
构建Digital Twin的基石： 高保真的系统仿真平台

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

智能终端

智能机械



智能制造



无人驾驶



IoT 平台

传感器数据
异常情况

应用
校正动作



高保真的系统仿真技术是基础！

数字孪生

试验
校正动作

仿真结果

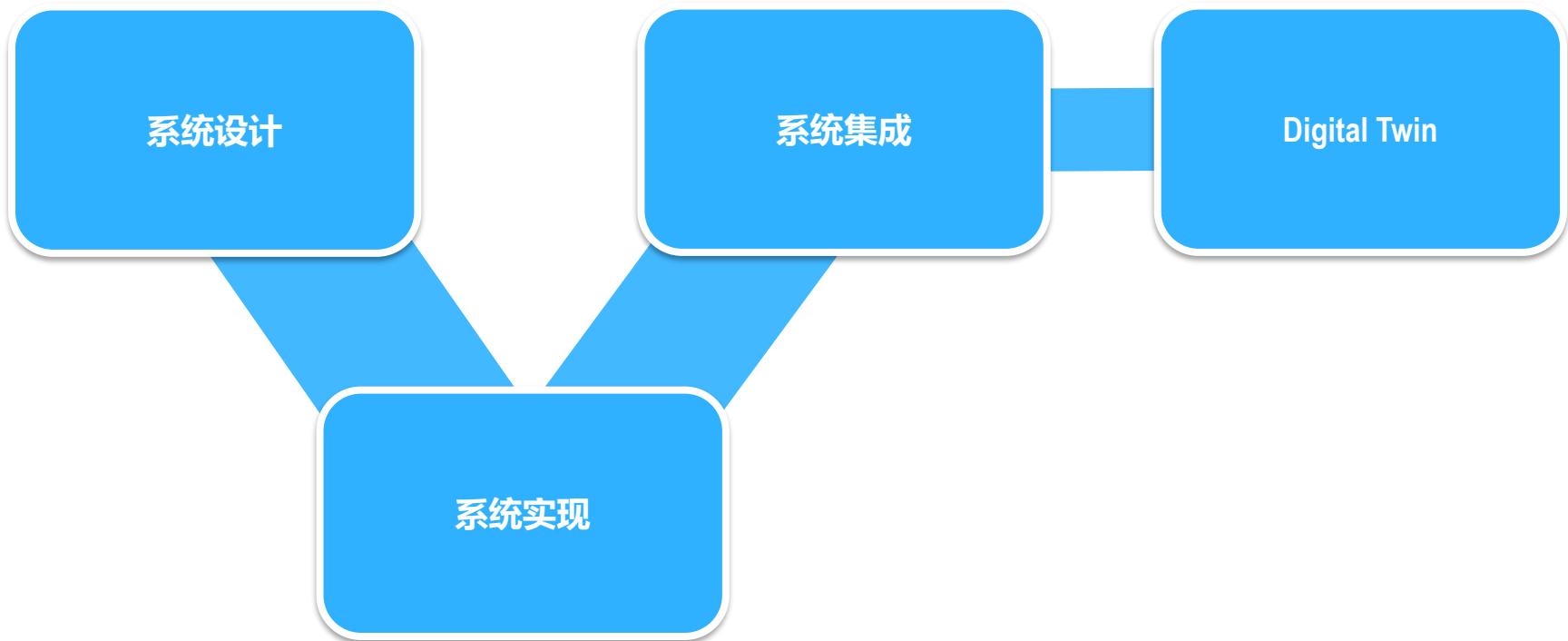


ANSYS云计算平台

ANSYS高保真系统仿真解决方案

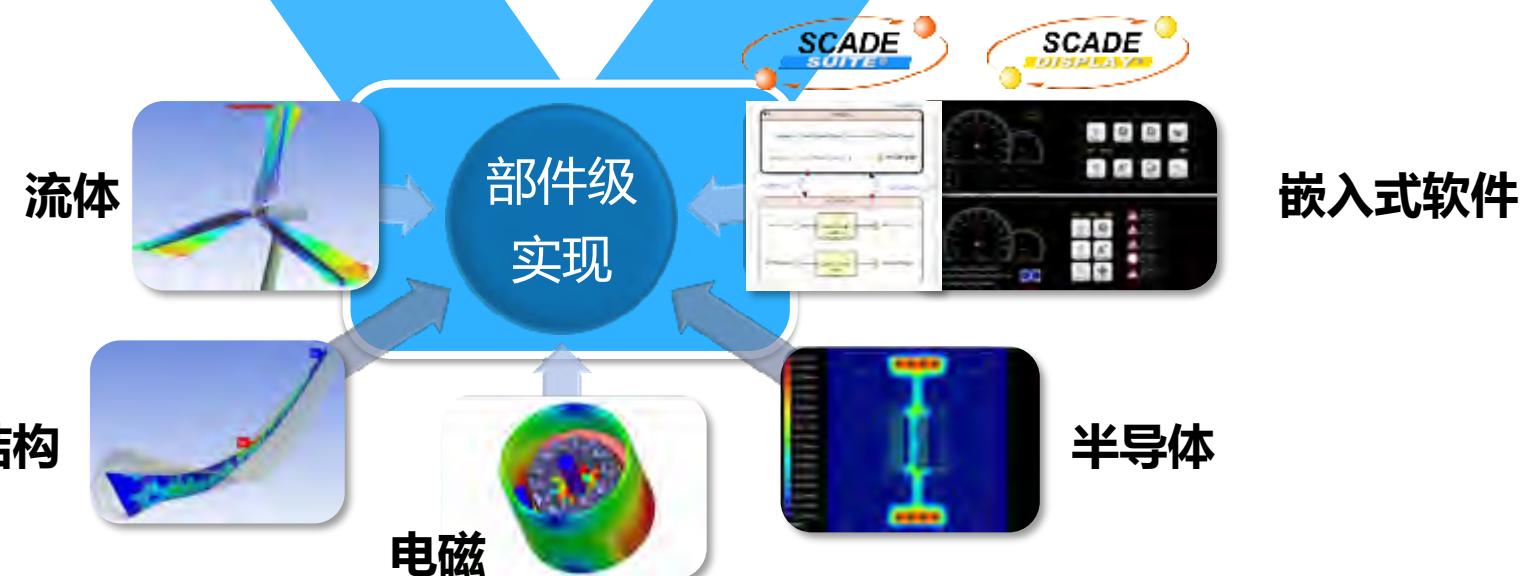
- 方案总览
- 强大的建模能力
- ROM的支持
- FMI的支持
- 案例

产品生命周期



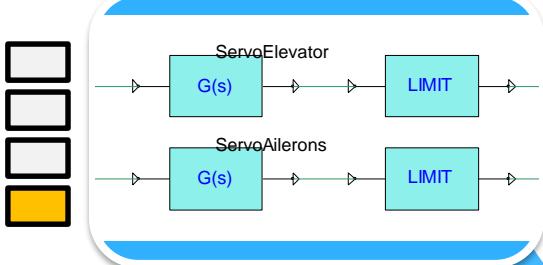
