application of simplified algorithm to dramatically reduce specific fuel consumption

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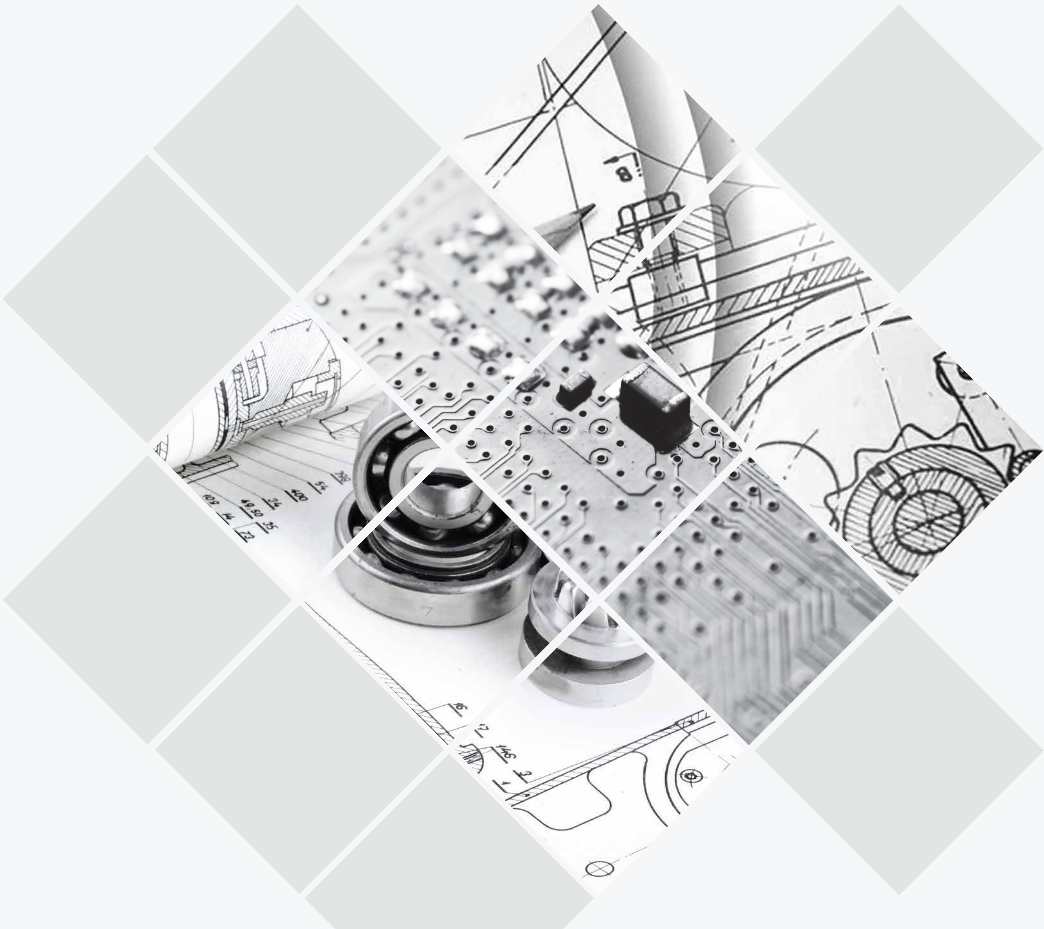

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Abstract

This white paper considers the challenges of turbine active clearance control and proposes a unique approach in reducing the tip clearance control of a civil aircraft engine. The algorithm proposed in this paper can be incorporated in the engine Digital Engine Control Unit (DECU) so that Active Clearance Control (ACC) systems can be more accurate and cost-effective. This new approach can save millions of dollars on fuel costs for the aircraft industry, which is already reeling under debt and faces major challenges in surviving because of economic uncertainties.

In the aerospace industry, as in many other industries, there is a strong interest to maximize the use of existing assets. The performance of ACC systems of a civil turbine engine is one such area in the aerospace industry where maximum use of current assets is gaining prominence. Among the various parts that make up the ACC system, tip clearance is considered an important area for improvement. The industry already understands that with a reduction in the tip clearance, aircraft manufacturers can anticipate dramatic savings in fuel, improvement in the engine's service life, and an overall enhancement in a turbine's performance.

These challenges present an opportunity to accelerate innovations in improving the service life of the turbine. A new approach and methodology to design the turbine's active clearance control can accelerate the process and challenge the status quo on the tip clearance control in the development of civil aircraft engines. Disruptive methodologies and new computational models that promise the advantage of significant Specific Fuel Consumption (SFC) are needed now more than ever.

