ADCSS 2016

October 20, 2016

Model Based AOCS Design and Automatic Flight Code Generation: Experience and Future Development

SATELLITE SYSTEMS

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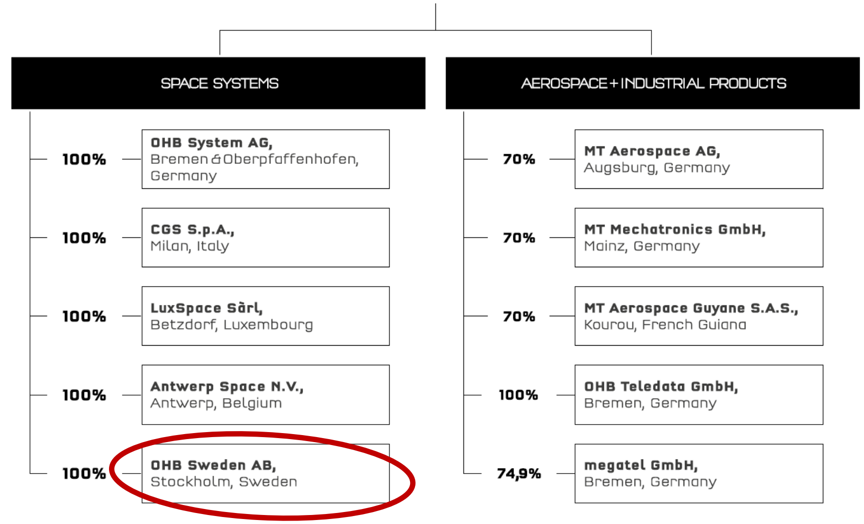
OHB Sweden

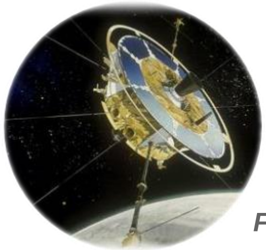
- Company Overview
- Autocoding Experience
  - *SMART-1*
  - *PRISMA*
  - *Telecom Projects*
- Future Development

OHB Sweden

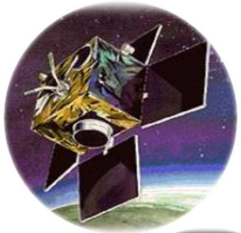
- Former Space Division of the Swedish Space Corporation
- Founded in 2011
- Swedish center of competence for space systems and satellites
- ~70 employees
- New facilities in Kista (Stockholm) since beginning of 2014 including new cleanroom
- Belongs to OHB Group which has subsidiaries in several European countries
- OHB Sweden is a self supporting company within the group



Early Scientific Satellites



Freja (1992)



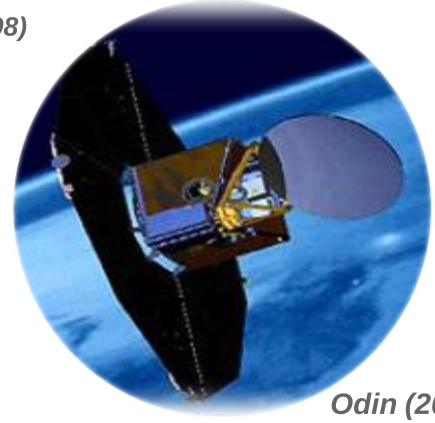
Astrid 1 (1995)

Astrid 2 (1998)

OHB Sweden Heritage

Provider of Complete Satellite Systems

Astronomy and Earth Observation

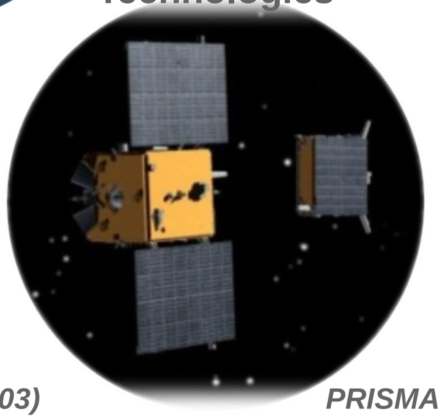


Odin (2001)

Lunar Science

SMART-1 (2003)

