Active Turbine Tip Clearance Control Research

OA Guo
Intelligent Control and Autonomy Branch
September 16-17, 2015

Team

- NASA GRC Research and Engineering Directorate (L):
  - Communication and Intelligent Systems Division (LC)
    - Intelligent Control and Autonomy Branch (LCC)
      - OA Guo, Dan Vrnak, Jonathan Kratz
    - Optics and Photonics Branch (LCP)
      - Mark Woike
    - Vantage Partners, LLC
      - Jeff Chapman
  - Propulsion Division (LT)
    - Turbomachinery and Turboelectric Systems Branch (LTE)
      - Mike Hathaway
  - Materials and Structures Division (LM)
    - Mechanisms and Tribology Branch (LMT)
      - Margaret Proctor
- Industry Partners
  - TBD

Outline

- Why turbine tip clearance control?
- List of challenges
  - Tip clearance estimation and measurement
  - Engine dynamics
  - Tip clearance dynamic modeling
  - Benefits and trade-offs
- Turbine tip clearance modeling for future engines
  - Goals
  - Modeling assumptions
  - Future development
- Summary

Why turbine tip clearance control?

Turbine tip clearance is important …

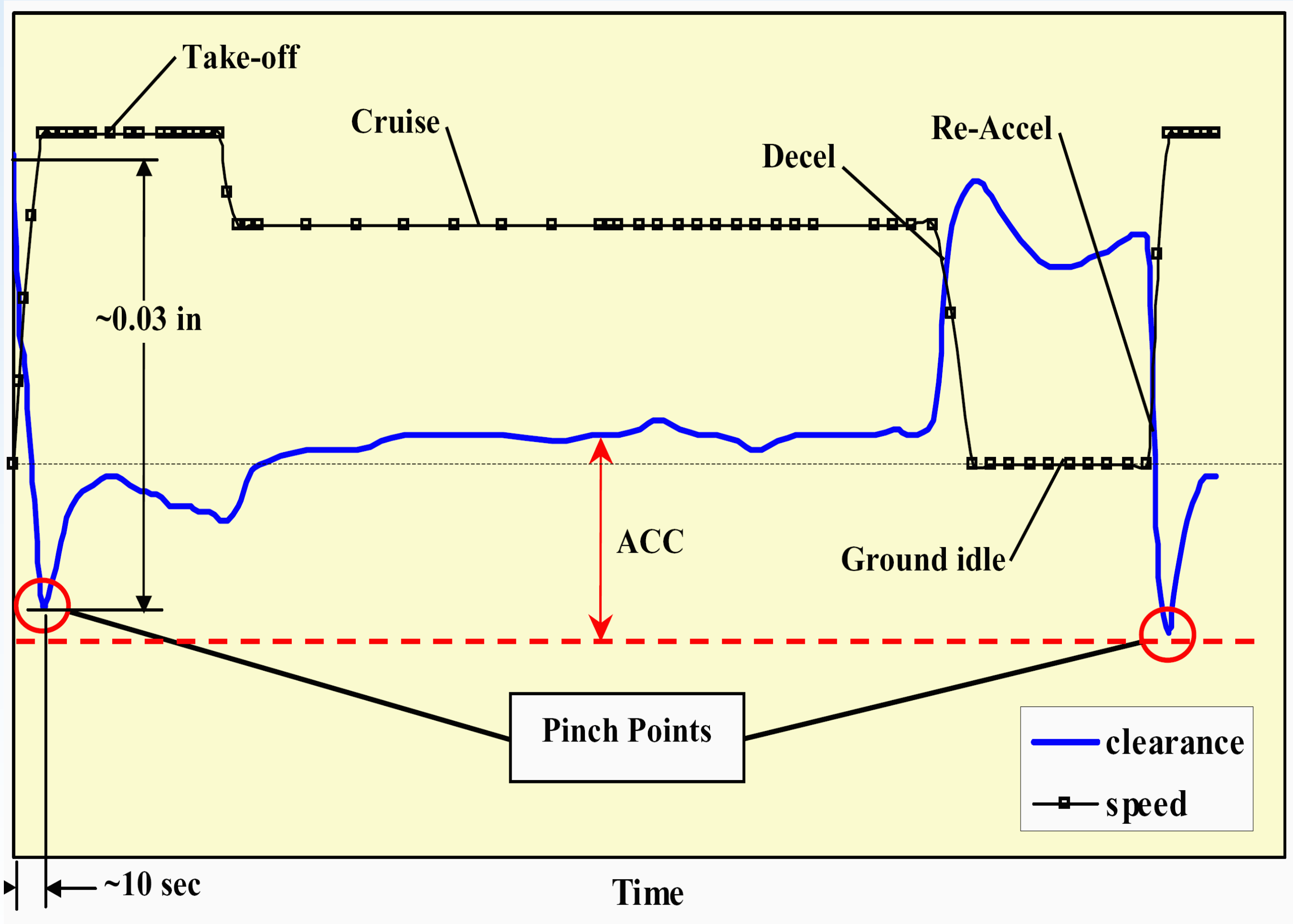
- Fuel efficiency is directly tied to turbine tip clearance
  - Roughly 1% increase in fuel efficiency for 10 mil decrease in turbine tip clearance for current large commercial engines
- Larger turbine tip clearance = Higher EGT
  - Roughly 10 ºC decrease for every 10 mil decrease
  - Higher EGT consumes engine life (LCF and others)

