NASA/CR—2005-213970

HPT Clearance Control

Intelligent Engine Systems—Phase 1

General Electric Aircraft Engines
Cincinnati, Ohio

October 2005

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Prepared under Contract NAS3–01135, Work element 3.4, Task order 23

National Aeronautics and
Space Administration

Glenn Research Center

October 2005

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1.0 Executive Summary

1.1 Background

HPT (high pressure turbine) blade tip clearance has a significant impact on fuel burn and emissions. Hence, developing an HPT clearance control system that can adapt to changing environment/requirements is of paramount importance. This will enable a pre-eminent U.S. position in the aerospace industry well into the 21st century.

When the HPT module of an engine is assembled, there is a certain amount of HPT blade tip clearance (i.e., gap between blade tip and shroud). This is called the assembly clearance or the cold build clearance. Its magnitude depends on:

- anticipated thermal and mechanical radial deflections of rotor and stator during flight cycle
- desired clearances during takeoff to achieve targeted performance parameters and to avoid blade tip rubs
- target operating clearance during cruise, and
- margin for protection against blade tip rubs due to dynamic events, hot rotor reburst, etc.

The mechanical deflections occur almost instantaneously – the stator reacts to pressure force and the rotor (disk) to centrifugal force. The blade too reacts rapidly to centrifugal and thermal forces. On the other hand, the disk and the case thermal deflections occur at a slower rate, which is governed by the time constant of each component. Although slow, the thermal deflections are significant in magnitude. Typically, blades have the smallest time constant followed by that of the stator, and then by that of the disk. This difference in time constants makes it difficult to set the clearances precisely.

1.1.1 Cruise performance considerations

Since cruise forms the longest segment of a flight cycle, SFC (specific fuel consumption) is the driving factor in setting the target cruise clearance. A current state-of-the-art HPT ACC (active clearance control) system is shown in figure 1. New engine build clearance is shown in figure 1(a). At cruise, both stator and rotor have grown radially out (thermally and mechanically) as shown in figure 1(b). HPT ACC system is used to cool the stator and bring it radially in, thus reducing the blade tip clearance.

On new engines, the system can close the gap to achieve design operating cruise clearance as shown in figure 1(c).

The engine deteriorates over time due to amongst other things blade tip loss. The current HPT ACC systems do not intelligently compensate for the blade tip loss over time. This leads to an increase in operating clearance as shown in figure 1(d) and hence SFC is impacted.

1.1.2 Conceptual design of an advanced HPT ACC

To overcome the shortfall of existing HPT ACC systems under deteriorated engine conditions, the blade tip clearances would need to be measured during engine operation and an HPT ACC system capable of maintaining these clearances at or near the new engine levels is required. Such a system can be thermal or mechanical.

A schematic of the HPT ACC concept at cruise conditions is shown in figure 2. As shown in figure 2(d), the blade tip has deteriorated causing increased clearances; but the HPT ACC system is able to compensate for the blade tip rub to close the gap back and retain the clearances at design level. Such a system will help maintain the SFC in spite of engine deterioration.

1.1.3 Mission

The current investigation "Propulsion 21 – HPT Clearance Control" (Work Element 3.4 of Task Order no. 23) is to analyze and develop an advanced HPT ACC system that will decrease cruise SFC.

