Dutch Space

Generic AOCS Simulator

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Introduction (1)

- AOCS hardware and software development relies on different simulation environments:
  - Engineering Simulator
  - Hard real-time HILT/SILT
- No commonality in the development and/or use of these simulation environments:
  - Internal: differences from project to project
  - External: prime/sub interfaces
- Solution: Generic AOCS simulation environment, to be used in European Space Community
  - Well documented
  - Validated models
  - Generic interfaces, etc.

Introduction (2)

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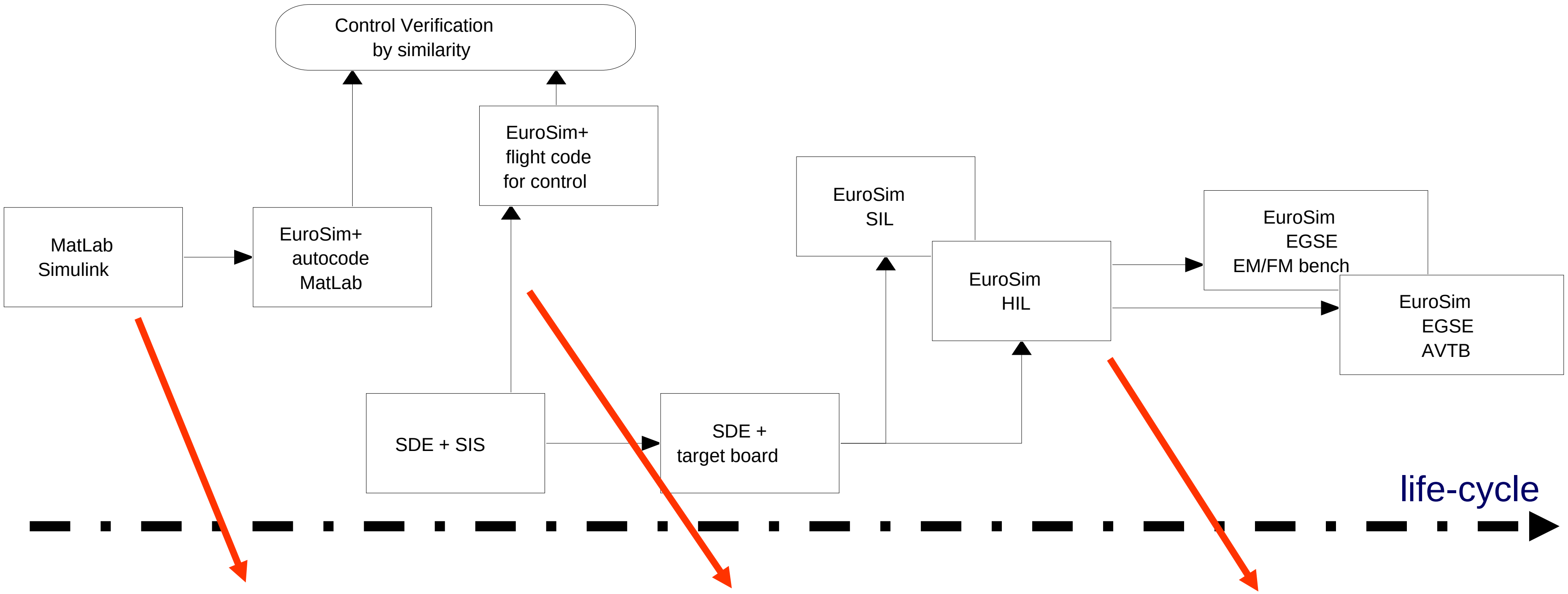

MATLAB / Simulink GAOCS Environment

Objectives:
- Sub-system Model Development and Testing
- Control Algorithm Design and Testing
- Engineering Simulations

Tools:
- User-friendly GUI for definition and plotting
- Generic Dynamics Core and Environmental Models
- Library of Sensor and Actuator Models
- User defined sub-systems can easily be added

EuroSim GAOCS Environment

Objectives:
- Real Time Simulations
- link to 2D/3D IGS Graphics
- add other “coded” models

Tools:
- Use of EuroSim GUI and plotting facilities
- Same Generic Dynamics Core and Environmental Models
- Same Library of Sensor and Actuator Models

EuroSim / HILT / SILT GAOCS Environment

Objectives:
- ASW validation
- SCOE backbone

Tools:
- MIL1553-bus communication
- Software in loop Simulations
- Hardware in loop Simulations

Overview

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- GAOCS Simulator elements
  - MATLAB/Simulink Environment:
    - Design philosophy
    - Physical modelling
    - Simulator architecture
    - Functional verification
  - EuroSim Environment
    - Interface mechanism with MATLAB/Simulink
    - Real-Time Workshop
- Examples
  - Adaptive satellite control
  - Herschel on-board software development
  - ConeXpress rendezvous and docking
- Current status and future work

MATLAB/Simulink Environment

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Design philosophy (1)

- Graphical User Interface to “learn” simulator and for quick access to simulation results
- Libraries with Simulink models and corresponding initialisation files
- Set-up of simulator with library links
- Instantiation of library models, automated initialisation of each instantiation
- CMEX functions
  - local workspace defined for definition of global variables
  - Instantiation of simulator core to allow for formation-flying simulator, rendezvous-and-docking simulator, ...

MATLAB/Simulink Environment

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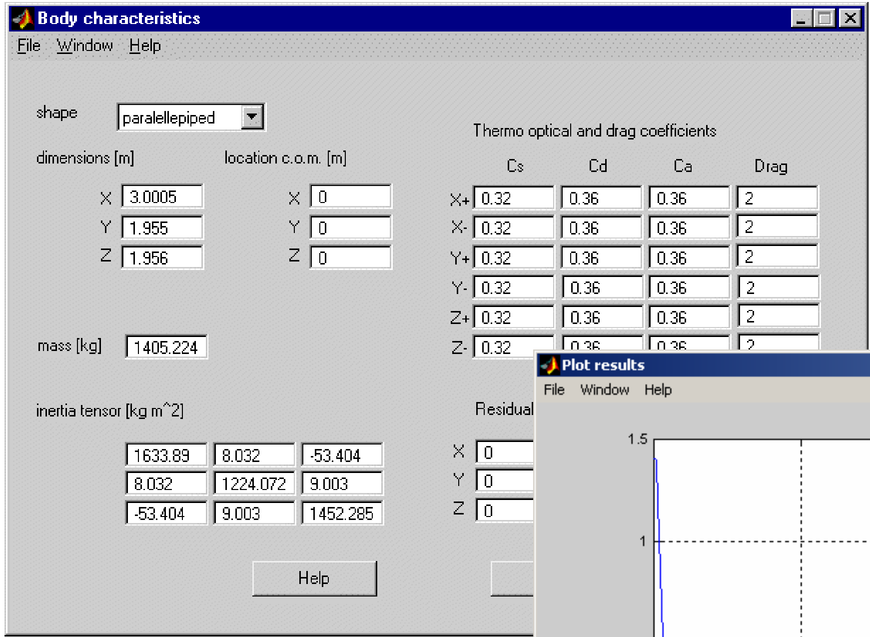
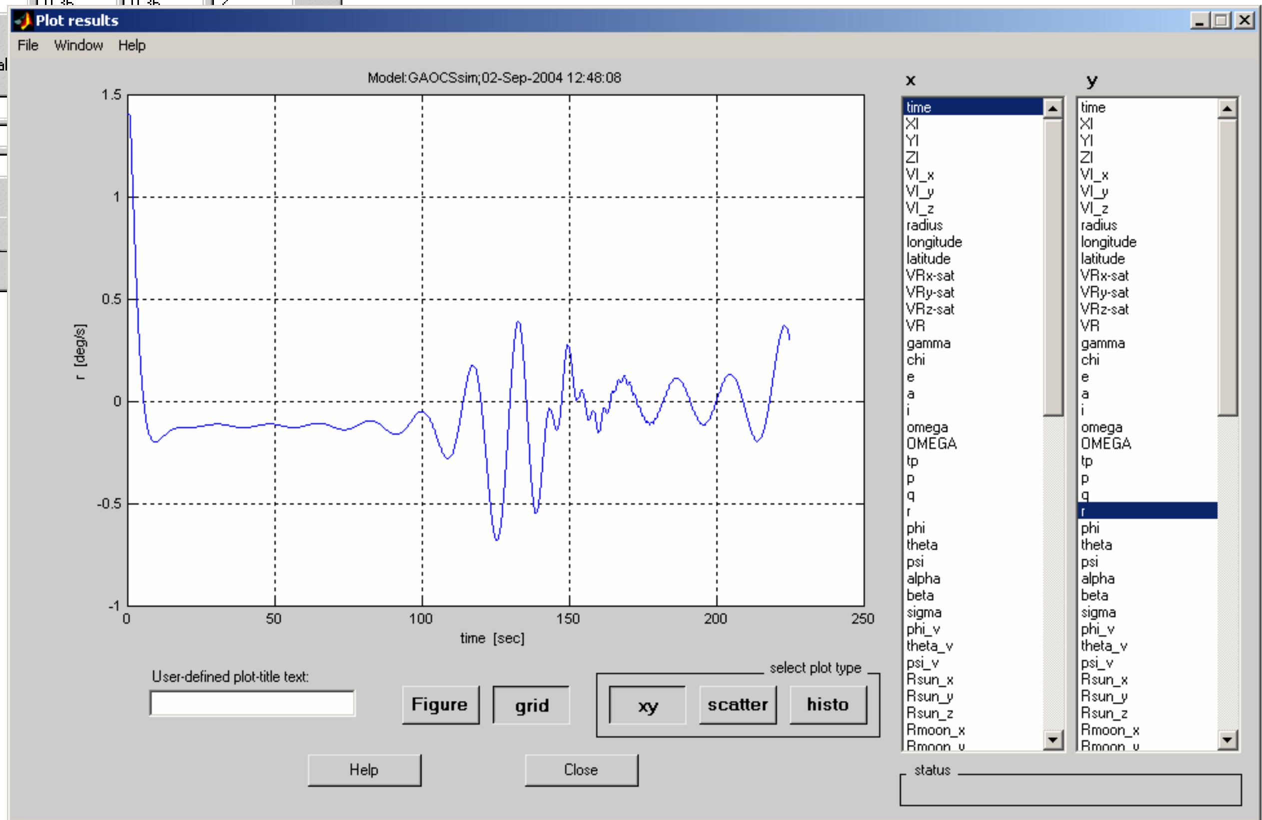
Design philosophy (2)



