

Design of the Attitude and Orbit Control System for ESA's Solar Orbiter

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Tessella Ltd.
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Overview

- Introduction to Tessella
- Our part in the Solar Orbiter programme
- Control Engineering with MathWorks
- Integrating MathWorks into large projects

Altran

GLOBAL LEADER IN ENGINEERING
AND INFORMATION SERVICES



23 countries



29k
employees

300 of the
Global 500
are clients

1.9 bn euros
revenues

Industries:
from **automotive**
to **utilities**





Tessella, Altran's World Class Center for Analytics

We use data science to accelerate evidence-based decision making

OPERATIONS

UK, US, NL, FR, ES
DE, SE, PT

EXPERIENCE

30+ years of experience
delivering 1000s of data
analytics projects

DNA

Data is in our DNA. 250
of the brightest scientific
minds, 50% hold PhDs

KNOWLEDGE

Unique combination of domain
knowledge, data engineering expertise,
maths & statistics excellence



Our work allows businesses to improve profitability, reduce costs, streamline operations, avoid errors and out-innovate the competition.



Predicting the best coatings for ships. Reducing fuel costs by up to 15%



Data analytics powers H3 Biosciences drug research. Reducing time to go from lab to clinic by 75%





**Streamlining the creation of
new oil wells . Saving BP
\$100s of million**



**Helping Unilever's customers
identify wholesome alternatives
to existing preferences**



**Generating maps of disease risk
in weeks not years. So medical
intervention is better targeted**



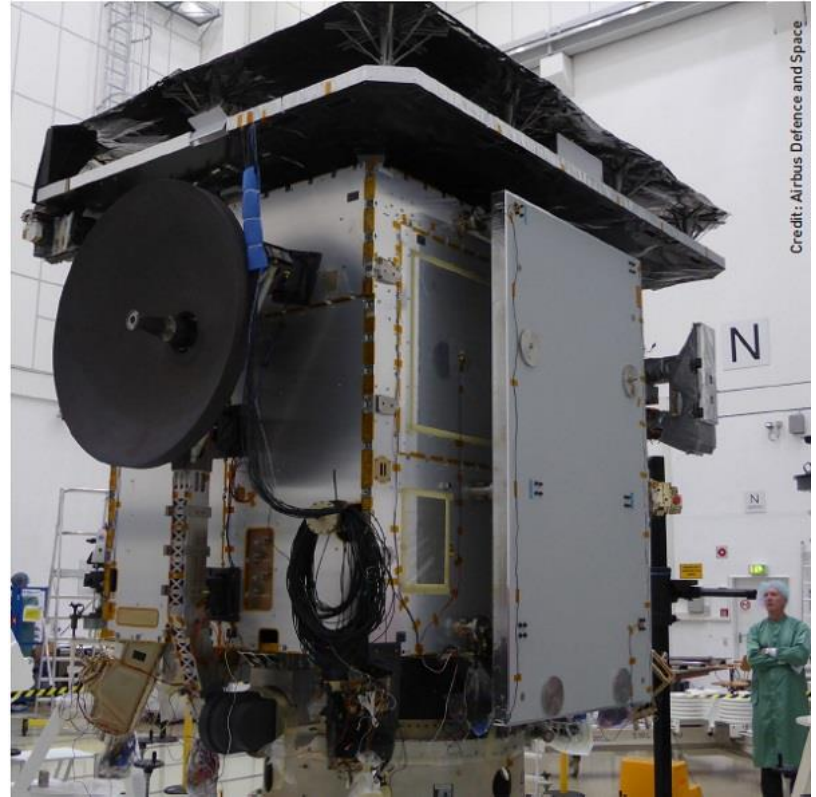
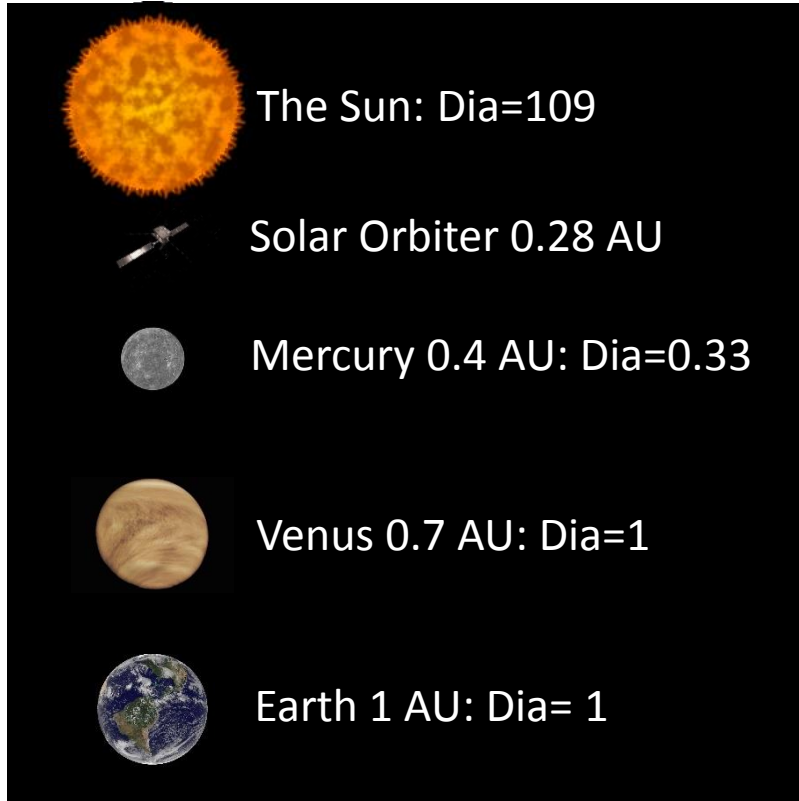
Tessella's part on Solar Orbiter

