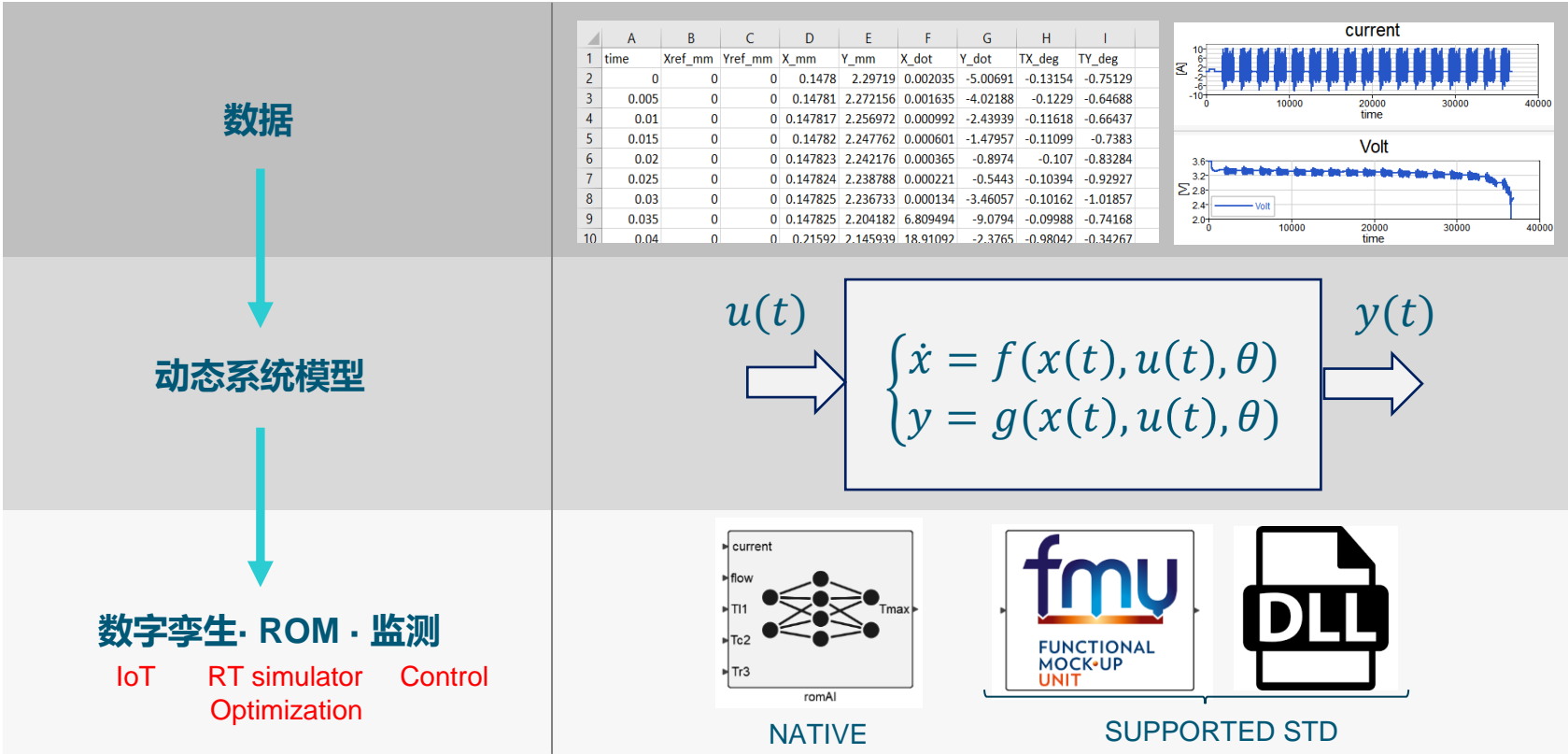


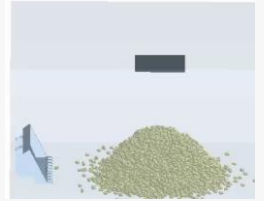
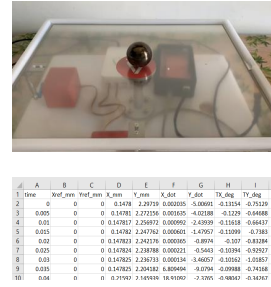
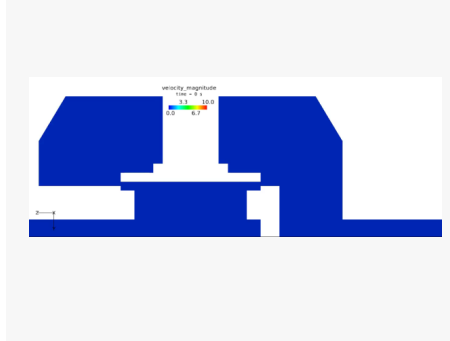
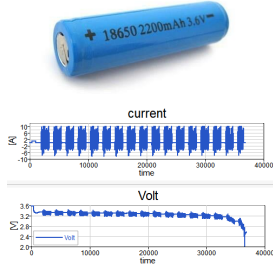
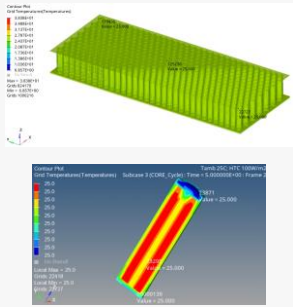


ALTAIR ROMAI: 利用AI和经典系统理论生成ROM

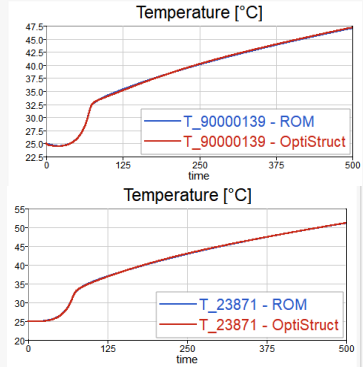
romAI 目的



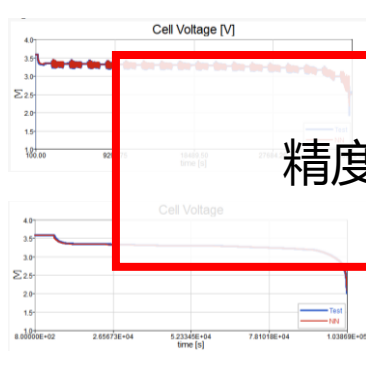
romAI 应用



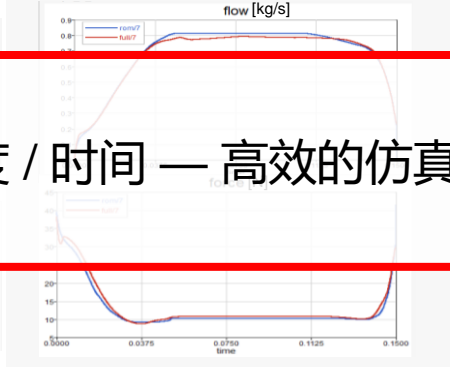
热学



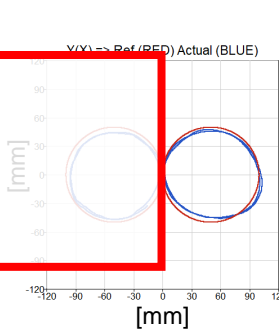
电学



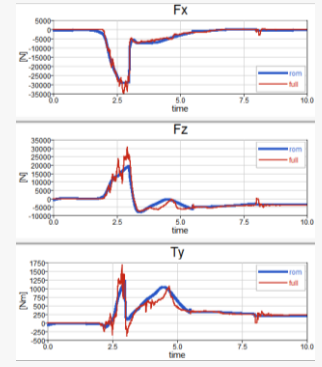
流体



机械

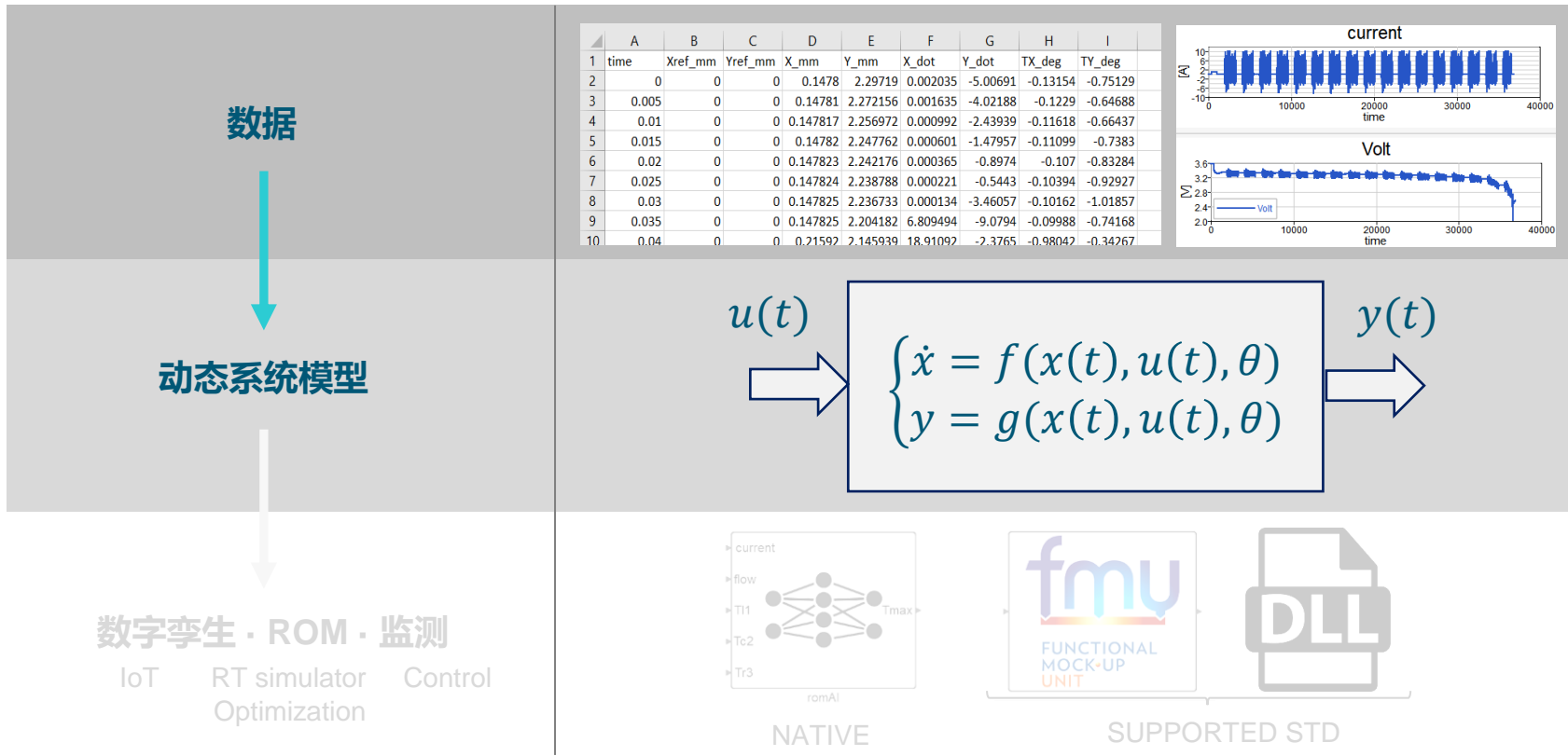


离散元



精度 / 时间 — 高效的仿真

romAI 目的

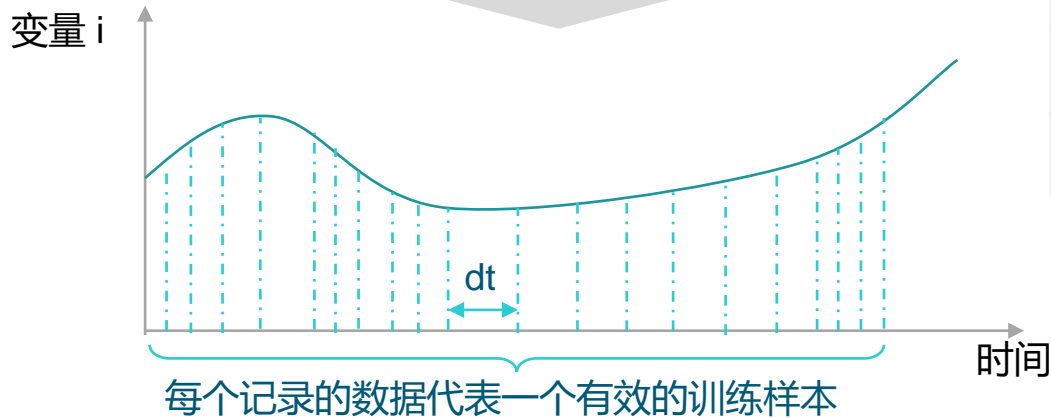


romAI: 基于数据生成的动态系统模型



少量的仿真/测试	
不受时间离散化影响	
集成用户的专业经验	
满足模型的泛化属性	

romAI: 数据



少量的仿真/测试



不受时间离散化影响



集成用户的专业经验

满足模型的泛化属性

romAI: 训练 (学习)



romAI Director 2021.2

Preprocessor Builder Viewer Time Sim

TrainData File: C:\Users\mariano\Desktop\TRAINING_MATH\romAI\Linear.csv
Dataset size: 30001

Data Labels:
time
s1
v1
s2
v2
F1
F2

Inputs: -

Physical constraints

Input Output State

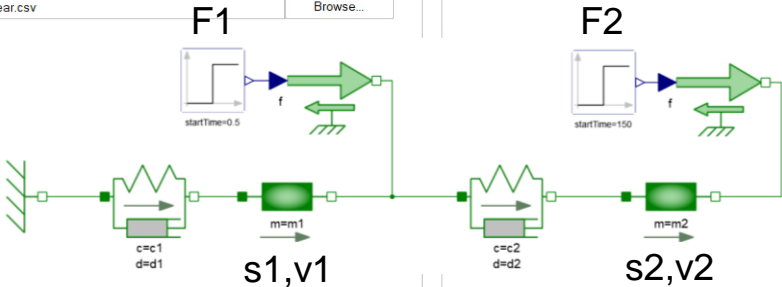
romAI Model Folder:

romAI Name:

Net Architecture:
Model Type: linear non linear
(Hidden) Activation Function: relu

Training Parameters:
 Output Normalization
Epochs: 10
Test Split Ratio: 0.2
 Early Stopping
Regularization Coefficient: 1e-6
Cross-validation Split Ratio: 0.25

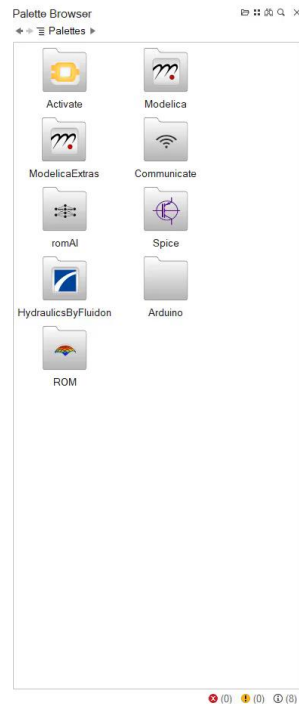
Reset Train



	time	s1	v1	s2	v2	F1	F2
71	0.69	0.014317	0.146037	0.000141	0.002504	1	0
72	0.7	0.015811	0.152854	0.000167	0.002839	1	0
73	0.71	0.017374	0.159567	0.000197	0.0032	1	0
74	0.72	0.019002	0.166174	0.000231	0.003589	1	0
75	0.73	0.020697	0.172672	0.000269	0.004005	1	0
76	0.74	0.022455	0.17906	0.000311	0.004451	1	0
77	0.75	0.024278	0.185334	0.000358	0.004925	1	0
78	0.76	0.026162	0.191495	0.00041	0.00543	1	0
79	0.77	0.028107	0.197539	0.000467	0.005966	1	0
80	0.78	0.030112	0.203465	0.000529	0.006533	1	0
81	0.79	0.032176	0.209271	0.000598	0.007132	1	0
82	0.8	0.034297	0.214957	0.000672	0.007763	1	0
83	0.81	0.036475	0.220519	0.000753	0.008428	1	0
84	0.82	0.038707	0.225957	0.000841	0.009126	1	0
85	0.83	0.040994	0.23127	0.000936	0.009859	1	0

