Advanced Transient Simulation with KULI and FASI

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Introduction

Traditionally a cooling system is dimensioned to survive ***worst-case stationary operating points*** like…
通常冷却系统被设计用以满足最坏稳态工况条件下的使用，例如：

… ***full load*** operation 最大负载

… ***mountain plus trailer*** 安置拖车

In real life application the cooling system then is ***over-dimensioned most of the time***.
在实际应用过程中，冷却系统在多数情况下被过高设计

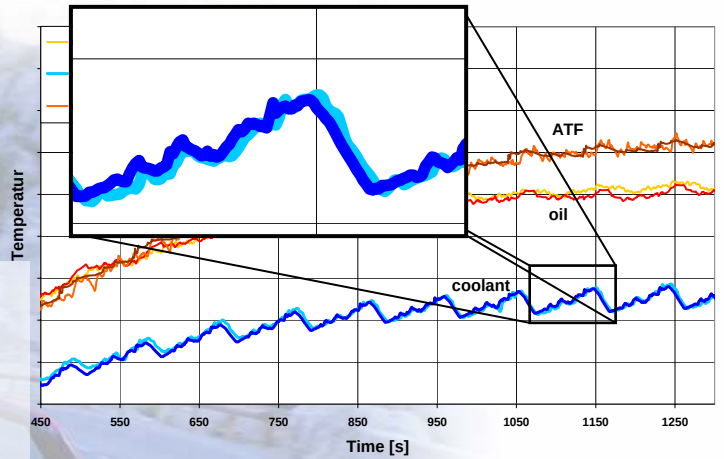
Cost pressure and ***emission regulations*** require more detailed simulation…
此外，实际的压力和排放的校对需要更详细的模拟……

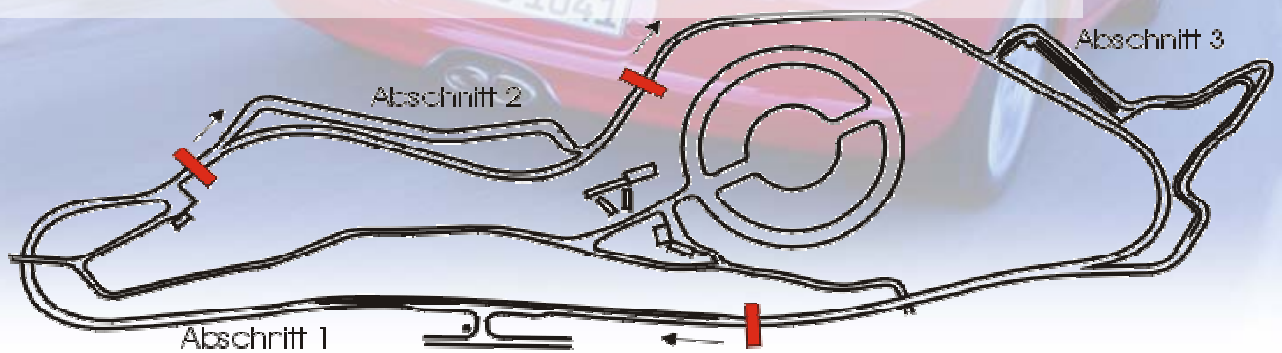
Transient Simulation!
瞬态模拟！

Contents

Sportscar Applications

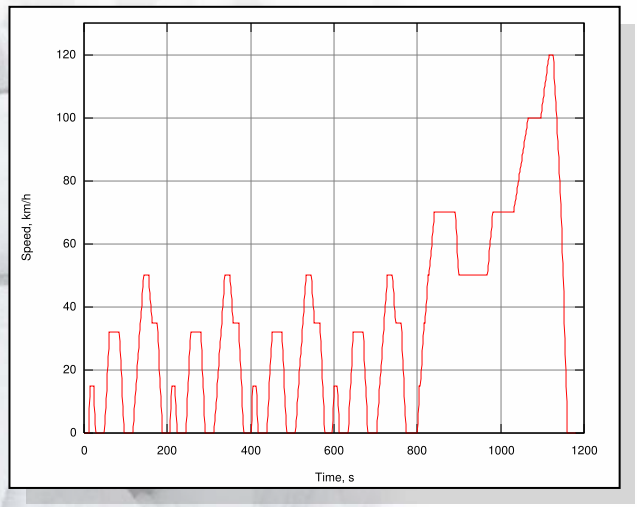
- ***Sportive*** driving 竞速行驶 ⟷ ***highly transient operating conditions***
  高强度的瞬态工况条件
- ***Engine***, ***gearbox*** and ***fluid circuits*** must be modeled ***transient***.
  引擎、变速箱以及流路都需要以瞬态的模型搭建
- Prediction of transient ***oil- and water temperatures*** for a ***race circuit***.
  预测瞬态下 油- 和 水- 的温度

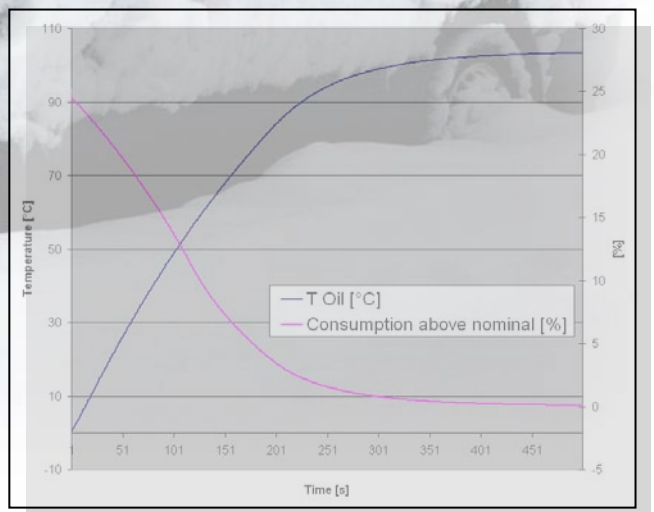




Warm-Up and Emission Reduction

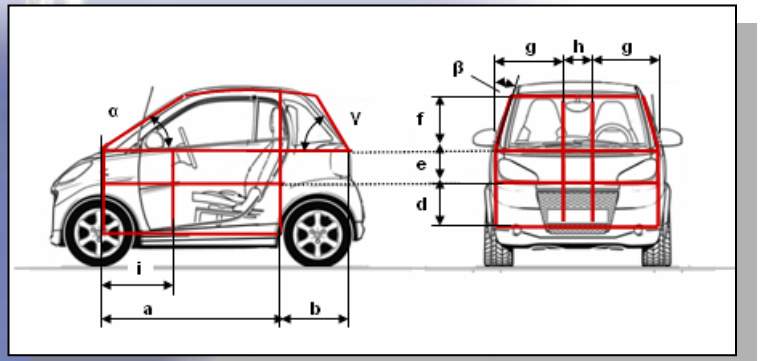
- ***Fuel Consumption*** and ***Emissions*** ⟷ ***engine temperatures***
  燃油消耗和排放 & 引擎温度
- Consumption is defined by standardized ***transient warm-up cycles*** (e.g. ***NEDC***)
  油耗使用标准瞬态warm-up循环NEDC来标定
- KULI ***simulates*** warm-up cycles ⟷ influence of ***thermal management!***
  使用KULI进行warm-up循环中的整车热管理