Fundamental AOCS requirements

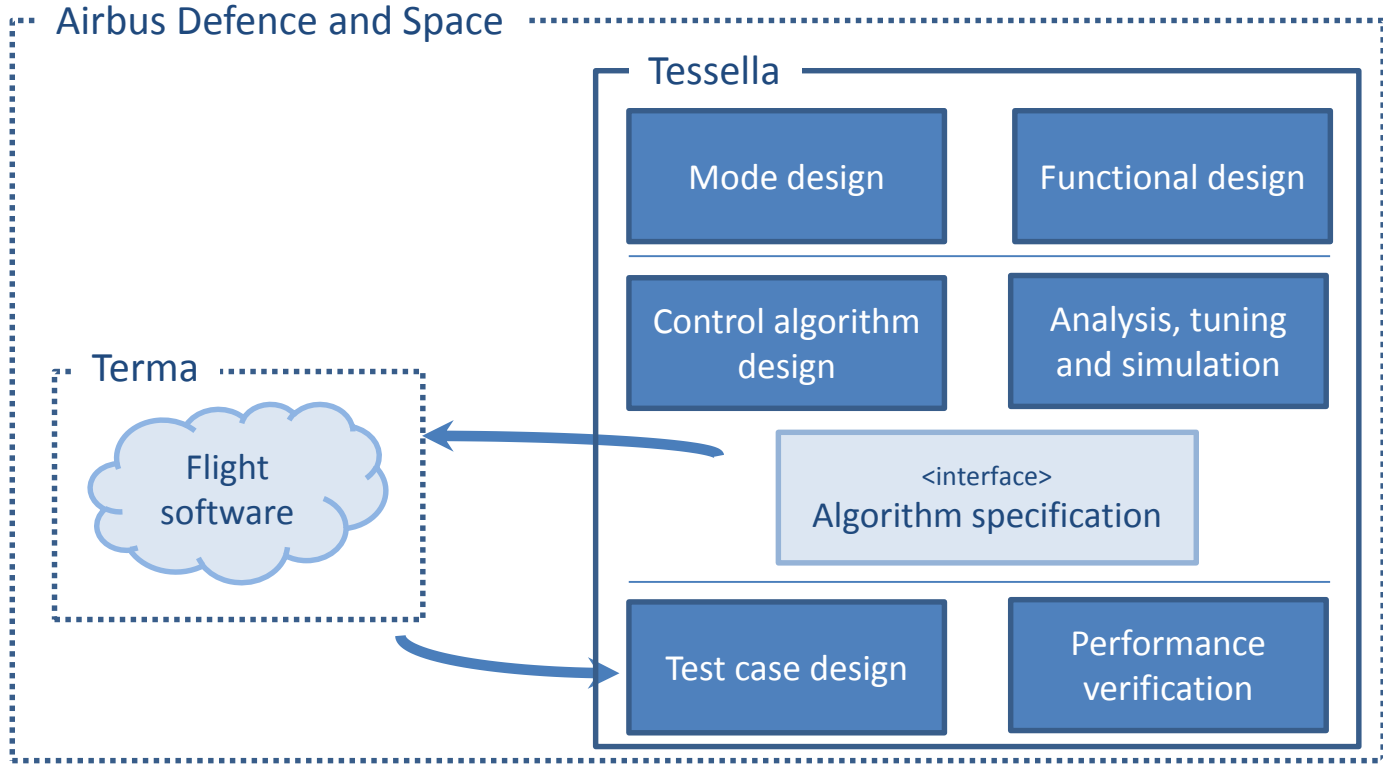
- Get it where it needs to be
- Point it in the right direction
- Keep it safe



