Active Turbine Tip Clearance Control Research

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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.

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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

Shroud/Case Growth
- Mechanisms
- Pressure
- Temperature

Rotor Disk Growth
- Mechanisms
- Rotation
- Temperature

Blade Growth
- Mechanisms
- Rotation
- Temperature

Deflection

ΔClearance

Engine Simulation

Outputs:
- $N_{shaft}$
- $P_{Compressor}$
- $T_{Compressor}$
- $P_{Turbine}$
- $T_{Turbine}$

Results: Deflections & Clearance

Results: Throttle & Shaft Speed

G/I

Max

Time (seconds)

0 10 20 30 40 50 60 70 80 90 100

0.7
0.95
1.2
1.45
1.7 $\times 10^4$

N (rpm)

Throttle

0 10 20 30 40 50 60 70 80 90 100

0 50 100 150

Deflection (mils)

Clearance (mils)

0 10 20 30 40 50 60 70 80 90 100

Cold Ground

Dynamic

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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 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

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System Simulation

Steady State

Pinch Point
Intelligent Control of Turbine Tip Clearance

- Transient Performance Model
- Structural Deformations – Casing & Blades
- Dynamic Material Models
- Active Shape and Vibration Control
- Coupled Thermo-electro-mechanical Response

Intelligent Controller

Interdisciplinary Transient Simulation

- Aerodynamic Loads
- Performance Losses
- Clearance Derivatives

Engine Model

- Casing & Blades

Smart Structures

- Dynamic Material Models
- Active Shape and Vibration Control

Turbine

- Coupled Thermo-electro-mechanical Response

Tip Clearance Measurement

- Tip Clearance Calculation
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