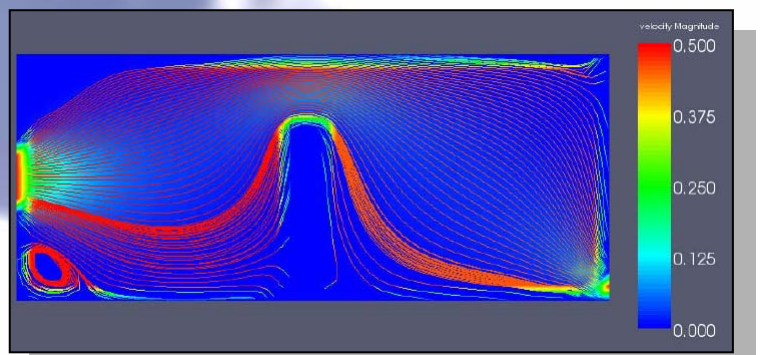




Warm-Up and Comfort

- ***Engine Warm-Up*** ⟷ ***heat*** used for engine, ***not for passengers***
  Engine warm-up单指引擎预热，而非用于乘客
- Simulation of ***electrical heaters***
  电子加热器的模拟
- Simulation of temperature distribution in ***passenger cabin***
  模拟乘客舱内的温度分布





Transient Components of a Car

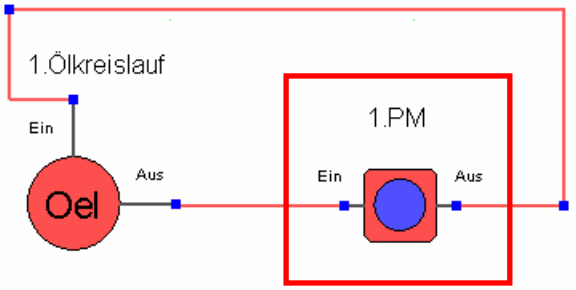
- ***The engine*** :
  Produces heat and has
  thermal capacity
  引擎输出热量并有热容影响
- ***Fluids*** in the circuits:
  Thermal capacity
  流体的热容
- ***Tubes*** and ***pipes***:
  Thermal capacity
  管路的热容
- ***Additional thermal capacities***
  以及其它热容
- ***Passenger cabin***
  乘客舱

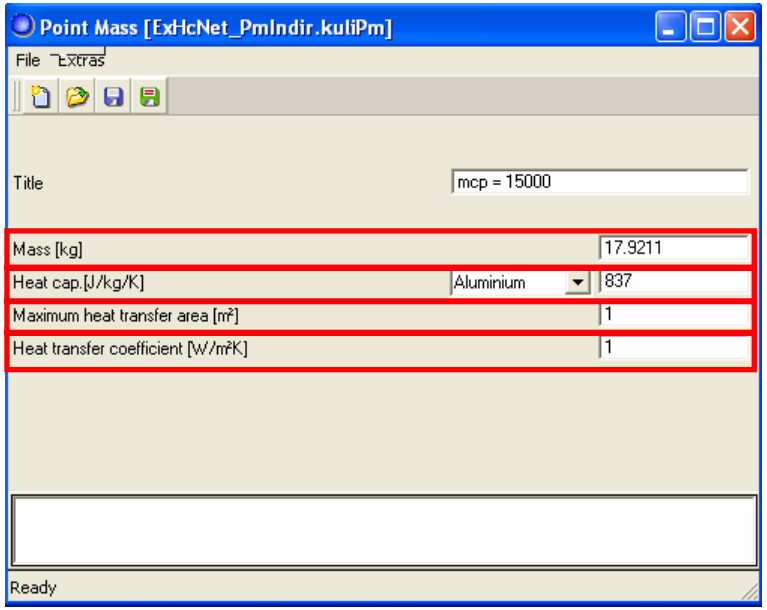
Heat exchange :

- ***Transport*** (fluid in tubes)
  流体与管路的热交换
- ***Convection*** (surfaces to fluids or air)
  从表面到流体或空气的热对流
- ***Conduction*** (inside components)
  零部件内部的热传导

Contents

Point Masses





A point mass is defined by
point mass的定义

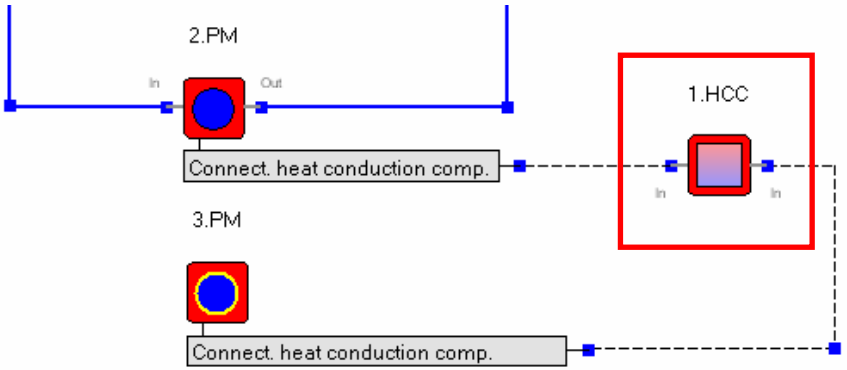
- ***mass*** *质量*
- ***specific thermal capacity*** *比热容*

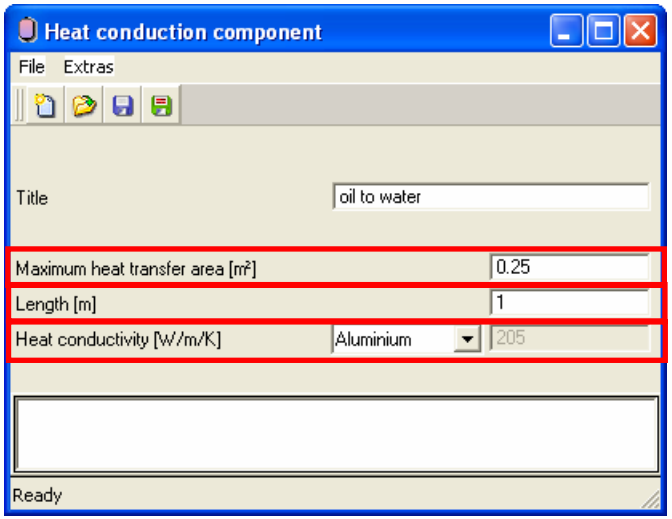
Heat exchanged with a ***circuit*** depends on
与回路中的热交换受影响于其

