IDAJ公司

高精度高取样频率被控发动机模型 GT-POWER xRT应用

IDAJ中国

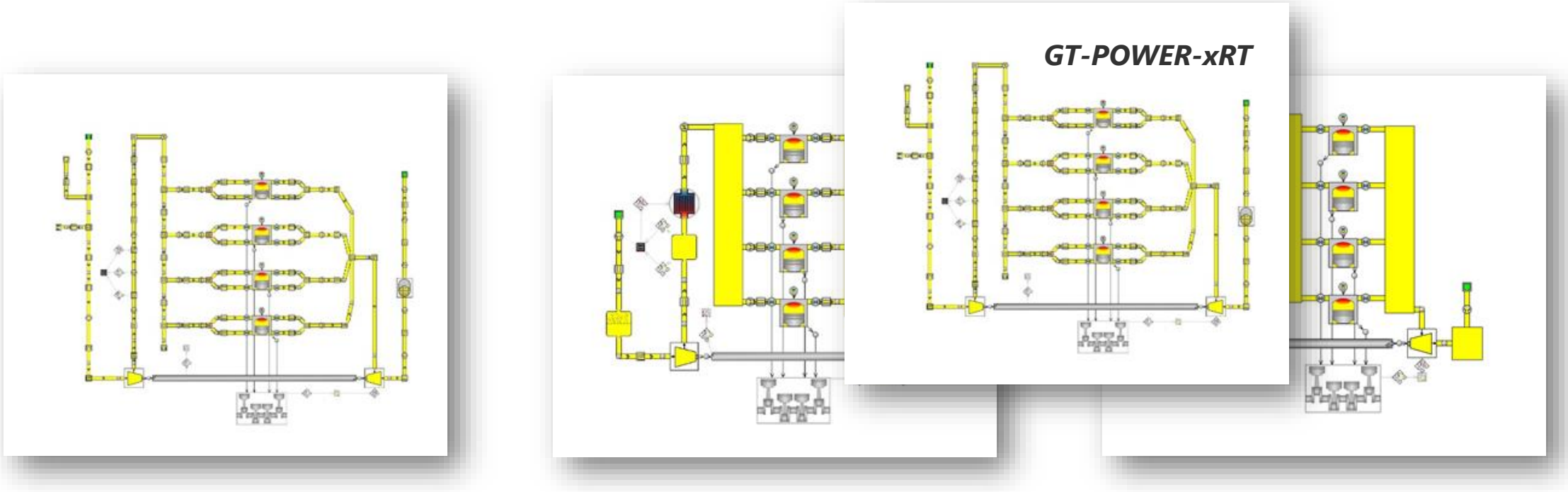
GT小组

目录

- GT-SUITE 基于物理模型
  - N-S 方程求解
  - 基于曲轴转角计算的喷射，燃烧，排放
- 瞬态动力学模型
- 完全可调的 模型能够平衡：
  - 计算精度和计算速度
  - 预测性的和测量辅助的精度

可调的Adjustable 模型保真度/速度

- (30 – 100 x RT)：详细的气体动力学，适合发动机设计
- (1 – 3 x RT)：较粗糙的气体动力学计算，适合 SiL
- (0.3 – 1 x RT)：速度调整. 适合 HiL
- (0.1 – 1 x RT)：GT-POWER-xRT 采用详细的气体动力学. 适合 SiL & HiL



支持此工作流程的高级工具- xRT

- GT-POWER-xRT是一个专门的发动机模型求解器:
  - 维护核心GT-POWER解决方案
  - 达到速度~10倍以上的 GT-POWER 求解器

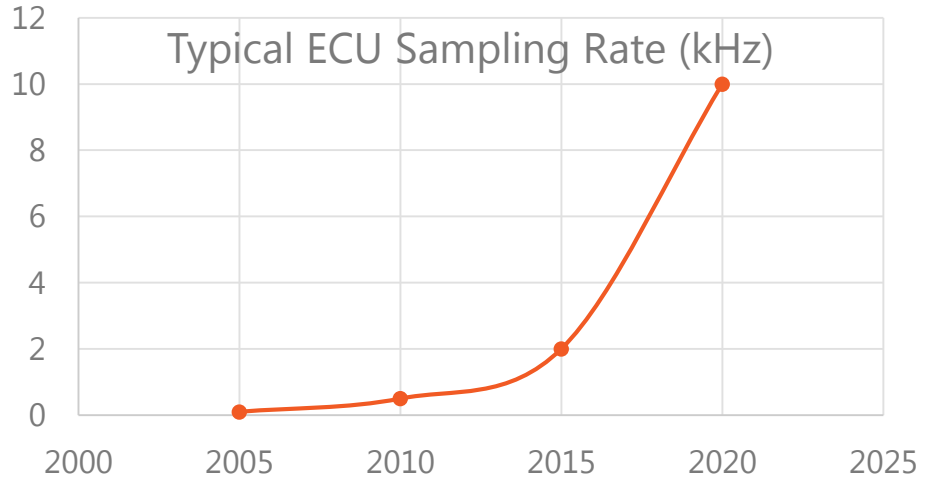
- GT-POWER-xRT 从以下方面提高速度:
  - 允许性能优化的GT模板和选项的子集
  - “surgical” 求解过程的修改，对结果的影响很小

支持此工作流程的高级工具- xRT

为什么开发 xRT?

- 在HiL系统上以一个小的固定时间步长运行详细的引擎模型
- 运行引擎模型在高引擎转速(如15000rpm)和/或大缸数

- ECU 更高的取样频率
  - 喷射控制
  - 燃烧控制
  - 曲柄转角位置



- 避免把时间花在简化发动机模型几何形状上

GT-POWER-xRT –示例

- 例子: 3.4L Twin Turbo V6 GDI
- 122 个流体控制体
- 固定时间步长= 0.06ms → 2.2°CA @ 6000rpm
- 实时因子: 0.89
- 燃烧模型: SIWi

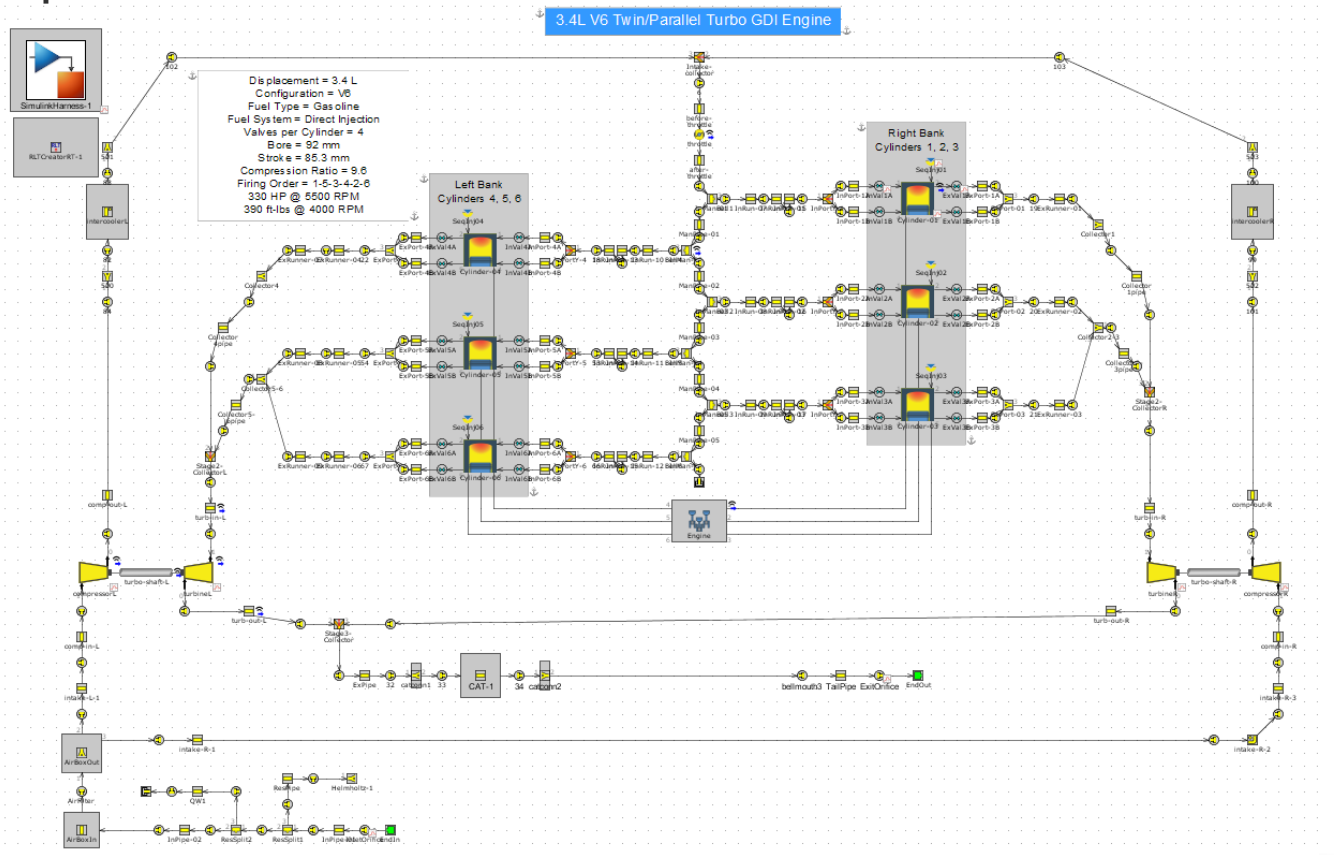
89s Clock time for
100s Simulation time

```
INFO Total Number of Parts =  341

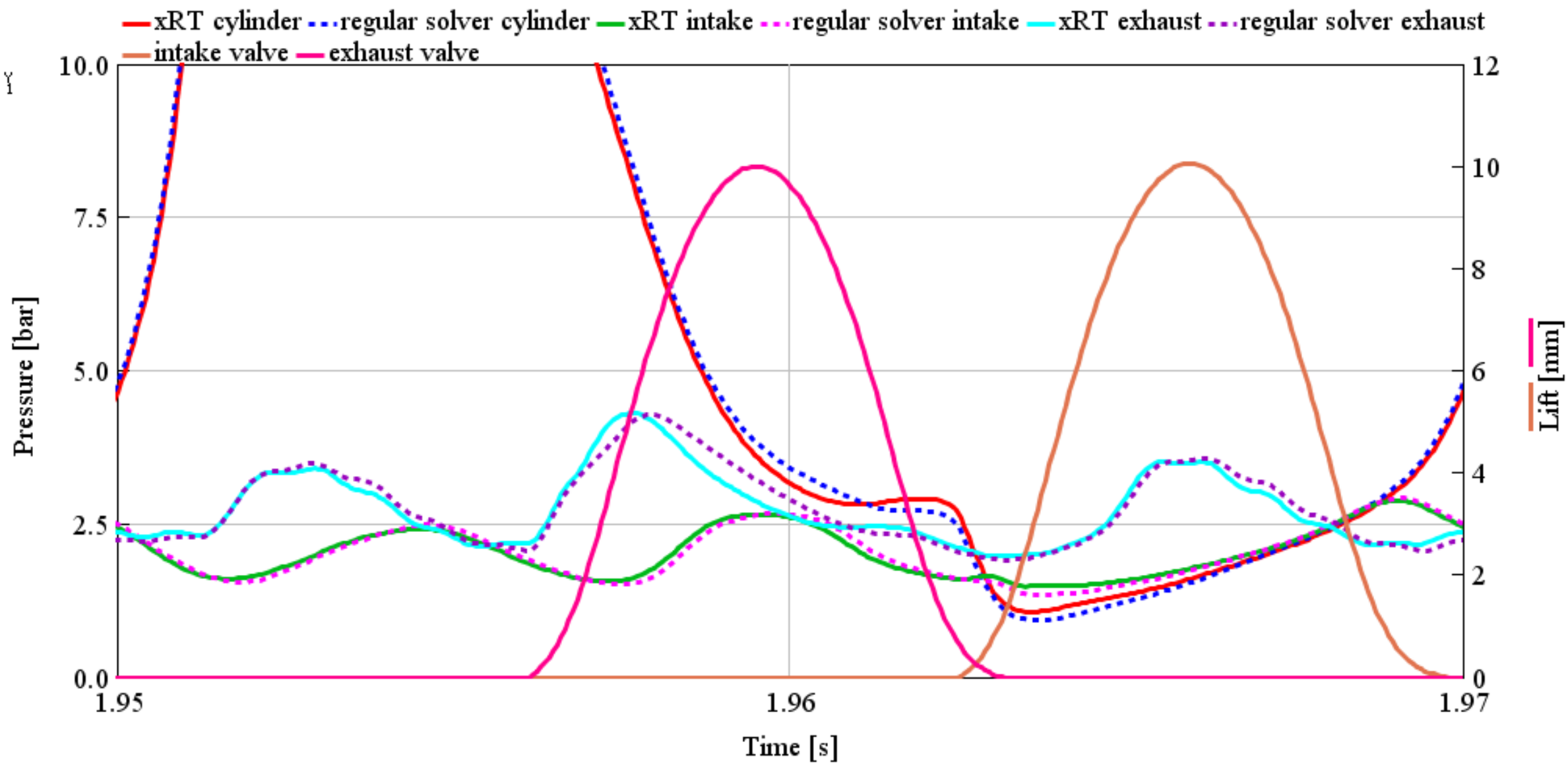
INFO The Performance plot is turned on. Screen and .out file output along
     with the stop simulation ability will be suppressed to improve the
     performance measurement. This plot can be turned on or off from
     Output Setup -> General.

 CASE    COMPUTATIONS:  Elapsed Time: 000:01:29.04

END OF RUN
Tue Nov 13 14:50:53 2018 Creating results (.gdx) file...
Tue Nov 13 14:50:53 2018 GDX file Step6.gdx generated successfully.
```



6000rpm WOT Comparison



GT-POWER-xRT – V16 Example

- V16 76.3l Twin Turbo Diesel
- 流体控制体总数：118
- 时间步长=0.12ms→1.4°CA@ 1900rpm
- 实时因子: 0.8
- 燃烧模型: DIPulse
-

80s Clock time for
100s Simulation time

```
INFO Total Number of Parts =  305

INFO The Performance plot is turned on. Screen and .out file output along
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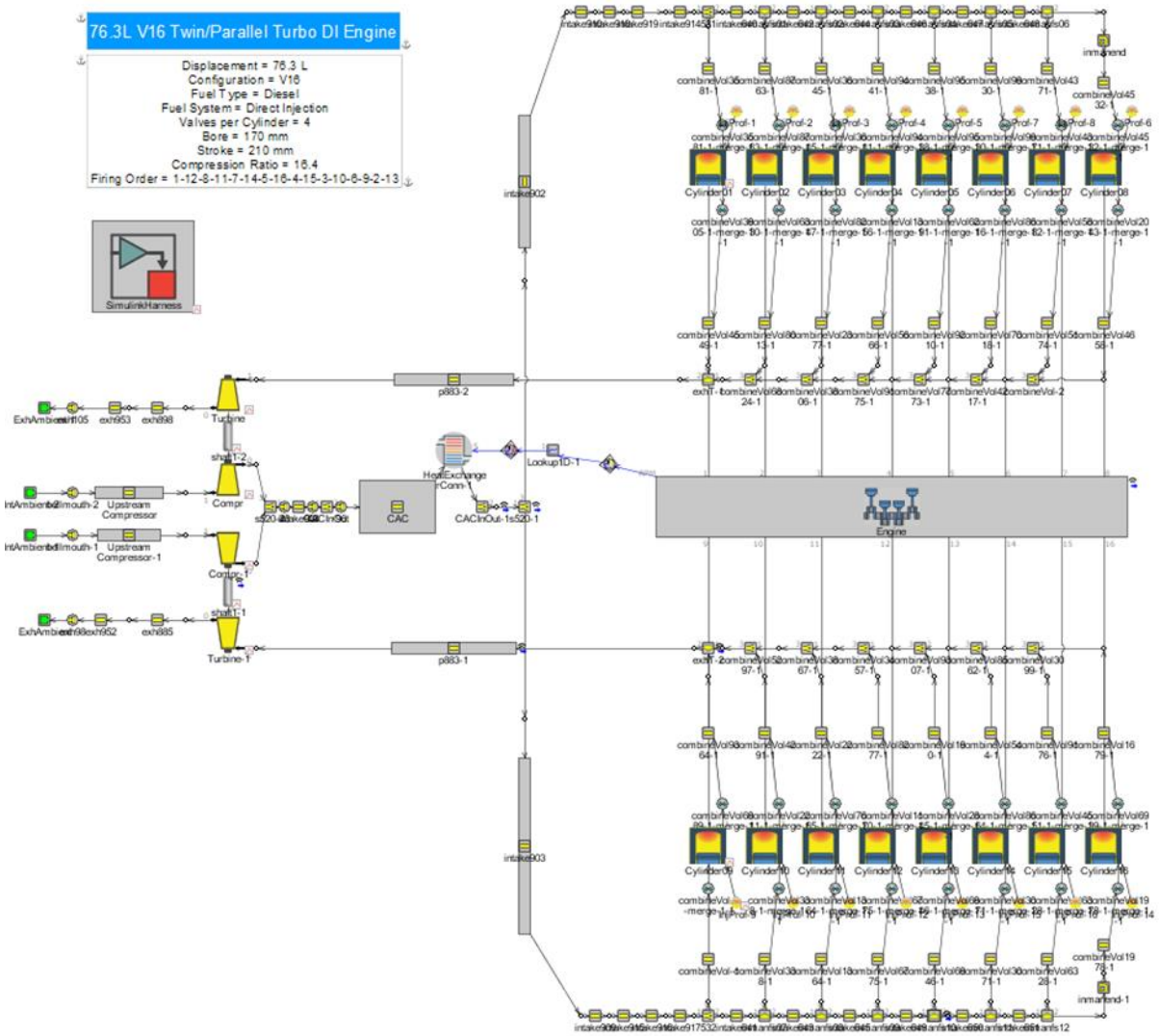


Model can be provided upon request.

GT-POWER-xRT – Example

- 例子: 4 Cylinder SI Turbo
- 10.37s 计算 100s的实例