ANSYS的全生命周期仿真支持

全系统仿真

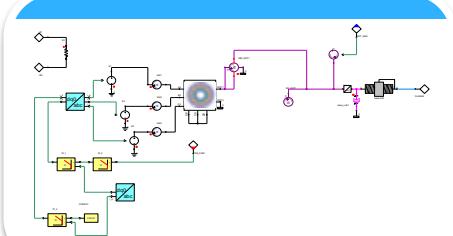


「系统仿真」贯穿整个产品生命周期

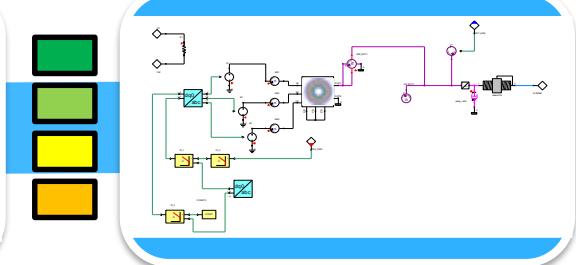
原型探索：理想简化模型



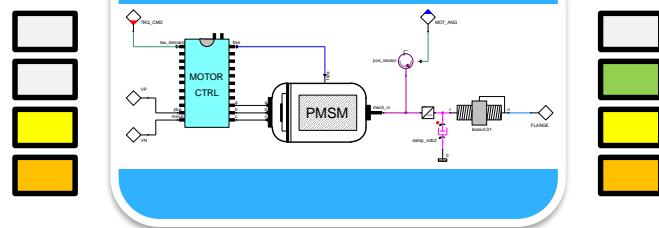
系统虚拟集成：基于ROM的极高保真模型



产品服役：基于ROM的极高保真模型



低保真度

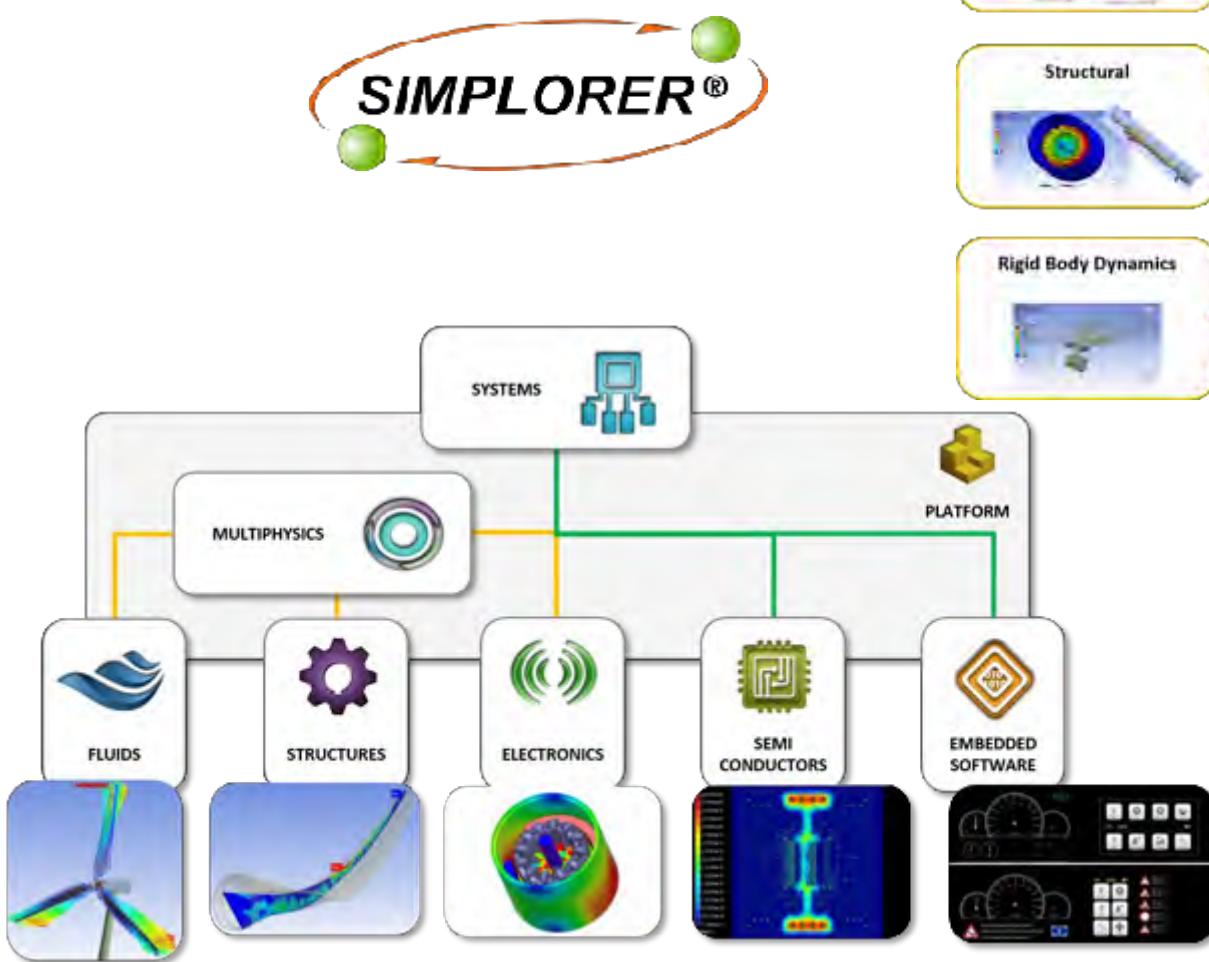


部件开发与测试：行为级中/高保真模型

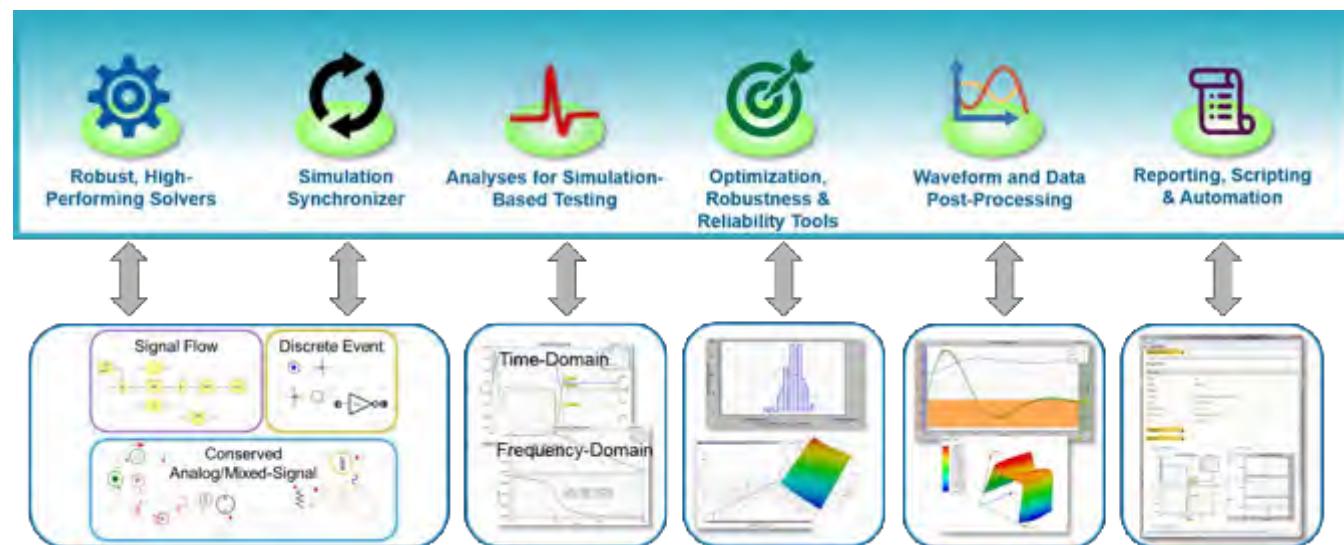
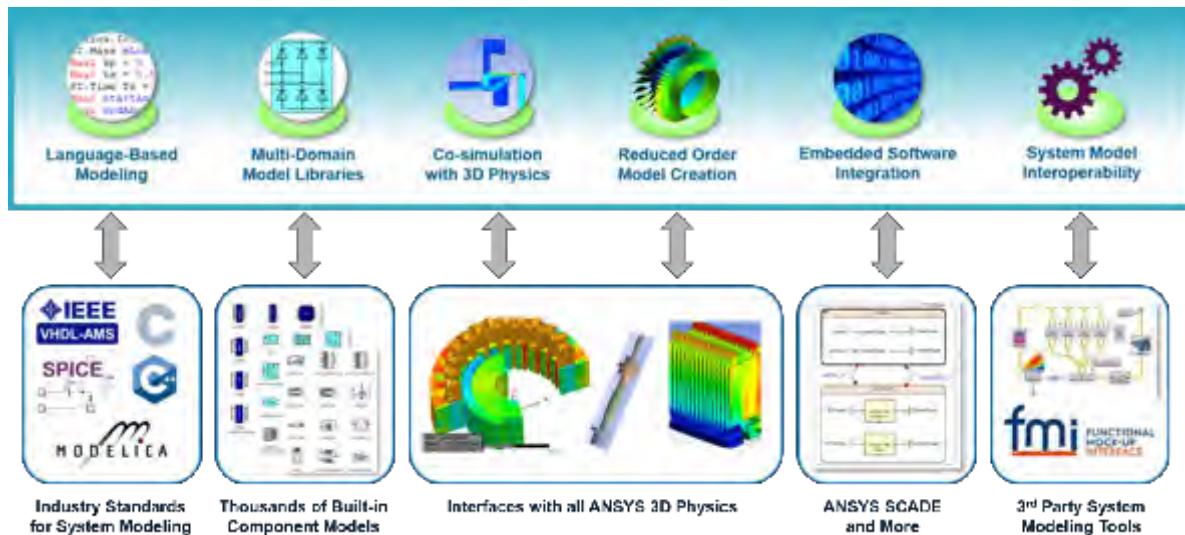
↑ 实测数据