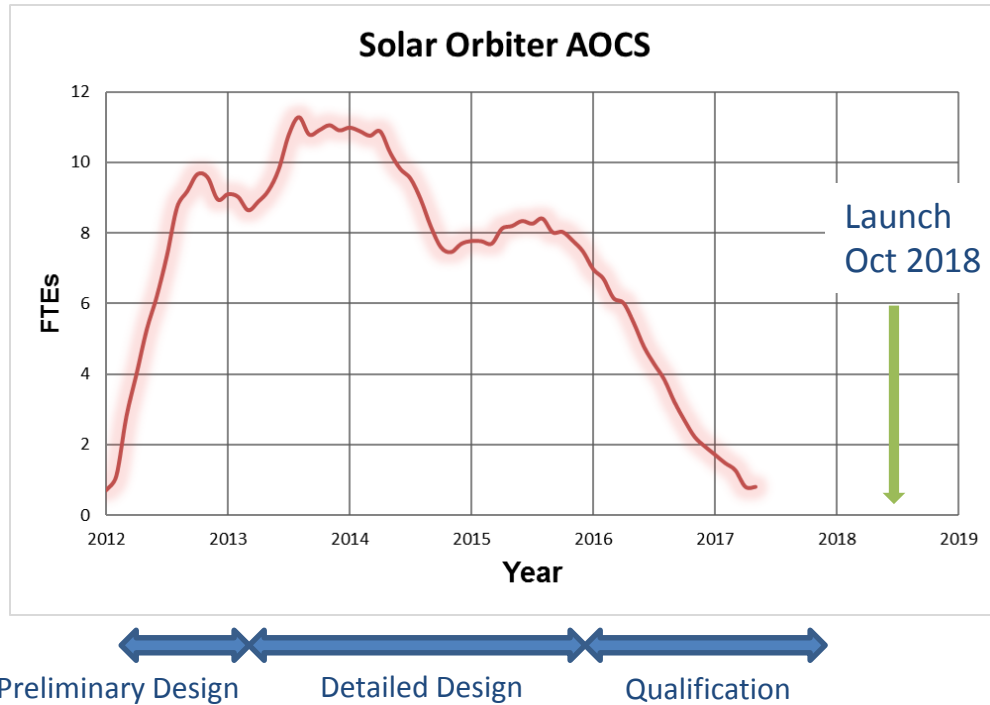
Scale



Scope



Tessella's Part in the AOCS Subsystem



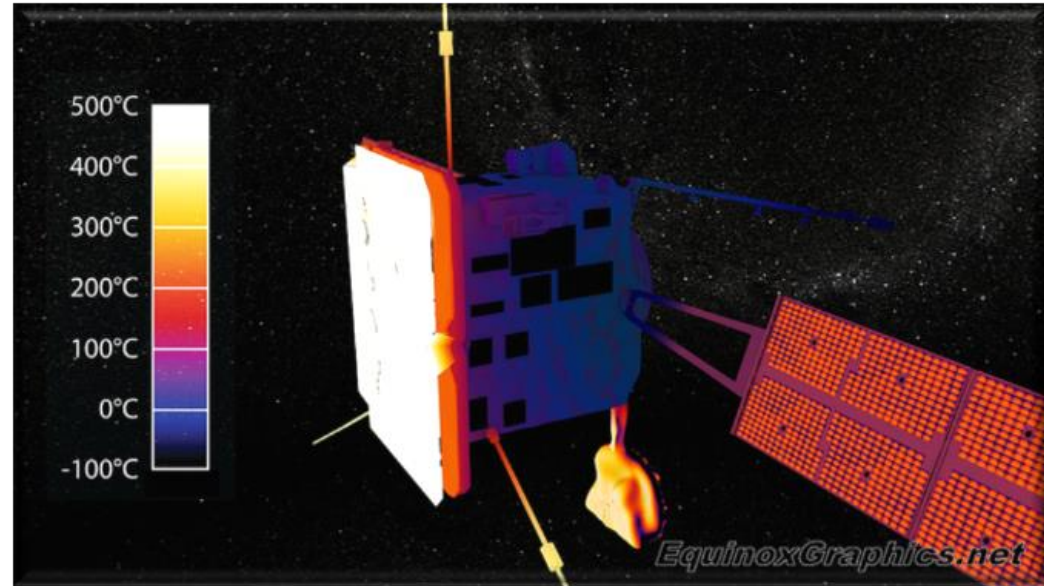


Control Engineering with Matlab & Simulink

*Andrew Pollard
Mathematical Modeller & Algorithm Developer
Tessella Ltd.*

Key Engineering Challenges

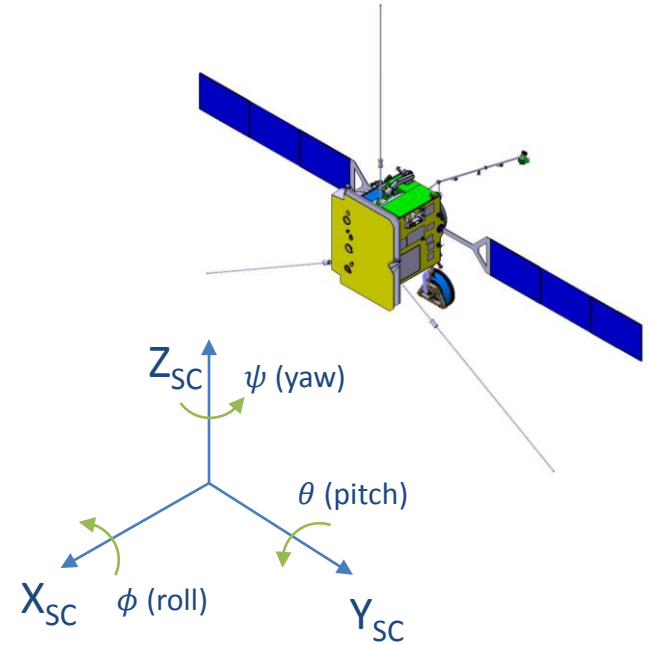
- Very extreme environment close to Sun
- Sun shield must remain pointed towards Sun, otherwise the heat will destroy the spacecraft
- Need to achieve precise trajectory for gravity assist manoeuvres



The Solution

AOCS: Attitude and Orbit Control Subsystem

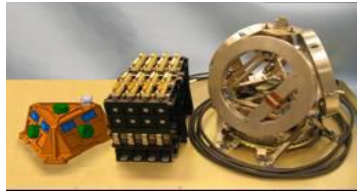
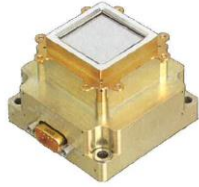
- Autonomously control angle of rotation around 3 axes to keep spacecraft correctly oriented and execute ground-commanded manoeuvres
- Perform orbit correction manoeuvres with thrusters
- A critical subsystem!



Spacecraft AOCS Hardware

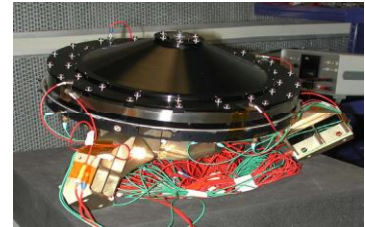
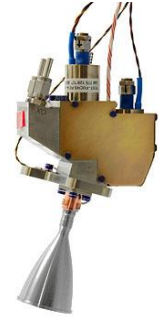
Sensors

