Dutch Space

Generic AOCS Simulator

2nd ESA Workshop on Astrodynamics Tools and Techniques

ESTEC, September 13-15, 2004

Erwin Mooij
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.
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

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

Objectives:
- ASW validation
- SCOE backbone

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

Introduction (2)
Overview

- **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

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

Design philosophy (2)

Facility to plot simulation results

Edit Window: Body Characteristics
MATLAB/Simulink Environment

Physical modelling

- 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
MATLAB/Simulink Environment

Simulator architecture (1)

User-defined sub-systems

Generic core

Main Simulink AOCS simulator window
MATLAB/Simulink Environment

Simulator architecture (2)

Simulink AOCS logic sub-system
MATLAB/Simulink Environment

Simulator architecture (3)

Main Library Simulink window

Sensor Library

Actuator Library
MATLAB/Simulink Environment

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)

- 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
MATLAB/Simulink Environment
Functional verification (2)

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Molniya-type orbit

goostationary transfer orbit
EuroSim Environment (1)

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
MRAC application (2)

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user specifications

reference input

adaptive gain

adaptive gain

reference state

output error

adaptive gain

adaptive gain

reference state
MRAC application (3)

- MRAC system
  - ADCS.Logic
  - Actuators
    - commanded actuator state
    - control forces and moments body frame
  - flight_dynamics
    - actual state
  - flight_dynamics
    - control forces and moments inertial frame
  - generic core
    - actual-state dependent parameters

- Actuator model (error generator)

- Sensor model (error generator)
MRAC application (4)

Top level Model Reference Adaptive Control System

includes C-code
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

MIL-bus frequency 50 & 20 Hz

EuroSim PSF

EuroSim SILT
GAOCS Herschel Implementation (1)

- 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)
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)

ConeXPress in mated configuration with target satellite
ConeXpress R&D simulator (2)

Waiting ellipse (relative position chaser-target)
Current status

- 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, ...
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)

- 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, …)