Modelling Gravitational Measurement Instruments and the Associated Drag Free Attitude Control Systems

Breaking the Traditional Borders between Platform and Payload Modelling in ESA Operational Simulators

M. Sarkarati , M. Spada , V. Reggestad

Main Objectives of Operational Simulators

- Support the overall ground segment validation
- Training of the Flight Control Team before and after the Launch
- Preparation and validation of the Flight Operation Procedures
- Simulation and training
  - contingency operations and recovery procedures
- A reference of the spacecraft after launch for
  - validation of new procedures
  - investigation of problems

Main Features of Operational Simulators

- **Include:**
  - The Spacecraft
  - The Space environment
  - Ground Station network
- **Real-Time** Simulation with faster than real time possibility
- Running the **real OBSW** with software emulation of the processor
- **Breakpointing**: possibility to save a simulation at a certain time, and reload it latter
- Seen from the Ground Systems as a **real spacecraft** (TM/TC)
- **Commanding** via script: possibility to generate failures, change simulation model configuration, etc.
- **Visibility** on published parameters through the MMI

Modelling Scope of Operational Simulators

- **Satellite Platform Subsystems**
  - The Electrical Power System
  - The Thermal Control System
  - The Radio Frequency System
  - The Propulsion System
  - The Attitude and Orbit Control System:
    - All sensors and actuators
  - The Command and Data Management Unit, including
    - the onboard computer and the emulated OBSW,
    - the communication busses and all I/O devices
- **The Ground Components**
  - SLE Ground Models (TMTCS model)
  - Interfaces to the TMTCS hardware as well as direct interface to the MCS

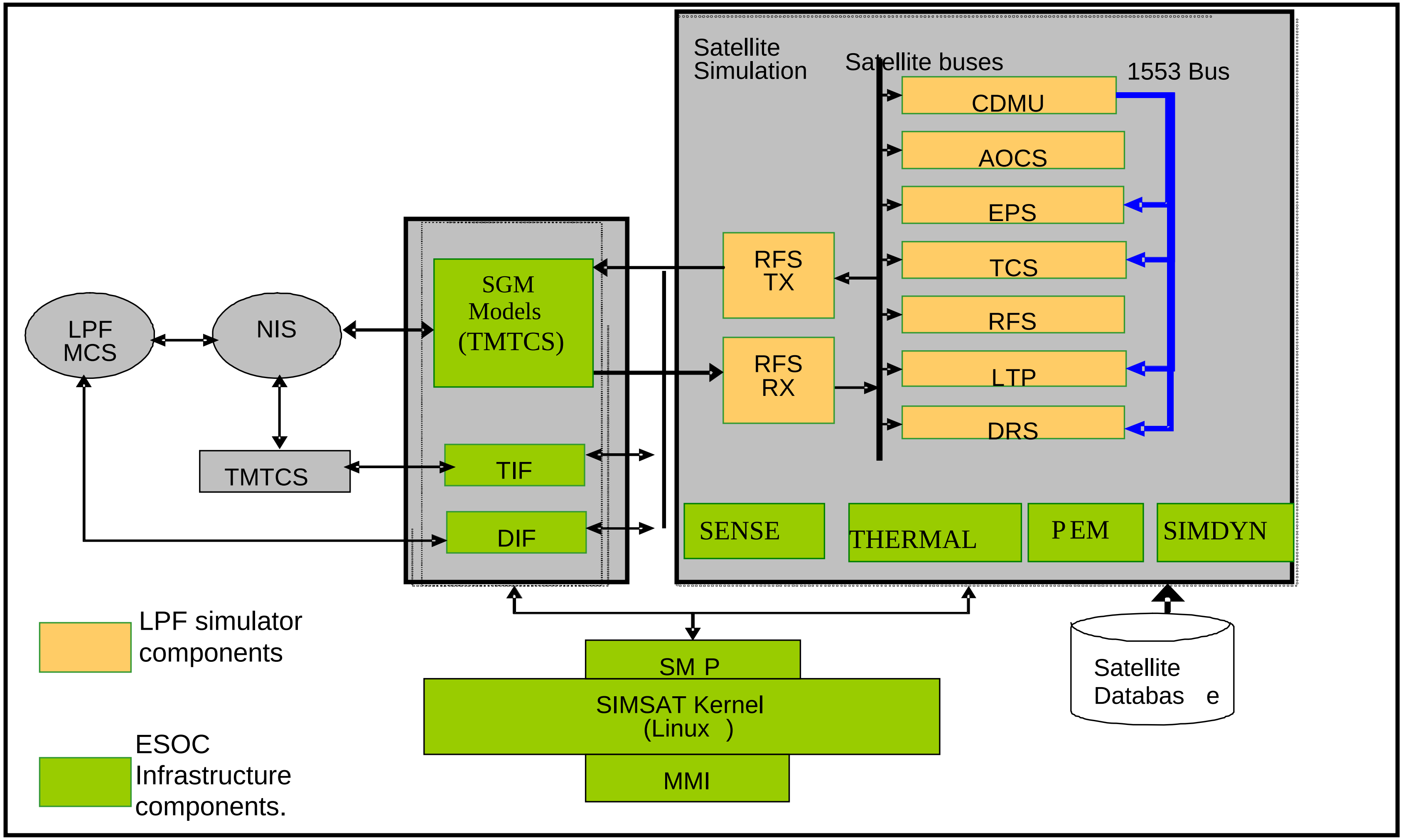
Modelling of Payloads in Operational Simulators

