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Aircraft Engine Condition Monitoring Using Trend Analysis for Predictive Maintenance

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ABSTRACT

An Aircraft Condition Monitoring System (ACMS) is an advanced predictive maintenance tool that integrates high- capacity flight data acquisition units with a network of sensors to continuously sample, monitor, and record critical flight parameters from major aircraft systems and components. This system enables precise monitoring of all aircraft subsystems, including engine performance, which is specifically managed through the Engine Monitoring System (EMS). Engine Condition Trend Monitoring (ECTM) plays a vital role in this process by utilizing engine operational data to detect early signs of damage, deterioration, or excessive wear. It serves as a continuous health monitoring technique that enhances engine reliability and operational safety. The primary objective of such monitoring systems is to improve efficiency and reduce maintenance costs by enabling advanced diagnosis, analysis, and prognosis of engine conditions. In this study, a 3007A turbofan engine is considered, where trend plots are analyzed to interpret engine performance behavior and provide troubleshooting guidance using the Fault Isolation Manual (FIM). The Engine Condition Monitoring (ECM) tool, COMPASS, is employed to conduct various analyses and evaluate engine performance trends. The results demonstrate that ECM is a highly effective optimization tool, as it provides valuable insights into engine health and performance. Trend analysis enables engineers to identify whether performance degradation is within expected limits or if significant deviations indicate potential hardware deterioration or failure, thereby supporting timely maintenance decisions and enhancing overall operational efficiency.

1. INTRODUCTION

1.1 Background

Modern aircraft systems are highly sophisticated and require continuous monitoring to ensure safety, reliability, and optimal performance. With increasing operational complexity, the aviation industry has shifted from traditional time- based maintenance to predictive and condition-based maintenance strategies. This transition is driven by the need to reduce maintenance costs, improve efficiency, and enhance flight safety. The Aircraft Condition Monitoring System (ACMS) plays a crucial role in enabling this transformation by providing real-time data acquisition and analysis of critical aircraft parameters.

1.2 Aircraft And Engine Monitoring Systems

The Aircraft Condition Monitoring System (ACMS) is an integrated system that collects, monitors, and records data from various aircraft subsystems through a network of sensors and high-capacity data acquisition units. These sensors measure parameters such as pressure, temperature, vibration, fuel flow, and rotational speeds, providing a comprehensive view of aircraft health.

Among all subsystems, the aircraft engine is one of the most critical components affecting performance, fuel efficiency, and safety. The Engine Monitoring System (EMS) is specifically designed to monitor engine parameters such as exhaust gas temperature, pressure ratios, fuel consumption, and rotational speeds. The integration of ACMS and EMS enables continuous monitoring and accurate assessment of engine performance under varying operating conditions.

1.3 Engine Condition Monitoring And Trend Analysis

Engine Condition Monitoring (ECM) and Engine Condition Trend Monitoring (ECTM) are essential techniques used to evaluate engine health over time. ECTM involves analyzing variations in engine parameters to detect early signs of deterioration, excessive wear, or abnormal performance. By comparing real-time data with baseline values, engineers can identify deviations that may indicate potential faults.

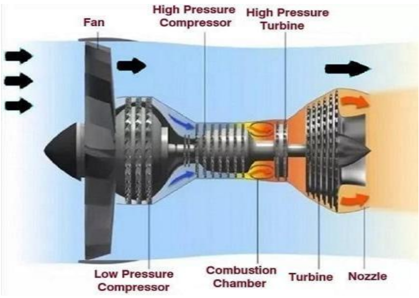


Fig. 1.Turbo Fan Engine

Advanced ECM tools, such as COMPASS, facilitate detailed analysis of engine data through trend plots and statistical methods. These tools support diagnosis and prognosis by helping engineers interpret complex datasets and correlate performance deviations with possible system faults. This approach significantly enhances predictive maintenance capabilities and reduces the risk of unexpected failures.

1.4 Objectives Of The Study

Based on the above framework, the objectives of this study are to understand the role of the Aircraft Condition Monitoring System (ACMS) and Engine Monitoring System (EMS) in evaluating aircraft and engine performance. The study aims to analyze engine performance using Engine Condition Trend Monitoring (ECTM) techniques and to utilize the COMPASS Engine Condition Monitoring (ECM) tool for interpreting engine data and trend plots. Furthermore, the research focuses on identifying performance degradation, detecting faults, and recognizing abnormal engine behavior. It also seeks to provide effective troubleshooting guidance using the Fault Isolation Manual (FIM). Finally, the study evaluates the effectiveness of ECM as a predictive maintenance and performance optimization tool in modern aircraft systems.

1.5 Significance And Scope Of The Study

This study contributes to the advancement of predictive maintenance in aerospace engineering by demonstrating the effectiveness of Engine Condition Monitoring systems. By enabling early fault detection and accurate performance evaluation, ECM helps reduce maintenance costs, improve fuel efficiency, and enhance aircraft safety. The scope of the study includes the analysis of a 3007A turbofan engine using ECM tools to interpret trend plots and assess engine performance. The findings highlight the importance of integrating monitoring systems such as ACMS, EMS, and ECM in modern aircraft operations, supporting efficient and reliable decision-making in maintenance and performance optimization.

