ANA's Predictive Maintenance Challenge
Replace Aircraft Parts Before They Break

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Agenda

1. Our Company
2. Predictive Maintenance of Commercial Aircraft
3. Case Study – Boeing 787 Air Conditioning System
4. Conclusion
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### ALL NIPPON AIRWAYS CO., LTD. (ANA)

<table>
<thead>
<tr>
<th><strong>Foundation</strong></th>
<th>December 27, 1952</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of employees</strong></td>
<td>13,689 employees (42,196 employees, ANA Group)</td>
</tr>
</tbody>
</table>

**Principal Purpose**

- Scheduled & Non-scheduled air transportation business
- Business of buying, selling, leasing and maintenance of aircraft and aircraft parts
- Aircraft transportation ground support business including passenger boarding procedures and loading of hand baggage

| **Number of Aircraft** | 227 Passenger aircraft
Airbus A320, A321, A380,
Boeing 737, 767, 777, 787
DHC-8-400
- 11 Cargo aircraft
Boeing 767, 777 |

(as of March 31, 2022)
1. Our Company
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Corrective maintenance is always unexpected and costs additional resources.

Predictive maintenance allows work to be performed at the optimal time, before failures.

Data analytics and solution services are also provided from manufacturers and MRO* companies.

*: Maintenance, Repair and Overhaul
What we do with MATLAB®

Operational Data | Domain Knowledge
--- | ---
Time series sensor data (QAR/CPL) | Various sensor data (QAR/CPL) can be acquired thanks to integration of avionics.
Maintenance records etc. | Finding insights requires vast and various data and analysis.

Data Analysis/Data Science
- Visualization
- Hypothesis testing
- Trouble-shooting
- Signs of failure

INSIGHTS

✓ Various sensor data (QAR/CPL) can be acquired thanks to integration of avionics.
✓ Finding insights requires vast and various data and analysis.
✓ MATLAB can not only visualize and analyze data, but also deploy models easily (p.17).
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Introduction of Air Conditioning System

Airplanes fly high altitude

Function of Air Conditioning System needs
- Maintain cabin pressure near ground level
- Maintain comfortability of cabin

Space of airplane is limited

Structure of Air Conditioning System needs
- Simple
- Compact
- Lightweight

Method of Air Cycle Refrigeration satisfy conditions

Location of Air Conditioning System

- Set two identical systems for safety reasons
- Located under cabin area (red and blue)
Overview of Air Conditioning System & Cabin Air Compressor

Source Air: **High temperature & High pressure air**

- **Generate steady air**
  - Low temperature
  - Low pressure

**Detail of One side**

- **External view**
  - From CAC1
  - From CAC2

**Cross Section view**

<table>
<thead>
<tr>
<th>Name</th>
<th>Cabin Air Compressor (CAC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>1st stage centrifugal compressor</td>
</tr>
<tr>
<td>Role</td>
<td>Compression of outside air</td>
</tr>
<tr>
<td>Main parts</td>
<td>① Journal Bearing, ② Thrust Bearing, ③ Stator, ④ Shaft, ⑤ Impeller</td>
</tr>
<tr>
<td>Specification</td>
<td>Type of Bearings are Air Bearing</td>
</tr>
</tbody>
</table>
Process of Analysis

1. Decision of Target Failure
2. Hypothesis Planning
3. Hypothesis Verification
Decision of Target Failure

Target Failure: Journal Bearing Failure

Failure parts of CAC:
- Journal Bearing: 51%
- Thrust Bearing: 4%
- Motor Stator: 40%
- Other: 5%

Diagram:
- External View
- Cross section View
- Air
- Shaft
- Outer Housing
- Top Foil
- Inner Foil
Process of Analysis 2

Hypothesis Planning

Use deep domain knowledge (2 elements)

Knowledge from Component

- Confirm condition of Journal Bearing
- Confirm other degradation

Inner of Journal bearing is deformed when degrade

Knowledge from Document or Flight Data

- Clarify operation & Behavior of CAC or Components around CAC

Degradation is related to other failure
  - Rubbing (Contact Impeller & Housing)
  - Burn out Stator (Contact Shaft & Stator)
Process of Analysis 3

Hypothesis Verification

Verify the hypothesis based on flight data
Based on Hypothesis & Flight data

Method
Using about 300 flight data.
(About 1 year of an aircraft)

- Download Flight Data from Server by CSV file
- Conversion to MAT file

Find feature of degradation on repeating trial and error
Result of Detection

- A. Calculate average of a parameter on a part of flight
- B. Compare other CAC operating in parallel
  - Calculate difference of CAC1 and CAC2

Found balance of CAC 1&2 was collapsed before failure
Comparing two systems running in parallel can make it challenging to set a threshold.

A machine learning model was developed using features extracted from sensor and external environment data. True labels were extracted from maintenance records.

- Developed a classification model using Statistics and Machine Learning Toolbox™ - Classification Learner (Narrow Neural Network)
Results / Prediction Accuracy

The model-based degradation index tends to increase as the failure approaches.

Placed a higher priority on precision to avoid false-positive alarms.

**Precision**
\[ \text{Precision} = \frac{\text{True Positives}}{\text{Retrieved Cases}} \]

77%

**Recall**
\[ \text{Recall} = \frac{\text{True Positives}}{\text{All Failure Cases}} \]

23%
Deploy and Operation

Data Correction
- Sensor data during flight
- Other external environments

Data Processing
- Pre-processing
- Estimation by ML model
- Output results

Monitoring / Visualization
- Degradation dashboard
- Maintenance Planning

Automated data pipeline by MATLAB Compiler™

Several CAC bearing degradations were found before failure
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 **Predictive maintenance** reduces aircraft downtime and improves the overall efficiency.

 Complex system data analysis (e.g. flight data) requires **domain knowledge**.

 Operators are trying to find **insights** from their domain knowledge and operational data.

 Case study shows that the **machine learning** can be also applied to anomaly detection based on the insights.

## Future Goals

 Improve **the precision & recall**, as well as **the interpretability** of machine learning models.

 Accelerate “**Data-driven maintenance**” in order to improve our productivity.
THANK YOU