Tip clearance changes with…

- Engine aging
  - Turbine tip clearance changes over the life of the engine, typically 20-50 mils
- Engine dynamics
  - Engine accel and decel will change the tip clearance

Goal of turbine tip clearance control is to have a tighter control of the tip clearance at cruise condition while having a controlled mechanism to avoid rubbing during transient operations.

Typical tip clearance variations during operation



List of challenges in active tip clearance control

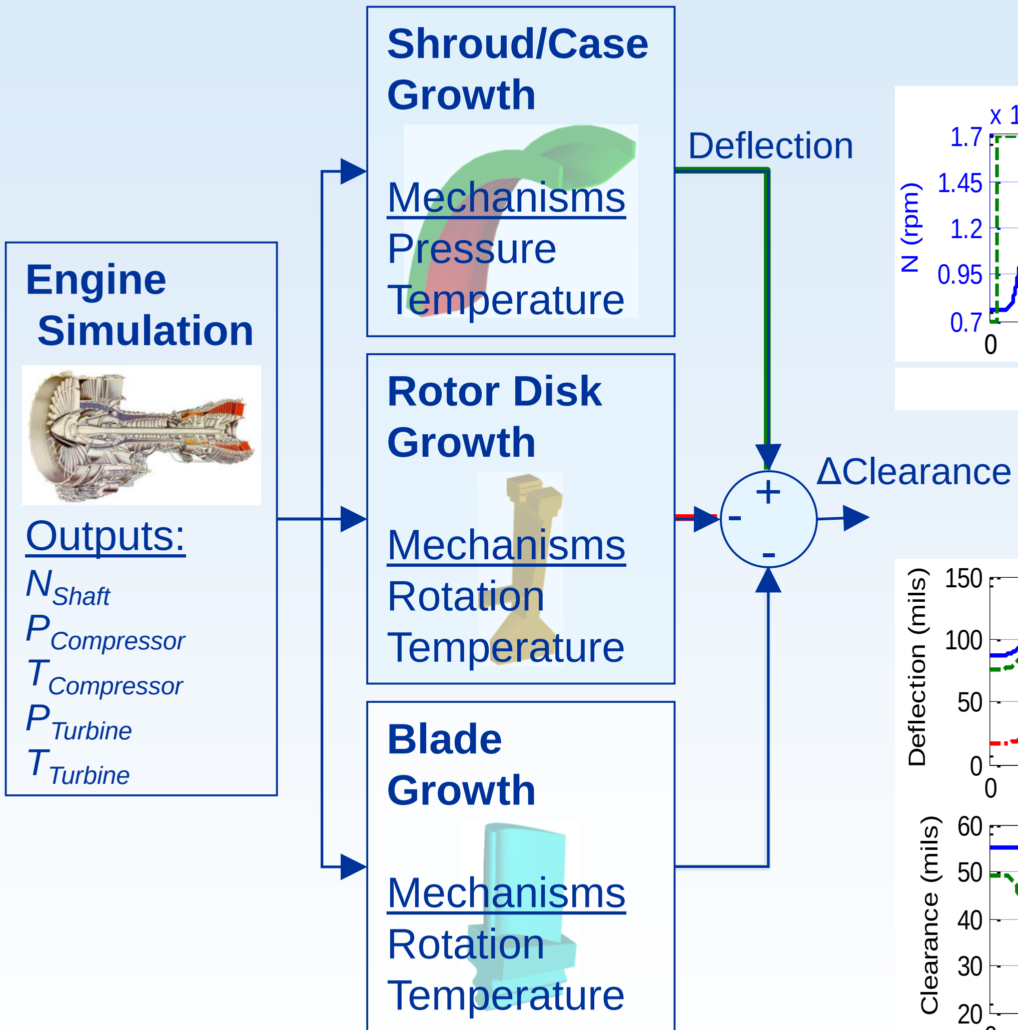
- Tip clearance estimation and measurement
  - New and degraded tip clearance
  - Measurement? Estimate?
- Tip clearance dynamics
  - Engine transient performance modeling
  - Tip clearance model based on engine transient
- Actuator and Control mechanism
  - Fast response mechanism
  - Control strategies
- Benefits and trade-offs
  - Can we quantify the benefit