实物系统

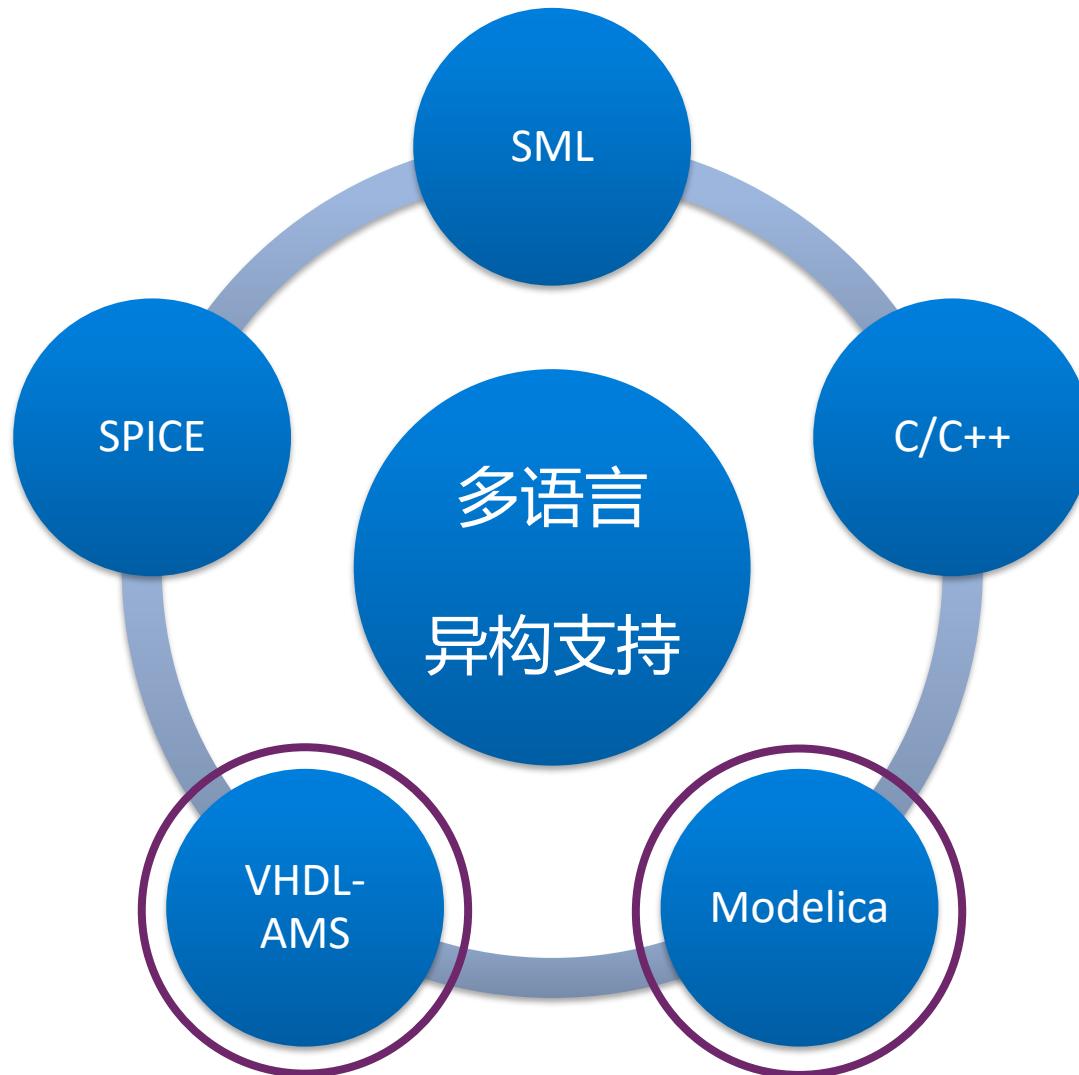
ANSYS系统仿真平台总览



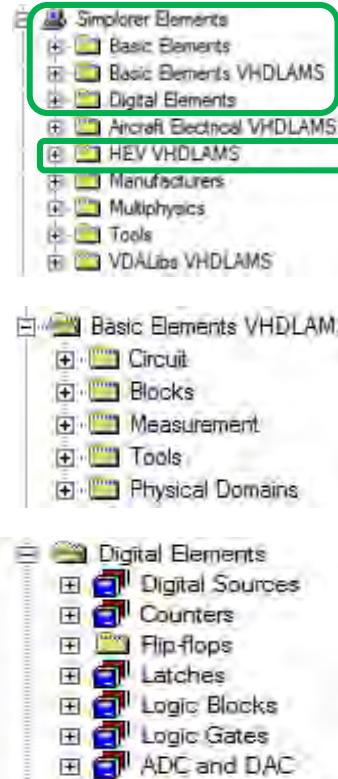
强大的系统建模能力



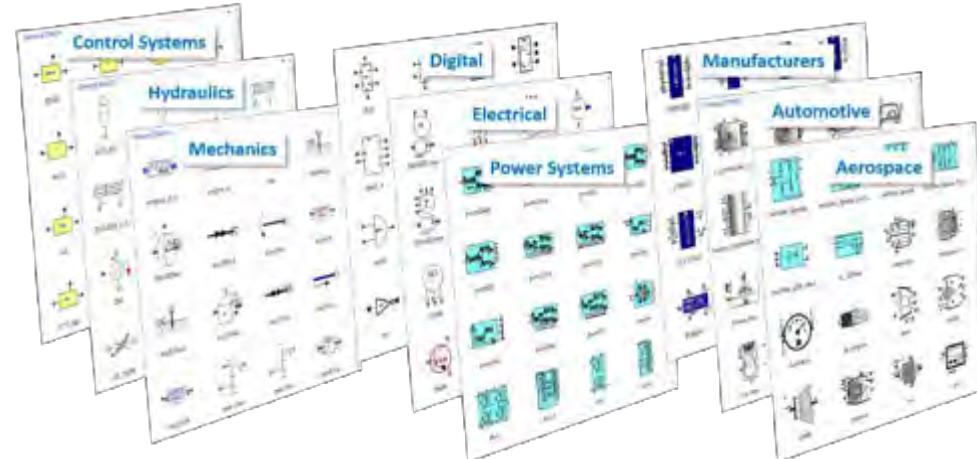
建模语言的支持



VHDL-AMS模型库

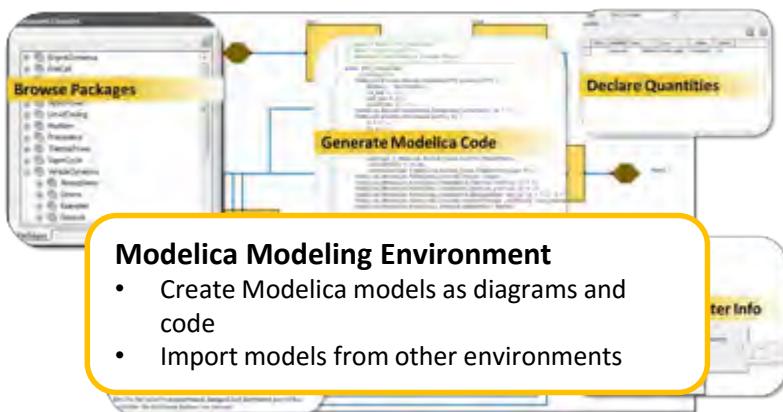


- Totally 9 libraries with 1700+ models.
- 700+ VHDL-AMS models
- Nearly 1000 demonstrative examples, with daily regression test.
- Nearly 150 basic components
 - Circuit & Physical Domains (like mechanical, thermal, fluidic and magnetic).
 - Blocks (continuous, discrete, sources, signal processing, 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.



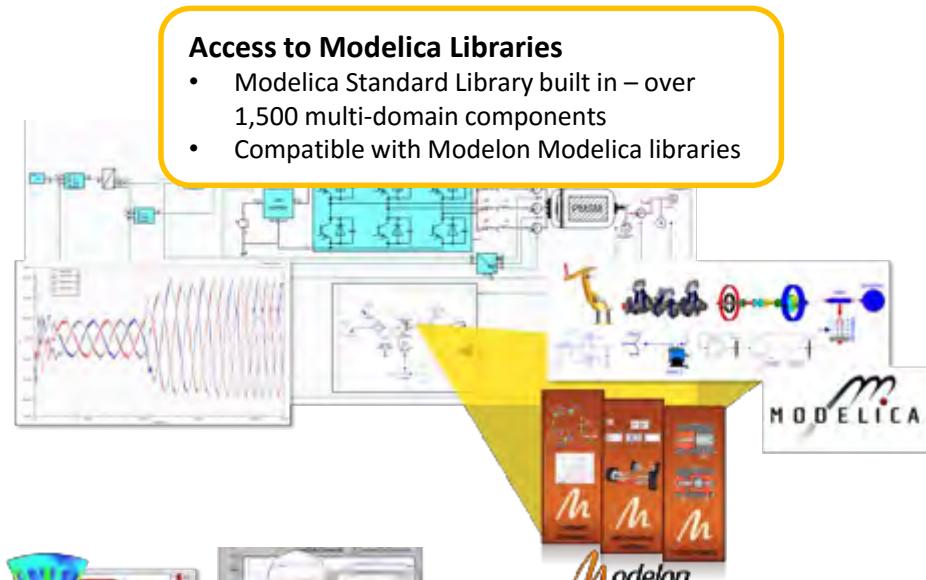
VHDL-AMS Model Libraries for Multi-Domain Systems

Simplorer对Modelica的支持



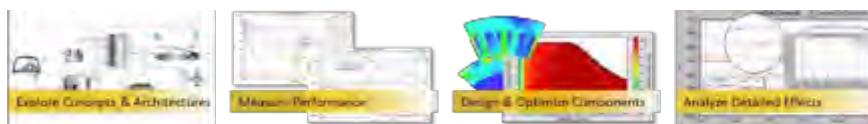
Modelica Modeling Environment

- 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



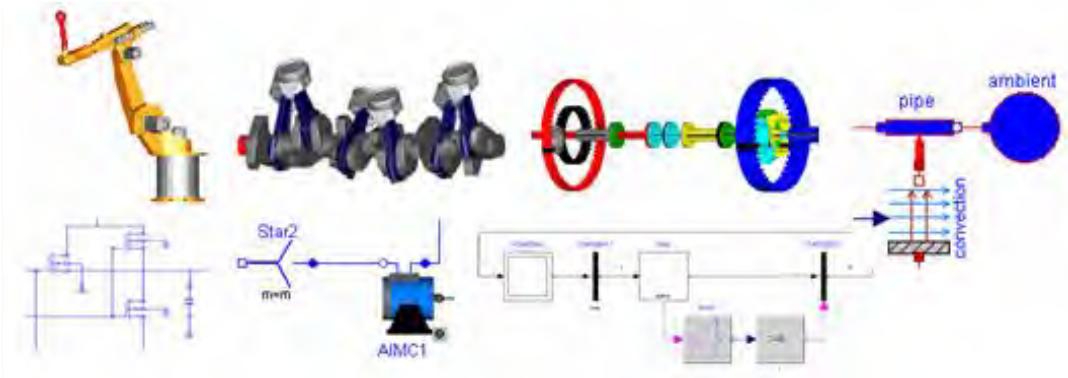
Simulate & Analyze Modelica with Simplorer



Access to Simplorer's Powerful Simulation Environment

- Time-domain studies through sophisticated statistical and optimization experiments

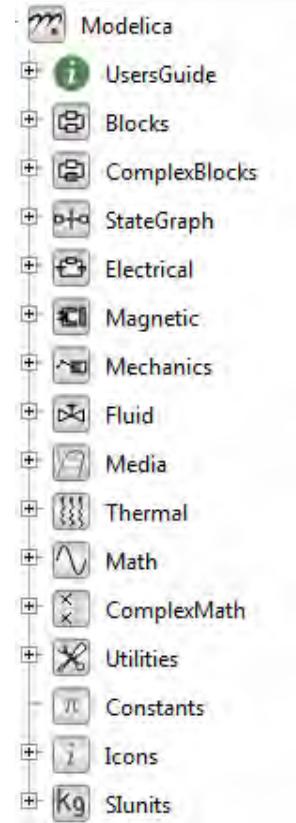
Modelica标准库



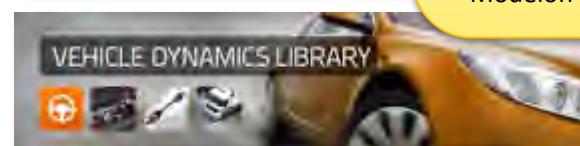
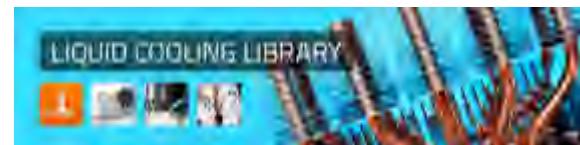
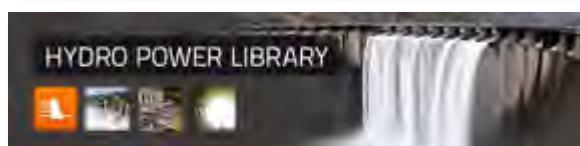
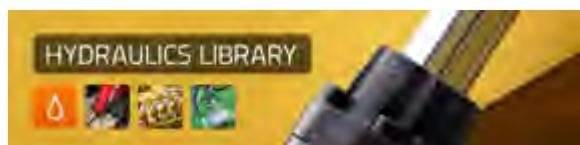
The **Modelica Standard Library (MSL)** is a free library from the Modelica Association with **over 1,500 components** for modeling mechanical, electrical, thermal, fluid, and control systems.