```
10  3  5.E-19  1.138526E-02  -2.E-18
10  4  5.E-19  1.138526E-02  -2.E-18
10  5  5.E-19  1.138526E-02  -2.E-18

Total number of FSPLITs 5
Detailed fsplits:       3

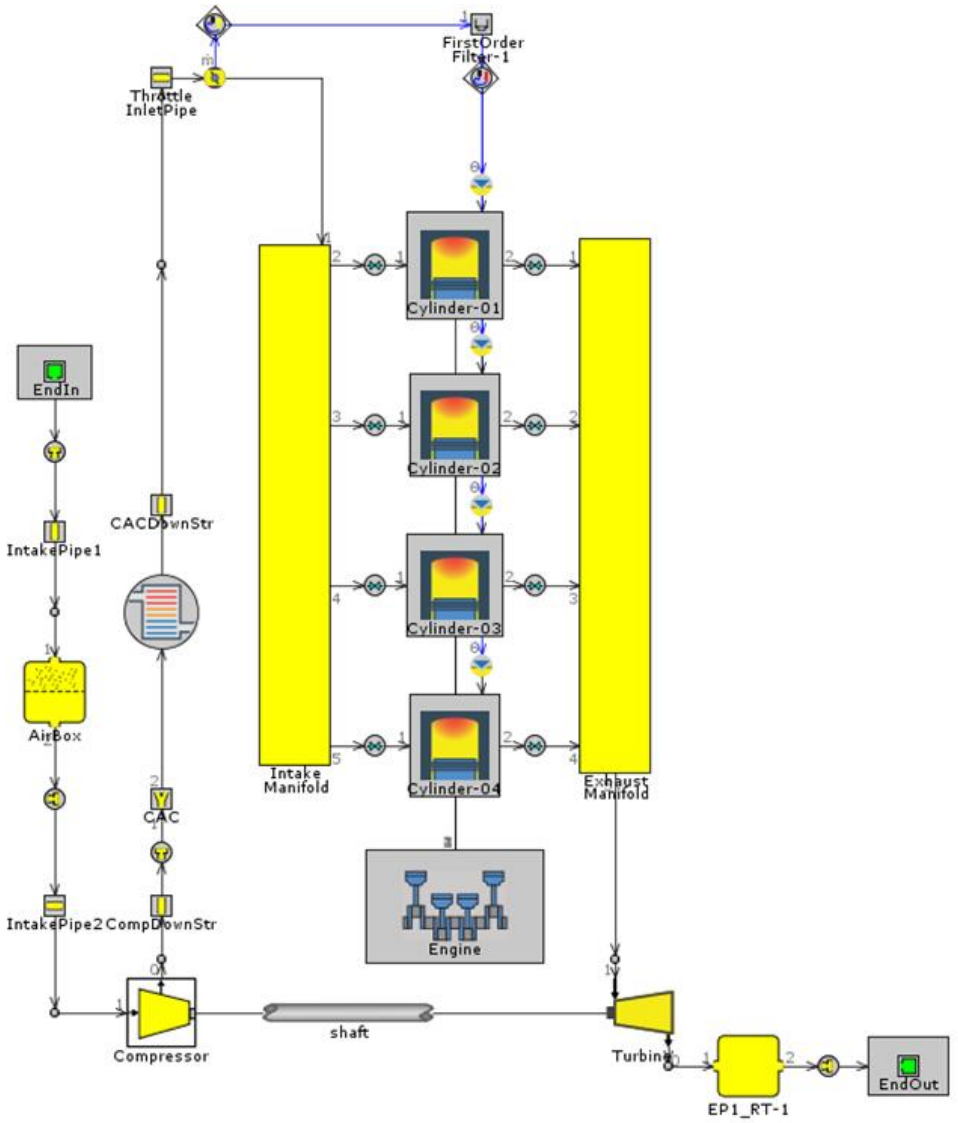
INFO Total Number of Parts =  73

INFO The Performance plot is turned on. Screen and .out file output along
     with the stop simulation ability will be suppressed to improve the
     performance measurement. This plot can be turned on or off from
     Output Setup -> General.

CASE     COMPUTATIONS:  Elapsed Time: 000:00:10.37
 FINAL   COMPUTATIONS:  Elapsed Time: 000:00:10.39