- Fine Sun Sensor
- Star Tracker
- Inertial Measurement Unit

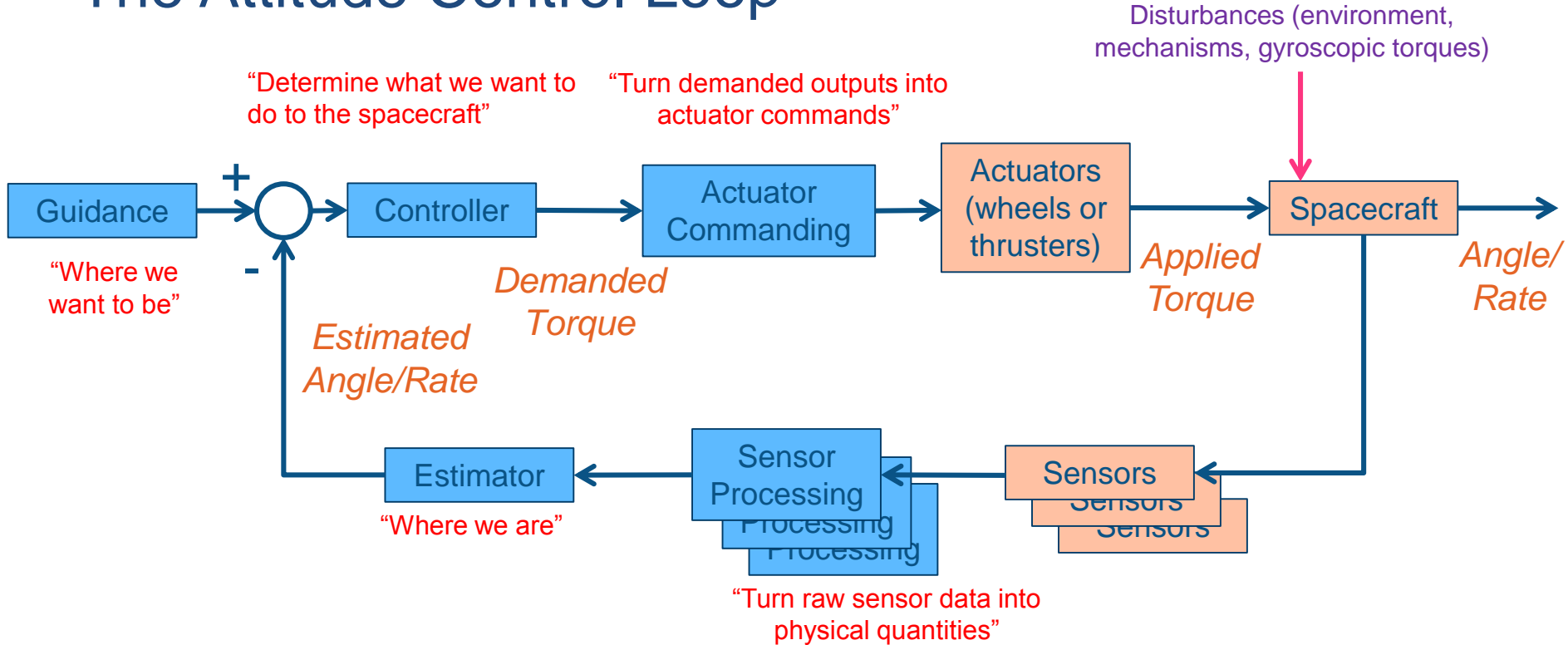


Actuators

- Reaction Control System (thrusters)
- Reaction Wheels



The Attitude Control Loop



Design Challenges

- Very stringent autonomous pointing requirements for making scientific observations:
Equivalent to pointing at this screen for 10 seconds... from Greenland!

Applicable  MathWorks® tools:

MATLAB & Control Systems Toolbox

- Flexible modes of appendages must not be excited

Control Systems Toolbox
& Signal Processing Toolbox

- Very limited fuel

Optimization Toolbox

- Complex system to model

Simulink

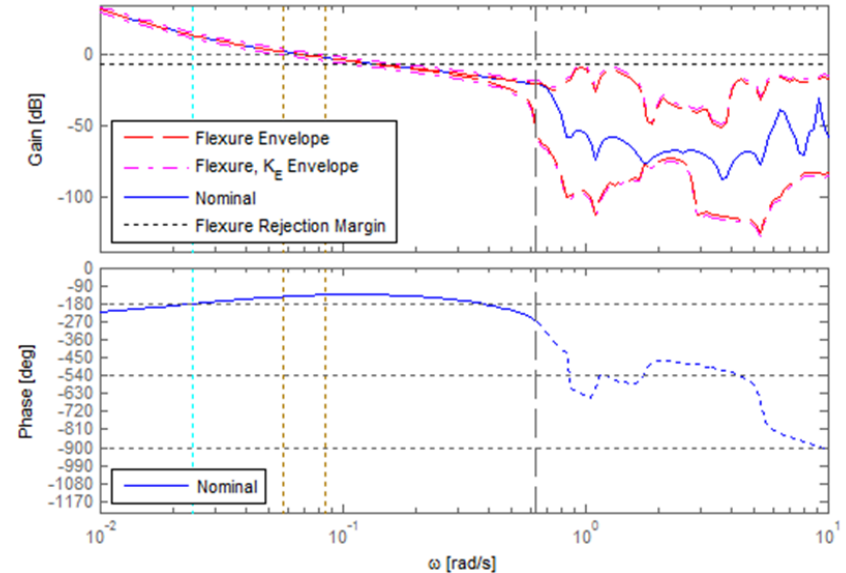
Autonomy

- “Safe modes” of AOCS need to be fully autonomous to recover quickly from hardware failure
- Any ground intervention occurs slowly – can take ~ 10 minutes for signal to reach spacecraft
- Up to 70 days no comms at all during solar conjunction
- Required orbit corrections calculated by ground operations team, but manoeuvre is autonomous