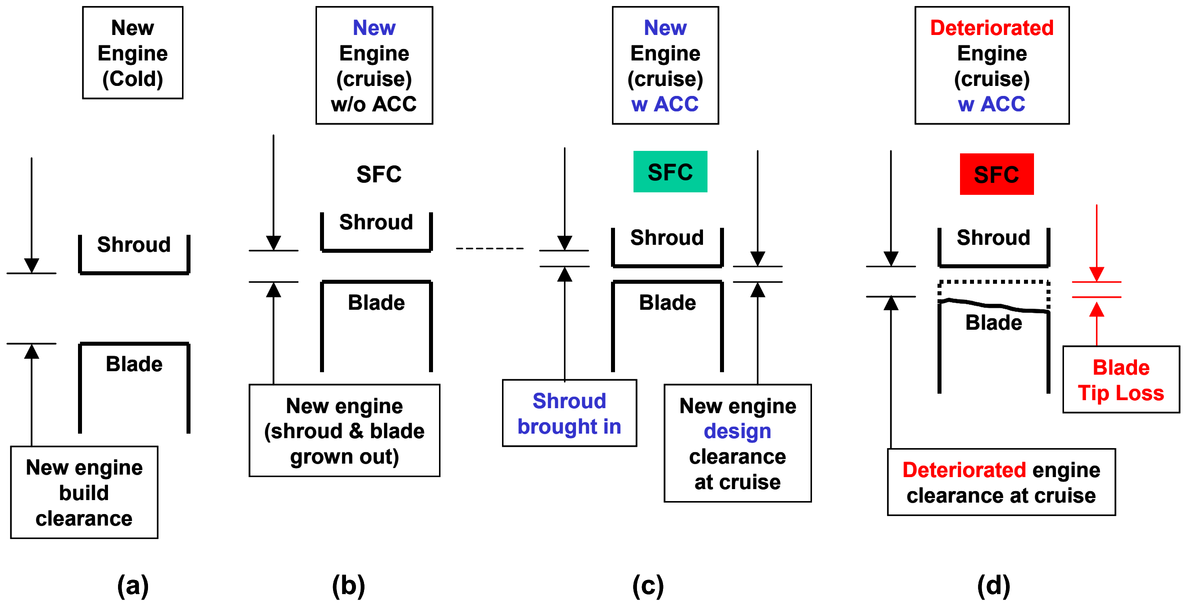

Figure 1.—Current HPT ACC System—New and deteriorated engine cruise clearances.

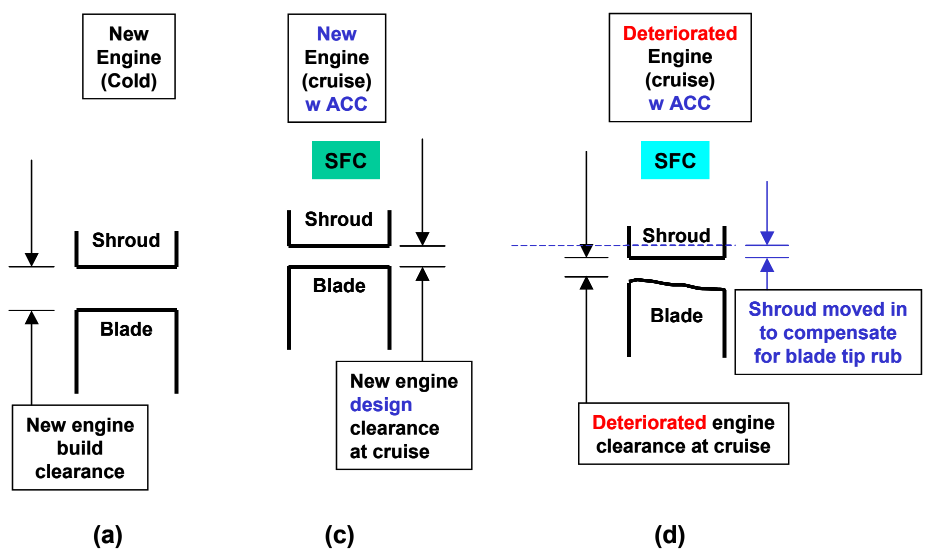

Figure 2.—Advanced HPT ACC system—SFC for new and deteriorated.

1.2 Study Results

The first step was to downselect an engine type to use as a baseline for further study. Impact of HPT clearances on engine performance parameters was evaluated for both small and large engines. Significant benefits in cruise fuel burn, range, and payload capability are achieved for the long range aircraft. This evaluation narrowed the candidate engines to large commercial engines. An engine with current state-of-the-art HPT ACC system was selected as the baseline engine/system.

Preliminary conceptual designs of potential advanced HPT ACC systems were made. The designs included thermal and mechanical systems. A standardized template was developed to evaluate and compare existing and potential systems on the same basis and to downselect promising systems for further study.

1.3 Conclusions

An advanced HPT ACC system can maintain cruise SFC despite engine deterioration at or near new engine levels.

2.0 HPT Blade Tip Clearance Control Systems

HPT clearance control systems can be categorized as passive and active, active being controlled via a hydro-mechanical control or via FADEC (full authority digital engine control). The systems can be further classified as either thermal or mechanical.

2.1 Fan and Compressor Air Based System

A thermal system uses temperature differential between fan/compressor air and flowpath air to control radial displacement of shrouds. A schematic of such a system is shown in figure 3. As shown, HPT ACC air (from fan/compressor) is used to control the radial deflection of shroud. The external view of such a system is shown in figure 4.