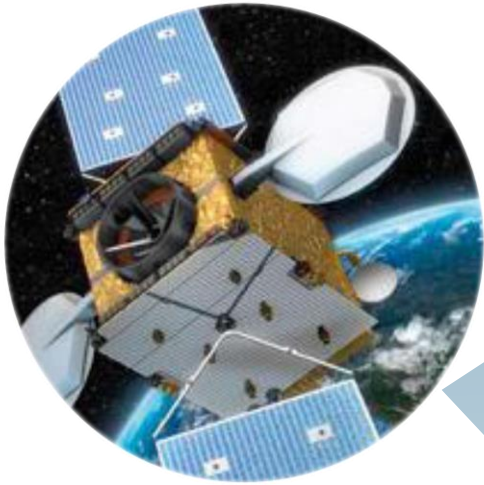
Formation Flying Technologies



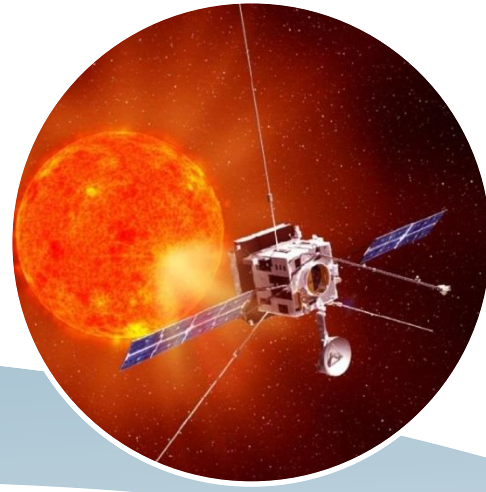
PRISMA (2010)

Company Overview

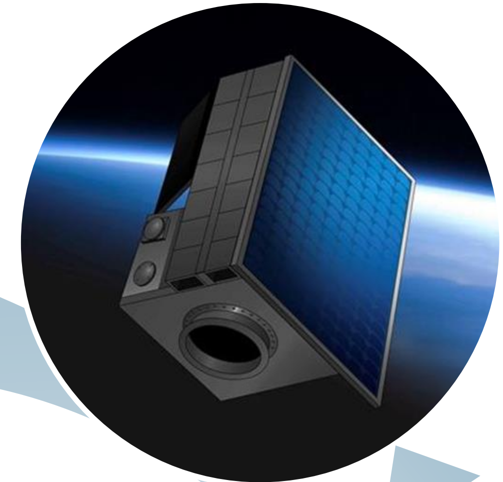
Telecom Satellites



Agency Scientific Satellites



Swedish National Program



OHB Sweden today provides:

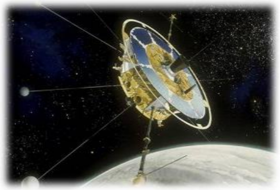
- ***Attitude Control Subsystems***
- ***Propulsion Subsystems***
- ***Small Satellite Systems***

within Telecom, Agency and National Programmes

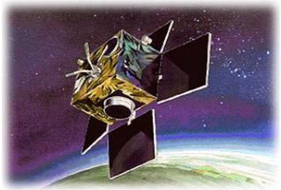
AOCS Experience

EARLY SATELLITES

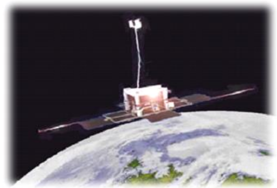
Spin stabilized attitude control



Freja (1992)



Astrid 1 (1995)



Astrid 2 (1998)

HIGH-PRECISION

Precise 3-axis attitude control for astronomy and Earth observation

Odin (2001)

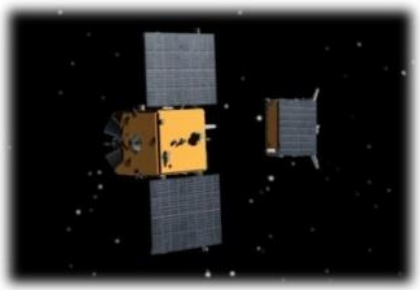
INTERPLANETARY

First ESA Lunar mission
Weak-thrust transfer to lunar orbit

SMART-1 (2003)

FORMATION-FLYING

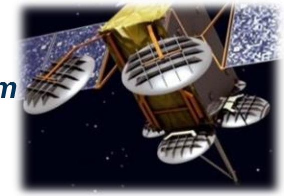
Demonstration of Formation-Flying & Rendezvous using GPS, Vision-Based, and RF-navigation



PRISMA (2010)

GEOSTATIONARY

Small GEO platform with EP station keeping



Small GEO (ongoing)

High Precision Pointing Laser Link with CP station keeping

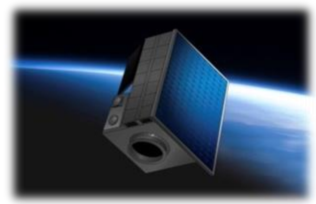
EDRS-C (ongoing)

EP Station Keeping and Full EO Transfer

Electra (ongoing)

LOW-COST

Medium pointing accuracy for scientific applications



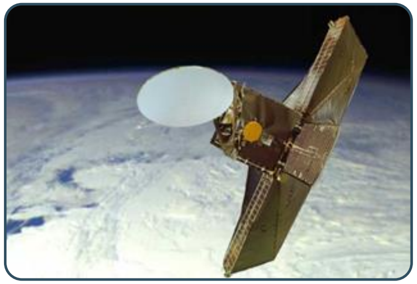
MATS (ongoing)