- ***heat transfer area*** *传热面积*
- ***heat transfer coefficient*** *传热系数*

$$\dot{Q} = k \cdot A \cdot \left(T_{circuit} - T_{mass}\right)$$

Heat Conduction





A heat conduction component is defined by heat conduction组件被定义于

- ***heat transfer area*** *传热面积*
- ***length*** *特性长度*
- ***thermal conductivity*** *热传导率*

$$\dot{Q} = \frac{\lambda \cdot A}{l} \cdot \Delta T$$

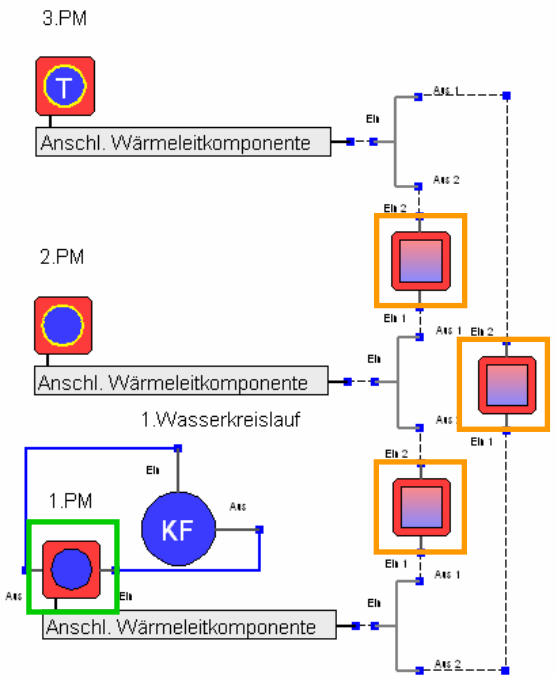
Thermal Network

A thermal network is described by a **system of differential equations**:
换热过程被描述为微分方程组：

$$\frac{dT_1}{dt} = \frac{1}{(m \cdot c_p)_1} \cdot \left[k \cdot A \cdot (T_K - T_1) + \left(\frac{\lambda \cdot A}{l}\right)_{12} \cdot (T_2 - T_1) + \left(\frac{\lambda \cdot A}{l}\right)_{13} \cdot (T_3 - T_1) \right]$$

$$\frac{dT_2}{dt} = \frac{1}{(m \cdot c_p)_2} \cdot \left[\left(\frac{\lambda \cdot A}{l}\right)_{12} \cdot (T_1 - T_2) + \left(\frac{\lambda \cdot A}{l}\right)_{23} \cdot (T_3 - T_2) \right]$$

$$\frac{dT_3}{dt} = 0$$



Mass 1: ***convection*** *热对流* and ***conduction*** *热传导*

Mass 2: ***conduction*** *热传导*

Mass 3: ***constant*** *常数*

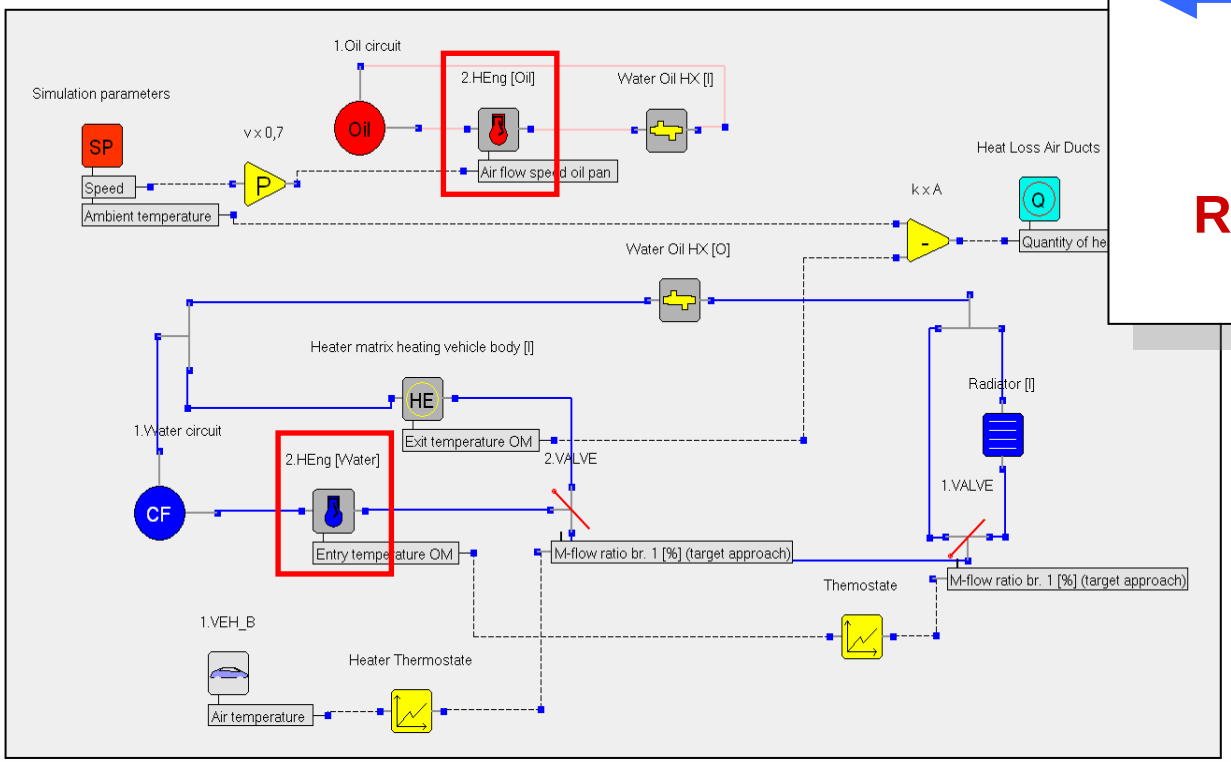
This is ***solved numerically!***
使用数值方法求解！

