POLITECNICO DI MILANO





Dipartimento di Elettronica e Informazione

MATEO-ANTASME Project meeting

Barcelona, October 31, 2006

MATEO
PROJET COFINANCE PAR L'UNION EUROPEENNE
Nord Est SUD Ouest INTERREG IIIC

Outline

2. Presentation of the research unit
3. Contributions to ANTASME
4. WP6: Object-oriented modelling of mechatronic electrohydraulic systems
5. WP7: Object-oriented modelling of spacecraft dynamics

The DEI research unit

Prof. Paolo Rocco (person in charge)

Prof. GianAntonio Magnani

Tiziano Pulecchi (PhD candidate)

Luca Viganò (PhD candidate)

About DEI (Dipartimento di Elettronica e Informazione):

- DEI is one of the largest Departments in Politecnico di Milano.
- The participants in this research all come from the Automation section of DEI.
- Several facilities are available at the Automation Laboratory, including experimental devices and advanced software packages for simulation.

Skills

- Algorithms and software for the **control of mechanical systems**
- **Modeling and simulation** of multi-body mechanical systems
- **Motion control**
- **Analysis and mechatronic design** of mechanical devices, with the use of advanced multi-domain simulation tools and the setup of virtual prototypes.

Contributions to ANTASME

- DEI will develop multi-domain modelling and simulation environments for aerospace systems, with specific attention to mechatronic electrohydraulic systems and to spacecraft attitude and orbit dynamics.
- The environments will offer hierarchical modular modelling capabilities, to ensure models reuse, and a “natural” (i.e. not requiring a specific modelling knowledge) approach to complex model definition.
- A library of basic models of the physical components for aerospace systems shall be developed.

The modelling language Modelica

Main features:

- Object-oriented language: ***class = model***
- Modelica is based on ***equation***, not on assignments:
  - Acausal approach.
  - Reuse of classes.
- *Multidomain approach*:
  - Electrical
  - Mechanical
  - Hydraulic
  - …