In Simpler:

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



Modelon库



In Simpler:

- 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

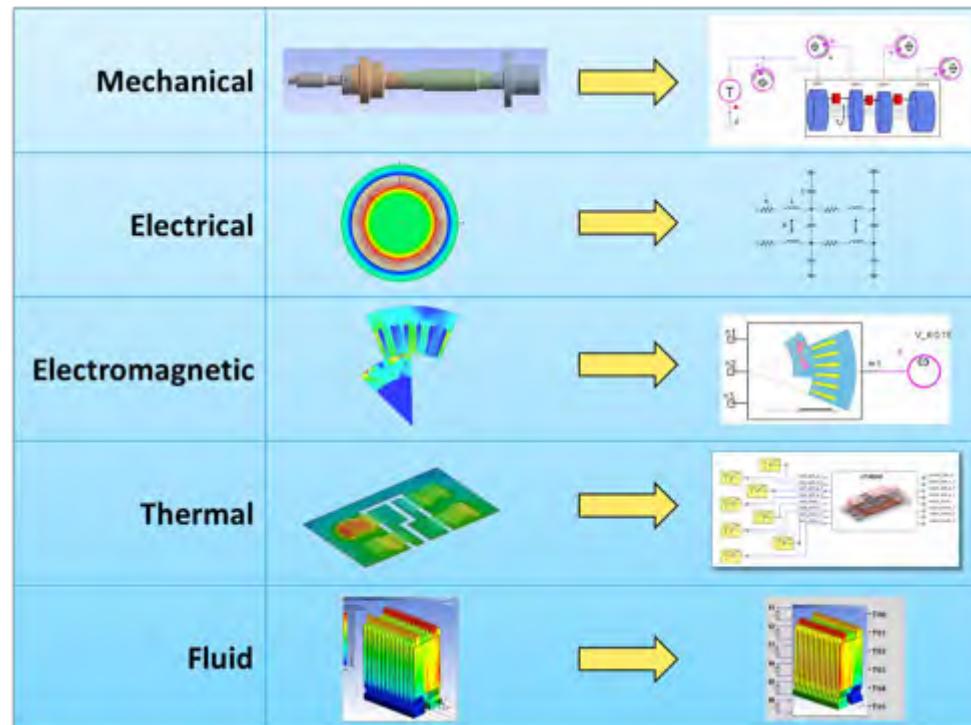
A Reduced Order Model (ROM)

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

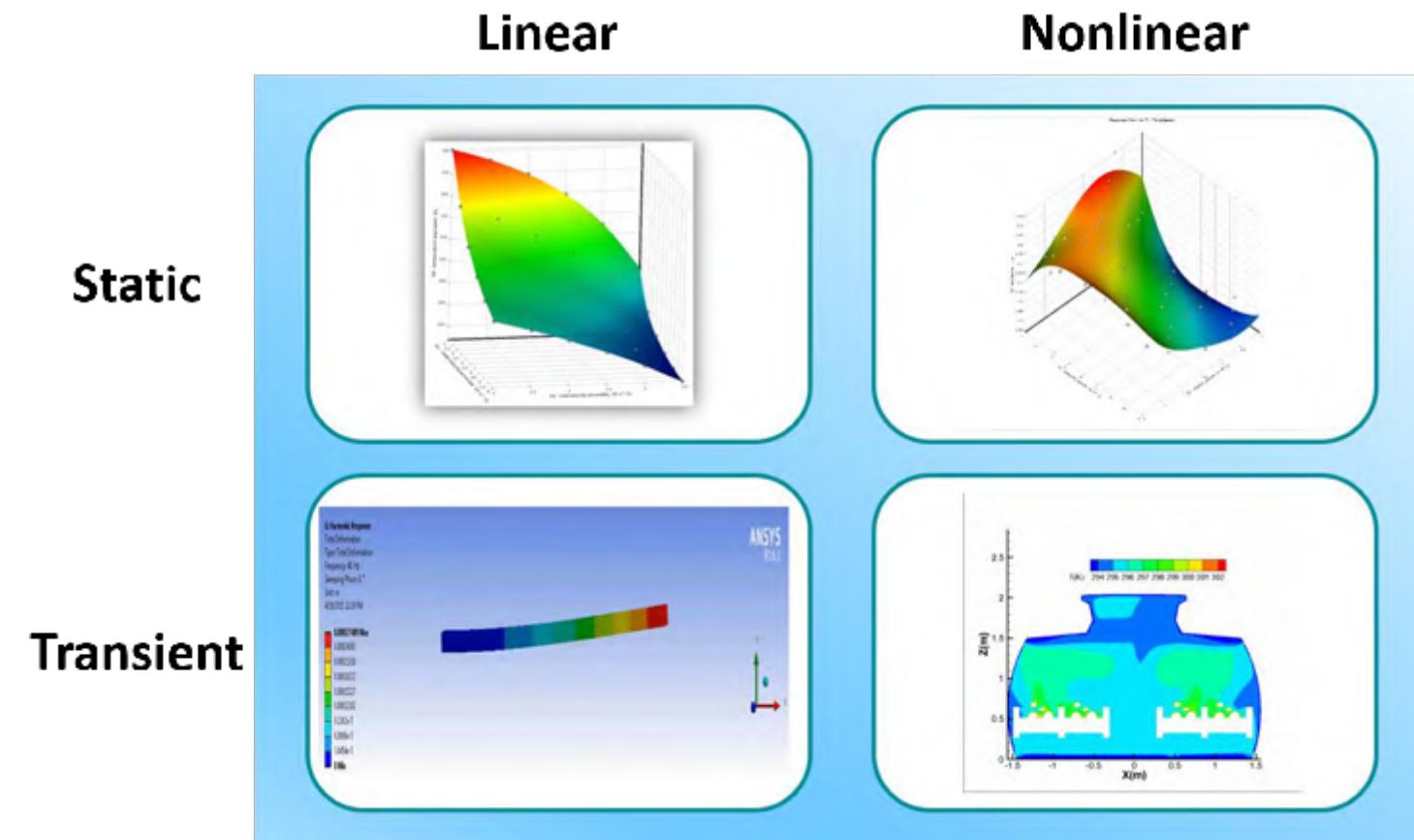


降阶模型

计算时间：秒级别

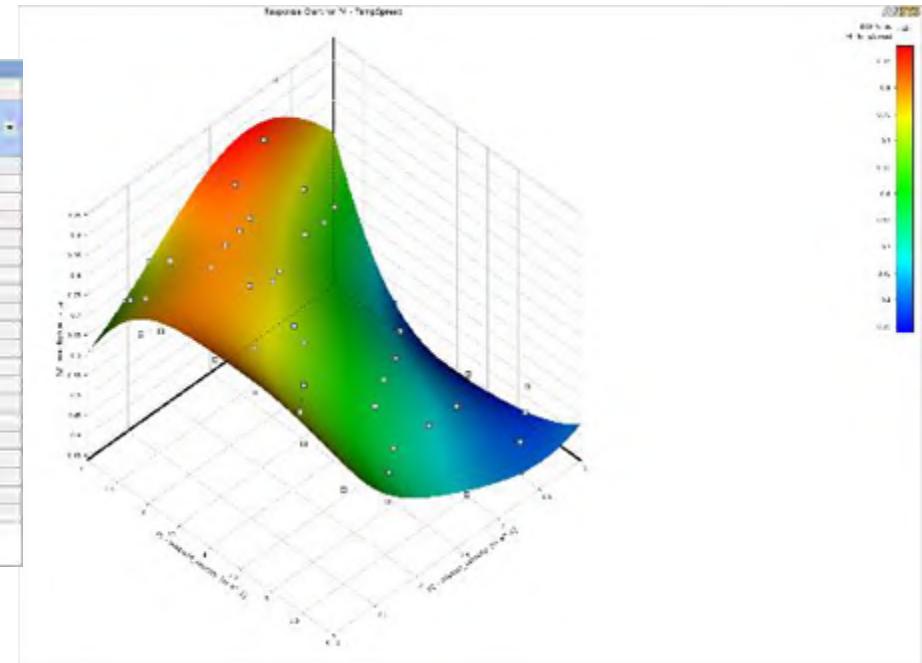
计算资源：PC机

ROM类型



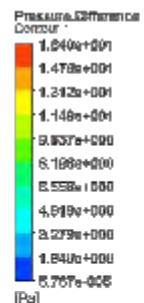
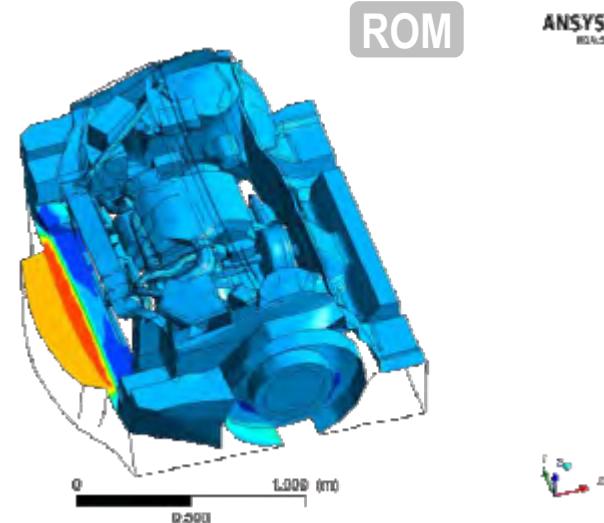
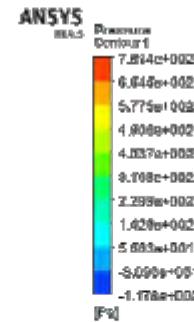
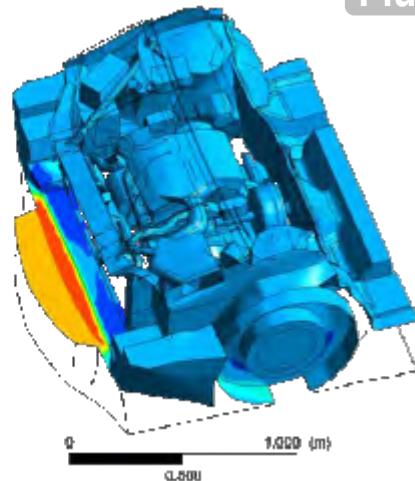
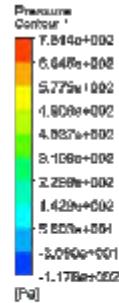
静态ROM——响应面法