HERITAGE → *ONGOING* →

Model Based Design and Autocoding Experience

Before1995

- MBD and autocoding of Odin Spacecraft System Simulator



1998

- MBD is an integral part of AOCS design and analysis.
- Decision taken to use autocoding for SMART-1 AOCS flight software

2005

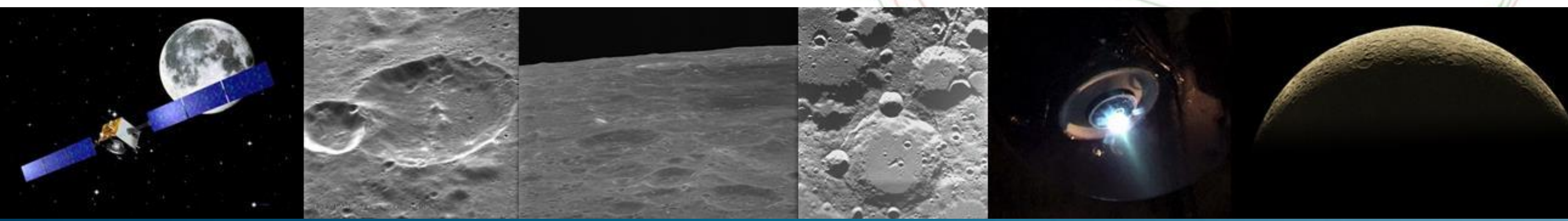
- Two formation flying satellites
- Autocoding of complete application flight software
- Integration of partner functionality into MBD framework

From 2008

- Autocoding of AOCS flight software for OHB Telecom missions
- Enhanced ECSS compliant development process

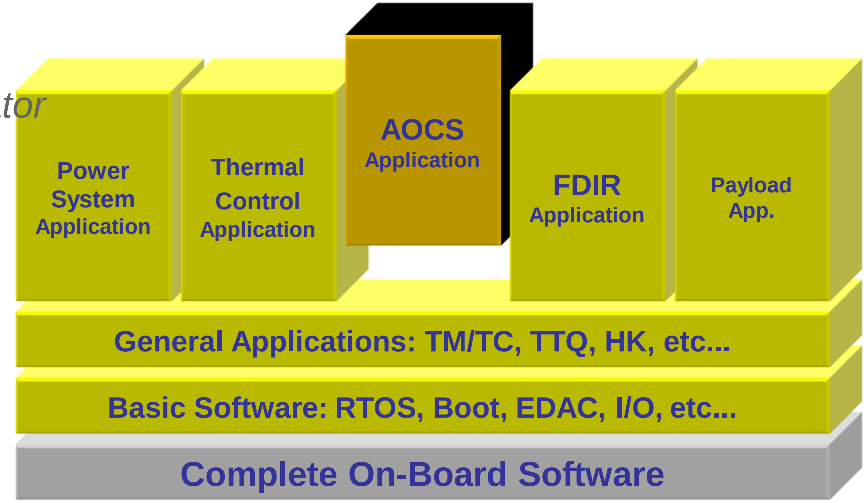
SMART-1: Overview

- SMART-1: Small Missions for Advanced Research and Technology
- Space Division of SSC (now OHB Sweden) was the prime contractor for SMART-1
- Mission
  - *Primary: Go to the Moon using Electric Primary Propulsion (Plasma Engine with 7 g thrust)*
  - *Secondary: X-ray/IR spectrometry, NIR camera, several technology experiments*
- SMART-1 was launched on September 27, 2003
- Reached Lunar orbit in November 2004
- Mission end with planned Lunar impact on September 3, 2006