Facility to plot simulation results



Edit Window: Body Characteristics

MATLAB/Simulink Environment

Physical modelling

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- Equations of (translational and rotational) motion for a rigid satellite with up to 4 solar panels, with Earth as central body
- Sun and Moon as perturbing third bodies
- Tabulated atmosphere according to MSIS-86
- Gravitational field according to inverse-square law (+J_2, J_3 and J_4) or GRIM-5C1 (spherical harmonics, n=m=99)
- Geomagnetic field based on IGRF-95 (spherical harmonics, n=m=10)
- Solar radiation according to inverse-square law

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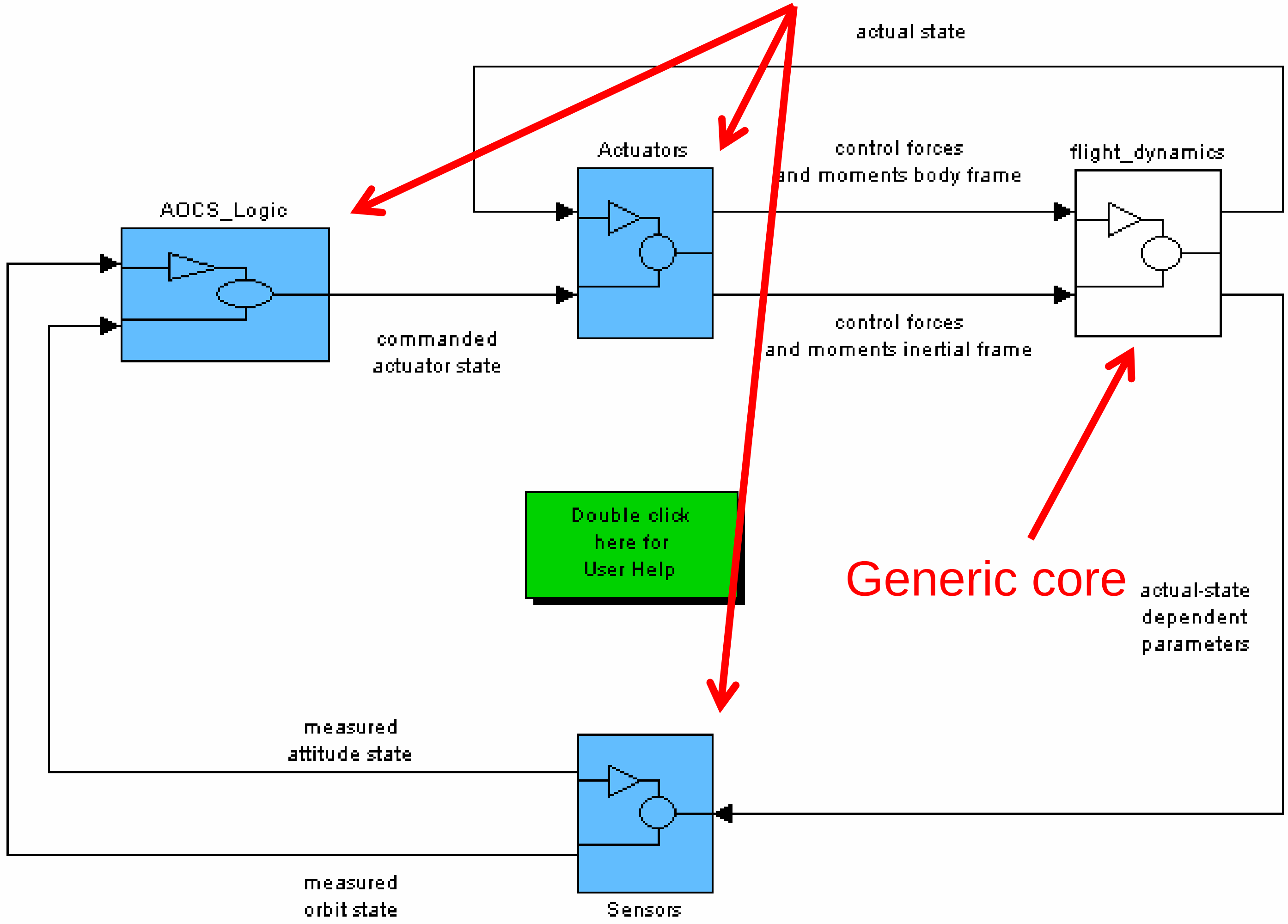
Simulator architecture (1)

User-defined sub-systems



Main Simulink AOCS simulator window

MATLAB/Simulink Environment

Simulator architecture (2)

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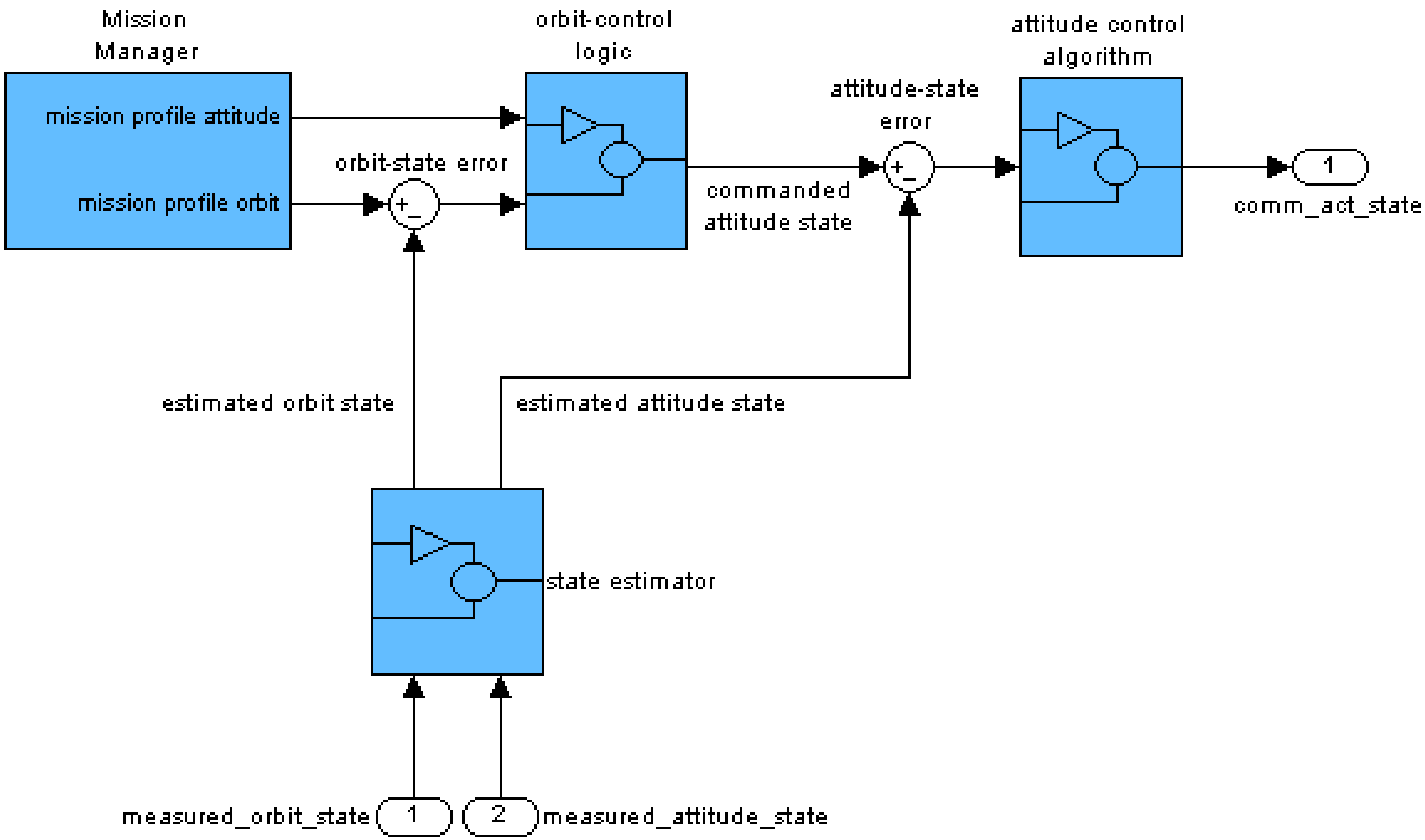

Simulink AOCS logic sub-system

MATLAB/Simulink Environment

Simulator architecture (3)