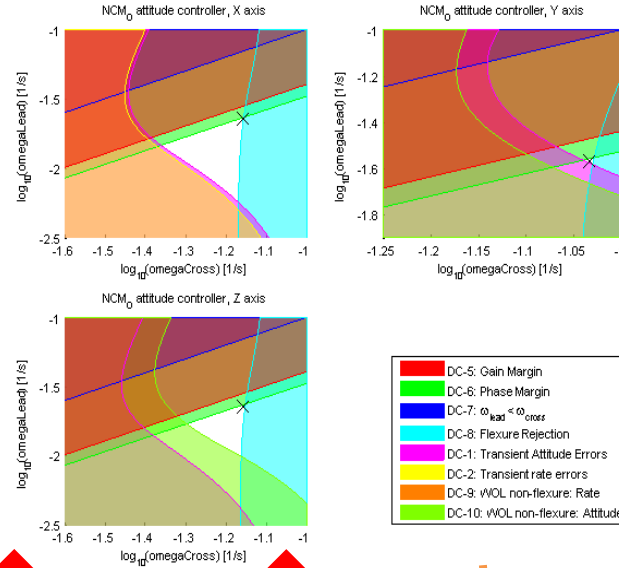
Controller Design and Tuning

- Control Systems Toolbox used to compute envelope of frequency responses in presence of uncertainty and variability.
 - *Ensures spacecraft is stable with enough margin*
 - *Robustness*
- Signal Processing Toolbox for candidate flexure filters. Genetic algorithm to investigate parameter improvements



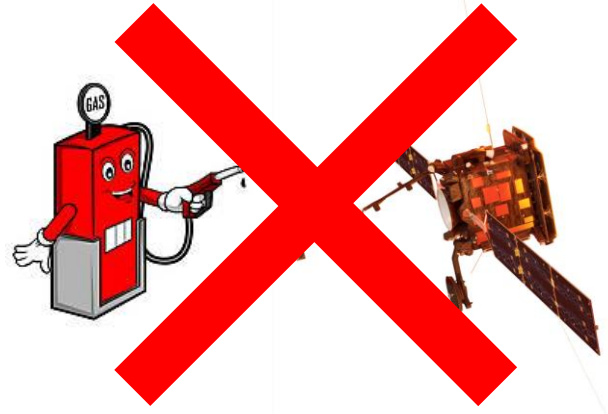
Controller Design and Tuning

- In-house tools developed in MATLAB for repeated tasks, such as:
 - Constraint & sensitivity analysis
 - Automated controller tuning
 - Reporting of analysis results
- Allows rapid response to changes in inputs



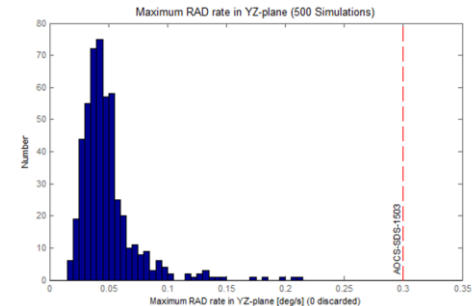
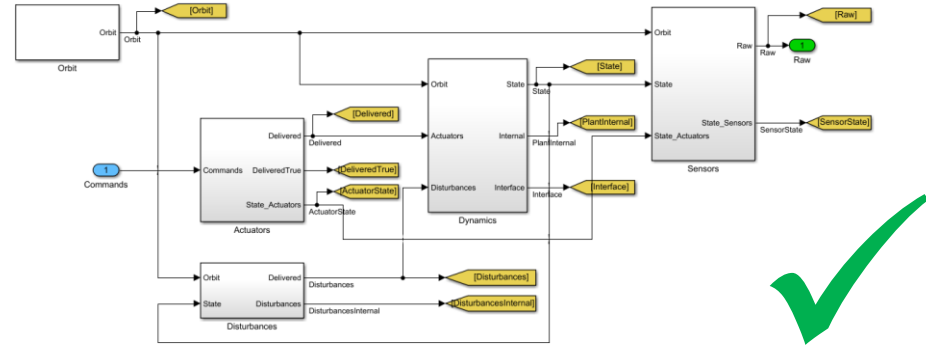
Controller Design and Tuning

- Optimization toolbox for thruster modulation proving 6-D control
 - Given force and torque demands, determine which thrusters to fire and for how long
 - Minimise fuel consumption



Controller Design and Tuning

- Simulink for modelling full control loop, including hardware models
 - Rapid prototyping and design trade-offs
 - Verification of performance and robustness of control algorithms via Monte Carlo campaigns
 - Simulation of specific scenarios



Key Benefits of MathWorks-based Solutions

- Control Systems toolbox for controller design
- Optimization toolbox for thruster modulation
- Simulink for modelling & simulation of full system

Benefits

The industry benchmark. Nothing else comes close for control engineering

Attitude control will use only 40 kg propellant in 10 years

No other tool gives us the multidomain simulation capability and block diagram environment in a way that is scalable to represent complex systems. That is why we use Simulink.