- 仿真/测试
- 时间离散化影响
- 用户的专业经验
- 模型的泛化属性

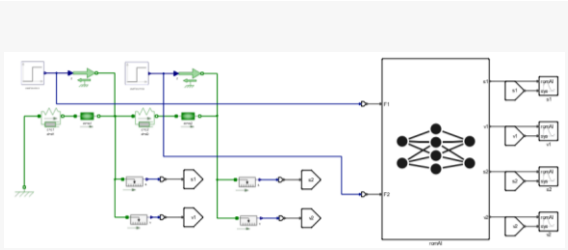
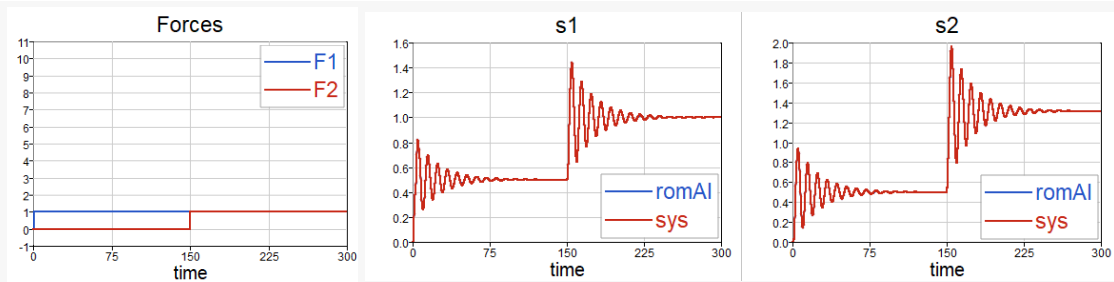
romAI: 动态系统



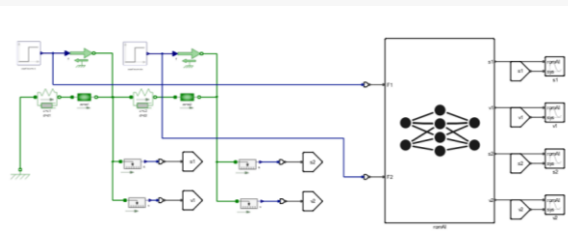
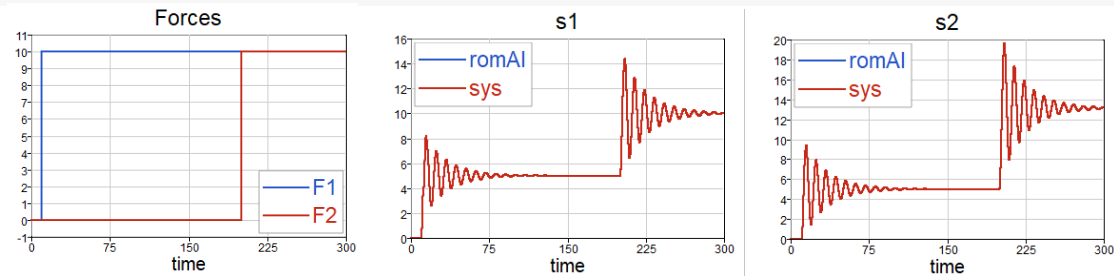
romAI: 动态系统



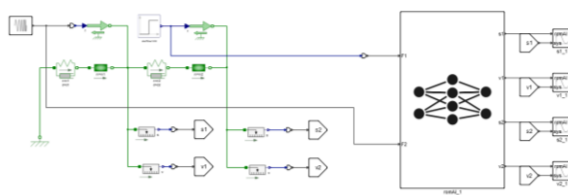
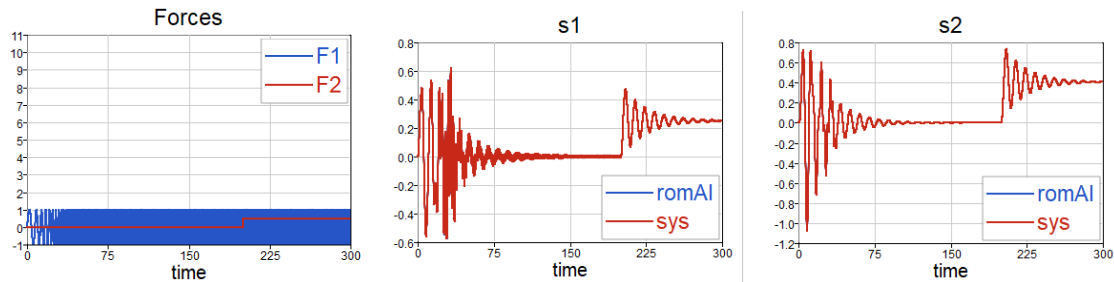
TRAINING SET



TEST 1



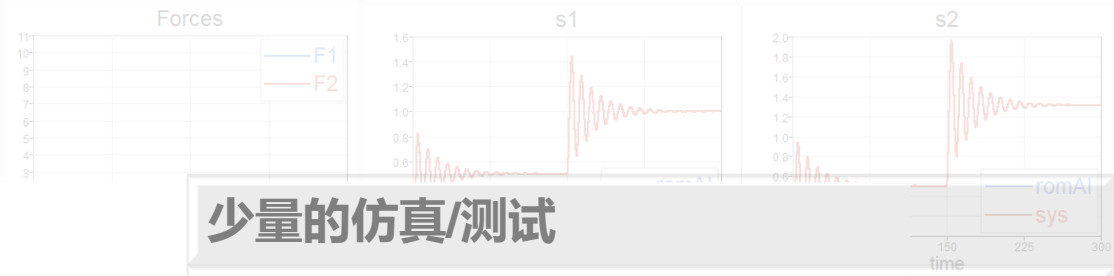
TEST 2



romAI: 动态系统



TRAINING SET

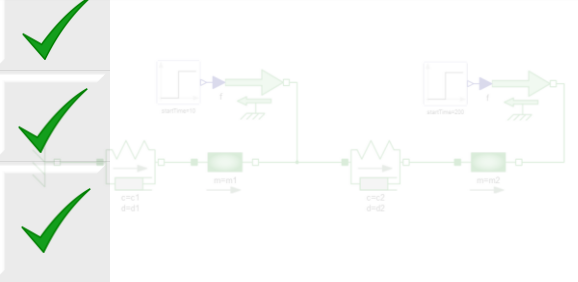
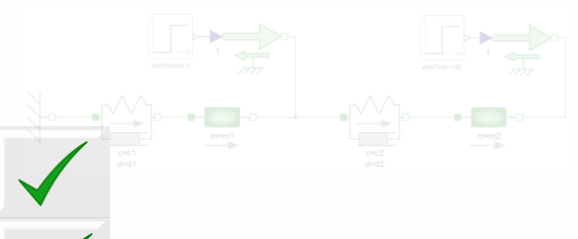


少量的仿真/测试

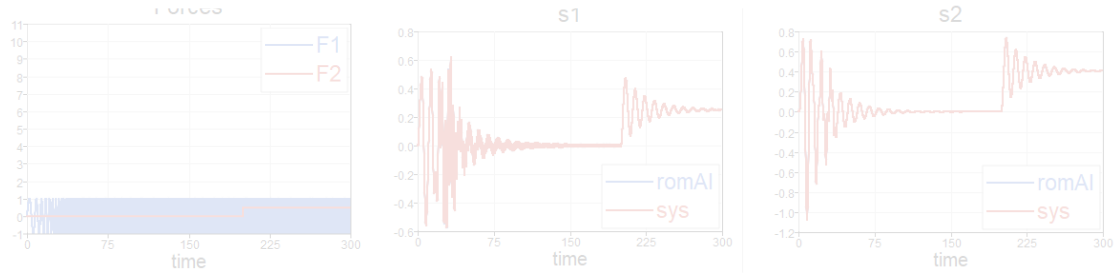
不受时间离散化影响

集成用户的专业经验

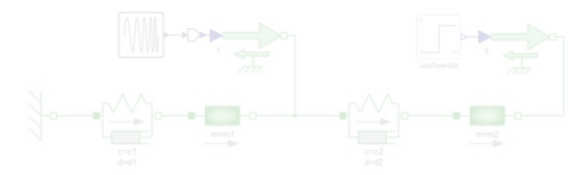
满足模型的泛化属性



T



TEST 2

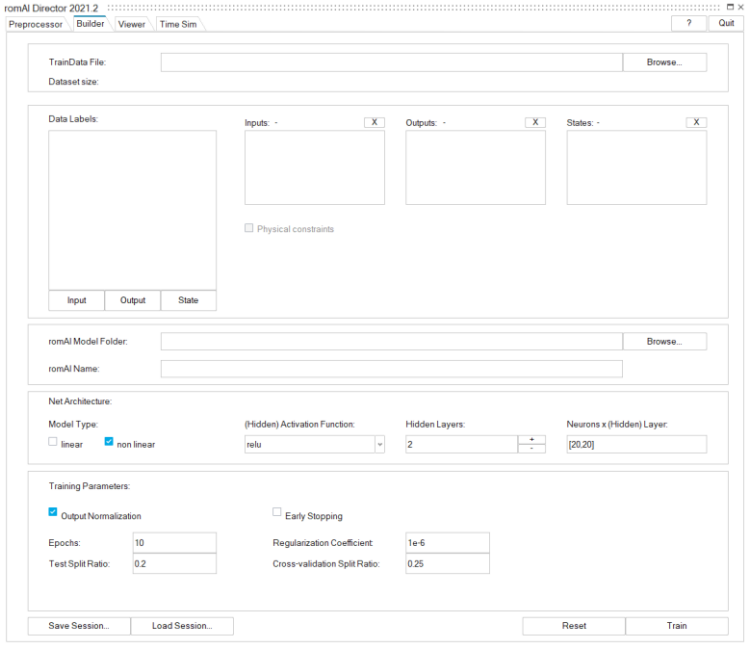


romAI

COMPOSE AND ACTIVATE

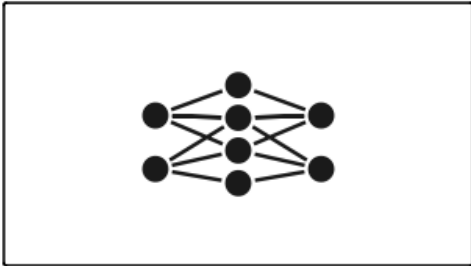
romAI tools

romAI Director



用于训练数据生成ROM



romAI block



romAI

用于时域系统仿真
(使用ROM)

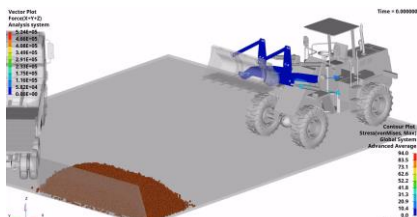
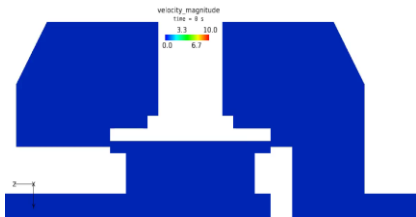
romAI: Activate/Compose

	romAI Director (*)	romAI block (*)
Compose 	✓	✗
Activate 	✓	✓

(* 需要在 Activate 、 Compose中安装 romAI library)

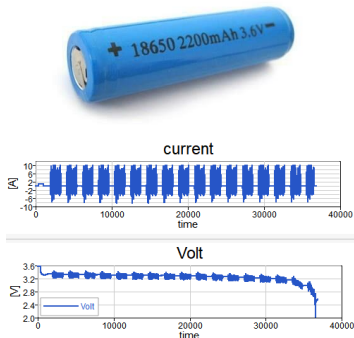
romAI 应用

Simulation



Reduced-Order Model

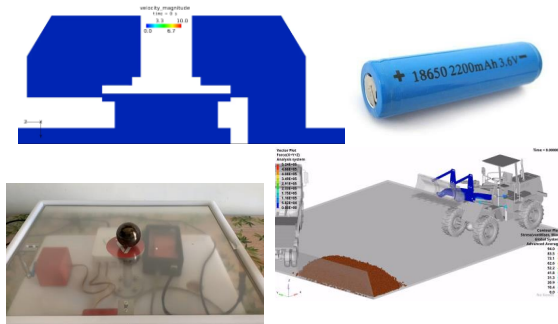
Real system



System Identification

romAI 使用流程 (ROM生成及应用)

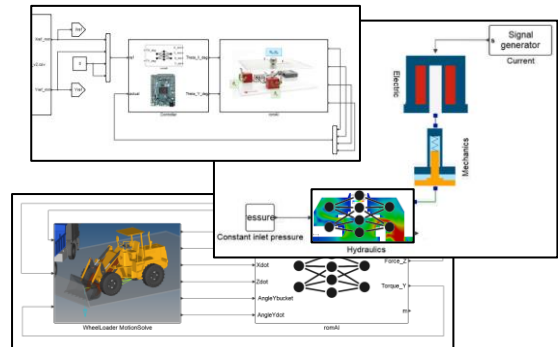
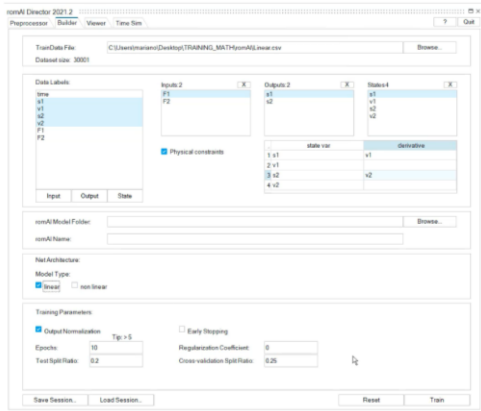
仿真或测试



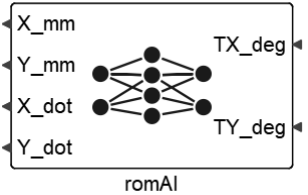
训练数据



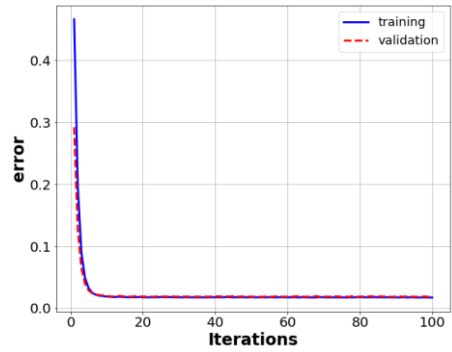
机器学习



系统仿真



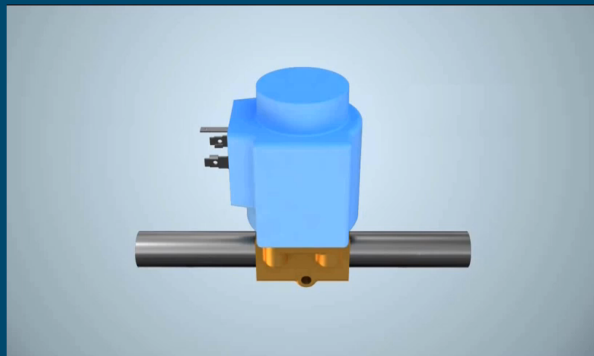
romAI



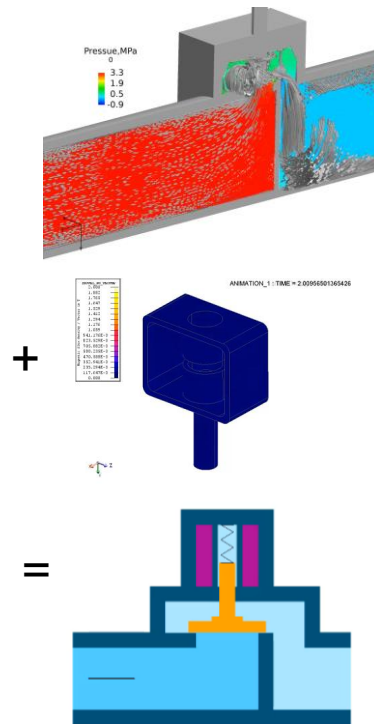


电磁阀 (SOLENOID VALVE)

