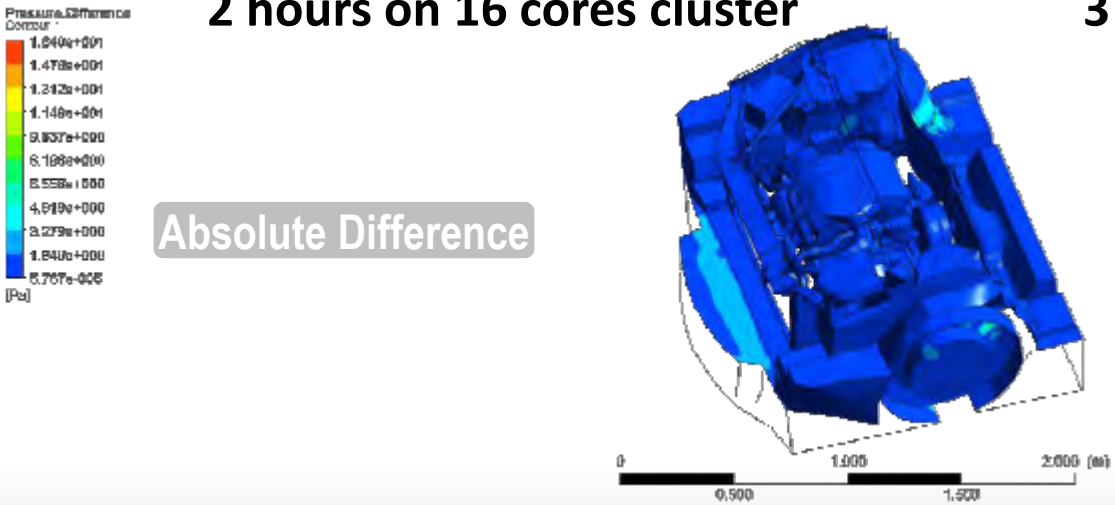
静态ROM的保真度





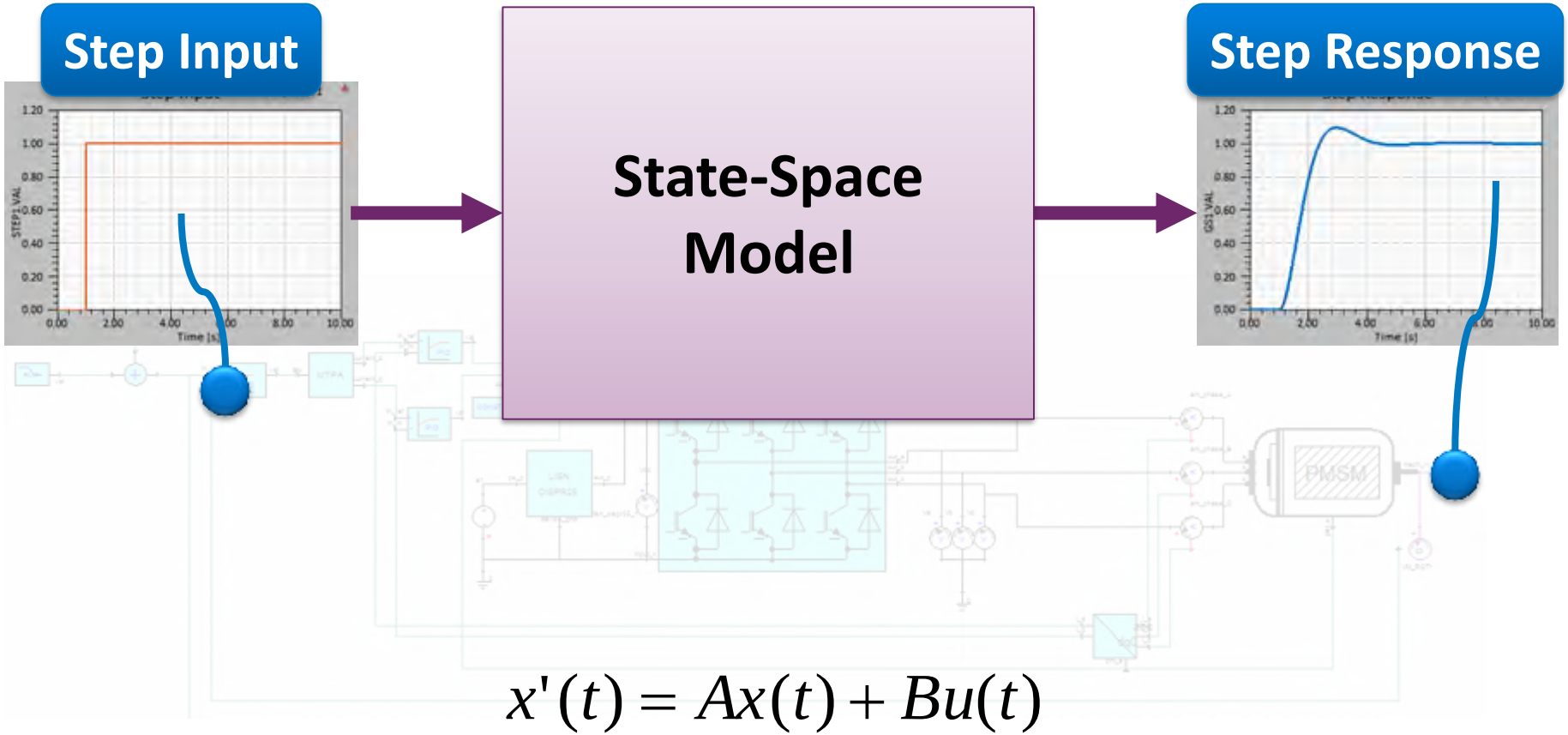
2 hours on 16 cores cluster

3 seconds on this laptop



Max difference: 1.2%

线性动态ROM——状态空间方法



$$x'(t) = Ax(t) + Bu(t)$$

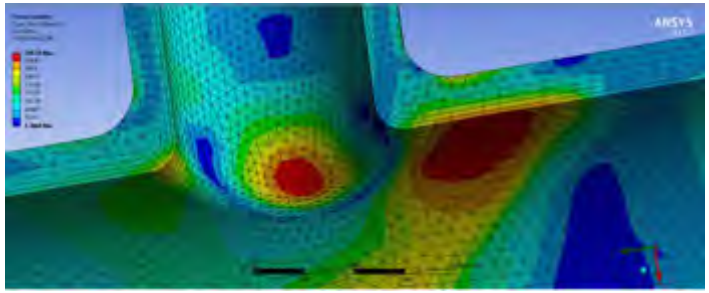
$$y(t) = Cx(t) + Du(t)$$

非线性动态ROM——机器学习+神经网络

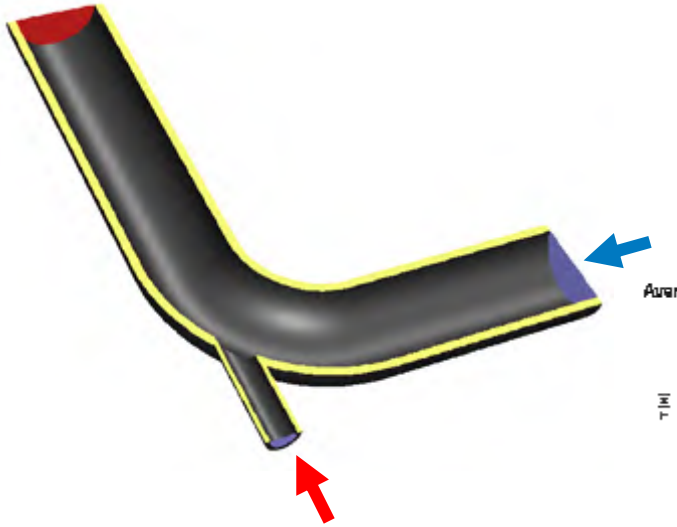
- Many classes of problems are intrinsically non-linear
- Again, the goal is often to simulate dynamic response to an arbitrary input signal in real-time or quasi real-time
- The following techniques for creating ROMs for non-linear systems are:
  - Projection methods on subspaces: SVD
  - Machine learning (Deep Learning): Recursive Neural Networks (RNN)

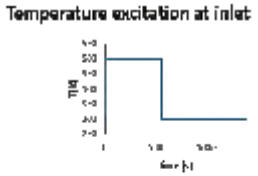
Applications

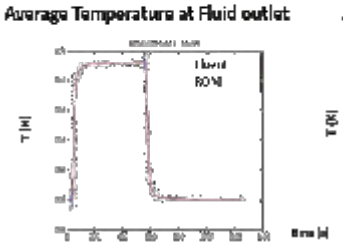
- Fluid flows
- Mechanical vibrations, stress and fatigue analysis
- …

