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AIRCRAFT VIBRATION FROM REACT TO PREDICT

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Abstract: Aircraft vibration is a natural occurrence due to various sources such as engine imbalance, aerodynamic forces, system abnormality, worn components, …. When aircraft vibration occurs, it can be identified by people inside the aircraft. Depending on the source of the vibration, it may be experienced either as a physical movement, or as noise, or as both a movement and noise. These experiences can cause passenger concern and discomfort. Today, the process to handle aircraft vibration is subjective and strongly dependent on pilot/flight crew. (ref [1])

This article will present an alternative process based on data for identifying, continuously monitoring vibration source(s) and then predicting the coming vibration event(s). Within this process, existing aircraft sensors (low bit depth and low sampling rate) will be processed and compared with a vibration database, flight by flight, for detecting any abnormal vibration. The vibration database has been built based on several ground/flight dynamic tests and validated aeroelastics models.

1 INTRODUCTION

Aircraft vibration is a natural occurrence due to various sources such as engine imbalance, aerodynamic forces, system abnormality, worn components, …. When aircraft vibration occurs, it can be identified by people inside the aircraft. Depending on the source of the vibration, it may be experienced either as a physical movement, or as noise, or as both a movement and noise. These experiences can cause passenger concern and discomfort. These vibrations do not create any handling or performance concern, and cannot diverge into flutter since they are damped by the surrounding structure and systems. However, to prevent further degradation of equipment, they should be resolved quickly.

Since airframe vibrations only occur during flight, to troubleshoot the vibration sources, maintenance personnel will need pilots to perform in-flight actions and to make observations of the vibration, then fulfill the Vibration Report Sheet (VRS). Today, the official process to handle aircraft vibration is subjective and strongly dependent on pilot/flight crew. (ref [1])

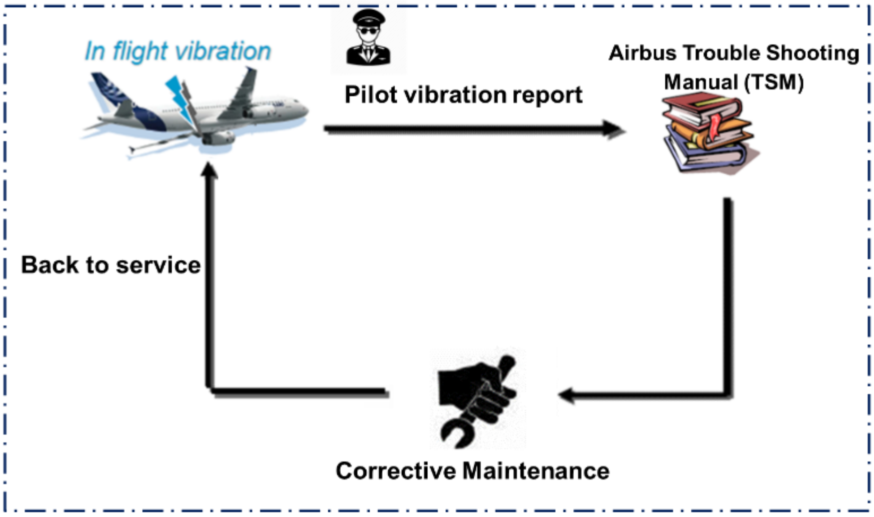


Figure 1 - Vibration troubleshooting process

In many cases, when the vibration occurs, the pilot can't perform all necessary in-flight actions and can't fulfill the VRS. Lack of information in the vibration report may lead to very long troubleshooting.