I	Run	P1 - initial velocity [m/s]		P2 - initial concentration [mol/l]		P3 - initial temperature [°C]		P4 - initial humidity [%]		P5 - pressure [bar]		P6 - pressure [bar]		P7 - temperature [°C]		P8 - humidity [%]		P9 - Temperature [°C]	
		P1 - initial velocity [m/s]	P1 - initial velocity [m/s]	P2 - initial concentration [mol/l]	P2 - initial concentration [mol/l]	P3 - initial temperature [°C]	P3 - initial temperature [°C]	P4 - initial humidity [%]	P4 - initial humidity [%]	P5 - pressure [bar]	P5 - pressure [bar]	P6 - pressure [bar]	P6 - pressure [bar]	P7 - temperature [°C]	P7 - temperature [°C]	P8 - humidity [%]	P8 - humidity [%]	P9 - Temperature [°C]	P9 - Temperature [°C]
2	1	3.0	3.0	0.0006	0.0007	1.1516	1.1516	79.293	79.293	0.0000	0.0000	0.0000	0.0000	321.67	321.67	299.4	299.4	319.76	319.76
3	2	5.7228	5.7228	0.027105	0.027105	1.0977	1.0977	79.284	79.284	7313.8	7313.8	9905.1	9905.1	325.88	325.88	293.47	293.47	338.48	338.48
4	3	5.9995	5.9995	0.32343	0.32343	1.2792	1.2792	40.443	40.443	0.00062	0.00062	0.0001	0.0001	301.05	301.05	279.32	279.32	301.63	301.63
5	5	3.2177	3.2177	5.7172	5.7172	5.7538	5.7538	40.502	40.502	11945	11945	5539.5	5539.5	307.67	307.67	302.93	302.93	296.64	296.64
6	6	5.4229	5.4229	5.9254	5.9254	5.9372	5.9372	79.314	79.314	34603	34603	32514	32514	338.08	338.08	300.76	300.76	338.27	338.27
7	7	5.9993	5.9993	0.14884	0.14884	5.8874	5.8874	76.348	76.348	37042	37042	36832	36832	333.68	333.68	300.99	300.99	331.42	331.42
8	8	6	6	1.1292	1.1292	9.4721	9.4721	1.0411	1.0411	77.542	77.542	1280.7	1280.7	328.86	328.86	306.4	306.4	332.95	332.95
9	9	5.9488	5.9488	5.8629	5.8629	5.7246	5.7246	42.517	42.517	35913	35913	33971	33971	308.08	308.08	294.8	294.8	308.25	308.25
10	10	5.7221	5.7221	0.6062	0.6062	1.1193	1.1193	41.793	41.793	7700.1	7700.1	0.0006	0.0006	304.99	304.99	286.23	286.23	304.73	304.73
11	11	3.1901	3.1901	8.7328	8.7328	1.098	1.098	40.283	40.283	1394.3	1394.3	1412.1	1412.1	306.55	306.55	292.63	292.63	305.21	305.21
12	12	3.7119	3.7119	0.22942	0.22942	5.584	5.584	40.576	40.576	11810	11810	6519.3	6519.3	305.1	305.1	299.39	299.39	292.52	292.52
13	13	5.5358	5.5358	0.47437	0.47437	5.7694	5.7694	29.703	29.703	13473	13473	7250.7	7250.7	335.98	335.98	323.43	323.43	313.71	313.71
14	14	5.9889	5.9889	0.42115	0.42115	5.8695	5.8695	40.941	40.941	38142	38142	35419	35419	305.42	305.42	298.35	298.35	303.74	303.74
15	15	5.7046	5.7046	0.29995	0.29995	1.0111	1.0111	47.395	47.395	1366.3	1366.3	1410.1	1410.1	310.05	310.05	299.46	299.46	308.45	308.45
16	16	1.1244	1.1244	5.9576	5.9576	5.693	5.693	79.866	79.866	11330	11330	6515.4	6515.4	341.18	341.18	329.82	329.82	333.97	333.97
17	17	3.2903	3.2903	7.2294	7.2294	1.1031	1.1031	76.349	76.349	2105.7	2105.7	2494	2494	328.99	328.99	295.12	295.12	334.73	334.73
18	18	5.6632	5.6632	5.1489	5.1489	79.241	79.241	20332	20332	23546	23546	337.52	337.52	290.35	290.35	336.7	336.7		
19	19	5.9814	5.9814	5.228	5.228	1.0898	1.0898	60.721	60.721	7880.3	7880.3	15979	15979	315.97	315.97	294.15	294.15	315.65	315.65
20	20	3.4144	3.4144	9.0548	9.0548	3.2845	3.2845	77.009	77.009	11685	11685	11912	11912	336.06	336.06	307.11	307.11	313.88	313.88
		Mean value of the parameters																	



- 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

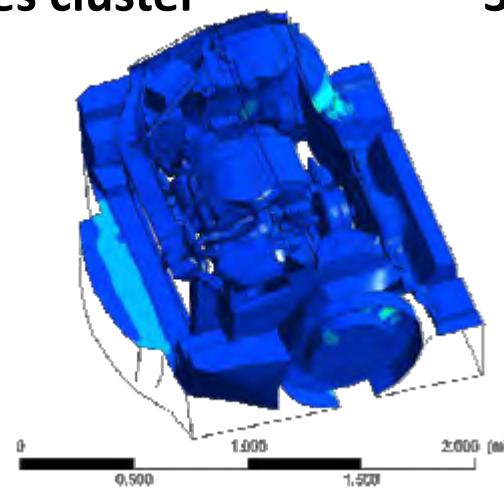


2 hours on 16 cores cluster

3 seconds on this laptop

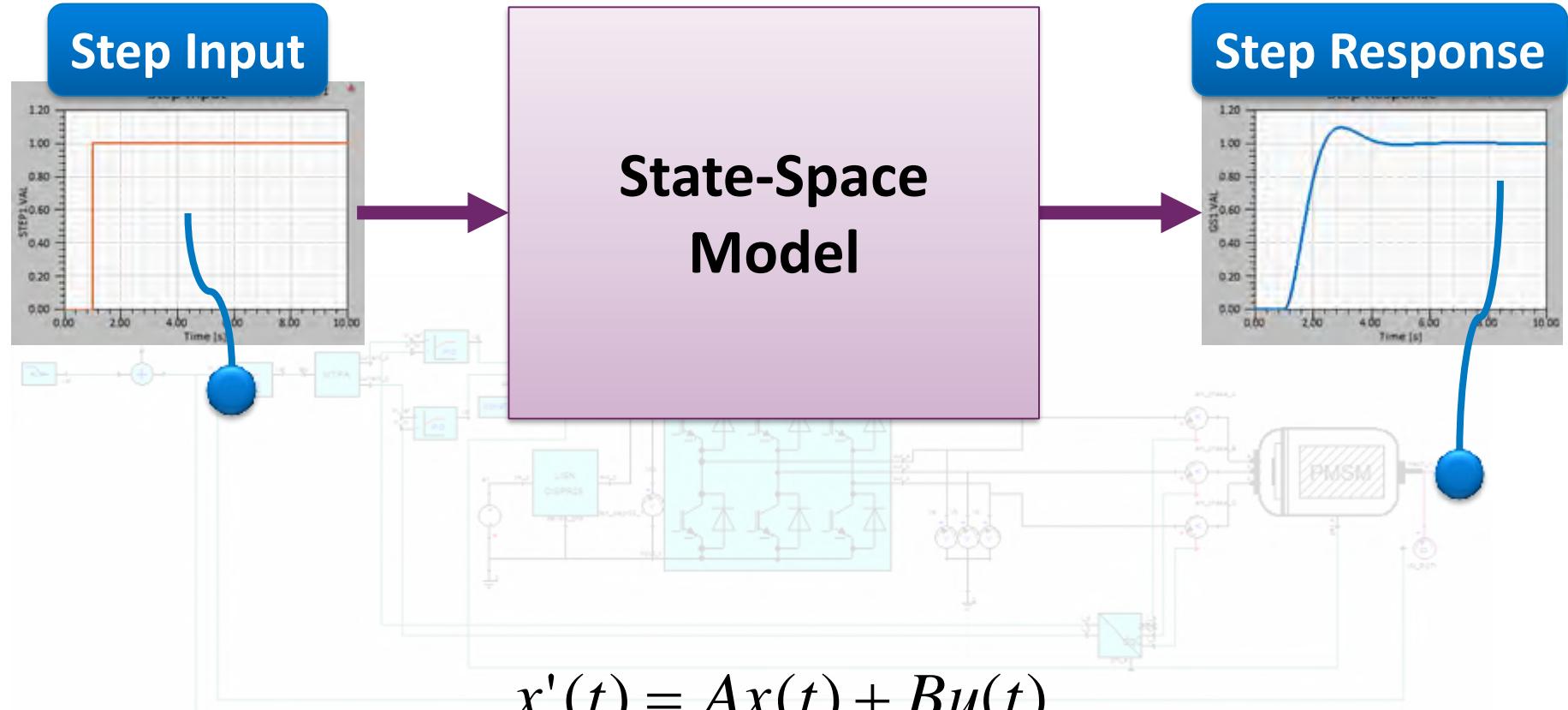
ANSYS RANS

Absolute Difference



Max difference: 1.2%

线性动态ROM——状态空间方法



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

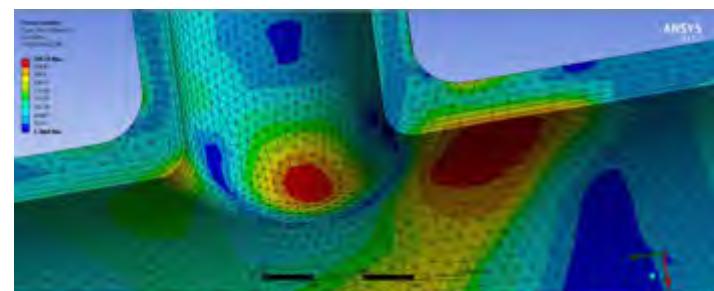
$$y(t) = Cx(t) + Du(t)$$

非线性动态ROM——机器学习+神经网络

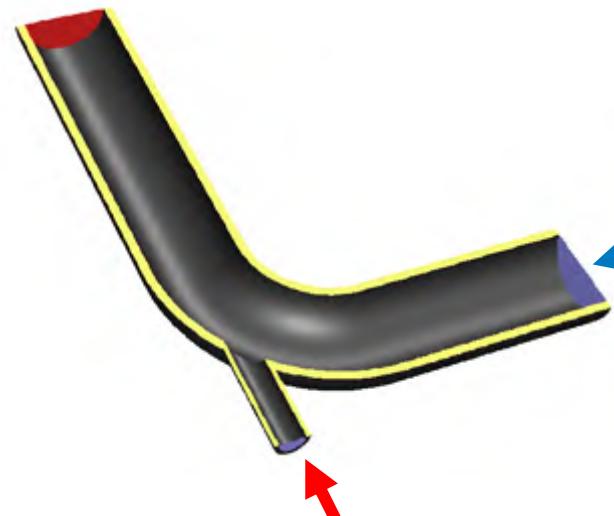
- Many classes of problems are intrinsically non-linear
- Again, the goal is often to simulate dynamic response to an arbitrary input signal in real-time or quasi real-time
- The following techniques for creating ROMs for non-linear systems are:
 - Projection methods on subspaces: SVD
 - Machine learning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

Applications

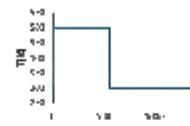
- Fluid flows
- Mechanical vibrations, stress and fatigue analysis
- ...