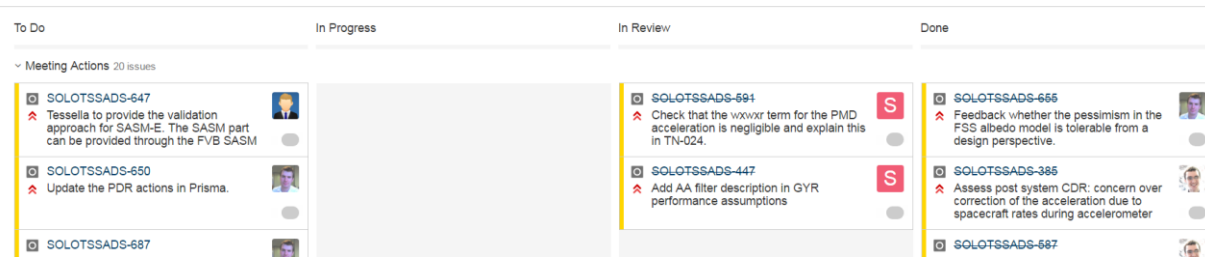
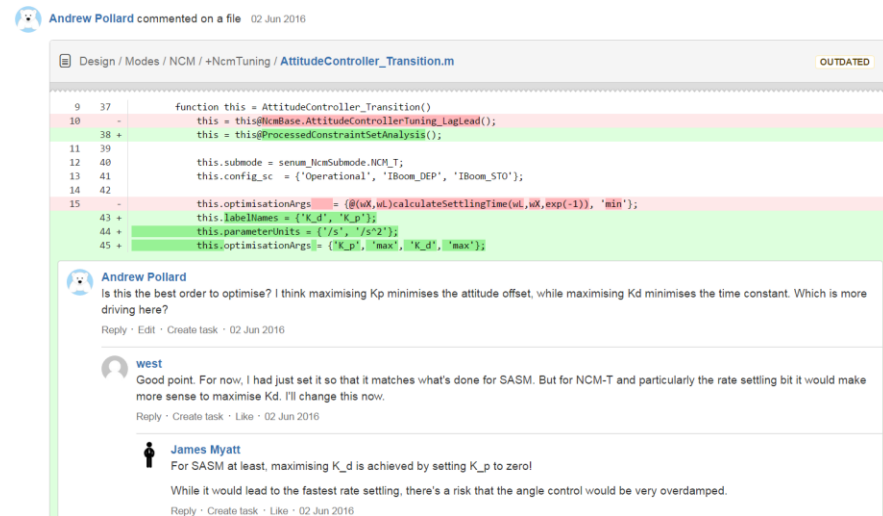
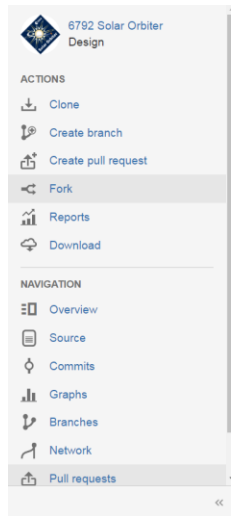
Integrating MathWorks into Large Projects

Further Challenges

- Schedule
 - Changing the launch date is major!
- Knowledge transfer in a changing project team
- Large-scale system design problem
 - SW alone has 100s of tuneable parameters
 - Cannot be held in the head of 1 person!