2.2 Enhanced Stator Thermal Expansion System

This system uses a modified shroud support made from a low α (coefficient of thermal expansion) material resulting in reduced operating clearances. This system has the capability to provide additional closure at altitude for deteriorated engines.

2.3 Solid-Liquid Phase Change System

This is a passive system without any moving parts. The concept behind this system is to use phase change material (PCM) to control stator time constant. Since additional heat is required to melt /solidify the PCM and since temperature does not change during phase change, the stator time constant increases during both accel and decel.

Advantages of this system are:

- Provides a 360° uniform stator temperature
- No changes to any of the existing flow circuits
- Capable of being combined with other systems

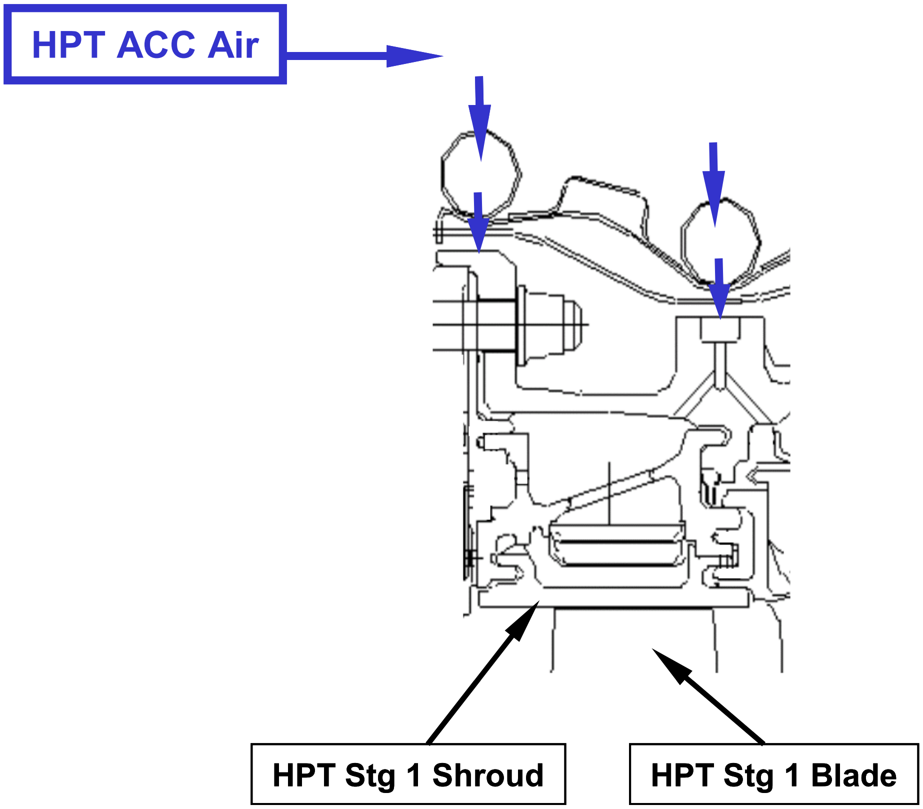

Figure 3.—Thermal based HPT ACC system schematic.