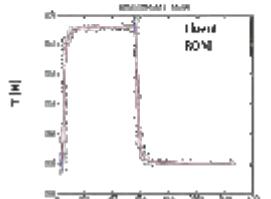
动态非线性ROM的保证度



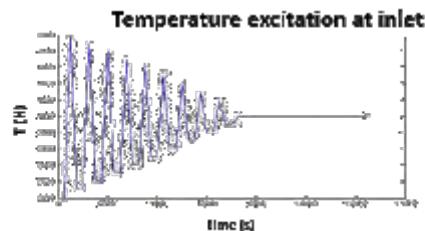
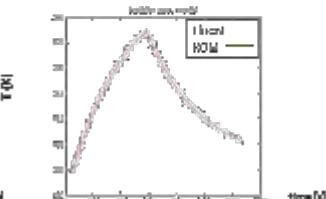
Temperature excitation at inlet



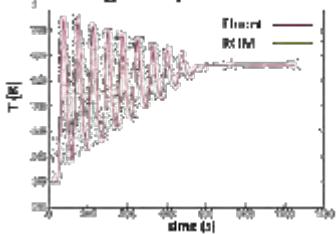
Average Temperature at Fluid outlet



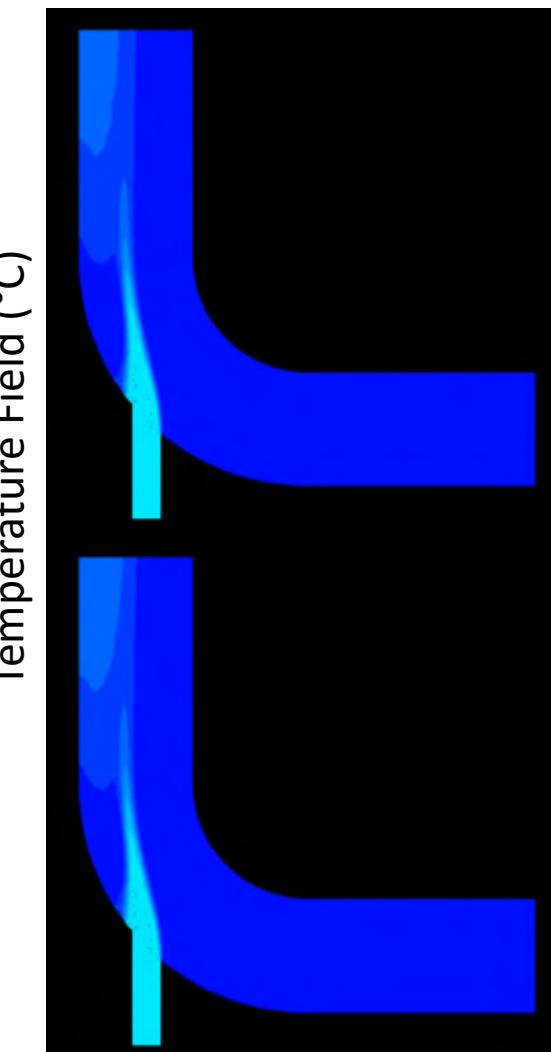
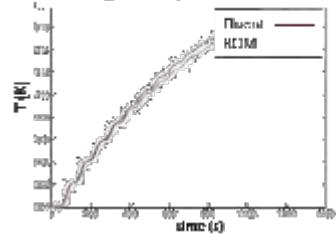
Average Temperature at Solid outlet