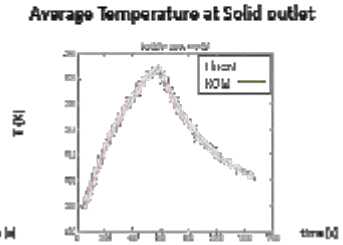


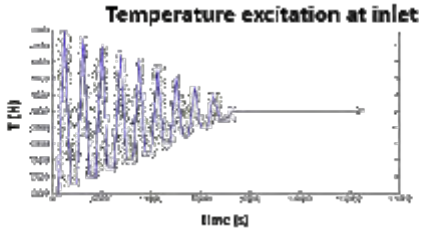
动态非线性ROM的保证度

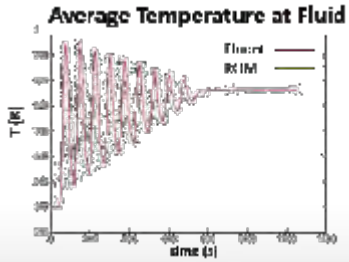


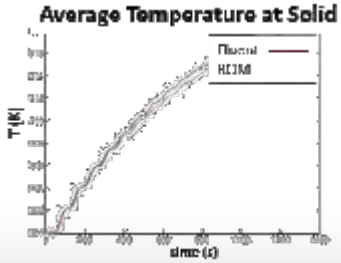










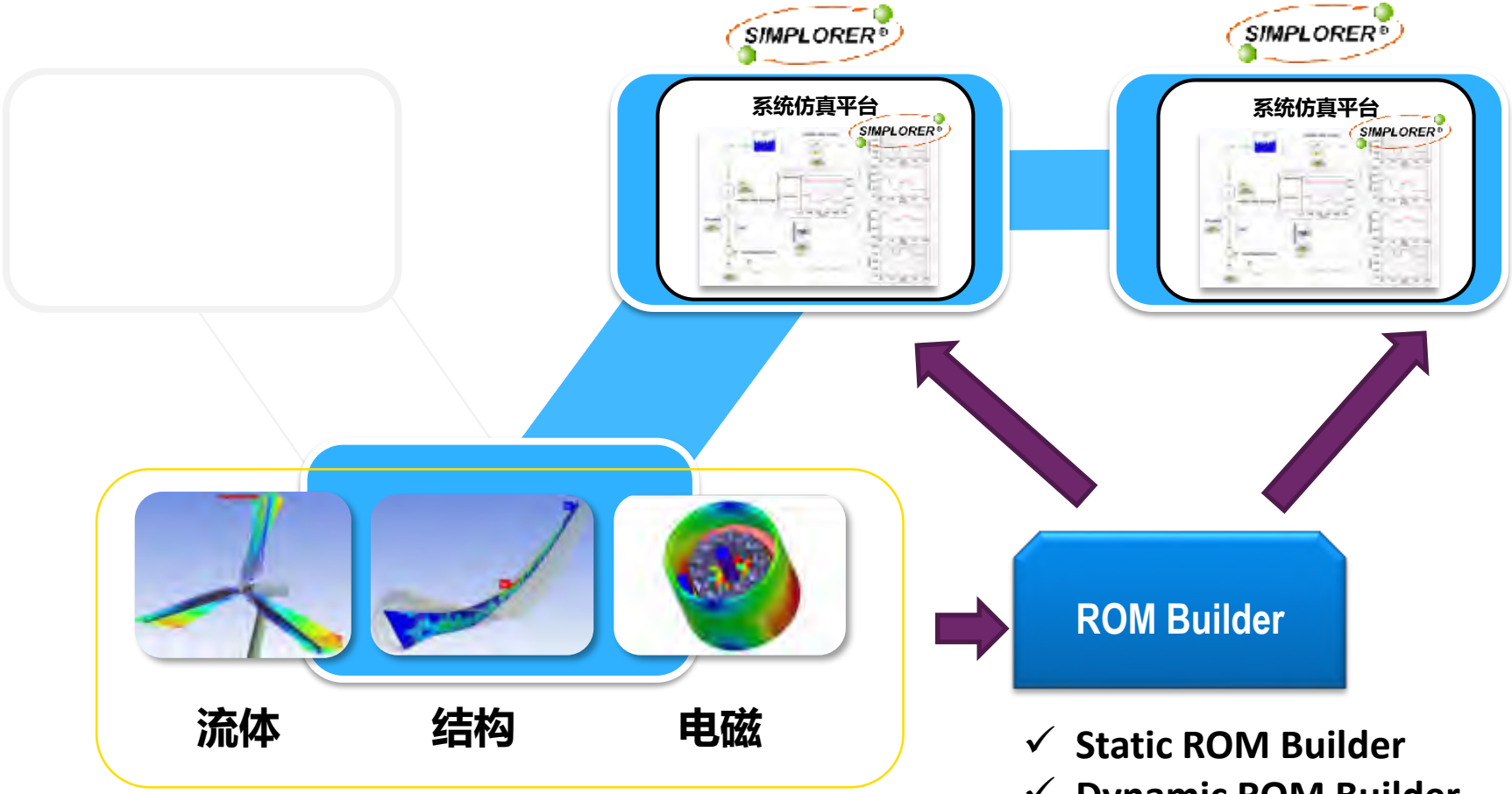


Fluent

Temperature Field (°C)

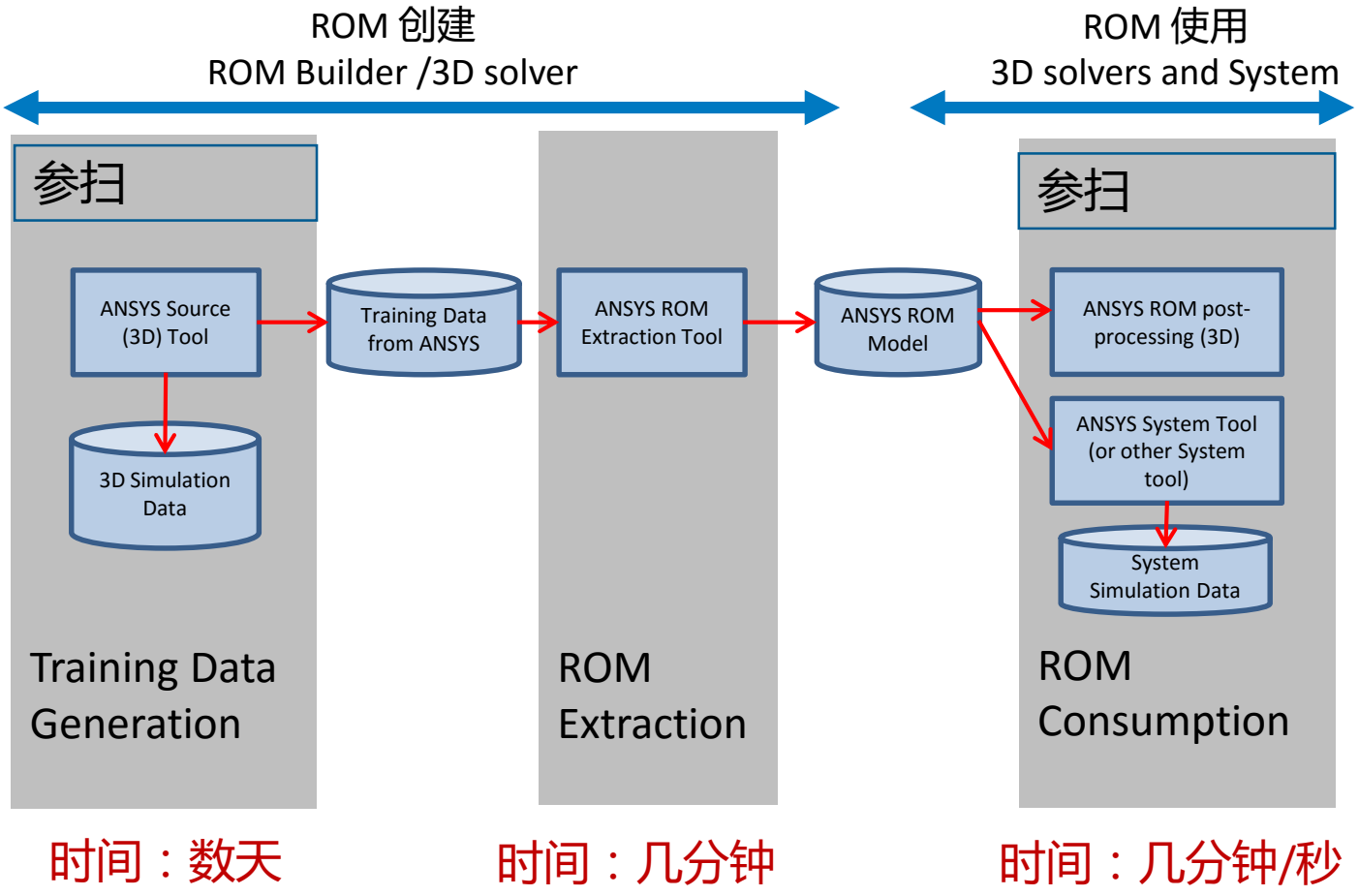
ROM

ROM的生成 (1/3)