AOCS Development Approach in SMART-1

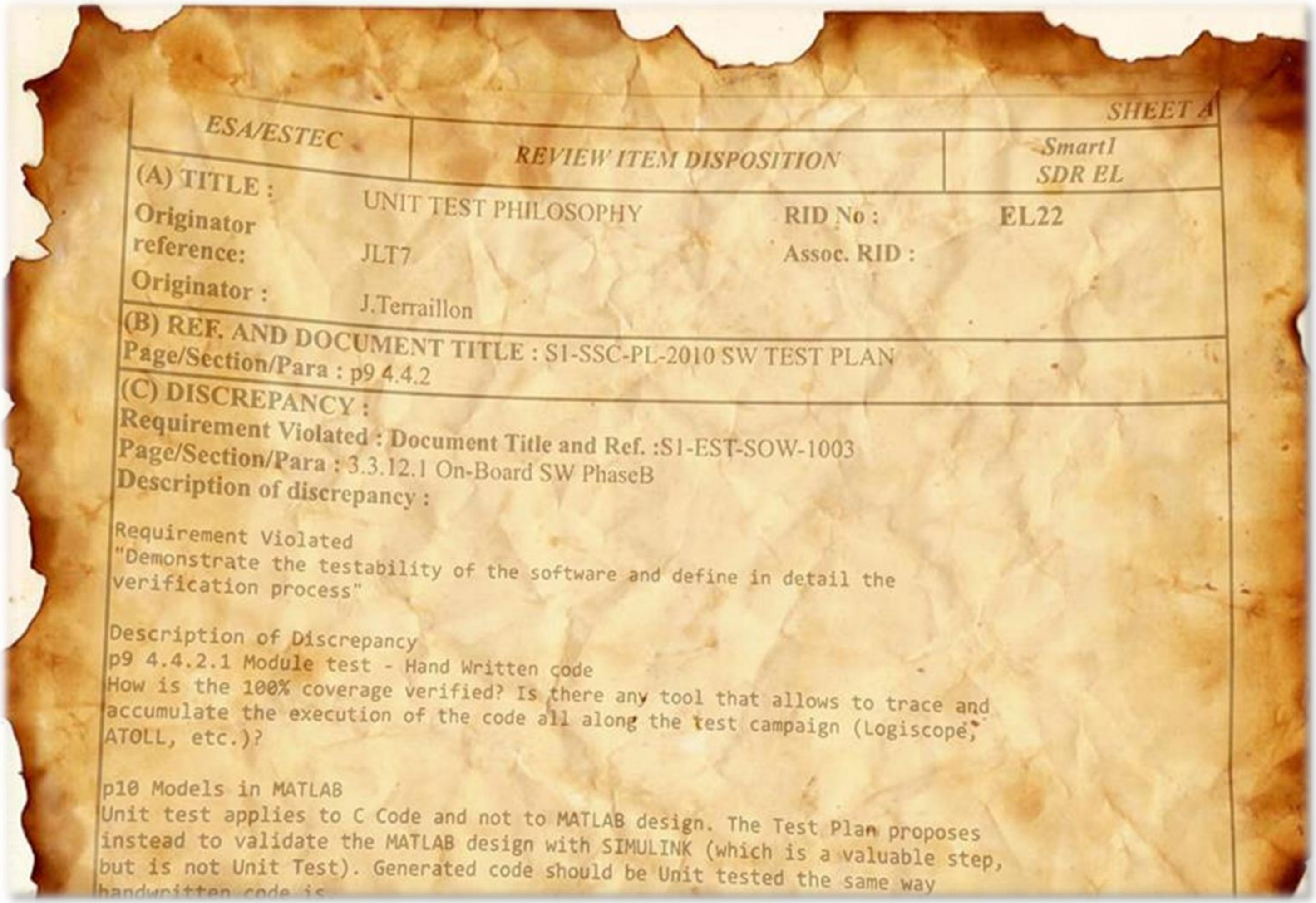
- Decision in 1998 to use single on-board processor with SPARC architecture
- Opened for possibility to use automatic coding for C-code generation
- SMART-1 was first ESA mission to use MathWorks coding technologies for flight code production
- Separate application software parts (Software Cores) were developed in-house for AOCS, Thermal, Power and FDIR
- C-code was generated for each Core. Code was compiled and linked into On-Board Software
- General On-Board Software was developed by SpaceBel (Belgium)
- Software Core: One single I/O+state function. Cyclically executed.
- Integrated in “Shell” structure interfacing with the I/O of the Core
- Development process essentially followed PSS-05-0
  - *Unit Testing (Black and white box) in Simulink + ERC32 emulator*
  - *Black box testing on integrated software running on EM-board against spacecraft simulator*
  - *Process ”lightweight” in terms of documentation*
  - *No particular focus on coding standard*
  - *”Common sense” modeling standards applied*



OHB SWEDEN

SMART-1 PDR RID where Unit Test approach was agreed

(closed February 2000)



ESA/ESTEC	REVIEW ITEM DISPOSITION	SHEET A Smart1 SDR EL

(A) TITLE : UNIT TEST PHILOSOPHY — RID No : EL22

Originator reference: JLT7 — Assoc. RID :

Originator : J.Terraillon

(B) REF. AND DOCUMENT TITLE : S1-SSC-PL-2010 SW TEST PLAN
Page/Section/Para : p9 4.4.2

(C) DISCREPANCY :
Requirement Violated : Document Title and Ref. :S1-EST-SOW-1003
Page/Section/Para : 3.3.12.1 On-Board SW PhaseB
Description of discrepancy :