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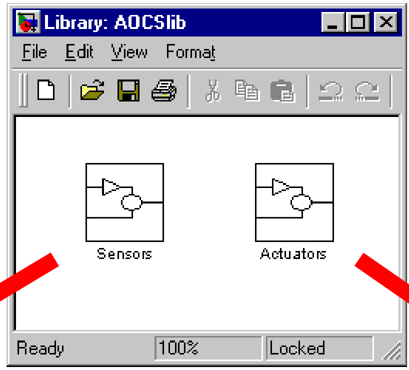
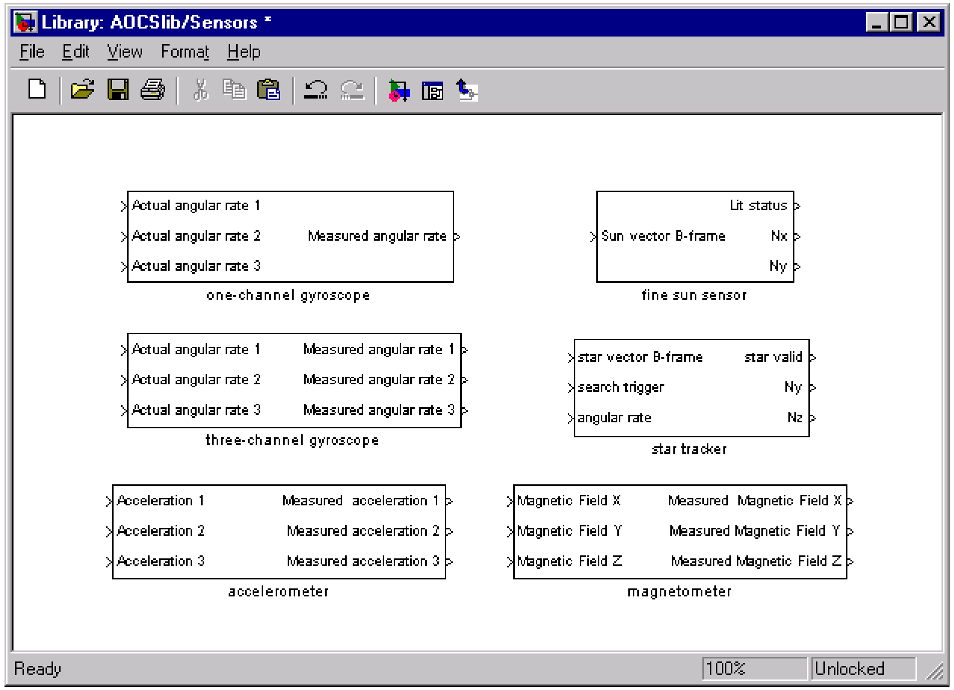
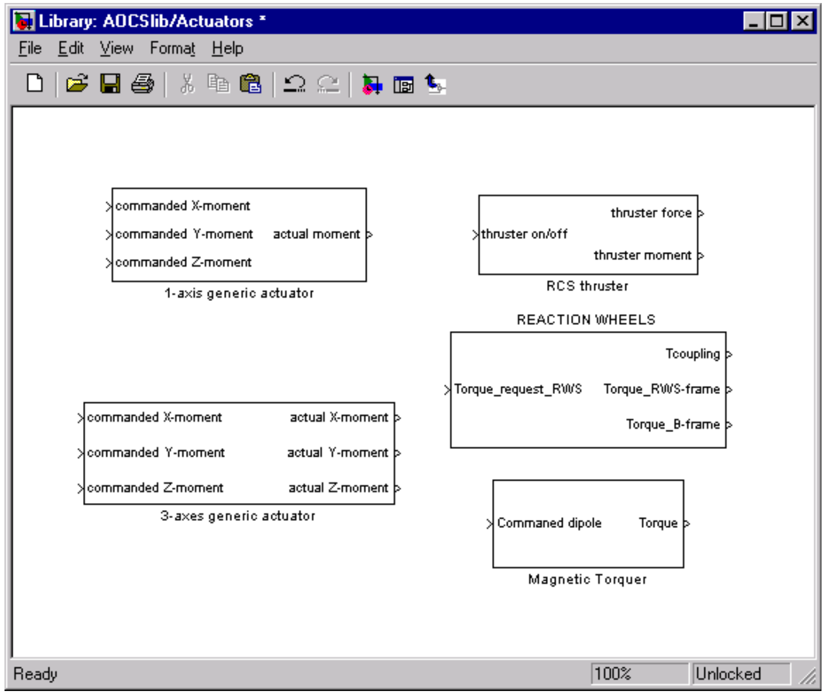
Main Library Simulink window



Sensor Library



Actuator Library



MATLAB/Simulink Environment

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Simulator architecture (4)

- Performance improvement by replacing MATLAB scripts by C-coded S-functions (so-called CMEX S-functions)
- Simulator porting to EuroSim: relatively easy due to use of CMEX functions
- Use Real-Time Workshop to autogenerate C-code of Simulink simulator structure (per sub-system)
- Porting process and integration has been automated to a large extent
- Alternative in latest version: integrate Simulink models *directly* in EuroSim model

MATLAB/Simulink Environment

Functional verification (1)

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- Time propagation, both in relative and absolute sense, and frame and co-ordinate transformations
- Environment, consisting of the Earth's gravitational and magnetic field, the Earth's atmosphere, the motion of Moon and Sun and the interplanetary environment
- Equations of motion, focusing on both translational and rotational motion, and the numerical aspects due to the integration of the differential equations
- Perturbations, of gravitational origin, due to third-bodies (Sun and Moon), the Earth-magnetic field, the Solar radiation and the working of the upper atmosphere

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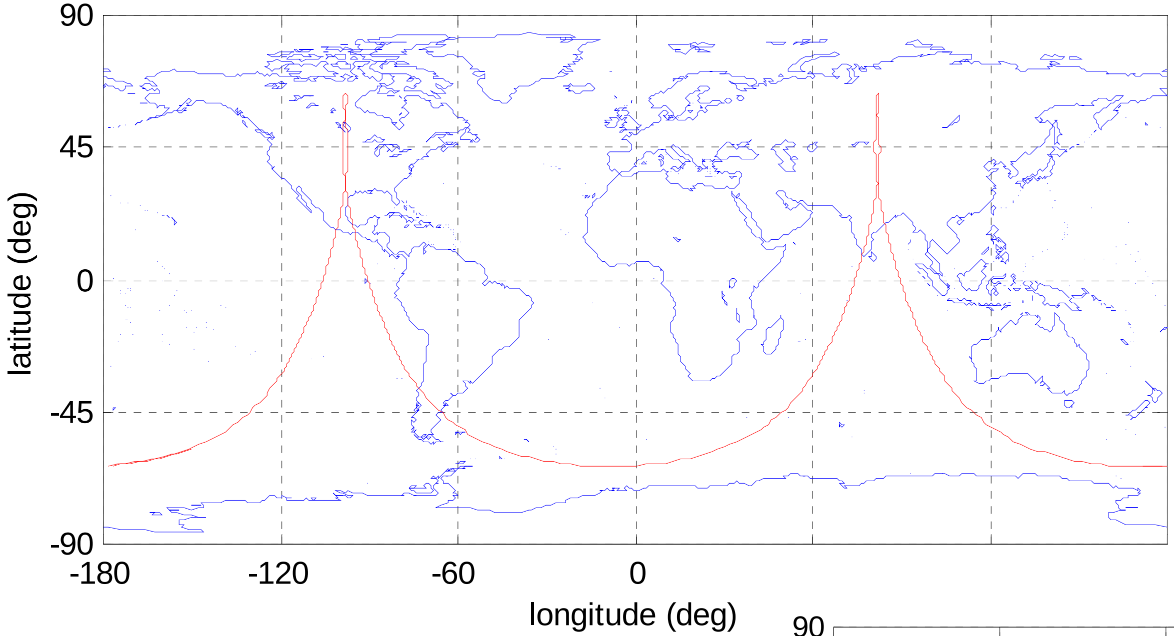
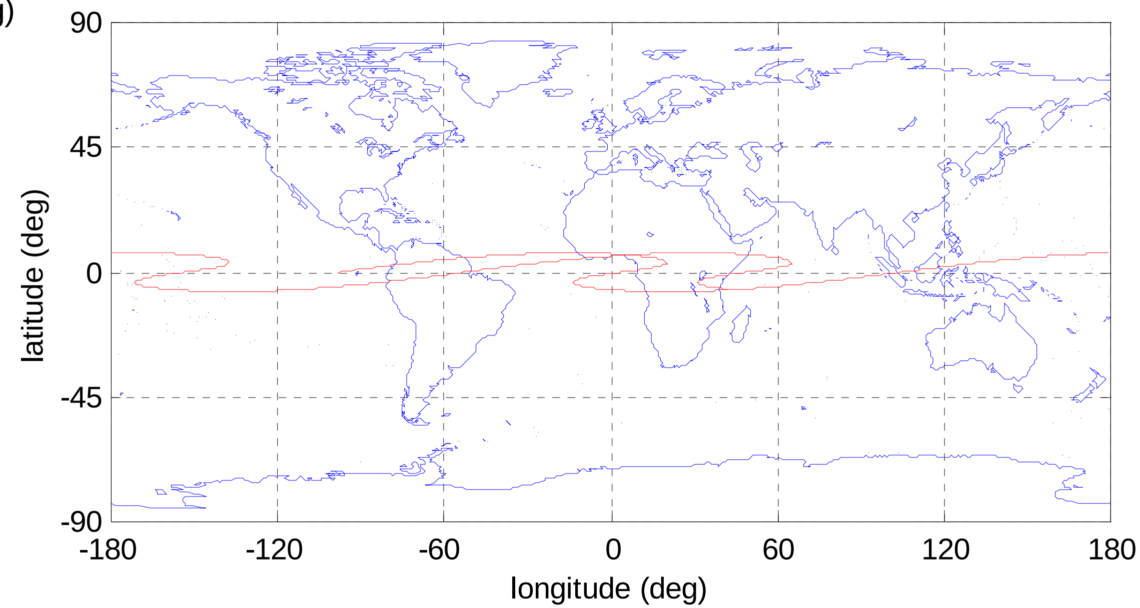
MATLAB/Simulink Environment