END OF RUN
Fri Aug 17 07:47:57 2018 Creating results (.gdx) file...
Fri Aug 17 07:47:57 2018 GDX file 4cyl_RunTimeTest-V2019.gdx generated successfull
```

- 实时因子: 0.1037
  - 有4个气缸和气路模型



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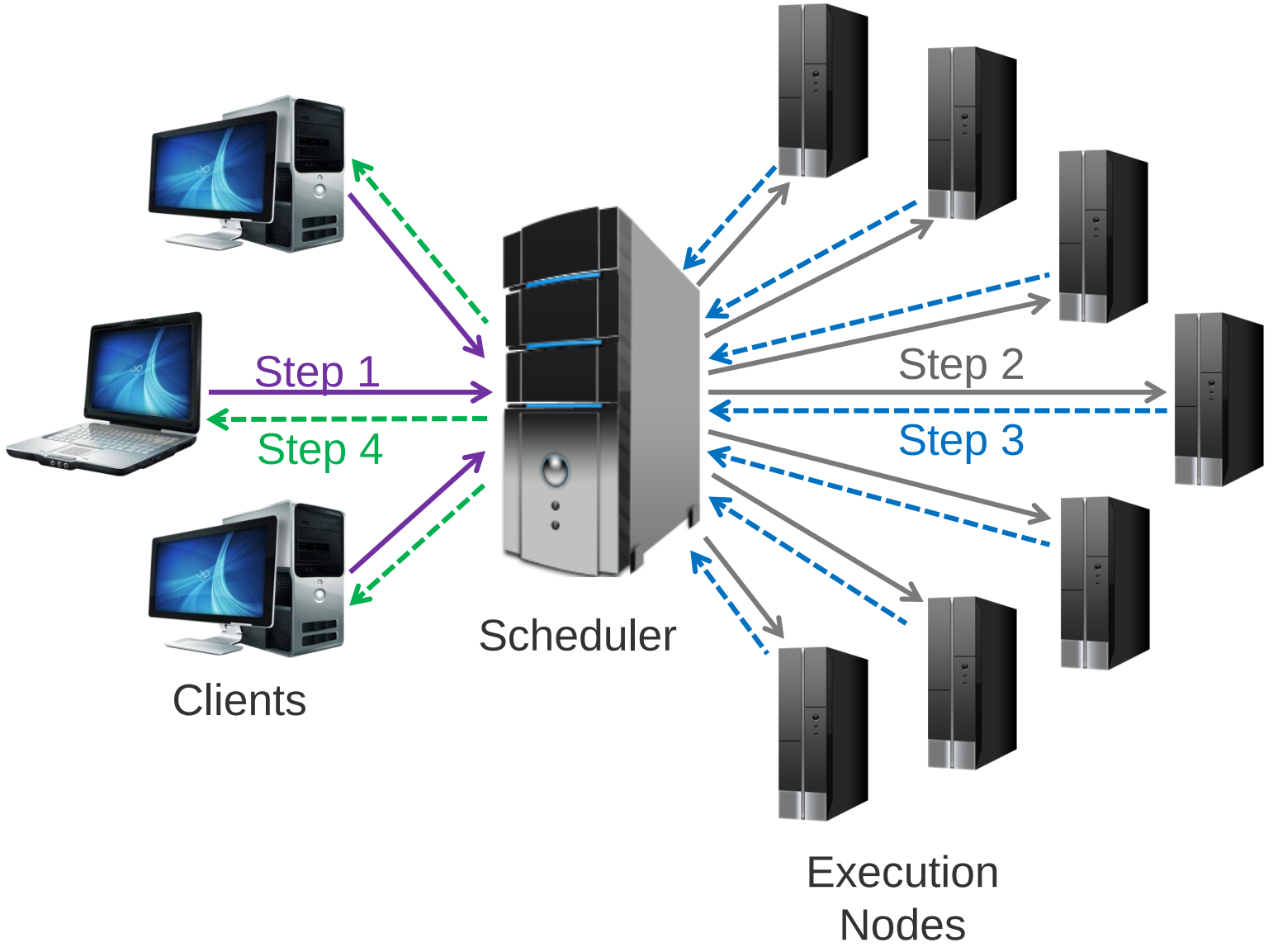
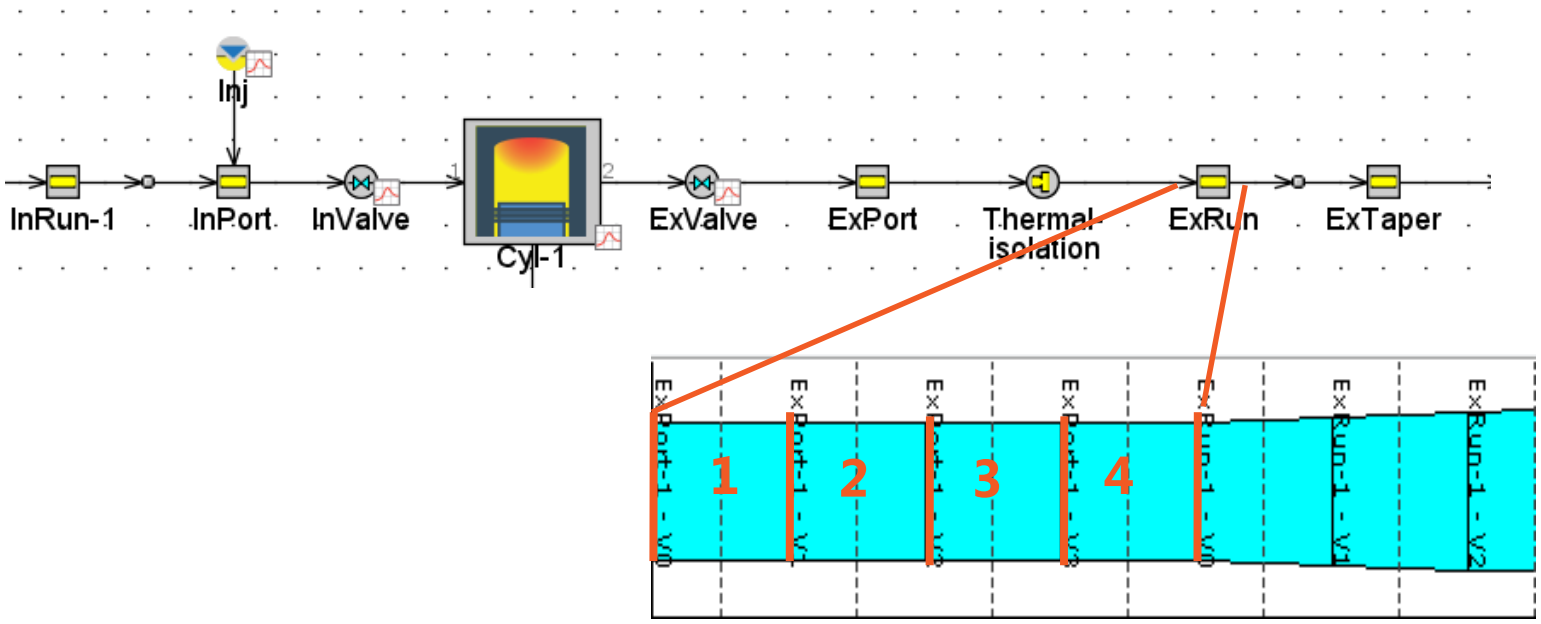
GT-POWER-xRT: 本地和分布式集群计算v2019 b2

- 提高了生产率
- 并行运行多个案例
- 优化



离散

- 将一个 pipe part 分成多个控制体
- 可以研究多控制体和单个控制体的差别
- 主要适用于 SI 发动机的 intake/exhaust runners/ports

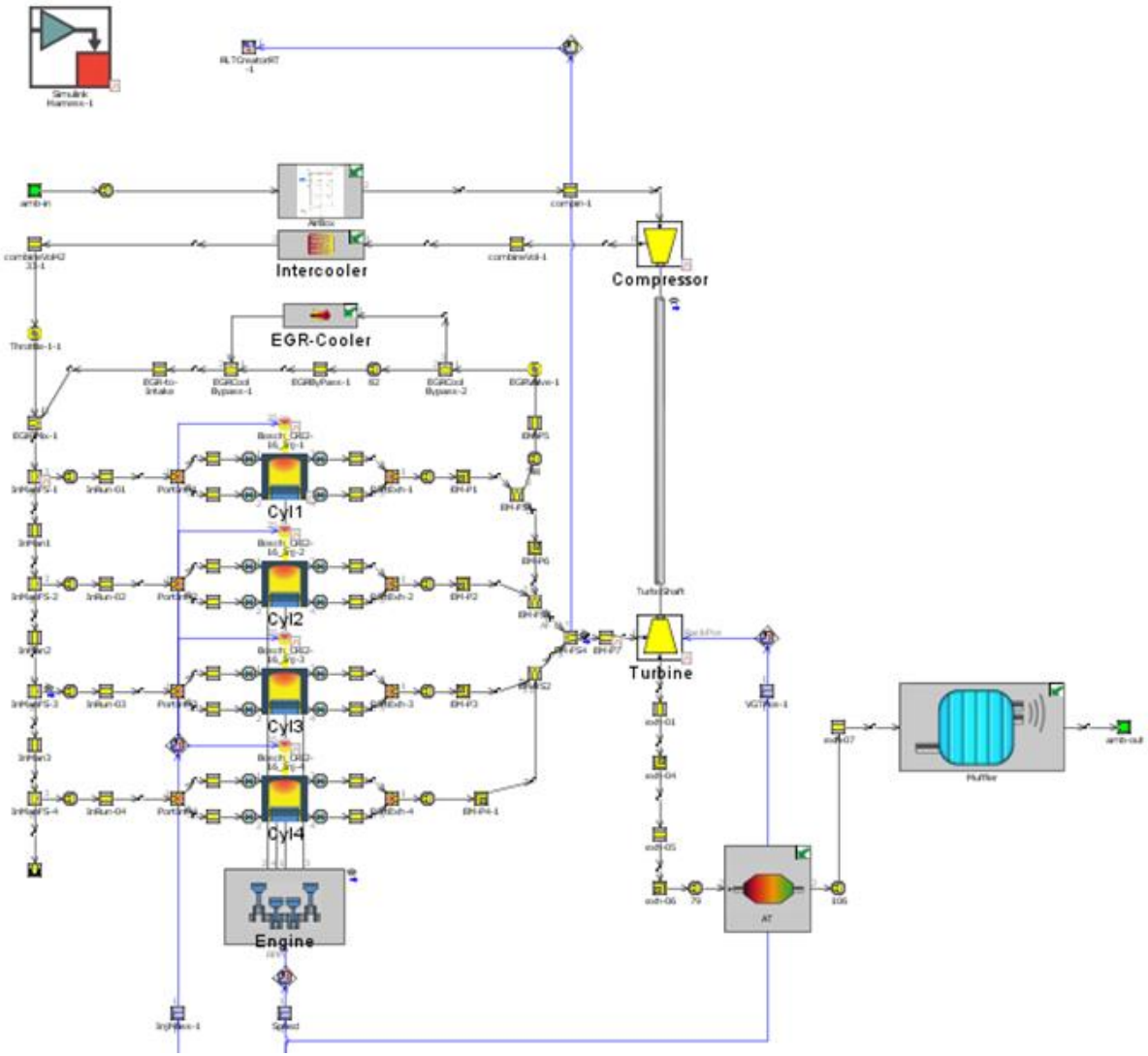


GT-POWER-xRT: 预测性的传热模型

- 简化 EngCylTWallSoln 的输入变量
- 单个热质量块
  - Head
  - Piston
  - Cylinder liner
  - Each valve
- 发动机散热的热质量温度
- Cylinder, pipe* 和 flowsplit 的传热传感器
- v2019 b2 可用

预测性的传热模型 v2019 b2

- 运行时对比：
- 常规求解器与GT-POWER-xRT
- NEDC驾驶循环
- 2.0L 4缸柴油机
- 燃烧：预测性 DIPulsee
- 气缸传热模型：预测性的 EngCylTWallSoln

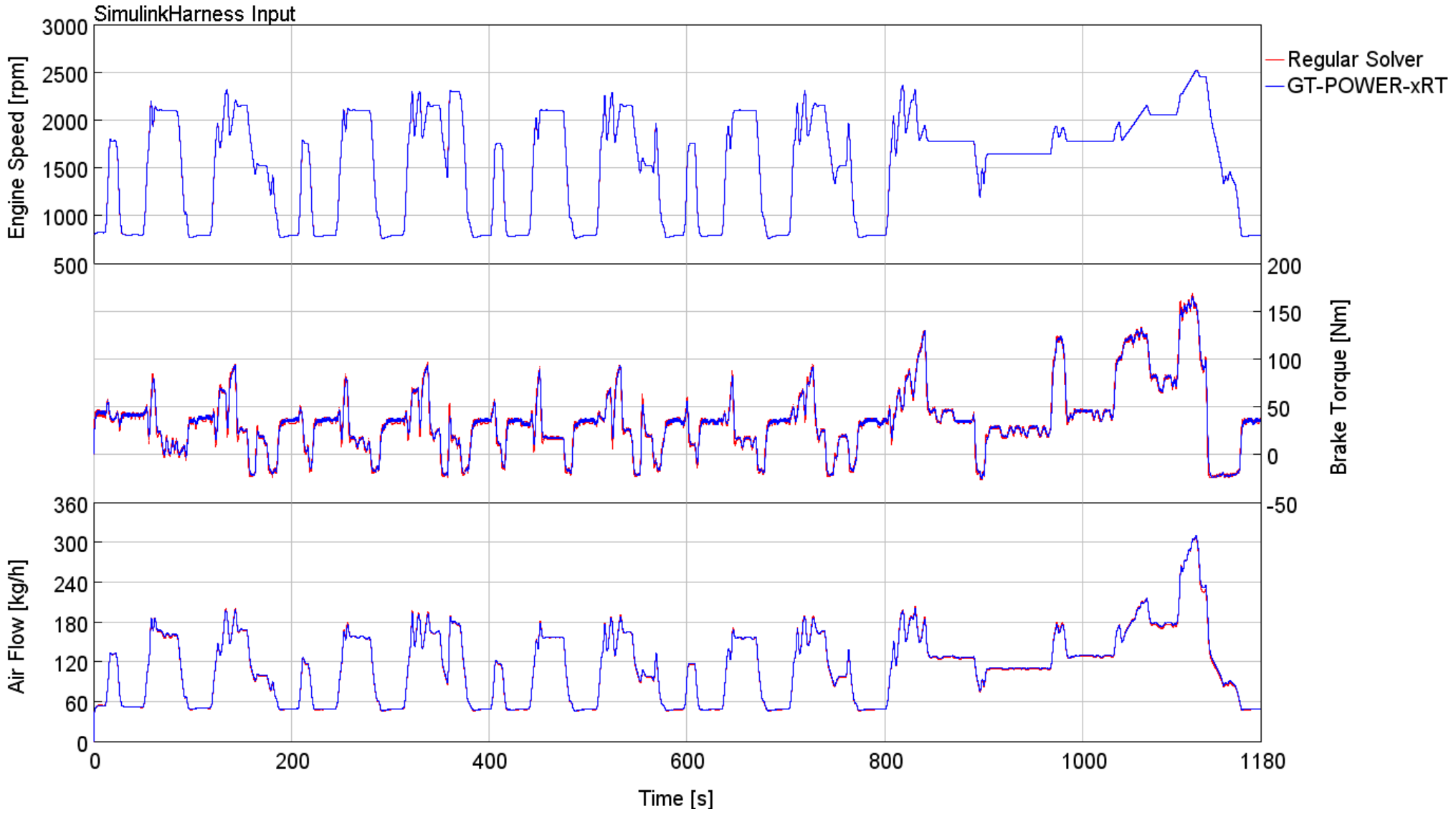


- 计算时间的因数对比

Regular Solver : 24.0

GT-POWER-xRT : 2.2!

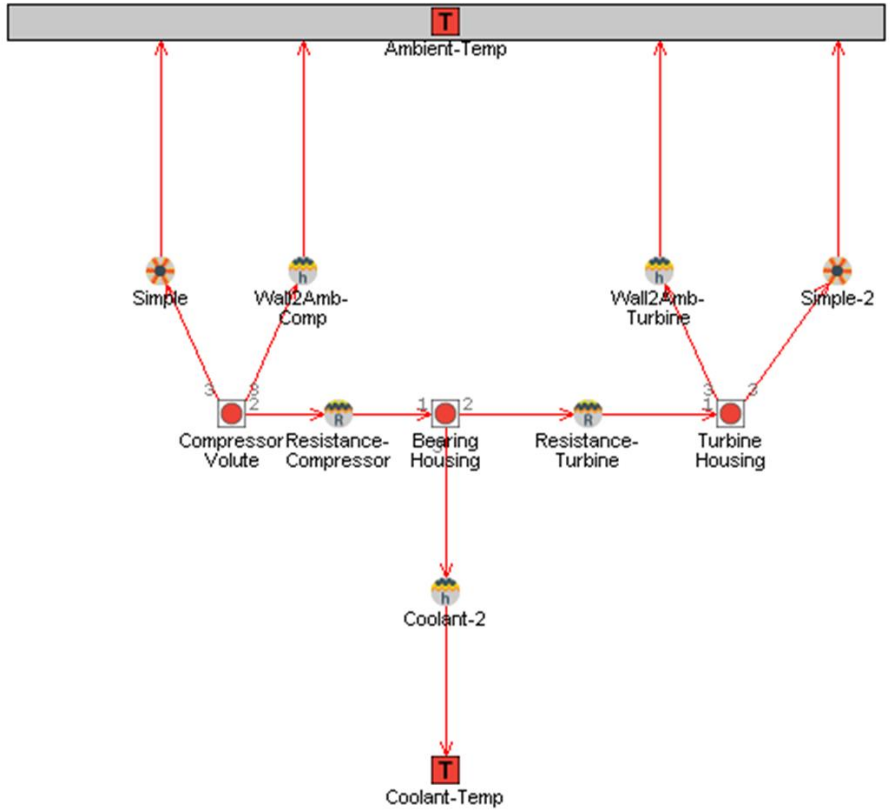
预测性的传热模型 v2019 b2

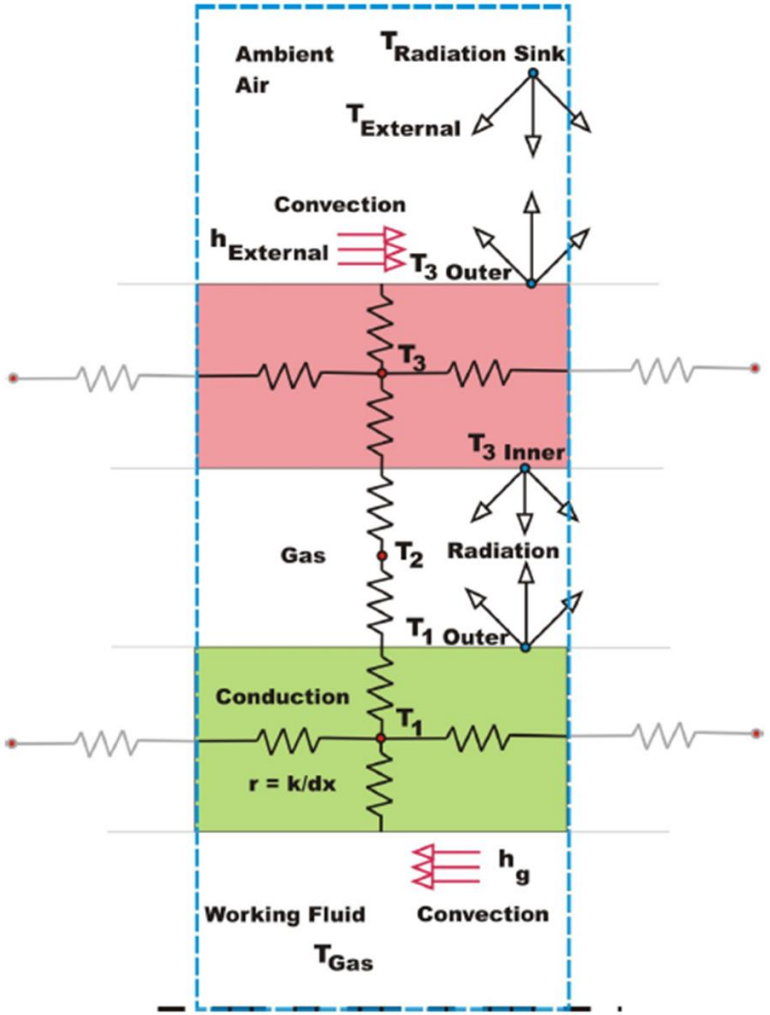


- Very good correlation between Regular Solver & GT-POWER-xRT

GT-POWER-xRT: 传热库(v2020 b1)

- 应用:
  - 涡轮的热模拟
  - 歧管的热模拟





GT-POWER-xRT缸内模型新特性

- 发动机控制应用的爆震预测
  - 可用选项:
    - Kinetics-Fit-Gasoline
    - Kinetics-Fit-Gasoline-Ethanol-Blend
    - Kinetics-Fit-Natural-Gas
    - Douaud&Eyzat

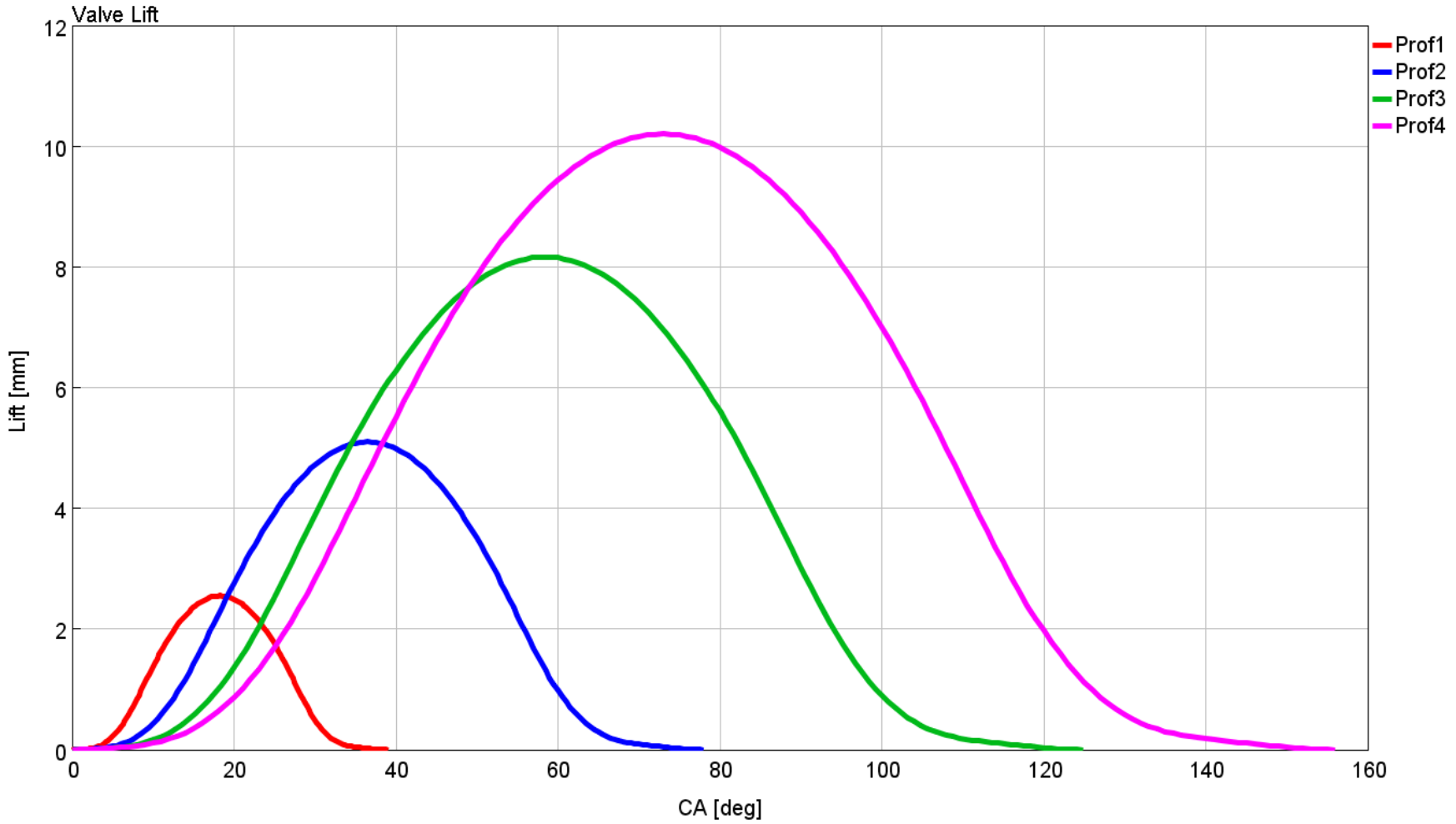
- 预测性的分层燃烧区 NOX排放模型
  （ DIPulse v2020 b1 ）
  - 内置的 extended Zeldovich mechanism

$$O + N_2 \leftrightarrow NO + N$$

$$N + O_2 \leftrightarrow NO + O$$

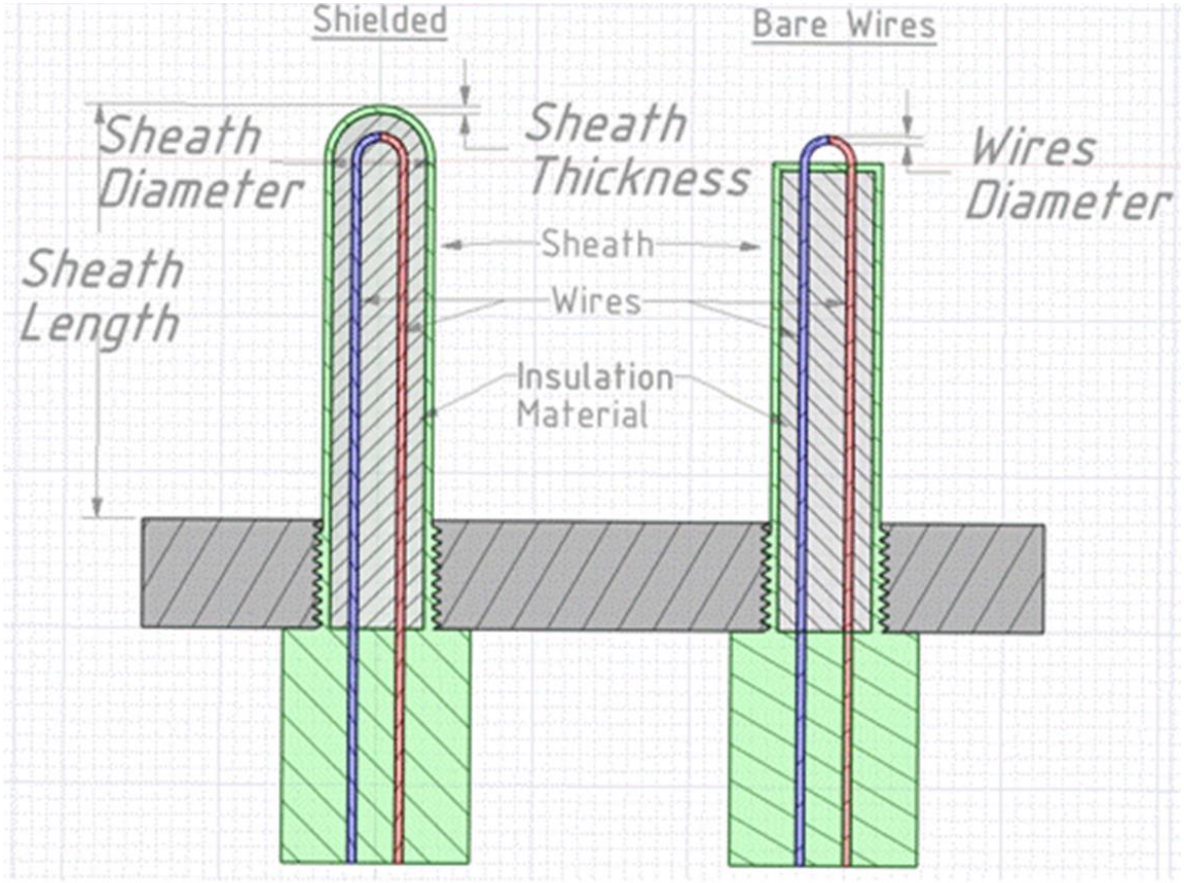
$$N + OH \leftrightarrow NO + H$$

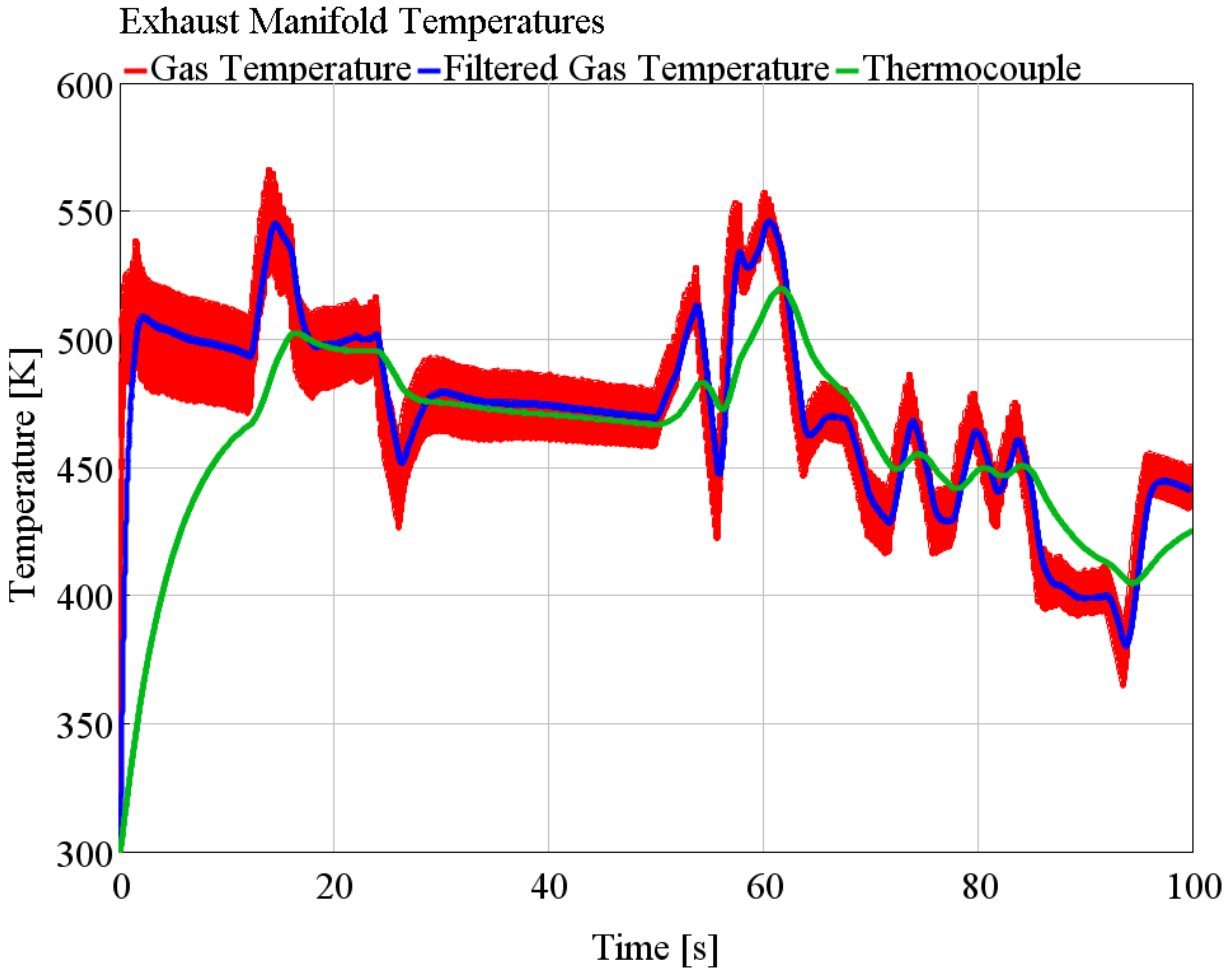
- XYTableOfMaps for RLTDependence
- 常见的使用：SI发动机的可变升程



热电偶 v2019 b2

- 支持热电偶测量比较和控制输入

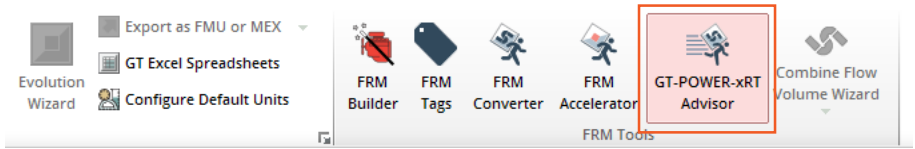




另外的新功能

- 监测任意流体部件的组分浓度 v2020 RC 和 v2019 b3
- 发动机气缸，监测燃烧始点燃烧质量百分数 v2020RC
- 汽缸已燃和未燃烧温度 v2020RC
- RLTDependenceXY 选项输出(Y) =输入(X) v2019 b2
- TurbineMapVGT v2019 b3

- 确保更快的转换过程
- 适用于GT-POWER-xRT设置
- 能够更好地比较结果



GT-POWER-xRT Model Analyzer

Itemized Recommendations