2. LITERATURE REVIEW AND PROBLEM IDENTIFICATION

2.1 Literature Review

2.1.1 Reference Engine: Rolls-Royce Ae3007 A1p

The Rolls-Royce AE3007 A1P turbofan engine is selected as the reference engine for this study due to its widespread application in regional jet aircraft, particularly the Embraer EMB-145 series. The development of this engine began in 1988 through a collaborative effort between Allison Engine Company, then owned by General Motors, and Rolls-Royce plc. The initial concept, identified as the RB580, was designed to generate approximately 33 kN of thrust and was intended to power the Short Brothers FJX regional jet. The design combined the T406 core with a low-pressure spool developed by Rolls-Royce. However, in 1989, Rolls-Royce withdrew from the project due to strategic priorities and uncertainties associated with the FJX program. Following this, Allison Engine Company independently continued the development and introduced key design improvements, including a wide-chord snubberless titanium fan and an enhanced low-pressure turbine. On March 23, 1990, the engine, renamed as the GMA 3007, was selected to power the Embraer EMB-145, marking its successful entry into the commercial aviation sector.

2.1.2 Engine Design And Configuration

The AE3007 is a direct-drive turbofan engine featuring a compact and efficient configuration. It consists of a single- stage fan, a 14-stage axial compressor with six stages of variable stator vanes, an annular combustion chamber, a two- stage high-pressure turbine, and a three-stage low-pressure turbine. The engine operates on a dual-rotor system, where the low-pressure rotor (N1) and high-pressure rotor (N2) rotate independently, enabling efficient performance across a range of operating conditions. The engine is equipped with dual-channel Full Authority Digital Engine Control (FADEC) systems, which ensure precise control and optimization of engine parameters. Additionally, the accessory gearbox is mounted at the bottom of the engine, and the design allows flexibility for both underwing and aft fuselage mounting configurations.

2.1.3 Engine System Description

The air inlet section of the engine comprises the fan case, fan rotor assembly, and front frame assembly. These components guide the airflow into the engine while maintaining structural integrity and safety through blade containment systems. The bypass section includes both inner and outer ducts that direct airflow around the core engine and contribute to thrust generation. Acoustic liners are incorporated within the bypass duct to reduce engine noise. The combustion section consists of a compressor diffuser, an annular combustion liner, fuel nozzles, and igniters. In this section, compressed air is mixed with fuel and ignited to produce high-energy gases. The turbine section includes a two- stage high-pressure turbine and a three-stage low-pressure turbine, which extract energy from the hot gases to drive the compressor and fan systems. The turbine assembly also incorporates bearings, seals, and structural supports to ensure efficient operation.

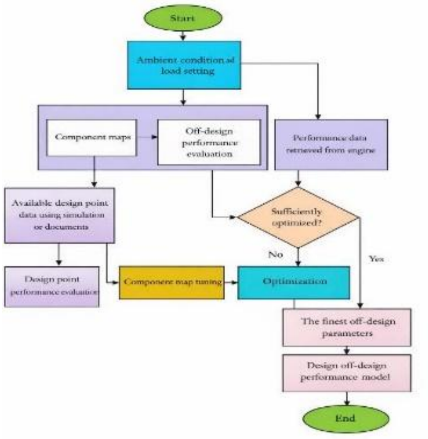
2.1.4 Turbofan Engine Working Principle

The turbofan engine operates based on the Brayton thermodynamic cycle. Air enters the engine through the inlet and is compressed by the compressor. The compressed air is then mixed with fuel and ignited in the combustion chamber, producing high-temperature and high-pressure gases. These gases expand through the turbine, generating mechanical energy that drives the compressor, fan, and accessory systems. The remaining energy in the exhaust gases produces thrust, enabling aircraft propulsion.

2.1.5 Engine Trend Analysis

Engine trend analysis is an essential aspect of modern aircraft maintenance, enabling the monitoring of engine performance over time. It involves analyzing variations in key parameters such as temperature, pressure, fuel flow, and rotational speed. For the AE3007A series engines, trend analysis is conducted using the COMPASS Navigator Trend Program (CNTP), which processes data recorded by the Central Maintenance Computer (CMC). Trend plots provide valuable insights into engine health by indicating whether performance degradation is gradual and expected or if there are sudden deviations caused by component failure or abnormal conditions. Regular monitoring and analysis allow for timely preventive maintenance, thereby reducing the risk of engine shutdowns and minimizing Aircraft on Ground (AOG) situations.

2.2 Problem Identification



Aircraft engines are among the most complex engineering systems, consisting of numerous interacting components operating under extreme thermal and mechanical conditions. For aircraft operators, it is critical to continuously monitor engine health and detect early signs of deterioration to prevent unplanned shutdowns or engine removals. One of the major challenges in engine condition monitoring is identifying the root causes of variations observed in engine trend data. These variations may indicate component wear, performance degradation, or potential failure; however, accurate interpretation requires advanced analytical techniques and domain expertise. Several technical challenges exist in this domain. The variability in trend data makes it difficult to accurately diagnose faults, and data is often collected under specific flight conditions, limiting its consistency. Additionally, the large volume of data generated requires sophisticated tools for effective analysis. Correlating observed trends with specific component failures also remains a complex task. Operational and safety challenges further complicate the problem. Engine malfunctions pose significant risks to aircraft safety and passenger well-being. In some cases, the lack of real-time monitoring capabilities delays decision-making, while reliance on manual interpretation increases the likelihood of human error. Economic and practical challenges also play a significant role. Engine monitoring systems are expensive to implement and require skilled personnel for data analysis and maintenance. Engine components are costly, and any failure can result in substantial financial losses. Data acquisition limitations, particularly in systems that rely on ground-based data collection, further hinder effective monitoring. Additionally, any detected abnormality may require grounding of the aircraft, leading to operational delays and increased costs.

