Slutseminarium, NRFP omgång 3

2018-11-15

SATELLITE SYSTEMS

Attitude Control of Spacecraft with Flexible Appendages

dnr: 104/15

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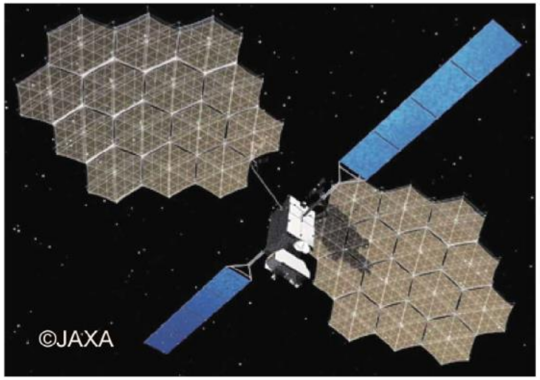
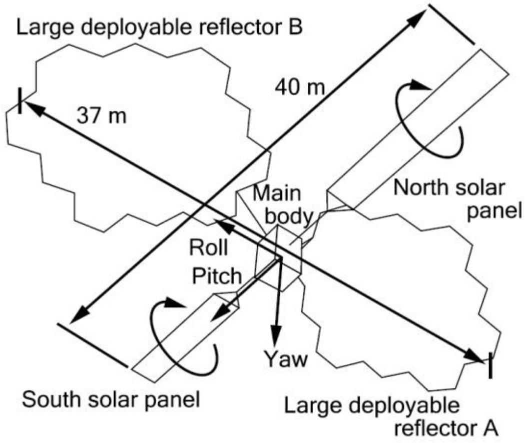
Outline

- Project Overview
- Background
- Summary of Project Results
- Master Thesis Continuation
- Conclusions

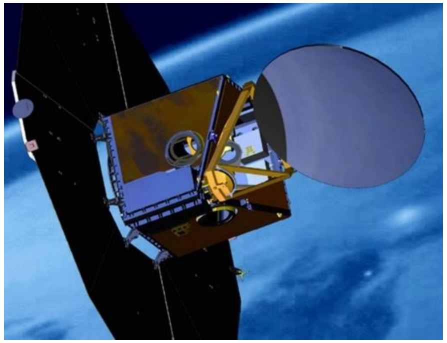
- Project was defined with Linköping University
- Purpose of project has been to investigate performance limitations for the attitude control of satellites with flexible appendages
- Propose and analyze new and better methods with the purpose to improve the attitude control performance
- Secondary objective
  - Provide an opportunity to for OHB Sweden to familiarize with modern control design methodologies and to arrive at a more efficient design process





History of SSC/OHB Sweden designs

Early Swedish satellites could be treated as rigid bodies	Flexible solar panels on SMART-1 was a fundamental performance limitation and required special analysis	Small GEO and EDRS-C: Larger solar panels and propellant sloshing	Electra: Even larger solar panels resulting in significant performance limitations



Modeling of flexible dynamics not necessary for attitude control design.

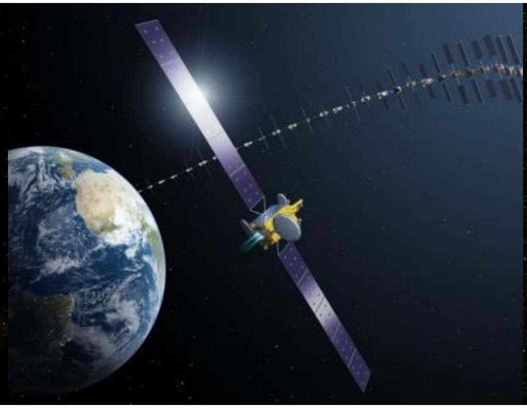
Design methodology developed based on classical control design techniques with straightforward investigation of robustness.

Need to investigate if new control design techniques can lead to improved performance.