To facilitate the troubleshooting process, especially in case of missing information from the pilot, a state-of-the-art solution has been developed based on

- Aircraft available data such as Aircraft Condition Monitoring System (ACMS) , Digital Flight Data Recorder (DFDR), Flight Operations & MAintenance eXchanger (FOMAX), …

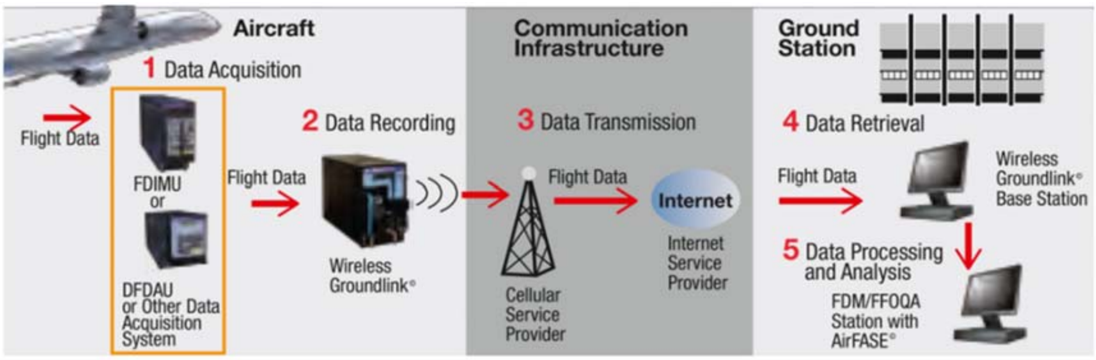


Figure 2 - Example of Wireless ground link system (ref [2])

- Airbus has many years of accumulated development experience (Ground Vibration Tests, Flight Vibration Tests) and in-service experience & vibration database.

Figure 3 - Ground Vibration Test (GVT) of the BelugaXL (Source ©Airbus Photolib)

2 AIRCRAFT VIBRATION OVERVIEW

Aircraft vibration is a natural occurrence due to various sources such as engine imbalance, aerodynamic forces, system abnormality, worn components, …. Depending on Aircraft type, the common sources of vibration can be varied from structure worn components to engine imbalance, aerodynamic excitation, … or combination of several sources. For the A320 Family, in 2010 Airbus organized a FAIR working group with airlines to identify the causes of vibration. (ref [1])

Figure 4. Reported Origin of Airframe Vibration

3 DATA BASED VIBRATION TROUBLESHOOTING PROCESS (REACT)

The main purposes of Data Based vibration troubleshooting process are

- to quickly identify the vibration source(s) by using Aircraft existing sensors (REACT)
- then, to monitor the vibration source(s) flight by flight, for detecting any coming abnormal vibration (PREDICT)

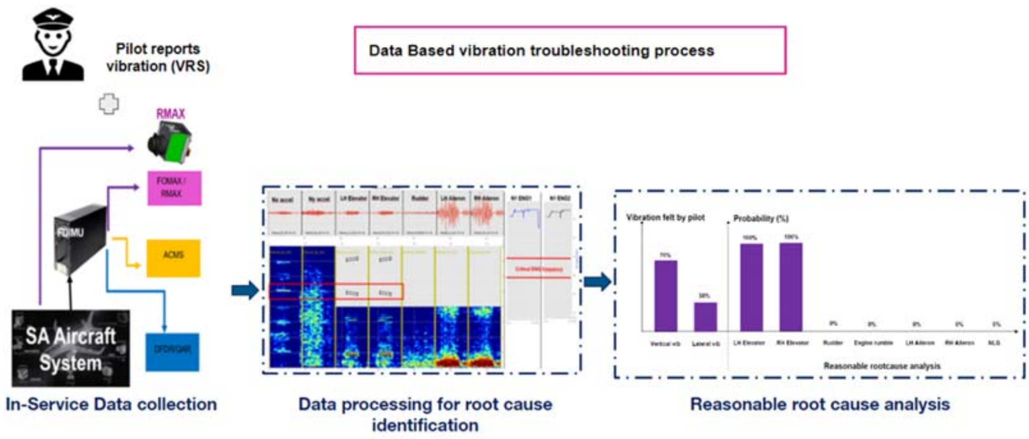
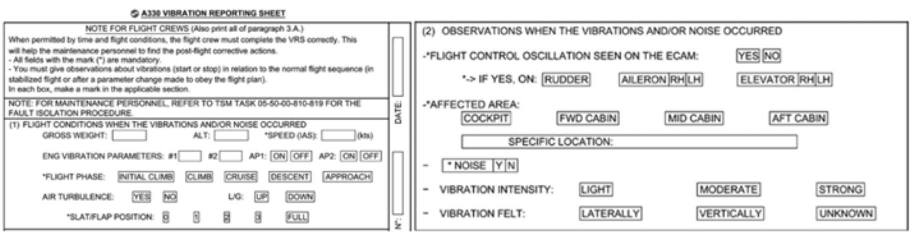


