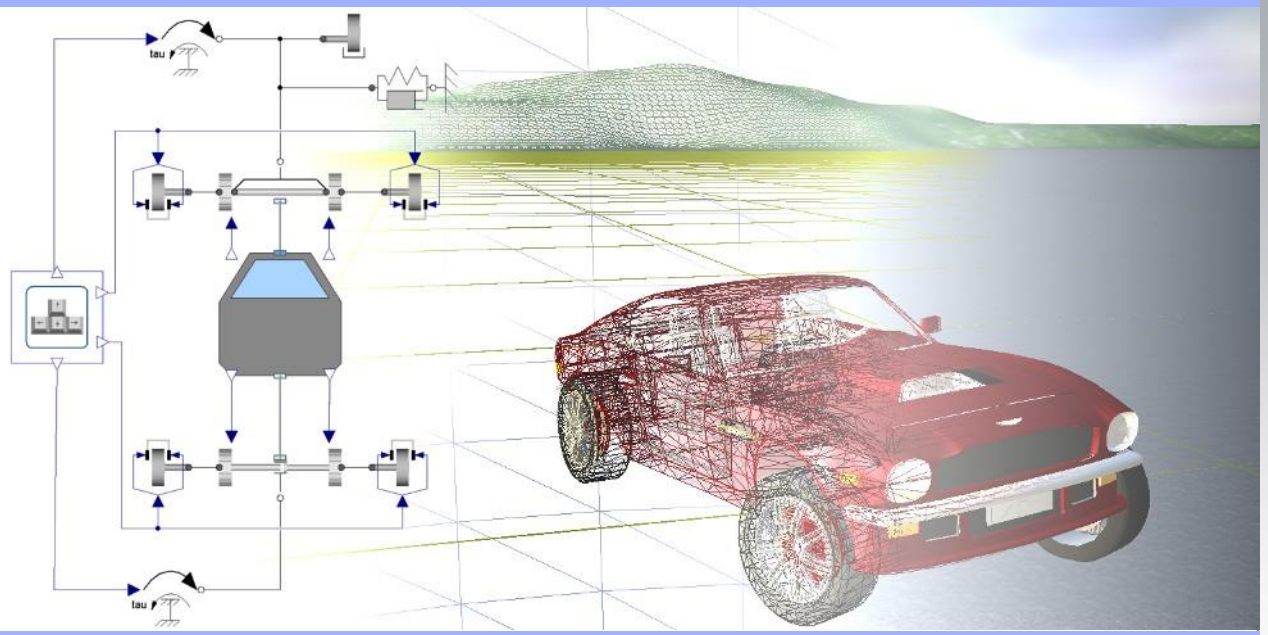
Virtual Physics Introduction

TUM, October 18, 2022

Using Modern Modeling Methodologies for Computer Simulation

```
equation
  sx0 = cos(frame_a.phi)*sx_norm + …
  sy0 = -sin(frame_a.phi)*sx_norm + …
  vy = der(frame_a.y);
  w_roll = der(flange_a.phi);
  v_long = vx*sx0 + vy*sy0;
  v_lat = -vx*sy0 + vy*sx0;
  v_slip_lat = v_lat - 0;
  v_slip_long = v_long - R*w_roll;

  v_slip = sqrt(v_slip_long^2 + …
  -f_long*R = flange_a.tau;
  frame_a.t = 0;
  f = N*. S_Func(vAdhesion,vSlide,…
  f_long =f*v_slip_long/v_slip;
  f_lat  =f*v_slip_lat/v_slip;
  f_long = frame_a.fx*sx0 + …
  f_lat = -frame_a.fx*sy0 + …
```



Dr. Dirk Zimmer

German Aerospace Center (DLR), Robotics and Mechatronics Centre

The German Aerospace Center

Robotics and Mechatronics Centre

- The DLR (German Aero Space Center) has >35 locations in Germany and international offices.
- The DLR Oberpfaffenhofen is located at the west side of Munich, between Gilching and Weßling.
- Number of Employees:
  > 9000 (all locations)
- The Robotics and Mechatronics Centre has more than 200 employees

M&S at DLR-RMC

Modeling at DLR-RMC concerns….