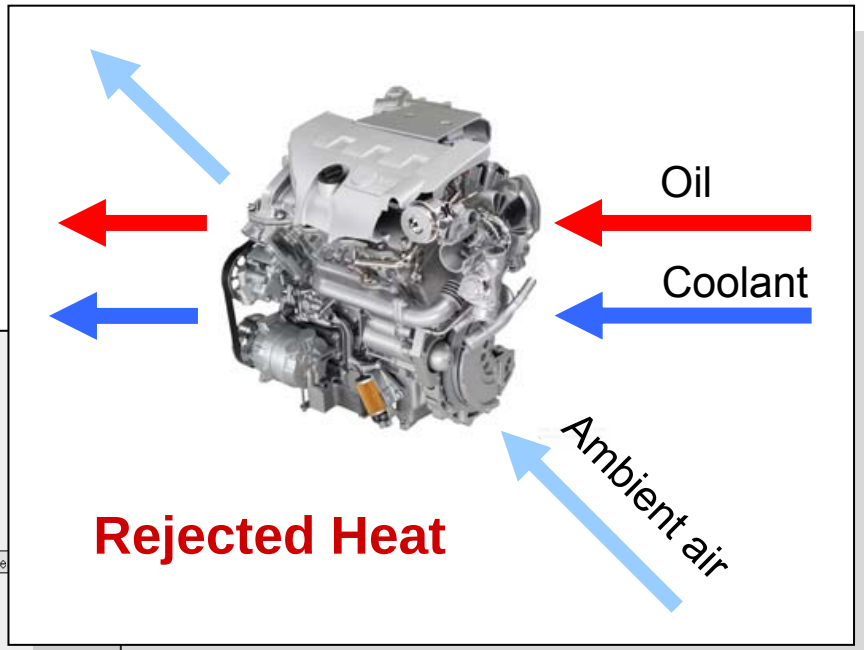
Contents

The KULI Engine Model

Influences…
影响参数

- ***Coolant*** *冷却水*
- ***Oil*** *冷却机油*
- ***Airflow*** *空气流路*

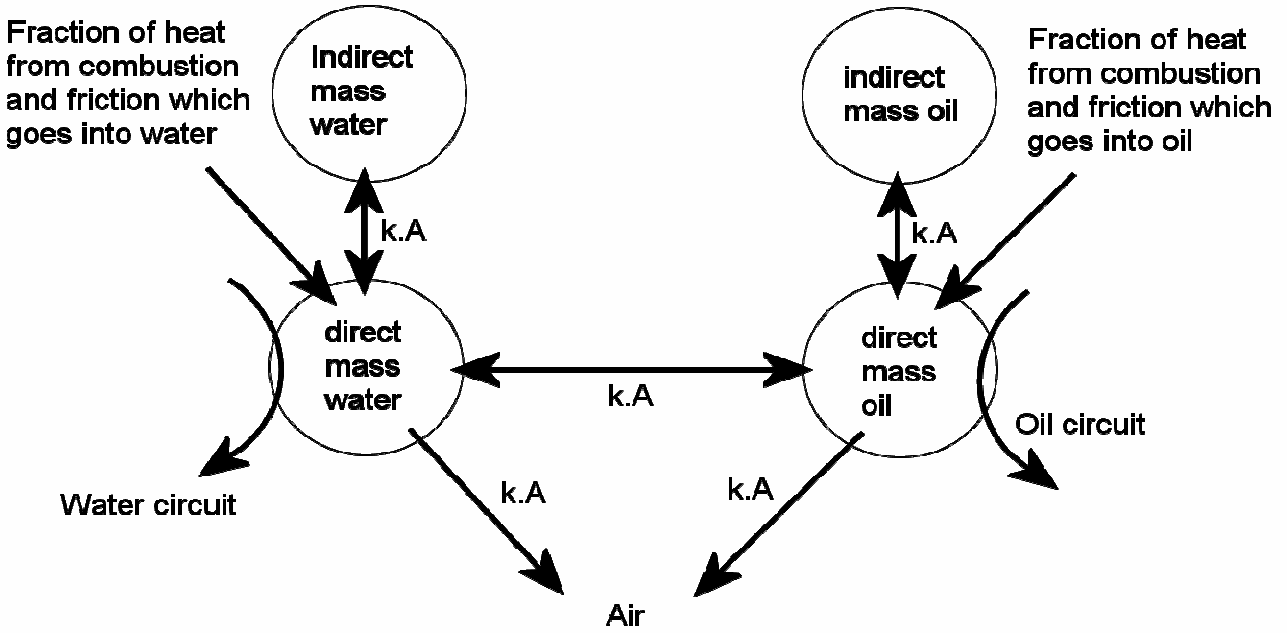




Heat from…
热量来源

- ***Combustion*** *燃烧*
- ***Friction*** *摩擦*

The 4-mass engine model



This is the simplest possible model to fulfill the main demands for cooling system simulation.
这个是最简单的模型以满足冷却系统模拟的要求

The model consists of four masses.
模型包含4个质量块

Oil- and water side are separated.
对水、油进行了区分

The masses are connected by heat conduction
质量块之间通过热传导组件连接

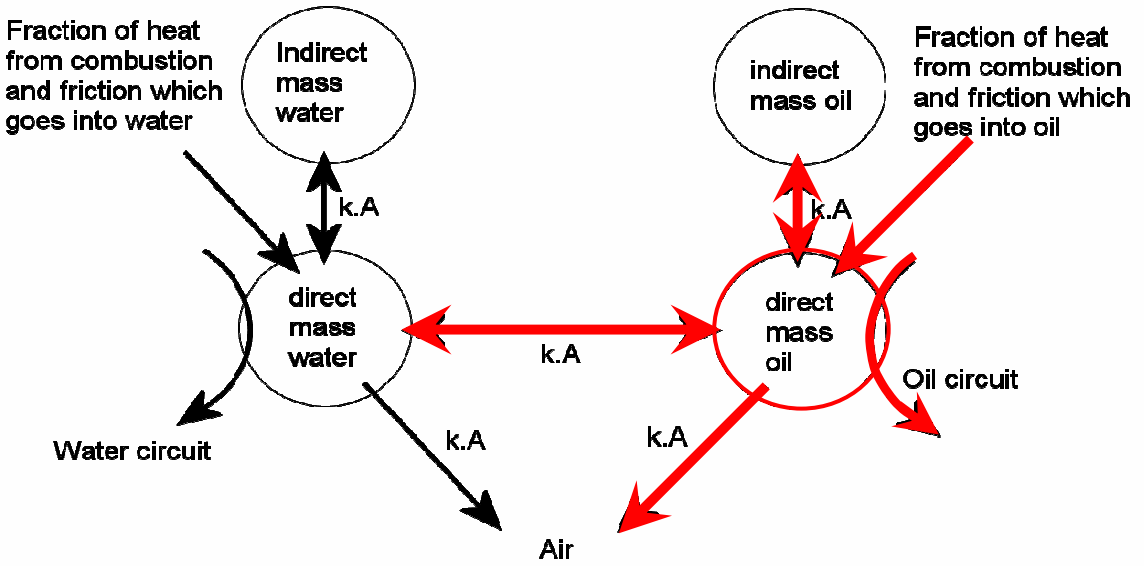
The direct masses are heated by combustion and friction.
直接质量块受燃烧以及摩擦热