The following attributes are recommended to be set prior to converting this model into a GT-POWER-xRT model. GT-POWER-xRT models have fewer attributes compared to GT-POWER models, and these recommendations will allow you to evaluate the impact of the attributes being removed. This will help assess the results changes expected when switching to a GT-POWER-xRT model.

Attribute Name	Template	Object/Part	Unit	Current Value	Recommended Value	New Value
Air Mass Flow Rate	InjAFSeqConn	SeqInjector	g/s	○	◉	◉
Initialization State	Run Setup	Initialization		previous_case	user_imposed	user_imposed
Part Attributes	Run Setup	Initialization			on	on
Fixed Time Step Size (Overrides Flow and Mech Step)	Advanced Setup	General	s	ign		Manual change ...

Print List　　Cancel　　Finish

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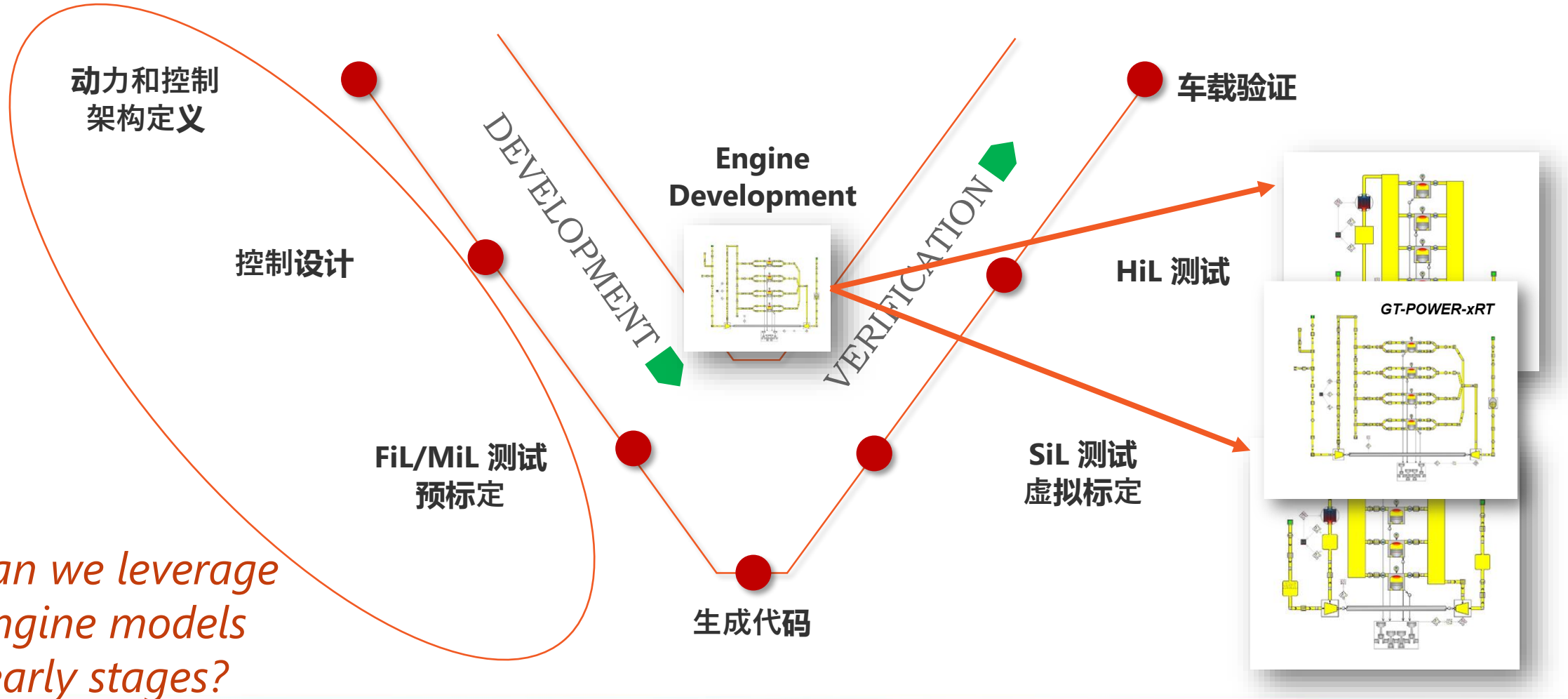
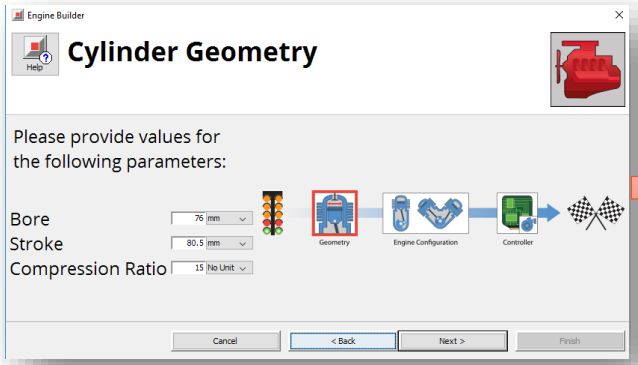
典型的ECU开发周期

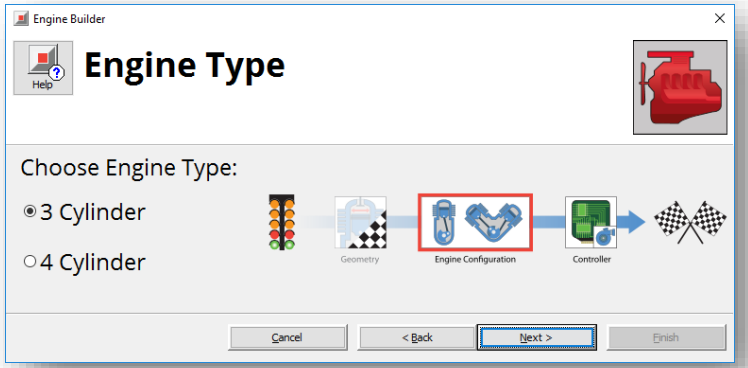


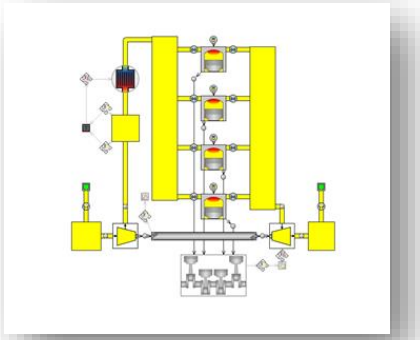
How can we leverage GT engine models in early stages?

用户可以使用两个工具

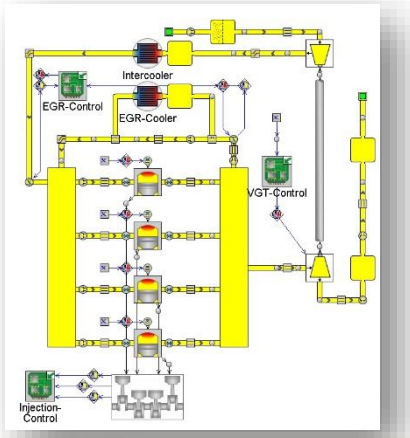
- FRM-d



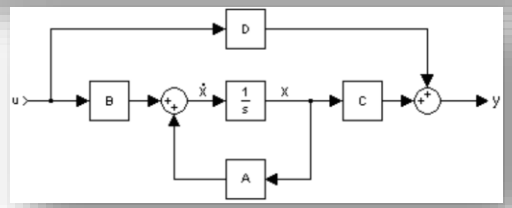




- 线性化模块



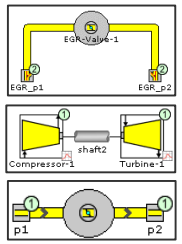
$$\dot{\mathbf{x}}(t) = A(t)\mathbf{x}(t) + B(t)\mathbf{u}(t)$$
$$\mathbf{y}(t) = C(t)\mathbf{x}(t) + D(t)\mathbf{u}(t)$$



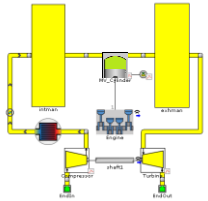
GT-SUITE 模型的状态空间形式

- Linearization with GT

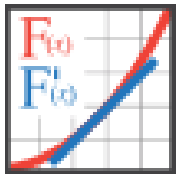
GT-SUITE Model



Components



Complete Engine

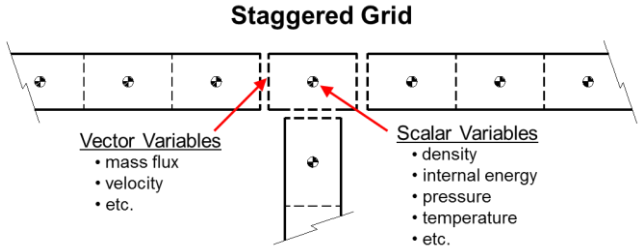


Direct Linearization of Navier Stokes 1D equations in GT around an operating point

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}[\rho u_j] = 0$$

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}[\rho u_i u_j + p\delta_{ij} - \tau_{ji}] = 0$$

$$\frac{\partial}{\partial t}(\rho e_0) + \frac{\partial}{\partial x_j}[\rho u_j e_0 + u_j p + q_j - u_i \tau_{ij}] = 0$$



$$\dot{\delta x} = \mathbf{A} \cdot \delta x + \mathbf{B} \cdot \delta u$$
$$\delta y = \mathbf{C} \cdot \delta x + \mathbf{D} \cdot \delta u$$

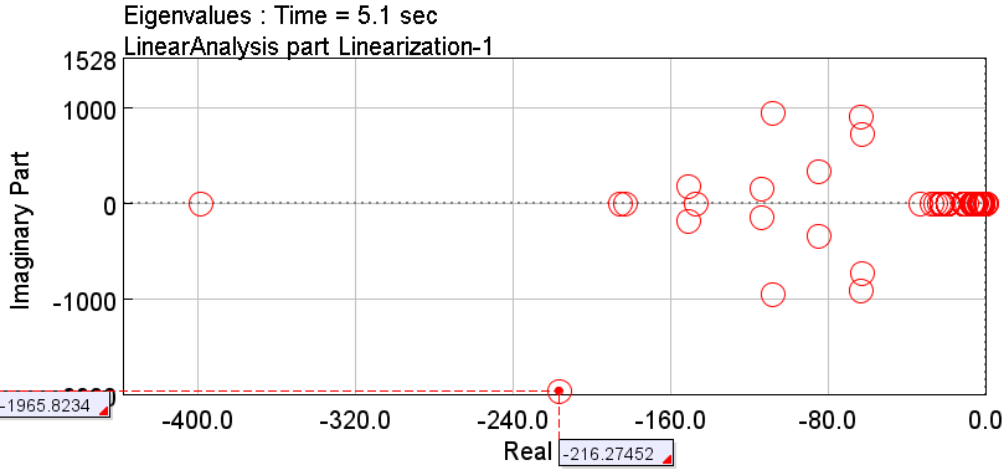
- MeanV-final-V2020_C008_L01_matrixA.csv
- MeanV-final-V2020_C008_L01_matrixB.csv
- MeanV-final-V2020_C008_L01_matrixC.csv
- MeanV-final-V2020_C008_L01_matrixD.csv
- MeanV-final-V2020_C008_L01_namesInputs.csv
- MeanV-final-V2020_C008_L01_namesOutputs.csv