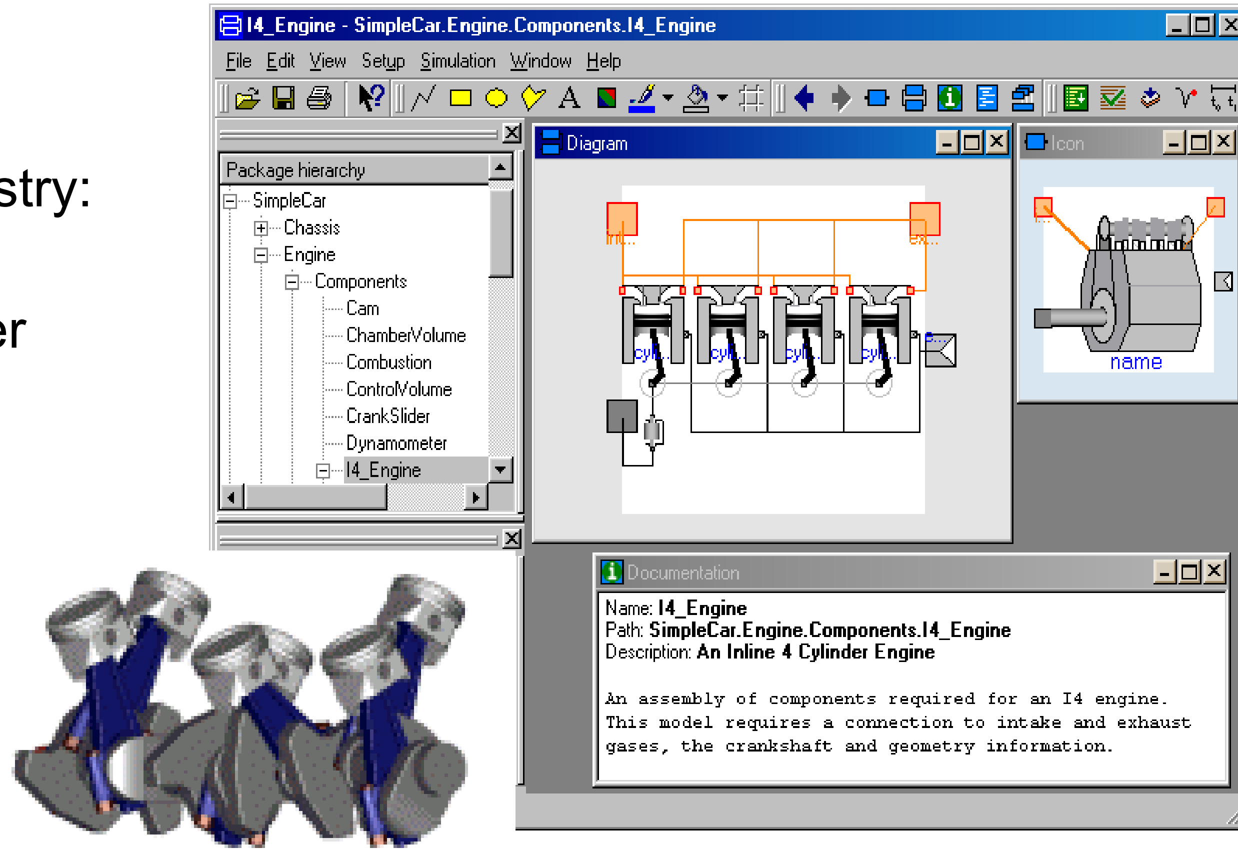
Website: `www.modelica.org`

The simulation environment Dymola

A commercial package for multi-domain simulation based on Modelica.

It is used both in the academy and in industry:

- Daimler Chrysler
- BMW
- Audi,
- Volkswagen
- Toyota
- …



Website: `www.dymola.com`

WP6: OO modelling of mechatronic electrohydraulic systems

Objectives:

- Models of DDV (Direct Drive Valve) electrohydraulic actuators;
- Integration of the model within a realistic helycopter system model.

Deliverables:

- 6.1 (after 6 months): "Design description of the object-oriented library for mechatronic electrohydraulic systems"
- 6.2 (after 12 months): "Assessment of the performance of the mechatronic electrohydraulic library in a case study"

Presented by <u>Luca Viganò</u>

DDV actuators library

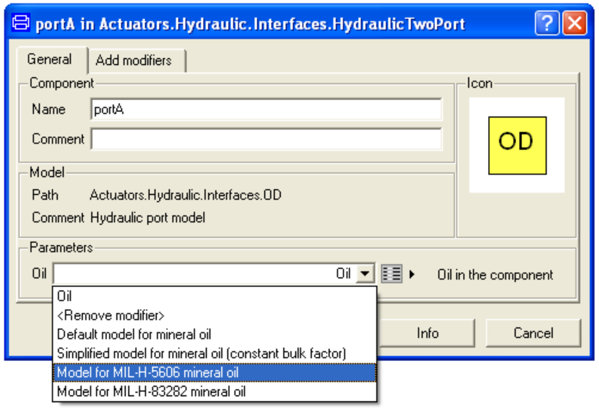
- Full-authority, fly-by-wire, autopilots for helicopters and fixed wing aircrafts require very performant and fault tolerant electrohydraulic actuators

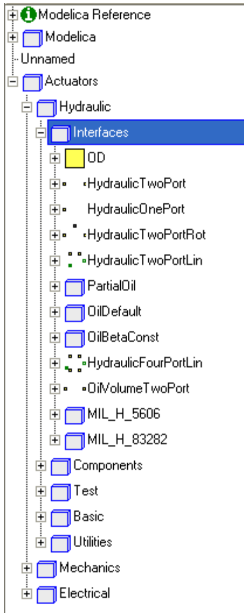
- Need for specific simulation tools:
  - modeling paradigms (acausality, modularity, reusability,…): Modelica language
  - Taking the best from existing Modelica libraries:
    - Modelica HyLib: the reference point but not up to date and deficient in actuator models; commercial!
    - Modelica Fluid: advanced paradigms (clever description of media) but too much complex for oleodynamics applications

DDV actuator library: architecture

1. Hydraulic Domain

- Definition of an abstract media object for hydraulic fluid (PartialOil):
  - Nominal density ρ_0
  - Bulk modulus $\beta(p)$ (Hoffmann's model)
  - Dynamic viscosity μ_0
  - Vapour pressure
  - …
- Choice of specific mineral oil model (extends PartialOil(.))
- Definition of hydraulic connector:
  - replaceable package Oil
  - effort variable: pressure p,
  - flow variable: mass flow rate