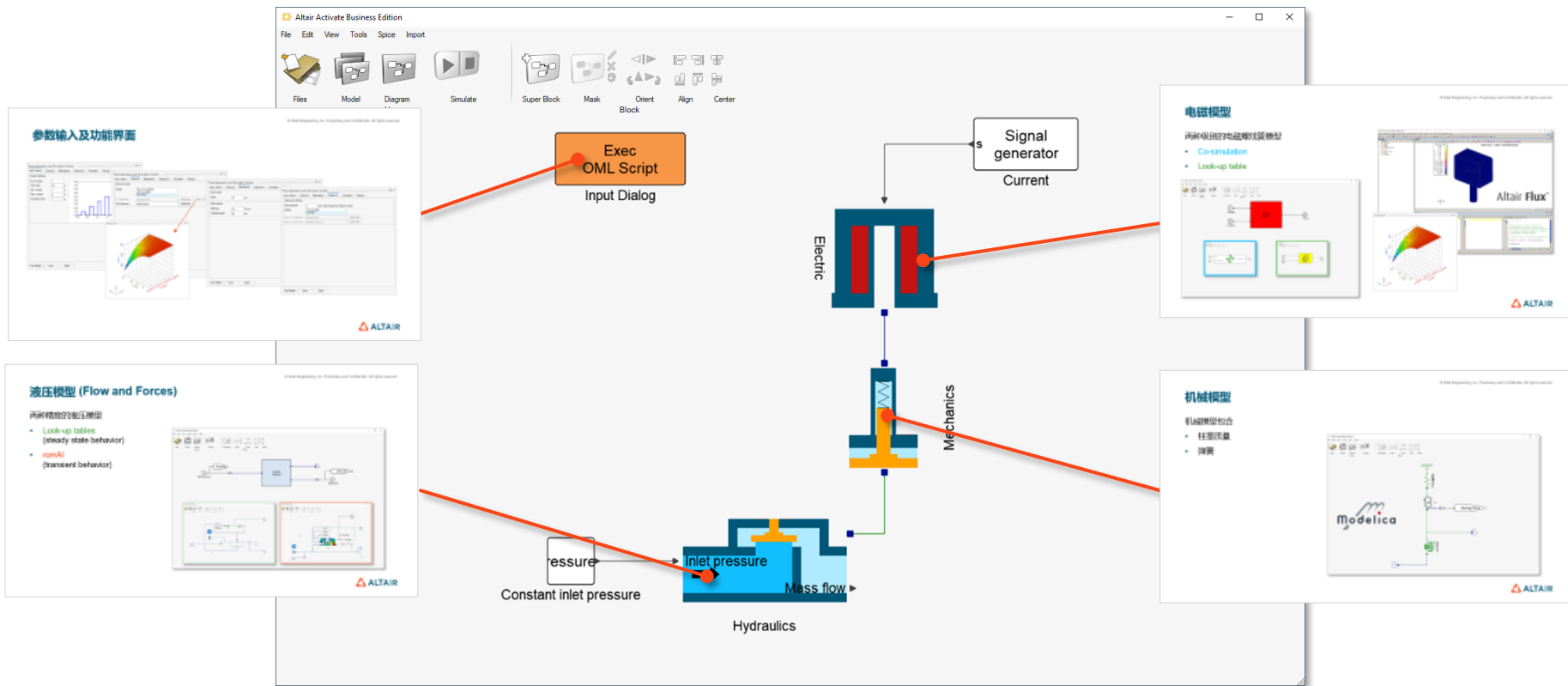
如何在保证精度的前提下减少仿真时间?



co-simulation



电磁阀系统分析模型



参数输入及功能界面

The image displays four overlapping windows from the Altair software interface, illustrating the parameterization and simulation control process.

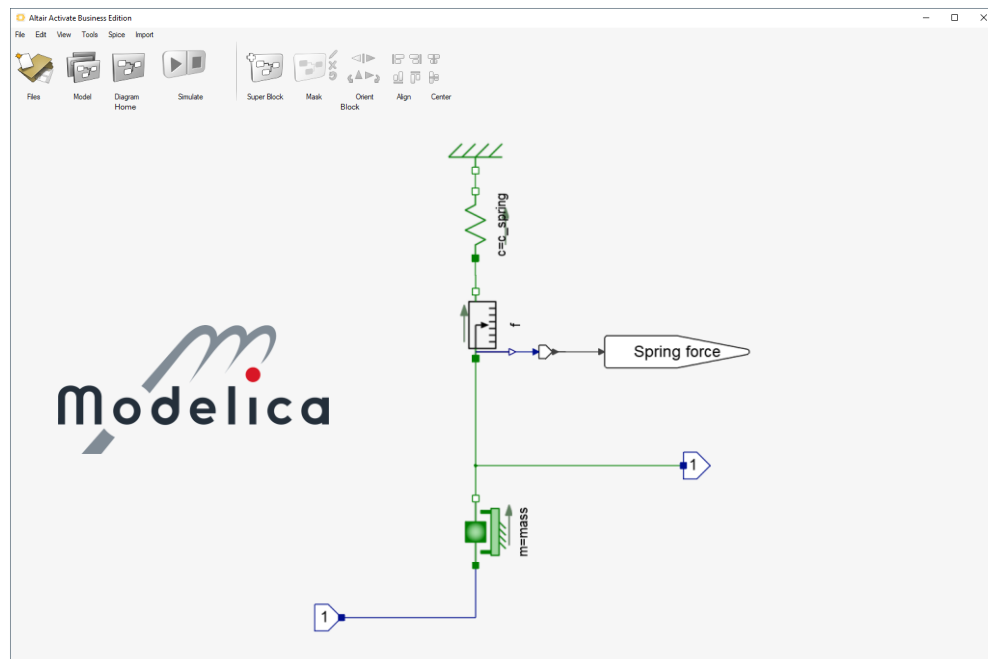
- Top Left Window:** "Parameterization and Simulation Control" with the "Input values" tab selected. It shows "Current settings" for simulation parameters: No. of steps (7), Time step (0.2 s), Min. current (1 A), Max. current (9 A), and Simulation time (3 s). A bar chart on the right shows current values over time.
- Top Middle Window:** "Parameterization and Simulation Control" with the "Solenoid" tab selected. It shows the "Solenoid model" configuration, including "Flux co-simulation", "Look-up table", and "Flux FMU". It also displays "LUT filename" (Solenoid.oml) and "FMU filename" (Solenoid.fmu) with "Select file" buttons. A red arrow points from the "Show LUT" button to the "Solenoid LUT" window.
- Top Right Window:** "Parameterization and Simulation Control" with the "Mechanics" tab selected. It shows "Valve body" settings: Mass (0.1 kg), "Valve spring" settings: Stiffness (0.5 N/mm) and Preload length (36 mm).
- Bottom Right Window:** "Parameterization and Simulation Control" with the "Hydraulics" tab selected. It shows "Hydraulics settings": Inlet pressure (2 bar), Model (Look-up table: neuROM), Row LUT filename (ValveFlow.txt), and Force LUT filename (HydraulicForce.bt).
- Bottom Center Window:** "Solenoid LUT" showing a 3D surface plot of the Look-Up Table (LUT) data. The plot shows a curved surface with a color gradient from blue to red, representing the relationship between input variables and output values. The axes are labeled X, Y, and Z.

Each window includes "Run Model", "Save", and "Close" buttons at the bottom.

机械模型

机械模型包含

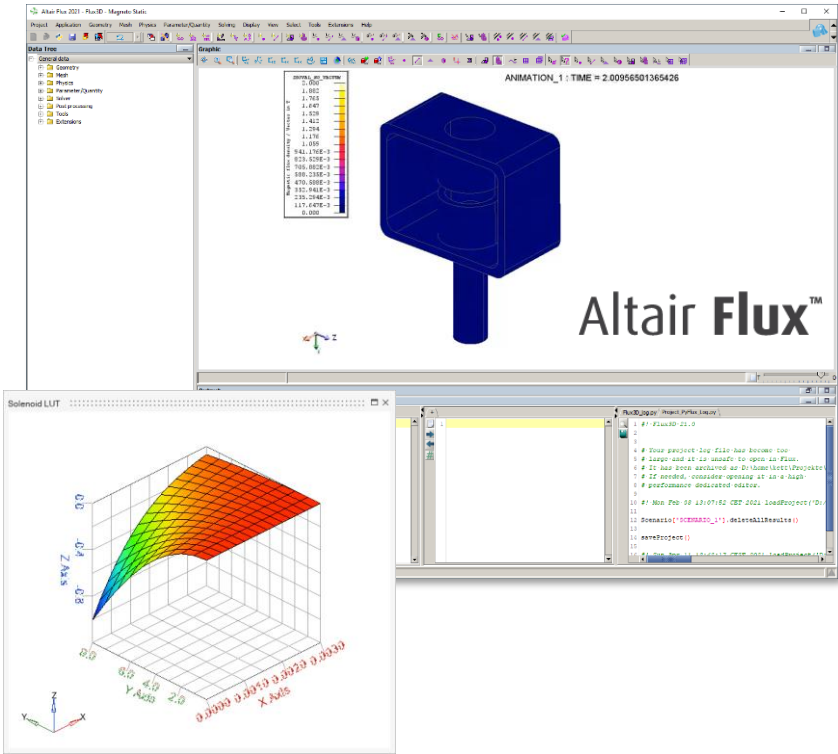
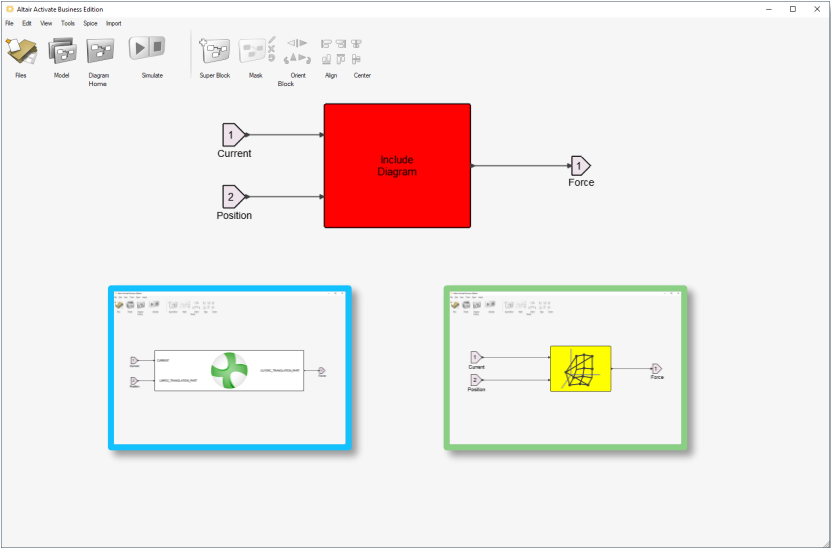
- 柱塞质量
- 弹簧



电磁模型

两种级别的电磁螺线管模型

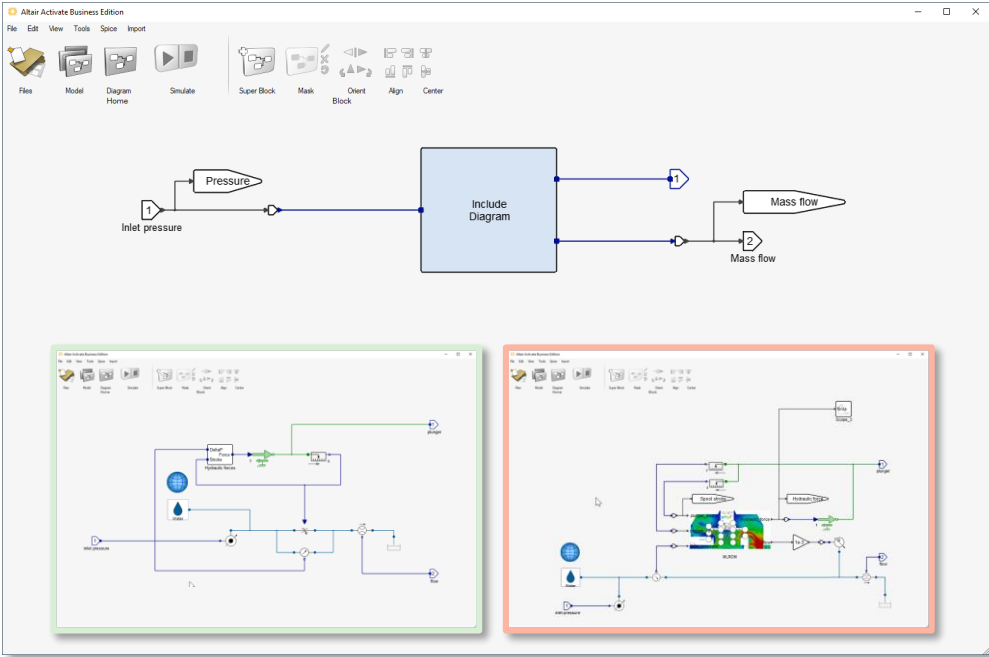
- Co-simulation
- Look-up table



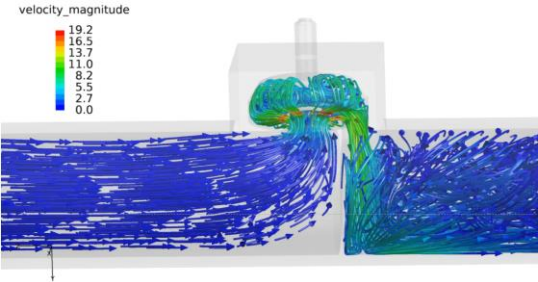
液压模型 (Flow and Forces)

两种精度的液压模型

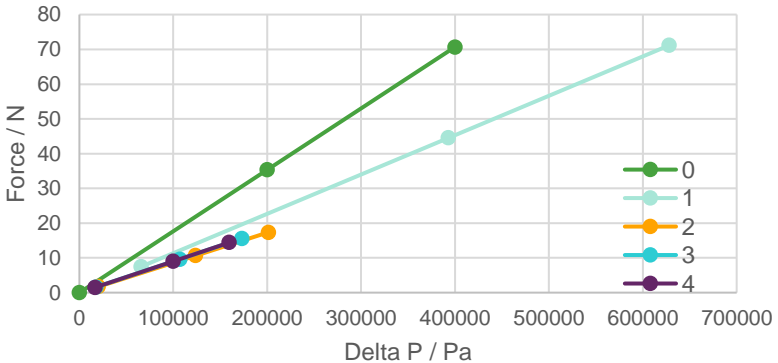
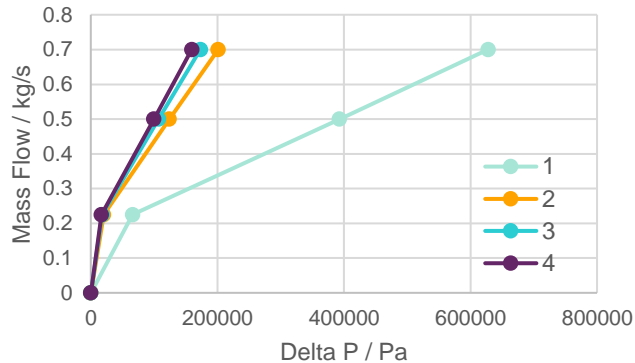
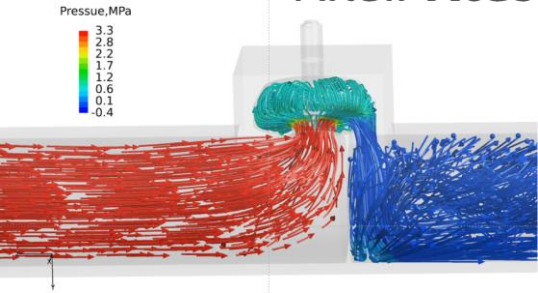
- Look-up tables (steady state behavior)
- romAI (transient behavior)