- ✓ Static ROM Builder
- ✓ Dynamic ROM Builder

ROM的生成 (2/3)


ROM 创建
ROM Builder /3D solver
ROM 使用
3D solvers and System
参扫
ANSYS Source (3D) Tool
3D Simulation Data
Training Data from ANSYS
Training Data Generation
ANSYS ROM Extraction Tool
ROM Extraction
ANSYS ROM Model
参扫
ANSYS ROM post-processing (3D)
ANSYS System Tool (or other System tool)
System Simulation Data
ROM Consumption
时间：数天
时间：几分钟
时间：几分钟/秒

ROM的生成 (3/3)

- 适用于所有的求解器，可生成响应面ROMs，静态/瞬态ROMs，具备ROM Viewing功能。
- 适用于静态仿真（静态ROM Builder）与瞬态仿真（瞬态ROM Builder）。
- ROM Builder具有独立的solver，借助于“机器学习技术”（SVD）生成ROMs.
- 一期发布的产品（R18）主要针对Fluent进行静态ROM的提取。
- 2017年及后期重点进行所有求解器的ROM提取，尤其是瞬态ROM的提取。

FMI：通用标准接口支持

获得主流仿真工具的支持

Simplorer – 0-D Circuit & System Simulation

- **Consumes FMUs for ME (1.0/2.0)**
- **Produces FMUs for ME (1.0, Modelica subsystems only)**