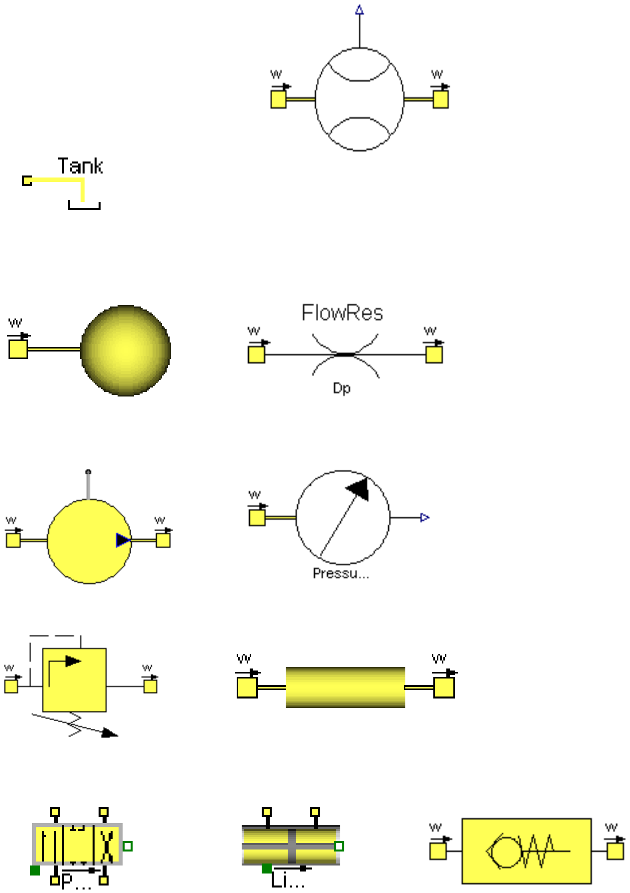




DDV actuator library: architecture

1. Hydraulic Domain

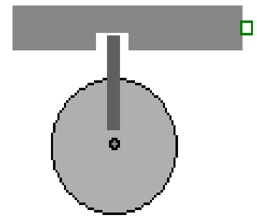
- "Superclasses" of abstract hydraulic components, with 1,2,4,… hydraulic ports and mechanical 1D (rotational-translational) flanges, plus internal storage or not.
- Basic (extend superclasses) and extended (extend basic too) hydraulic components already developed:
  - Ideal flow/pressure sources
  - Volumetric pumps
  - Hydraulic resistances (laminar/turbulent)
  - Lumped volume
  - Elastic pipes
  - Check/relief valves
  - Pressure/flow sensors
  - Single/tandem proportional valve
  - Single/tandem linear actuator

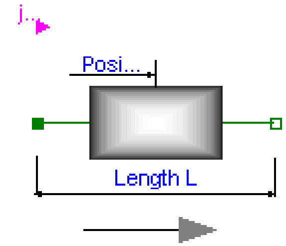


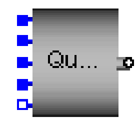
DDV Actuator library: architecture

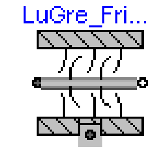
2. ElectroMechanical Domain

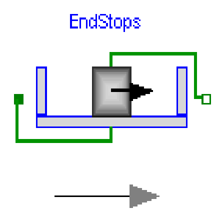
- Eccentric shaft
- Stiff end stops
- LuGre friction model (rot/transl.)
- Quadruplex DC motor
- Quadruplex DC motor driver
- Ideal LVDTs
- …