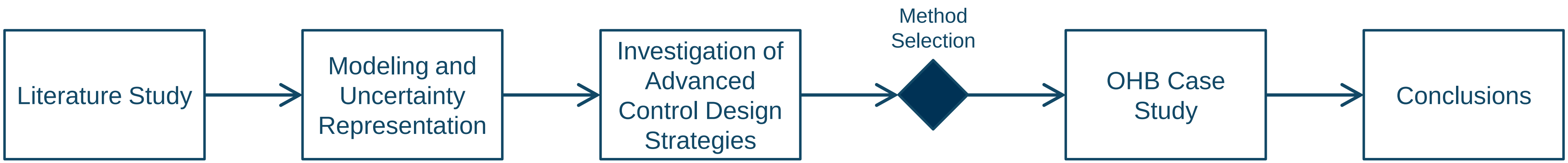
Trend in Attitude Control

- Electric Propulsion is becoming more and more common and is also one of the key competence areas of OHB Sweden
- All such missions will have relatively large solar panels. Especially in for the different configurations studied for the Electra telecommunication platform developed by the OHB Group
- Flexible dynamics are also an essential ingredient in the analysis associated with different Active Debris Removal studies or with exploration missions to the outer solar system
- Customer demands tend to increase in terms of proving stability and performance in the presence of substantial system parameter variation and uncertainties (so called Robust Stability and Performance)

Need for a systematic and efficient design process based on modern multivariable Robust Control methodologies.

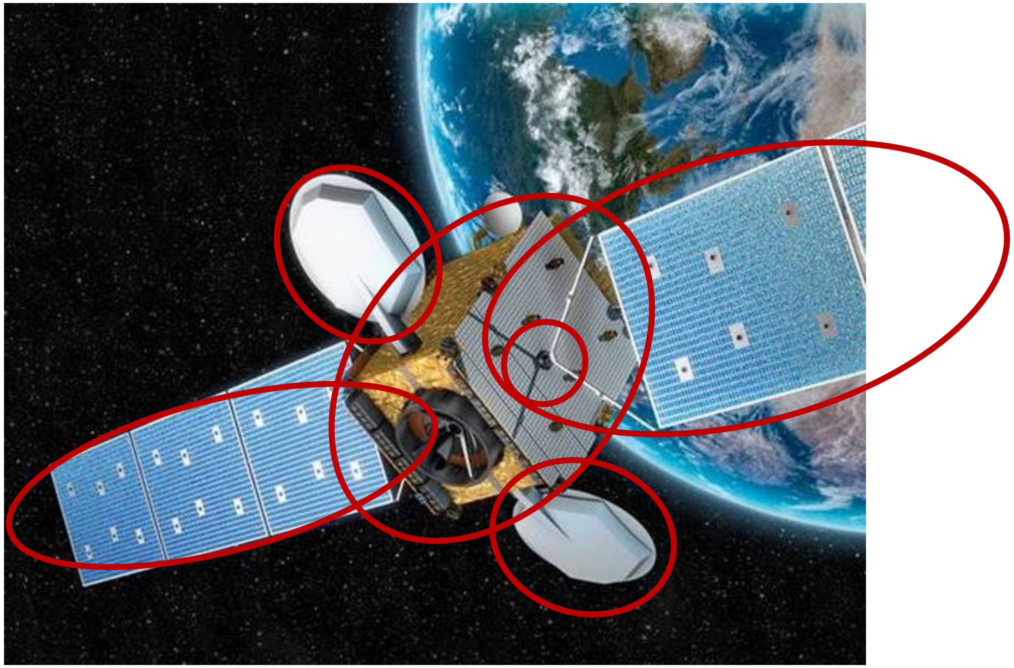



Project Outline

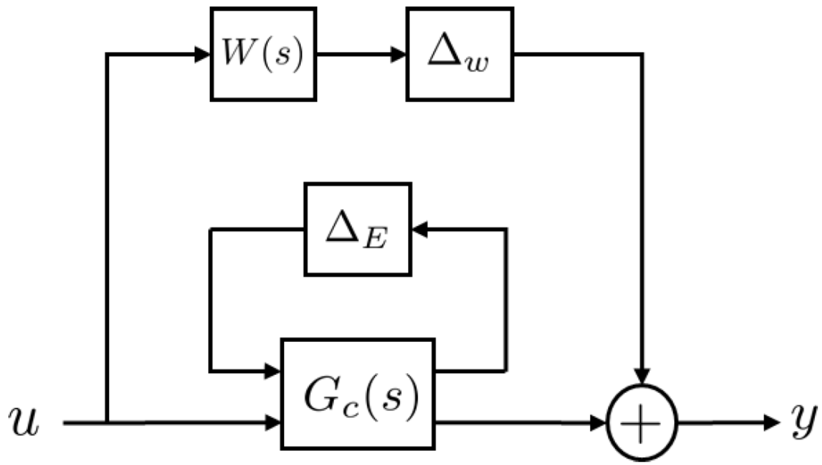


Study Model

- Flexible appendages. E.g. solar panels and antennas
- Solar panels can rotate
- Rigid central body with collocated sensors and actuators
- Significant uncertainties in the flexible dynamics:
    - Eigen-frequencies
    - Damping factors
    - Dynamic coupling
    - Mass properties



