A Systems Perspective on Future Aircraft Engine Control

Dr. Wolfgang Horn

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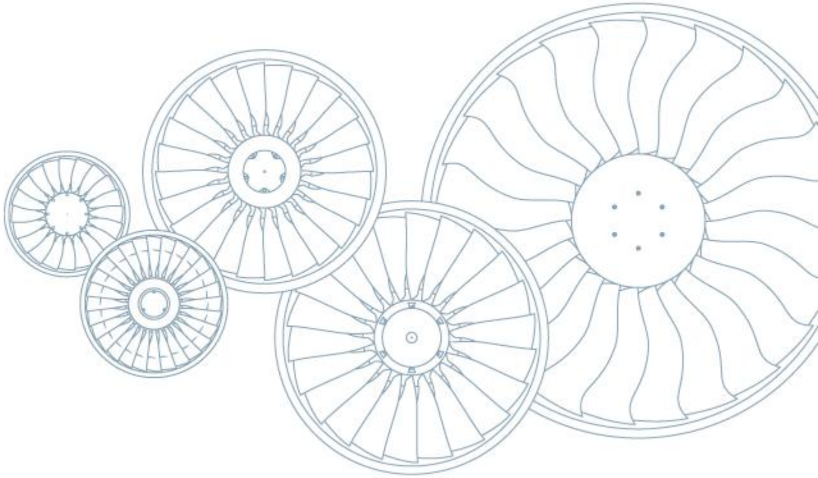


Overview

- High Level Objectives
- Model-Based Control
- Active Control
- Engine Condition Monitoring
- Challenges

High Level Objectives for Future Aircraft Engines

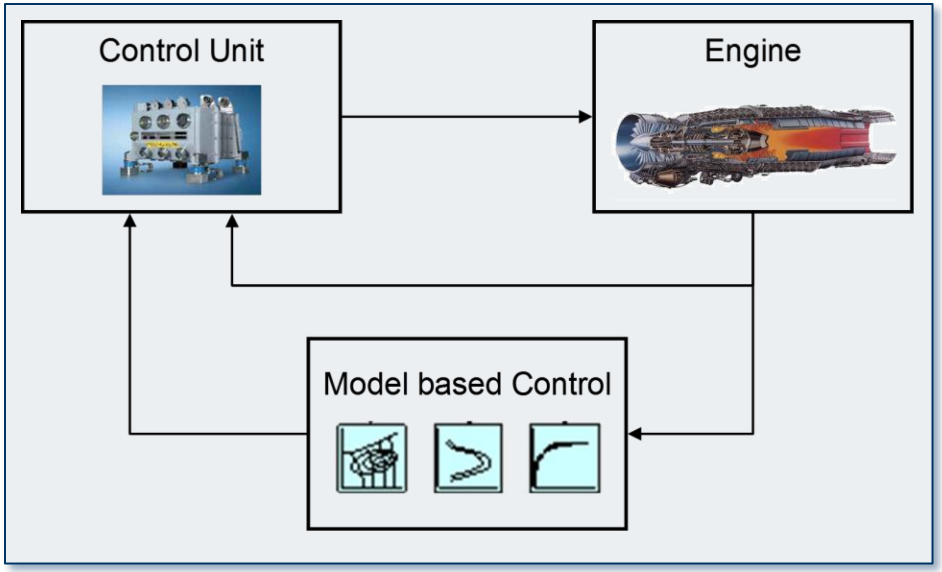
	Fuel Efficiency	Emissions	Affordability	Capability
ACARE 2020 Target*	-20% SFC	-80% NOx -10 EPNdB	Operating Cost Reduction	-80% Accident Rate
Implication for Controls	• Use existing margins • Optimize engine cycle • Adapt component characteristics	• Adapt component geometries • Control combustion process • Control noise	• Provide maintenance indication • Avoid secondary damages • Reduce life consumption	• Extend operational limits • Improve engine response • Avoid in-flight shutdowns

* Advisory Council of Aeronautical Research in Europe (ACARE),
Required aircraft engine contribution to meet 2020 air traffic vision

Exploiting Existing Operational Margins by Model-Based Control

Current control concepts

- Conservative design for worst engine in worst operating condition
- Control schedules not adapted to individual state and actual requirement
- Engine does not operate at its potential optimum



Approach of model-based control

- Identify the actual state of the engine
- Adapt model to individual engine
- Optimize performance within given limits
- Detect failures and substitute signal

➔ *Robust model and control*
➔ *Adaptive to individual engine*
➔ *Full thermodynamic simulation*
➔ *Powerful control hardware*