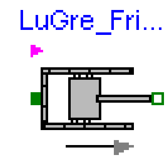


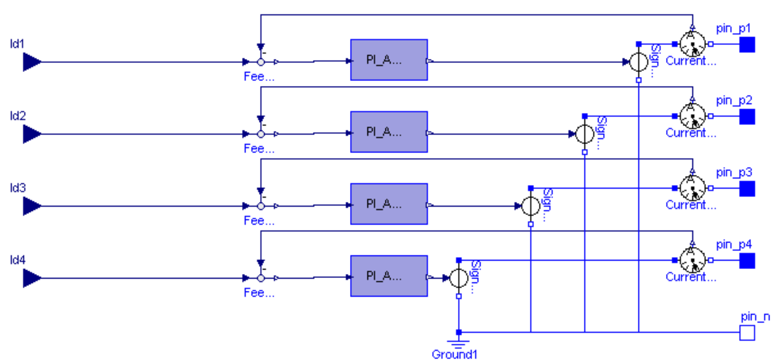


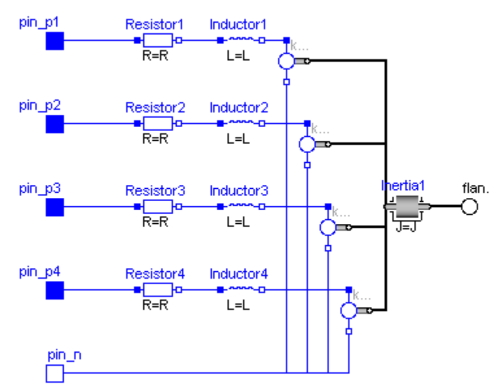








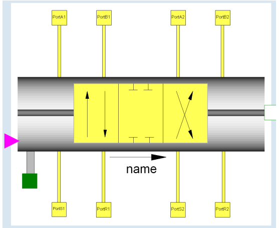


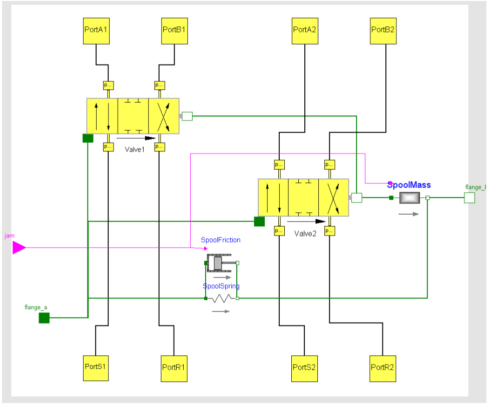


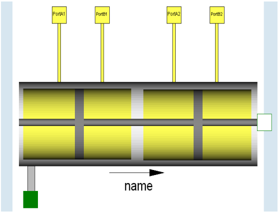
DDV actuator library: architecture

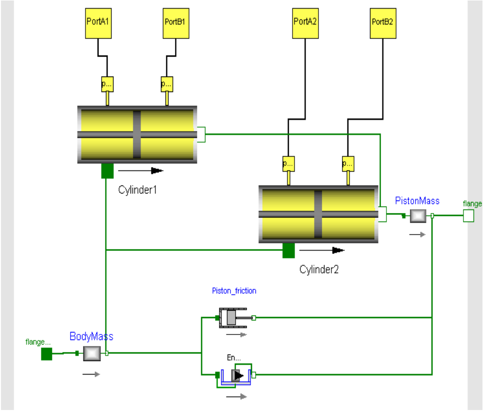
3. Fly-by-wire actuator model

- **Direct-drive valve model**:
  - Proportional valve model:
    - Simple idealised model (Merritt)
    - Detailed prop.valve model featuring:
      - Laminar/turbulent flow transition
      - Spool land overlap/underlap
      - Internal leakage
      - Internal flow forces
  - Single/tandem valve
  - Single / Dual-concentric body for spool
  - Valve jam condition
  - Quadruplex DC motor / driver
- **Tandem linear actuator**:
  - Internal leakage
  - Nonlinear friction
  - Mechanical end stops (not saturation!)
  - Elastic support
  - Elastic load