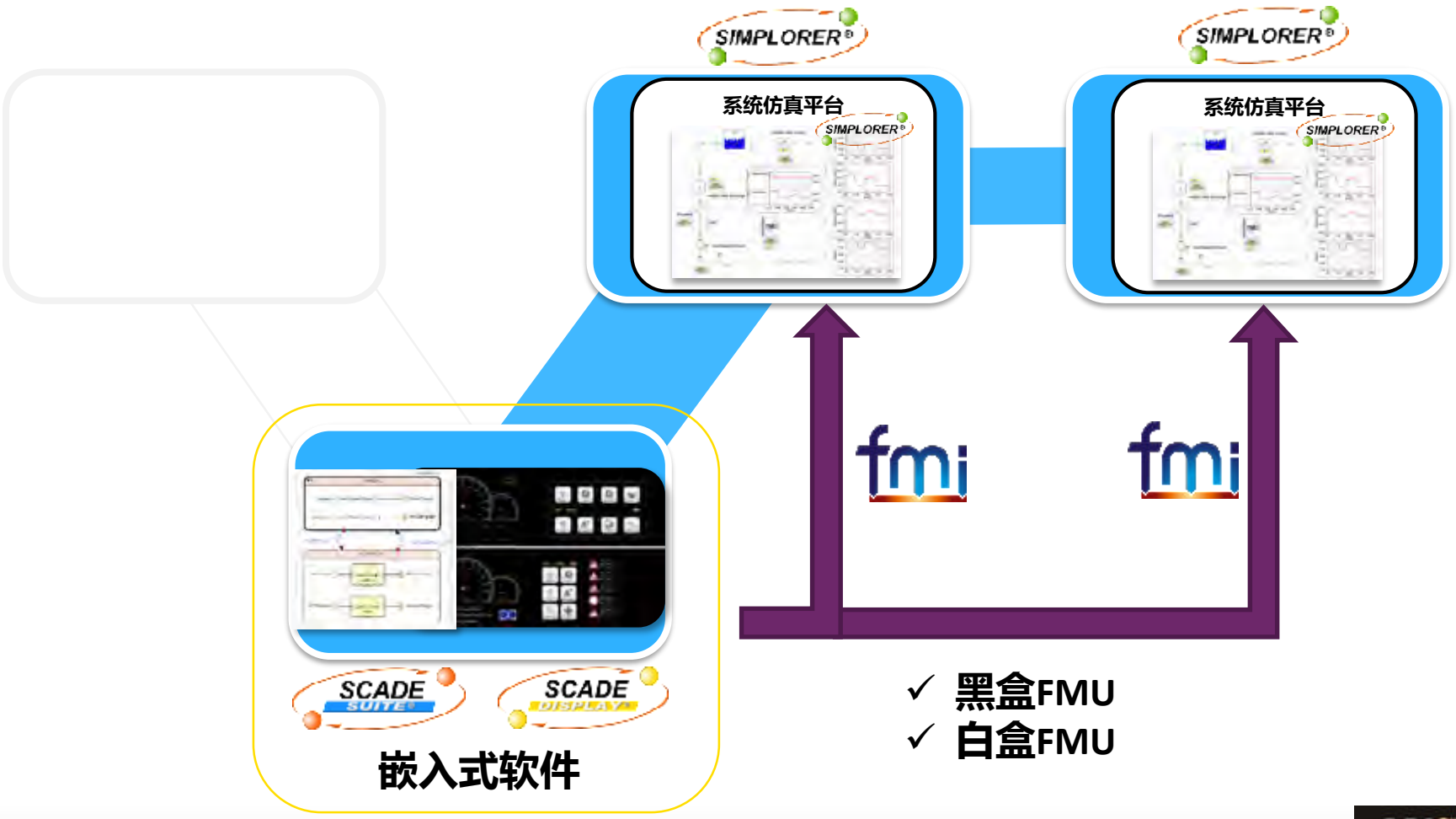
SCADE Suite – Embedded Control Design

- **Produces FMUs for ME and CS (1.0/2.0)**

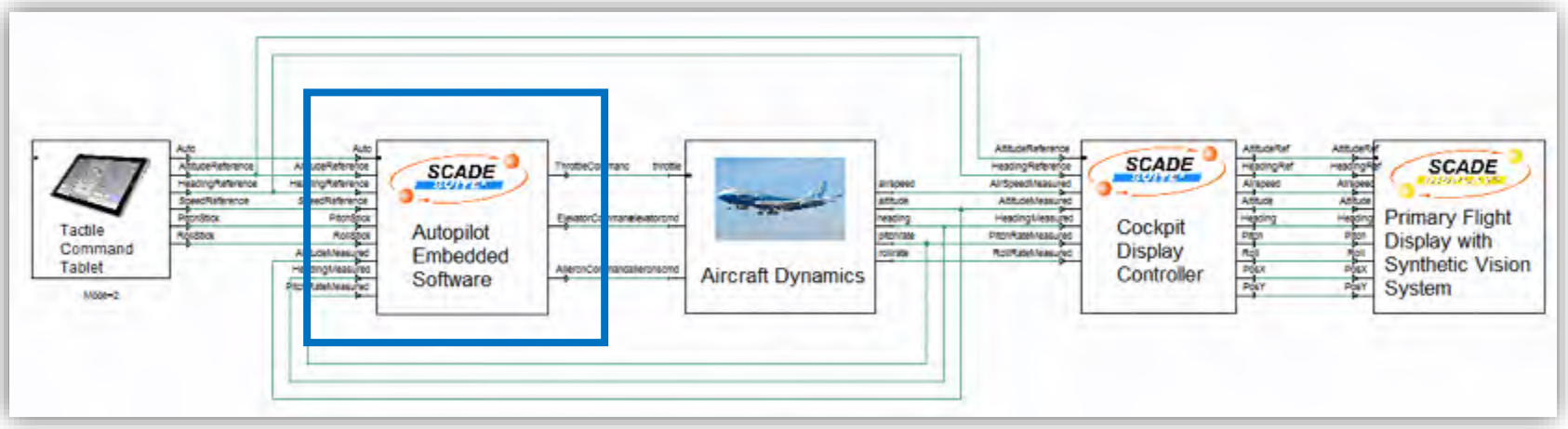
SCADE Display – HMI Software Design

- **Produces FMUs for ME (1.0/2.0)**