- Industrial Robots

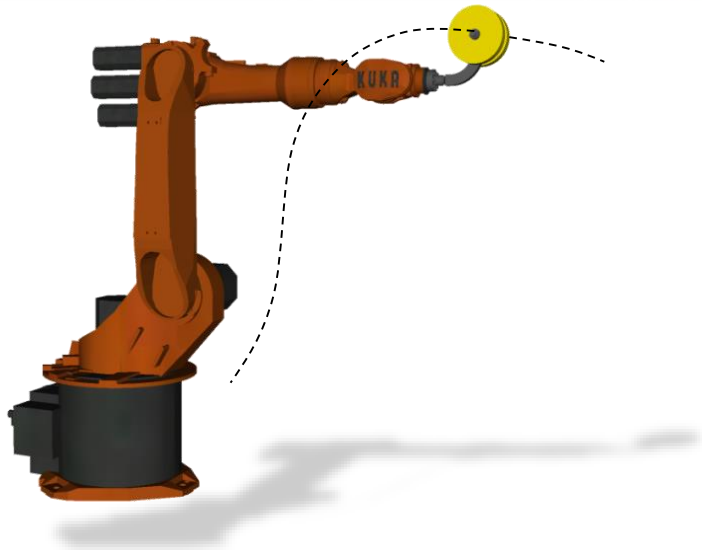
  Here the models are used to optimize the control of the robot.

  The simulation of the robot-model is embedded in the controller and performed in real-time.

  Use in modern manufacturing and human robot interaction

- Space Robots

  Special-purpose robots are developed for their use in space missions.



M&S at DLR-RMC

Modeling at DLR-RMC concerns…

- Automobiles

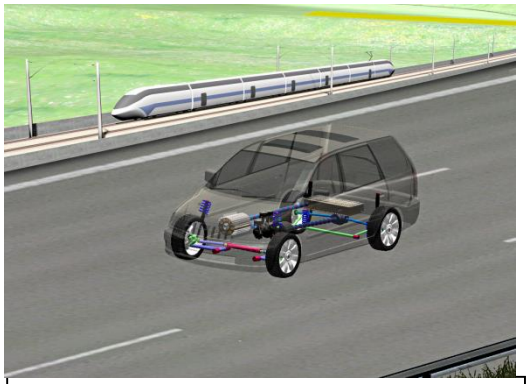
  The dynamics of a vehicle can be modeled in detail, including engine, gearbox, suspensions and wheels.

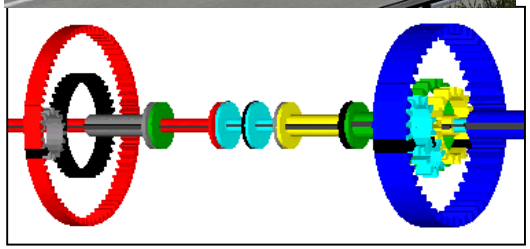
- Electrical Vehicles

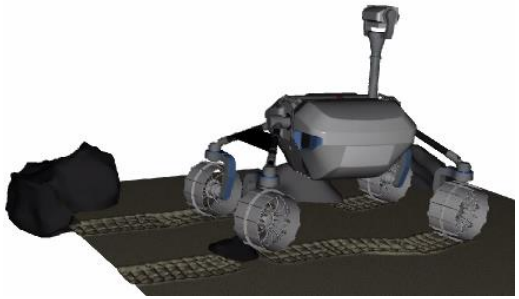
  A new electric vehicle has been designed, modeled, and built by the DLR.

  Each of the four wheels contains an engine and can be steered individually.

- Rovers







M&S at DLR-RMC

Modeling at DLR-RMC concerns…

- Real-Time Simulation

  The car can be simulated in real-time. The controller of the steering balances the forces acting on each tire.