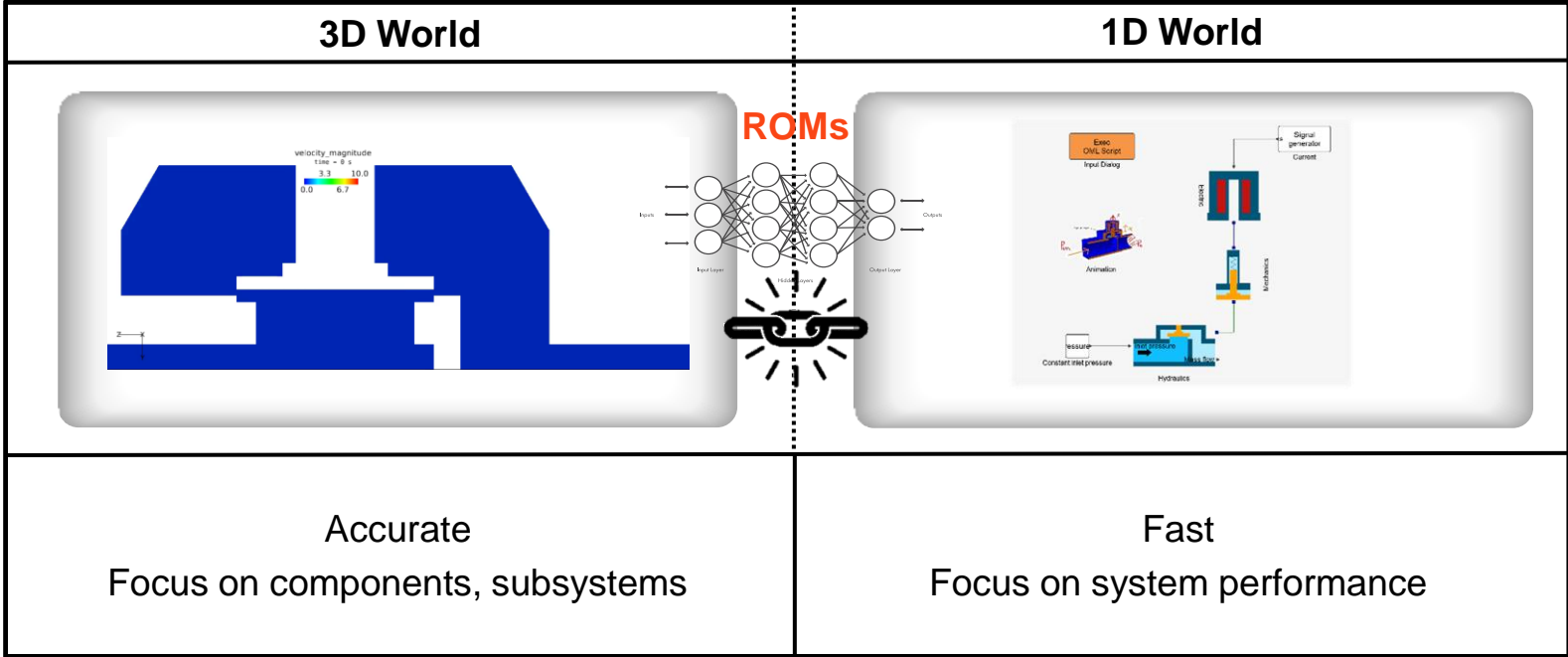
LUT Model – Flow and Force



Altair AcuSolve™

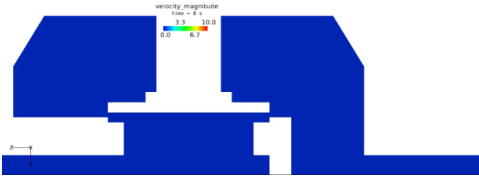


romAI – Best of Both Worlds



romAI – Generation and Usage

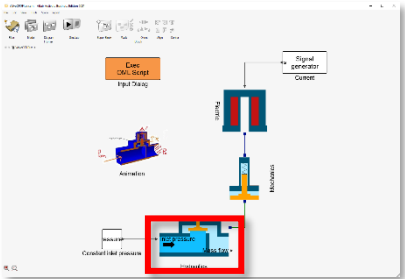
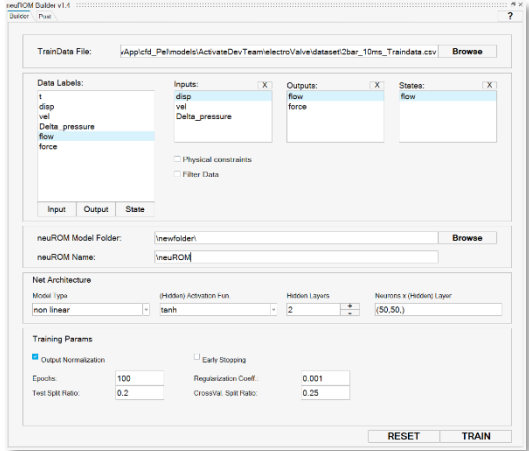
3D analysis



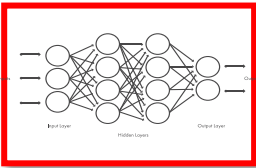
Training data

$$\begin{bmatrix} x(t_i) \\ v(t_i) \\ \Delta p(t_i) \\ Q(t_i) \\ F(t_i) \end{bmatrix}$$

Machine learning

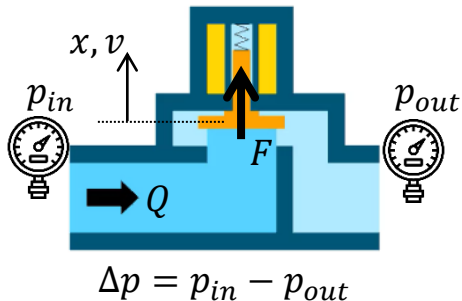


System simulation



romAI

romAI – CFD 问题描述



INPUTS:

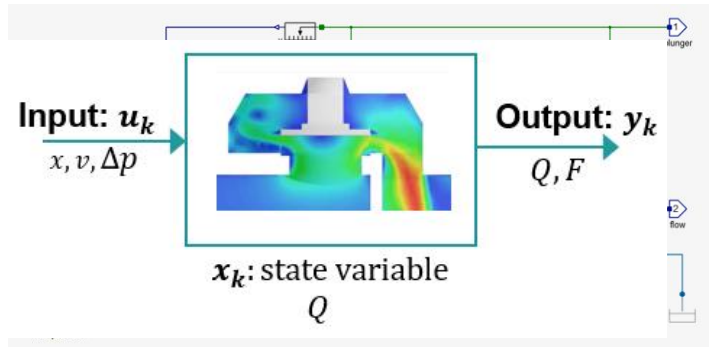
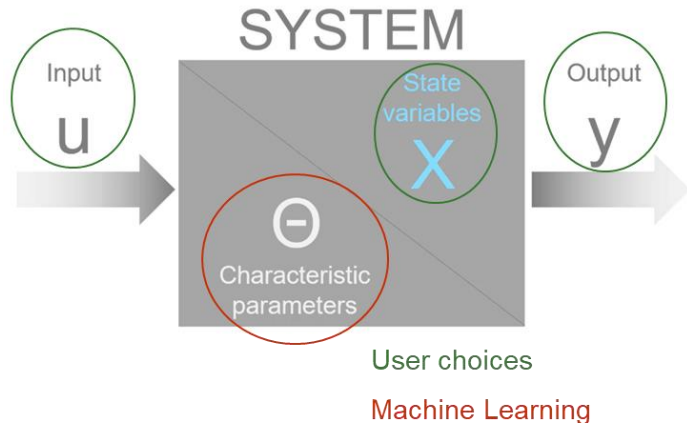
Plunger 位移 x
Plunger 速度 v
压力差 Δp

STATE VARIABLE:

流量 Q

OUTPUTS:

流量 Q
液压力 F

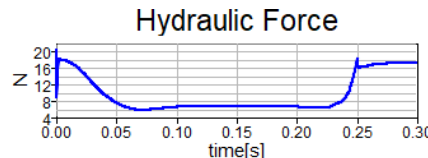
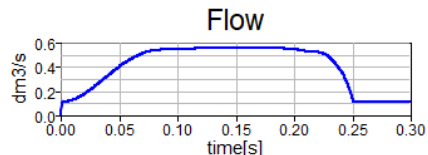
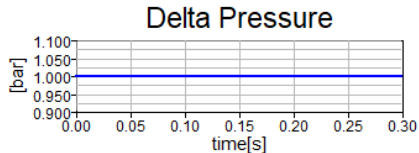
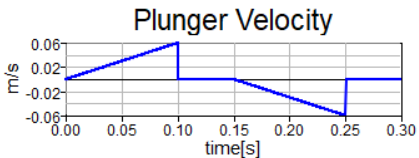
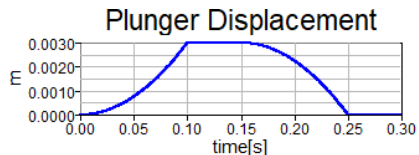
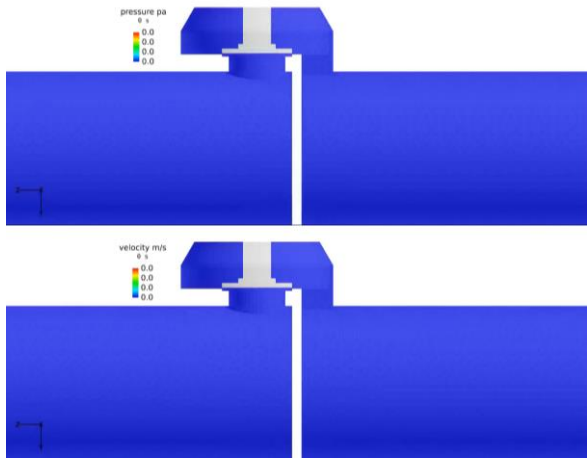


romAI – 从 CFD 仿真获得数据

训练数据通过采用CFD瞬态仿真4中不同工况获得 (~ 1700数据点) :

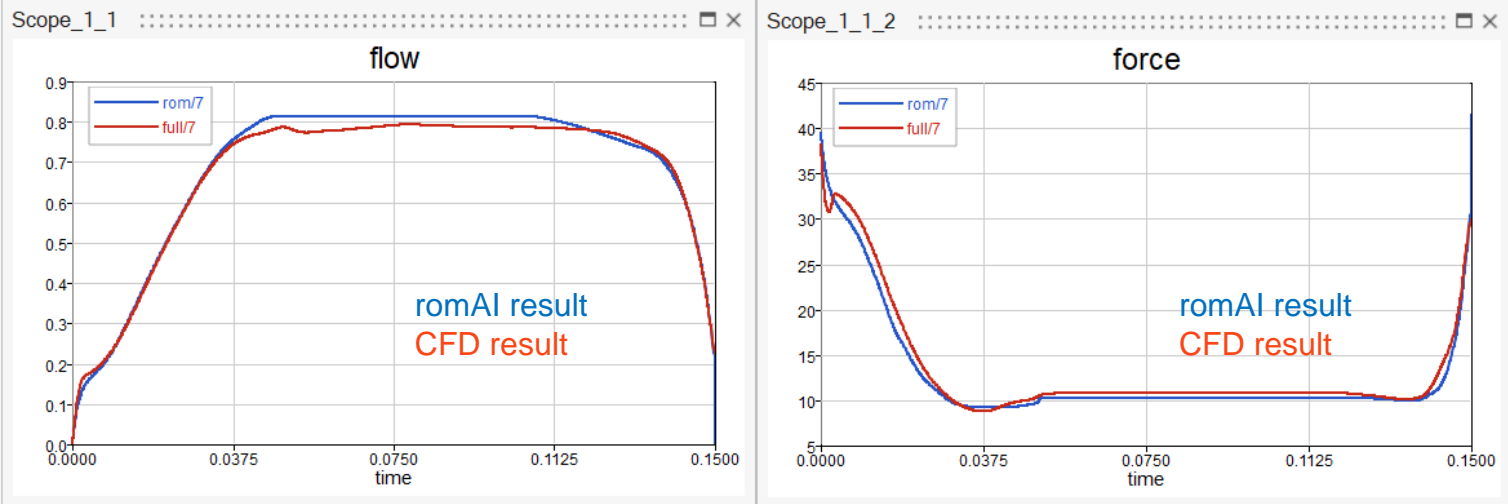
pInlet 2 bar, 4 bar
Opening time 10 ms, 100 ms

Example: results @ 2 bar inlet pressure and 100 ms opening time



romAI – CFD 仿真结果 vs romAI

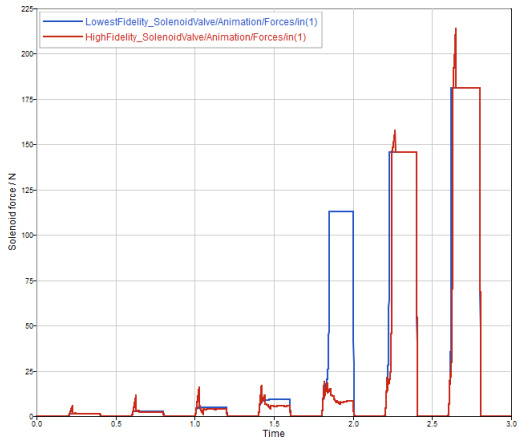
Test dataset @ 3 bar inlet pressure and 50 ms opening time.



两种模型系统仿真结果对比

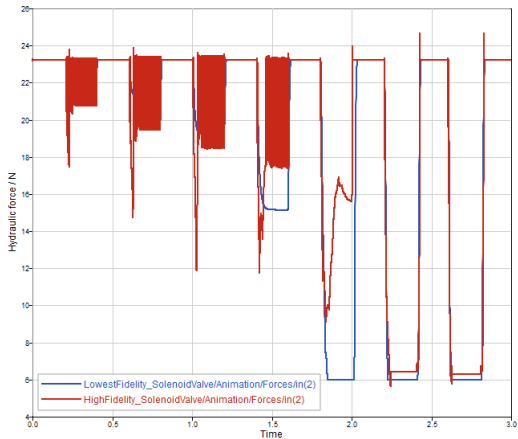
LUT vs. romAI

Solenoid force

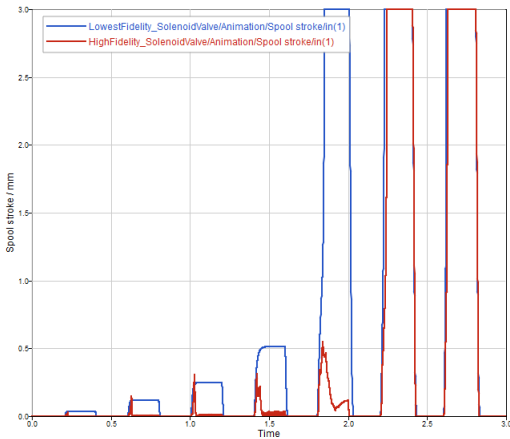


Hydraulic force

Lowest fidelity model Highest fidelity model



Spool stroke



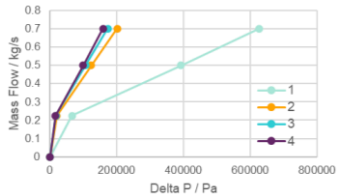
romAI 模型能够反映更多的系统动态行为，如力和行程结果的过冲。

Oscillation in hydraulic force is caused by missing CFD data for closed valve and simplification in transition to small openings.