Heat dissipates to water, oil and air.
热量通过水、油以及空气被发散

Mathematical Formulation Engine

The thermal network again is a **system of differential equations.**
通过热网络建立微分方程组
The formula contains:
公式包含

- the thermal capacities,
  热容量
- heat conduction between masses
  pm间的热传导,
- heat sources and
  热源以及
- heat sinks 热降



$$\forall i \in \{1 \ldots N\} \quad \frac{dT_i}{dt} = \frac{1}{m_i \cdot c_{p,i}} \cdot \left(\sum_{j=1}^{N} (kA)_{ij} \cdot (T_j - T_i) + P_{combustion\ ,i} + P_{friction\ ,i} - P_{circuit\ ,i} \right)$$

Contents

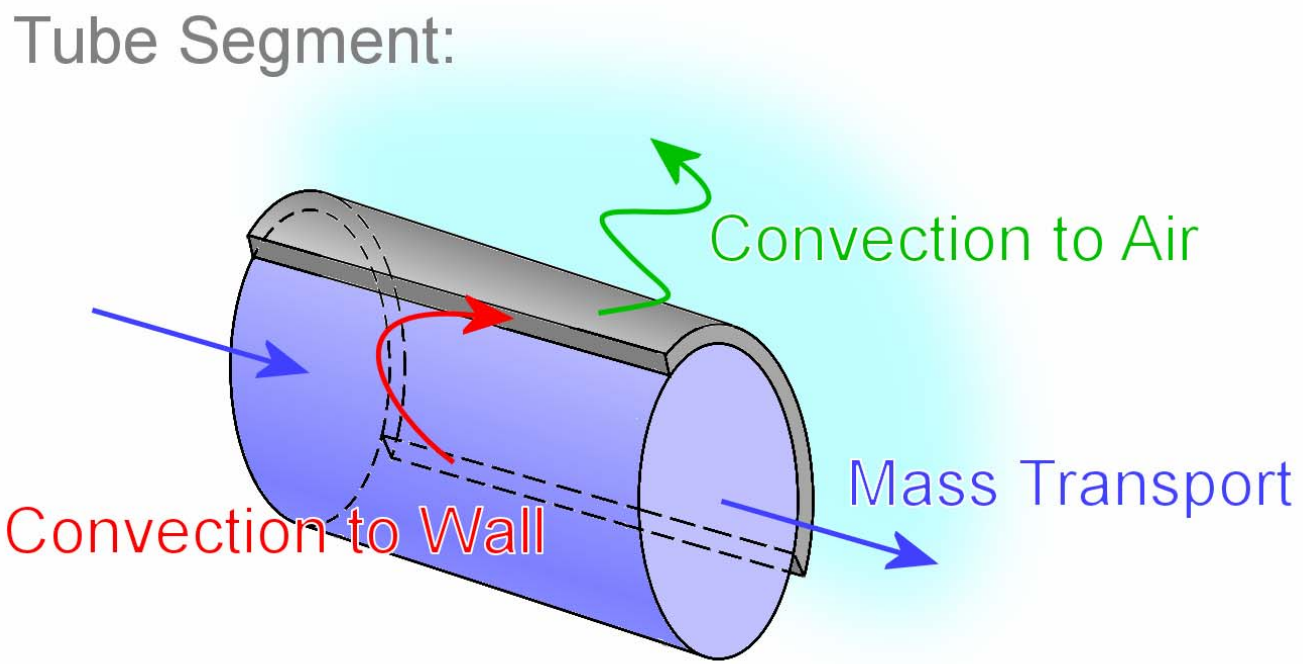
Transient Effects of a Tube

- Total ***Fluid in Tubes*** 在管路中的流体 → ***Thermal Capacity*** 热容量
- ***Length of Tube*** 管路的长度 → ***Delay*** 延迟效应

- ***Turbulences*** → ***Diffusion***

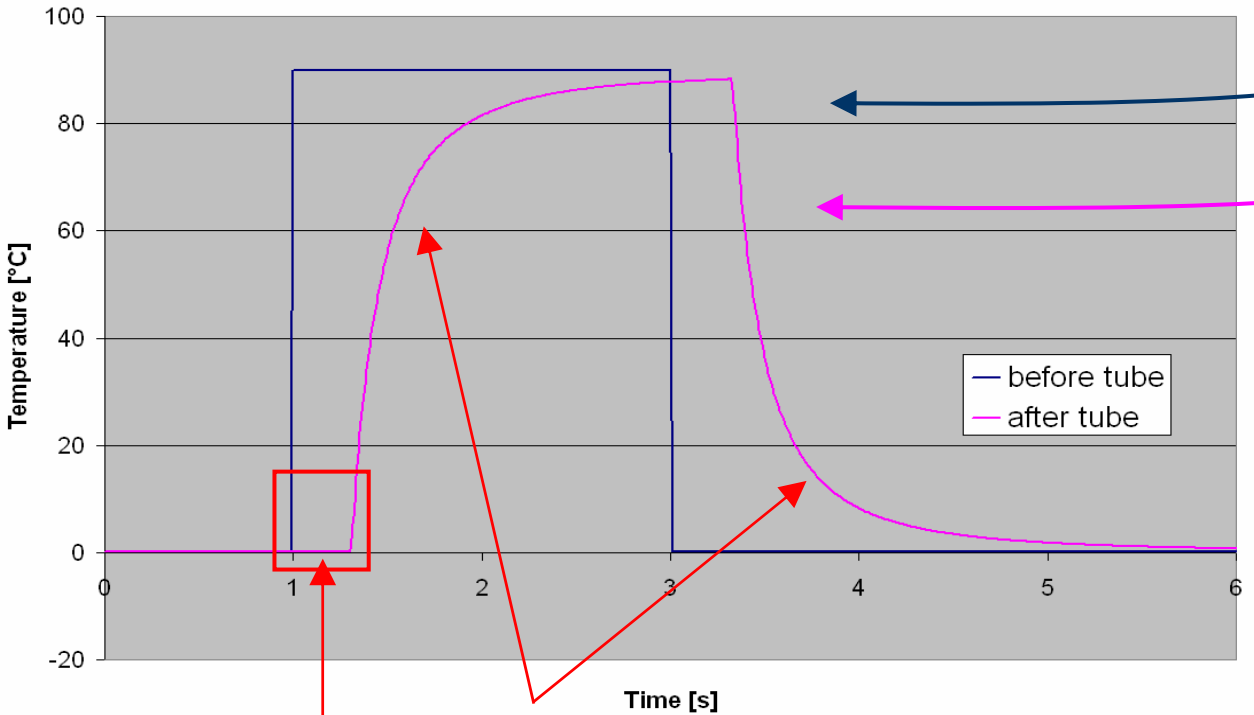
Modelling a Tube

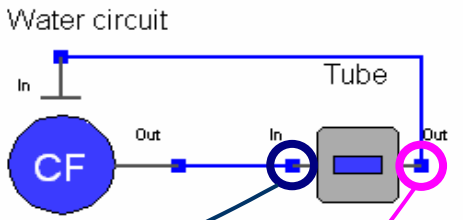
The tube is ***divided into segments***…
管子被分割成几个部分