- Robotic Motion Simulator

  The forces acting on the driver can be computed.

  These are the simulated using the robocoaster.

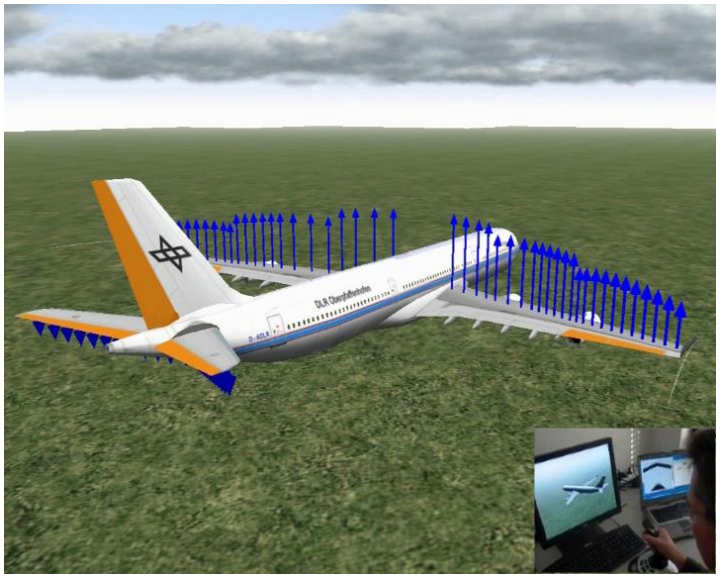
  This is an industrial robot with a mounted cabin.

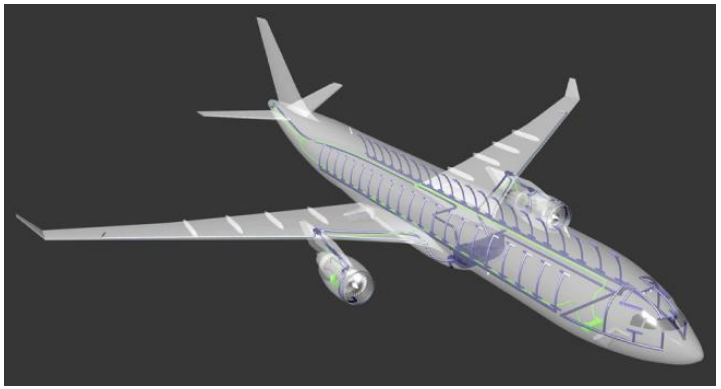
DLR Robotic Motion Simulator
Utilizing the DLR Flight Dynamics Library