Improving Component Characteristics by Active Control

Active control approach

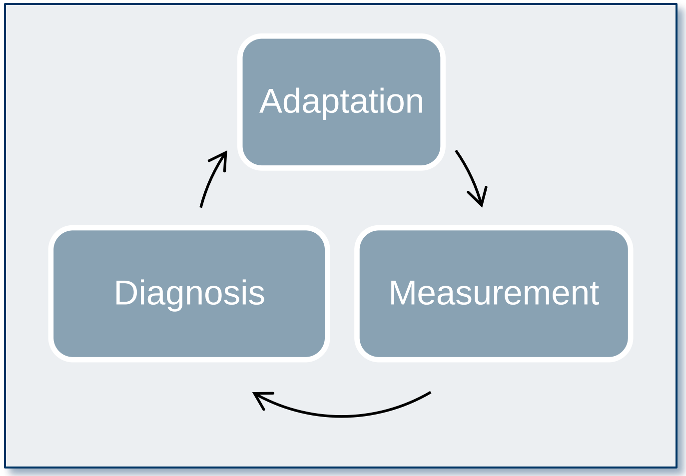
- Identify current condition by sensor or model
- Modify component behavior by actuators

➔ Enhance component characteristic with extended limits

➔ Optimized engine cycle design

Promising technologies include

- Active clearance control
- Compressor stability control
- Active flow control
- Turbine cooling air control
- Variable nozzle



ACC demonstrator with closed-loop mechanical actuation

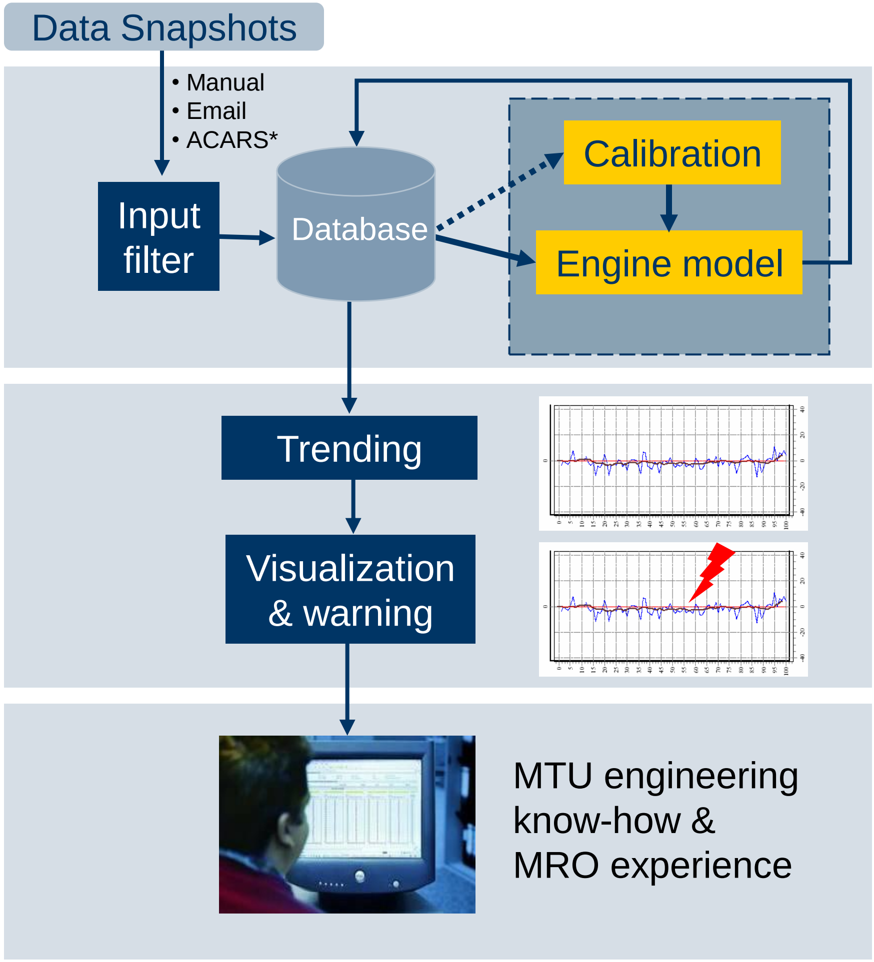
Reducing Operating Cost by Engine Monitoring

- Keeping the engine “in the air” is key interest for operators (traditional) and maintenance providers (Fly-by-Hour)
- Life and fuel savings can be achieved on the basis of diagnostic and prognostic models
- State of the art ECM allows for detection of incipient failures, avoiding secondary damages