- MeanV-final-V2020_C008_L01_namesStates.csv

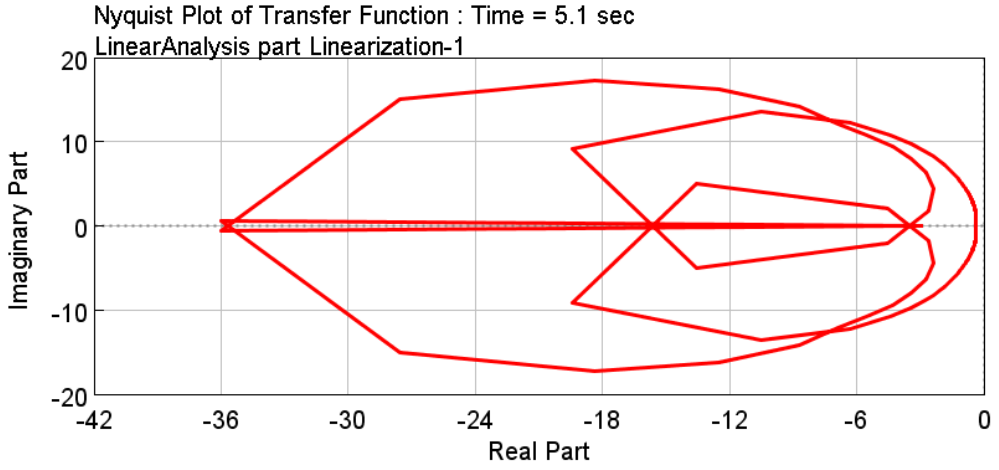
- 直接基于物理的线性模型
- 不需要一步一步的识别线性系统
- 访问所有向量和标量变量
- 考虑系统和相关控制器之间的交互和相互依赖关系的可能性

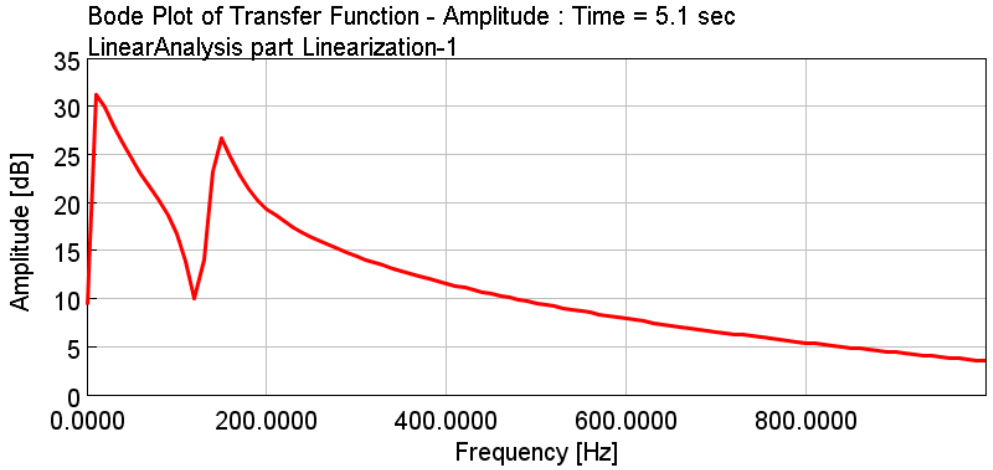
⇒ **Multi-variables Control Design**

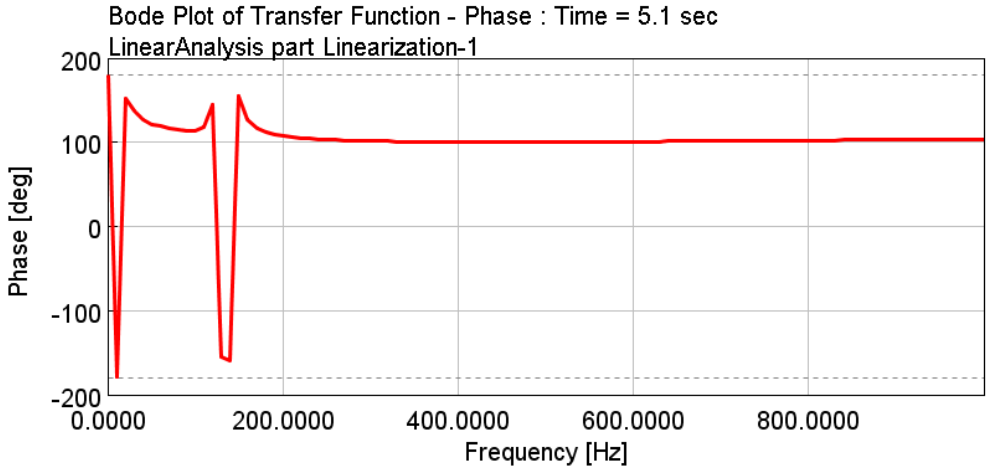
线性化 –强大的分析功能

- 输出 Eigenvalues, Bode Plots, Nyquist
  - 有助于理解系统的动态行为(甚至不运行模型)





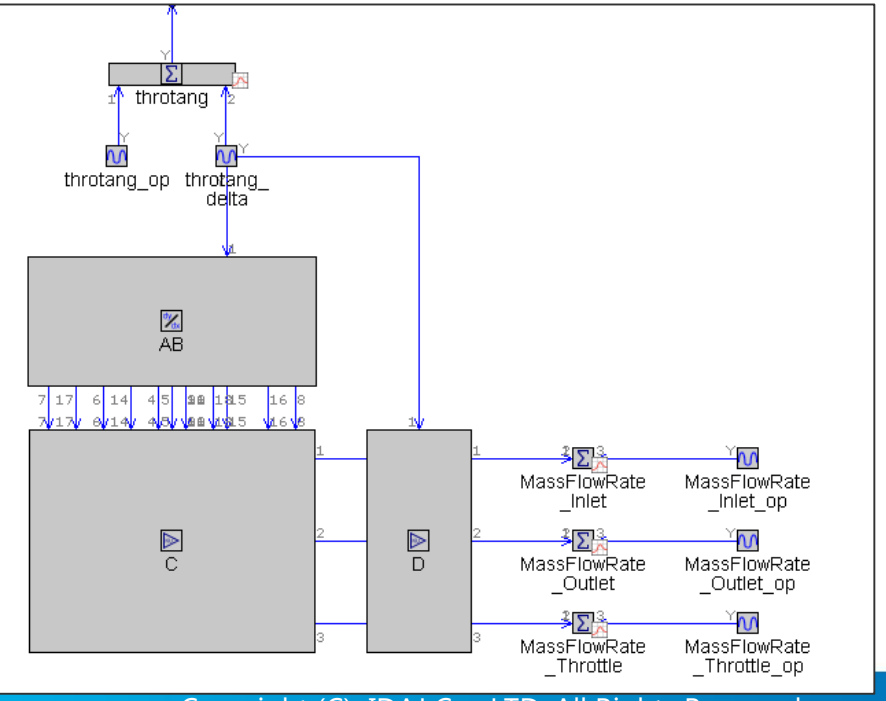




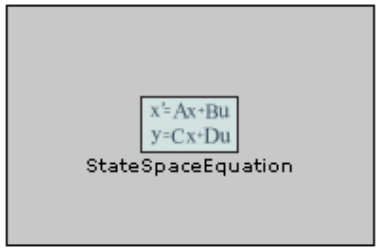
线性化 –线性模型验证

- 新模型 StateSpaceEquation
  - 直接使用“线性分析”生成的状态空间矩阵
  - 更快(从1小时到1分钟)，验证模型的设置更少出错

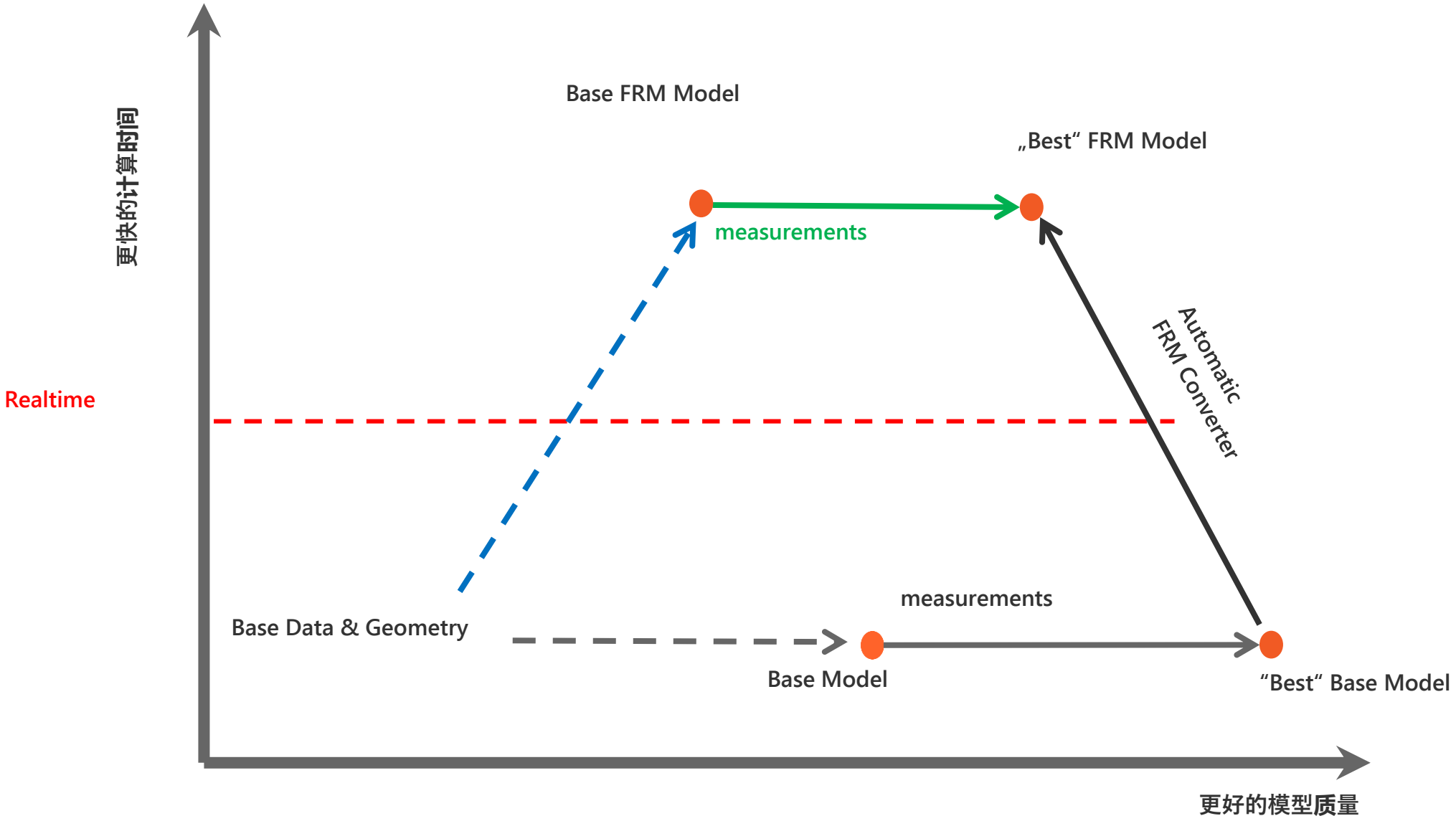
v2019



v2020

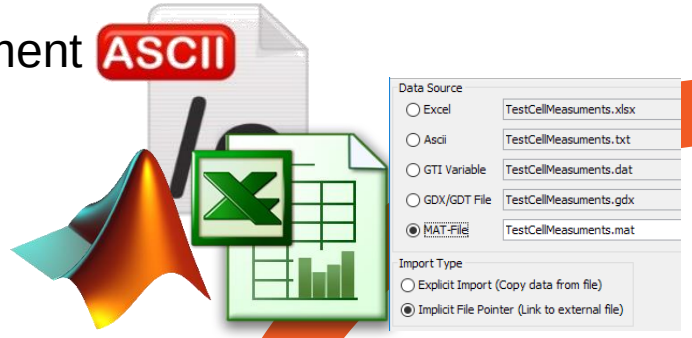


FRM Builder

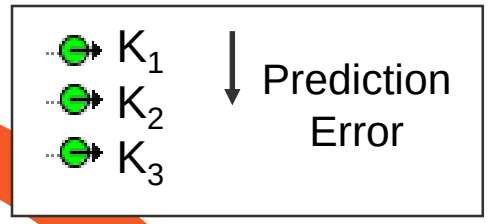


FRM-d 基于测量数据

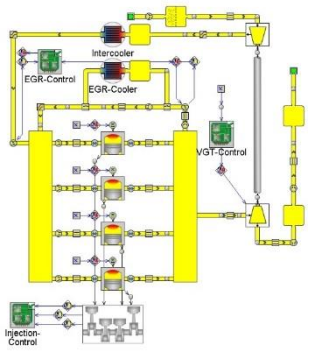
Measurement Data



Define Optimization Factors and Objective(s)

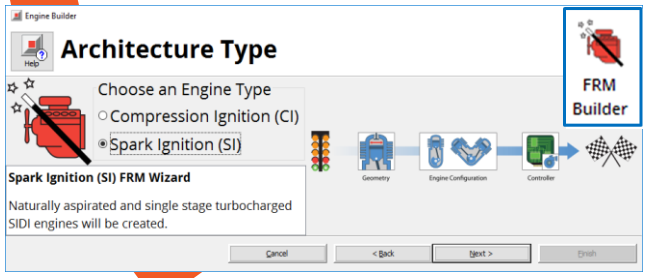


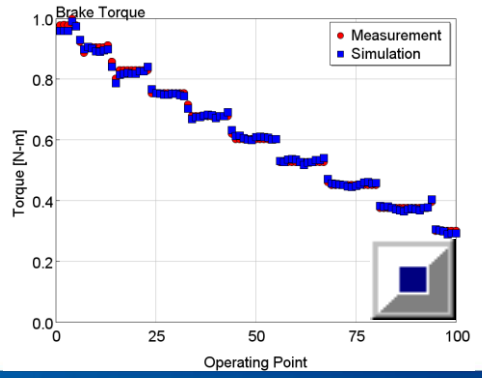
FRM Engine Model



Run Optimization

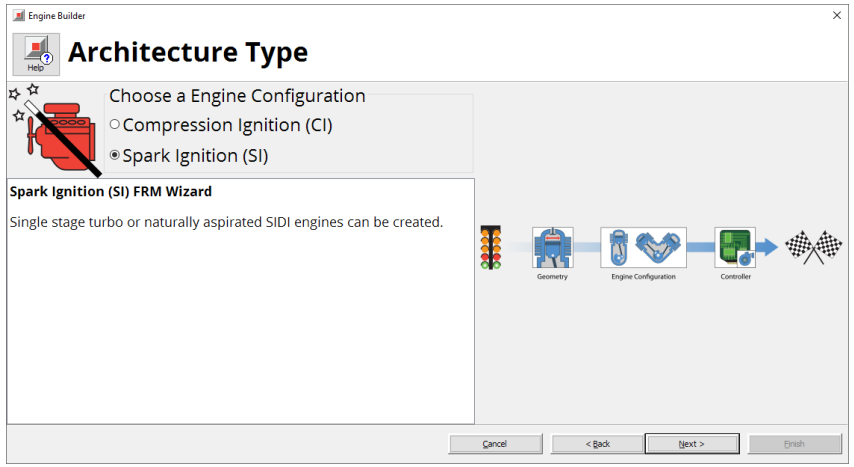
FRM Builder



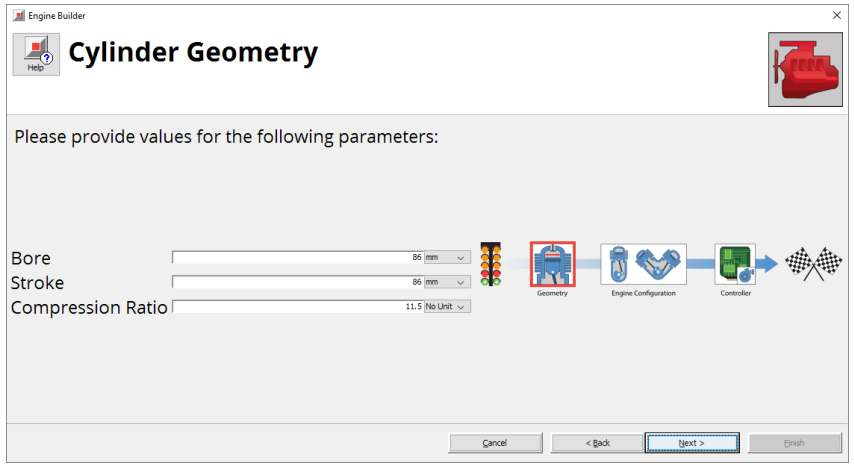


FRM-d Builder

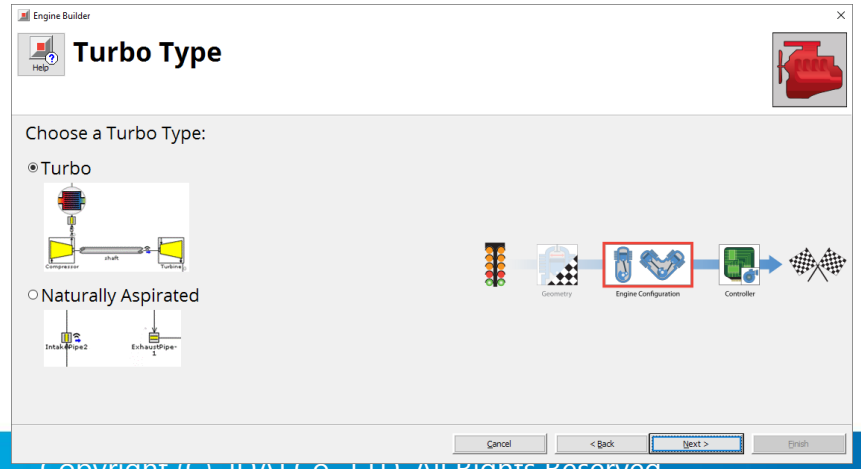
Step 1
创建FRM



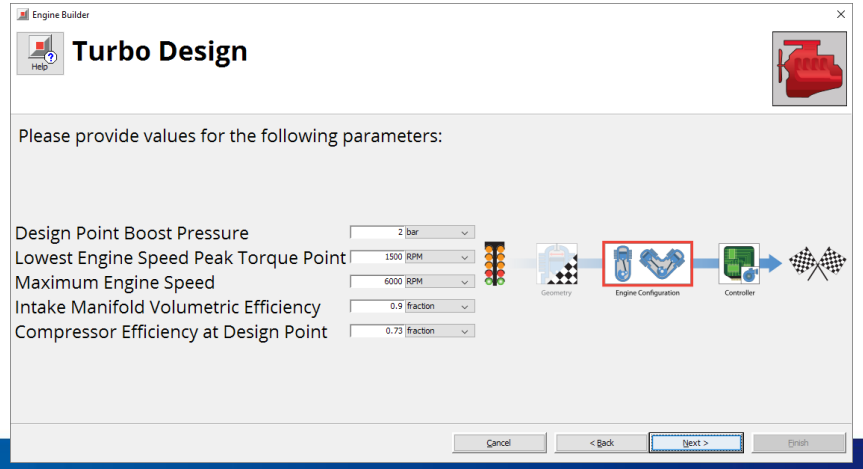
Step 2
输入



Step 3

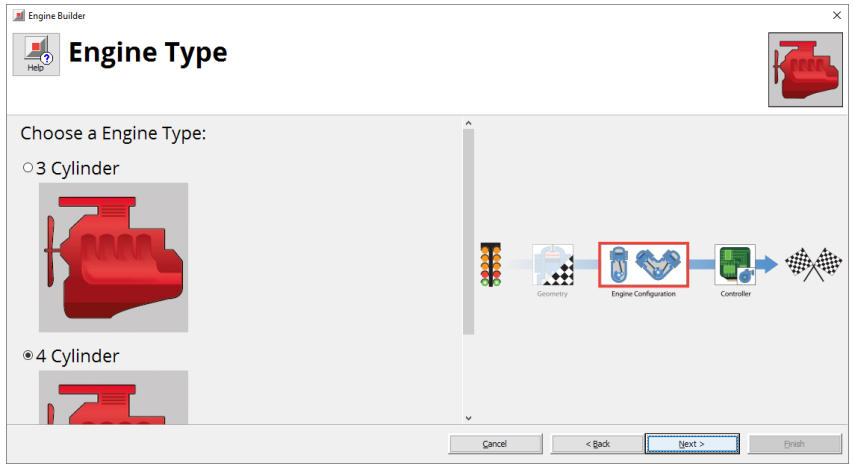


Step 4
增压器输入



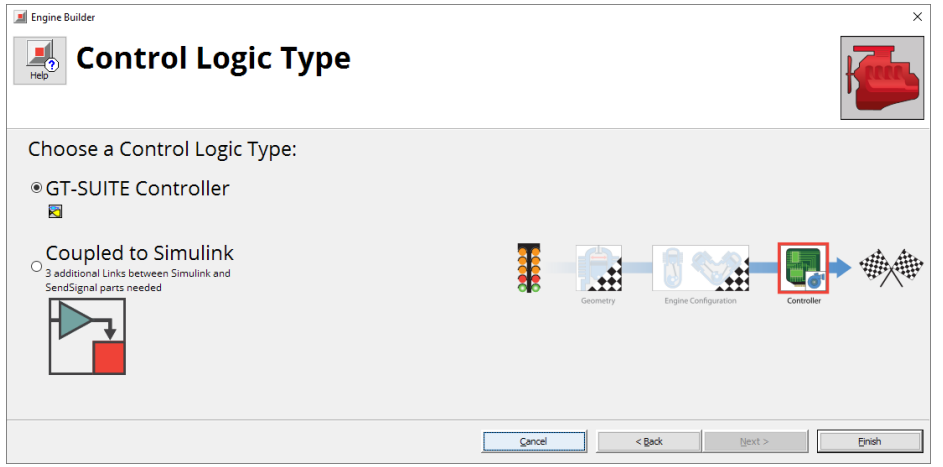
FRM-d Builder

Step 5



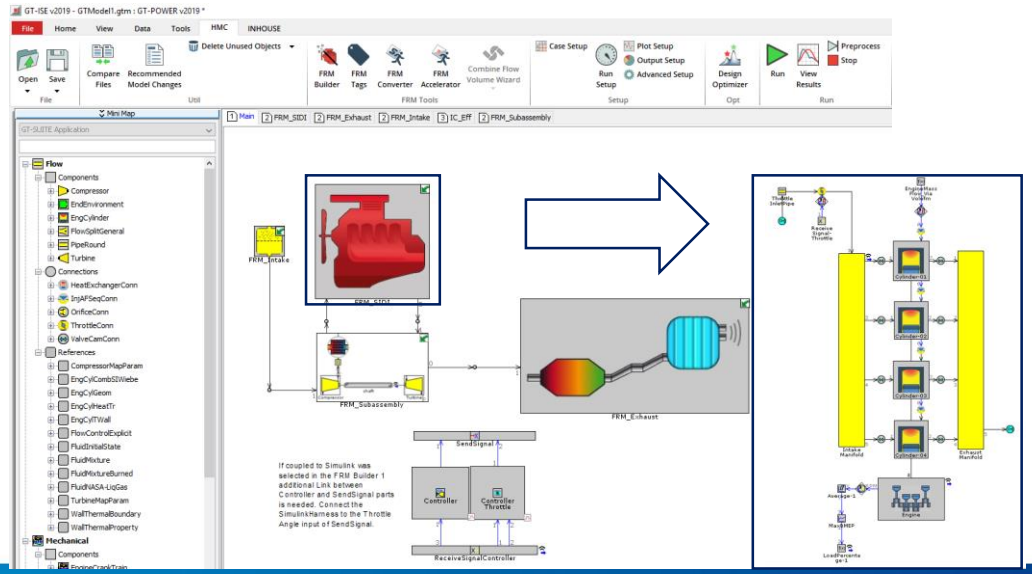
Step 6

Finish

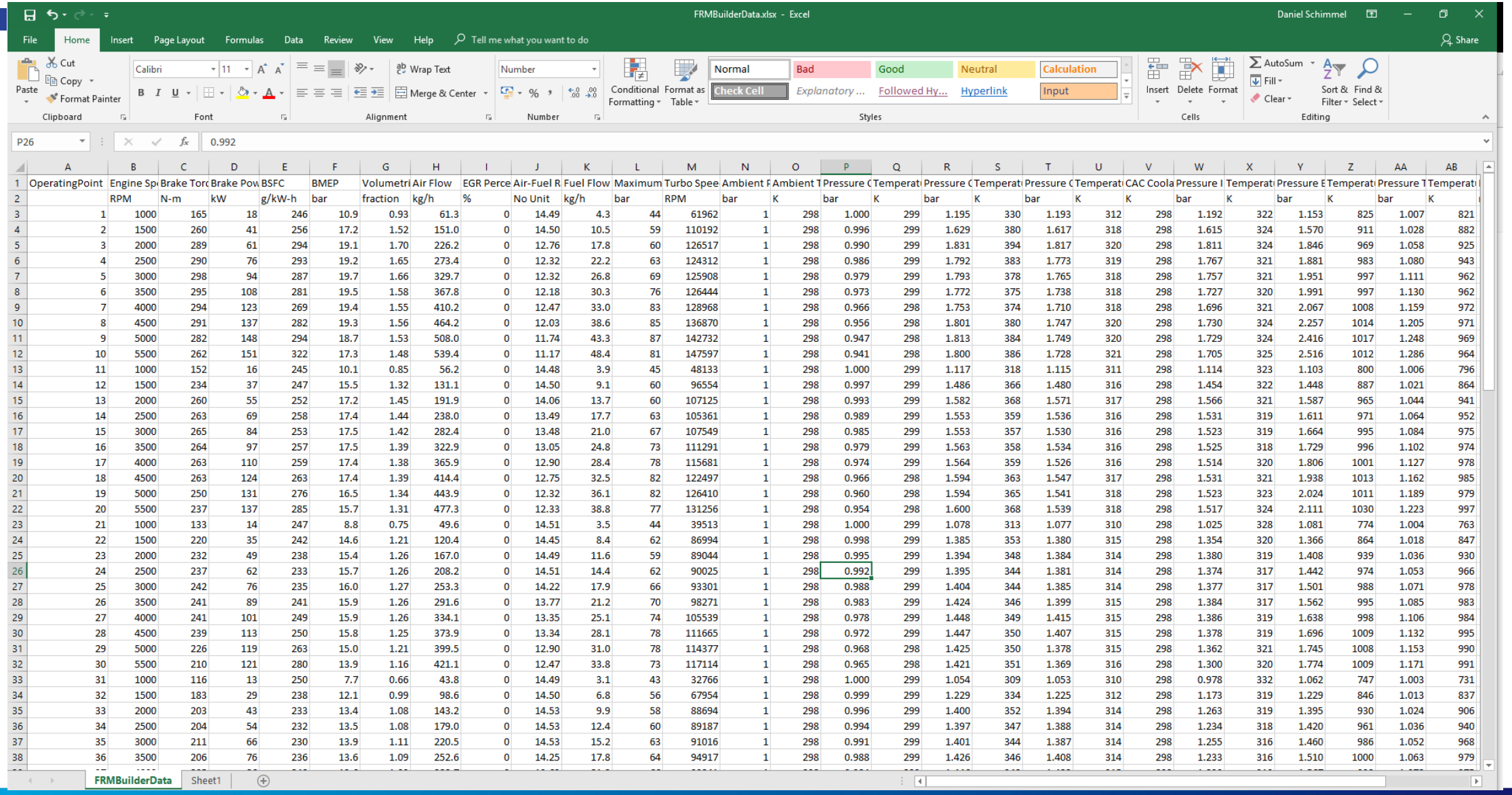


Step 7

RT Capable

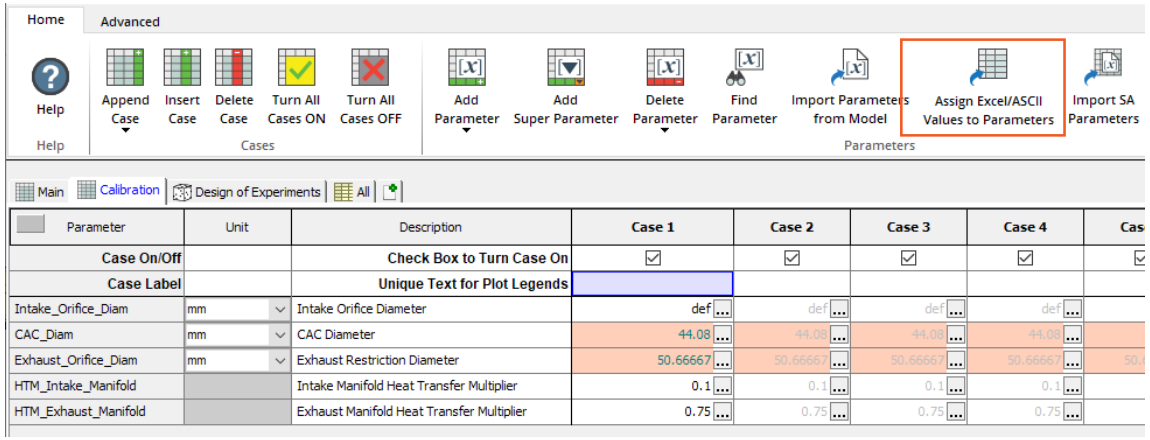


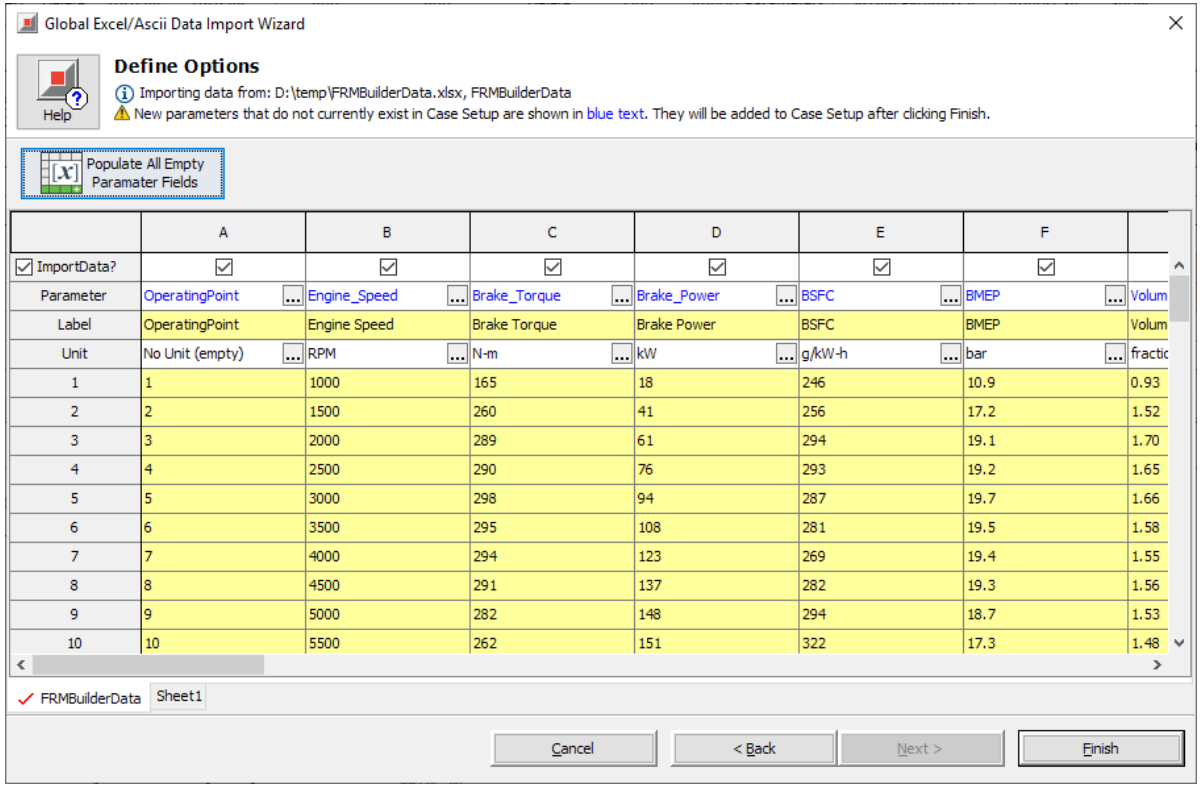
将实测数据导入模型



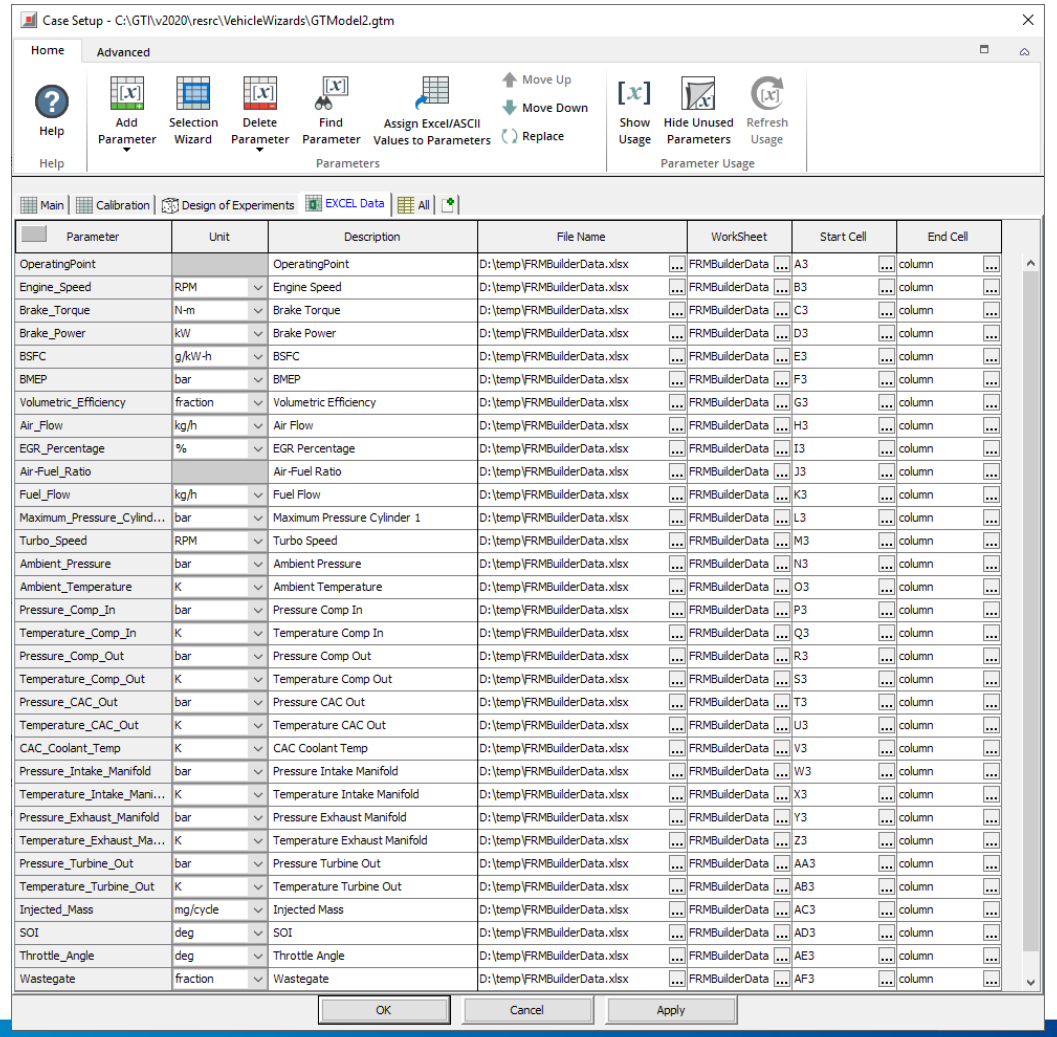
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
1	OperatingPoint	Engine Sp	Brake Torc	Brake Pow	BSFC	BMEP	Volumetri	Air Flow	EGR Perce	Air-Fuel R	Fuel Flow	Maximum	Turbo Spee	Ambient F	Ambient T	Pressure C	Temperat	Pressure C	Temperat	Pressure C	Temperat	CAC Coola	Pressure I	Temperat	Pressure E	Temperat	Pressure T	Temperat
2		RPM	N-m	kW	g/kW-h	bar	fraction	kg/h	%	No Unit	kg/h	bar	RPM	bar	K	bar	K	bar	K	bar	K	K	bar	K	bar	K	bar	K
3	1	1000	165	18	246	10.9	0.93	61.3	0	14.49	4.3	44	61962	1	298	1.000	299	1.195	330	1.193	312	298	1.192	322	1.153	825	1.007	821