M&S at DLR-RMC

Modeling at DLR-RMC concerns…

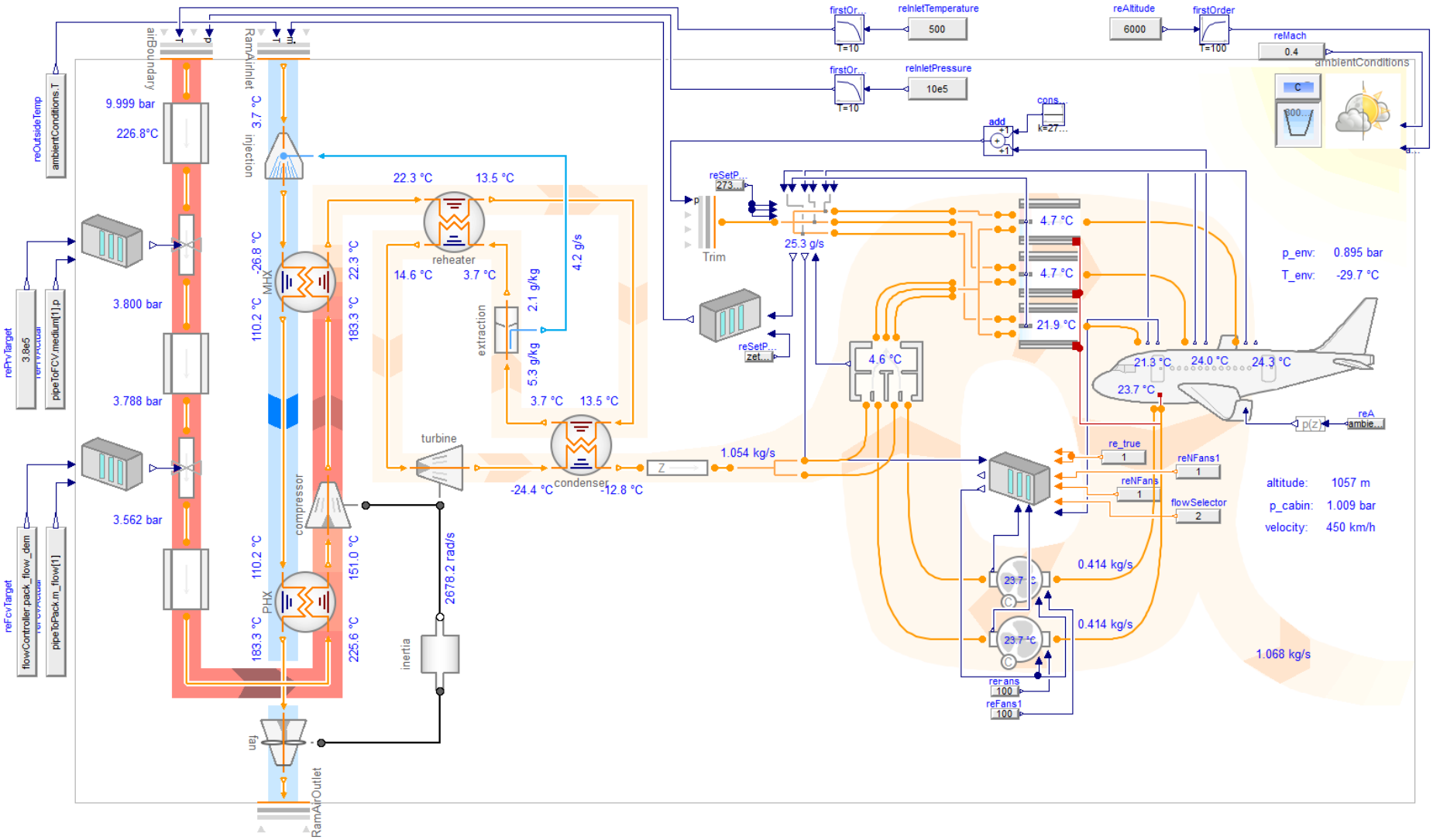
- **Aircraft Systems**
  Flight Simulation of Aircrafts and loads analysis
- **Cooling and Climate:**
  Design of environmental control systems and avionics cooling systems.
- **Power Supply:**
  Design and optimization of a reliable power supply .
- **Actuators:**
  Health Monitoring and fault detection of electro-mechanical actuators