Turbine Tip Clearance Modeling Goals

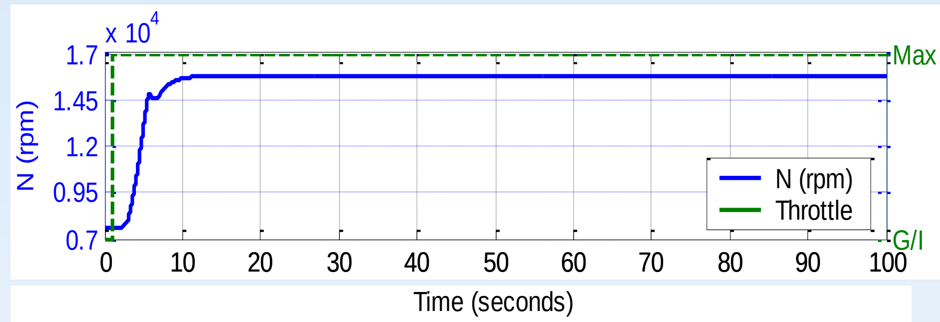
- Simulate the turbine tip clearance dynamic for the current engine
- Identify parameters needed for tip clearance prediction
  - Material property
  - Seal Configuration
  - Operating conditions (Temperature, Speed..)
  - Etc.

- Apply the model for future engine configuration such as N+2/N+3 to learn:
  - The parameters that would affect the tip clearance
  - Turbine tip clearance dynamic during the transient
  - Sensor and actuator requirements for advanced tip clearance control