Figure 5 - Data Based vibration troubleshooting process

When an aircraft experiences vibration occurs in flight or on ground, the pilot will report the vibration event via Vibration Report Sheet. Data Based Vibration troubleshooting process will be launched with below steps.

3.1 STEP1 : In-service Data collection

The information of vibration event can be extracted from Vibration Reporting Sheet . In many cases, the report has not been fulfilled, and there is only some general information of the eventful flight such as data, GMT, altitude, …


A330 VIBRATION REPORTING SHEET

NOTE FOR FLIGHT CREWS (Also print all of paragraph 3.A.)
When permitted by time and flight conditions, the flight crew must complete the VRS correctly. This will help the maintenance personnel to find the post-flight corrective actions.
- All fields with the mark (*) are mandatory.
- You must give observations about vibrations (start or stop) in relation to the normal flight sequence (in stabilized flight or after a parameter change made to obey the flight plan).
In each box, make a mark in the applicable section.

NOTE: FOR MAINTENANCE PERSONNEL, REFER TO TSM TASK 05-50-00-810-819 FOR THE FAULT ISOLATION PROCEDURE.

(1) FLIGHT CONDITIONS WHEN THE VIBRATIONS AND/OR NOISE OCCURRED
GROSS WEIGHT: ALT: *SPEED (IAS): (kts)
ENG VIBRATION PARAMETERS: #1 #2 AP1: ON OFF AP2: ON OFF
*FLIGHT PHASE: INITIAL CLIMB CLIMB CRUISE DESCENT APPROACH
AIR TURBULENCE: YES NO L/G: UP DOWN
*SLAT/FLAP POSITION: 0 1 2 3 FULL

DATE:
N°:

(2) OBSERVATIONS WHEN THE VIBRATIONS AND/OR NOISE OCCURRED
-*FLIGHT CONTROL OSCILLATION SEEN ON THE ECAM: YES NO
*-> IF YES, ON: RUDDER AILERON RH LH ELEVATOR RH LH
-*AFFECTED AREA:
COCKPIT FWD CABIN MID CABIN AFT CABIN
SPECIFIC LOCATION:
- * NOISE Y N
- VIBRATION INTENSITY: LIGHT MODERATE STRONG
- VIBRATION FELT: LATERALLY VERTICALLY UNKNOWN

Figure 6 – The Vibration Reporting sheet (ref [1])

Aircraft data of eventful flight will be collected. Depending on the available data recorder(s), aircraft data can be automatically collected (FOMAX/RMAX) or manually collected (ACMS/DFDR/QAR). Then vibration event (GMT, altitude, …) will be correlated with Aircraft data (acceleration, altitude, airspeed, control surface position, …) for identifying the period of event.

3.2 STEP2: Data processing for root cause identification

Correlated aircraft data from previous step will be then analyzed and compare with Airbus Vibration database (see Fig.5) for identifying the root cause

When using Aircraft sensors for detecting vibration, there are two major challenges to be overcome

- limit number of sensors (accelerometers , displacement sensors, ..) can be used for detecting vibration
- Sensors have very low sampling rate (less than one-half of vibration's frequency - 'Nyquist frequency')

A state of the art for solving the above major challenges has been developed and patented [Ref.4] . Based on many years of accumulated development experience and in-service experience, the vibration database has been generated for each production aircraft. The vibration database is composed of the signature of vibration (frequency, aircraft deformation , altitude , airspeed , …). This vibration database has been continuously updated with big data collection from in-service aircrafts and testing aircrafts (Ground Vibration Tests [Ref.3], Flight Vibration Tests) .

