

# Advanced Thermal Control Consortium

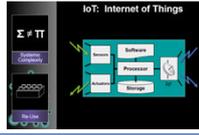
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## Technology trends

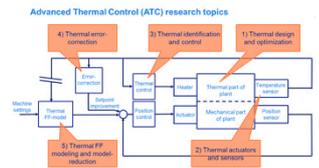
- Smart systems will be where the value is delivered
  - Modern mechatronics systems increasingly complex
  - Correct system architectures critical to performance and manufacturability
    - Hierarchical system decomposition (system<sup>x</sup> where x is increasing)
    - Ability to identify critical feedback parameters (or metrics) flowing to and from different sub-systems
  - Increasing complexity of systems paired with increasing reliability requirements - well structured, verifiable or automatically generated software

in the future advances in robotics will be significantly based on the rising complexity of mechatronic systems' Berthold Bauml , German Aerospace Center

## ATC Project Overview

- Industrial research on the field of advanced thermal control of high precision systems
  - advance the theoretical and applied approaches to design, simulation, measurement and compensation techniques





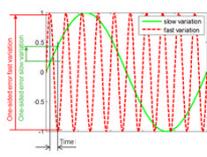
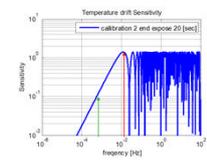






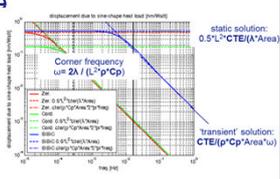

## Research Programme

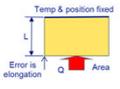
- Thermal Design & Optimisation
  - Transients more important for precision systems than steady-state effects
  - Metrology calibration at relatively high frequencies
  - Reduced sensitivity to slow temperature variations
  - Relatively high sensitivity for high-frequency variations

## Research Programme

- Thermal Design & Optimisation
  - Dimensions of the relevant structures shrinking
  - $f_{cal} \gg$  than the corner frequency at which the thermo-dynamics becomes pre-dominantly transient
  - Metrology calibration frequency in range where transient behavior dominant





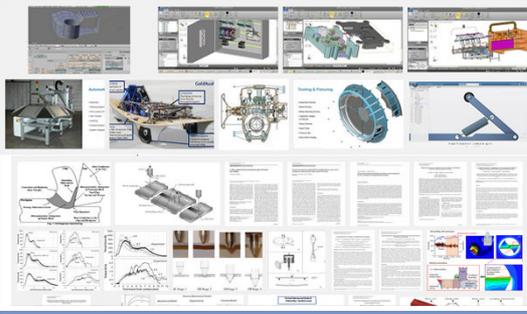
## Thermal Design & Optimisation

Mechanical modeling tools



Thermo-mechanical modeling tools





## Thermal Design & Optimisation

- Design Freedom**
  - New modeling & simulation approaches
  - Metrology for manufacturing
- Equipment Optimisation**
  - Resolution & speed
  - Process control
  - Dynamics
- Materials**
  - Structural integrity
  - Surfaces
  - Multi-material
  - Nanomaterials

**AM Challenges & Opportunities**

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## Thermal Design & Optimisation

- Next generation topology optimisation tools
- Starting point developments on so-called 'augmented adjoint sensitivities'\*
  - thermal modal basis used to speed up thermal transient optimization
- Improvements:
  - Mode selection
  - Integration of feedback-control

Courtesy TU Delft (Prof. Fred van Keulen)

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## Thermal Design & Optimisation

- Efficient and effective optimization tools to improve transient thermo-mechanics, by improving:
  - The geometry of the structure including position of coolant
  - The heat transfer coefficient of coolant.
  - The material properties, including material combinations

Time frame:	0 - 1e1	0 - 1e3	0 - 1e7	Steady-state
Obj:	1.101e-3	3.264	4.747	5.09 (at 1e7 sec)
Design:				

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## Research Program

- Advanced Identification & Control for Thermal Systems
  - "Overlay" error in photolith of order one nanometer
  - Thermal control next generation printheads increasingly difficult problem.
  - Advanced servo (or position) control of high-accuracy electro-mechanical devices long-standing and well developed competence
- Overlay/relative alignment not only determined by structural dynamics of mechanical physics and its position control, but dynamics of thermal physics and its control

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## Research Program

- Focus on advanced methods for:
  - experimental modelling (i.e. identification)
  - feedback control for thermal problems
- Advanced servo position control can be re-used and tailor-made to advanced thermal modelling and control
  - differences in time scales and spectral contents of the disturbances
- Experimental modelling of the plant "P"
  - feedback and feedforward control design
- Advanced inferential control

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## Research Program

- Next Generation Model Reduction
  - Create compact models that allow for fast and accurate simulations (time & frequency domains)
  - Suitable for controller design
  - Strategies for model reduction of complex systems
    - Coupling approaches
  - Address non-linear effects & parametric reduction

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## Overview

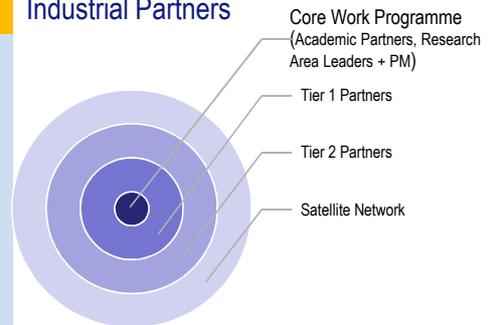
- Design rules & optimisation tools for module designer
  - Optimisation for systems under feedback control.
- Advanced methods for experimental modelling (i.e. identification) and feedback control for thermal problems.
- Model reduction including next generation techniques for complex systems.

Also:

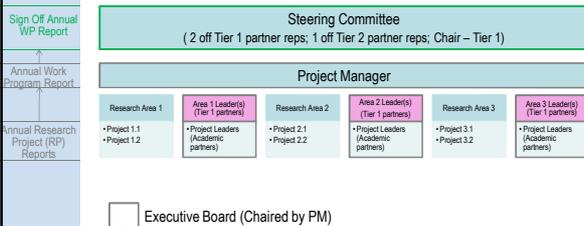
- Multivariable feedback control for thermal applications. Controller design methods.
- Systematic and effective tools for observer design.
- Thermal management of optical systems.

ASML FEI IBS VDI PHILIPS ccm TU/e TUDelft

## Industrial Partners



## Advanced Thermal Control Consortium



## Satellite Network

- Body of international expertise and interest in the field
  - Insight on developments within the generic research of the consortium.
  - Annual workshop attendance (incl. invitation to present).
  - Copy of annual report and cleared publications.
  - Preferred supplier status in regard to the project research activities.
  - Inclusion and access re any roadmapping activities.

Forum for sharing industry perspectives and academic developments.  
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