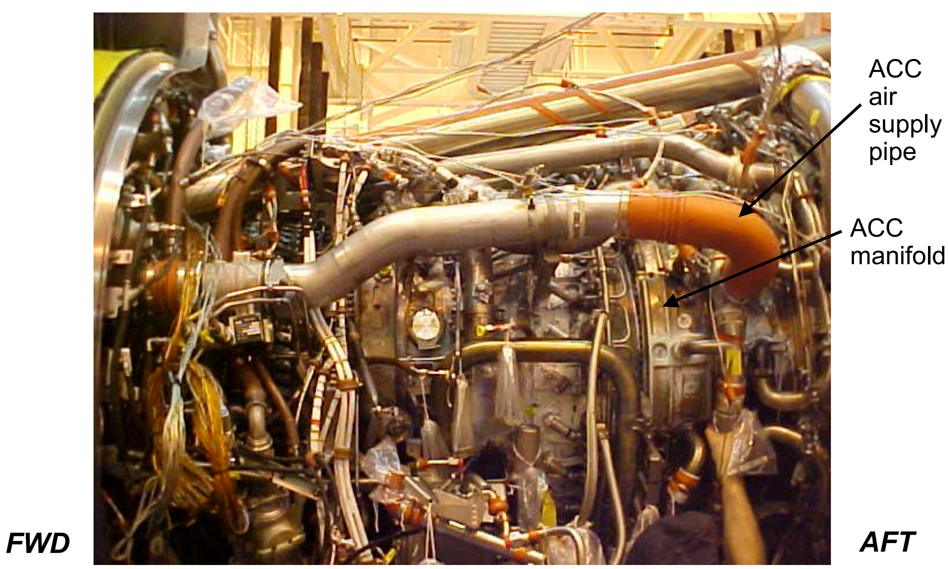

Figure 4.—Thermal based HPT ACC system hardware configuration.

2.4 Mechanically Actuated Stator System

The concept behind this system is to control HPT blade tip clearance by controlling the shroud position by means of mechanical actuators. A schematic of such a system (United States Patent 5,056,988) is shown in figure 5.

Together with clearance sensors, this system can:

- Provide on demand clearance control
- Have a significant clearance closure capability
- Manage stator ovalization
- Work equally effectively on both new and deteriorated engines
- Provide rotor reburst protection

3.0 HPT Clearance Control System Scorecard

In order to benchmark current HPT clearance systems and to compare new systems to the existing ones, it is necessary to develop an overall system scorecard.

Such a scorecard has been developed to address all major items for comparing existing and potential systems. The items addressed are:

- System Level
- Performance
- Thermal
- Mechanical

CTQs (critical to quality) items from each category have been identified and a scoring method has been established. All HPT ACC systems will be scored based on this for a data driven comparison of the systems.

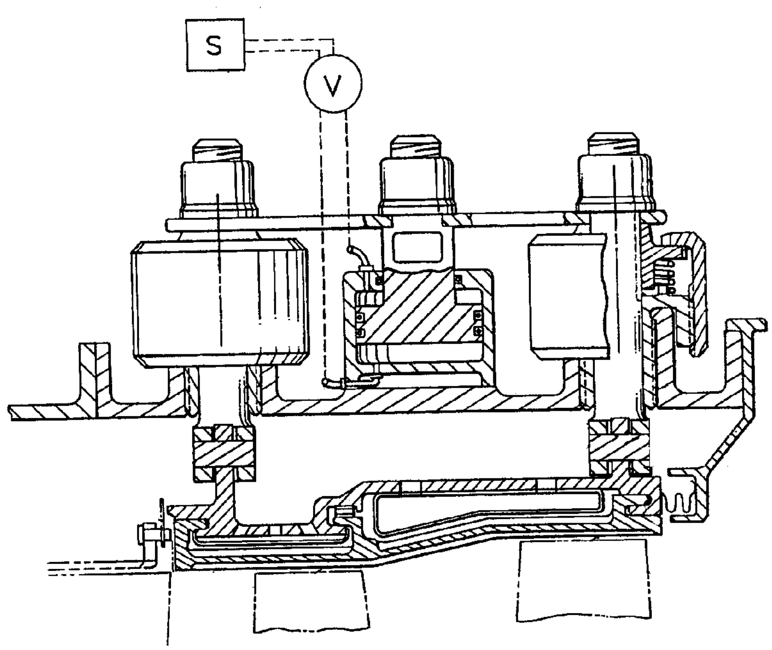

Figure 5.—Mechanical based HPT ACC system schematic.

4.0 Engine Size and Flight Cycle Selection

All existing and potential HPT ACC systems have been reviewed. It is now necessary to identify the engine/aircraft system on which such a system will be most beneficial. This engine/aircraft system will be used as baseline to compare all HPT ACC systems on.

After a careful evaluation of performance and emissions benefits associated with a +1 percent HPT efficiency gain, a “large engine”/“long range twin isle aircraft” system was chosen as the base engine/aircraft system.

4.1 General Considerations

Fuel Burn and Range

- Generate engine performance data for the reference engine and the reference engine with +1 percent HPT efficiency.
- “Fly” each set of engine data and identify fuel burn, range, and payload benefit from improved HPT efficiency.

Emissions

- Generate emissions data for the reference engine the reference engine with +1 percent HPT efficiency.
- Measure engine data and identify impact on emissions.

4.2 Performance Considerations

For a 1 percent HPT efficiency increase on a “large engine/long range aircraft” system:

- Fuel burn decreases by 0.93 percent.