3. METHODOLOGY

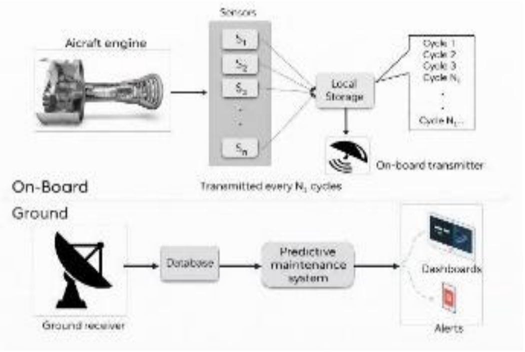


Fig.2. Aircraft engine monitoring Fig.2. Optimizing components and performance

3.1 Overview

The proposed methodology focuses on the interpretation of engine trend plots for the 3007A series engine to support condition monitoring and fault diagnosis. The approach integrates data acquisition, trend analysis, parameter evaluation, and diagnostic techniques to identify engine deterioration and recommend maintenance actions. Engine trend analysis provides a reliable means to detect both gradual degradation and sudden performance deviations caused by hardware failures. This methodology ensures improved engine reliability and minimizes aircraft downtime.

3.2 Data Acquisition And Preprocessing

Engine performance data are acquired from onboard sensors under various operating conditions. The key parameters considered include:

- Inter Turbine Temperature (ITT)
- Fuel Flow (FF)
- High-Pressure Shaft Speed (N2)
- Low- and High-Pressure Vibrations (LPVIB, HPVIB)

The collected data are subjected to pre-processing steps such as filtering, validation, and normalization to eliminate noise and measurement inconsistencies. This ensures the accuracy and reliability of subsequent analysis. Trend Plot Generation and Baseline Comparison Trend plots are generated for both cruise and take-off conditions **using** raw (unsmoothed) and processed (smoothed) data. The performance of the engine is evaluated using delta values**,** defined as deviations from baseline (maiden) engine performance:

- ΔITT
- ΔFF
- ΔN2

It is important to note that delta values relative to the maiden point provide a more accurate indication of engine deterioration compared to values referenced to nominal zero.

3.1 Cruise Condition Analysis

Cruise condition data represent steady-state operation and are therefore highly suitable for detecting gradual engine degradation. The typical behavior of parameters during deterioration is as follows:

- ΔITT: Increases consistently with deterioration severity
- ΔFF: Increases with deterioration but with lower sensitivity
- ΔN2: May increase or decrease depending on LP or HP system degradation A decrease in ΔITT or ΔFF may indicate instrumentation or measurement errors rather than actual engine improvement. Trend monitoring over time enables:
- Identification of long-term performance degradation
- Prediction of maintenance requirements
- Early detection of abnormal engine behavior

3.2 Take-Off Margin Analysis

Take-off margin analysis evaluates the engine's ability to operate safely under maximum thrust conditions. The margin is defined as the difference between the maximum allowable limit (red line) and the actual engine parameter value.

- ITT Margin
- N2 Margin

Fuel flow is excluded due to measurement inaccuracies during transient conditions. Based on margin evaluation:

- Positive margin indicates safe operation
- Zero margin indicates operation at limit
- Negative margin requires further assessment

3.3 Sloatl-Based Operational Assessment

The Sea Level Outside Air Temperature Limit (SLOATL) represents the maximum ambient temperature at which the engine can safely operate at sea level under negative margin conditions.

Engine operation is considered safe only if:

- Ambient temperature ≤ SLOATL

SLOATL is applicable primarily for sea-level conditions and is not suitable for high-altitude operations due to variation in rating characteristics.

3.4 Compass Trend Plot Analysis

The COMPASS system provides multiple trend plots for performance evaluation: Cruise Condition Plots

- Unsmoothed plots for detecting short-term variations
- Smoothed plots for identifying long-term deterioration
- Rate-of-change plots for predicting future limit exceedance

Take-Off Condition Plots

- Take-off margin plots for performance evaluation
- SLOATL plots for temperature limit assessment

3.5 Parameter Ratio-Based Fault Diagnosis

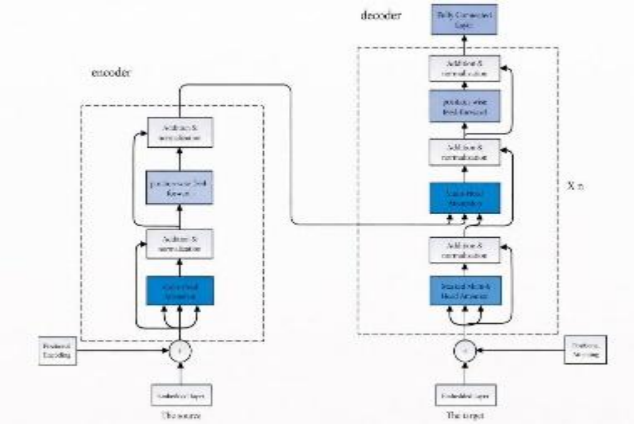


Fig.3. Transformer model architecture flowchart

To enhance diagnostic accuracy, a parameter ratio method is employed. This method uses ITT as the reference parameter and evaluates relative changes:

- ITT Ratio = ΔITT / ΔITT
- FF Ratio = ΔFF / ΔITT
- N2 Ratio = ΔN2 / ΔITT

These ratios are compared with predefined reference values to identify specific engine faults. Illustrative Example

For an observed condition:

- ΔITT = 90°C
- ΔFF = 11.7%
- ΔN2 = 1.4%

The resulting ratios:

- ITT = 1.00
- FF = 0.130
- N2 = 0.016

These values closely correspond to an overboard bleed fault, such as a bleed tube failure. Limitations

- Effective for single-component faults

- Limited applicability for multi-component degradation scenarios

3.6 Integrated Diagnostic Framework

The proposed methodology integrates:

- Trend plot analysis
- Parameter ratio evaluation
- Fault diagnosis charts (FIM)

This combined approach improves fault identification accuracy and supports predictive maintenance strategies.