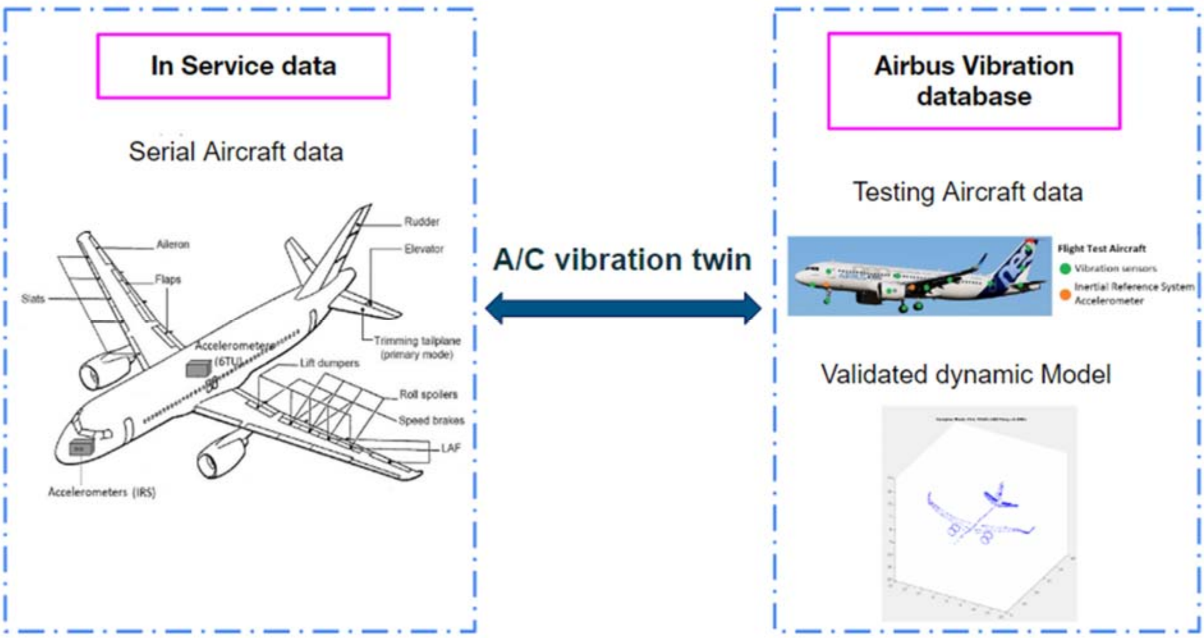


figure 7 - Aircraft vibration twin

By the combination of the data from different ATAs (accelerations from Inertial Reference System , altitude , airspeed, control surfaces' positions, aircraft weight & CG, …) , the root cause of vibration can be identified and associated with vibration amplitude measured by Inertial Reference System.

A team of airbus specialists for vibration starts to analyze this data. With the knowledge of the aircraft dynamics and the dynamics of components specific tools/methods have been created.

Another crucial aspect is distinguishing between normal vibrations caused by turbulence and abnormal vibrations originating from the aircraft itself, see figure 8 with various types of loadings and vibrations.