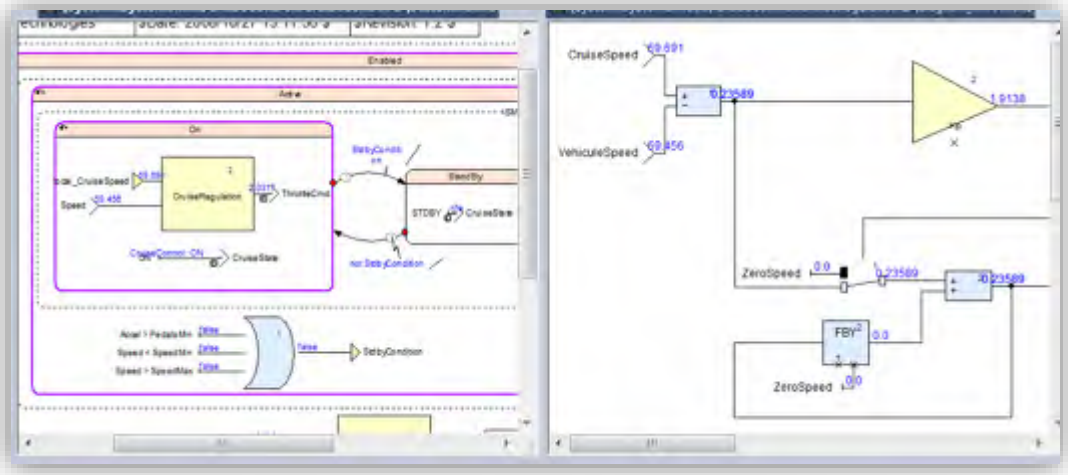
通过FMI集成SCADE模型



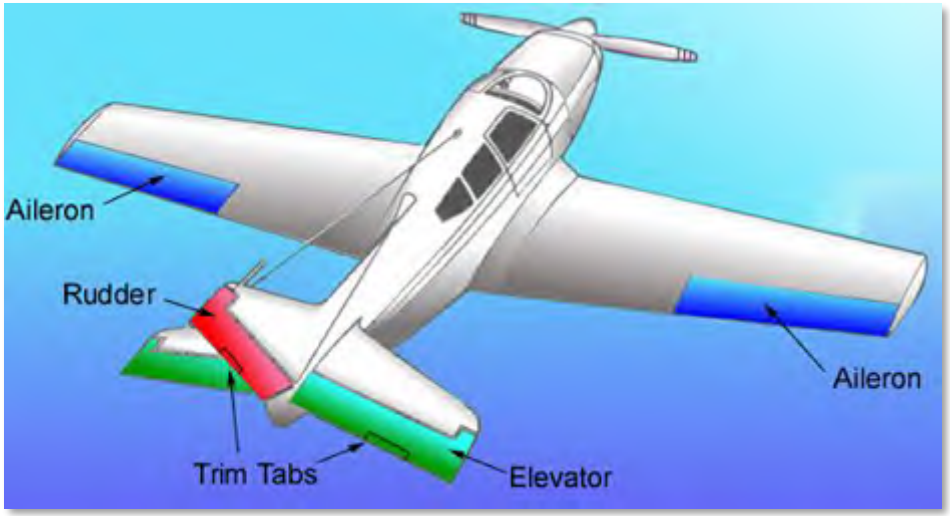
SCADE模型在Simplorer中的白盒仿真

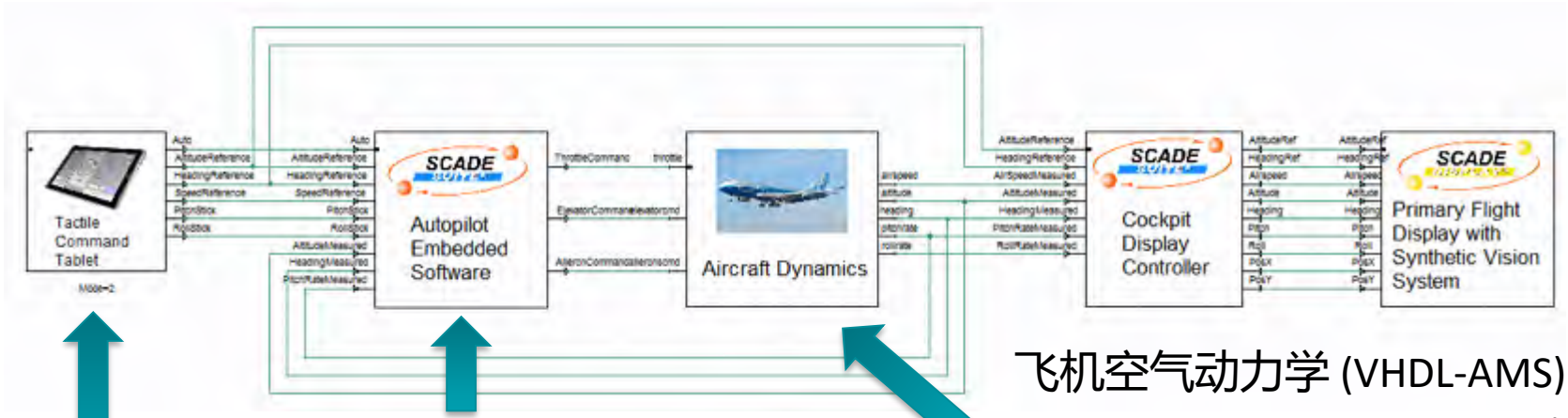


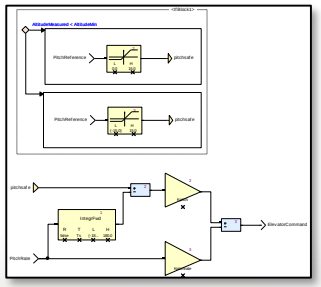
同步仿真



案例——飞控系统







飞机空气动力学 (VHDL-AMS)