4. RESULTS AND DISCUSSION

4.1 Trend Guideline Charts

Trend guideline charts are used as a primary reference for interpreting variations in engine parameters under different operating conditions. These charts correlate changes in ΔITT, ΔFF, ΔN2, and vibration parameters with specific component-level faults. Tables 3.1.1 and 3.1.2 provide standard trend patterns for fault identification. These charts help distinguish between gradual deterioration, sudden component failure, and instrumentation or measurement errors. The guideline charts serve as the first step in fault diagnosis.

4.2 Parameter Ratio Chart Analysis

The parameter ratio method provides a quantitative approach for identifying engine faults by comparing relative parameter variations. The ratios are defined as ITT Ratio = ΔITT / ΔITT, Fuel Flow Ratio = ΔFF / ΔITT, and Speed Ratio = ΔN2 / ΔITT. These ratios are compared with reference values derived from engine models. This method enables precise identification of single-component faults and improves diagnostic accuracy when combined with trend analysis.

4.3 Component Failure Case Studies

4.3.1 Start Bleed Tube Failure (Compressor Air Leakage)

Loose or failed connections in the bleed system cause compressor air leakage. Observed trends show an increase in ITT, FF, and N2 at cruise, along with a decrease in ITT and N2 margins at take-off. A step increase in trend plots is also observed. For example, ΔITT = 46°C, ΔFF = 6.0%, and ΔN2 = 0.8%, resulting in ratios of ITT = 1.00, FF = 0.130, and N2 = 0.017. These values confirm a bleed leak fault. This condition indicates compressor inefficiency and requires inspection of bleed tubes and connections.

4.3.2 Burned Hp Turbine Nozzle Guide Vanes

This case represents a hot section failure. The observed trends include an increase in ITT and FF, a decrease in N2 at cruise, and a decrease in ITT margin with an increase in N2 margin at take-off. For example, ΔITT = 25°C, ΔFF = 2.0%, and ΔN2 = −0.3%, resulting in ratios of ITT = 1.00, FF = 0.080, and N2 ≈ −0.012. These values indicate HP turbine deterioration and were confirmed through borescope inspection.

4.3.3 Sticking Compressor Bleed Valve

A sticking bleed valve causes intermittent spikes in take-off data. The observed behavior includes spikes in ITT and N2 margins during take-off, while cruise data remains normal. This indicates temporary valve opening due to sticking. Cleaning or replacement of the bleed valve is recommended.

4.3.4 Circumferential Temperature Profile Shift

Large fluctuations in ITT (greater than ±10°C) are observed in this condition. Possible causes include thermocouple failure, fuel nozzle deterioration, or combustion liner distress. This condition significantly affects ITT but has minimal effect on N2. It represents measurement distortion rather than actual performance degradation.

4.4 Data Acquisition And Testing Procedure

4.4.1 Central Maintenance Computer (Cmc) Testing

The Central Maintenance Computer ensures proper system operation by verifying data memory, program memory, timers, and the interrupt controller. It performs continuous self-tests using Built-In Test Equipment (BITE). Any malfunction is indicated by a **CMC FAIL message** on the EICAS display.

4.4.2 Data Collection Methods

Two types of data collection are used: data through the Multi-Function Display (MFD) and data through a personal computer using the Data Acquisition System (DAS).

4.4.3 Mfd Data Download Procedure

The procedure involves energizing the aircraft using an external DC power supply and accessing the maintenance page through the MFD by selecting MFD, JSTK, and MAINT options. Maintenance messages are then displayed and can be reset if required using the CMC RESET switch, which must be held for 10 seconds.