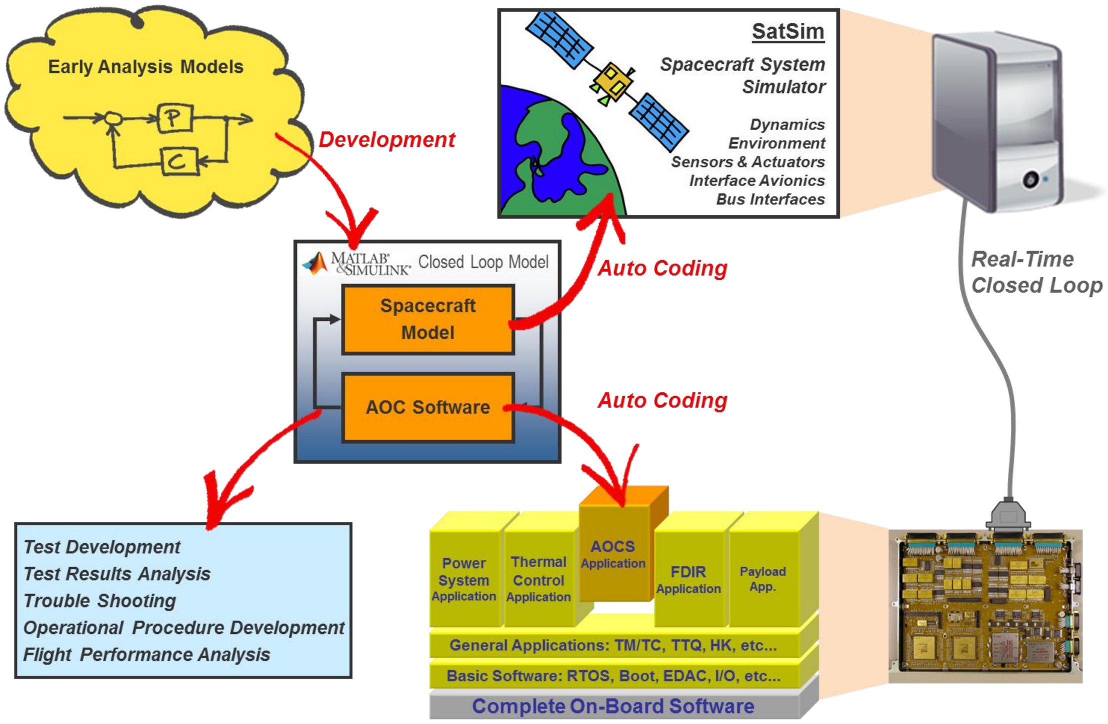
Requirement Violated
"Demonstrate the testability of the software and define in detail the verification process"

Description of Discrepancy
p9 4.4.2.1 Module test - Hand Written code
How is the 100% coverage verified? Is there any tool that allows to trace and accumulate the execution of the code all along the test campaign (Logiscope, ATOLL, etc.)?

p10 Models in MATLAB
Unit test applies to C Code and not to MATLAB design. The Test Plan proposes instead to validate the MATLAB design with SIMULINK (which is a valuable step, but is not Unit Test). Generated code should be Unit tested the same way handwritten code is

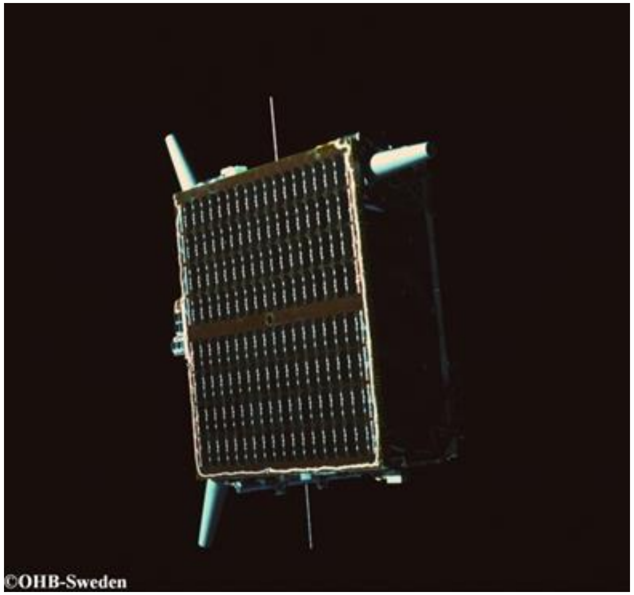
Experience from Model Based Design in SMART-1