Functional verification (2)



Molniya-type orbit



geostationary
transfer orbit

EuroSim Environment (1)

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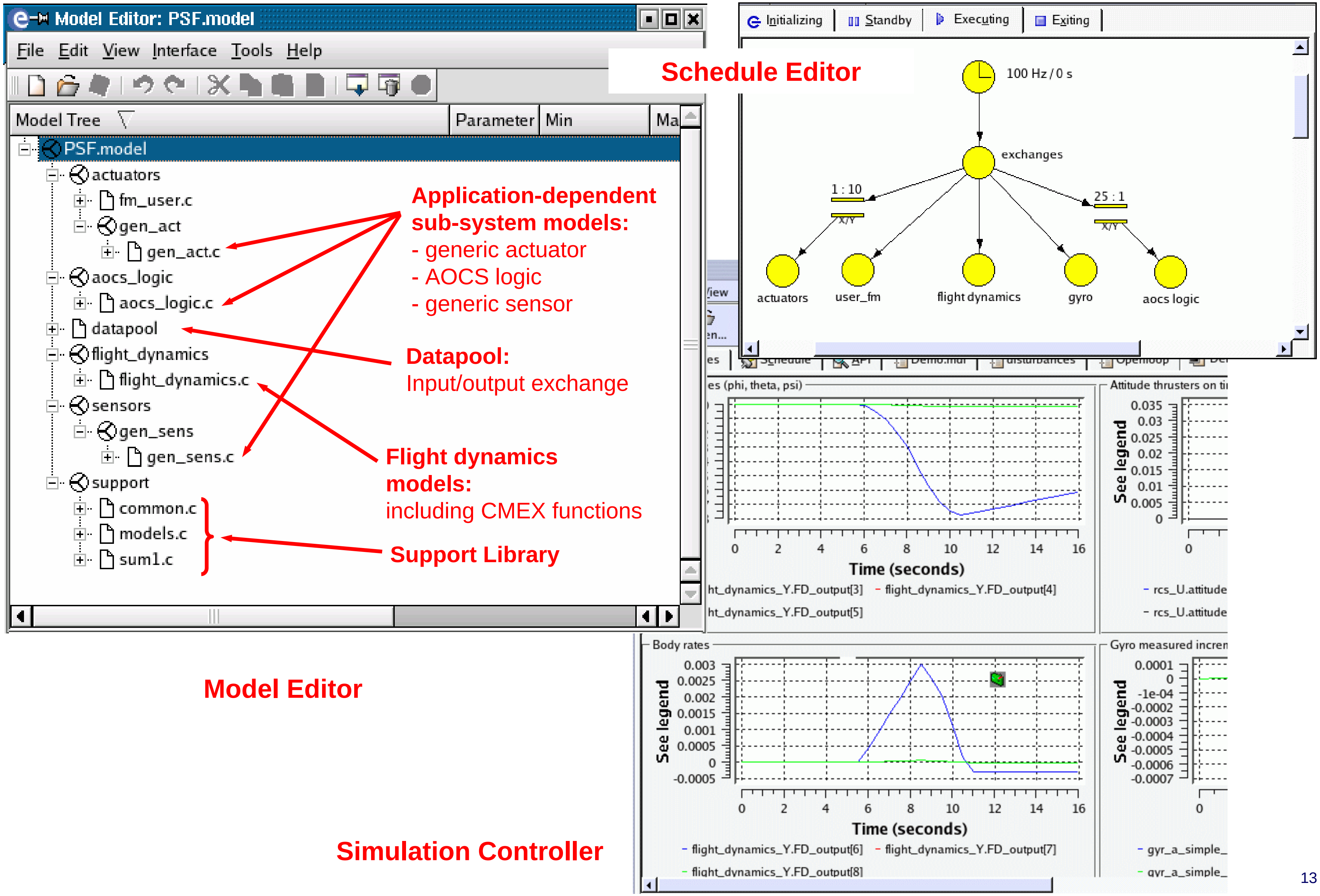

Schedule Editor

Application-dependent sub-system models:
- generic actuator
- AOCS logic
- generic sensor

Datapool:
Input/output exchange

Flight dynamics models:
including CMEX functions

Support Library

Model Editor

Simulation Controller

EuroSim Environment (2)

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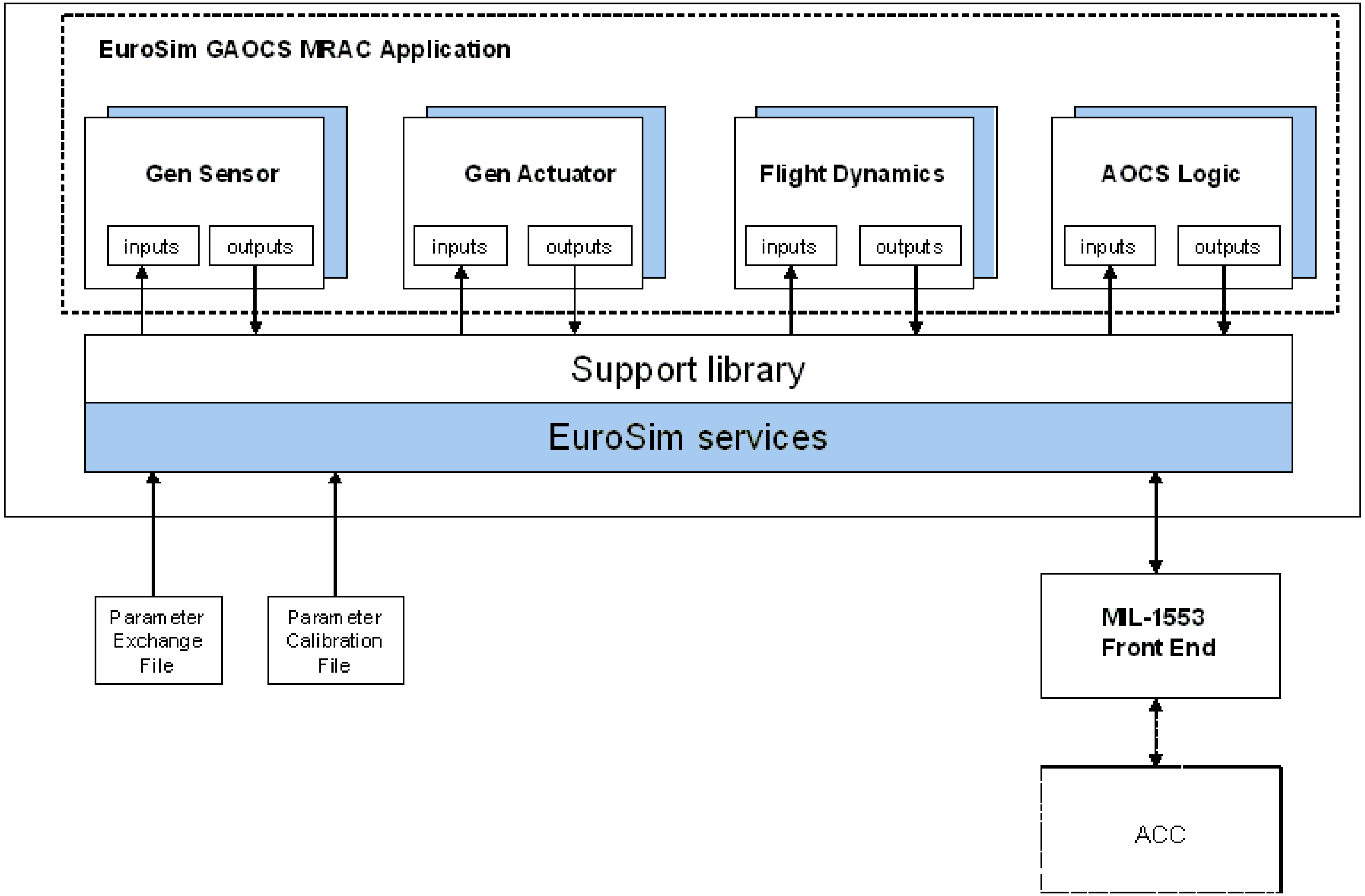

EuroSim – SILT Architecture

MRAC application (1)

- Design of MRAC for a satellite in a perturbing environment (LEO, solar-radiation pressure and aerodynamic drag)
- Tuning of controller parameters in ideal environment, with ideal sensors and actuators (MATLAB/Simulink)
  - corrective control roll channel
  - slew maneuver pitch channel
  - scanning pattern yaw channel
- Transfer of models to EuroSim:
  - inclusion of imperfect sensors and actuators, and perturbed environment
  - step response on roll angle, stability check
- Inclusion of MIL-1553 communication, bus frequency check