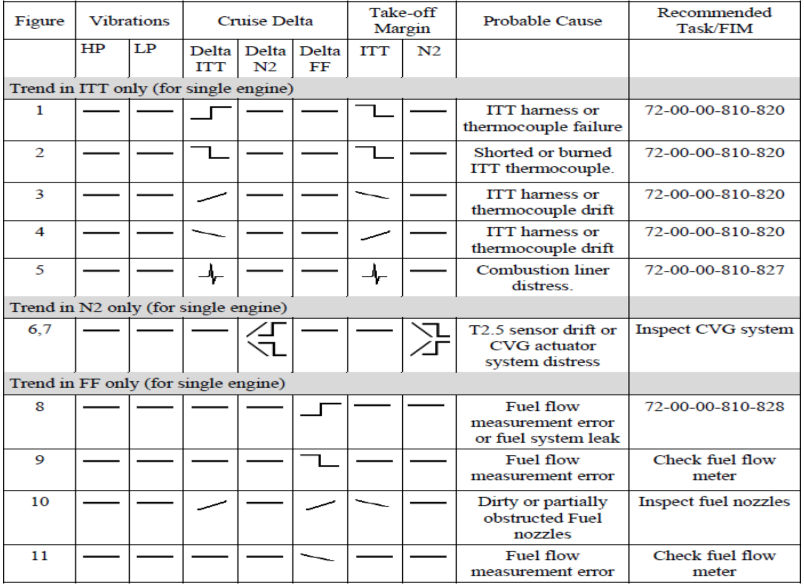


Figure	Vibrations		Cruise Delta			Take-off Margin		Probable Cause	Recommended Task/FIM
	HP	LP	Delta ITT	Delta N2	Delta FF	ITT	N2		
Trend in ITT only (for single engine)									
1	—	—	_|‾	—	—	‾|_	—	ITT harness or thermocouple failure	72-00-00-810-820
2	—	—	‾|_	—	—	‾|_	—	Shorted or burned ITT thermocouple.	72-00-00-810-820
3	—	—	/	—	—	\	—	ITT harness or thermocouple drift	72-00-00-810-820
4	—	—	\	—	—	/	—	ITT harness or thermocouple drift	72-00-00-810-820
5	—	—	-/\/-	—	—	-/\/-	—	Combustion liner distress.	72-00-00-810-827
Trend in N2 only (for single engine)									
6,7	—	—	—	/_|‾ \‾|_	—	—	\‾|_ /_|‾	T2.5 sensor drift or CVG actuator system distress	Inspect CVG system
Trend in FF only (for single engine)									
8	—	—	—	—	_|‾	—	—	Fuel flow measurement error or fuel system leak	72-00-00-810-828
9	—	—	—	—	‾|_	—	—	Fuel flow measurement error	Check fuel flow meter
10	—	—	/	—	/	\	—	Dirty or partially obstructed Fuel nozzles	Inspect fuel nozzles
11	—	—	—	—	\	—	—	Fuel flow measurement error	Check fuel flow meter

Fig .4. Trend Guideline Chart 2

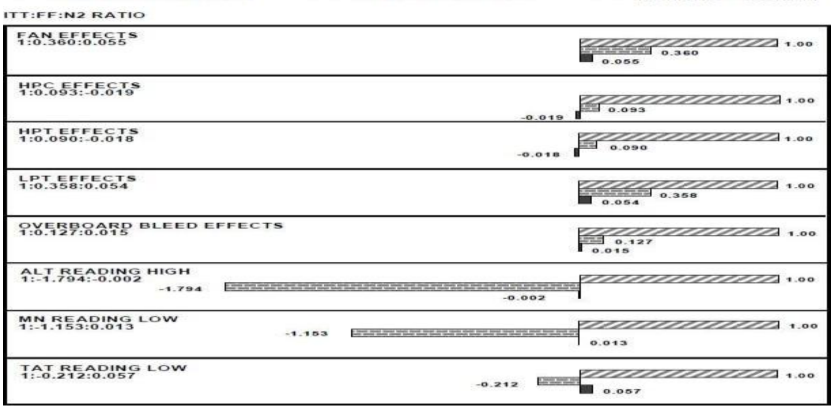


Fig .6. Ratio Chart

4.5 Component-To-Component Critical Failure Data

Engine trend monitoring enables identification of critical component failures through analysis of parameter variations such as ΔITT, ΔFF, and ΔN2. The following case studies illustrate typical failure modes and their corresponding trend signatures.

4.5.1 Start Bleed Tube Failure (Compressor Air Leakage)

Loose connections or failed tubes connecting the start bleed control valve to compressor air bleed valves result in **compressor air leakage**. This leakage leads to an increase in **Inter Turbine Temperature (ITT)**, **Fuel Flow (FF)**, and **High-Pressure Shaft Speed (N2)**.

At cruise conditions, the parameter ratio for compressor air leakage is approximately **1.00:0.127:0.015**.

Observed Trends:

- Step increase in ITT, FF, and N2 at cruise
- Step decrease in ITT and N2 margins at take-off

Example Calculation:

- ΔITT = 46°C
- ΔFF = 6.0%
- ΔN2 = 0.8%

Ratios:

- ITT = 1.000
- FF = 0.130
- N2 = 0.017

These values confirm a **bleed leak fault**, indicating compressor inefficiency due to air loss.

4.5.2 Burned Hp Turbine Nozzle Guide Vanes

A deteriorated high-pressure turbine (hot section damage) is characterized by abnormal thermal behavior.

Observed Trends:
- Increase in ITT and FF
- Decrease in N2 at cruise
- Decrease in ITT margin and increase in N2 margin at take-off

Example Calculation:
- $\Delta ITT = 25°C$
- $\Delta FF = 2.0\%$
- $\Delta N2 = -0.3\%$

Ratios:
- ITT = 1.000
- FF = 0.080
- $N2 \approx -0.012$

These values correspond to **HP turbine deterioration**, confirmed via borescope inspection. The accelerated deterioration rate indicates severe hot section damage.

4.5.3 Sticking Compressor Bleed Valve

A sticking compressor bleed valve causes intermittent performance deviations.

Observed Behavior:
- Spikes in ITT and N2 margins during take-off
- Normal parameter trends during cruise

This indicates that the valve remains temporarily open during take-off and closes once pressure increases. The absence of cruise anomalies confirms intermittent malfunction.

Corrective Action:

Cleaning or replacement of the bleed valve.