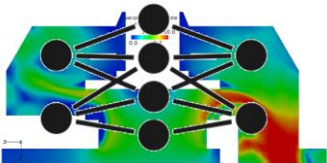
在瞬态和稳态状态下都保持较好的精度

STEADY STATE

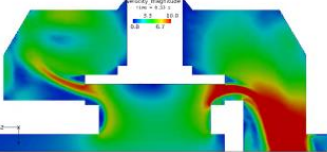
TRANSIENT



look-up table



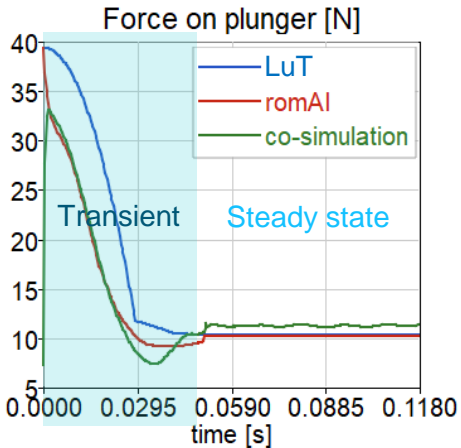
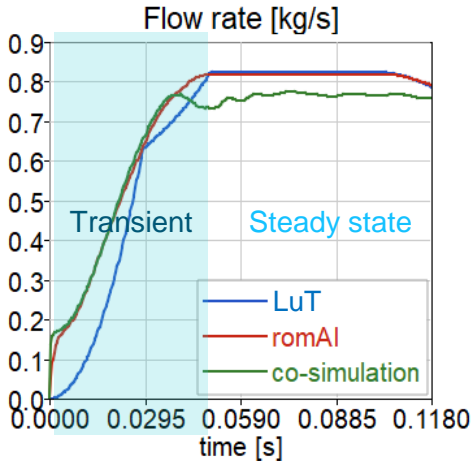
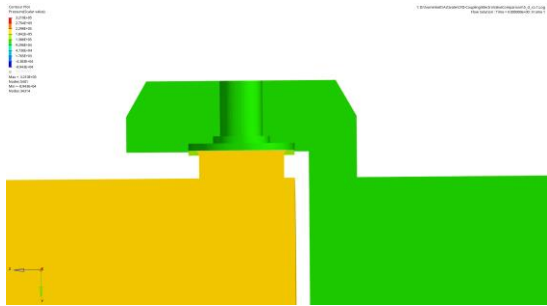
romAI



co-simulation



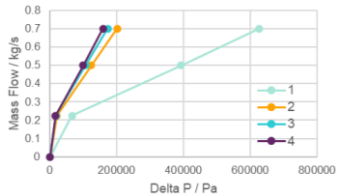
valve opening



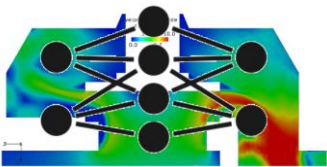
高效的兼容实时运行 (Real-time) 的降阶模型

STEADY STATE

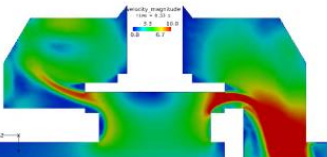
TRANSIENT



look-up table



romAI



co-simulation

ACCURACY

仿真时间

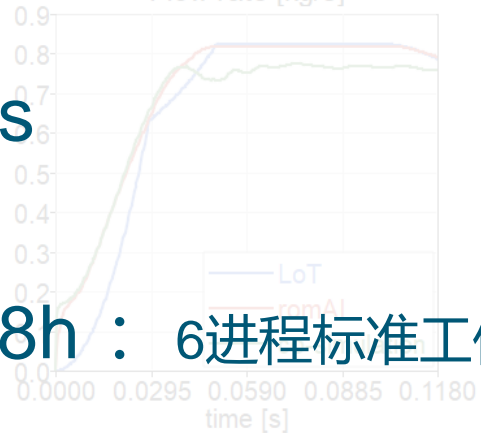
valve opening

<1s



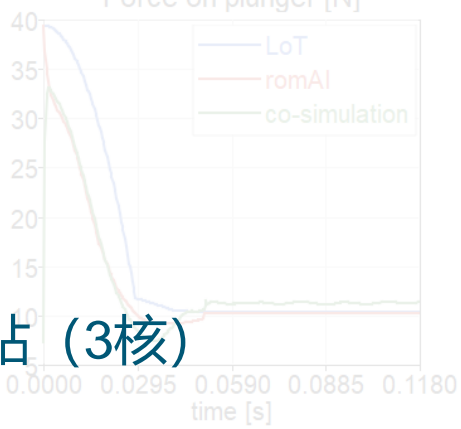
Flow rate [kg/s]

<1s



Force on plunger [N]

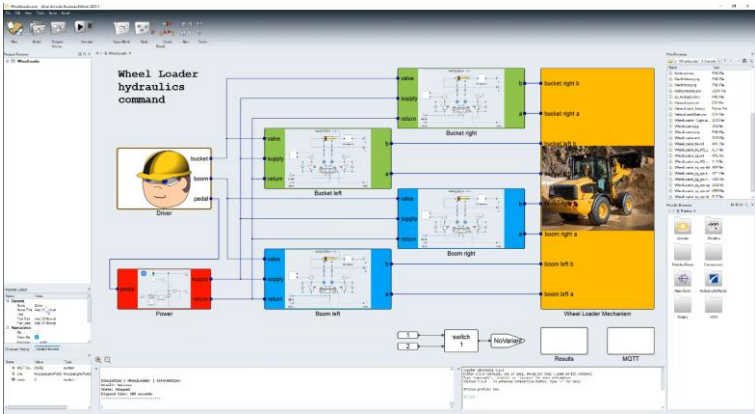
~18h : 6进程标准工作站 (3核)



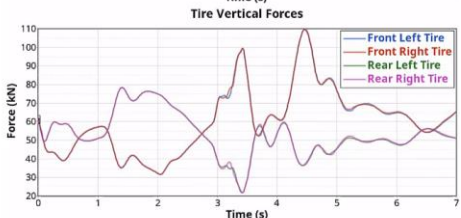
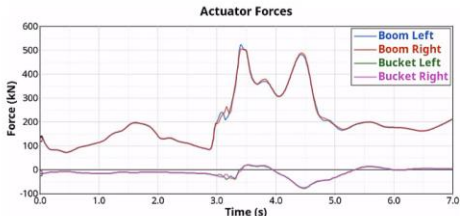
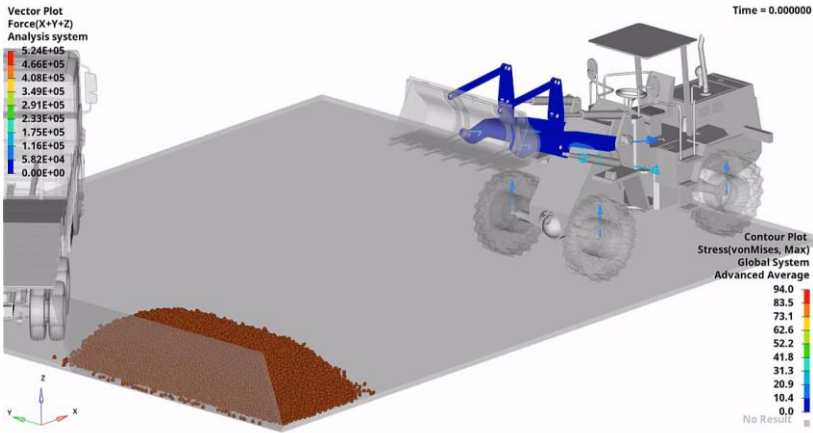


轮式装载机 (WHEEL LOADER)

系统集成



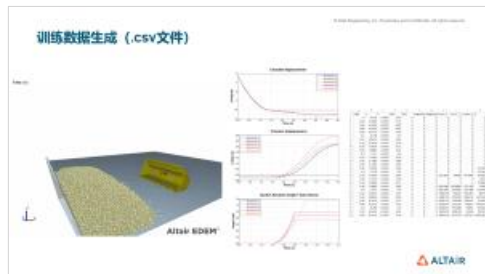
- 控制系统
- 液压执行机构
- 包含柔性组件的多体
- 散装物料



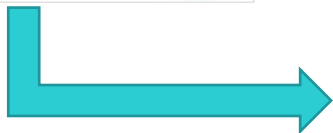
是否希望在保持精度的前提下减少仿真时间？

Wheel loader: 保持精度的前提下减少仿真时间

数据生成



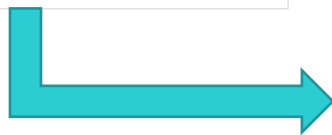
30 min



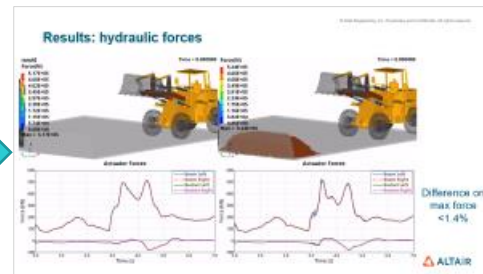
ROM 生成 & 验证



8h



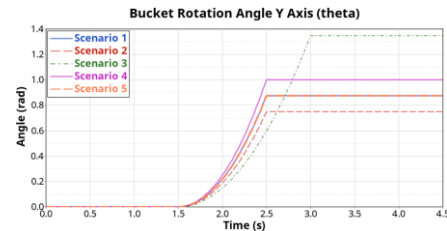
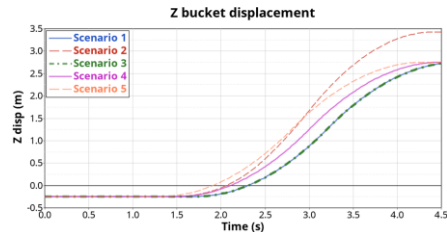
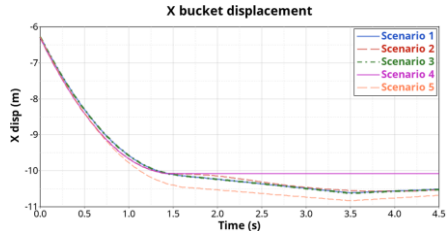
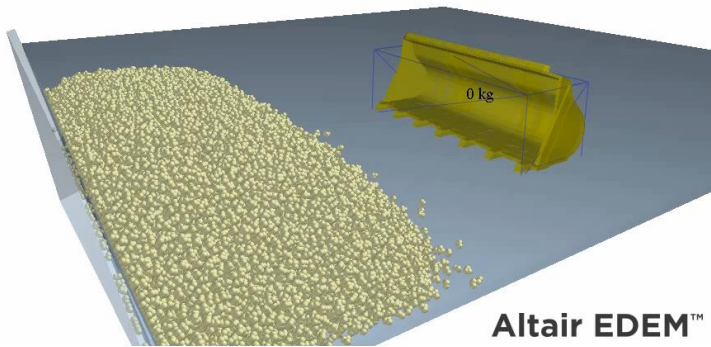
结果评估



15min

训练数据生成 (.csv文件)

Time: 0 s



TIME	X	Z	Xdot	Zdot	AngleYBuc	AngleYdot	Force_X	Force_Z	Torque_Y	Q	K
1	0	-6.273	-0.2452	-4.74	0	0	0	0	0	0	0
2	0.02	-6.3684	-0.2452	-4.74	0	0	0	0	0	0	0
3	0.04	-6.4626	-0.2452	-4.68	0	0	0	0	0	0	0
4	0.06	-6.5556	-0.2452	-4.62	0	0	0	0	0	0	0
5	0.08	-6.6474	-0.2452	-4.56	0	0	0	0	0	0	0
6	0.1	-6.738	-0.2452	-4.5	0	0	0	0	0	0	0
7	0.12	-6.8274	-0.2452	-4.44	0	0	0	0	0	0	0
8	0.14	-6.9156	-0.2452	-4.38	0	0	0	0	0	0	0
9	0.16	-7.0026	-0.2452	-4.32	0	0	0	0	0	0	0
10	0.18	-7.0884	-0.2452	-4.26	0	0	0	0	0	0	0
11	0.2	-7.173	-0.2452	-4.2	0	0	0	0	0	0	0
12	0.22	-7.2564	-0.2452	-4.14	0	0	0	0	0	0	0
13	0.24	-7.3386	-0.2452	-4.08	0	0	0	0	0	0	0
14	0.26	-7.4196	-0.2452	-4.02	0	0	0	0	0	0	0
15	0.28	-7.4994	-0.2452	-3.96	0	0	0	0	0	0	0.2399
16	0.3	-7.578	-0.2452	-3.9	0	0	0	0	0	0	0.7196
17	0.32	-7.6554	-0.2452	-3.84	0	0	0	131.3939	8.0284	-46.7906	0.9595
18	0.34	-7.7316	-0.2452	-3.78	0	0	0	0	0	0	1.679
19	0.36	-7.8066	-0.2452	-3.72	0	0	0	0	0	0	2.3986
20	0.38	-7.8804	-0.2452	-3.66	0	0	0	639.1005	155.8986	-157.428	3.598
21	0.4	-7.953	-0.2452	-3.6	0	0	0	903.5947	-16.2967	-373.388	6.7162
22	0.42	-8.0244	-0.2452	-3.54	0	0	0	1938.924	-250.81	-943.867	8.875
23	0.44	-8.0946	-0.2452	-3.48	0	0	0	3309.716	-379.431	-1601.52	15.1114
24	0.46	-8.1636	-0.2452	-3.42	0	0	0	8204.357	-1318.88	-4244.61	26.385
25	0.48	-8.2314	-0.2452	-3.36	0	0	0	20781.18	-1113.39	-9066.3	40.0573
26	0.5	-8.298	-0.2452	-3.3	0	0	0	25284.27	-441.686	-10315	56.368
27	0.52	-8.3634	-0.2452	-3.24	0	0	0	34529.97	-1000.55	-14196	79.395
28	0.54	-8.4276	-0.2452	-3.18	0	0	0	34452.39	-957.725	-14115.5	108.4185

数据训练 (生成ROM)

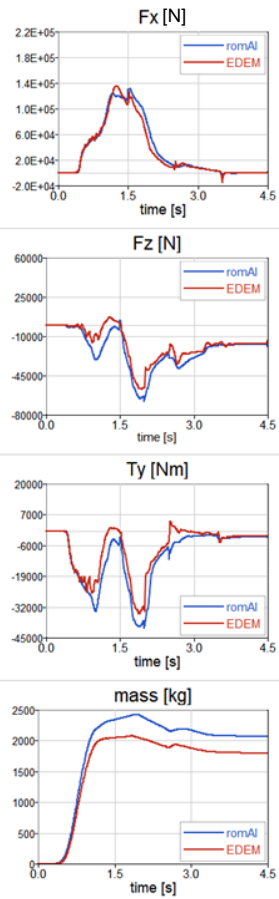
The screenshot displays the romAI Director 2021.2 software interface. The main window is titled "romAI Director 2021.2" and has a menu bar with "Preprocessor", "Builder", "Viewer", and "Time Sim". The interface is divided into several sections:

- TrainData File:** A text field with a "Browse..." button.
- Dataset size:** A text field.
- Data Labels:** A large empty text area with "Input", "Output", and "State" buttons below it.
- Inputs:** A text field with a "- X" button.
- Outputs:** A text field with a "- X" button.
- States:** A text field with a "- X" button.
- Physical constraints:** A checkbox labeled "Physical constraints".
- romAI Model Folder:** A text field with a "Browse..." button.
- romAI Name:** A text field.
- Net Architecture:**
 - Model Type:** Radio buttons for "linear" and "non linear" (selected).
 - (Hidden) Activation Function:** A dropdown menu showing "relu".
 - Hidden Layers:** A spinner box showing "2".
 - Neurons x (Hidden) Layer:** A text field showing "[20,20]".
- Training Parameters:**
 - Output Normalization:** A checked checkbox with a "Tip: > 9" note.
 - Early Stopping:** An unchecked checkbox.
 - Epochs:** A text field showing "10".
 - Regularization Coefficient:** A text field showing "1e-6".
 - Test Split Ratio:** A text field showing "0.2".
 - Cross-validation Split Ratio:** A text field showing "0.25".
- Buttons:** "Save Session...", "Load Session...", "Reset", and "Train".