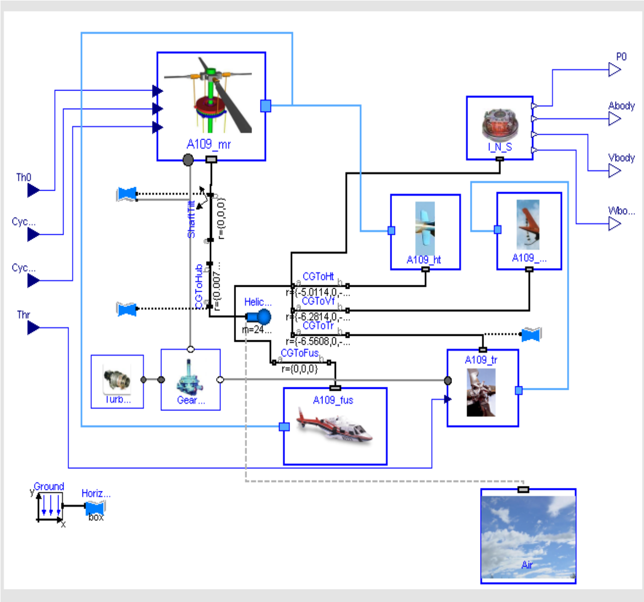


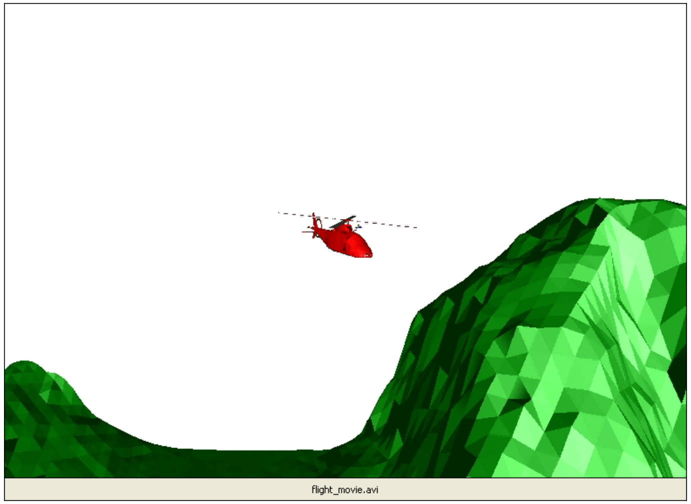
State of the work

- What we can reproduce by means of simulation now:
  - Nominal (design) responses of DDV actuators (compared with validated but simpler Simulink models)
  - Failure conditions:
    - Valve jam
    - Hydraulic failure (e.g. pressure loss)
    - Electrical failure
    - Control fault
- What we have to do:
  - Integrate in a sufficiently realistic way the actuator model with an existing helicopter flight mechanics model (Modelica Conference 2006)
  - Evaluate the effects of actuator failures on the helicopter closed-loop performances

Helicopter flight mechanics model

- Flight mechanics (not aeroelastic!) model
- Fully parametrized
- Some features:
  - MBC rotor model, Pitt-Peters/Keller dynamic wake
  - Engine RPM dynamics
  - Aerodynamics of lifting surfaces and fuselage (look-up-table based)
  - Atmospheric gust
  - Gain-scheduled LQ-SOF autostabilizer
  - 3D virtual environment





WP7: OO modelling of spacecraft dynamics

Objectives:

- Development of a library for simulation of spacecraft attitude and orbit dynamics
- Verification in a case study in cooperation with Carlo Gavazzi Space SpA

Deliverables:

- 7.1 (after 6 months): "Design description of the modelling library for spacecraft dynamics"
- 7.2 (after 12 months): "Assessment of the performance of the spacecraft dynamics library in a realistic case study"

Presented by *Tiziano Pulecchi*

Why a Modelica Space Flight Dynamics Library?

- Within the aerospace community: increasing need for efficient AOCS design tools (reusable, flexible and modular)

- Unavailability of commercial tools covering the whole AOCS development cycle

- SFD library: the project aims at a unified environment to be used throughout the AOCS design cycle:
  - Mission analysis;
  - Preliminary/detailed design and simulation;
  - On-board code generation and testing;
  - Post-launch data analysis

Why a Modelica Space Flight Dynamics Library?

- SFD library shall encompasses all necessary utilities to rapidly and reliably setup a scenario for a generic space mission

- Space environment description: gravity and magnetic fields, solar radiation pressure, aerodynamics, …

- Wide choice of models for most commonly used
  - On-board sensors (star trackers, gyros, magnetometers, GPS receivers, …)
  - Actuators (reaction wheels, CMGs, magnetotorquers, jets, …)

- Packages of datasheets for most common sensors, actuators, orbits, planets, spacecraft inertial data and configurations, ...