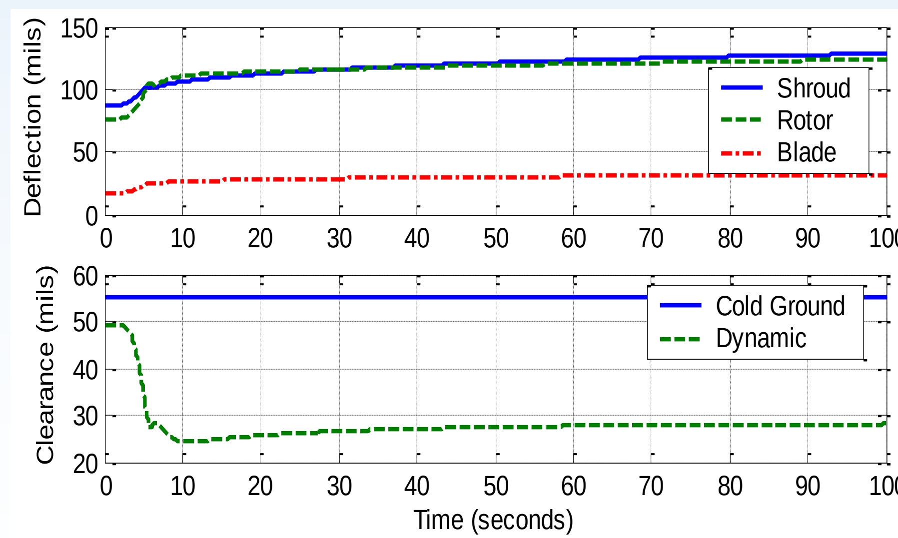
First Principles Based Clearance Model



Results: Throttle & Shaft Speed



Results: Deflections & Clearance

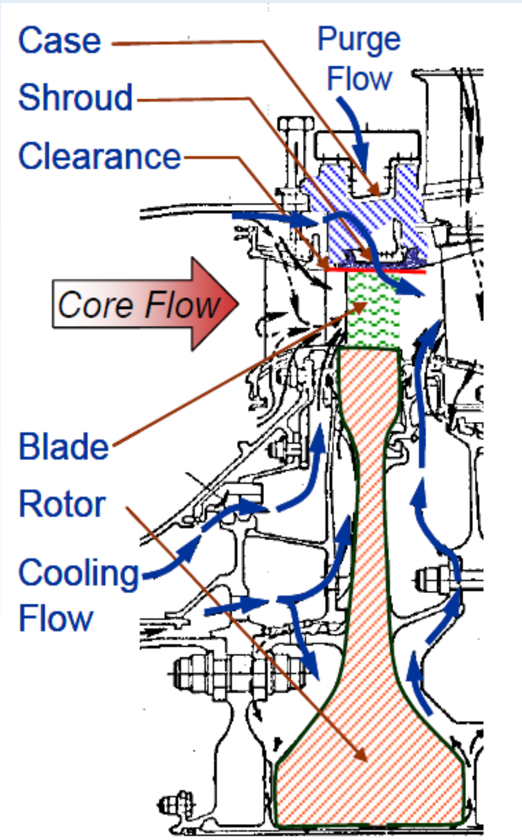


Turbine Tip Clearance Modeling Assumptions

- HPT blade tip clearance is primarily a function of deformation in 3 components

$$TC(t) = TC_{nominal} + (\delta_{shroud} - \delta_{rotor} - \delta_{blade})$$

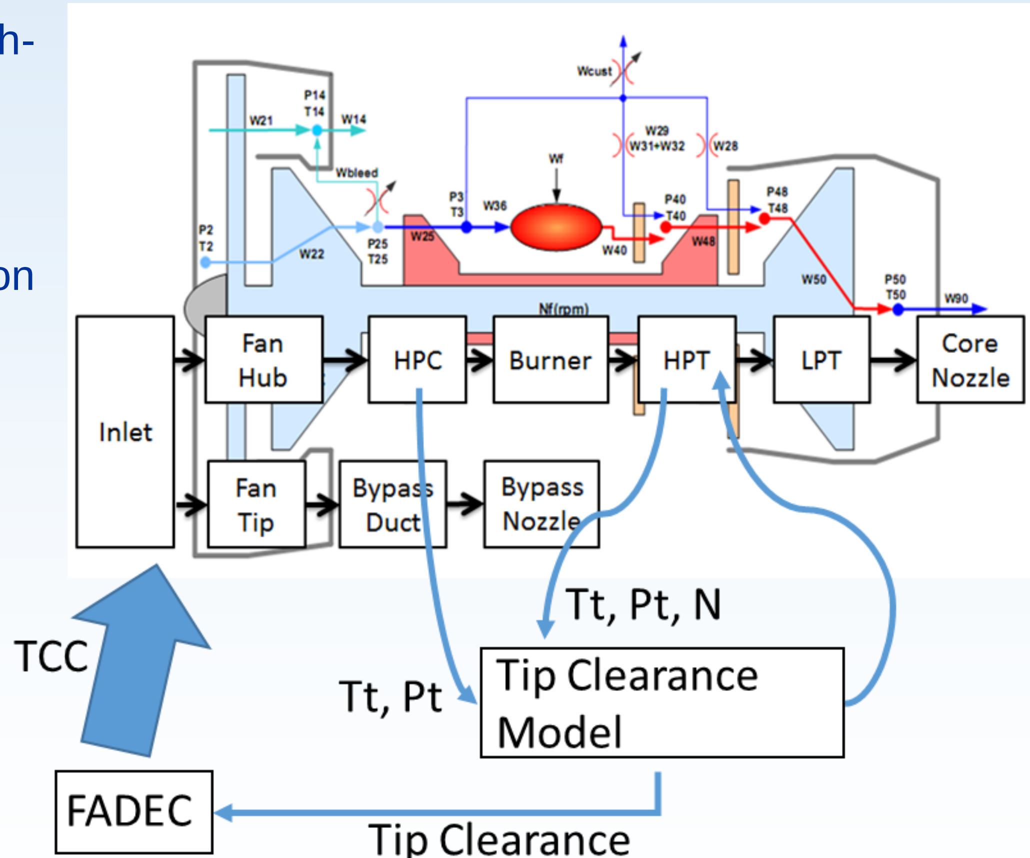
- Considered Deflection Effectors
  - Temperatures
  - Pressures
  - Centrifugal force
- Modeling assumptions
  - All deformations are elastic and axisymmetric
  - Component surfaces are exposed to convection
  - For strain purposes, component temperature is assumed to be constant throughout material
  - Component heat transfer is 1-D for the rotor and shroud and 0-D for turbine blades
  - Material properties are constant (may be updated as necessary)
  - Heat transfer from HPT rotor to blade is negligible
  - Thermal expansion of the shroud is independent of the casing