Even a small percentage of SFC reduction can result in saving millions of dollars in fuel cost, and a marginal decrease in Exhaust Gas Temperature (EGT) can increase the time-on wing of the aircraft. In general, for large turbine civil engines, tip clearance reductions of the order of 0.010 inches can produce a 1% decrease in SFC and 10ºC decrease in EGT. Improved tip clearances of this magnitude can produce fuel and maintenance savings over hundreds of millions of dollars per year.

Background

As aircraft engine designs continue to push the performance envelope with fewer parts, and the market drives manufacturers to increase service life, the need for advanced ACC systems continues to grow.

The performance of gas turbines for use in civil aircraft has improved over the decades since its first development in 1930s. Apart from the giant strides made by pioneers over the last decade, design changes are usually incremental, and most technical improvements occur after the expenditure of considerable time and money in research and development.

A closer collaboration between the manufacturers and centers of excellence for the aircraft industry that have invested in advancing the design methodologies will be beneficial. Innovations in the SFC reduction area, besides many other critical areas of the civil turbine design, and development will bear fruit in the coming decades.

New Computational Models Can Deliver New Levels of Innovation

A significant trend in all research, development and design of civil turbines is the increasing use of computational methods. Growth in computingpower and improvements in modeling, particularly on thermal and mechanical loads of the rotating and stationary structures has quickened the pace. However, the more sophisticated the computational code, the greater the need to validate its output using reliable data. Turbine research is increasingly directed towards code validation using data obtained from engine tests or flight performance data models of engine components.

Challenges in Developing Optimum Tip Clearance

Turbine blades enclosure and sealing enclosures are segmented to accommodate thermal expansion in a turbine. In a typical turbine, the deterioration of components is caused mainly by increased EGT margin, which in the long term affects the performance of the engine. When the tip clearance increases, the hot section component degrades and therefore contributes to lower-performance of the engine.

Casing Enclosure Expansion and its Effects on Thermal and Mechanical Loads

Blade tip clearance and inter-stage sealing in the interiors of the casing has been a challenge since the development of turbine engines for civil aircraft. Today, in engine development, more focus is given to gaining control over the clearance because it is one of major factors in the wear and tear of the rotating and stationary structures of the engine.

A tiny variation in the diameter of tip clearance, caused by thermal and mechanical loads, can considerably change the functioning and performance of the turbine blades during flight transient operations. Blade tips and shrouds wear over a period of time because of friction when clearances are too tight. As the engine deteriorates, EGT increases, and this accelerates the gas path deterioration process. This may result in the blade tip touching the casing, a condition known as a rub, which decreases engine performance and reduces the lifespan of the blades as well as casing enclosures.

Deterioration of EGT Margin and Effective Clearance Management

As rotating and stationary components degrade, and clearance between the blade tips and the seal on the interior of the casing increase, the engine has to work harder to develop the same thrust. Once an engine reaches its EGT limit, which is an indication that the high-pressure turbine disk is reaching its upper temperature limit, the engine must be sent for maintenance.

Maintenance costs for major overhauls of today's large commercial turbine engines can easily exceed thousands of dollars. Deterioration of the EGT margin is the primary reason for removing an aircraft engine from service. (EGT is used to indicate the performance of the turbine.)

Tip clearances change during the operation of the engine and vary depending on rotor speeds, temperatures, and mechanical deterioration. An improved clearance management promises to dramatically improve engine service life and reduce the maintenance cost over the long haul of the aircraft.

The problem in minimizing the tip clearance is that the blade tip length from rotor tip center or engine axis grows at a different rate than the casing, which may not be able to accommodate the change in blade length, especially during engine transient operations. The clearances should therefore be minimized while avoiding rubs between the turbine blade tips and shrouds. SFC reduction is possible by reducing the tip clearance to an acceptable level.

Industry Standard Approaches and their Limitations

The aerospace industry is currently considering the following three approaches to improve the ACC system and to reduce SFC:

a) Increasing the bypass ratios by over 10

b) Implementing un-ducted fan configurations

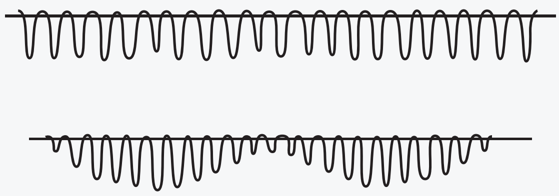
c) Increasing the engine’s overall pressure ratio

However, these have mechanical and aerodynamic limitations and challenges in moving cost-effectively from the design to the implementation phases. In addition, since all aero engines today employ DECU, it will be easier to incorporate a proven algorithm than to attempt the three approaches that have longer time-to-market and may include considerable costs for developing the technologies.