This leads to a ***differential equation*** again.
同样被构成微分方程

Transient delay and diffusion of a single tube



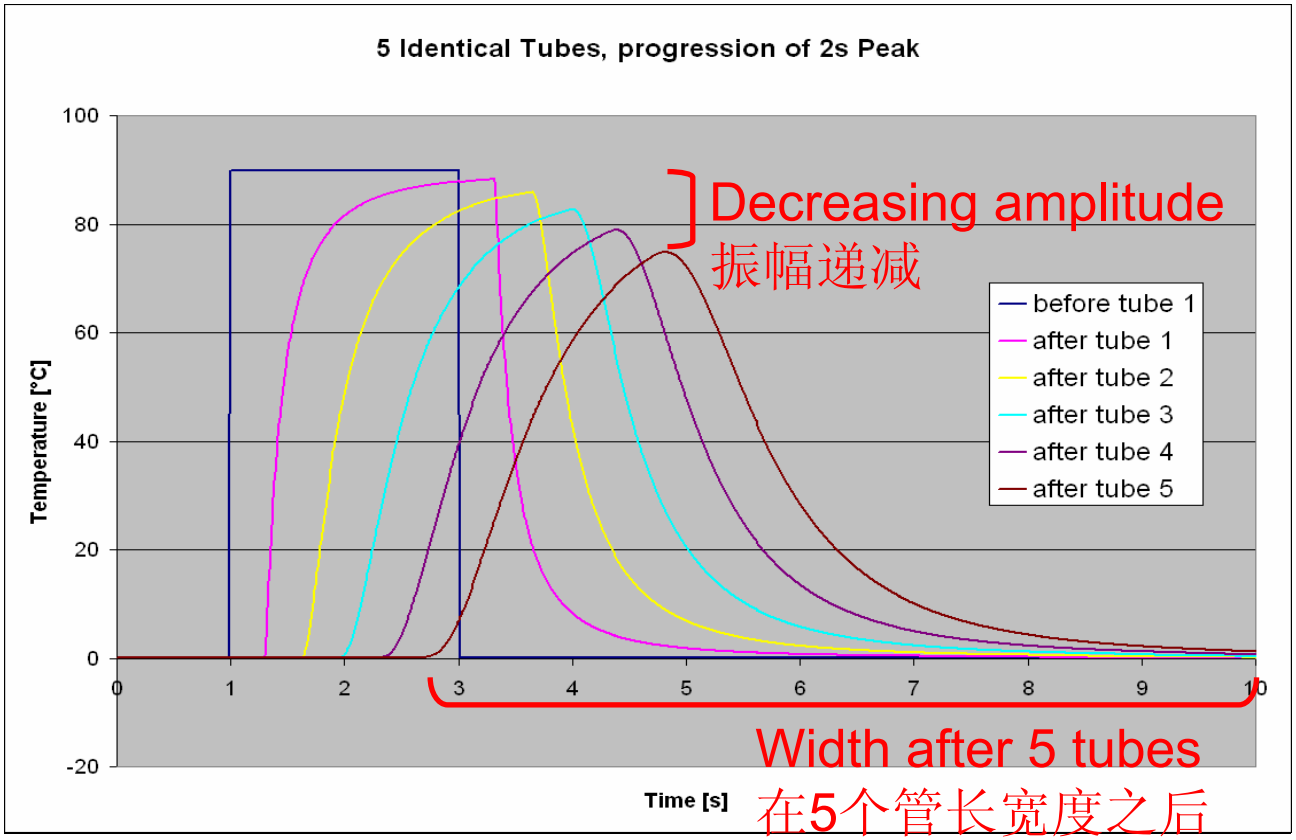


Tube length:	1m
Diameter:	20mm
Vol.Flow:	0,5kg/s

Diffusion effects

Initial delay

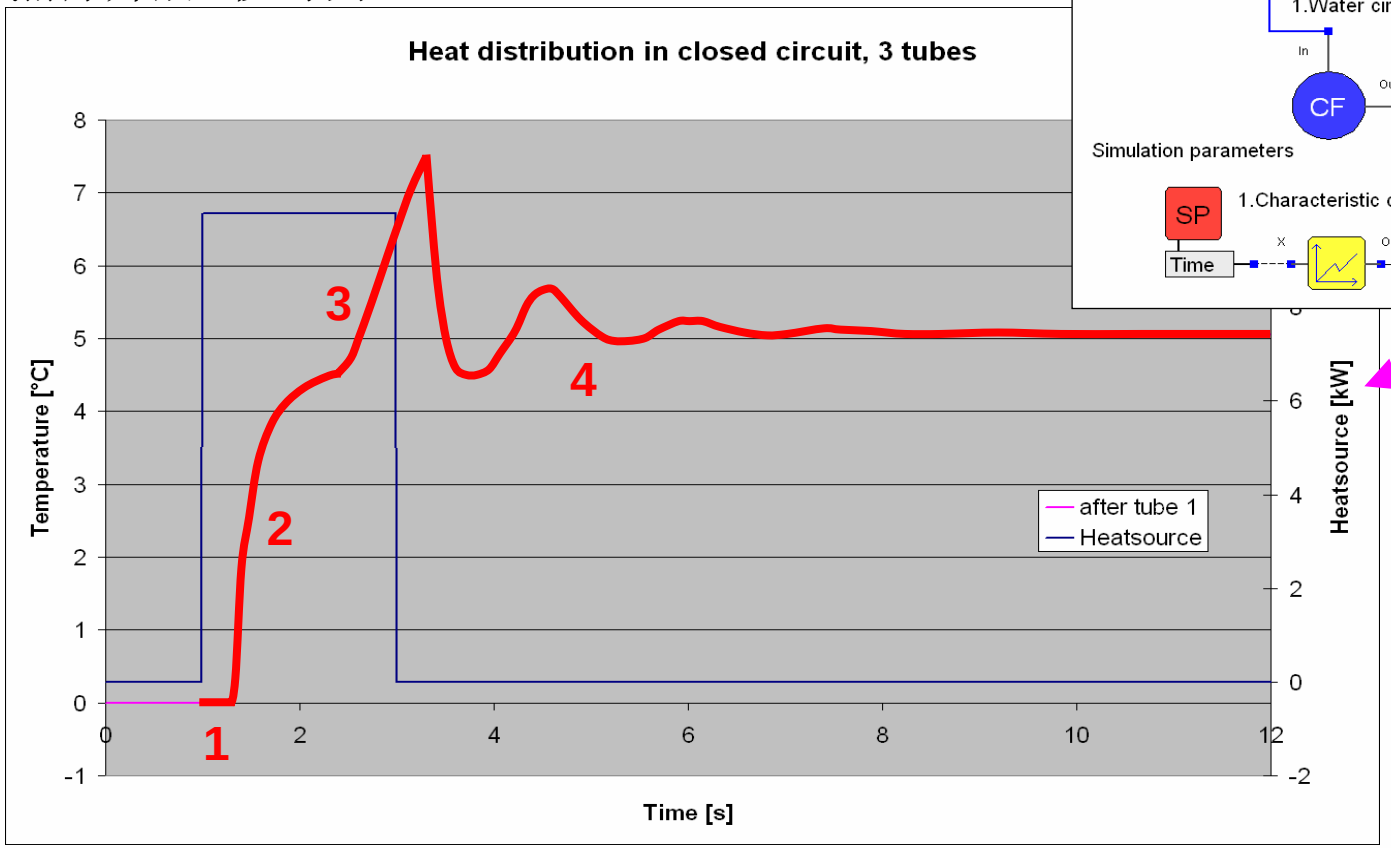
Delay and diffusion, 5 consecutive tubes