M&S at DLR-RMC

Robotics and Mechatronics Centre

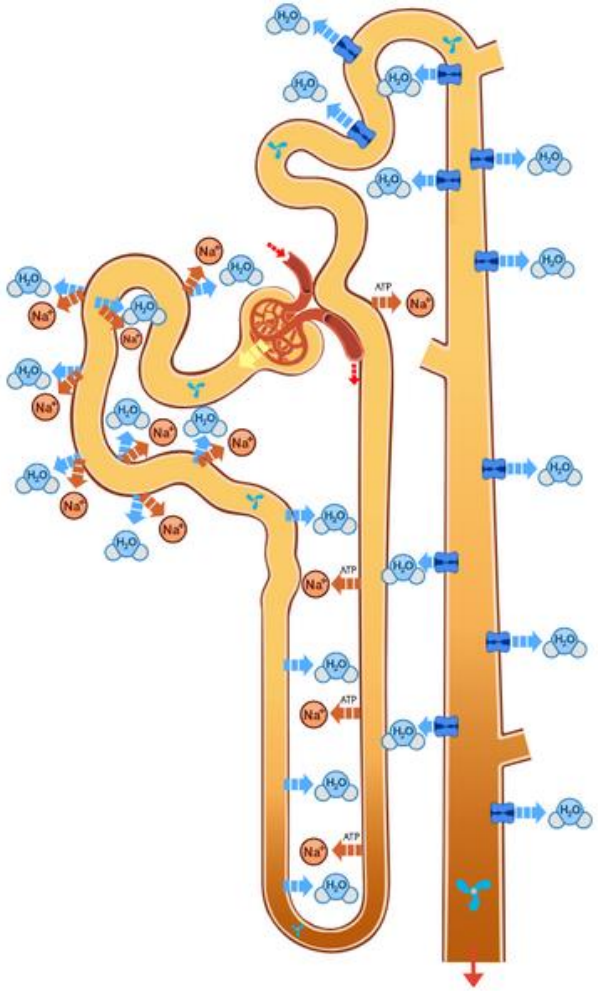


M&S at DLR-RMC

Modeling at DLR-RMC concerns…

- Models in the energy sector
- In particular wind-power is a field bringing together multiple domains:
  - Rotoraeroelastic
  - Mechanical Powertrain
  - Electrical Powersystem
  - Control

M&S in other fields



https://bodylight.physiome.cz

https://www.jmir.org/2019/7/e14160/

- Modeling of biological systems
  - Blood circulation
  - Population dynamics
  - Industrial dynamics

Why?


Early Design
Control Design
Operation
Human Interaction
Learning System

Why?

- Simulate a large number of design cases.
- Identify critircal cases
- Determine loads on your systems upfront.
- Simulate large number of failure cases
- Optimize your system

Why?

- Develop simplified plant model for control design.
- Test against high-fidelity model
- Test robustness of controller
- Use model within control scheme (model-predictive control)
- Design system with controller in the loop (e.g. energy management)

Why?

- State Estimation
- Estimate wear
- Health Monitoring: Are the paramters in a healthy state?
- Fault Detection: Compare with different faulty configurations in order to detect an error