- **Traditional approaches:**
  - Model Housekeeping TM only
  - Science data is either:
    - Not modelled
    - Static replay of recorded sample data
    - Just empty dummy data.
  - Functional models of the payload instruments modes and commands.

- **Justification:**
  - Clear split between Payload and platform.
  - Science data not required for the ESOC usage of the Operational Simulators

- **New challenges introduced:**
  - Data from scientific payloads is used actively onboard by the platform.
  - Tight coupling between payload and platform

Modelling Scope of Operational Simulators



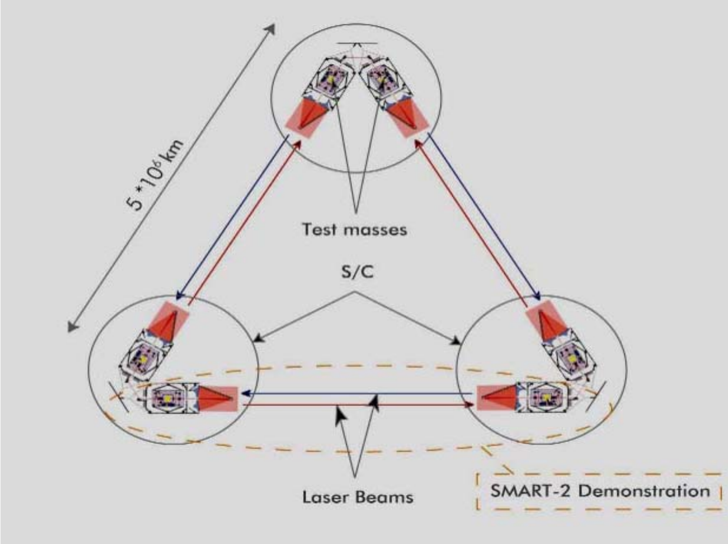
🟧 LPF simulator components

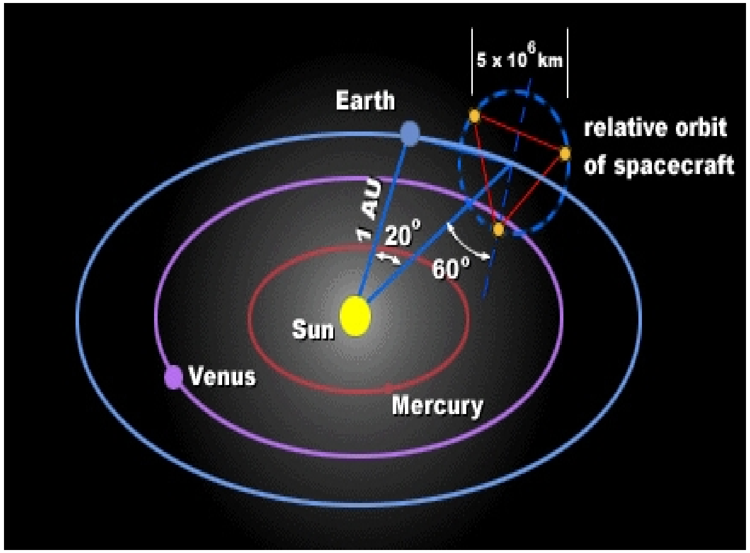
🟩 ESOC Infrastructure components.