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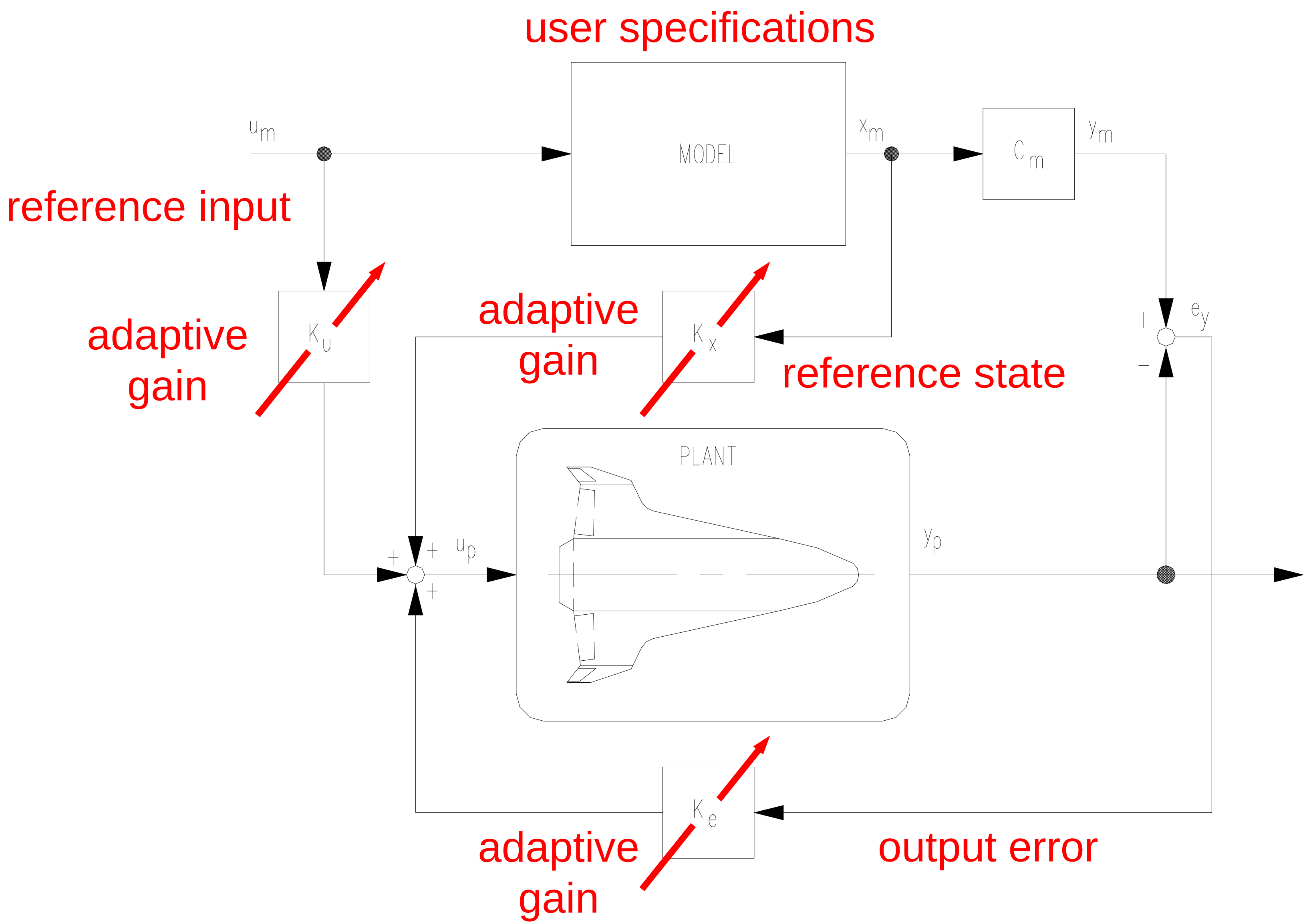
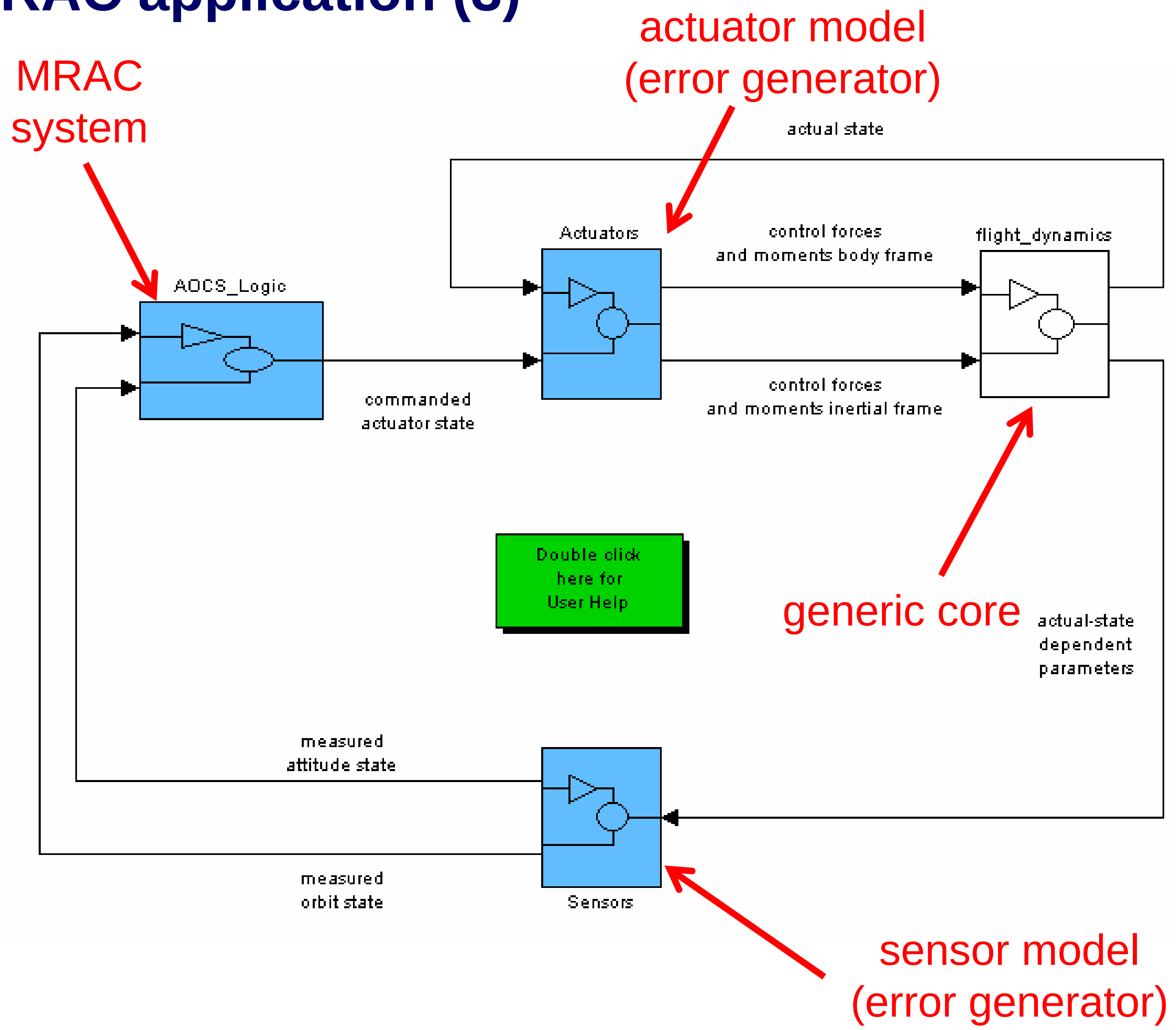
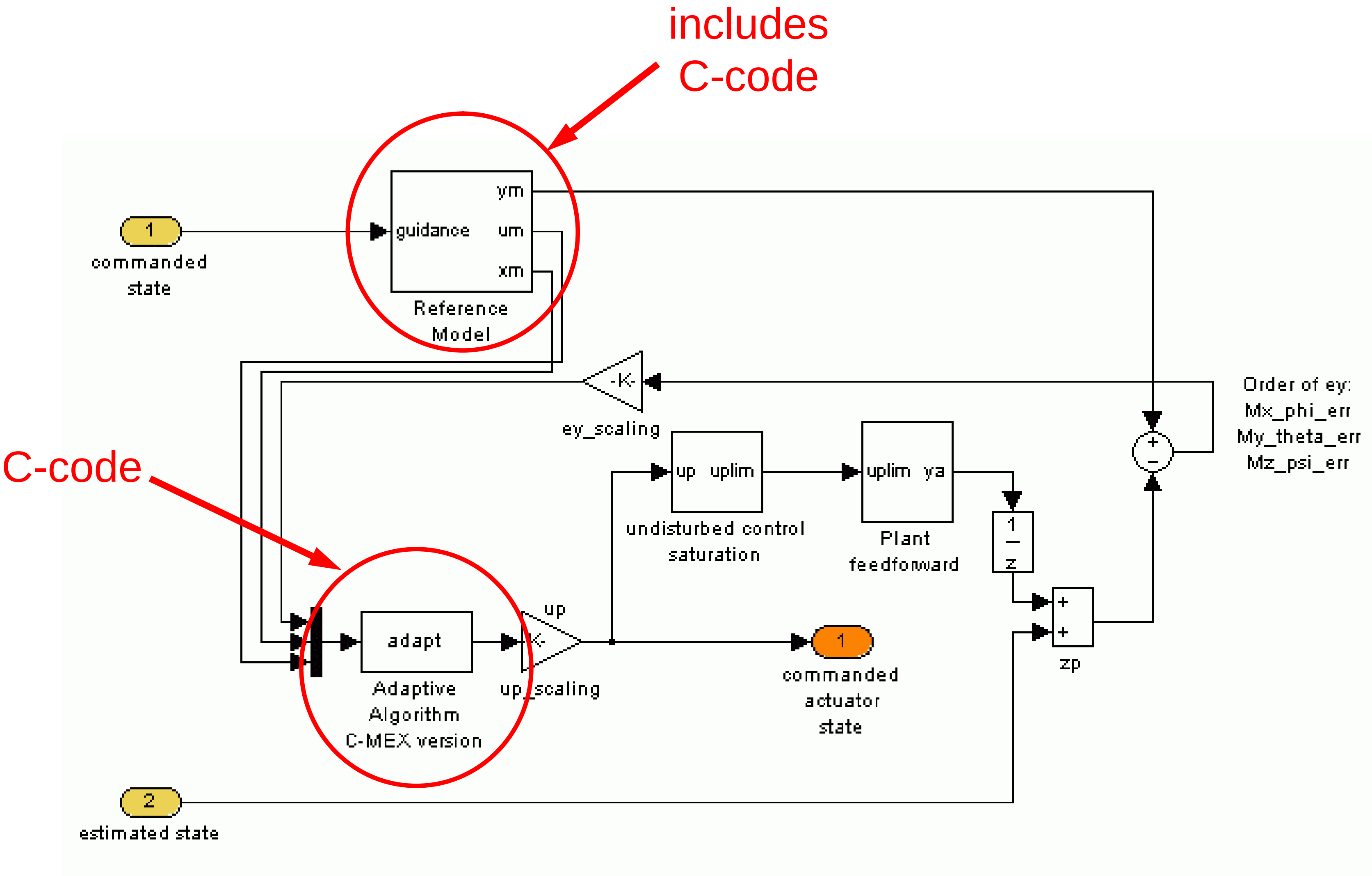
MRAC application (2)