4	2	1500	260	41	256	17.2	1.52	151.0	0	14.50	10.5	59	110192	1	298	0.996	299	1.629	380	1.617	318	298	1.615	324	1.570	911	1.028	882
5	3	2000	289	61	294	19.1	1.70	226.2	0	12.76	17.8	60	126517	1	298	0.990	299	1.831	394	1.817	320	298	1.811	324	1.846	969	1.058	925
6	4	2500	290	76	293	19.2	1.65	273.4	0	12.32	22.2	63	124312	1	298	0.986	299	1.792	383	1.773	319	298	1.767	321	1.881	983	1.080	943
7	5	3000	298	94	287	19.7	1.66	329.7	0	12.32	26.8	69	125908	1	298	0.979	299	1.793	378	1.765	318	298	1.757	321	1.951	997	1.111	962
8	6	3500	295	108	281	19.5	1.58	367.8	0	12.18	30.3	76	126444	1	298	0.973	299	1.772	375	1.738	318	298	1.727	320	1.991	997	1.130	962
9	7	4000	294	123	269	19.4	1.55	410.2	0	12.47	33.0	83	128968	1	298	0.966	298	1.753	374	1.710	318	298	1.696	321	2.067	1008	1.159	972
10	8	4500	291	137	282	19.3	1.56	464.2	0	12.03	38.6	85	136870	1	298	0.956	298	1.801	380	1.747	320	298	1.730	324	2.257	1014	1.205	971
11	9	5000	282	148	294	18.7	1.53	508.0	0	11.74	43.3	87	142732	1	298	0.947	298	1.813	384	1.749	320	298	1.729	324	2.416	1017	1.248	969
12	10	5500	262	151	322	17.3	1.48	539.4	0	11.17	48.4	81	147597	1	298	0.941	298	1.800	386	1.728	321	298	1.705	325	2.516	1012	1.286	964
13	11	1000	152	16	245	10.1	0.85	56.2	0	14.48	3.9	45	48133	1	298	1.000	299	1.117	318	1.115	311	298	1.114	323	1.103	800	1.006	796
14	12	1500	234	37	247	15.5	1.32	131.1	0	14.50	9.1	60	96554	1	298	0.997	299	1.486	366	1.480	316	298	1.454	322	1.448	887	1.021	864
15	13	2000	260	55	252	17.2	1.45	191.9	0	14.06	13.7	60	107125	1	298	0.993	299	1.582	368	1.571	317	298	1.566	321	1.587	965	1.044	941
16	14	2500	263	69	258	17.4	1.44	238.0	0	13.49	17.7	63	105361	1	298	0.989	299	1.553	359	1.536	316	298	1.531	319	1.611	971	1.064	952
17	15	3000	265	84	253	17.5	1.42	282.4	0	13.48	21.0	67	107549	1	298	0.985	299	1.553	357	1.530	316	298	1.523	319	1.664	995	1.084	975
18	16	3500	264	97	257	17.5	1.39	322.9	0	13.05	24.8	73	111291	1	298	0.979	299	1.563	358	1.534	316	298	1.525	318	1.729	996	1.102	974
19	17	4000	263	110	259	17.4	1.38	365.9	0	12.90	28.4	78	115681	1	298	0.974	299	1.564	359	1.526	316	298	1.514	320	1.806	1001	1.127	978
20	18	4500	263	124	263	17.4	1.39	414.4	0	12.75	32.5	82	122497	1	298	0.966	298	1.594	363	1.547	317	298	1.531	321	1.938	1013	1.162	985