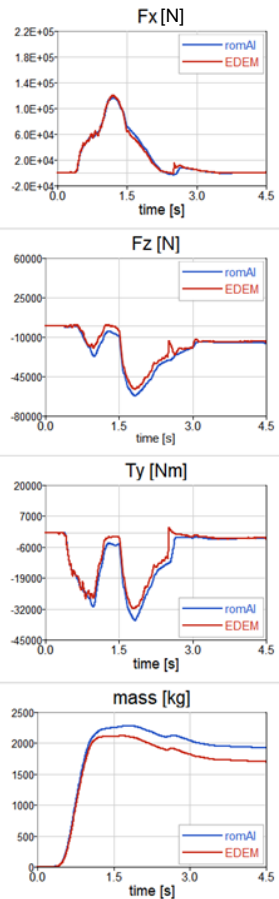
On the right side, there is a "Python Window" titled "Python Window" with a tab "In [11]:" and a large empty area for code.

模型验证

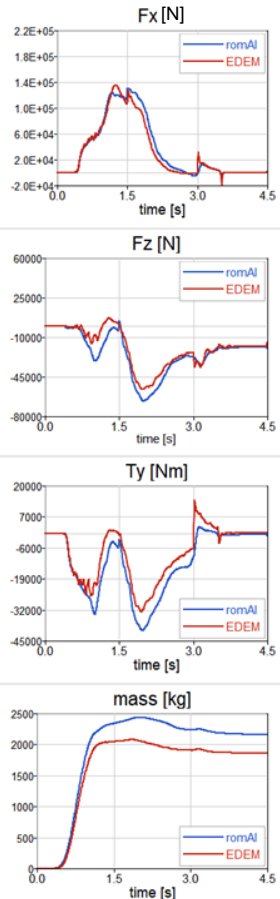
1st Simulation



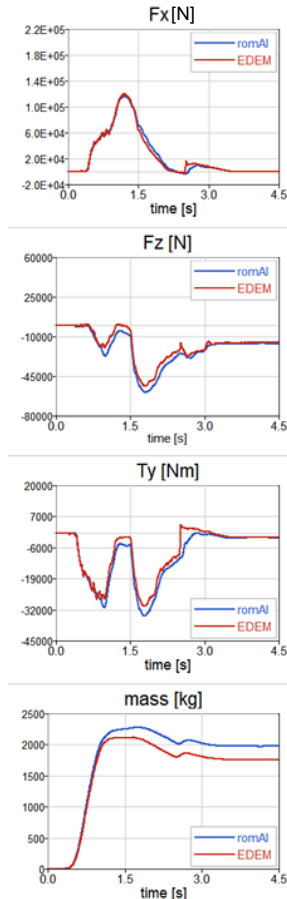
2nd Simulation



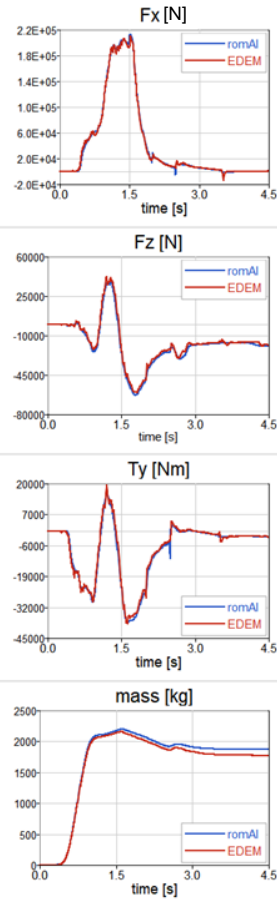
3rd Simulation



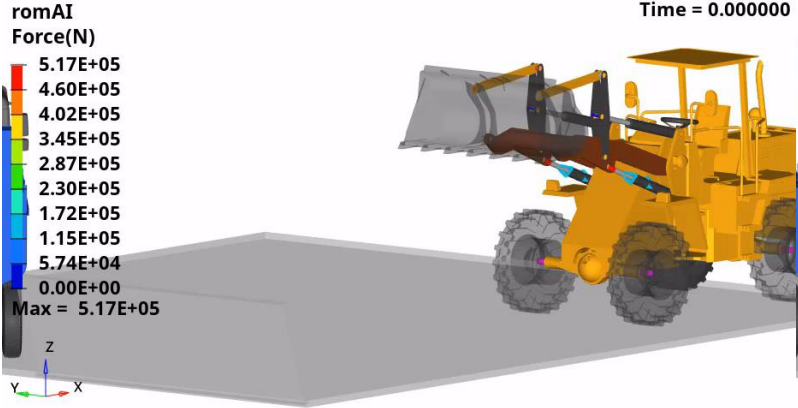
4th Simulation



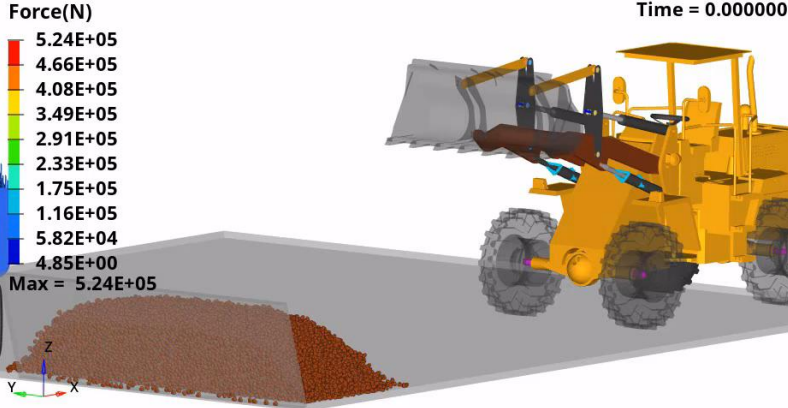
5th Simulation



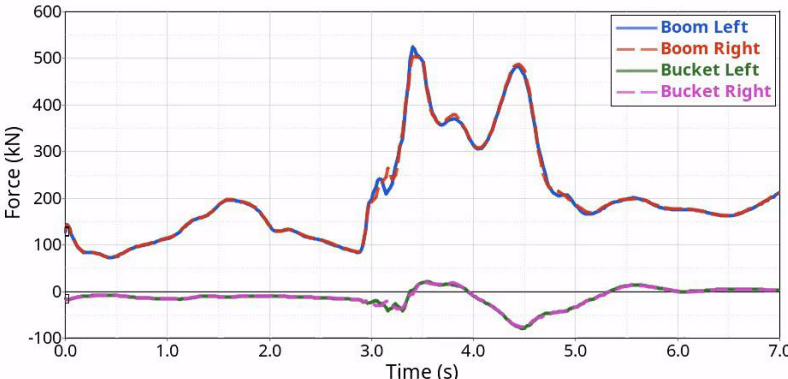
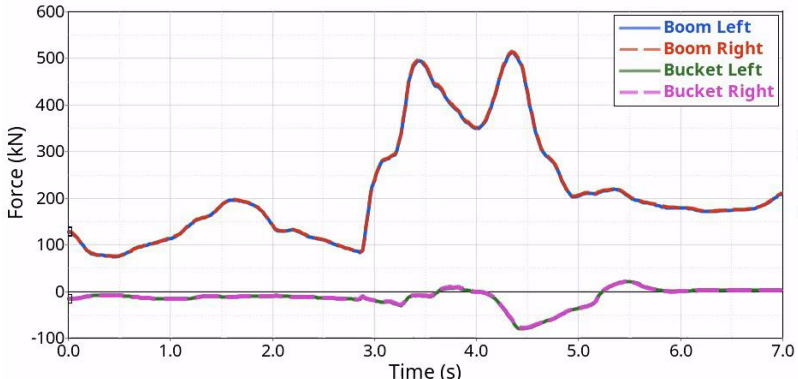
Results: hydraulic forces



Actuator Forces

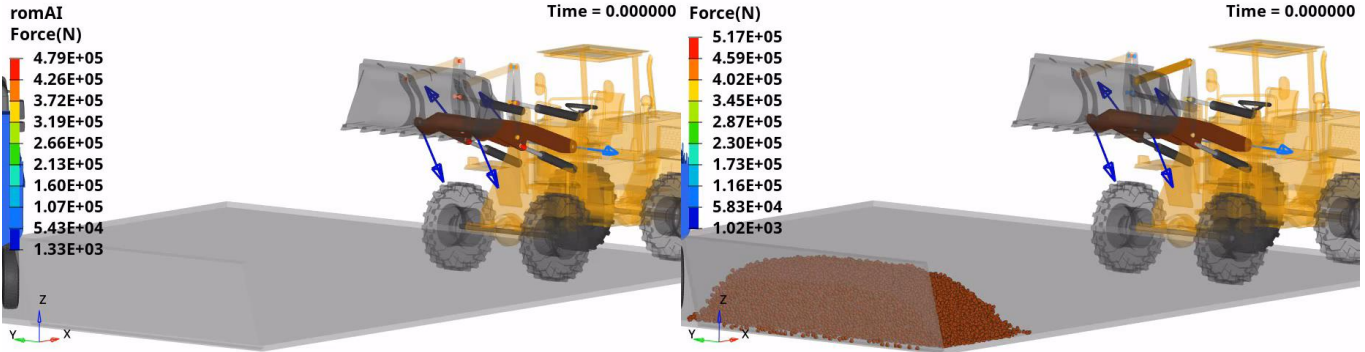
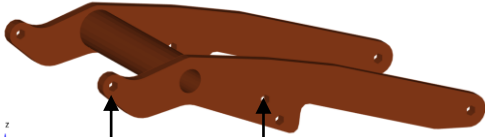


Actuator Forces



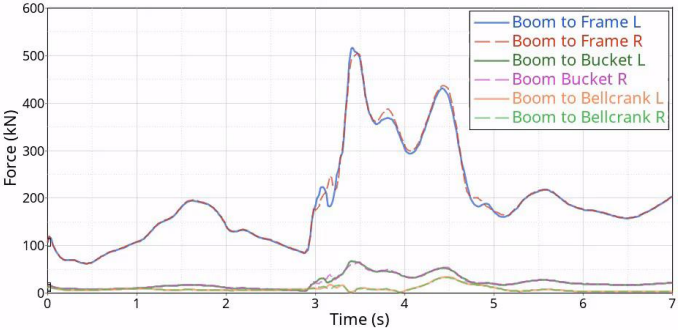
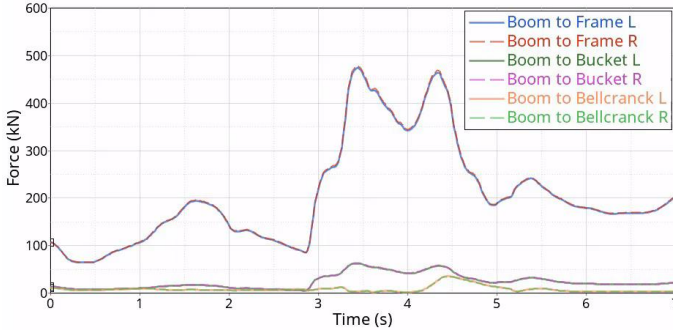
Difference on max force <1.4%

Results: joint forces



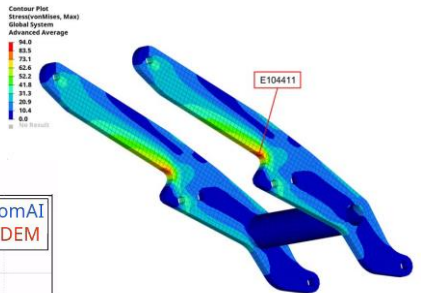
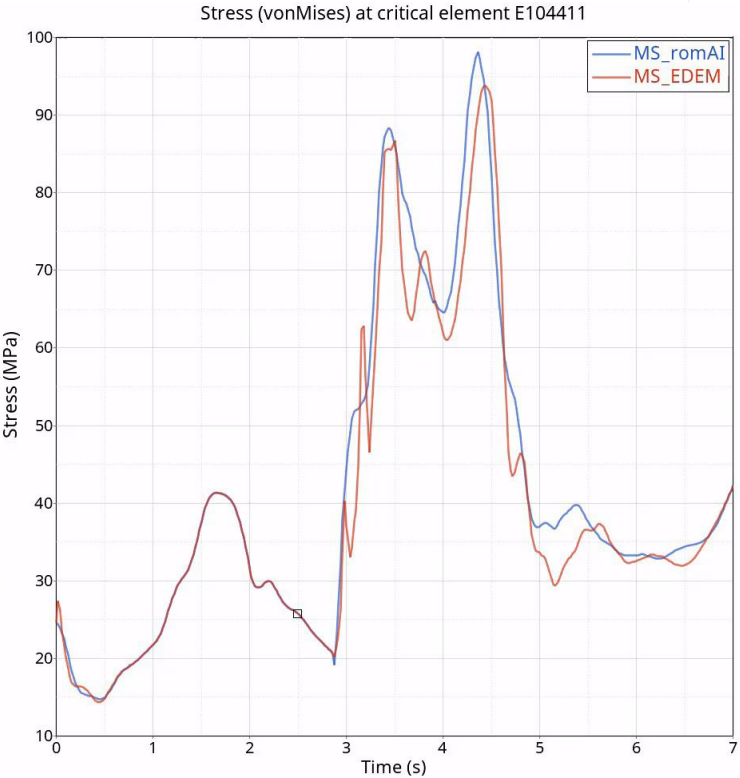
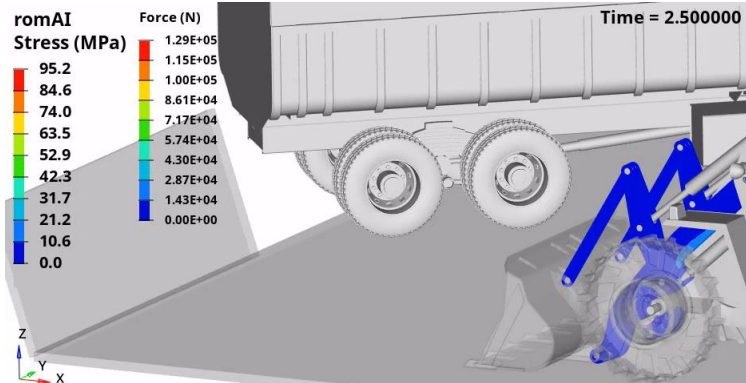
Boom Joint Forces (FM)

Boom Joint Forces (FM)