MRAC application (3)



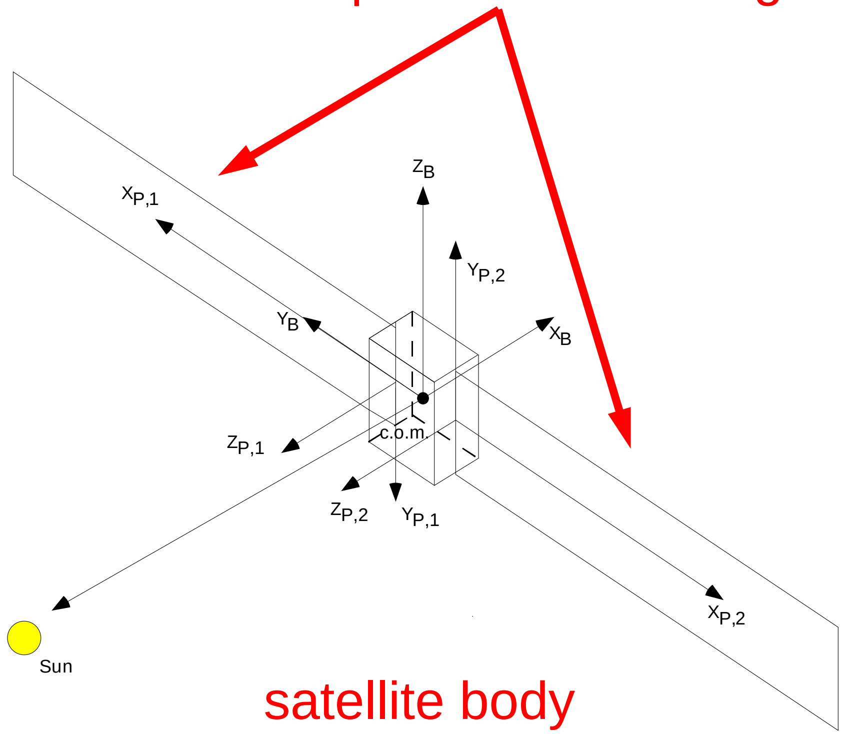
MRAC application (4)



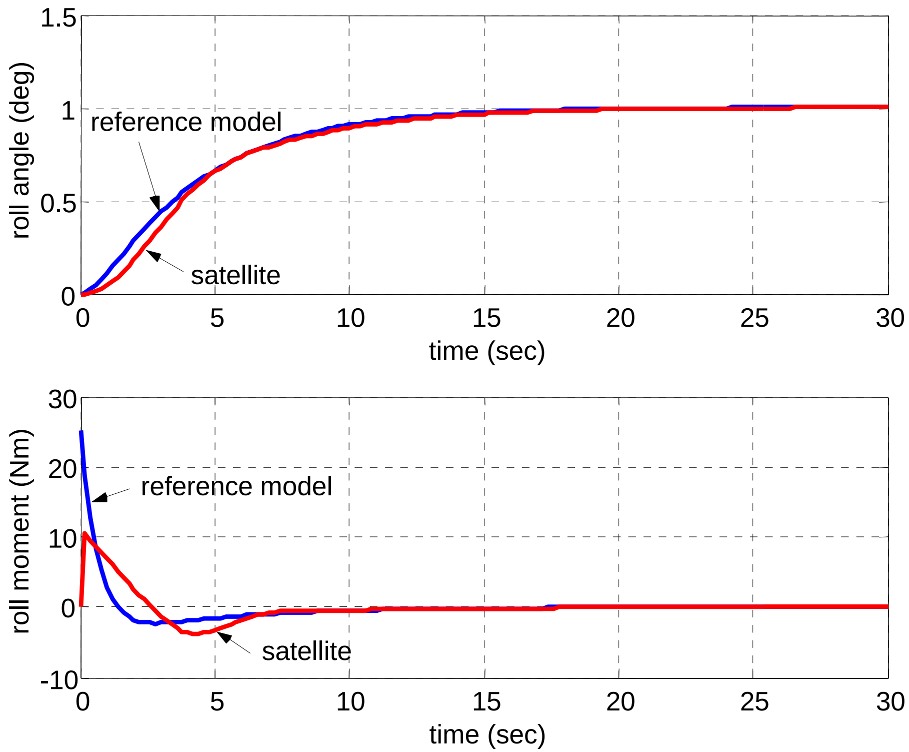
Top level Model Reference Adaptive Control System

MRAC application (5)

solar panel mass: 40 kg



satellite body
mass: 1600 kg



LEO (300x300 km), satellite in full view of Sun

step-function roll response

MRAC application (6)

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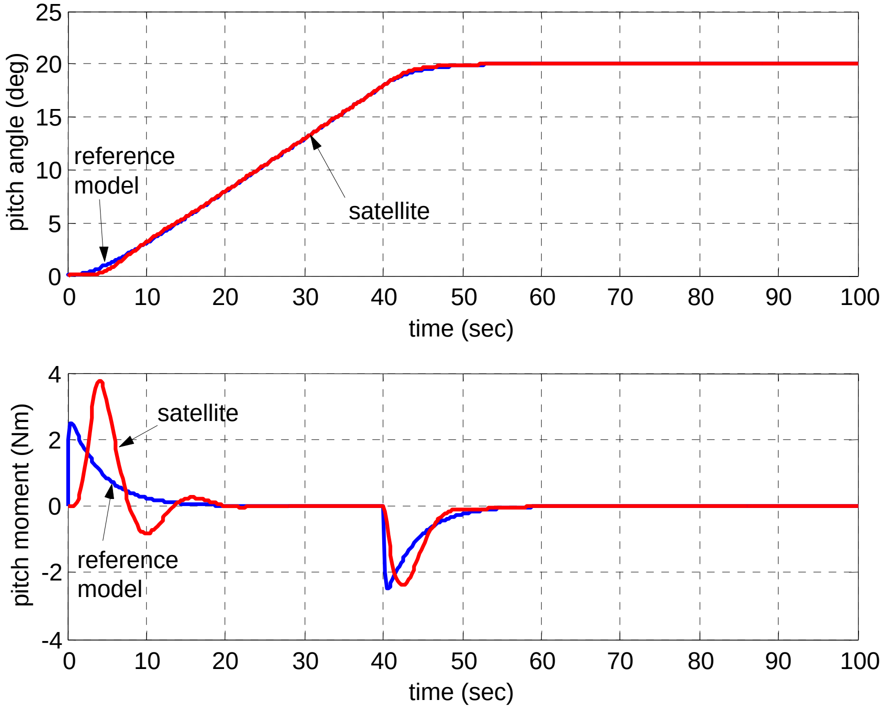
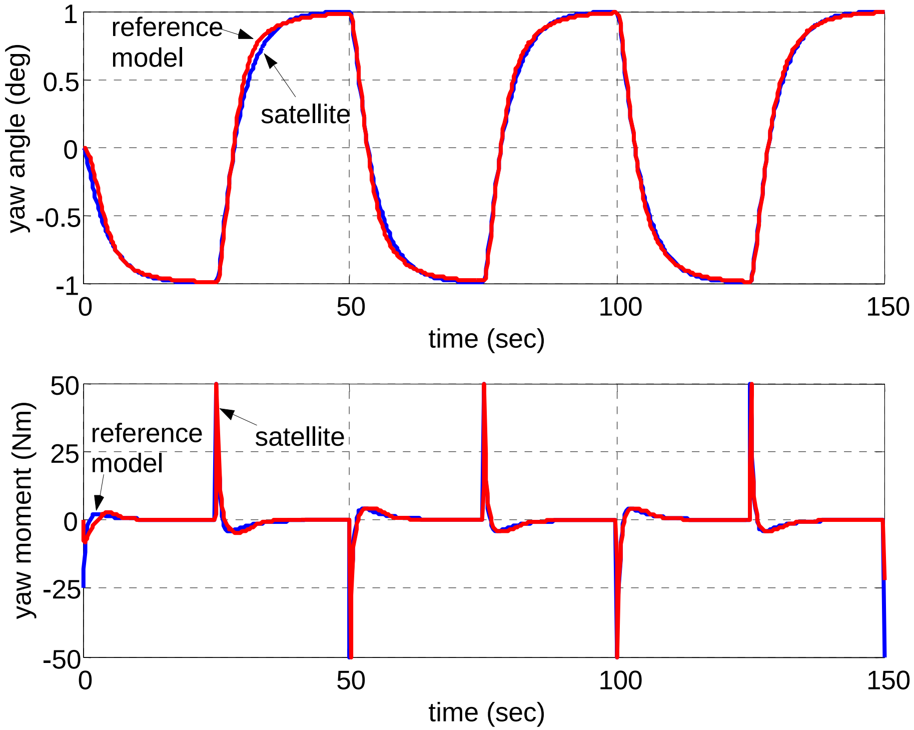


ramp-function
pitch response



square-wave
yaw response

MRAC application (7)