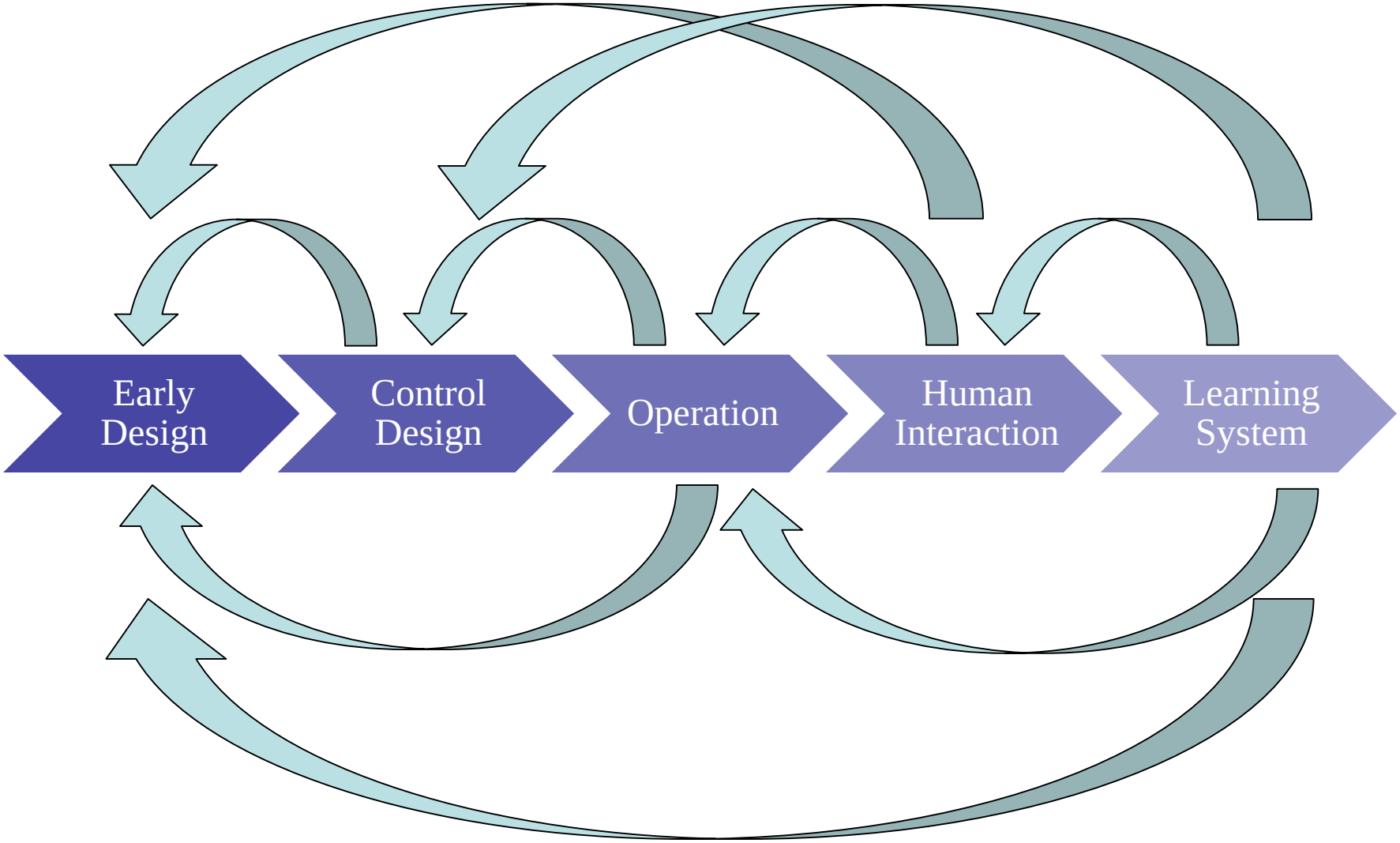
Why?

- Simulate user experience and do research on it.
- Train operating personal for dangerous situations
- Have fun!
- Use for marketing!

Why?

- Integrate AI Methods in controllers
- Learn over lifetime
- Train AI within computer simulations
- Simulate evolution of devices (mechanical design and control together)

Reality is a mess…



Physical Domains

- We see that the given demonstrations include the modeling of various physical domains:
  - Mechanic Systems
  - Electric Systems
  - Hydraulic Systems
  - Thermal Systems
  - Convective Mass-Flows

- But the modeling of all these different physical domains is performed by one common methodology.

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Learning this methodology is the essential goal of this lecture!

Your Challenge

- Model your own car…

- … and simulate it in real time!

Your Challenge

- We will model the car, starting by first principles
- To this end, we build or own mechanical modeling library.
- You will learn, know, and understand every single underlying equation of the complete car model. It will be surprisingly simple.
- You will learn the basic techniques to create a computable code out of the physical model and to perform a simulation.
- You will learn to handle a real-time simulation with user-input and 3D-visulization.
- Finally, you can extend and modify the model and follow your own ideas.