The following sections consider the factors that affect the performance of the blade tip clearance, and propose building a unique algorithm that combines actual flight performance deck with a computational model.

ACC Systems and Measuring the Tip Clearance

As part of the engine-life enhancing technologies in use, ACC systems have become an integral part of modern commercial turbine engines. They are used to improve performance and lower specific fuel consumption, thereby lowering turbine operating temperatures and extending engine life. ACC is an attempt to improve engine efficiency by manipulating the transient and steady state clearances during operation. Some of the preferred sensors for turbine clearance measurement that are in use today are the traverse probe and capacitive type.



Algorithm Development Methodology for Turbine Tip ACC

Formulation of the Problem

The objective of the problem is to obtain certain pressures, temperatures, and the mass flow data that correspond to a combination that offers the best SFC, best thrust, and reduced emissions within a particular range. To develop the algorithm, the values are computed for turbine tip ACC. To compute the values, the performance deck (computer software) of the engine is used to design the algorithm to develop the lowest SFC possible for a typical transient operating state of a civil turbine.

Algorithm

Fitness parameters and constraints for the problem are finalized after the solution representation is developed using the values from the performance deck and combining it with the algorithm. The following steps are then defined to form the base of the algorithm:

Evaluation

The process of evaluating the parameters and constraints consists of the following steps:

Step 1: Firstly, flight conditions are selected and the typical pressures, temperatures, and mass flow required for ACC are computed using the detailed performance deck of the engine.

Step 2: The values derived from Step 1 are correlated with respect to standard entry conditions and plotted against the engine RPM (corrected to standard conditions). The plots or functional relationships represent the simplified algorithm representing the non-dimensional performance of the engine.

Step 3: Evaluating the constraints with respect to performance deck. Now both the detailed engine performance deck and the simplified algorithm are computed.

Constraints

The values computed using Step 1 and 2 should match within 5% (approximately) and this is used as the validation criteria of the algorithm.

Termination Criterion

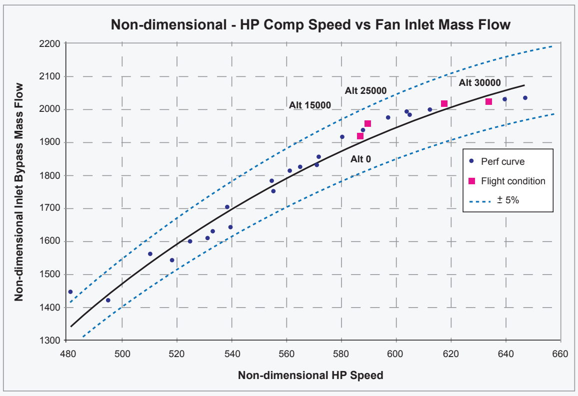
The algorithm formulated and developed must meet the 5% criteria limit and then is incorporated in the DECU of the engine.

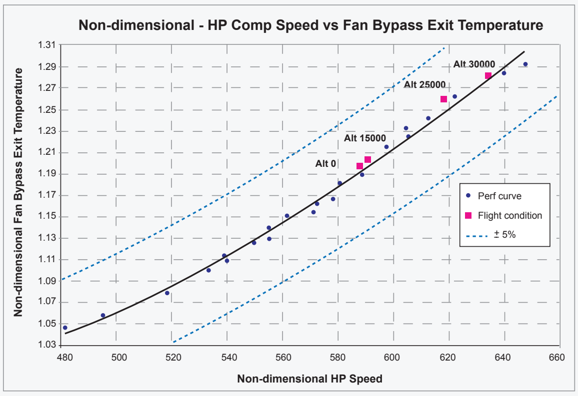
Limitations of the Algorithm

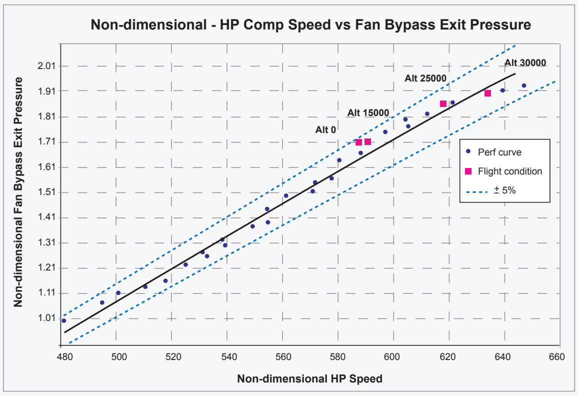
Acceptance of this approach has little implications on the existing turbine engine development. However, the challenge is effective implementation and efficient functioning of the algorithm embedded in the DECU of the aircraft engine. This challenge can be addressed during the algorithm design stage for a particular ACC system.