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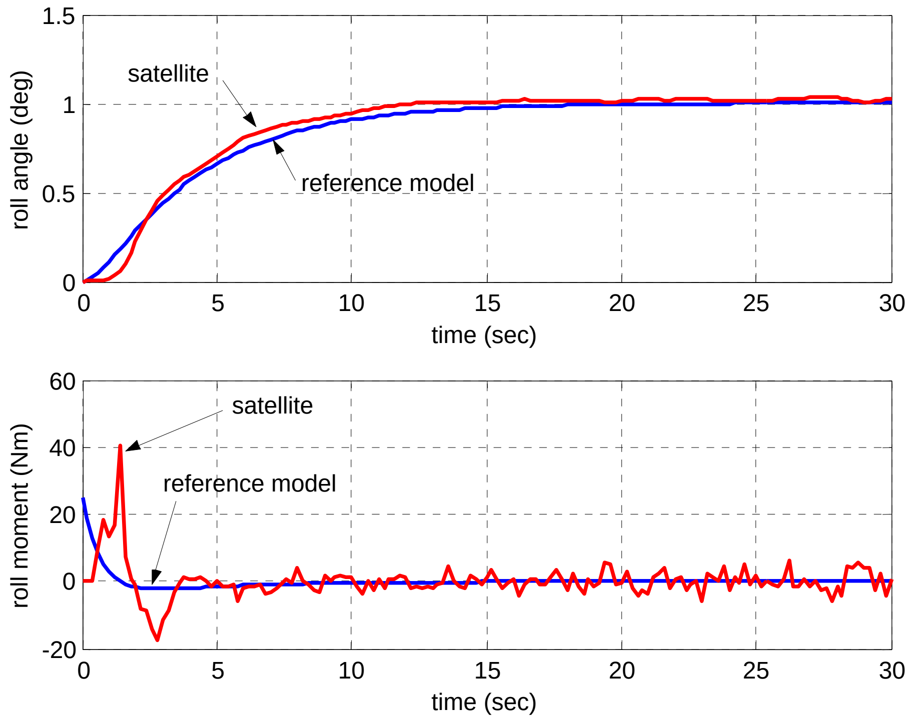
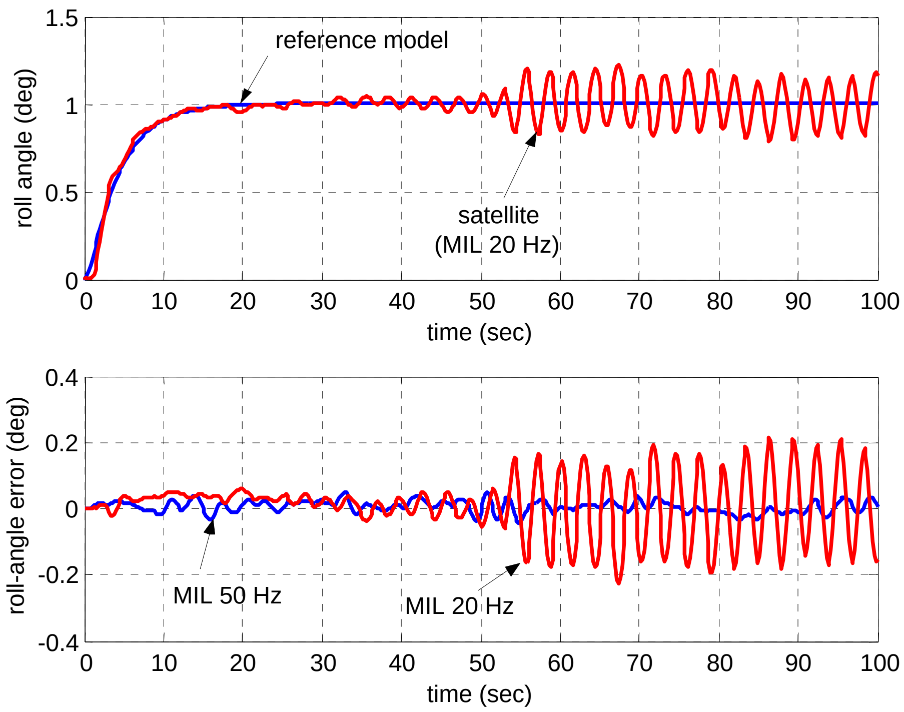
100 Hz



EuroSim PSF

MIL-bus frequency 50 & 20 Hz



EuroSim SILT

GAOCS Herschel Implementation (1)

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- MATLAB / Simulink Environment
- Generic Core (Flight Dynamics and Environmental Models)
- (External) Sensor Models (3 versions):
  - 2 Star tracker models
  - 4 Gyros
  - 2 Quartz rate sensors
  - Attitude Anomaly Detector
  - 2 Sun Acquisition sensors
- (External) Actuator Models (3 versions):
  - RCS
  - 4 Reaction wheels
- Controller Models:
  - RCS controller (in-house)
  - RWS controller (external)

GAOCS Herschel Implementation (2)

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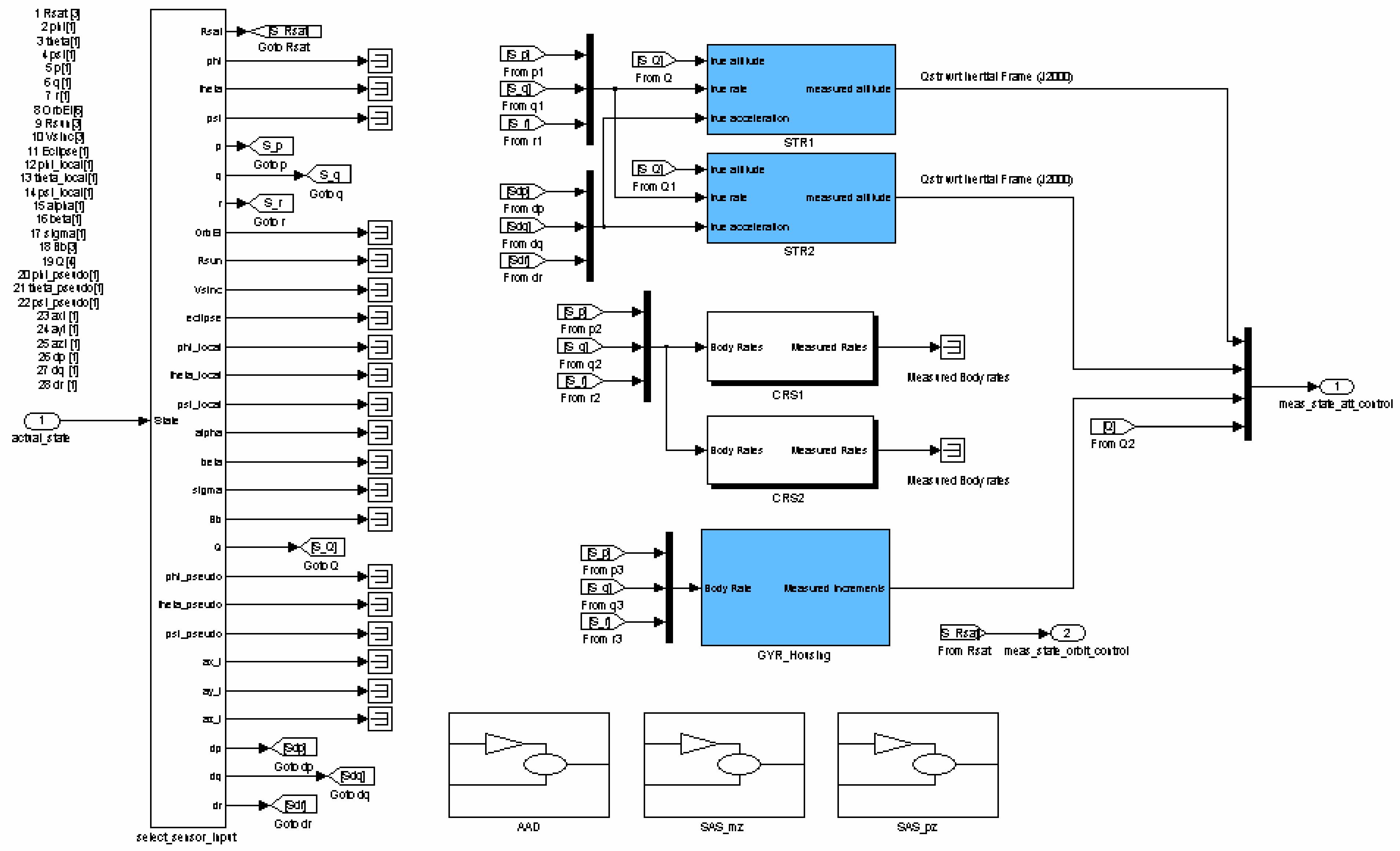

GAOCS Herschel Implementation (3)

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The Herschel PSF:

- EuroSim Environment under Linux
- Functional (PDR) unit models
- Models ported from MATLAB/Simulink using Real Time Workshop
- Defining the EuroSim schedule similar to Simulink execution order
- Verification against MATLAB/Simulink results:
    EuroSim based PSF_V0 Simulator with qualitatively similar results
- CDR unit models integrated, verification against PDR results
- Hardware interfaces integrated
- Integration of on-board software

ConeXpress R&D simulator (1)