+

Electromechanical Actuation for Elevator

#0 = 理想执行机构动力学

#1 = 行为级执行机构动力学

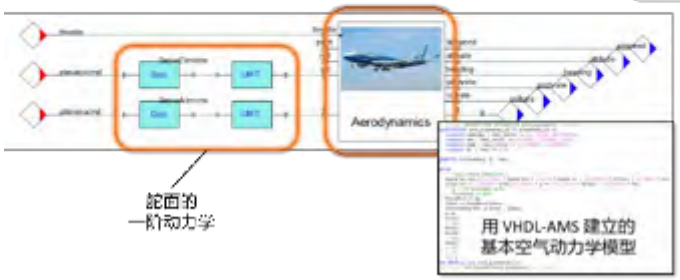
#2 = 2D 仿真模型的降阶模型 ROM

#3 = 3D 仿真模型的降阶模型 ROM

前期：原型探索

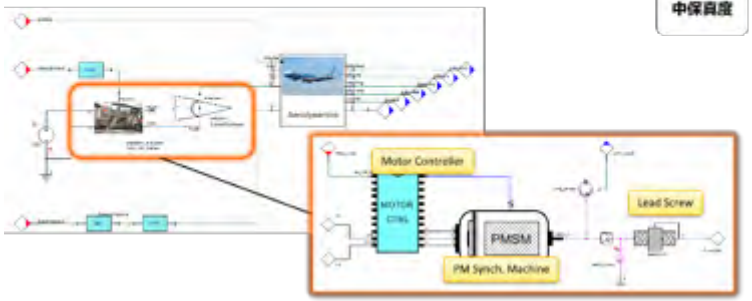
- 用 VHDL-AMS 语言描述的空气动力学特性
- 理想的（一阶）舵面动力学

低保真度



- 用 VHDL-AMS 语言描述的空气动力学特性
- Simplorer 库中的升降舵动力学标准模型

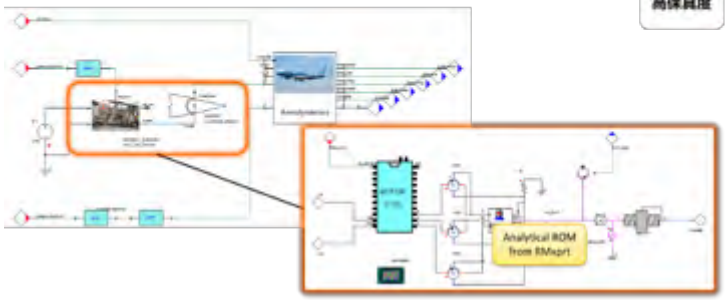
中保真度



后期：高保真系统

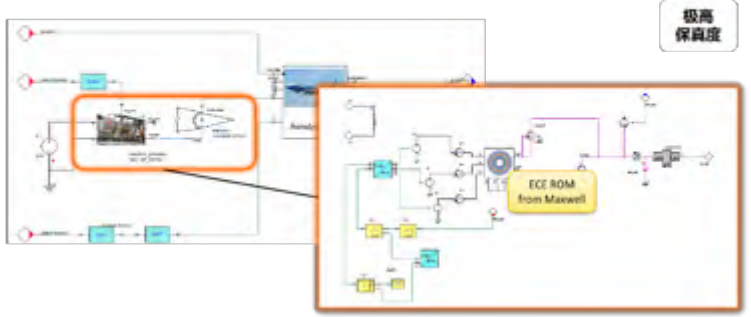
- 用 VHDL-AMS 语言描述的空气动力学特性
- ANSYS RMxprt 的 ROM 改进升降舵动力学的保真度

高保真度



- ANSYS Fluent 的 ROM 提升空气动力学特性保真度
- ANSYS Maxwell 的 ROM 增强升降舵动力学保真度

极高保真度



总结

ANSYS系统仿真平台关键技术点

支持产品全生命周期的仿真

多语言异构建模支持

多学科、多种类、高精度ROM模型支持

FMI标准支持，无限扩展能力

ANSYS系统仿真平台全面提供了构建Digital Twin所需的技术基础和能力！

感谢聆听