Running the Project

- Very large collection of MATLAB code for long-term internal use by a large team
- Rigorous software engineering practices & tools appropriate for maintaining this code:
 - Bitbucket for distributed Git version control to promote code review, linked to CI server
 - JIRA Issue Tracking System linked to version control
 - TeamCity Continuous Integration for automated tests, and long-running analyses / simulations



Benefits of Continuous Integration

We used continuous integration to:

- Automatically run unit tests & integration tests daily to check impact of code changes
 - Help with configuration management of delivered files
 - Run simulation campaigns on a server at the press of a button
 - Run lengthy analyses and enable configuration management of the results
- Improved response time & verification

The screenshot displays a CI/CD dashboard for a project named '6792 - SOLO'. The interface includes a navigation bar with 'Projects', 'Changes', 'Agents', and 'Build Queue'. The main content area shows a list of build configurations under the 'Overview' tab. The configurations are grouped into categories: Experimental Builds, Generic Functions, Simulations, and Solar Orbiter AOCS. Each configuration has a status indicator (e.g., '2 successful', '1 failing', '10 successful') and a 'Run' button. The 'Solar Orbiter AOCS' section shows a 'CAS Checks' configuration with 'Tests: 6' and 'Pending (8)'. Below this, there are two build entries for the 'develop' branch, one with 'Tests passed: 3' and another with 'Tests failed: 19, passed: 5283'.

Object-Oriented Programming in MATLAB

- Improve traceability of a parameter by storing metadata in an object, e.g.
 - where the value is documented
 - in which database version was it last changed
 - which program calculated it, etc.
- Automatic unit conversions reduce the occurrence of mistakes & hardcoded numbers
- Other uses of OOP included standardising how tuning & analysis functions are used
 - Easy to learn how to update documents

```
>> params.Design.SASM.Objective.LOS.sigma_ang_ctrl_farSun
ans =
    ParameterValue
        name: Design.SASM.Objective.LOS.sigma_ang_ctrl_farSun
    design ref: calculateSASMPointingObjectiveLOS
    reference: SASM Tuning and Stability Analysis (SOL.S.ASTR.TN.00373 2 draft)
        source: Objectives / DesignDB_SASM v4_01.xml
        version: 4.1
        author: TESSELLA
        status: Derived
        datatype: double

value [rad]:
0.0116

value [deg]:
0.6655
```

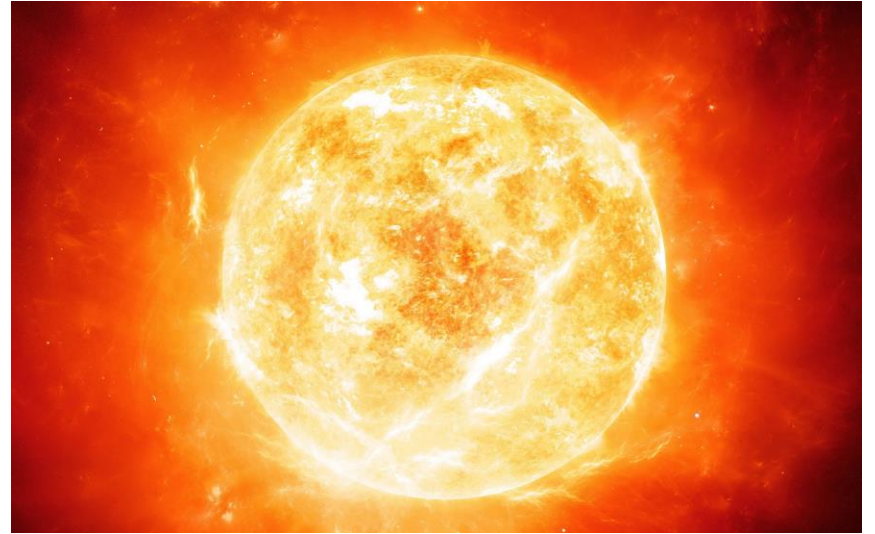

Lessons Learnt



- Results of complex analyses require high level of traceability
 - E.g. “Which parameters were used to produce these results from 2 years ago?”
 - Traceability requires configuration management
 - Continuous integration supports this
- Review of code, models & analysis has high value even if not deliverable
 - Everyone’s work is reviewed, and everyone reviews work
- Document your modelling assumptions
 - Turn into tests where possible

The Project Today

- Tessella's key deliveries are complete
- Detailed testing of AOCS algorithms being carried out by Airbus DS; we continue providing support
- Next stop... **THE SUN!**



Summary

- Solar Orbiter is an exciting ESA mission at the forefront of science, and a very complex engineering challenge
- Tessella made good use of MATLAB & Simulink to develop the algorithms for one of Solar Orbiter's key autonomous control systems
- Supporting tools and good software engineering practices were also used to get the best out of MATLAB on a large project, and these practices can be used in other domains



Further information

- MATLAB File Exchange
www.mathworks.com/matlabcentral/fileexchange/
- Solar Orbiter
sci.esa.int/solar-orbiter/
- Tessella
Come and see our stand at the expo!
<https://tessella.com/>
- MathWorks Training Services
www.mathworks.com/services/training.html



Questions