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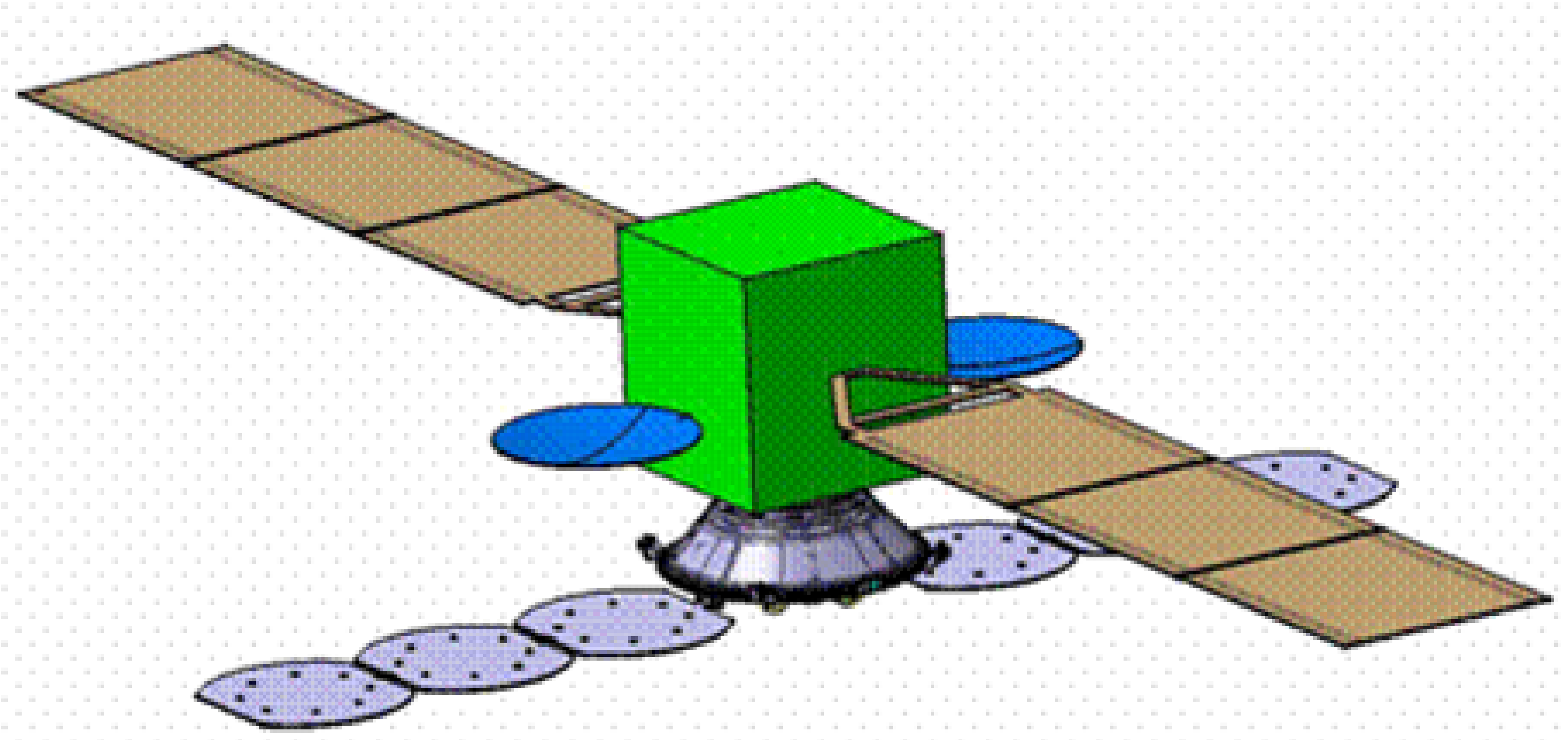

ConeXPress in mated configuration with target satellite

ConeXpress R&D simulator (2)

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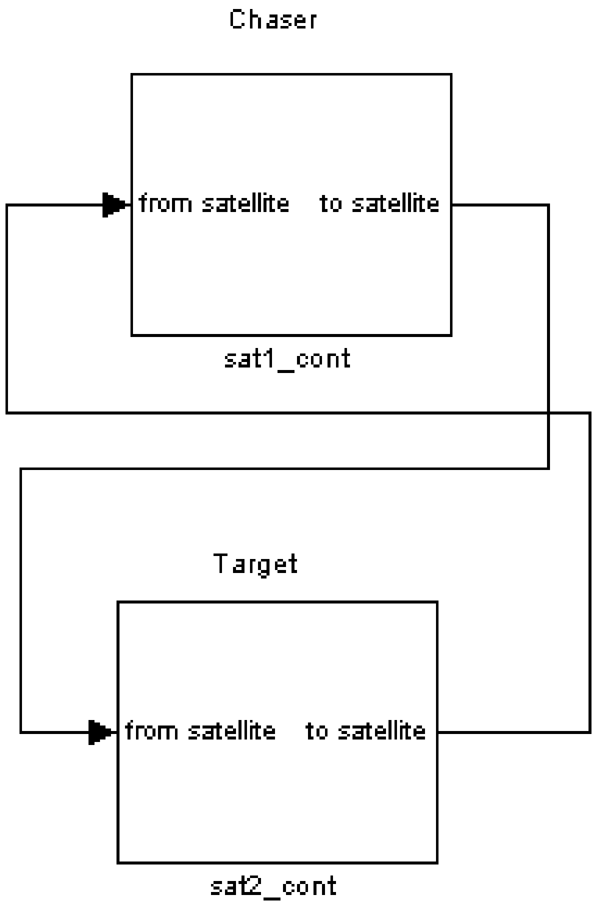
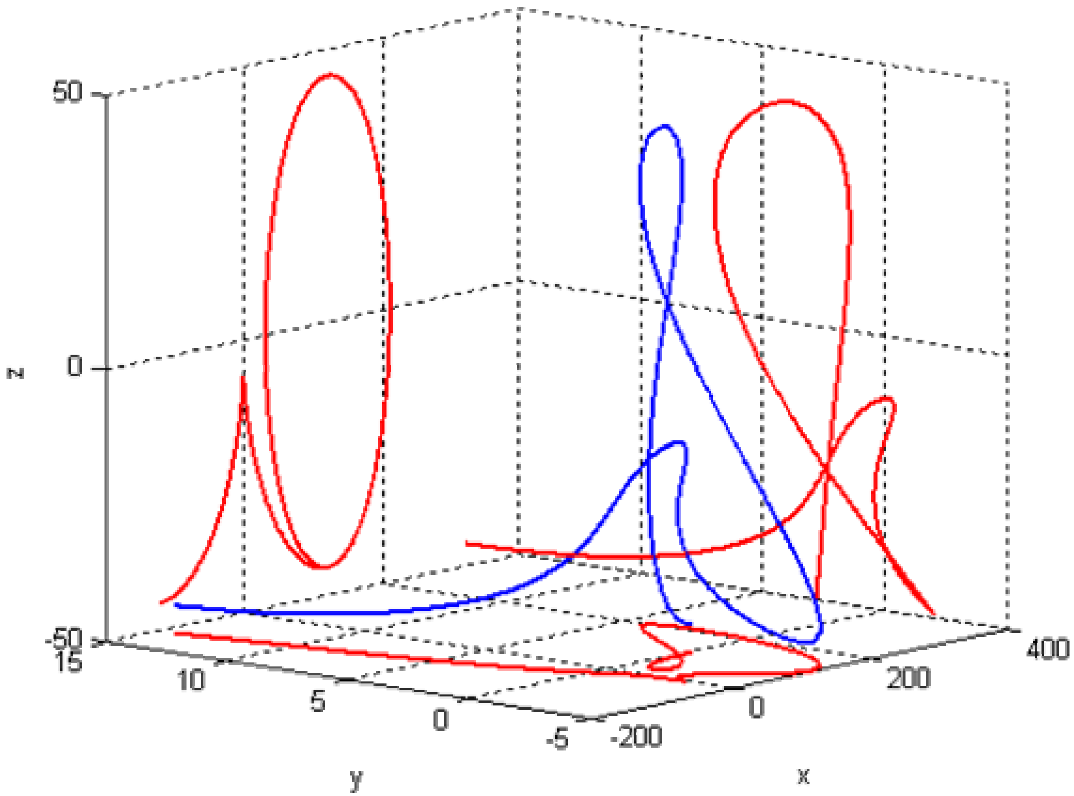


Waiting ellipse (relative position chaser-target)



Current status

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- Generic simulator for rigid satellites in Earth environment has been designed and implemented in MATLAB/Simulink
- Each of the individual models as well as the combination of several models has been evaluated and judged to be correctly implemented
- Performance improvement by factor of 20, by using C-coded S-functions
- Basis for further development of Generic EuroSim AOCS simulation environment for SIL and HIL testing
- (Potential) customers: HERSCHEL, ConeXpres, EarthCare, EXPERT re-entry vehicle, Virtual Satellite, *your satellite,* ...

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Current and future work (1)

- Modelling:
  - √ Additional satellite shapes, i.e., cone and sphere, which includes the adjustment of the solar-radiation pressure and atmospheric perturbation models
  - ➢ Flexible appendages (NASTRAN data files with mode shapes, etc.)
  - ➢ Addition of tip masses to the appendages
  - √ Mass variation due to fuel consumption, including sloshing models
  - – Sun as central body for interplanetary missions
  - – Etc.
- EuroSim:
  - – Development of GUI, possibly combined with MATLAB/Simulink
- SILT/HILT:
  - – GAOCS simulator with MIL-1553 communication ➔Herschel
  - – Dedicated (flight) hardware in loop ➔ Herschel

Current and future work (2)

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- Goal: one AOCS simulation and test environment for European Space Programmes (ESA), possible funding GSTP/TRP/?
- Open source of GAOCS Simulator elements
- Central management of GAOCS Simulation Environment :
  - Feedback of user models from industry
  - Screening for potential implementation
  - Validation of user models and implementation in baseline
  - Release of next version of GAOCS Simulation Environment
  - Documentation
- Set-up of data interfaces with COTS products (STK, simsat, …)