21	19	5000	250	131	276	16.5	1.34	443.9	0	12.32	36.1	82	126410	1	298	0.960	298	1.594	365	1.541	318	298	1.523	323	2.024	1011	1.189	979
22	20	5500	237	137	285	15.7	1.31	477.3	0	12.33	38.8	77	131256	1	298	0.954	298	1.600	368	1.539	318	298	1.517	324	2.111	1030	1.223	997
23	21	1000	133	14	247	8.8	0.75	49.6	0	14.51	3.5	44	39513	1	298	1.000	299	1.078	313	1.077	310	298	1.025	328	1.081	774	1.004	763
24	22	1500	220	35	242	14.6	1.21	120.4	0	14.45	8.4	62	86994	1	298	0.998	299	1.385	353	1.380	315	298	1.354	320	1.366	864	1.018	847
25	23	2000	232	49	238	15.4	1.26	167.0	0	14.49	11.6	59	89044	1	298	0.995	299	1.394	348	1.384	314	298	1.380	319	1.408	939	1.036	930
26	24	2500	237	62	233	15.7	1.26	208.2	0	14.51	14.4	62	90025	1	298	0.992	299	1.395	344	1.381	314	298	1.374	317	1.442	974	1.053	966
27	25	3000	242	76	235	16.0	1.27	253.3	0	14.22	17.9	66	93301	1	298	0.988	299	1.404	344	1.385	314	298	1.377	317	1.501	988	1.071	978
28	26	3500	241	89	241	15.9	1.26	291.6	0	13.77	21.2	70	98271	1	298	0.983	299	1.424	346	1.399	315	298	1.384	317	1.562	995	1.085	983
29	27	4000	241	101	249	15.9	1.26	334.1	0	13.35	25.1	74	105539	1	298	0.978	299	1.448	349	1.415	315	298	1.386	319	1.638	998	1.106	984
30	28	4500	239	113	250	15.8	1.25	373.9	0	13.34	28.1	78	111665	1	298	0.972	299	1.447	350	1.407	315	298	1.378	319	1.696	1009	1.132	995
31	29	5000	226	119	263	15.0	1.21	399.5	0	12.90	31.0	78	114377	1	298	0.968	298	1.425	350	1.378	315	298	1.362	321	1.745	1008	1.153	990
32	30	5500	210	121	280	13.9	1.16	421.1	0	12.47	33.8	73	117114	1	298	0.965	298	1.421	351	1.369	316	298	1.300	320	1.774	1009	1.171	991
33	31	1000	116	13	250	7.7	0.66	43.8	0	14.49	3.1	43	32766	1	298	1.000	299	1.054	309	1.053	310	298	0.978	332	1.062	747	1.003	731
34	32	1500	183	29	238	12.1	0.99	98.6	0	14.50	6.8	56	67954	1	298	0.999	299	1.229	334	1.225	312	298	1.173	319	1.229	846	1.013	837
35	33	2000	203	43	233	13.4	1.08	143.2	0	14.53	9.9	58	88694	1	298	0.996	299	1.400	352	1.394	314	298	1.263	319	1.395	930	1.024	906
36	34	2500	204	54	232	13.5	1.08	179.0	0	14.53	12.4	60	89187	1	298	0.994	299	1.397	347	1.388	314	298	1.234	318	1.420	961	1.036	940
37	35	3000	211	66	230	13.9	1.11	220.5	0	14.53	15.2	63	91016	1	298	0.991	299	1.401	344	1.387	314	298	1.255	316	1.460	986	1.052	968