4.5.4 Circumferential Temperature Profile Shift

Large fluctuations in ITT (greater than ±10°C) indicate a circumferential temperature distribution issue.

Possible Causes:
- Thermocouple failure
- Fuel nozzle deterioration
- Combustion liner distress

This condition significantly affects ITT but has minimal influence on N2. Since ITT is an average of multiple thermocouples, uneven temperature distribution results in measurement fluctuations rather than actual performance degradation.

4.6 Data Acquisition And Methodology

4.6.1 Central Maintenance Computer (Cmc) Operational Test

The Central Maintenance Computer (CMC) ensures proper system functionality through:
- Verification of data memory, program memory, timers, and interrupt controller
- ARINC bus input checks
- Continuous self-testing using Built-In Test Equipment (BITE)

Any malfunction is indicated by a **CMC FAIL message** on the Engine Indicating and Crew Alerting System (EICAS).

4.6.2 Data Collection Methods

Two methods are used for engine data collection:
1. **Multi-Function Display (MFD) based data retrieval**
2. **Personal Computer (PC) based data acquisition using DAS software**

4.6.3 Cmc Data Download Using Mfd Procedure:

1. Energize aircraft using external DC power
2. Access maintenance page:
    ○ Press MFD → JSTK → MAINT
3. View maintenance messages
4. Reset messages if required using CMC RESET (hold for 10 seconds) This method allows quick onboard diagnostics.

4.6.4 Cmc Data Download Using Personal Computer Procedure:

1. Ensure aircraft is safe and powered
2. Connect PC to CMC maintenance connector
3. Launch Data Acquisition Software (DAS)
4. Select **“Trend & Exceedance”** for data download
5. Save and analyze data

For aircraft with non-serviceable CMC, manual data recording is performed under stabilized flight conditions above 20,000 ft.

4.6.5 Manual Flight Data Recording

Under steady flight conditions, the following parameters are recorded:

- Aircraft identification
- Date and time
- N1 and N2 (%)
- Fuel flow
- Mach number
- Vibration parameters (VB1, VB2)

4.7 Engine Trend Analysis

Engine trend data is analyzed using specialized tools such as **Compass Navigator Trend Program**. The analysis identifies:

- Step changes (sudden faults)
- Gradual trends (deterioration)
- Spikes (intermittent faults)

4.8 Discussion

The analysis demonstrates that:

- Trend monitoring enables early fault detection
- Parameter ratios improve diagnostic accuracy
- Combined analysis reduces maintenance cost and prevents major failures However, challenges include:
- Multiple component degradation affecting accuracy
- Instrumentation errors leading to misinterpretation

5. IMPLEMENTATION AND INDUSTRIAL RELEVANCE

5.1 Maintenance Planning Using Engine Trend Monitoring

Engine trend monitoring supports predictive maintenance by identifying performance degradation early. For example, detection of abnormal temperature rise and fuel consumption can indicate compressor damage, preventing severe failures and reducing maintenance costs.

5.2 Role Of Big Data In Aviation Maintenance

Modern aircraft generate large volumes of data per flight. Analysis of this data enables:

- Improved fuel efficiency
- Enhanced safety monitoring
- Better operational decision-making

Key Benefits:

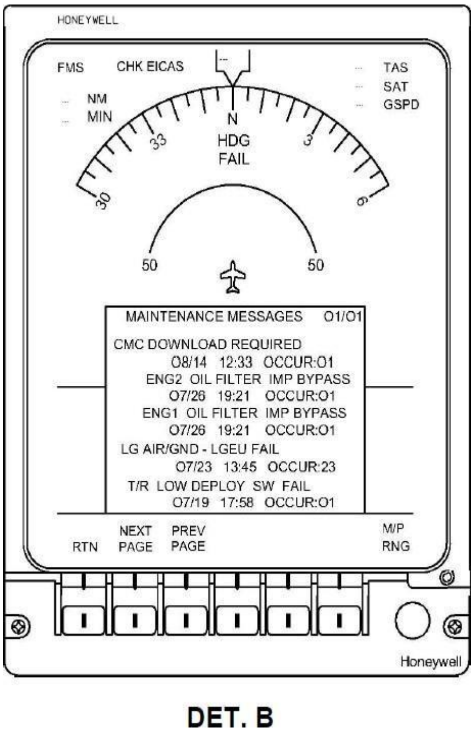
1. **Smarter Maintenance**
   - Optimizes fuel consumption
   - Reduces operational costs
2. **Safer Flights**
   - Identifies risks using flight data
   - Improves regulatory decision-making

5.3 Predictive Maintenance Systems

Advanced predictive maintenance systems provide:

- Real-time monitoring
- Alerts and notifications
- Maintenance dashboards
- Inventory and cost tracking

These systems reduce unplanned maintenance, minimize downtime, and improve overall operational efficiency.