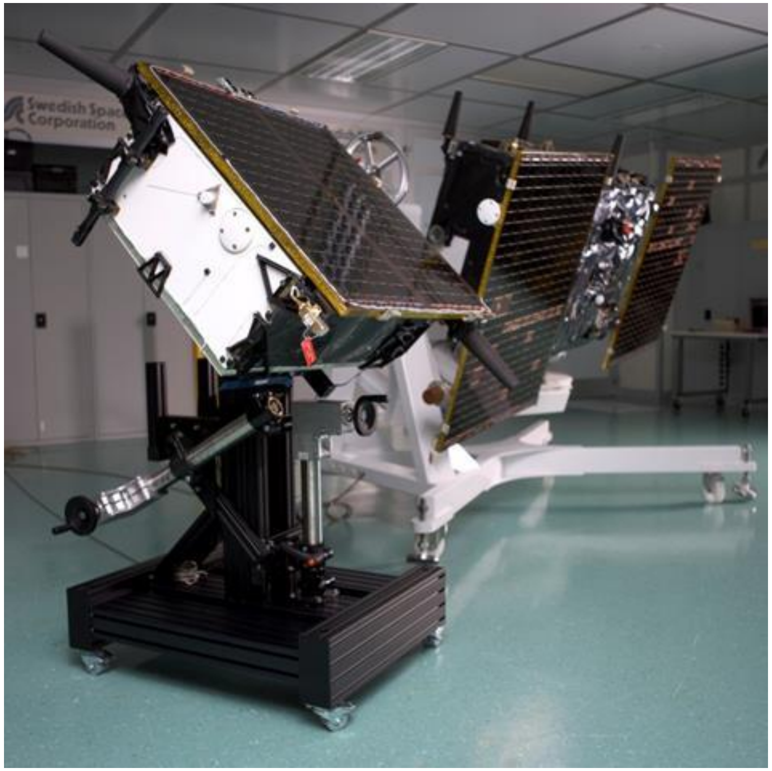
- Core/shell inteface:
  - *Efficient interface between two organizations*
- Keep it simple:
  - *Core is single task with functions configured by mode handler*
  - *Resticted set of simulink blocks*
    - *Predictable behavior of generated code*
    - *Clarity of implementation*
- Code robustness:
  - *No traditional ”bugs” found during Unit Testing*
  - *Only logical software problems found and corrected*
- Simulink Closed Loop Model
  - *Efficient tool througout project*
  - *High correspondence w.r.t system behavior*
  - *Used for:*
    - *Test development for AIT*
    - *Test results analysis*
    - *Operational procedure development*
    - *Flight performance analysis*



PRISMA: Overview

- Two satellites to demonstrate strategies and technologies for formation flying and rendezvous
- Initiated by SSC (now OHB Sweden) in 2004, funded by the Swedish National Space Board
- Supported by the DLR, CNES and by the Technical University of Denmark (DTU)
- Launched in June 2010
- Nominal and extended mission phases ended in Dec. 2012
- Technologies
  - *Relative GPS navigation*
  - *Vision Based Navigation*
  - *RF Sensor Navigation*
  - *Propulsion Systems*
- Distances
  - *30 km to 1 m*





PRISMA: Nominal and Extended Mission Experiments

OHB SWEDEN

Autonomous Formation Flying in passive relative orbits
Forced Motion Proximity Operations and Final Approach/Recede
Vision Based Autonomous Rendezvous

DLR

GPS Navigation System
AFC: Autonomous Formation Control
AOK: Autonomous Orbit Keeping