Average Temperature at Fluid outlet

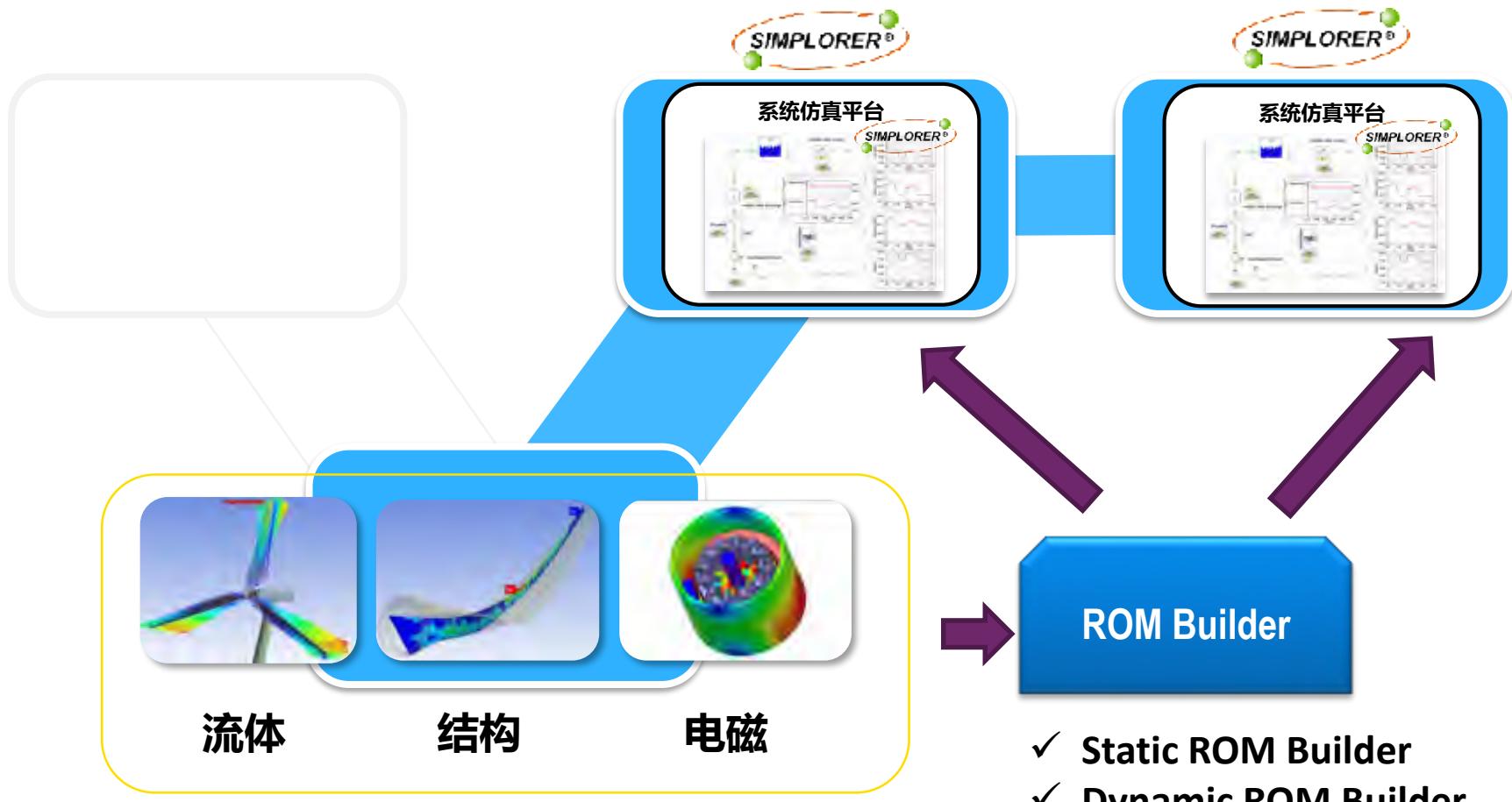


Average Temperature at Solid outlet

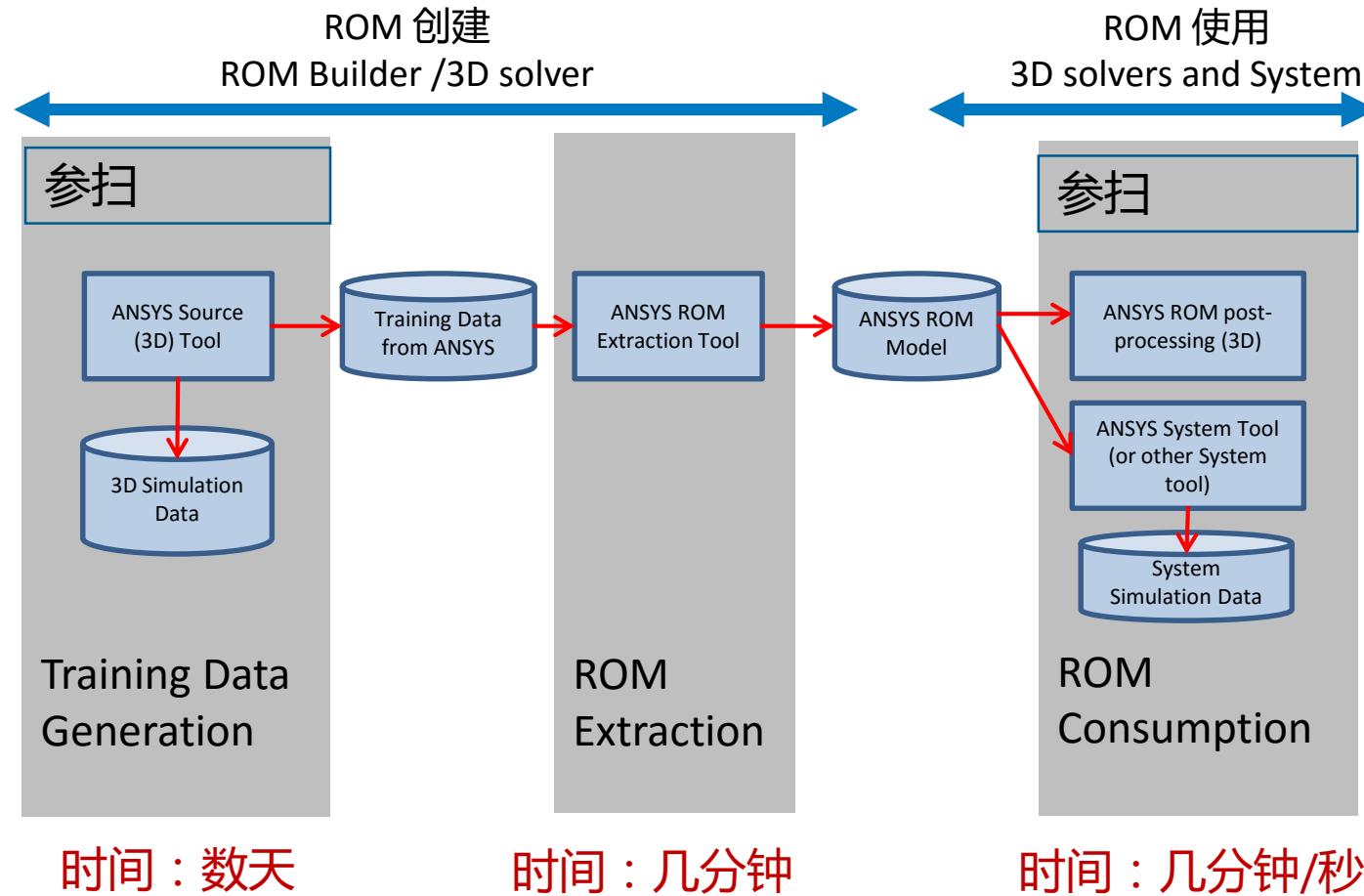


ROM

ROM的生成 (1/3)



ROM的生成 (2/3)



ROM的生成 (3/3)

ROM Builder

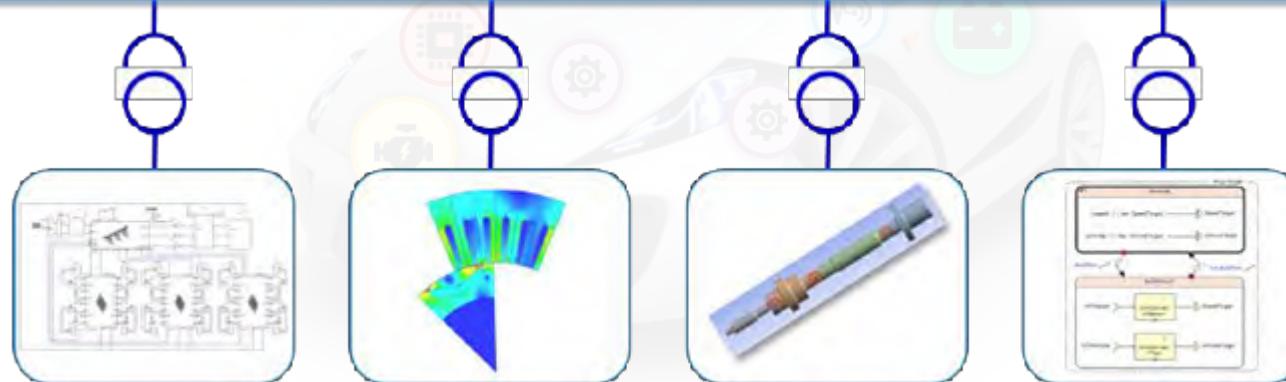
- 适用于所有的求解器，可生成响应面ROMs，静态/瞬态ROMs，具备ROM Viewing功能。
- 适用于静态仿真（静态ROM Builder）与瞬态仿真（瞬态ROM Builder）。
- ROM Builder具有独立的solver，借助于“机器学习技术”（SVD）生成ROMs.
- 一期发布的产品（R18）主要针对Fluent进行静态ROM的提取。
- 2017年及后期重点进行所有求解器的ROM提取，尤其是瞬态ROM的提取。

FMI : 通用标准接口支持



The FMI logo features the letters "fmi" in a stylized blue and orange font, followed by "FUNCTIONAL MOCK-UP INTERFACE" in a smaller, sans-serif font.

Enabling:
MODEL PORTABILITY
TOOL INTEROPERABILITY
ENTERPRISE DEPLOYABILITY



Four icons representing different simulation tools, each connected to a central circular node:

- A schematic diagram of a circuit or system.
- A 3D visualization of a mechanical part, possibly a fan or motor.
- A 3D visualization of a mechanical component, possibly a shaft or bearing.
- A block diagram of a control system with various nodes and connections.



Four overlapping windows showing software interfaces, likely for system simulation or control design.

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)

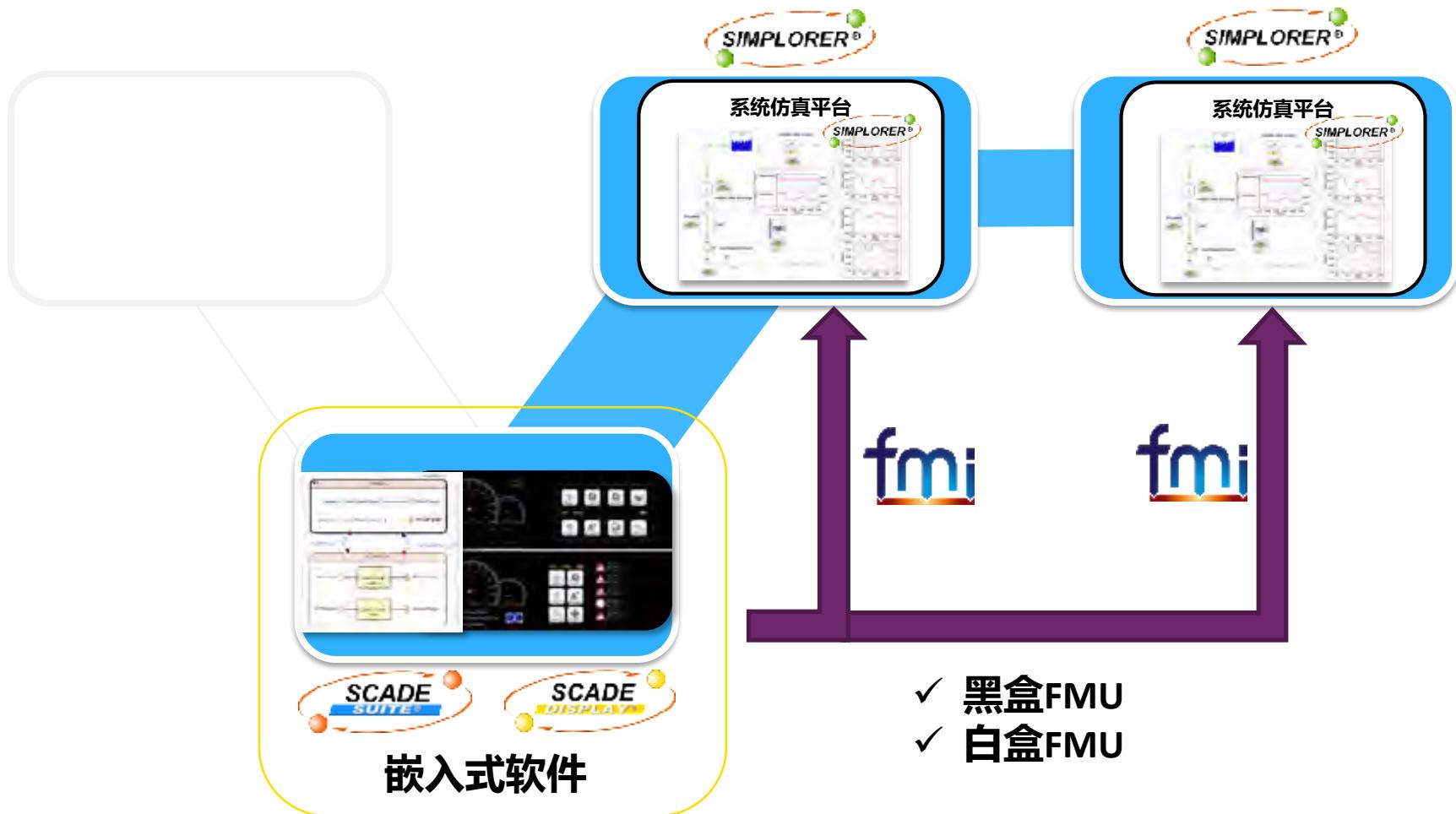
SCADE Suite – Embedded Control Design

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

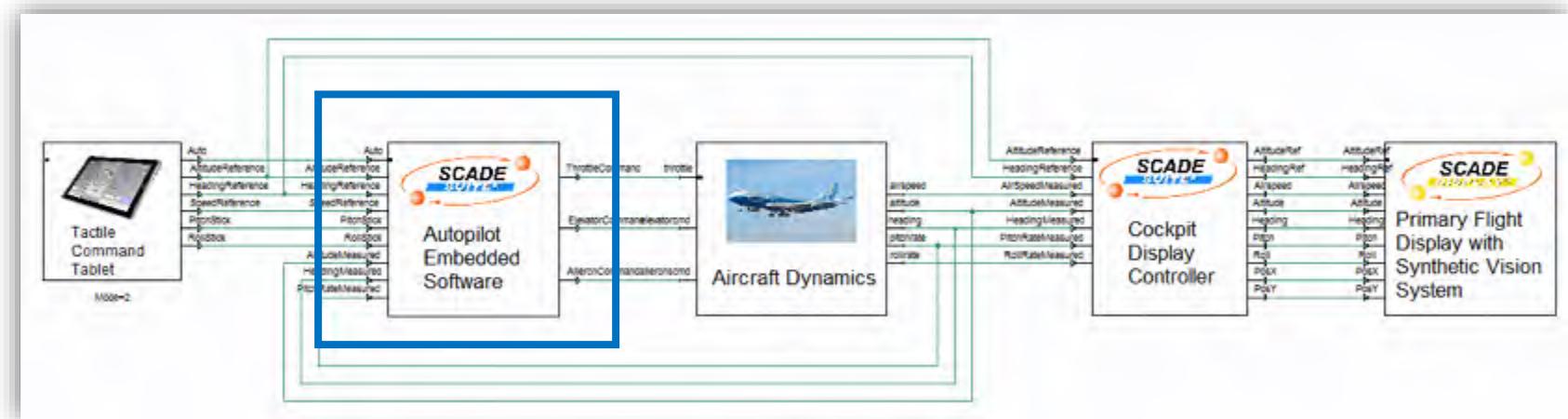
SCADE Display – HMI Software Design

- Produces FMUs for ME (1.0/2.0)