Basic components

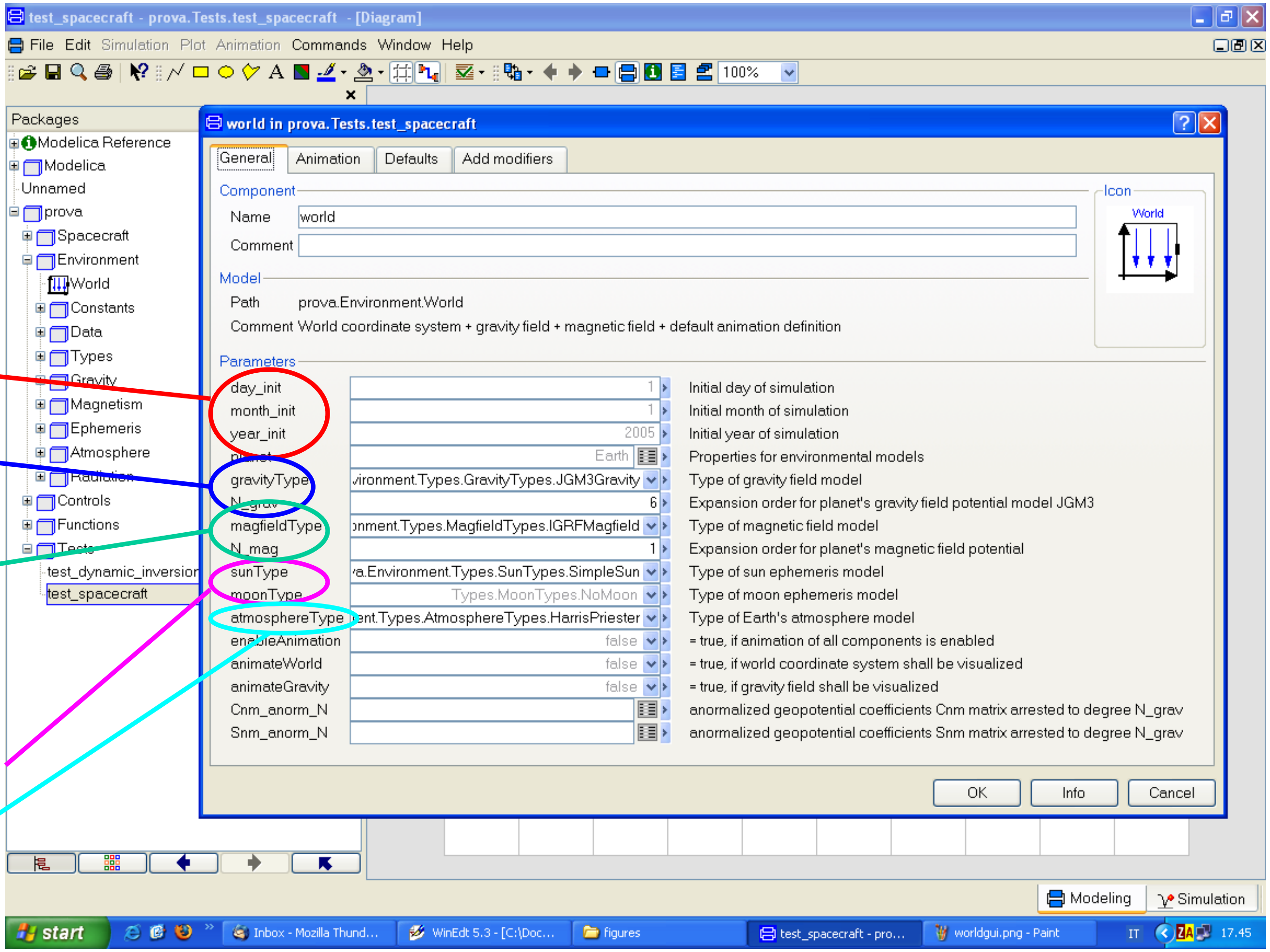
The generic spacecraft simulator shall consist of:

- An extended **World** model:
  - Extends **Modelica.MultiBody.World** model;
  - Provides a complete description of the space environment, including increasing level of complexity models for gravity, magnetic, atmospheric, solar radiation fields.

- One or more completely reconfigurable **Spacecraft** models**:**
  - Extends **Modelica.MultiBody.Parts.Body** model;
  - Comprises components:
    - **SpacecraftDynamics**;
    - **SensorBlock**;
    - **ActuatorBlock**;
    - **ControlBlock**.