cnes

FFRF Metrology Qualification
FFIORD: Closed loop orbit control

DTU

Vision Based Sensor

SSC ECAPS

HPGP: High Performance Green Propellant

SSC NANOSPACE

Micropropulsion System

IRF

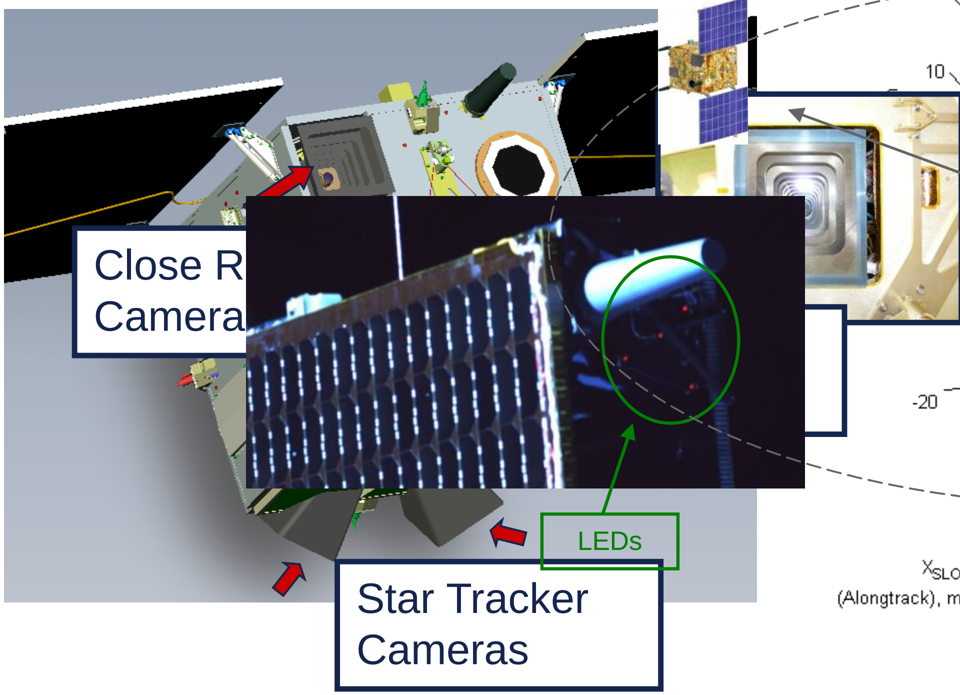
PRIMA: PRISMA Mass Analyzer

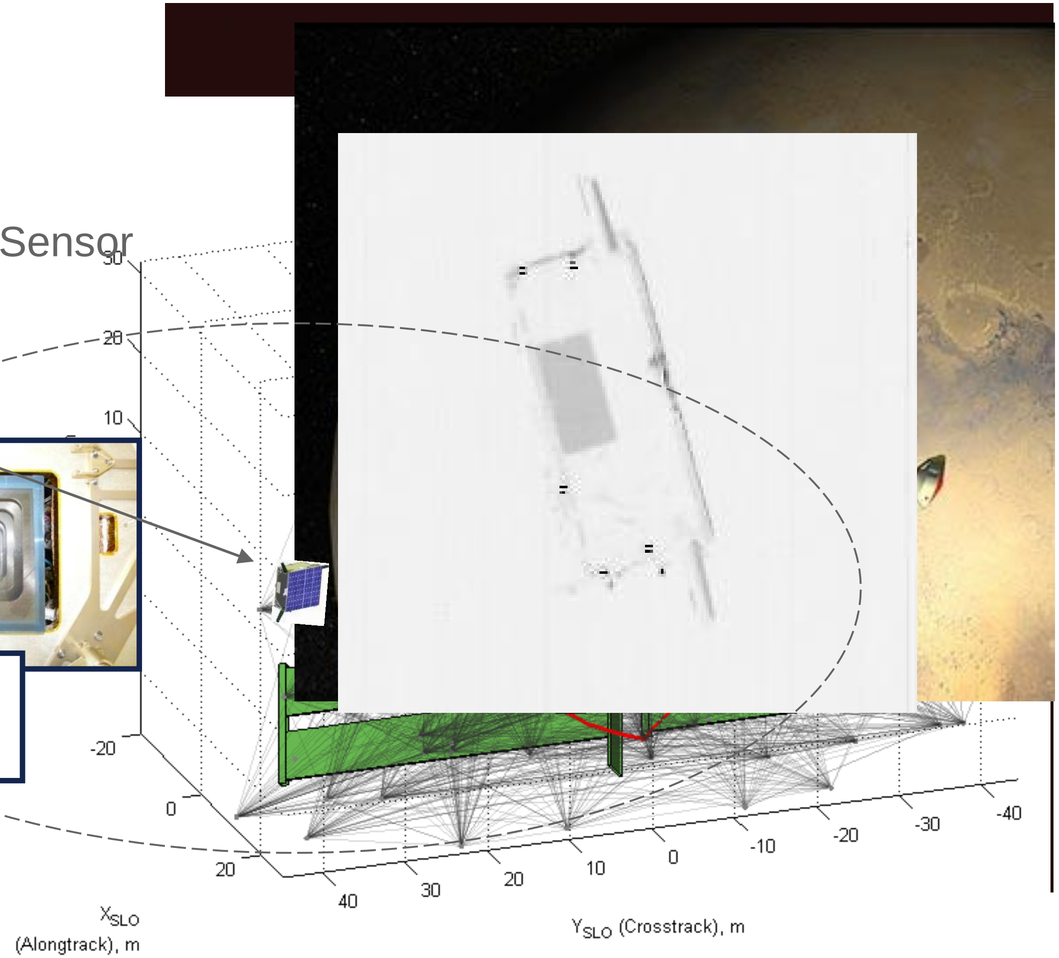
Techno System developments

DVS: Digital Video System

Guidance, Navigation and Control Experiments

- Passive Formation Flying based on GPS
- Proximity Operations based on relative GPS
- Navigation in virtual space structure
- Proximity operations based on Vision Based Sensor
- Autonomous Rendezvous