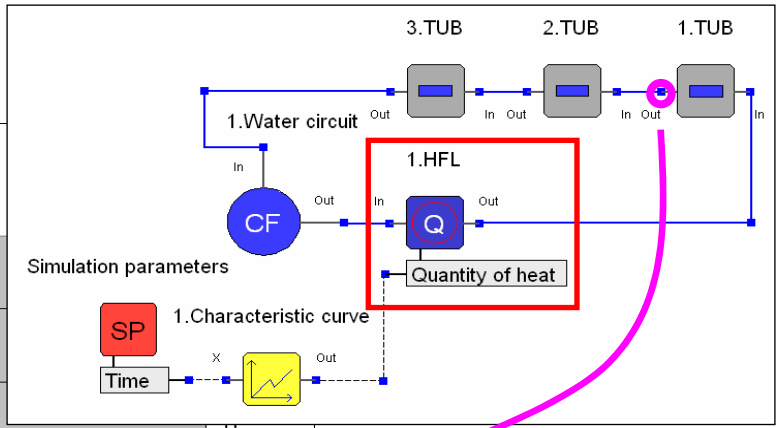


Same situation as before, this time 5 consecutive tubes.
同样的情形发生在连续的5个管长之后

Closed Circuit

Heat source is switched on for 2 seconds.
热源开启2秒时间





1) Delay 延迟

2) Warm-up 温升

3) Warm-up with recirculated hot water
由于循环的热水再温升

4) Diffusion, no heat source
无热源的传播

Contents

Cabin Model - Workflow

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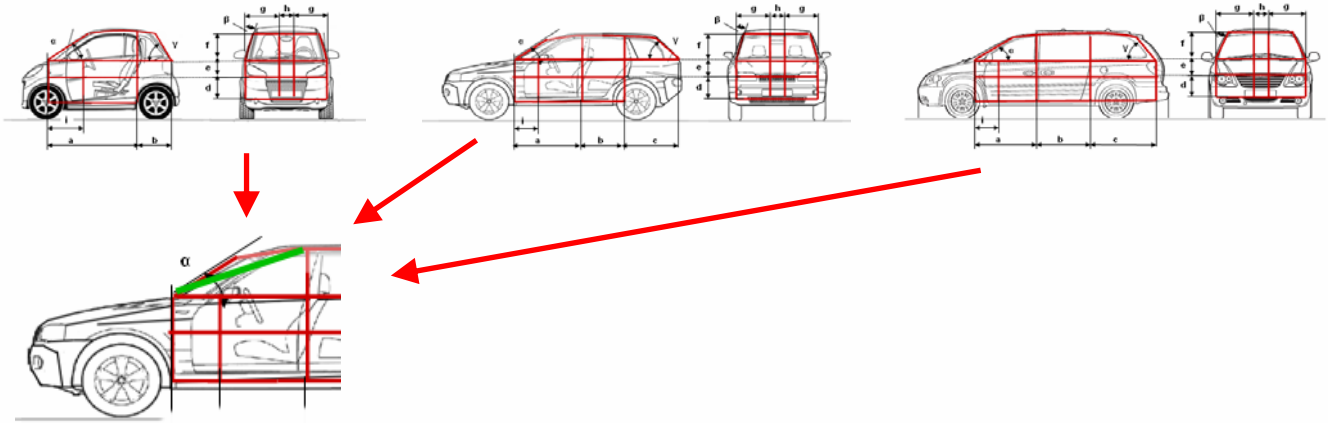
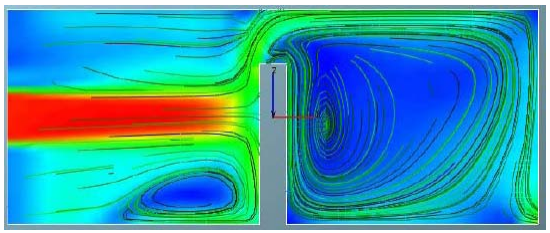
1) Select ***type***
形式选择



2) Define ***geometry***
几何定义

3) Define ***airflow***
空气流路



4) ***Simulate:***
运行模拟

Boundary conditions &
convection
边界条件 & 热对流

Applications of the Cabin Model

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The cabin model can be used to answer questions like…
乘客舱模型可以用于解决如下问题……

- How long until the ***driver*** gets a ***cool head in a hot car***?
  将驾驶员头部的温度冷却到一定温度需要多长的时间？
  → ***multiple temperature zones*** *多温度场区域的划分*

- How to distribute the inlet airflow to ***prevent uncomfortable air drafts***?
  如何合理分配空气流动以避免不适的设计？
  → ***multiple air inlets*** *多风道入口设计*

- What is the influence of ***ambient temperature*** and ***sunshine***?
  环境温度以及日晒会造成怎样的影响？
  → ***wall and radiation models*** *壁面&辐射影响的考虑*