MAINTENANCE MESSAGES 01/01
CMC DOWNLOAD REQUIRED
08/14 12:33 OCCUR:01
ENG2 OIL FILTER IMP BYPASS
07/26 19:21 OCCUR:01
ENG1 OIL FILTER IMP BYPASS
07/26 19:21 OCCUR:01
LG AIR/GND - LGEU FAIL
07/23 13:45 OCCUR:23
T/R LOW DEPLOY SW FAIL
07/19 17:58 OCCUR:01

Fig. 7 . MFD Data

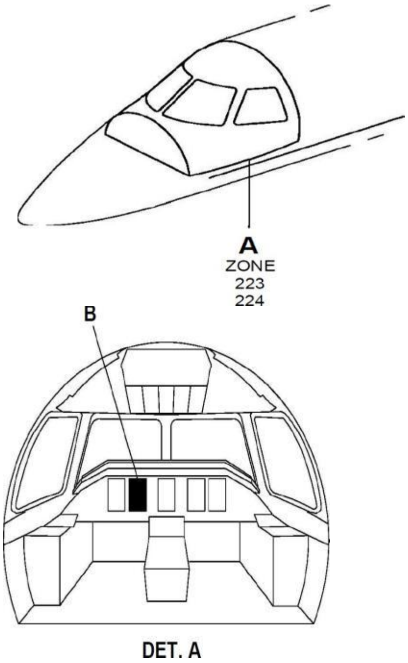


Fig. 8 . Location

Table 201 - ENGINE TREND DOWNLOAD/ANALYSIS DATA COLLECT FORM

FLIGHT DATA		
Aircraft S/N or Identification______	Data of record:___/___/____	
TAT (Degrees °C)______________	Time of record:__________	
Mach number:________________	Aircraft altitude:__________	
Engine Data	LEFT ENGINE	RIGHT ENGINE
N1 (%)		
FADEC in control		
ITT (Degrees °C)		
N2 (%)		
Fuel flow (lb/hr or Kg/hr)		
VB1 (ips)		
VB2 (ips)		

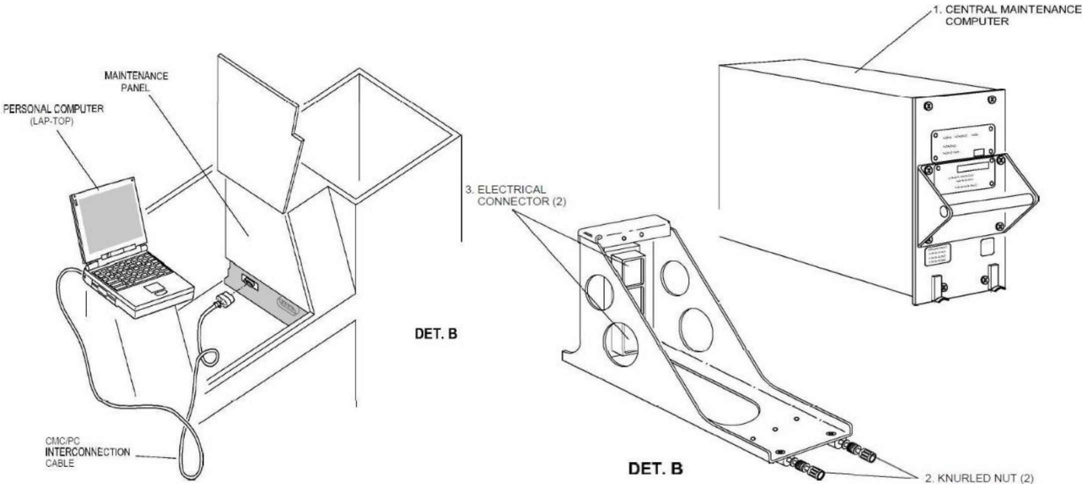
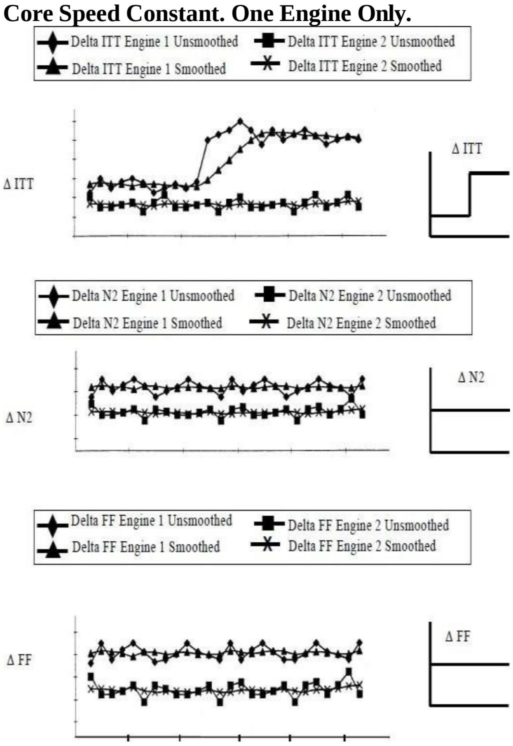


Fig 9. Manual Flight Data

5.4 Figures

Cruise Symptom: Step Change Increase In Delta Itt (Decrease In Itt Margin).
Fuel Flow Constant. Core Speed Constant. One Engine
Take-Off Symptom: Step Change Decrease in ITT Margin.
Core Speed Constant. One Engine Only.