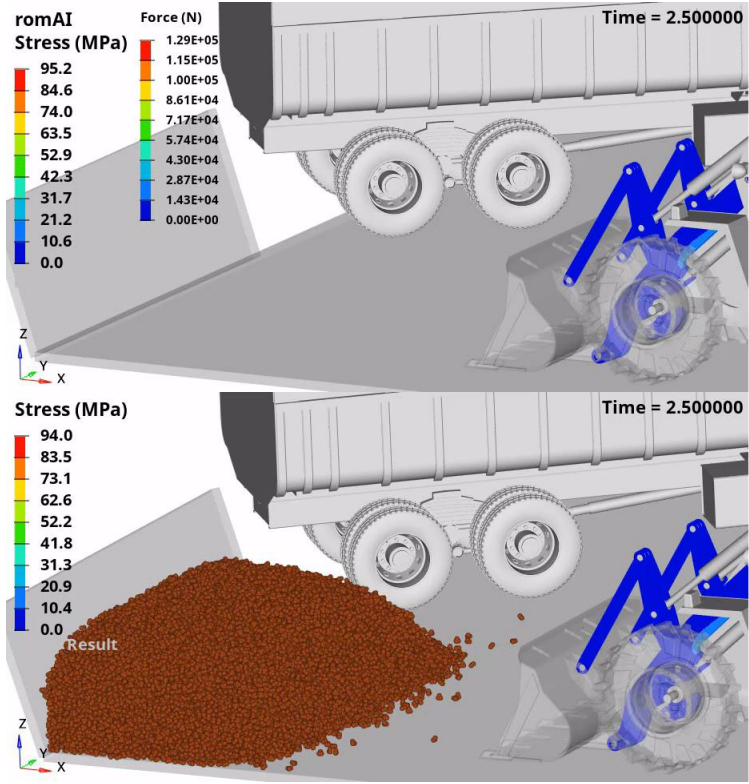
Difference on max force <7.4%

Results: 关键部位的 VonMises 应力



Difference on max stress <1.3%

Results: run time



20s
Motion - romAI

Vs

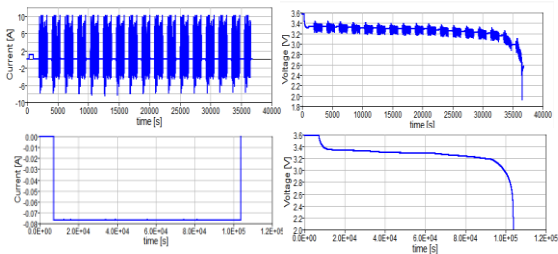
680s
Motion - EDEM



BATTERY CELL MODEL

Battery Cell: dynamical system

实验数据



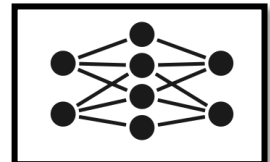
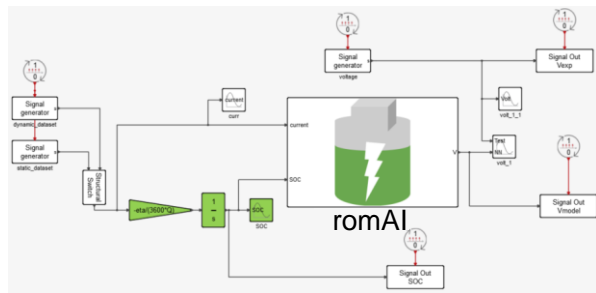
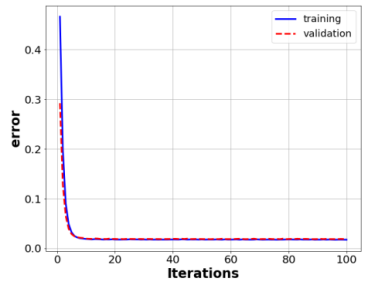
训练数据

$$\begin{bmatrix} i(t_i) \\ V(t_i) \\ SOC(t_i) \end{bmatrix}$$



x : state variables
SOC

机器学习

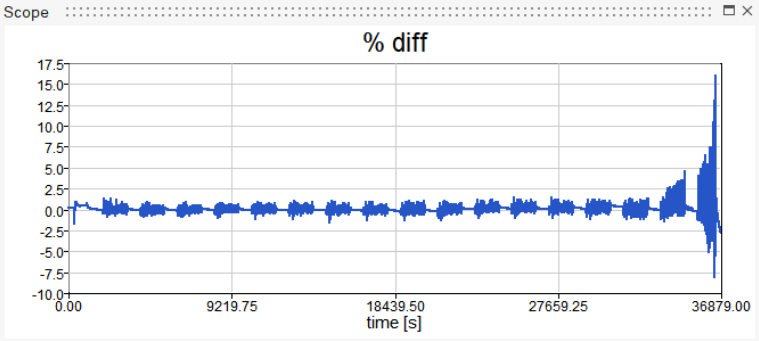
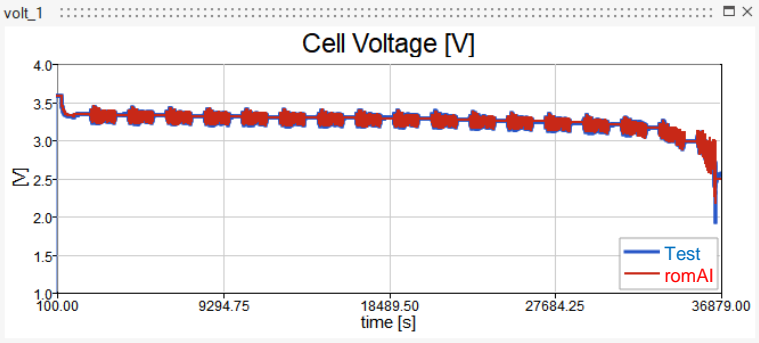


romAI

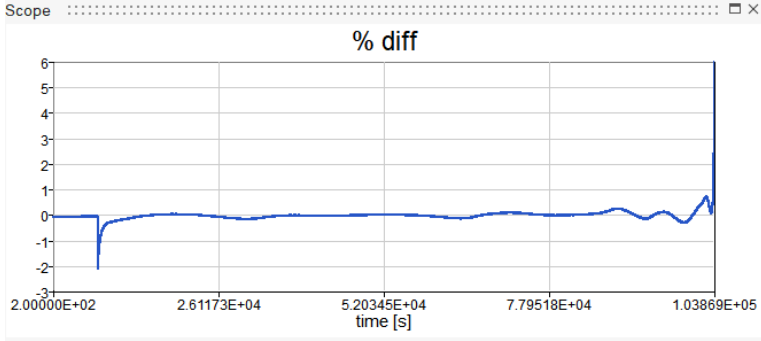
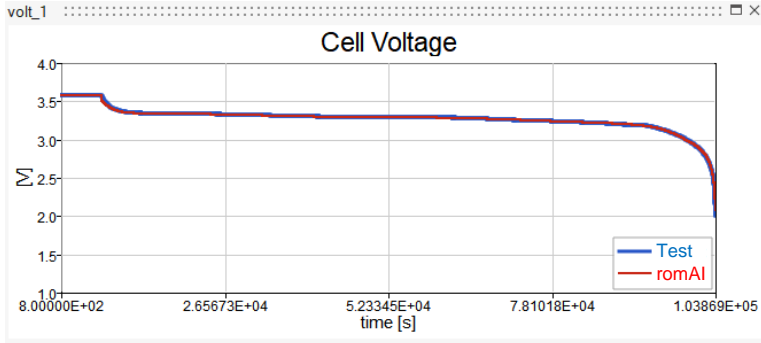
系统仿真

Results: dynamic and quasi-static tests

Dynamic



Quasi-Static

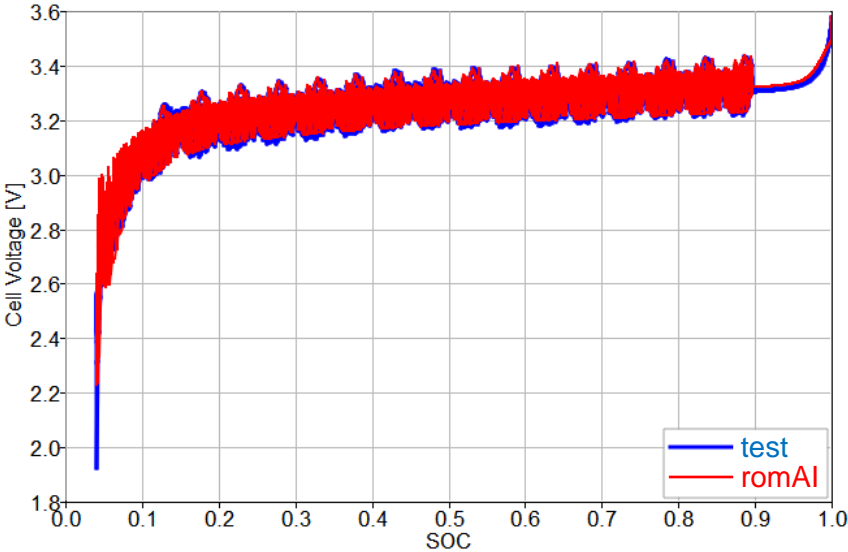


Difference mostly less than 2.5%

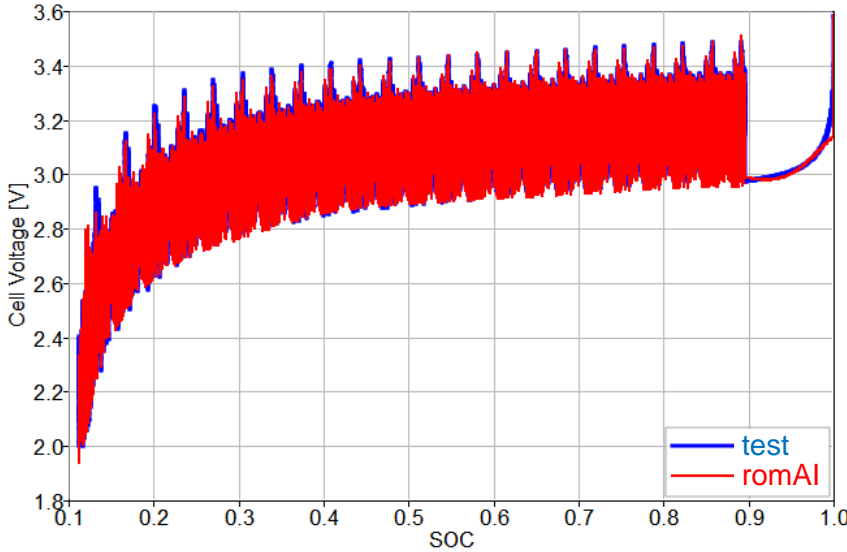


Results: Hysteresis

T = +25 degC

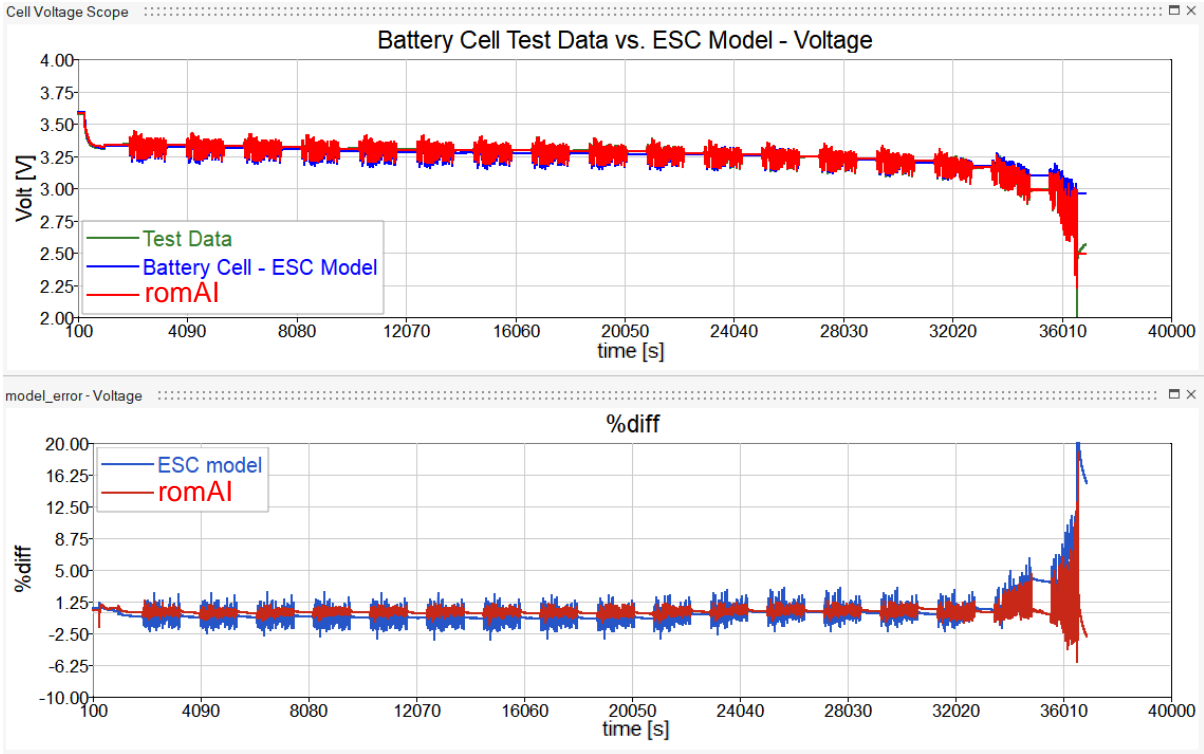


T = -25 degC



Very good modeling of the hysteretic behavior

Results: romAI vs ESC battery model



T = +25 degC

romAI performs better than ESC battery model





BALL AND BALANCING TABLE

BBT: 利用人工智能设计控制器

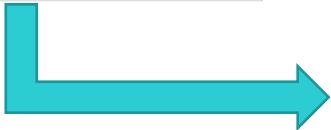


Control of the Ball Balancing Table (BBT) from Acrome

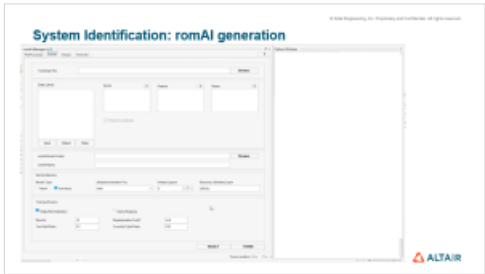
数据生成



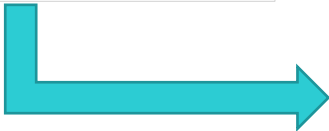
110s



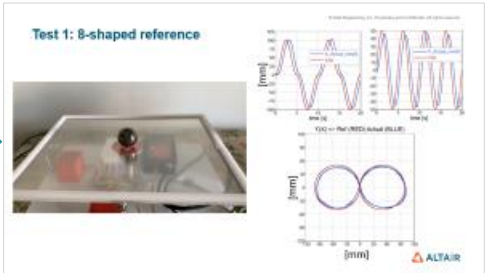
系统辨识 & 控制设计



4.5h



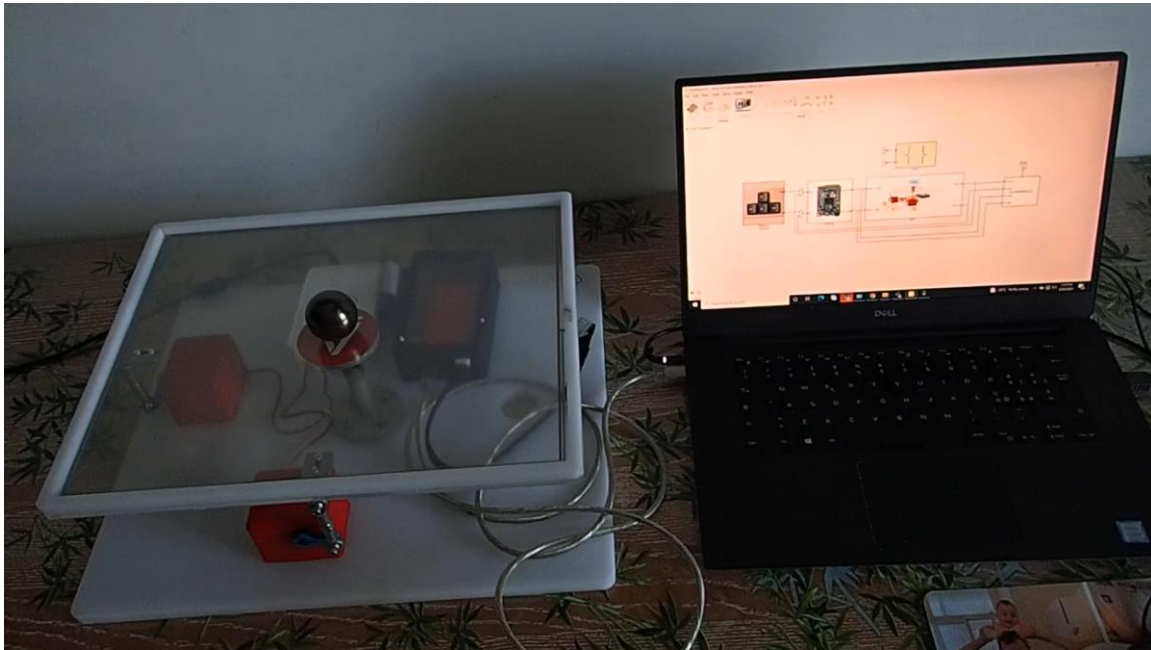
测试



15min

数据生成 (.csv文件)