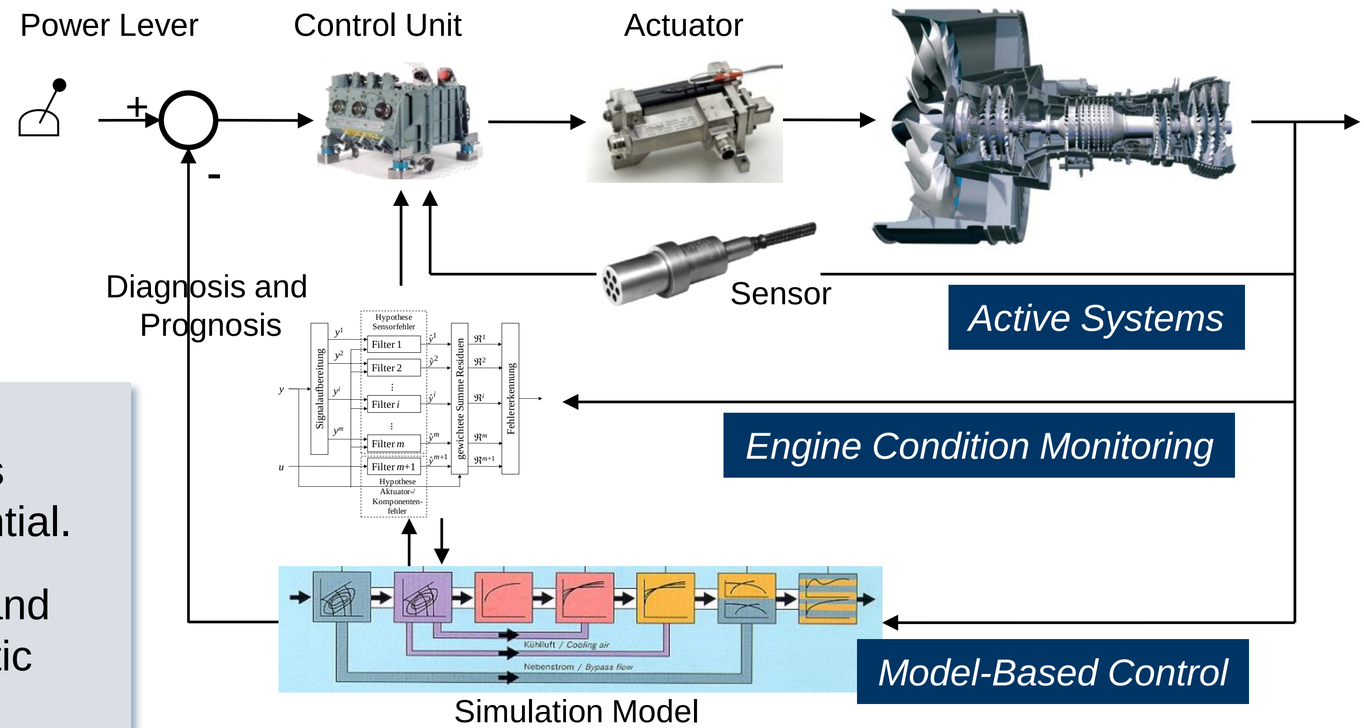
- Future trends:

➔ On-line diagnosis on component level

➔ Off-line improved monitoring (EGT margin, fuel burn analysis)



Integrating Control Components to an Intelligent Engine



Combining advanced control elements offers large technology potential.

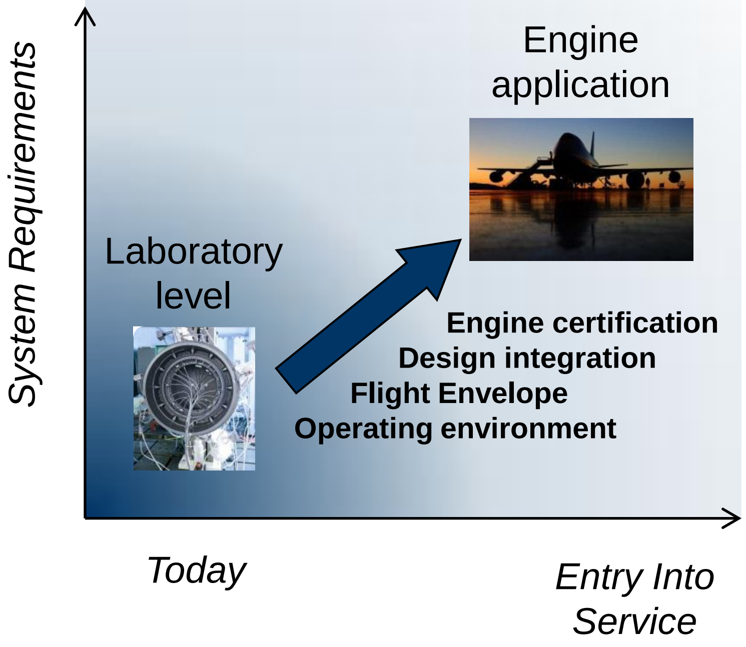
The basis is a robust and individualized diagnostic and prognostic model.

Perspective for intelligent sub-systems and distributed control architecture.

Challenges on the Way to Technology Readiness

- Meet life and reliability demands
- Reduce in-flight measurement uncertainty
- Reduce weight and size of actuators
- Advanced algorithms for model adaptation
- Increasing complexity of control architecture
- Integration of engine control and aircraft control
- Certification of control system with active and model-based elements

Roadmap of Advanced Controls Towards Technology Readiness



Conclusion

- Enhanced engine performance controls and diagnostics offer the opportunity to contribute to future air traffic demands.
- The use of models in the control loop is a promising way forward.
- Diagnostic algorithms still have development potential and might become a part of the control system.
- Technologies for active systems have been identified and developed on a laboratory level.
- Technology improvements will be required to reach certification readiness.