38	36	3500	206	76	236	13.6	1.09	252.6	0	14.25	17.8	64	94917	1	298	0.988	299	1.426	346	1.408	314	298	1.233	316	1.510	1000	1.063	979

- 引导选项指向Excel数据

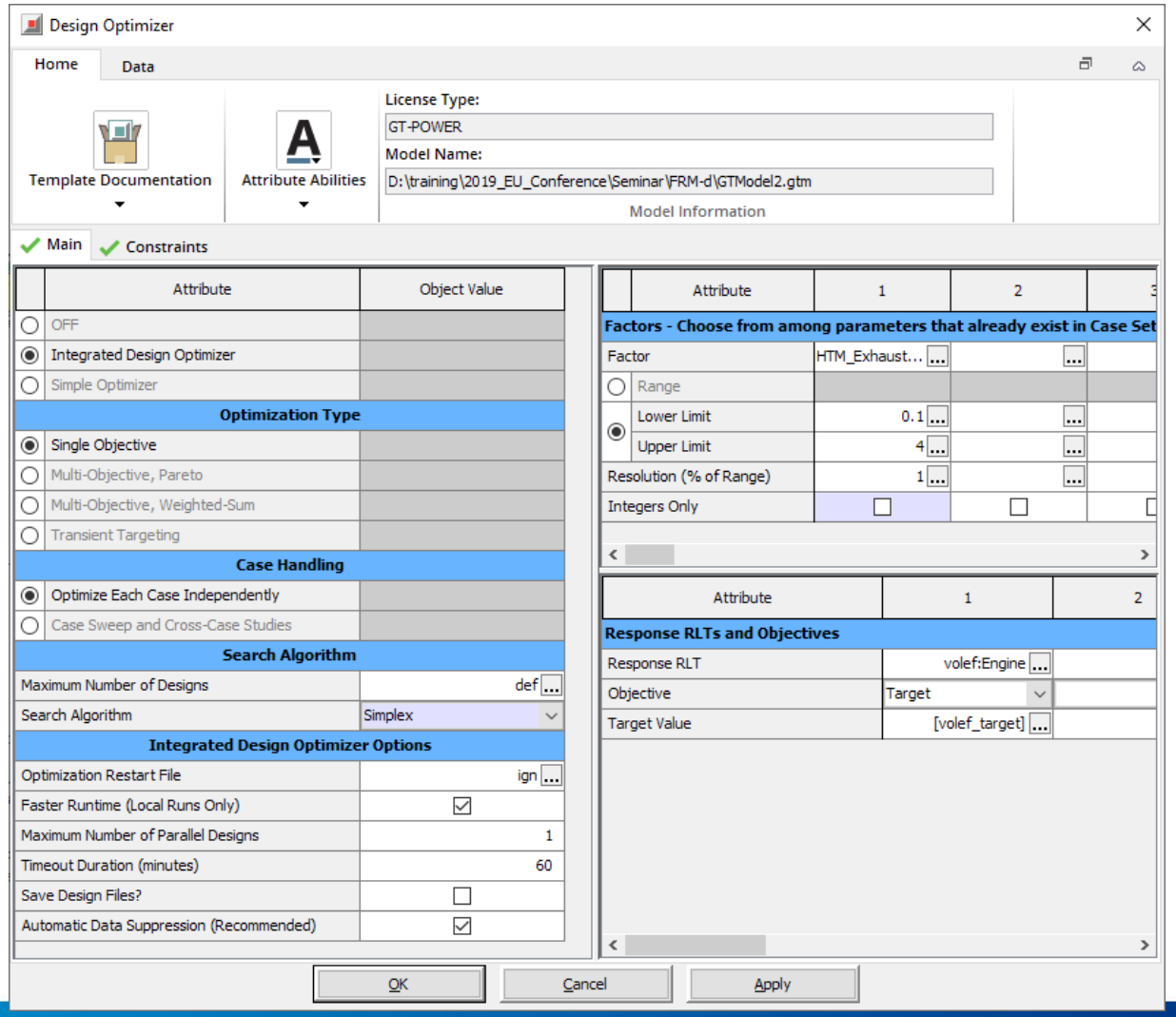




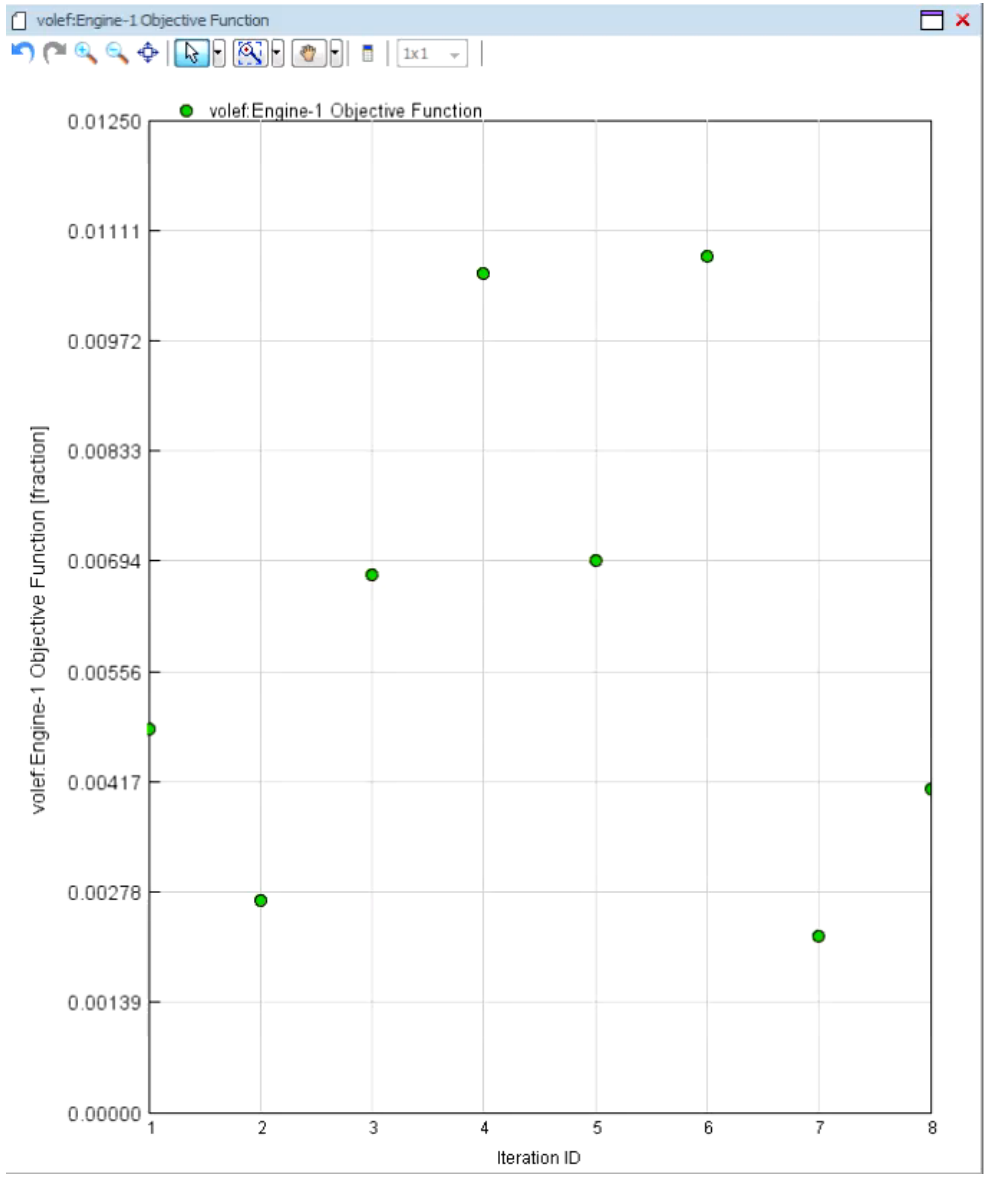
- 在 Case Setup 中快速设置参数

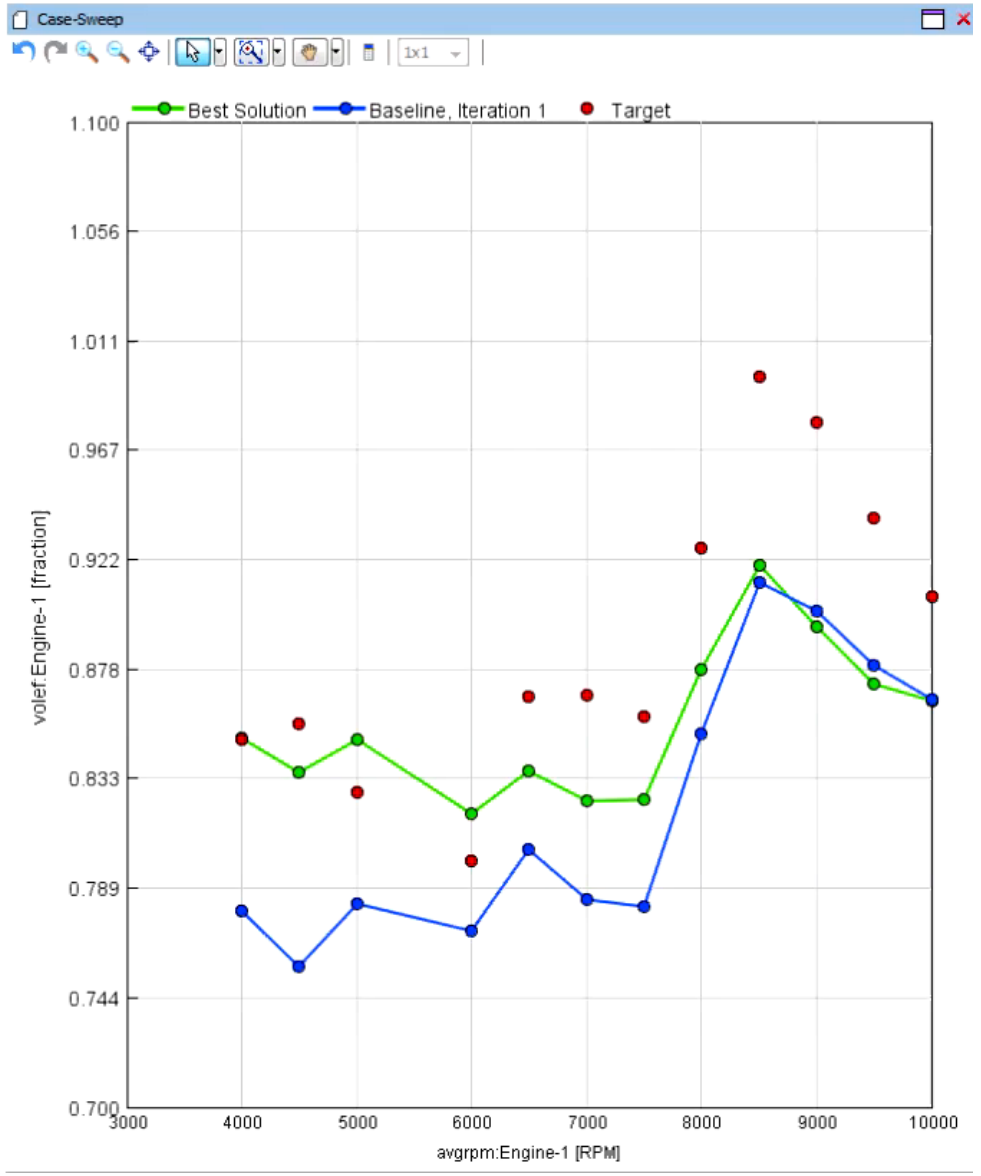


- 使用 Design Optimizer 标定

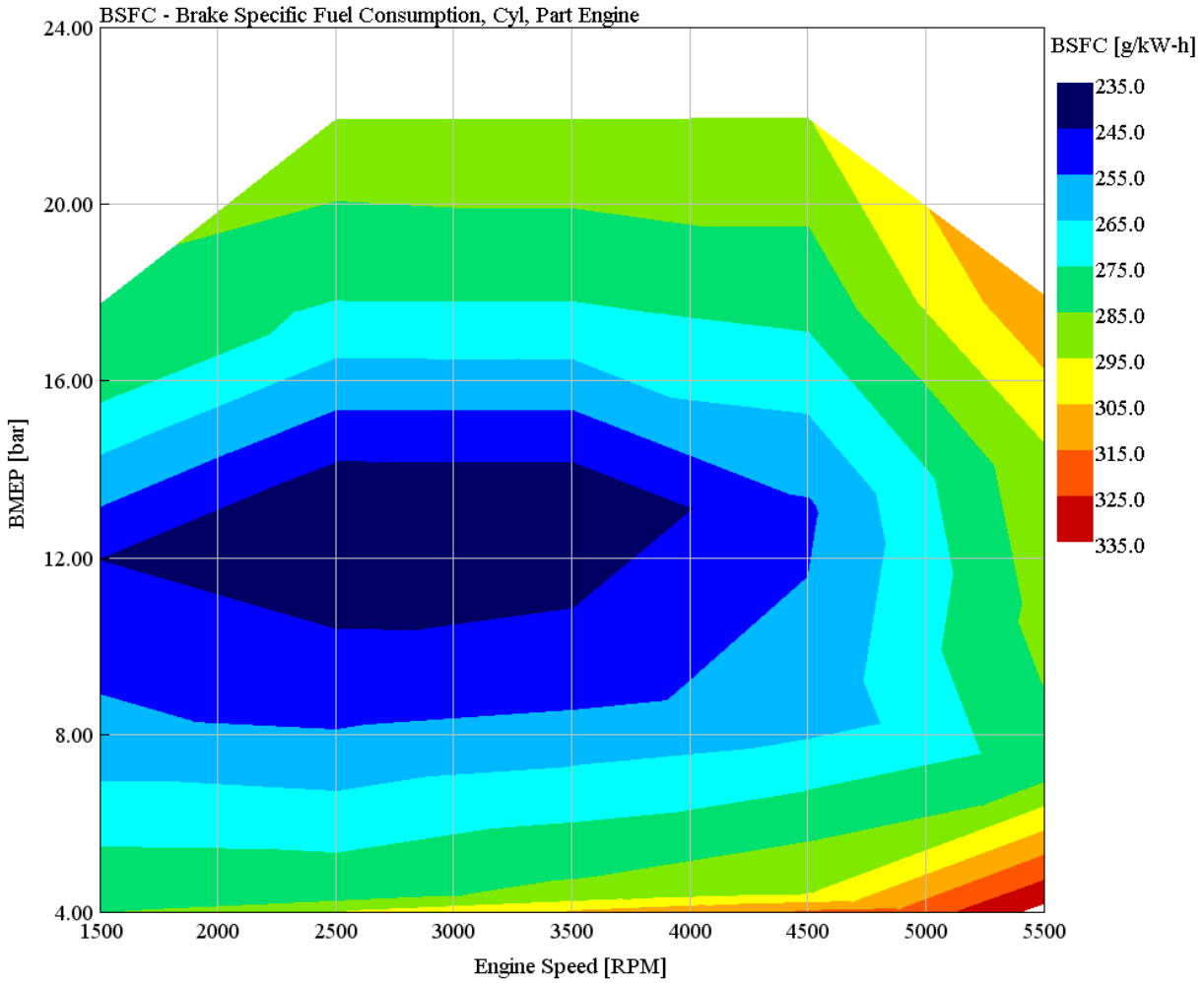


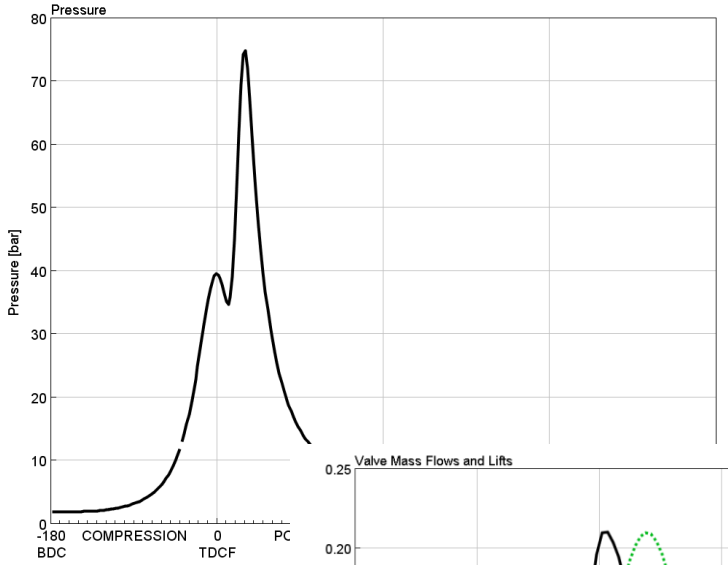
Example:发动机充气效率标定

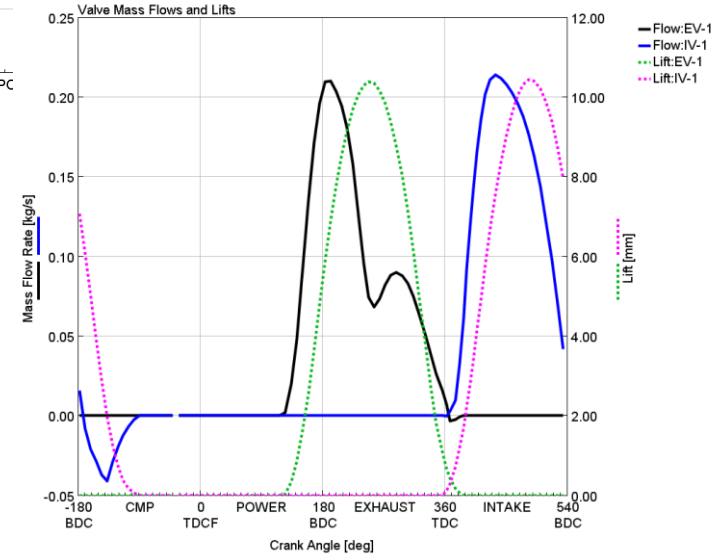




- Results:

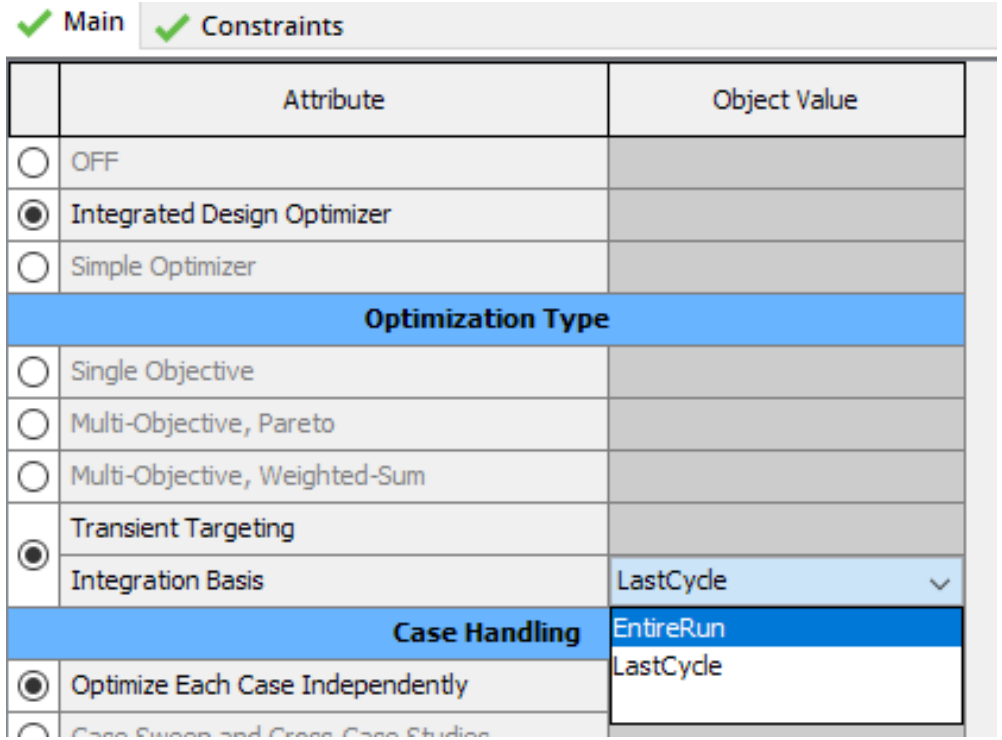






瞬态模型标定：瞬态目标优化

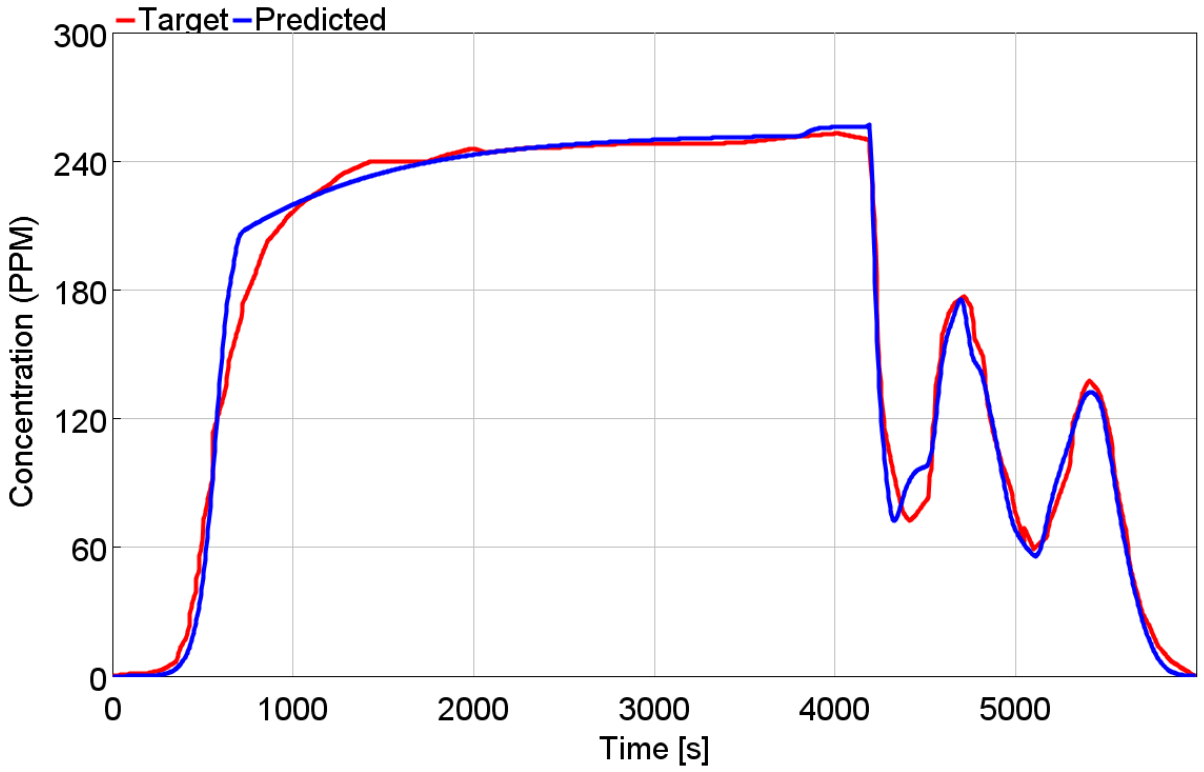
- 在优化器中设置
- 最小化均方差的自动化

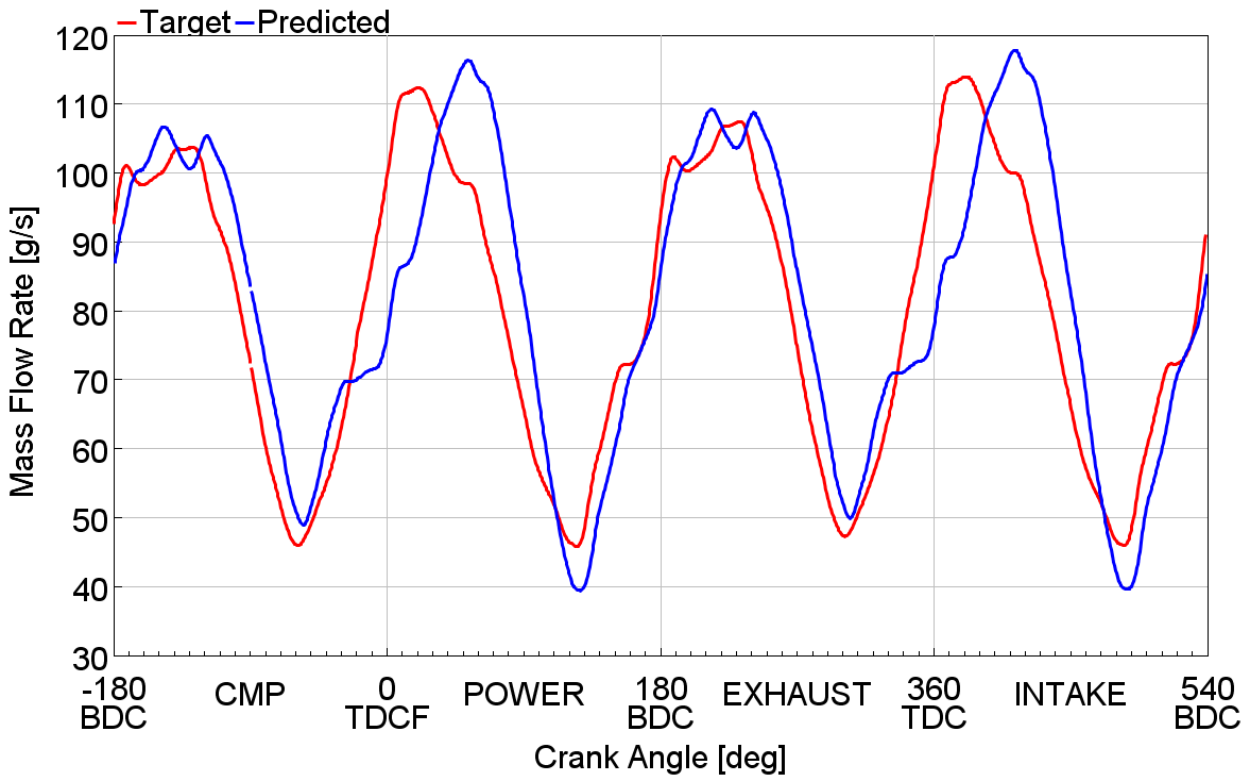


Attribute	Unit	1	2	3
Transient Targeting				
Signal or Time RLT		btq:Engine	1:Collector1:25:25	2:ExPipe:32:32
Target Profile		Torque_Profile	Meas_Exh_Pressure	Meas_Exh_Temperature
Term Weight		def (=1)	def (=1)	def (=1)
Start Time	s	def (=0)	def (=0)	def (=0)
End Time	s	def (=case end)	def (=case end)	def (=case end)

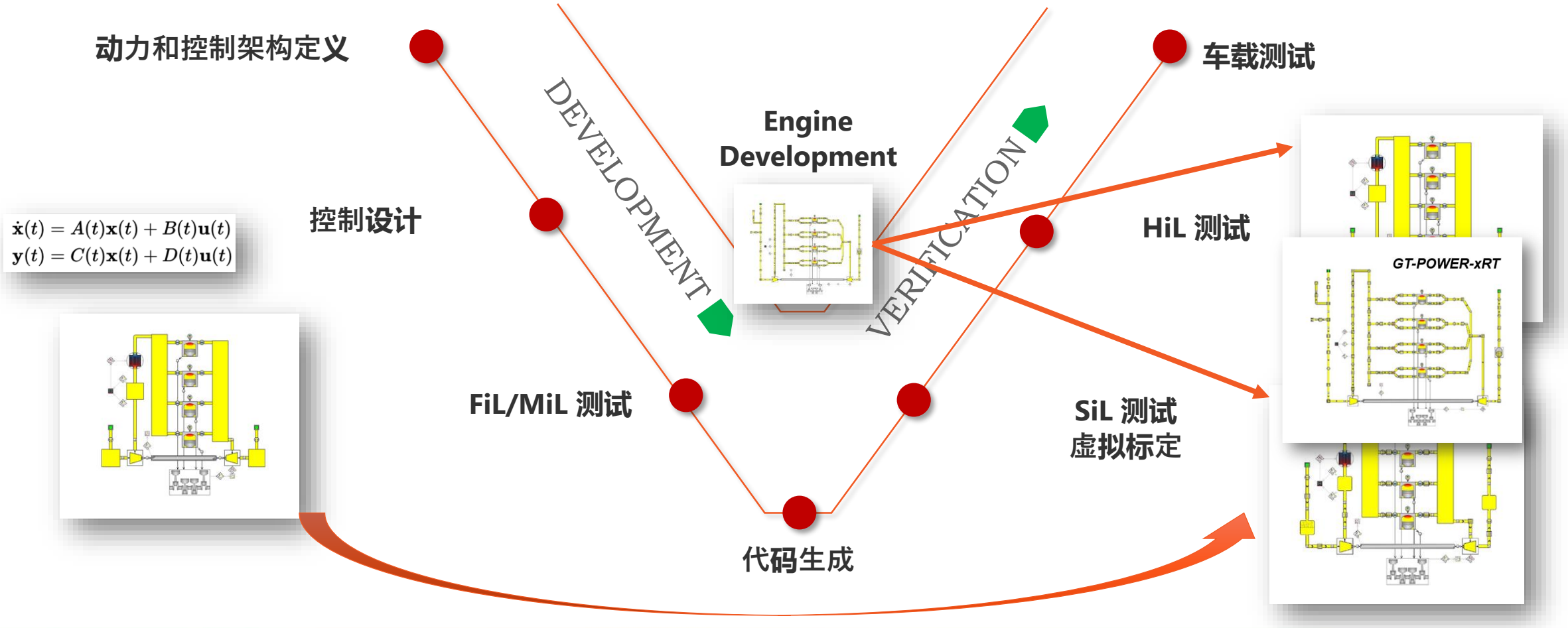
瞬态目标优化

- 标定瞬态信号和TimeRLTs与试验结果





GT-SUITE 可以在整个开发周期中使用

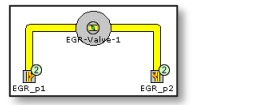


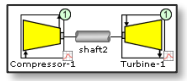
GT-SUITE 优势

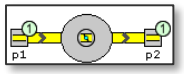
- 模拟
  - 确保可预测性并最大化测量数据的效果
  - 保持模型拓扑和建模元素
  - 能够满足对模型复杂性/速度的广泛需求

- 工作流程
  - 利用现有的GT模型或支持从空白页创建
  - 单一工具贯穿整个开发周期、组间的公共语言、共享的子系统模型
  - 更好的可跟踪性和模型管理
  - 快速的计算时间，便于通过试验数据增强模型实用性
  - 与MATLAB/Simulink和标定/验证平台无缝连接

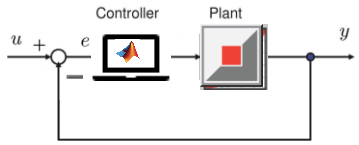
完整的GT解決方案 XiL (MiL, SiL, HiL)



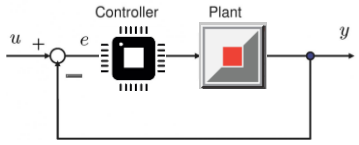




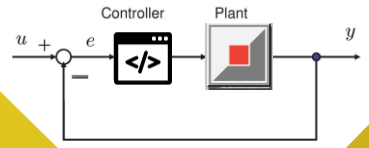
MiL



HiL



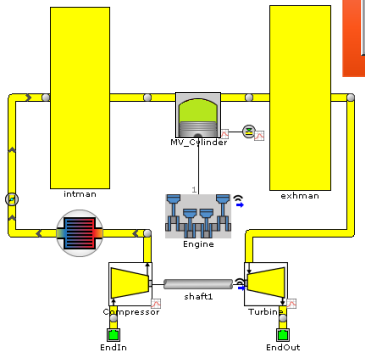
SiL



GT-Linearization

Functions specification

GT-Mean Value Cylinder Model

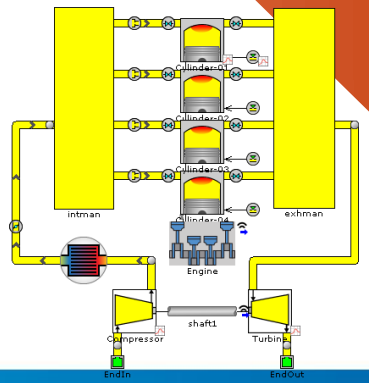


Controller design

GT-Builder

GT-Engine Database

Automatic GT-Converter



Software calibration & validation

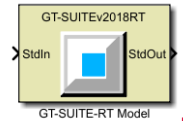
GT-Cluster Solver

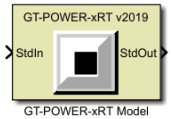
Software calibration & validation

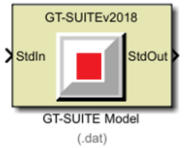
GT-POWER-xRT

GT-SUITE-RT

Service Provider







RT Platform

S-Function for GT-POWER

GT-POWER Model

感谢倾听
期待与您合作 ☺

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