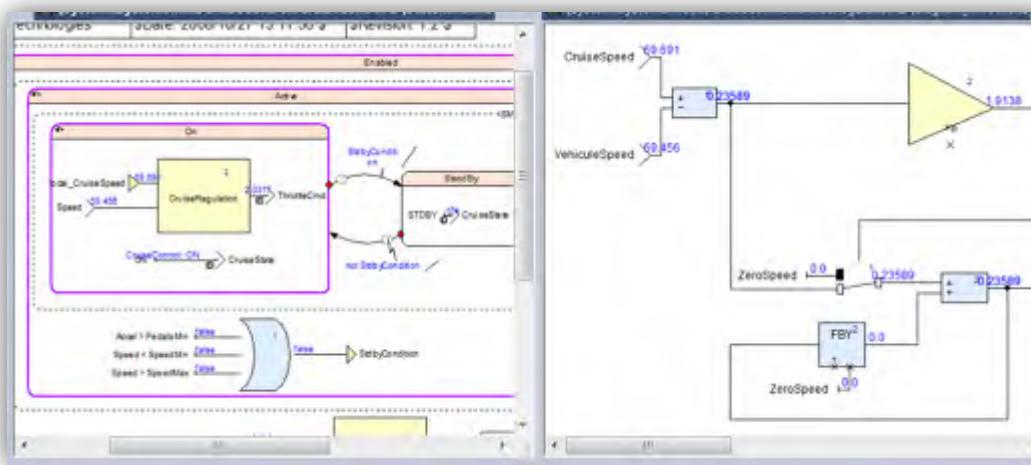
通过FMI集成SCADE模型



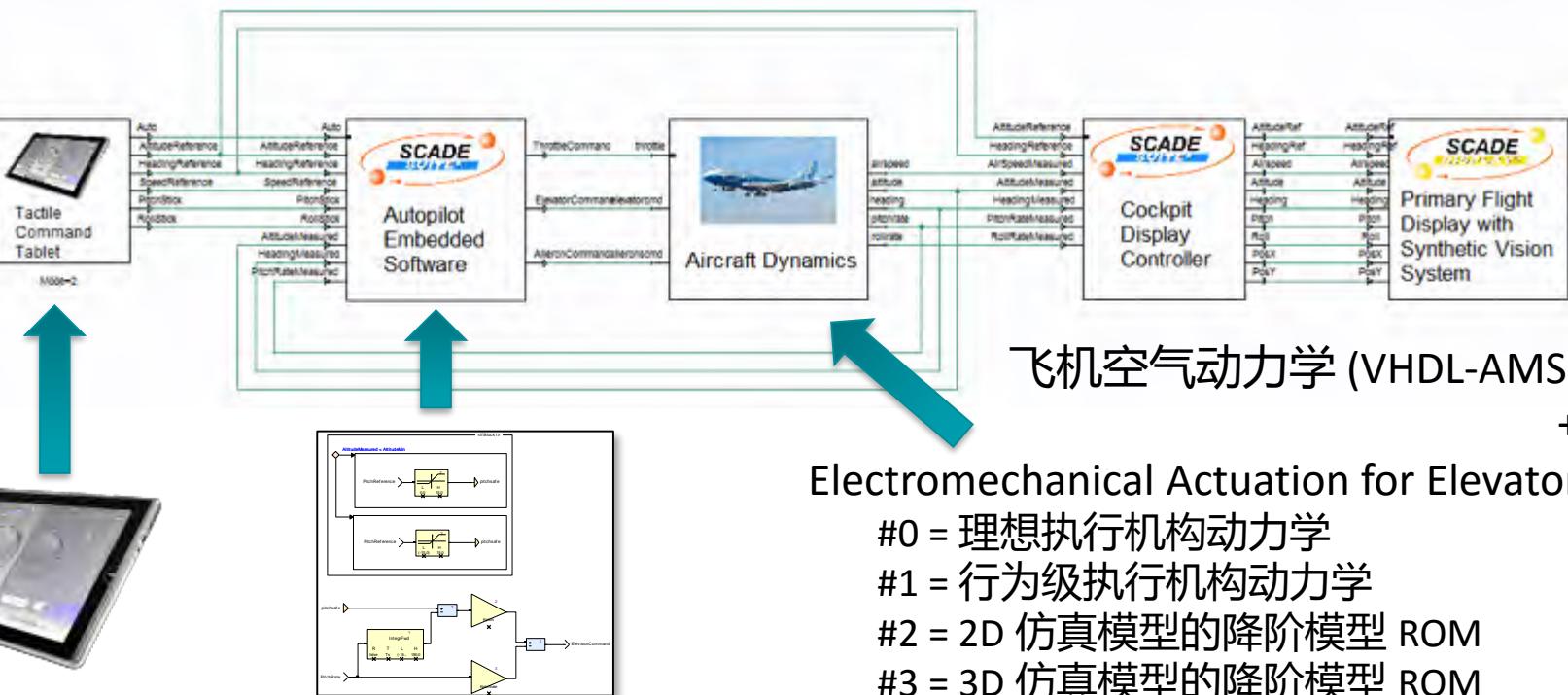
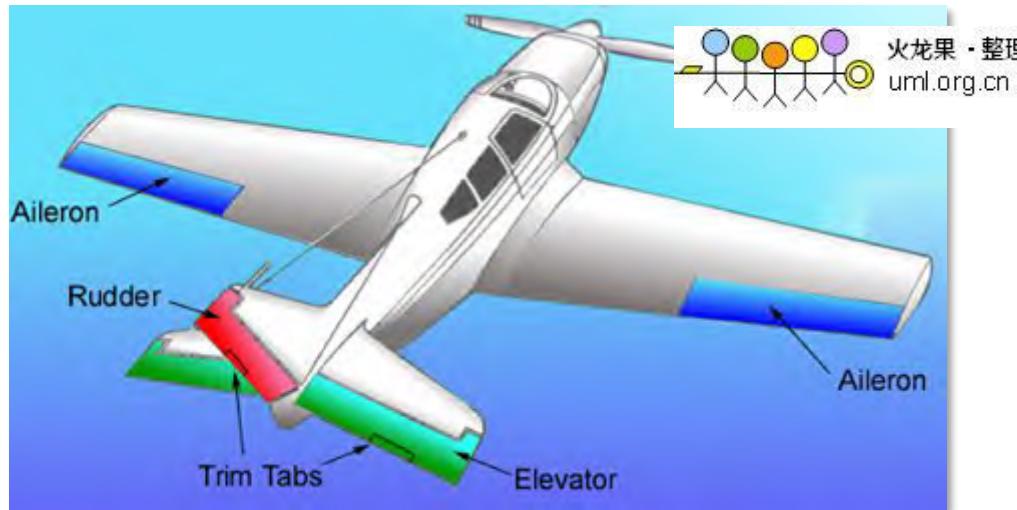
SCADE模型在Simplorer中的白盒仿真



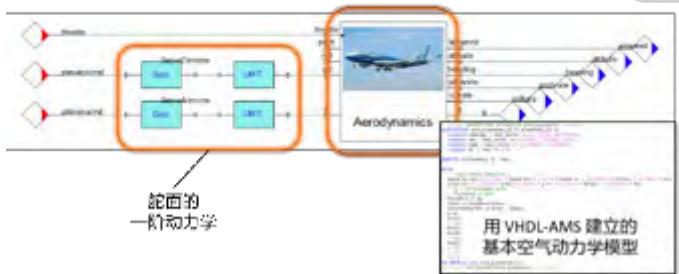
 同步仿真



案例——飞控系统

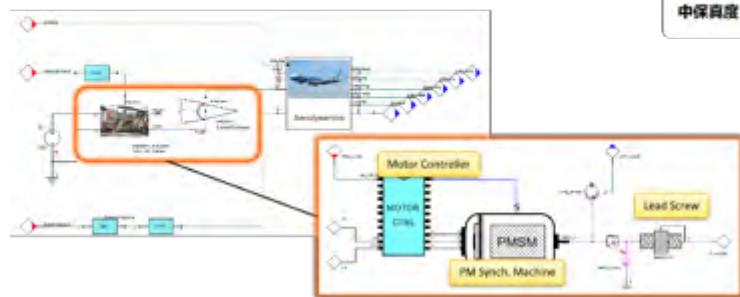


- 用 VHDL-AMS 语言描述的空气动力学特性
- 理想的 (一阶) 舵面动力学

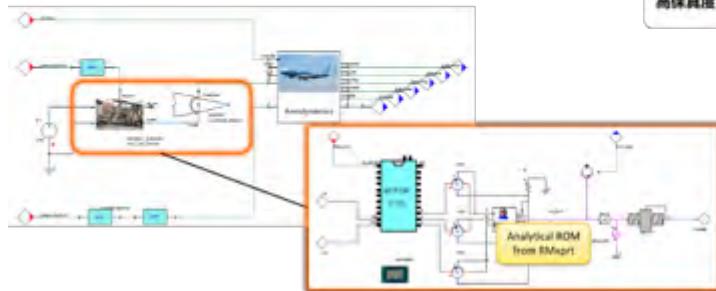


前期 · 原型探索

- 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



- 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



后期 · 高保真系统

- 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