The LISA Pathfinder Mission

- Technology demonstrator for the joint ESA/NASA corner-stone mission LISA, Laser Interferometer Space Antenna
  - The Drag-Free Attitude Control System, DFACS, of the spacecraft
  - The inertial sensing and high precision Laser interferometry technology
  - The micro propulsion technologies

- LISA Scientific Objective: Detect and observe low frequency gravitational waves



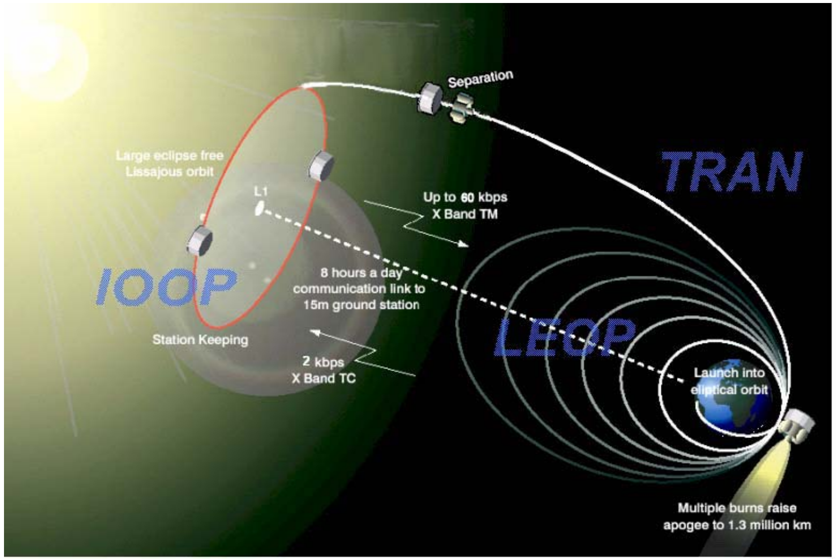


The LISA Pathfinder Mission

- Two scientific payloads:
  - LISA Test Package (ESA)
  - Disturbance Reduction System (NASA)

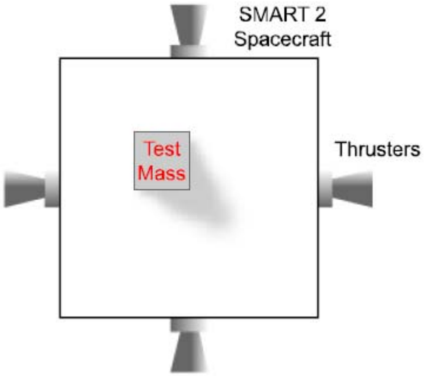
- LTP has 2 reference test masses.
  - One LISA arm squeeze from 5x10^6 km to a few centimetres.

- Laser interferometer measures the movements of the 2 test masses.

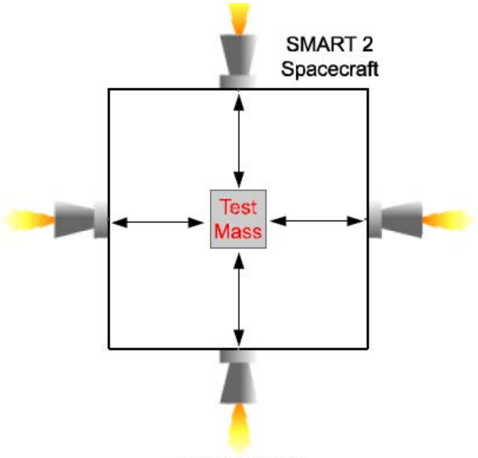


The Drag Free Attitude Control System (DFACS)

- Shield the test masses from the influence of the external disturbances
- Position of the test mass relative to the spacecraft is measured.
  - Inertial sensors are integrated in the payload.
- The required forces/torques to compensate the disturbance forces are calculated
- Closed Loop: Spacecraft follows the free-flying test mass