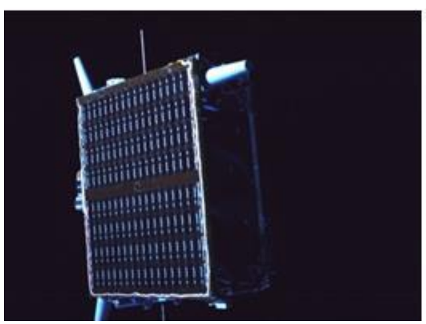


AOCS and Software Development Approach in PRISMA

- Single on-board computer: LEON based on FPGA technology
- Model Based Design with MATLAB/Simulink + Embedded Coder for complete on-board software except low-level parts
- As in SMART-1: AOCS, Thermal, Power, Failure Handling
- Now also: Data handling, interface of application software parts, implementation of PUS services
- All on-board software developed in-house but with a separate team for the AOCS part
- Swedish national project: More freedom for design decisions and quality level
- Less rigorous development than in SMART-1 (w.r.t. code coverage, requirements, etc…)
- More focus on testing on Real-Time System Simulator (developed in xPC Target) and on FM satellite tesing

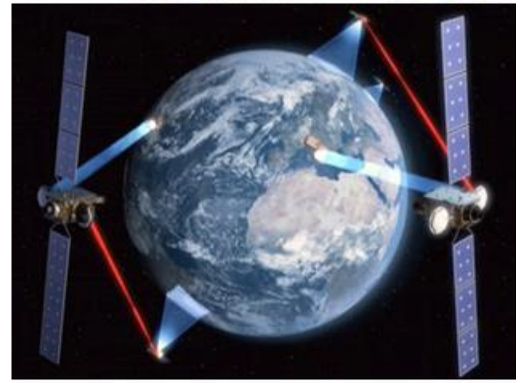
Experience from Model Based Design in PRISMA

- Complete flight application software was generated from a Simulink model
  - *Simulink works best for ”signal-oriented” functions, such as controllers, filters, etc.*
  - *Less efficient for data-handling, ended up as S-functions in many cases*
- Simplified development process
  - *Reduced testing of non-critical functions*
  - *100% coverage not required on unit level*
  - *Still very robust behavior in system testing and in flight*
  - *Representative system level tests of critical functionalities: Closed loop testing with RF-stimulation of the relative GPS navigation system*
- Closed Loop Simulink Model (two spacecraft)
  - *Used for generation of test and flight procedures*
  - *Framework for Automatic generation of PLUTO scripts from Matlab test descriptions (used in AIT and in flight)*



Telecom Projects

- OHB Sweden is responsible for the AOCS algorithm and flight software development for the OHB Telecom missions
  - *Small GEO HAG1: Chemical Propulsion for orbit transfer and Electric Propulsion for station keeping*
  - *EDRS-C: Chemical Propulsion for orbit transfer and station keeping*
  - *Electra: Electric Propulsion for orbit transfer and station keeping*
- AOCS application software is developed using Model Based Design and autocoding built on the heritage from the SMART-1 and PRISMA missions
- ECSS compliant development process
  - *Unit Testing on simulated target processor (TSIM)*
  - *Scenario Testing: Software qualification on Simulink Closed Loop model with complementary testing on SVF*
  - *Unit and Scenario Test framework developed allowing for automatic execution and test reporting*
  - *Coding Standards*
    - *Modeling Standard developed control the use of Simulink blocks and code generation settings*
    - *Tailored MISRA coding standard developed*
    - *Simulink model checking tools used to ensure adherence to modeling and coding standards*



Current Status and Observations

- Efficient use of Model Based Design and autocoding
- Integrated AOCS and Software teams
  - *Focus on the AOCS design*
  - *Software expertise primarily used for infrastructure, framework, and static testing*
- Too much time is spent on validation against TS and structural tests
- The ECSS compliant processes requires a significant amount of manual work other than the coding itself:
  - *Verification steps are often manual*
  - *Manual development of coverage testing*
  - *Retrieval of evidence and documentation*
  - *Administration of software milestone reviews*
- Possibilities for automation of all the steps within the software develpment process needs to be examined in order to fully make use of the benefits from MBD and autocoding
- When assessing the benefits from MBD and autocoding for AOCS, it is important to compare Model Based AOCS & Software together against AOCS & Manual Software development

Future Development

- Simulink Models
  - *View models as Executable Design Specifications*
  - *Design should rely on analyses conatined in the AOCS DJF*
  - *Document inside models and do not produce other descriptions of the algorithms*
- Reduction of testing time
  - *Focus on validation against TS: The engineer developing the model shall also (simultaneously) develop the associated functional tests within the design framework*
  - *Structural testing: Automation of Model, Code, Signal, and Condition coverage as well as out-of-range testing*
  - *Examine the possibility to qualify functions separately*
- Automation of software development processes
  - *Possibilities for automation of verification and documentation steps within the software development process should be examined*
  - *OHB Sweden participates in the AMASS* (H2020) project in which some process automation aspects will be addressed*

*AMASS: Architecture-driven, Multi-concern and Seamless Assurance and Certification of Cyber-Physical Systems