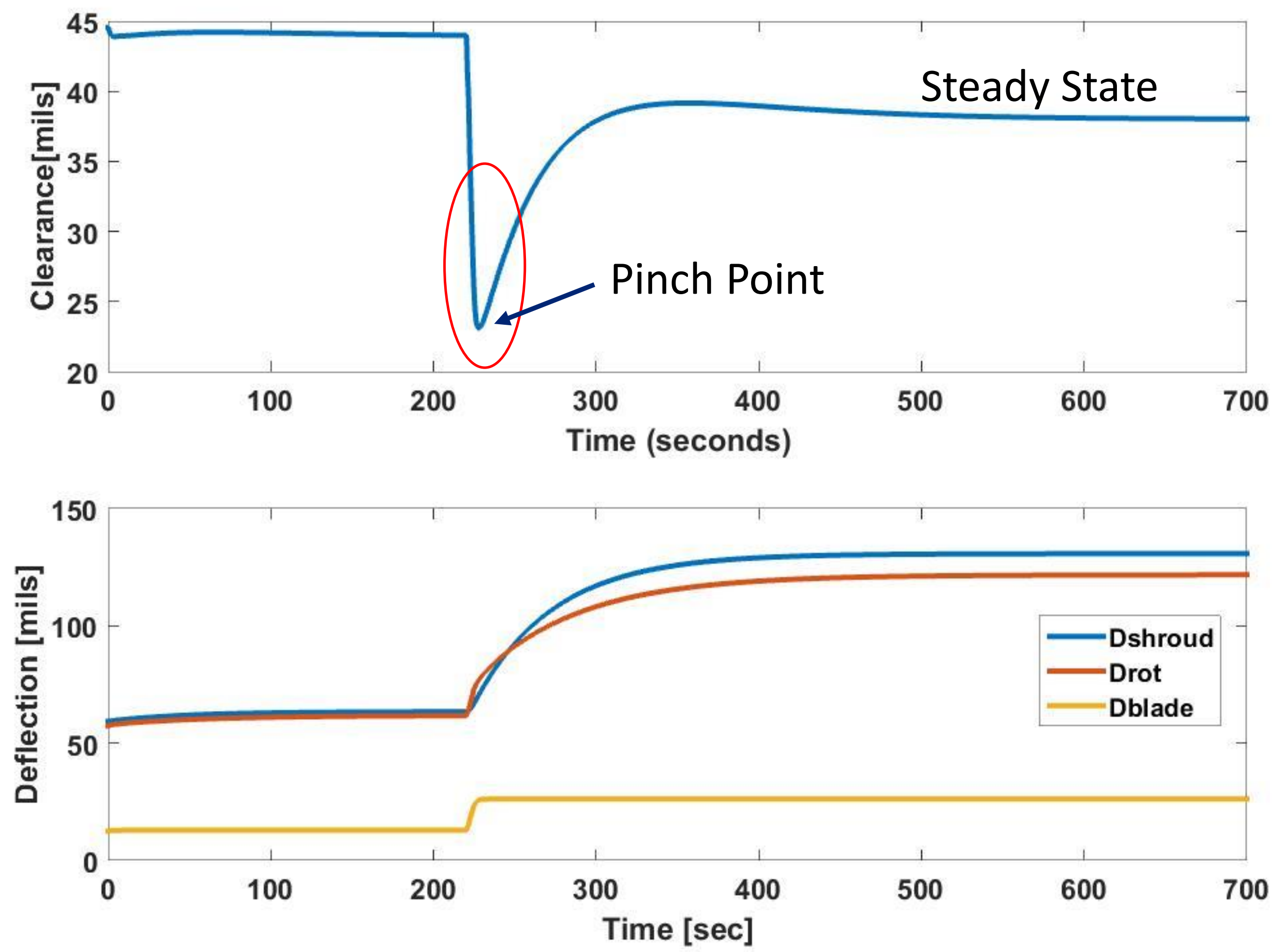
Virtual Platform

- Tip clearance model was integrated with C-MAPSS40k to create a virtual test bed for active tip clearance control research and design

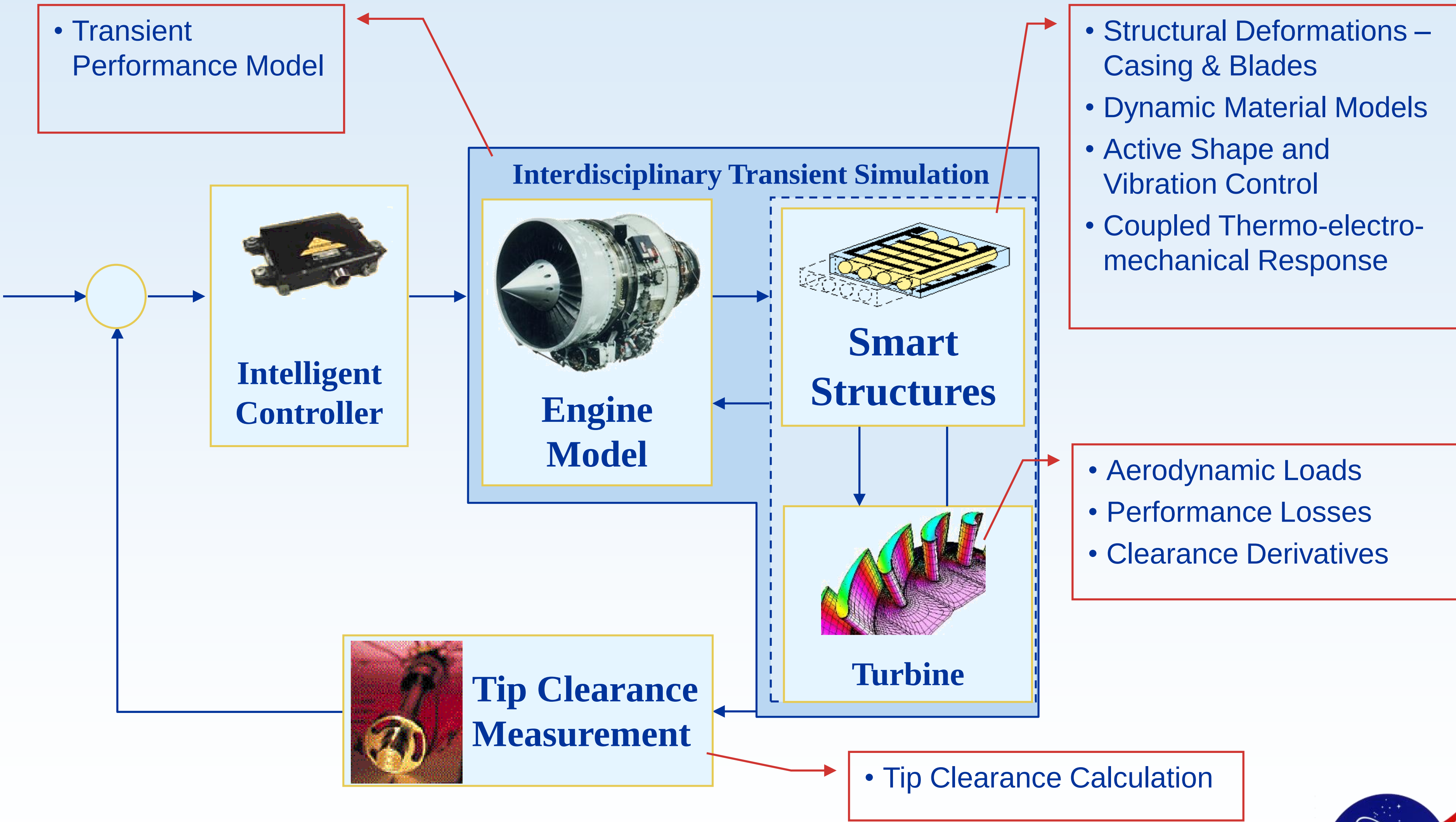
- C-MAPSS40k offers an all inclusive high-bypass, dual-spool turbofan simulation
  - 40,000-lb$_f$ thrust class
  - MATLAB/Simulink
  - Steady state and dynamic operation
  - Realistic control system
- Enables testing of advanced tip clearance control methods with full engine simulation
  - Control algorithm development
  - Actuation system testing