Validating the Output - Results

It can be seen from the plots that the values of pressure, temperature, and mass flow obtained from the simplified algorithm match with those obtained using the detailed engine performance deck within 3%, which is sufficient for the DECU purposes.







Conclusion

The implementation of the algorithm leads to significant savings in costs for the aerospace industry in the maintenance of the turbine as well as from the massive reduction in SFC. Other industries can also benefit from this fresh approach of reducing SFC by modifying the algorithm to suit several other turbine application areas.

The other major impact this algorithm can have is on the reduction of emissions due to lesser fuel burn. An improved blade tip sealing in the rotating and stationary parts can also improve the engine's service life and compressor's stall margin as well as an increase payload and range capabilities. To develop the algorithm, an engine performance deck and data on mass flow, pressures, and temperatures are the only required parameters for reducing the SFC.

With this new approach – reducing SFC and improving the overall performance of the ACC system – DECU performance will dramatically increase and the overall impact on the airline operator's bottom line can be quickly realized through savings on the maintenance and fuel costs.

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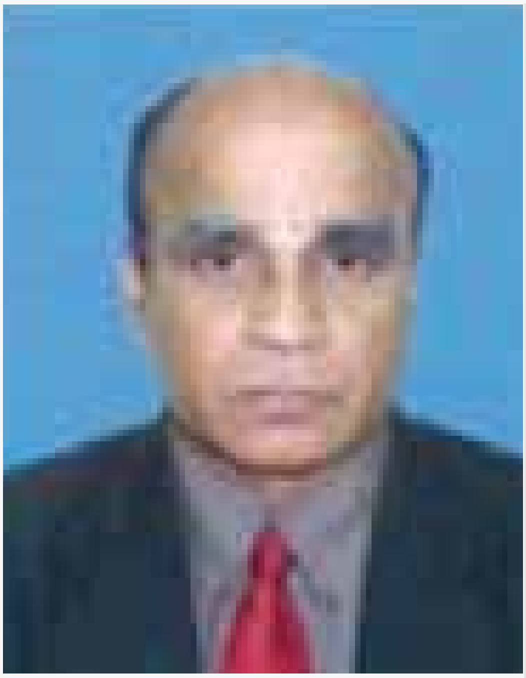
Author Profile



Sundararajan

Sundararajan retired as Director of Gas Turbine Research Establishment (GTRE), Ministry of Defense, in 2002, after 37 years of service (20 years in Senior Management positions). Post retirement, for six years, he served as Advisor-Technology at Honeywell Technology Solutions Lab. (HTSL) Pvt. Ltd., Bangalore, where he supported competency development and technology enhancement. He joined QuEST on March 2nd, 2009.

His core areas of technical expertise are:

- Conceptual design and engine performance prediction and analysis
- Gas turbine engine, its components and sub systems
- Engine simulation and modeling
- Engine control system including D&D of FADEC system for Kaveri Engine
- Engine testing and performance evaluation
- Afterburner design and development
- Airframe-engine integration and integrated performance
- Engine model specification and ICD preparation
- Engine certification and qualification

He is highly respected in the aerospace industry and academic circles for his knowledge, simplicity, and enthusiasm. He has been a focal point for a number of industry-university collaborations. He has also driven a number of technology initiatives in his previous assignments. He is an accomplished trainer and has successfully mentored many engineers during his career. The Gas Turbine course delivered by Sundararajan is a must-do for every engineer in the aerospace domain. At QuEST, Sundarajan is the Head of the Technical Excellence Group. Sundararajan's accomplishments include:

- Responsible for the indigenous design, development, testing and integration of a contemporary fighter aircraft
- Published more than 50 papers in national and international journals, seminars, and symposiums
- Chairman of the Propulsion Panel of the Aeronautical Research & Development Board (AR&DB), DRDO, and Ministry of Defense
- Indian Representative for the International Society for Air breathing Engines (ISOABE)

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About QuEST Global

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QuEST partners with customers to continuously create value through customer-centric culture, continuous improvement mind-set, as well as domain specific engineering capability. Through its local-global model, QuEST provides maximum value engineering interactions locally, along with high quality deliveries at optimal cost from global locations. The company comprises of more than 7,000 passionate engineers of nine different nationalities intent on making a positive impact to the business of world class customers, transforming the way they do engineering.

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