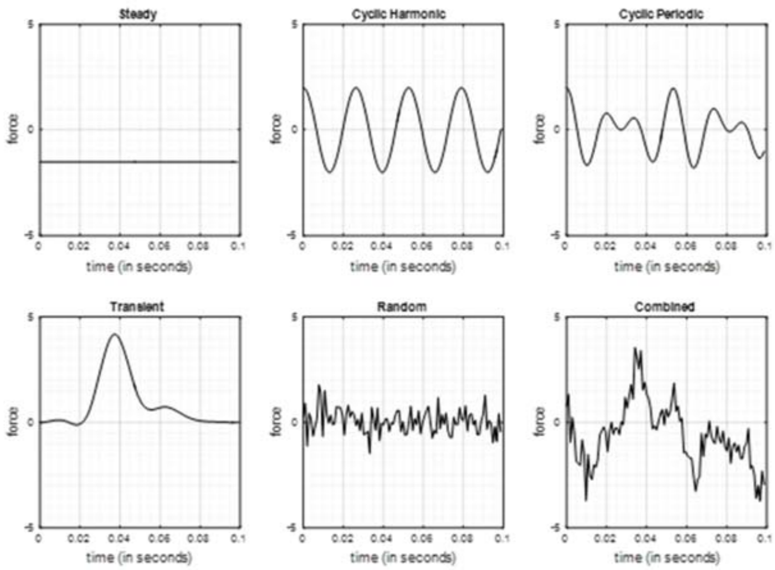


figure 8 - Various loading and vibration types

In some cases, the data may have low sample rates, making it challenging to accurately represent the vibration frequencies. However, with the data from the development aircraft and the experience of the vibration specialists these frequencies can still be visualized. Techniques, such as signal processing algorithms and spectral analysis, together with a good understanding of the signal path inside the aircraft, enabling the identification of vibration frequencies, see figures 9 & 10.

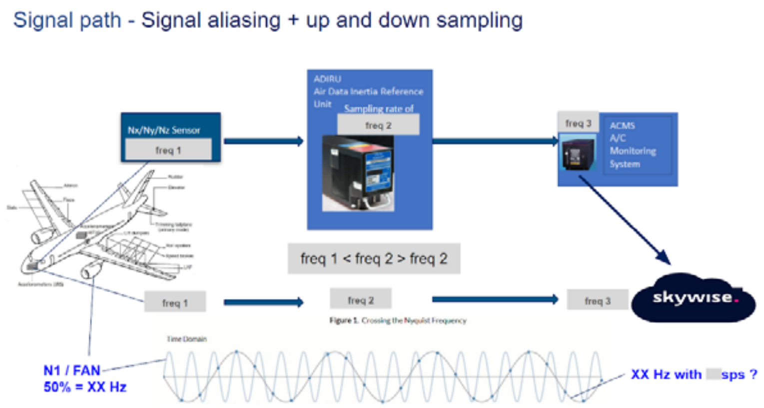


Figure 9 - Signal path aliasing effect

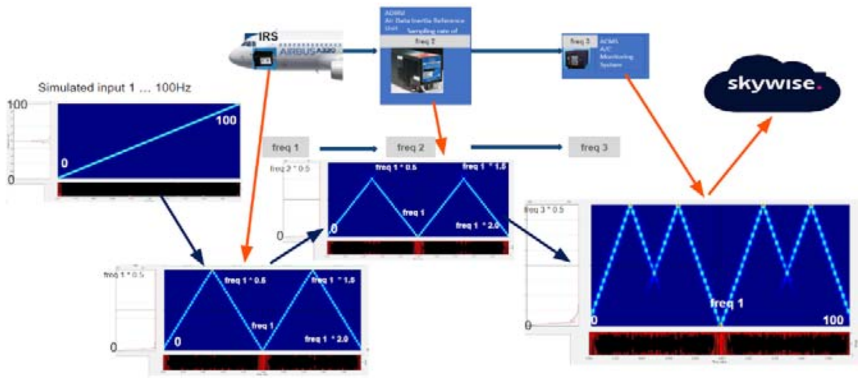


Figure 10 - Signal path Aliasing + up and down sampling

Additionally, demonstrators of several machine learning algorithms have already been implemented and tested. This is also part of the project, to get accurate inputs with the vibration signatures for the machine learning process.

These specific codes/methods (figure 11) were used for troubleshooting and were also partially implemented in the big data environment from Palantir / skywise.

