And now, welcome to...

Technical University of Denmark - 8th November

DTU Mechanical Engineering
Department of Mechanical Engineering
Thanks to our sponsors

Software Partners:

Media Partners:
Some practicalities

Network: dtuguest

1. Accept the term
2. Add your email
3. Open your email and click activate
4. You’re online!
Why Robust Design?

“Robust Design is the designing of products, devices & production equipment so that their performance is insensitive to different sources of variation, e.g. manufacturing, external noise factors, degradation, etc.”

Design Parameters:
1. Length of legs
2. Angle of legs
3. Flatness of seat
4. Flatness of ground
5. etc....

Source: Skakoon (2009) – Exact constraint
Why Robust Design research?

Source: Harvard atlas of economic complexity [http://atlas.cid.harvard.edu/](http://atlas.cid.harvard.edu/)
Looking forward to four exciting topic areas!

Session 1: Innovation through Robust Design

Session 2: Simulation-driven Robust design

Session 3: Workshop: Trade-off avoidance

Session 4: Balancing Simulation & Prototyping
News and updates from the Robust Design group
First of all
Congratulations

Dr. Srinivasa Murthy Boorla
‘Zero Variation Manufacturing (ZVM) Strategy for robust products with zero perceivable variation’

April 16th 2017
DTU Robust Design Group

**... in facts and figures**

2017 – 2018

- 3 finished PhD projects
- 9 new publications
- In total 430 students in RD course
- 19 student collaboration projects
- 2 RD Days
- Before 2017
Ph.D. student: Kristian Bjarklev
Project: ‘Key Characteristics Management’
Identification and communication of relevant variation influences and KC in integrated device

Industrial Ph.D.: Nökkvi S. Sigurðarson
Project: ‘Trade-off avoidance in early design’
Enabling Robustness by trade-off avoidance and guidelines on trade-off archetypes

Ph.D. student: tbd.
Project: ‘Electro-mechanical Robustness’
Start: Mid – 2019

Industrial Ph.D.: will be named
Project: ‘Virtual Robustness Assessment’
Start: January 2019

Ph.D. student: tbd.
Project: ‘Simulation-driven RD for residual stress variation in casted brake parts’
Start: January 2019

Our students:
Siw Toft
Emil Traidl
Information on:

- publications from the DTU Robust Design Group
- DTU Robust Design education
- student projects in collaboration with industry
- Our workshop series – ‘Applying Robust Design’
- etc.
Sections K&P as well as MPP

... in the foyer
Basic challenge of Robust Design?
(despite its long history)

"Cost is more important than quality, but quality is the best way to reduce costs"

- Genichi Taguchi -
Basic challenge of (Robust) Design?

Good mechanical design implies a translation of **multiple functional objectives** (potentially contradicting) into a usually **complex assembly** of several interacting parts that can be **produced efficiently**.
Basic challenges of (Robust) Design?
But instead ...

A large focus is DIGITAL TWINs
Top 10 strategic technology trend in 2017 and 2018
“will exist for billions of things in the near future”
“Potentially billions of dollars of savings in maintenance repair and operation”

What does it offer for Robust Design?
(first fully CAD developed aircraft: Boeing 777 in 1994)
Basic challenges of (Robust) Design?

Heavily CAE driven design processes

- ... imply high modelling & computational cost (and still require specialist knowledge)!
- ... limit the possibility to explore full design space!
- ... result far too often in extremely long iteration cycles!

A coherent approach for actually using the available CAE / simulation capabilities along all design phases is lacking!
Basic challenges of (Robust) Design?

Heavily CAE driven design processes

... are the basis for our current robustness considerations (based on long existing/formal representations)

\[ M_{2D} = 3(4-1)-8=1 \]
\[ M_{3D} = 6(4-1)-18=0 \]

Important step to achieve Predictability, but what about Performance and Robustness?
‘Many good reasons for overconstraints’
(due to production constraints, performance requirements, expected reliability, etc.)!

A heavily over constrained design (with 7 inline main bearings) which nevertheless allows for optimal performance and product longevity.

BMW K1600 (2012)

Nimbus 750 (1934)

Kinematical correct main bearing arrangement until the engine is running. In service crankshaft bends and creates unintended overconstraints. If used hard enough, connection rods are known to break.

Courtesy: Thanks to Karl Hartmeyer, Coloplast A/S
A good understanding that variation is critical (also in design)!

But we are not checking how:

• to design for improved performance/longevity of our products during service.
• to develop more robust product concepts.

The state of the drunk at his average position is ALIVE.

But the average state of the drunk is DEAD.

Or in other words:

Image source: https://web.stanford.edu
“True efficiency is about more than a good energy rating. It’s about creating ‘lean’ machines which maintain high performance, produce no extra waste, and pass no hidden costs onto the user across their lifetime”

- James Dyson -


From design guidelines to a coherent approach for Lifecycle Robustness
Achieving Lifecycle Robustness

A coherent approach ...

... to design for ‘Lifecycle Robustness’

Working Definition:

“Designing products with a high and consistent performance as well as a predictable service life”

Source: Thomas J. Howard, keynote at Robust Design Day ’16
Achieving Lifecycle Robustness
A coherent approach ...