4.3 Emissions Considerations

For a 1 percent HPT efficiency increase on a “large engine/long range aircraft” system:

- The NO_x fraction decreases by ~10 percent
- The CO fraction decreases by ~ 16 percent
- The HC fraction increases by ~ 49 percent

Although the increase in HC fraction is large on a percent basis, it is not of concern since its EI (emissions index) for HC is insignificant (<1).

5.0 Process for Evaluating HPT ACC Systems

A process has been developed to evaluate various concepts and existing systems to identify the best system.

There are three legs to this process initially. Two of them are more or less a one time event. They are:

- Establish a scorecard to benchmark existing HPT ACC systems on GE engines in the field, at systems, performance, thermal, and mechanical levels
  - develop a scoring criteria to score items on the scorecard. This weighted scoring is to highlight the CTQs (critical to quality).
- Select a baseline engine model to compare all systems against.
  - select a transient cycle/mission to evaluate the concepts.

The third leg, "first pass template" is to describe each new process in enough detail and is particular to the system under consideration.

6.0 Summary of Current Work

The following work has been completed to satisfy the Phase I Deliverables for the "HPT Clearance Control" project under NASA–GRC's "Intelligent Engine Systems" program.

- Need for the development of an advanced HPT ACC system has been very clearly laid out.
- Several existing and potential clearance control systems have been reviewed.
- A scorecard has been developed to document the system, performance (fuel burn, range, payload, etc.), thermal, and mechanical characteristics of the existing clearance control systems.
- Engine size and flight cycle selection for the advanced HPT ACC system has been reviewed with "large engine"/"long range mission" combination showing the most benefit.
- A scoring criteria has been developed to tie together performance parameters for an objective, data driven comparison of competing systems.
- The existing HPT ACC systems have been scored based on this scoring system.

7.0 Future Work Recommendations

7.1 Phase II Work

Starting from the technological foundation laid in the current phase of the "HPT Clearance Control" project under NASA–GRC's "Intelligent Engine Systems" program, the following work needs to be completed to design and develop an advanced HPT ACC system. This system is to address the performance degradation associated with engine deterioration.

- Score the selected HPT ACC concepts
- Compare the scores of concept systems and existing systems
- Identify an optimum HPT ACC system design based on overall performance benefit, reliability, maintainability, cost, and weight.
- Perform detailed design and development of the system.
- Design and develop a FADEC system to monitor and control the HPT ACC system.

7.2 Phase III Work

- The advanced HPT ACC system designed and developed in Phase II will be fabricated and tested on a large commercial engine with the corresponding long range flight cycle.
- Back to back engine tests (sea level static and flight) will be performed on new and deteriorated engines to demonstrate improvement in overall engine performance.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
October 2005

3. REPORT TYPE AND DATES COVERED
Final Contractor Report

4. TITLE AND SUBTITLE

HPT Clearance Control
Intelligent Engine Systems—Phase 1

5. FUNDING NUMBERS

WBS–22–714–92–50
NAS3–01135
Work element 3.4, Task order 23

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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Cincinnati, Ohio 45215–1915

8. PERFORMING ORGANIZATION REPORT NUMBER

E–15288

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA CR—2005–213970

11. SUPPLEMENTARY NOTES

Project Manager, Clayton L. Meyers, Aeronautics Division, NASA Glenn Research Center, organization code PRV, 216–433–3882.

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Unclassified - Unlimited
Subject Category: 07

Available electronically at http://gltrs.grc.nasa.gov

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12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

The following work has been completed to satisfy the Phase I Deliverables for the "HPT Clearance Control" project under NASA—GRC's "Intelligent Engine Systems" program: (1) Need for the development of an advanced HPT ACC system has been very clearly laid out, (2) Several existing and potential clearance control systems have been reviewed, (3) A scorecard has been developed to document the system, performance (fuel burn, range, payload, etc.), thermal, and mechanical characteristics of the existing clearance control systems, (4) Engine size and flight cycle selection for the advanced HPT ACC system has been reviewed with "large engine"/"long range mission" combination showing the most benefit, (5) A scoring criteria has been developed to tie together performance parameters for an objective, data driven comparison of competing systems, and (6) The existing HPT ACC systems have been scored based on this scoring system.

14. SUBJECT TERMS

Propulsion systems (aircraft)

15. NUMBER OF PAGES
15

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	