Extended World model

- Provides to the Spacecraft models all functions needed to describe the space environment:
- Initial date and time
- J2, J4, JGM3 gravity field models;
- Dipole, quadrupole, IGRF magnetic field model;
- Sun/Moon ephemeris
- Atmosphere model



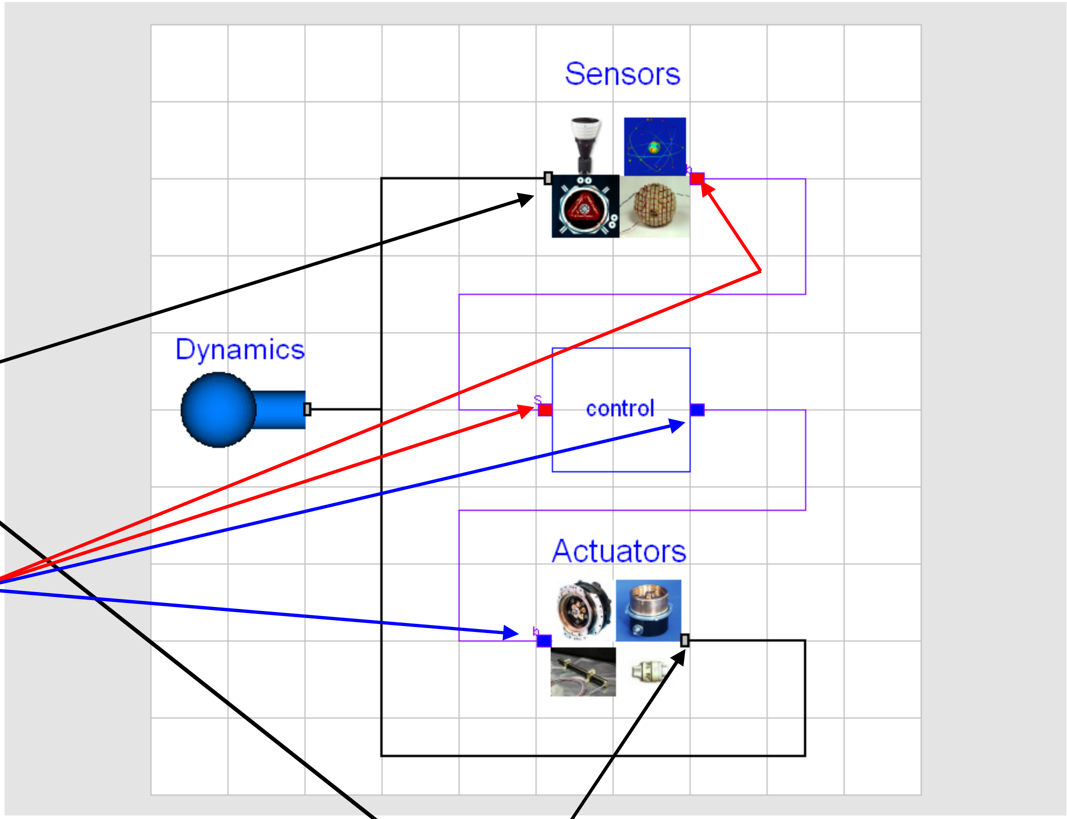
Spacecraft model

Shall comprise four replaceable models:

- **SpacecraftDynamics**;
- **SensorBlock**;
- **ActuatorBlock**.
- **ControlBlock**;

Standard Modelica mechanical connectors

Expandable Data busses



Spacecraft dynamics

- Extends **Modelica.MultiBody.Parts.Body** model
- Defines spacecraft/environment interaction
- Two initialization options
- Orbital parameters computation.

- Selective inclusion of the following disturbance forces and torques:
  - Gravity gradient torques
  - Magnetic torques (spacecraft residual dipole)
  - Aerodynamic forces and torques (planet atmosphere)
  - Solar radiation pressure forces and torques (including eclipse phenomena)

Conclusions on SDL

SDL shall:

- match the requirements for efficient AOCS design tool (reusable, flexible and modular);
- include detailed physical models for the space environment description;
- encompass wide choice of models for most commonly used sensors and actuators;
- allow for the simulation of satellite constellations as well as single spacecraft in a natural way.