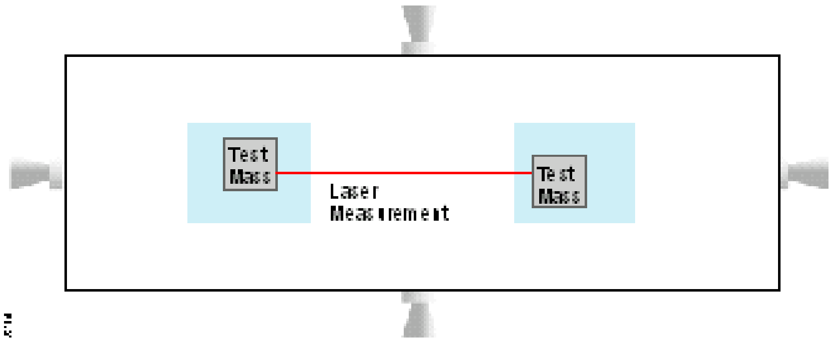


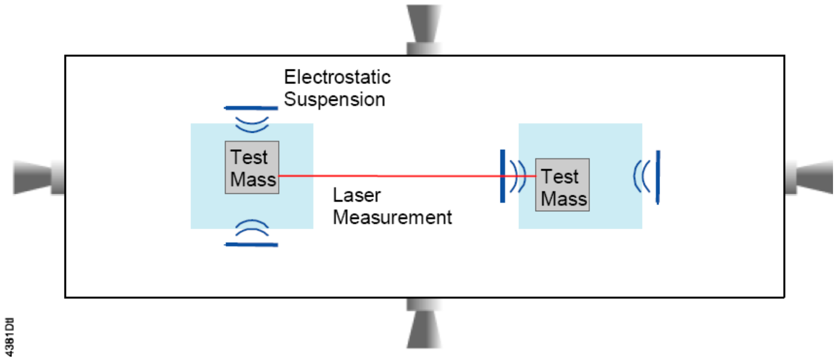
TM in pure free-fall
inside S2– no
disturbances



DFACS system
centres SC over
free-flying TM

The Drag Free Attitude Control System (DFACS)





- To maintain the relative position of the test mass:
  - Electro static actuation subsystem is used

- Relative (differential) acceleration of the test masses is measured inside the payload,
  - using the response from the electrostatic suspension system and, laser interferometry optical bench

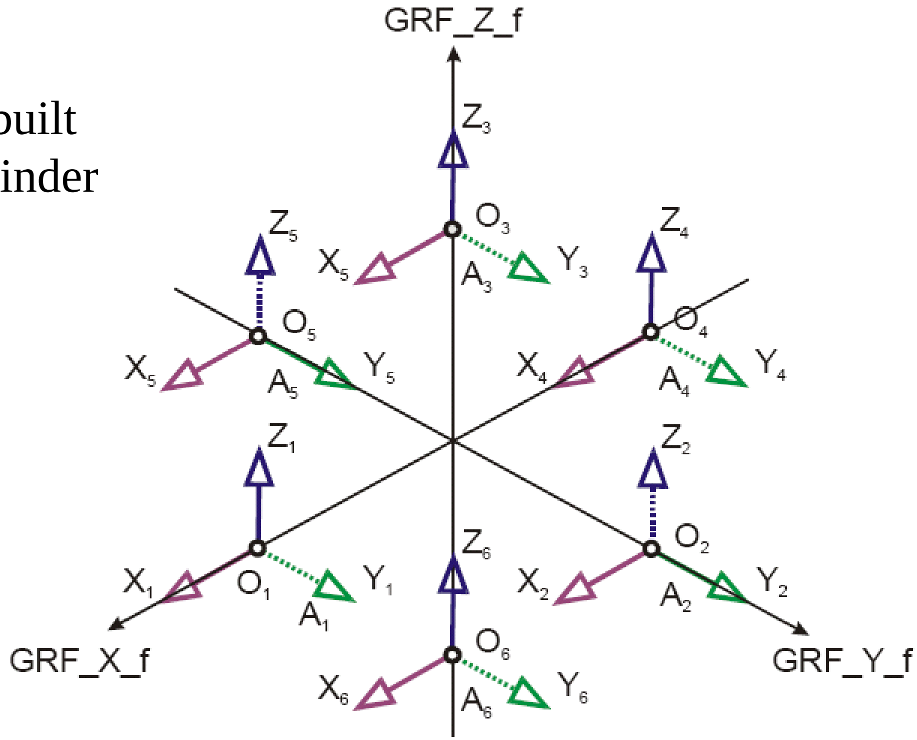
The GOCE Mission

- The ESA Gravity field and steady-state Ocean Circulation Explorer mission, GOCE, measures the Earth's gravity field

- Three-axis electrostatic gravity gradiometer measures gravity gradients in all spatial directions for the first time

- The payload of the GOCE mission is built on the same principles as the LISA Pathfinder

- GOCE has 6 test masses
  - Can measure the gravity gradient along all access.