Lecture Outline

- Lecture 1 (18.10.2022):
  Introduction and Outline: Motivation and Purpose of Modeling and Simulation
- Lecture 2 (08.11.2022): History of object-orientation modeling of physical systems
- Lecture 3 (08.11.2022 / 15.11.2022): The Modelica language
- Lecture 4 (15.11.2022): Compiling the Modelica language
- Lecture 5 (22.11.2022): Introduction to 1D and 2D mechanical systems
- Exercise Session (29.11.2022): Additional Training
- Lecture 6 (06.12.2022): Planar mechanical systems I+II.
- Lecture 7 (13.12.2022): 3D Mechanics

Lecture Outline

- Lecture 8 (20.12.2022): Modeling the Car and Real-Time Simulation
- Lecture 9 (10.01.2023): Higher-Level Modeling Tasks: Parameterization and Stability Analysis
- Lecture 10 (27.01.2023): Analytical vs. Numerical Stability and Higher-Order ODE Solvers
- Lecture 11 (24.01.2023): Events and discontinuous systems
- Lecture 12 (31.01.2023): Control + Exam Preparation I
- Lecture 13 (07.02.2023): Bonus Lecture, Exam Preparation II

WWW

- All slides and exercises can be downloaded from the course web site.

  http://rmc.dlr.de/sr/de/staff/dirk.zimmer/VirtualPhysics

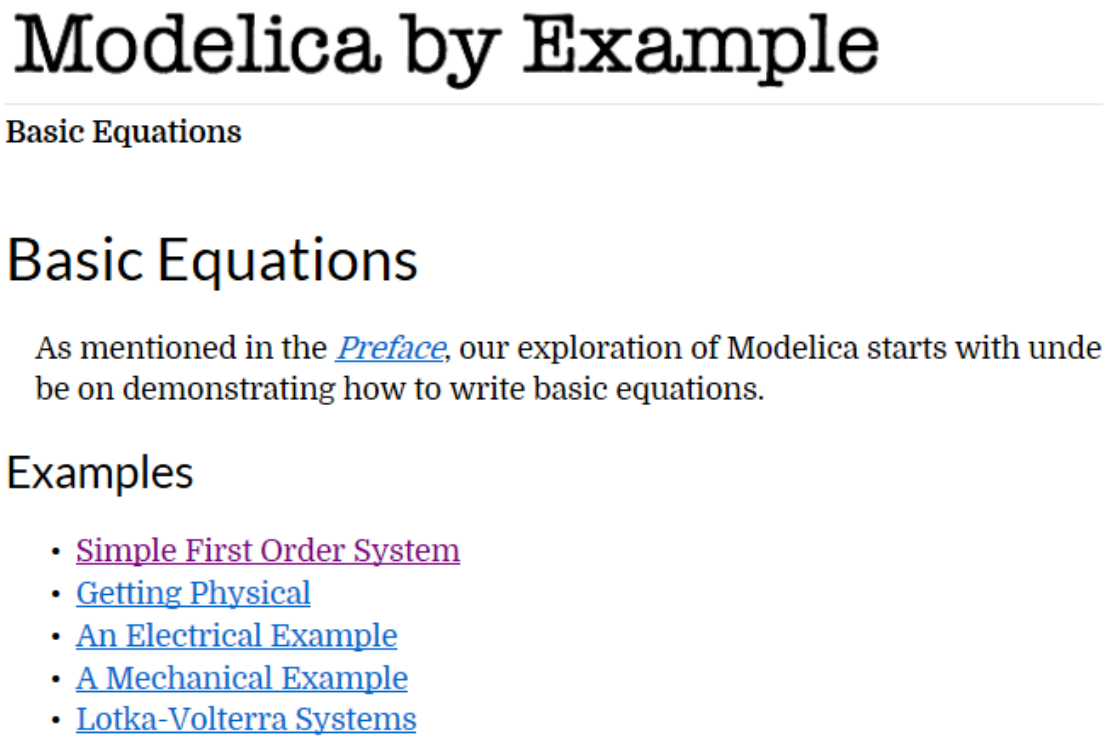
- Most important information can be found at:

  www.modelica.org

- There you find:
  - A Modelica Tutorial (outdated)
  - The Modelica Language Specification