System Simulation



Intelligent Control of Turbine Tip Clearance



Summary

- Fast-response active clearance control identified as a critical technology for improving performance and increasing engine on-wing life.
- A Matlab based simulation has been used to successfully simulate the transient behaviors of the turbine tip clearance
- The simulation package can be further developed for future engine configurations for tip clearance research to study:
  - Impacts of different engine configurations
  - Impacts of different material
  - Sensor requirements
  - Actuator design and requirements
  - Active tip clearance control strategies

References

- Steinetz, B. M., Lattime, S.B., Taylor S., DeCastro, J. A., Oswald, J., Melcher, K. J., "Evaluation of an Active Clearance Control System Concept," 41th Joint Propulsion Conference and Exhibit, AIAA/ASME/SAE/ASEE, Tucson, AZ, July 10-13, 2005. AIAA-2005-3989.
- DeCastro, J. A., Melcher, K. J., "A Study on the Requirements for Fast Active Turbine Tip Clearance Control Systems," 40th Joint Propulsion Conference and Exhibit, AIAA/ASME/SAE/ASEE, Fort Lauderdale, FL, July 11-14, 2004. AIAA-2004-4176.
- Melcher, K. J., Kypuros, J. A., "Toward a Fast-Response Active Turbine Tip Clearance Control," Proceedings of the XVI International Symposium on Air Breathing Engines, Cleveland, OH, August 31-September 5, 2003.
- Kypuros, J. A., Melcher, K. J., "A Reduced Model for Prediction of Thermal and Rotational Effects on Turbine Tip Clearance," NASA Technical Memorandum, NASA TM-2003-212226.
- Steinetz, B. M., Taylor S., Oswald, J., DeCastro, J. A., "Seal Investigations of an Active Clearance Control System Concept," 11th International Symposium on Transport Phenomena and Dynamics of Rotating Machinery, Honolulu, HI, Feb. 26-March 2, 2006, 120-ISROMAC-11