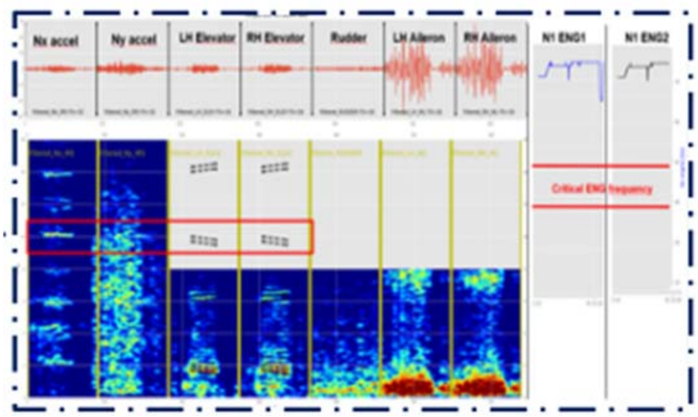


figure 11 - Tools and methods for troubleshooting

Below figure (Fig.12) shows an example for an aircraft engine N1/Fan imbalance, which may trigger a specific airframe eigenfrequency. This is known as engine / cabin rumble noise and could lead to comfort issues. The cabin rumbling noise phenomenon is also linked to a 3D-resonance of the air volume inside the fuselage. With the current investigations it is possible to make this effect visible for low sampled data from in-service aircrafts.

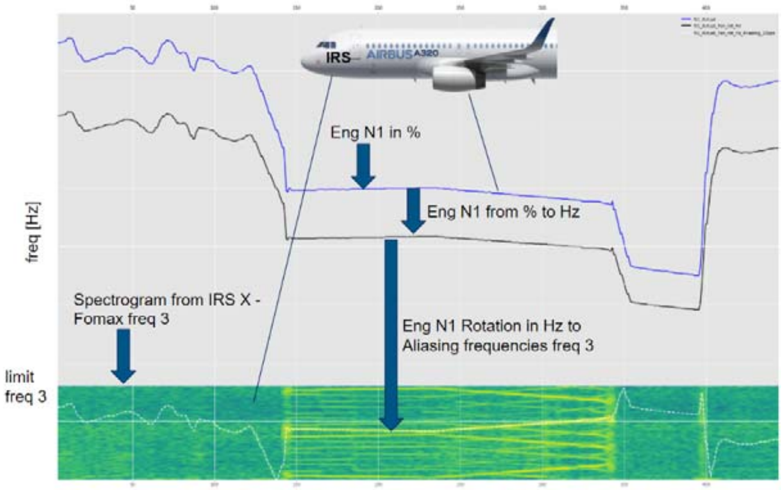


Figure 12 - Example N1 Fan imbalance

3.3 STEP3: Reasonable rootcause analysis

In this step, the vibration level correlated with pilot / flight crew report and suspected rootcause(s) with a given probability will be shown (Fig.13). In some cases, the vibration can be caused by several components.

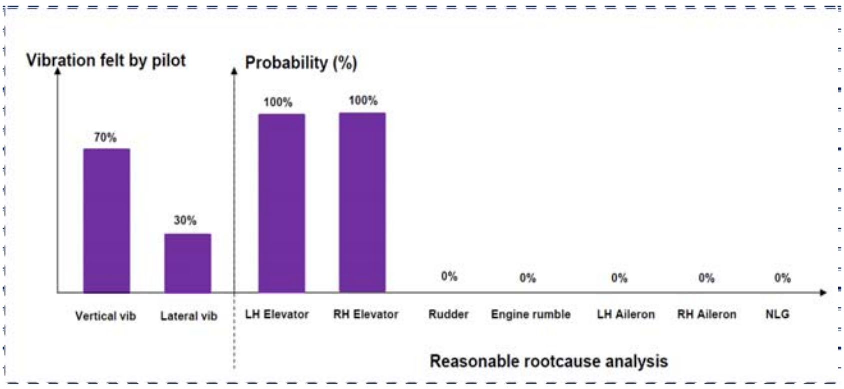


Figure 13 - Example of elevator vibration from Reasonable rootcause analysis

For each rootcause identified, the vibration troubleshooting process will propose to the maintenance team the relevant maintenance task(s) to solve the problem. The maintenance tasks can be a specific Troubleshooting Manual (TSM) or specific Aircraft Maintenance Manual (AMM).