DFACS in Operational Simulator

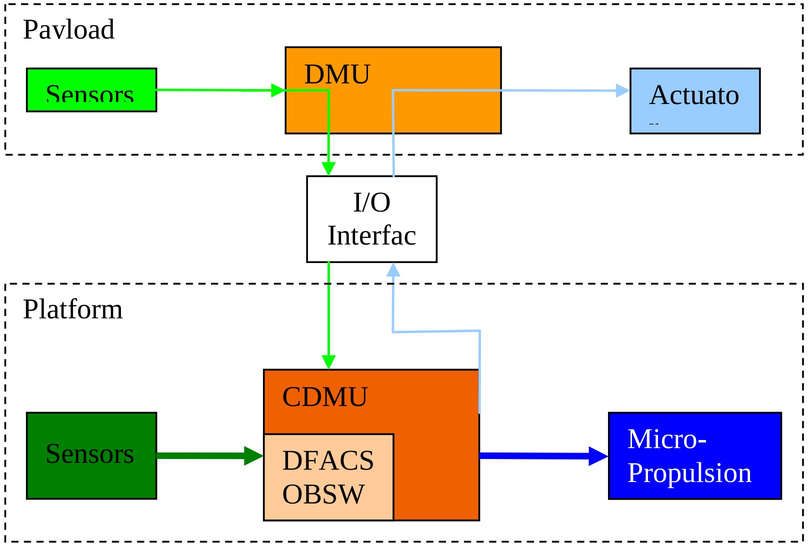
- Sophisticated Payload: Internal sensor and actuator subsystems as well as a dedicated data management units

- Payload is integrated in the real-time DFACS control loop like a platform AOCS sensor/actuator

- Modelling focused on the simulation of the correct interaction with the OBSW
  - To keep the emulated OBSW "happy"
  - Reduced accuracy of the science data modelling.

- Not in the scope of the Operational Simulator
  - Modelling of the exact scientific measurements
  - Validation of DFACS

- Other dedicated simulators for these purposes



Payload

Sensors

DMU

Actuato

I/O
Interfac

Platform

CDMU

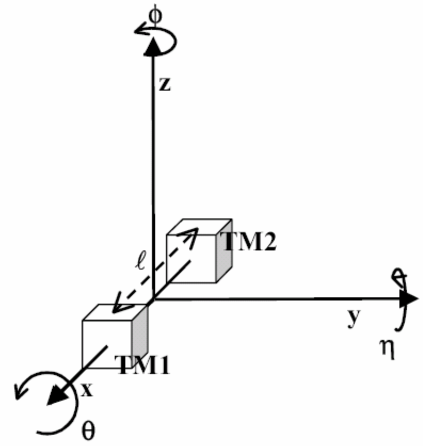
Sensors

DFACS
OBSW

Micro-
Propulsion

Modelling Gravitational Payload Instruments

- The equation of motion of the spacecraft and its test masses can be modelled in the payload simulation model
  - The payload may look complicated, but its just accelerometers.
- The angular and linear velocities of the spacecraft are known from the generic satellite dynamic modelling
- The stiffness forces can be incorporated as configurable noise functions in the model
- The gravity field gradient U calculated from well known environmental models.
  - First order approximation from the spacecraft orbit position is sufficient.
  - A variable component can also be forced as a stimuli to the model.



$$a_i = (U - [\Omega][\Omega] - [\dot{\Omega}])d_i + da + s_i + m_i$$

- a is the acceleration at the location of accelerometer.
- U is the gravity field gradient.
- Ω is the angular velocity of the spacecraft.
- d is the displacement from accelerometer to spacecraft COM.
- da is the linear acceleration of spacecraft COM
- s and m is the disturbance forces.

Results from GOCE

- DFACS integration into the simulator successful.
- Gradiometer TM modelled:
  - To a DFACS level of accuracy
  - No Science possible

- DFACS performance remain well inside OBSW FDIR limits.
  - Drag Free environment for the proof masses achieved.
  - Ion Engine thrust to compensate Air Drag.

- System level performance:
  - Drag Free mode causes slight raise in orbit
    - Acceptable since DFACS validation is not the scope of the operational simulator.

Conclusions

- Modelling DFACS and the corresponding gravitational measurement payload instruments introduce new challenges in the domain of operational spacecraft simulation development.

- The first implementation in the GOCE mission has shown that
  - The overall system may look complicated at the first glance,
  - Simple models based on rigid body mechanics are sufficient for the operational simulator.

- The needs of the operational simulator are that the OBSW is stable and continues to function correctly with the provided simulated DFACS data from the payloads.

- The GOCE operational simulator has successfully implemented, verified and integrated the above described DFACS models
  - Successfully used during the GOCE prelaunch simulation campaign.

- Following the same approach the development of DFACS models for the LISA Pathfinder operational simulator is an achievable goal,
  - still presenting a challenge for the future,
  - requires a systematic approach, and close cooperation between teams.