- There is a now complete online book available for free. My recommendation:

  http://book.xogeny.com/



Modelica by Example

Basic Equations

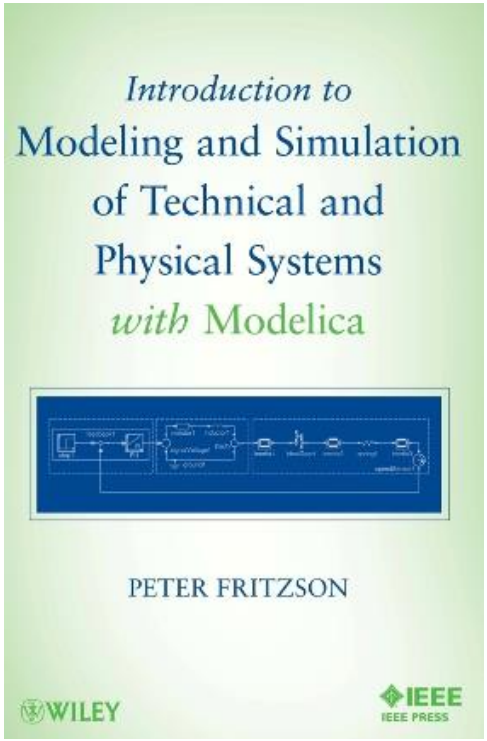
Basic Equations

As mentioned in the *Preface*, our exploration of Modelica starts with unde
be on demonstrating how to write basic equations.

Examples

- Simple First Order System
- Getting Physical
- An Electrical Example
- A Mechanical Example
- Lotka-Volterra Systems

Physical Reading Material



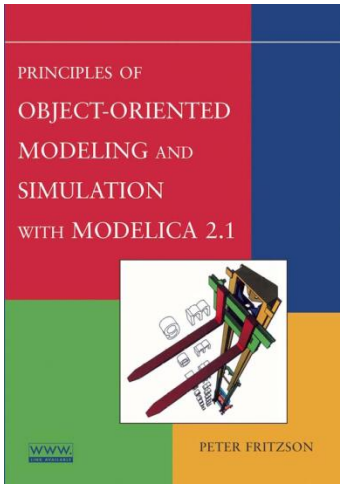
- Peter Fritzson (2011) :

  Introduction to Modelica and Simulation of Technical and Physical Systems *with Modelica*

  232 pages about 45 Euro

  Wiley IEEE

Physical Reading Material



- Peter Fritzson (2003) :

  Principles of Object-Oriented Modeling and Simulation with Modelica 2.1

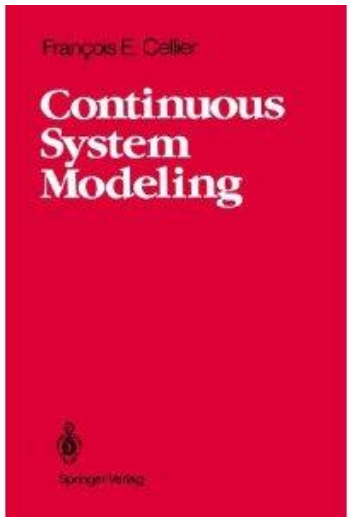
  Wiley IEEE

- Michael Tiller (2000):

  Introduction to Physical Modeling with Modelica

  Springer

Physical Reading Material



- François Cellier

  Continuous System Simulation (2006)

  and

  Continuous System Modeling (1991 - outdated)

  Springer

Required Software

- Further Required: MS Visual Studio C++ Compiler
  Free: Visual Studio 2017 Express Edition.
  (simply google it)

- Further Software will be distributed during the course.

Required Software

- In order to obtain a student license:
  - Sign the license agreement and hand it in at the lecture or scan it and email me the pdf. Make sure the filename contains your name.
  - Send me an email: dirk.zimmer@dlr.de.
  - Heading. “[Dymola License]”.
  - Containing your name, student-id number, and department.
  - You will get the license file attached to my reply.
  - You will also receive the username and password that is required for the software download.
- Required Software for MS Windows: http://www.3ds.com/products-services/catia/products/dymola/trial-version/
- Fill out the form and mention your license number.
- Open Source Alternative: OpenModelica.org