4 PREDICTIVE MAINTENANCE FOR AIRCRAFT VIBRATION

In order to be a step ahead of vibration events, we propose the predictive maintenance approach for aircraft vibration. By monitoring the vibration source(s) flight by flight, it's possible to early detect the coming abnormal vibration to avoid Operational Interruption (OI) and Aircraft On Ground (AOG) due to vibration.

Aircraft data from each flight will be automatically collected and analyzed through Data Based troubleshooting Process. For each vibration source, the level of vibration will be compared with a threshold (Fig.14). The threshold is specific for each vibration source and has been created based on the Airbus vibration database. When the level of vibration exceeds the threshold, the cumulative event indicator will be increased (Fig.15). When the cumulative event exceeds a given threshold, the aircraft becomes prone to vibration and the maintenance task associated with vibration source must be performed to avoid the severe vibration.

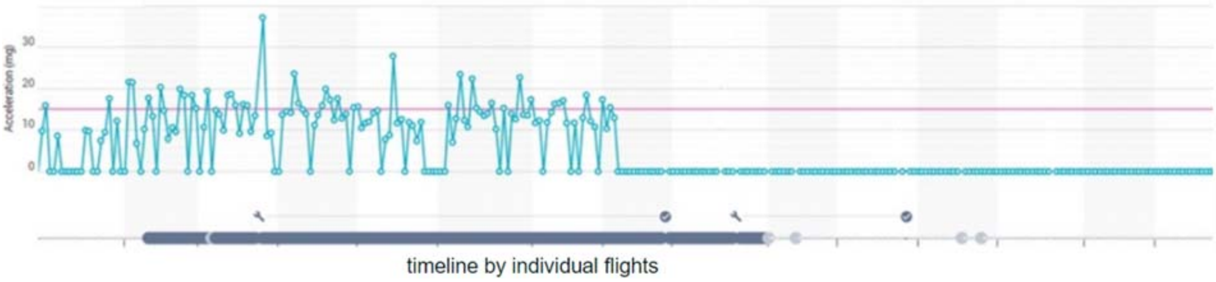


Figure 14 - Example of vibration monitoring flight by flight

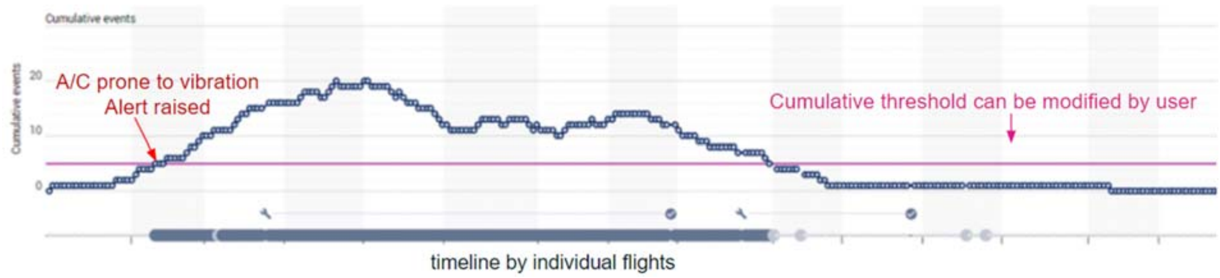


Figure 15 - Example of cumulative event index for triggering maintenance task

5 CONCLUSIONS

Today, the Airbus fleet benefits from many years of accumulated development and in-service experience, and is relatively free from reports of airframe vibration during flight. However, airframe vibrations are still sometimes reported. To speed up the troubleshooting process, we develop a state-of-the-art solution based on Aircraft existing data and Airbus vibration database. For some vibration sources, to avoid the Operational Interruption (OI) and Aircraft On Ground (AOG), we propose the Predictive Maintenance approach.

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