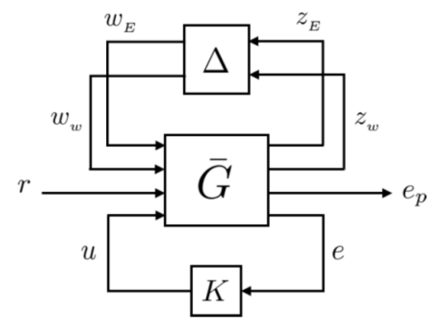
Modeling and Uncertainty Description



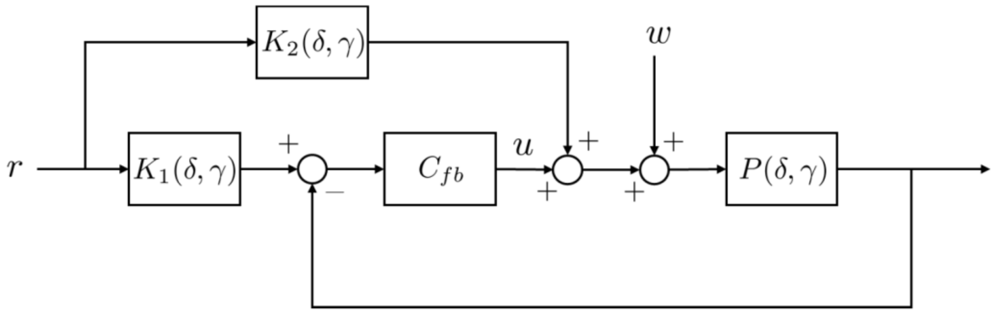
- Standard modal model description used as starting point
- Partitioning of the dynamics into
  - Controlled flexible modes
  - Residual flexible modes
- Uncertainty Description
  - Neglected (residual) modes treated as uncertainty
  - Parametric uncertainty of controlled flexible modes
  - Demonstrated how the uncertainties arising from rotation of the solar panels can be treated as a vertex bounded representation - allows for gain scheduling control
  - Complete uncertainty here covered by a bound in the frequency domain

Control Design Methods and Selection

- Robust Control Design (µ-synthesis)
  - Guarantee robust stability and performance
  - Closed loop performance specifications in the frequency domain
  - Find controller that is ”optimal” under the constraints of the structure of the model uncertainty
  - Advantage: Powerful way to specify performance criteria
  - Drawback: May be too conservative and may have difficulties in generating solutions. May lead to high-order controllers.



- 2DOF Collocated Output Feedback
  - Gain-scheduled control
  - Robustrly stabilizing controllers
  - Based on H-infinity norm minimization
  - Performance through reference model following
  - Advantage: More straightforward
  - Disadvantage: No clear possibility to take modal parameter uncertainties into account to guarantee performance



Robust Control Design is selected for its suitability for the type of system studied.