Contents

Defining Transient Operating Points in KULI

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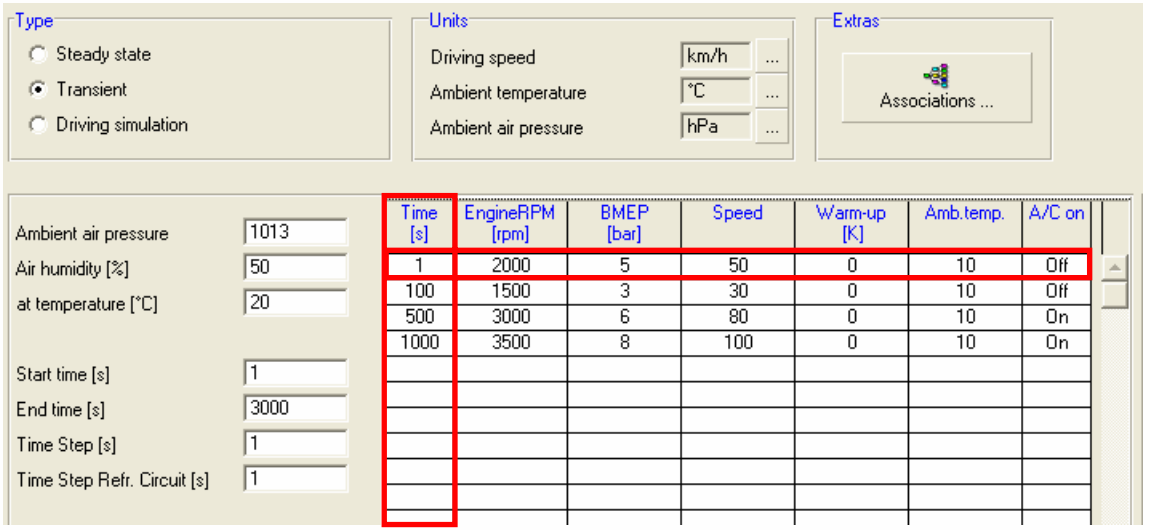
Transient sequence of **operating points**:
瞬态工况的定义

… for ***different times***
对应不同的时间
… ***different operating conditions*** can be defined
以及不同的工况点



Engine RPM,
BMEP,
→ Engine operating point 引擎工况

Driving speed,
Temperature offset underhood,
Ambient temperature,
→ Air flow conditions 空气流动

AC status
→ Additional heat source 其它热源

Defining Transient Operating Points in FASI

Only KULI
*仅使用**KULI***

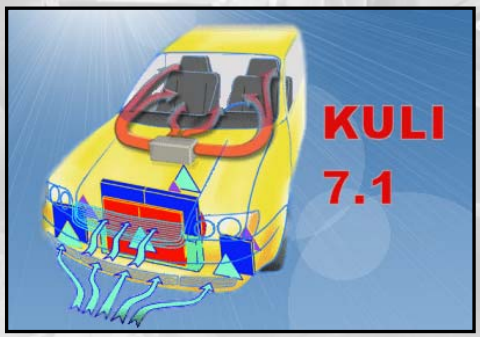
→ Engine operating point defined directly by ***RPM and BMEP***
引擎的工况点使用转速和平均有效压力来定义

KULI and FASI
*联合**KULI&FASI***

→ FASI sets ***throttle*** 油门开度
↓
KULI calculates ***RPM and BMEP***
↓
KULI ***simulates temperatures***
↓
KULI calculates ***available engine momentum***
↓
FASI ***tries*** to reach ***target speed***

Iteration
迭代

Coupling KULI and FASI



Driving Simulation

- Route and vehicle 道路以及车体
- Sets throttle to reach speed 油门以及速度
- Adjusts throttle to available power
  根据可用功率调整节气门

Throttle
节气门

Available engine momentum
可用引擎动量

Thermal Simulation

- Converts throttle to operating point
  计算模拟工况点
- Provides engine momentum 提供引擎动量
- Fluid circuit temperatures 计算循环温度

FASI Areas of Application

Trucks
卡车

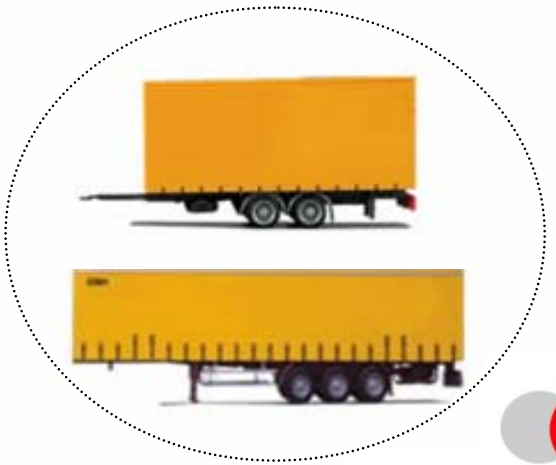
Motor Tractors
牵引车

Farm Tractors
农用车

Passenger Cars
乘用车

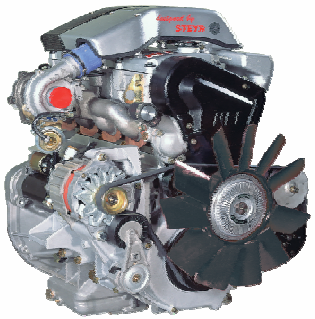
Motorcycles 摩托车

+



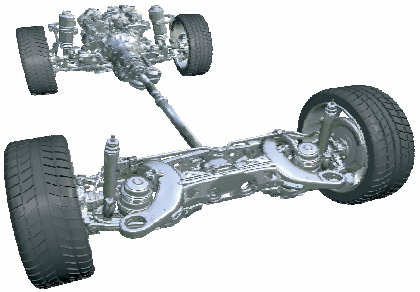
90% of all available vehicles can be simulated
90%的车可以使用FASI进行模拟

FASI Input Parameters



Engine
引擎

Gearbox
变速箱



Axles and Tires
传动轴以及轮胎

Driver
驾驶者

Route
路谱

Vehicle
整车

Typical Questions FASI

- Finding an optimal vehicle configuration
  寻找最佳的车辆配置

  Which gearbox is optimal for my vehicle?
  哪款变速箱最适合我的车型？
- ***Saving fuel*** and ***reducing emissions***
  减少油耗及排放

  How are the energy flows distributed?
  能量如何分配？
- Comparing the performance of different components
  比较不同零部件的性能

  What difference makes an improved engine?
  改进引擎升级后的影响？
- Engine operating points for KULI
  输出KULi所需要的引擎工况

  Operating point at 30km/h and 12% ascent?
  在30km/h，12%坡度下的表现？
- Define ***load statistics*** 定义载荷统计

  Dimensioning a rear axle 计算后轴

FASI operates as a stand alone program as well!
FASI同样能够单独运行！

Contents

Conclusions and Outlook

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KULI and FASI cover a wide range of transient applications…

• Thermal Network	**Already available in KULI 7.1**
• Engine Model	**Already available in KULI 7.1**
• Transient Tubes	**New in KULI 8 (Summer 2008)**
• Cabin Model	**Improved in KULI 8 (Summer 2008)**
• KULI – FASI Interface	**New in KULI 8 (Summer 2008)**

Thank you for your attention!