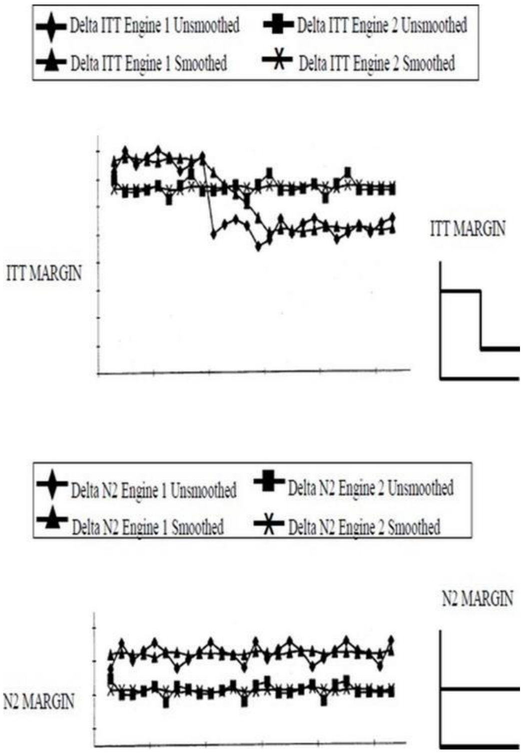
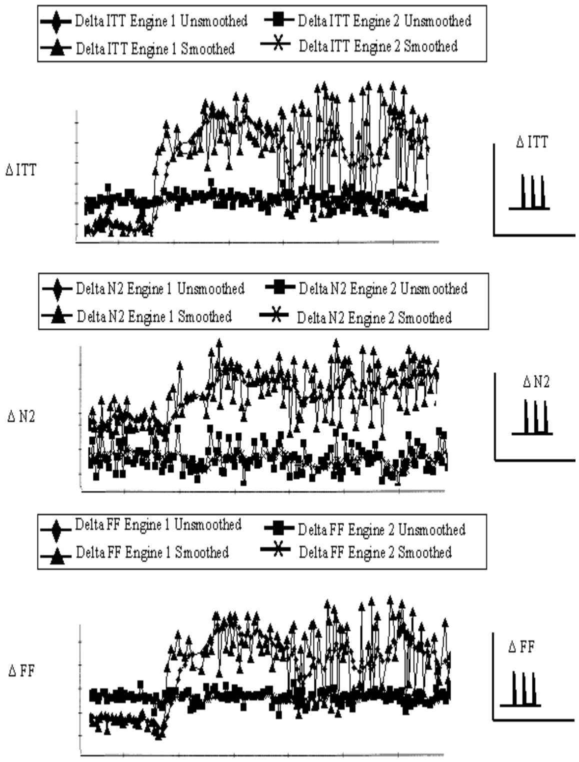
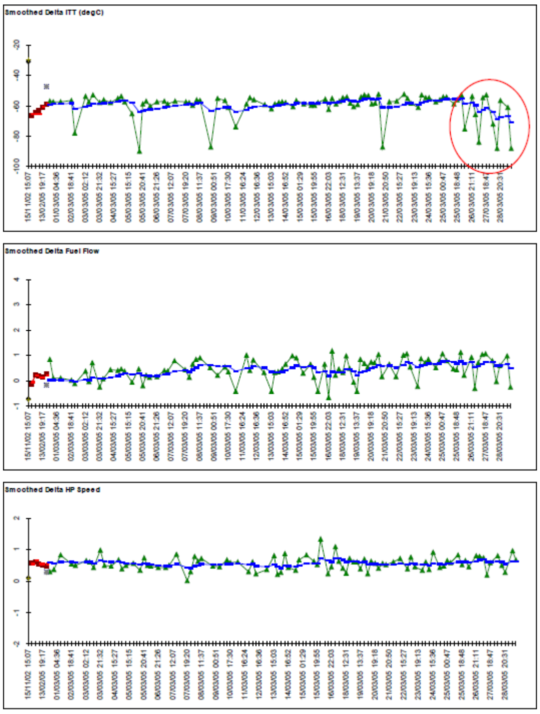


Fig 10. Constant Graph

Fig11. Step Down

CRUISE SYPMPOM: STEP AND/OR SPIKES IN DELTA ITT, FUEL FLOW AND CORE SPEED ONE ENGINE.





Combustion Liner Distress (Spikes) - Cruise Trends

Fig 11. Spike Graph

Fig12. Combustion Liner

Distress Graph

Fig 13.Full Fledge AI Installation with 24 x7 monitoring

6. CONCLUSION

This study demonstrates the effectiveness of Aircraft Engine Condition Monitoring (ECM) systems in enhancing engine reliability, safety, and operational efficiency. By utilizing Engine Condition Trend Monitoring (ECTM) techniques, critical engine parameters such as Inter Turbine Temperature (ITT), Fuel Flow (FF), and High-Pressure Shaft Speed (N2) were analyzed to assess engine performance and detect early signs of deterioration.

The results confirm that trend analysis is a powerful diagnostic tool capable of identifying both gradual degradation and sudden performance deviations caused by component failures. The integration of COMPASS-based trend plots with parameter ratio methods significantly improves fault detection accuracy and supports efficient troubleshooting using the Fault Isolation Manual (FIM). Furthermore, the study highlights that monitoring engine performance under both cruise and take-off conditions provides a comprehensive understanding of engine health. The use of margin analysis and SLOATL-based assessment ensures safe engine operation within prescribed limits. The parameter ratio method proves particularly effective in diagnosing single-component faults, although its applicability is limited in cases involving multiple component degradation.

Overall, the implementation of ECM enables predictive maintenance, reducing unplanned engine removals, minimizing Aircraft-on-Ground (AOG) situations, and lowering maintenance costs. The study emphasizes that advanced data-driven monitoring systems are essential for modern aviation, as they enhance decision-making, improve fuel efficiency, and ensure safe aircraft operations. Future advancements may include the integration of machine learning and artificial intelligence techniques for automated fault detection and real-time predictive analysis, further improving the effectiveness of engine condition monitoring systems.

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