Design Results and Conclusion

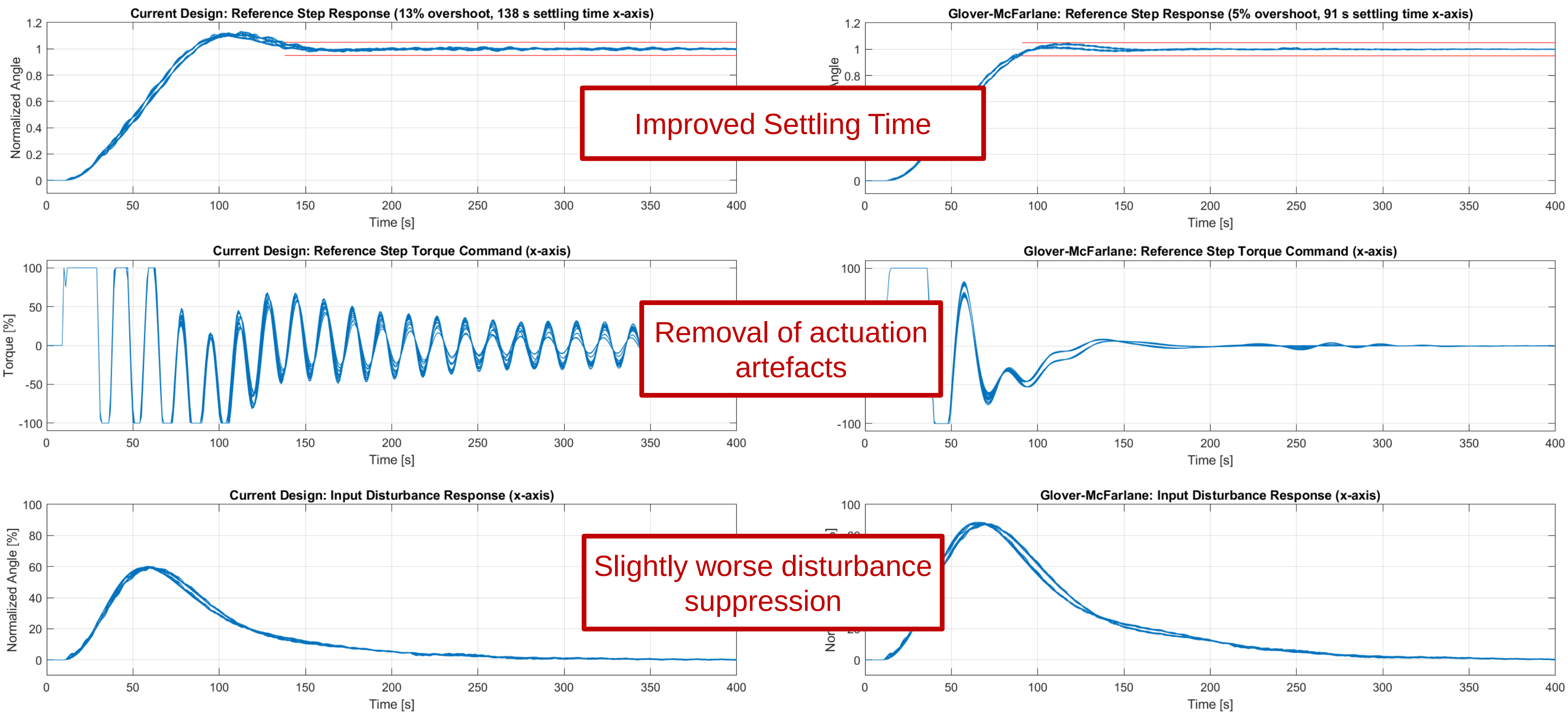
- Robust Control Design applied to a satellite with two solar panels that are possible to rotate
- Dynamics relevant for telecom satellite with large solar panels (typically a Electric Propulsion based platform)
- Extensive search was made in the parameter space of the selected design weights
- Results:
  - It was not possible to find robustly stabilizing controllers
  - Stabilizing controllers were possible to find in case the model uncertainties were reduced
  - Model uncertainty of dominating modes is too large to allow for robust control within the corresponding frequency region.
  - Lowest flexible modes are indeed a fundamental limitation of system performance
  - Possible way forward:
    - *Reduce model uncertainties (difficult for this type of systems)*
    - *Make use of on-board system identification (characterization of modal parameters) to allow for a ”cautious” cancellation of dominating modes (Has been done in NASA missions)*
- Way forward
  - We wanted to investigate further the possibilities to select weight functions to try to find solutions that guarantee robust stability and performance.
  - A master thesis project was defined with KTH to allow for further investigation

Master Thesis – taking one step back...

- Perform a first analysis with a simple system: SISO with one flexible mode
- Find out fundamental properties and investigate design methodologies
    - Mixed Sensitivity H-infinity (closed-loop specification)
    - Glover-McFarlane (open loop loop-shaping design similar to classical control design)
- When the right control architecture has been established
    - Move to MIMO system and successively add complexity to the dynamical model
- The work is almost finished and preliminary (positive) results have been obtained

Master Thesis – preliminary results

Benchmark | *Glover-McFarlane*



Conclusions

- Slightly improved performance
- The benchmark design is near-optimal
- However, the real advantage is that the NRFP-project together with the Master Thesis project provides
  - *An improved and fast design process*
  - *Systematic assessment of robust stability and performance margins*
  - *Familiarization with modern control design techniques*

For OHB Sweden this means improved competitiveness and better possibilities to meet future customer expectations.

Thank You!