Randomly playing for 110s



	A	B	C	D	E	F	G	H	I
1	time	Xref_mm	Yref_mm	X_mm	Y_mm	X_dot	Y_dot	TX_deg	TY_deg
2	0	0	0	0.1478	2.29719	0.002035	-5.00691	-0.13154	-0.75129
3	0.005	0	0	0.14781	2.272156	0.001635	-4.02188	-0.1229	-0.64688
4	0.01	0	0	0.147817	2.256972	0.000992	-2.43939	-0.11618	-0.66437
5	0.015	0	0	0.14782	2.247762	0.000601	-1.47957	-0.11099	-0.7383
6	0.02	0	0	0.147823	2.242176	0.000365	-0.8974	-0.107	-0.83284
7	0.025	0	0	0.147824	2.238788	0.000221	-0.5443	-0.10394	-0.92927
8	0.03	0	0	0.147825	2.236733	0.000134	-3.46057	-0.10162	-1.01857
9	0.035	0	0	0.147825	2.204182	6.809494	-9.0794	-0.09988	-0.74168
10	0.04	0	0	0.21592	2.145939	18.91092	-2.3765	-0.98042	-0.34267
11	0.045	0	0	0.336935	2.180417	7.056906	-5.306	-2.24316	-0.92738
12	0.05	0	0	0.286489	2.092879	4.280232	-16.1617	-1.14808	-0.10704
13	0.055	0	0	0.379737	2.0188	14.98058	-11.9009	-2.05039	0.374543
14	0.06	0	0	0.436295	1.97387	9.086187	-7.21829	-2.32564	0.459276
15	0.065	0	0	0.470599	1.946618	5.511053	-4.37812	-2.28084	0.348852
16	0.07	0	0	0.491405	1.930088	3.342624	-2.65546	-2.08883	0.155527
17	0.075	0	0	0.504025	1.920063	2.027405	-1.61062	-1.8441	-0.06046
18	0.08	0	0	0.511679	1.913982	-8.50653	-0.97689	-1.59585	-0.26867
19	0.085	0	0	0.41896	1.910294	-7.55573	-0.59251	-0.13833	-0.45542
20	0.09	0	0	0.436122	1.908057	5.153426	-0.35938	-0.41061	-0.6161
21	0.095	0	0	0.470494	1.9067	12.33139	-0.21797	-0.79145	-0.75081
22	0.1	0	0	0.559436	1.905877	12.52391	-0.13221	-1.81248	-0.86185
23	0.105	0	0	0.595733	1.905378	0.786723	-0.08019	-1.85986	-0.95238
24	0.11	0	0	0.567303	1.905075	-4.56737	-0.04864	-1.18889	-1.02565
25	0.115	0	0	0.550059	1.904892	-2.77025	-0.0295	-0.79696	-1.08473

Yes, only 110s!

System Identification: romAI generation

The screenshot displays the romAI Manager v2.0 software interface. The main window is titled "romAI Manager v2.0" and contains several configuration sections:

- TrainData File:** A text input field with a "Browse" button.
- Data Labels:** A large empty rectangular area.
- Inputs:** A text input field with an "X" button.
- Outputs:** A text input field with an "X" button.
- States:** A text input field with an "X" button.
- Physical constraints:** A checkbox that is currently unchecked.
- romAI Model Folder:** A text input field with a "Browse" button.
- romAI Name:** A text input field.
- Net Architecture:**
 - Model Type:** Radio buttons for "linear" (unchecked) and "non linear" (checked).
 - (Hidden) Activation Fun.:** A dropdown menu showing "tanh".
 - Hidden Layers:** A numeric input field with "2" and increment/decrement buttons.
 - Neurons x (Hidden) Layer:** A text input field containing "(50,50)".
- Training Params:**
 - Output Normalization:** A checked checkbox.
 - Early Stopping:** An unchecked checkbox.
 - Epochs:** A text input field with "10".
 - Regularization Coeff.:** A text input field with "1e-6".
 - Test Split Ratio:** A text input field with "0.2".
 - CrossVal. Split Ratio:** A text input field with "0.25".

At the bottom of the interface are "RESET" and "TRAIN" buttons. A status bar at the very bottom indicates "Cursor position: (X = - , Y = -)". To the right of the main window is a "Python Window" which is currently empty.



Linearization: automatic A,B,C,D matrices generation

Linearize.scm - Altair Activate Business Edition 2021.1.1

File Edit View Tools Spice Import ROM

Files Model Diagram Home Simulate

Super Block Mask Orient Block Align Center

Variable Browser

Name	Value	Type
------	-------	------

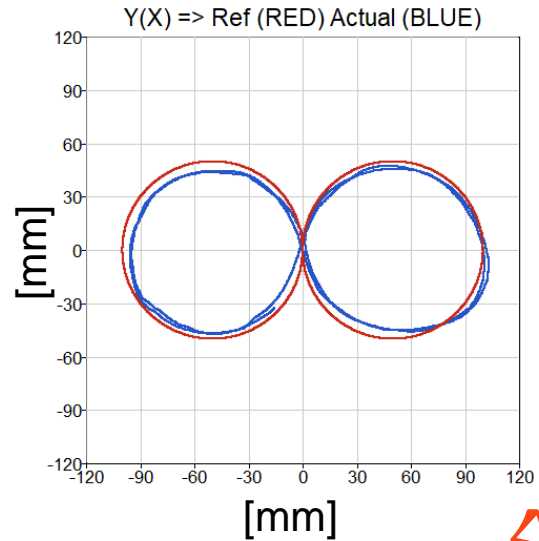
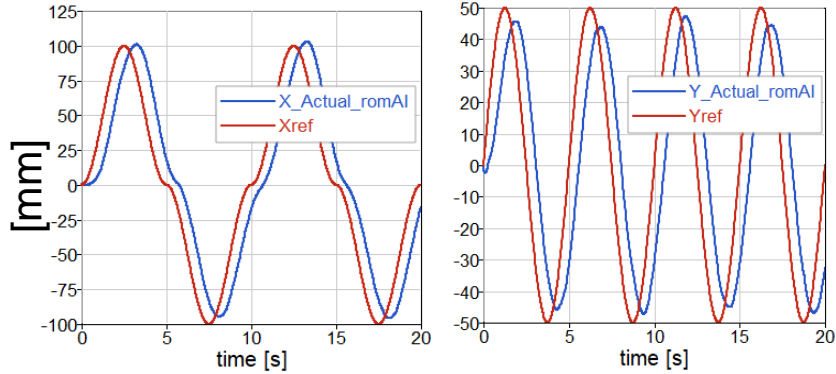
Diagram showing a control system with a Controller block, a romAI block, and two Scope outputs (Scope 0 and Scope 1).

Optimal Control design: automatic gain matrix generation

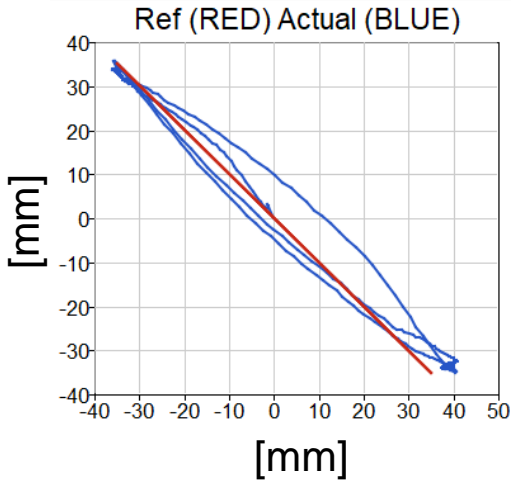
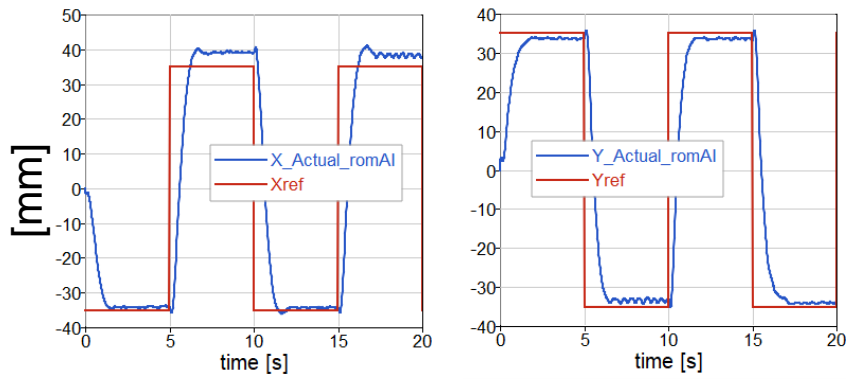
```
31 load('ABCD.mat');
32 Anew=C*A*C^(-1);
33 Bnew=C*B;
34 Cnew=eye(4,4);
35 Dnew=D;
36
37 %Optimal Controller
38
39 Q(1,1)=1;% X
40 Q(2,2)=1; %Y
41 Q(3,3)=0.1; %Xdot
42 Q(4,4)=0.1; %Ydot
43 R(1,1)=10;
44 R(2,2)=10;
45
46 K=lqr(Anew,Bnew,Q,R);
--
```

使用Activate® 控制库中内嵌的 *lqr* 函数

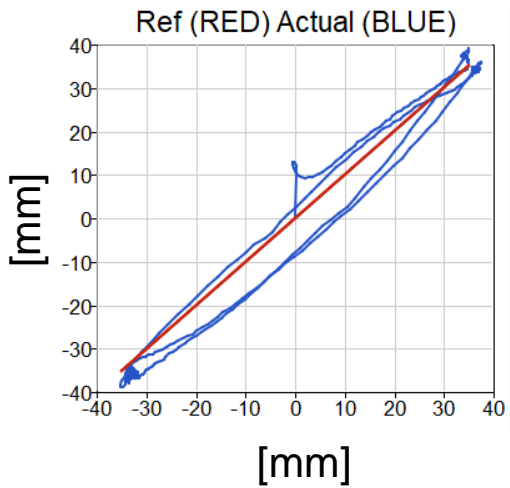
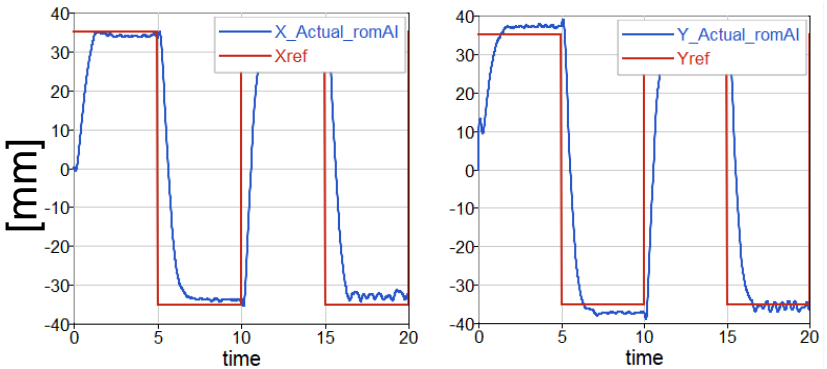
Test 1: 8-shaped reference



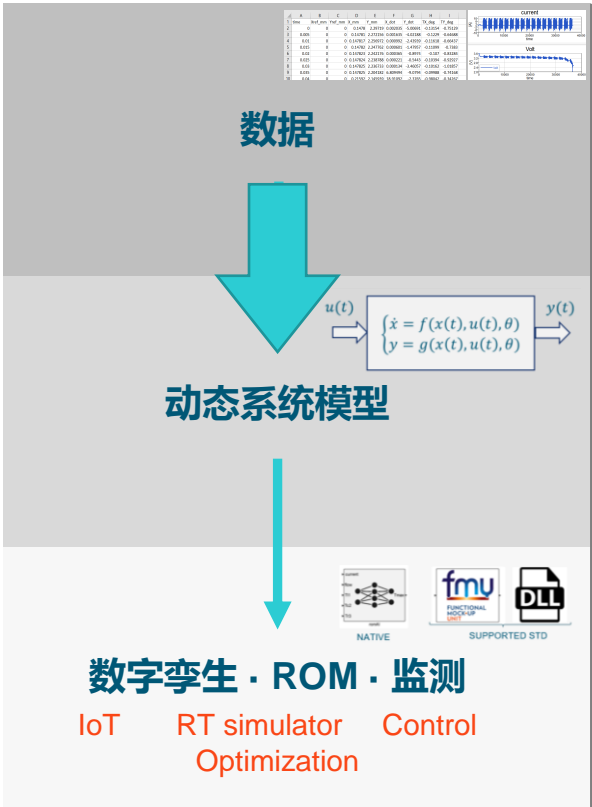
Test 2: Step-wise reference 1



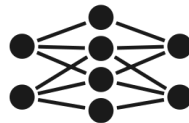
Test 3: Step-wise reference 2



总结



romAI



人工智能

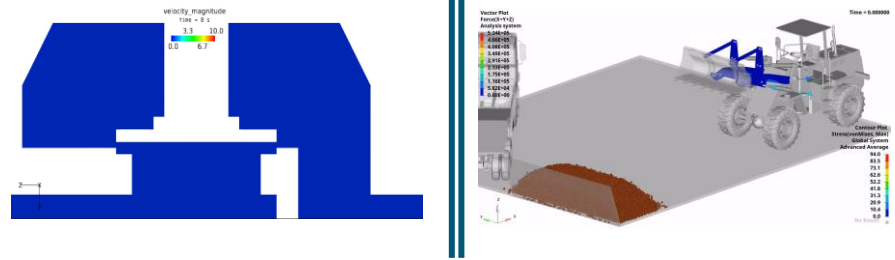
少量的仿真/测试

不受时间离散化影响

集成用户的专业经验

满足模型的泛化属性

Simulation

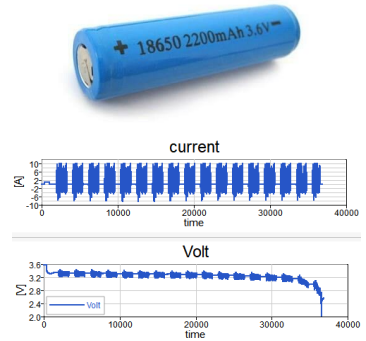


Reduced-Order Model

18h => 1s with romAI

680s => 20s with romAI

Real system



System Identification

Higher accuracy than std ESC battery model

Advanced control design:

- No measurements
- No Math calculations

Few simulations/tests needed



THANK YOU

altair.com



#ONLYFORWARD