... to design for ‘Lifecycle Robustness’

Working Definition:
”Designing products with a high and consistent performance as well as a predictable service life”

Aims of using Robust Design:
• Increase predictability
• Improve performance
• Ensure robustness
• Predict inlife variation (wear / deterioration / etc.)
• Improve in-life behaviour
Robust Design? All well and good, but in our highly integrated products we necessarily have couplings and need to find a good solution for the resulting trade-offs.”

Paraphrased from discussions

Source: Keynote ‘Trade-off between complexity and robustness’ at Robust Design Day ’17
Achieving Lifecycle Robustness
A coherent approach ... ... which enables robustness, performance, and longevity

Five principles for ‘Lifecycle Robustness’:

1. ‘Consider contradictions’ – for the selection of robust concepts and product layouts.
2. ‘Decompose the design task’ – based on identified contradictions/interactions to prioritise efforts accordingly.
3. Understand the constraint status of your assembly and – ‘Deviate from exact constraints if beneficial’.
4. ‘Use simulations for complex trade-off decisions’ – to exploit non-linearities / balance performance and longevity.
5. ‘Focus on the right fidelity of models/analyses’ – to continuously check the usefulness of results in early design.
A coherent approach for Lifecycle Robustness

Choice of robust concepts and layouts

① ‘Consider contradictions’

Innovation by Robust Design

Choice of robust concepts with less contradictions

Designing robust mechanical assemblies

Use our understanding of contradictions to design more robust mechanics.

Darrell Mann
Systematic Innovation Ltd.
‘TRIZ for Robustness’

Nökkvi S. Sigurðarson,
Industrial PhD (Novo Nordisk / DTU)
‘Introduction to Contradictions Analysis’

DTU Robust Design Group
A coherent approach for Lifecycle Robustness Modelling & System decomposition

② ‘Decompose the design task’

What we usually do:
Analyse interactions once we have designed the full system (qualitatively/quantitatively)

Source: Pimmler and Eppinger (1994) - ‘Integration Analysis of product decompositions’

How to do it for new designs? (Look forward to the workshop)

Source: https://wwwavl.com
A coherent approach for Lifecycle Robustness

Exploit the compliance of parts

③ ‘Deviate from exact constraints if beneficial’

(or where it is unavoidable to economically ensure KCs)

Sometimes it is simple
A coherent approach for Lifecycle Robustness Variation-based System Design

④ ‘Use simulations for complex trade-off decisions’
(to balance performance and longevity)

Variation-analysis of sub-modules

- Parametrisation and DoE-/ space filling-based sampling

- Systematic evaluation of interactions / relevant parameters and fitting

- sensitivity studies (global/local) and systematic design improvements

Numerical wear analysis

- Simulation based on Archard (incl. discretisation of element/motion as well as cycle step extrapolation)

- Clearance variation study (wear behaviour in mechanisms)

- Mechanism Design guide
A coherent approach for Lifecycle Robustness
Variation-based component design

4 ‘Use simulations for complex trade-off decisions’
(to increase component robustness and longevity)

Numerical modal analysis
(for dynamic use cases)

• Efficient simulation in frequency domain.
• early model validation (for the mode shape prediction) by experimental model analysis.

• Identification and evaluation of stress concentrations on part level.
• Design & Robustness Improvements based on probabilistic analysis (Parametrisation / Variation Simulation / Sensitivity)

Dr.-Ing. Stefan Kemmler
Knorr Bremse, Systeme für Nutzfahrzeuge
‘Variation-based product design’
A coherent approach for Lifecycle Robustness

Early Validation activities

⑤ ‘Focus on the right fidelity of models/analyses’

Fitting of Simulation to available test equipment

Aims: • Reduce cost/efforts of a full system test for module supplier
• early proof of concept for validation of business case

Procedure: • Simulation of overall test set-up (experimental analysis on 6 DOF shaker)
• Identification system interactions
• Sensitivity to frequency changes

New PhD project starting in 2019
‘Simulation-driven RD for residual stress variation in casted brake parts’
Five principles for ‘Lifecycle Robustness’:

1. ‘Consider contradictions’ – for the selection of robust concepts and product layouts.
2. ‘Decompose the design task’ – based on identified contradictions/interactions to prioritise efforts accordingly.
3. Understand the constraint status of your assembly and – ‘Deviate from exact constraints if beneficial’.
4. ‘Use simulations for complex trade-off decisions’ – to exploit non-linearities / balance performance and longevity.
5. ‘Focus on the right fidelity of models/analyses’ – to continuously check the usefulness of results in early design.
Key take aways

- ‘hard to optimise your way our of a bad design’
  (good mechanical design is essential for robustness)

- ‘Many good reasons for overconstraints’
  (lack of approaches for actually considering them)

- ‘RD Simulation is essential for complex assemblies’
  (to increase robustness, performance, and longevity)

- ‘Understand the contradictions/interactions’
  (for a coherent RD process and lifecycle robustness)

„If we overconstrain it needs to be for good reason and the challenges well understood!“


Source: Thomas J. Howard, keynote at Robust Design Day ‘16
Key take aways

- ‘hard to optimise your way our of a bad design’
  (good mechanical design is essential for robustness)

- ‘Many good reasons for overconstraints’
  (lack of approaches for actually considering them)

- ‘RD Simulation is essential for complex assemblies’
  (to increase robustness, performance, and longevity)

- ‘Understand the contradictions/interactions’
  (for a coherent RD process and lifecycle robustness)

„If we overconstrain it needs to be for good reason and the challenges well understood!“

Thank You