GROUND TEST VIBRATIONS AS NON-CONSERVATIVE MEANS OF COMPLIANCE FOR VIBRATION AIRWORTHINESS REQUIREMENTS OF A/C MECHANICAL SYSTEMS DESIGN.

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*Summary:* Vibrations requirements for aircraft (A/C) mechanical systems design are limited to series of standard environmental test conditions and procedures, which may be used to support compliance, as RTCA-DO160 or MIL-STD normative. Nevertheless, these procedures could be non-conservative in systems embedded in high airflow due to the fluid-structure coupling. This paper describes an example of real engineering equipment as the Auxiliary Power Unit (APU) flap door where the situation previously described takes place.

## ABSTRACT

It is extended practice in industry to justify vibrations requirements (CS-25.301, CS-25.305 and CS-25.1309) for design by means of qualifying the system against a standard spectrum as RTCA-DO160 or MIL-STD810.

This methodology can be adequate for non-aerodynamic structures, but when the mechanical system is embedded into high speed airflow, physic changes due to the effect of fluid-structure coupling could make the vibration spectrum not conservative: real responses of the structures during normal operation could be higher than the responses obtained on the shaker table.

The present work shows a real engineering application where this event can be found and it confirms this effect of fluid-structure coupling in the system structural response. In-flight and wind tunnel test vibrations of APU intake system are monitored with accelerometers and compared to ground qualification tests performed on shakers and FEM (Finite Element Model) random vibration analysis showing that the real excitation is higher than responses due to ground test spectrums.

## 1. EQUIPMENT DESCRIPTION

The APU air inlet is illustrated in Figure 1. The inlet duct provides the flow path of air to the APU. A side cooling duct is attached to the inlet via four joints on the side, and bonded to the upper flange. The cooling duct provides flow directly to the bay. The APU Inlet is located at the Rear End Fuselage of the aircraft. During the whole flight envelope, the APU air inlet door is subjected to unsteady aerodynamic excitation that leads to vibrations in the door. In this work, the flap door acceleration levels registered in flight test and wind tunnel tests are compared to acceleration levels measured in RTCA-DO160 ground vibration tests spectrum and to the response obtained from simulation when applying to the FEM the MIL-STD810 spectrum.

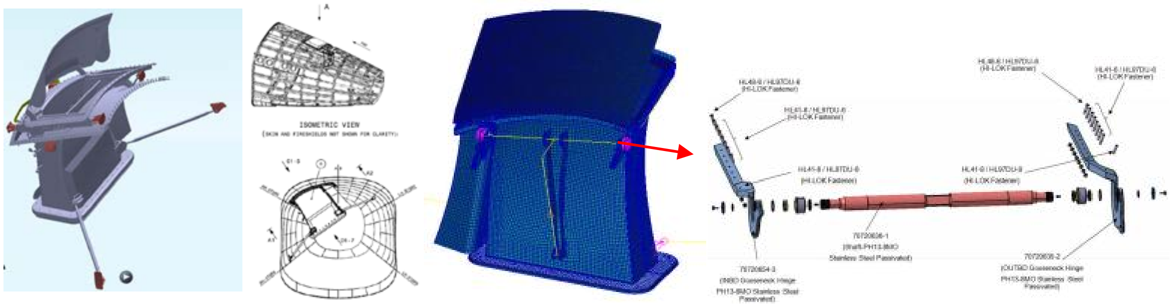



**Figure 1: APU air inlet design, location in the A/C, FEM and mechanism description.**

Previous experiences show that real response of some systems is higher than the response measured on the qualification tests. These qualification tests are run against RTCA-DO160 curves C&C1. Moreover, Certification Review Item (Reference 3) which states:

> *"For the system assessment the vibration spectrum used for the qualification of equipment according DO-160 must be validated by flight test to ensure that the vibratory loads experienced on the aircraft are not in excess of the levels defined by DO-160."*

# 2. EXPERIMENTAL PROCEDURE

## 2.1 QUALIFICATION TEST

Random vibration testing was performed to show that the APU Inlet System remains functional and exhibits no separation or de-bonding of the interior acoustic treatment panels from the honeycomb after loading per the requirements defined in Radio Technical Commission for Aeronautics (RTCA). The equipment used for this qualification test is composed mainly of accelerometers in the door and other parts of the intake. With regards to the accelerometers 3 sensors are needed, installed on external side of the flap door.

### 2.1.1 Equipment Description

This analysis is performed by means of a frequency sweep in a test bench, measuring the response accelerations obtained. The equipment and instrumentation is shown in Figure 2:

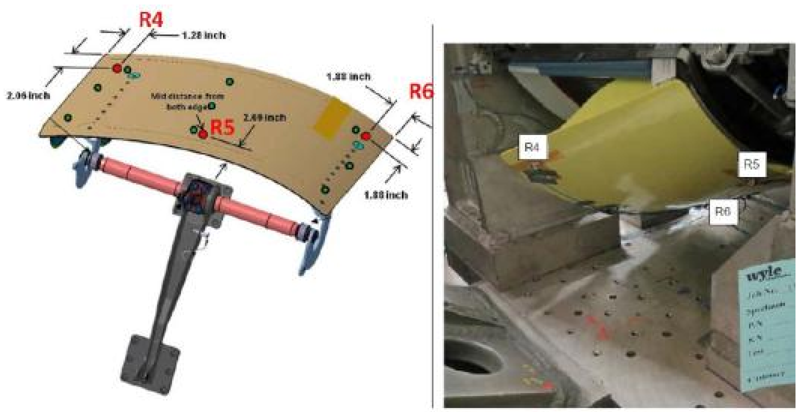



**Figure 2: APU Flap Qualification Test Equipment**

### 2.1.2 Data Processing and Analysis Method

The test methods simulate the vibration, shock and crash environment to which the component will be exposed during in-service use. The APU Inlet Duct was tested in accordance with the requirements: Radio Technical Commission for Aeronautics (RTCA), DO-160E, Section 8, Category R, Curves C and C1 with Curve C being run for duration of 30 minutes and Curve C1 for duration of 3 hours.

The test article consisted of a complete inlet duct assembly with the door secured in the 20 degree open position. The door was secured by a production actuator which will be installed on the inlet duct assembly. The test fixture was as rigid as possible in order to avoid any coupling from the fixture and that of the APU Inlet Duct Assembly. The assembly was installed in an inverted installation position in order to keep the center of gravity (CG) as low as possible in the test fixture. The assembly attachment points within the fixture reflected as accurately as possible the boundary conditions that would exist when the assembly is installed in the aircraft.

#### 2.1.3 Results

Results from the qualification test against RTCA-DO160 are shown in Figure 3:

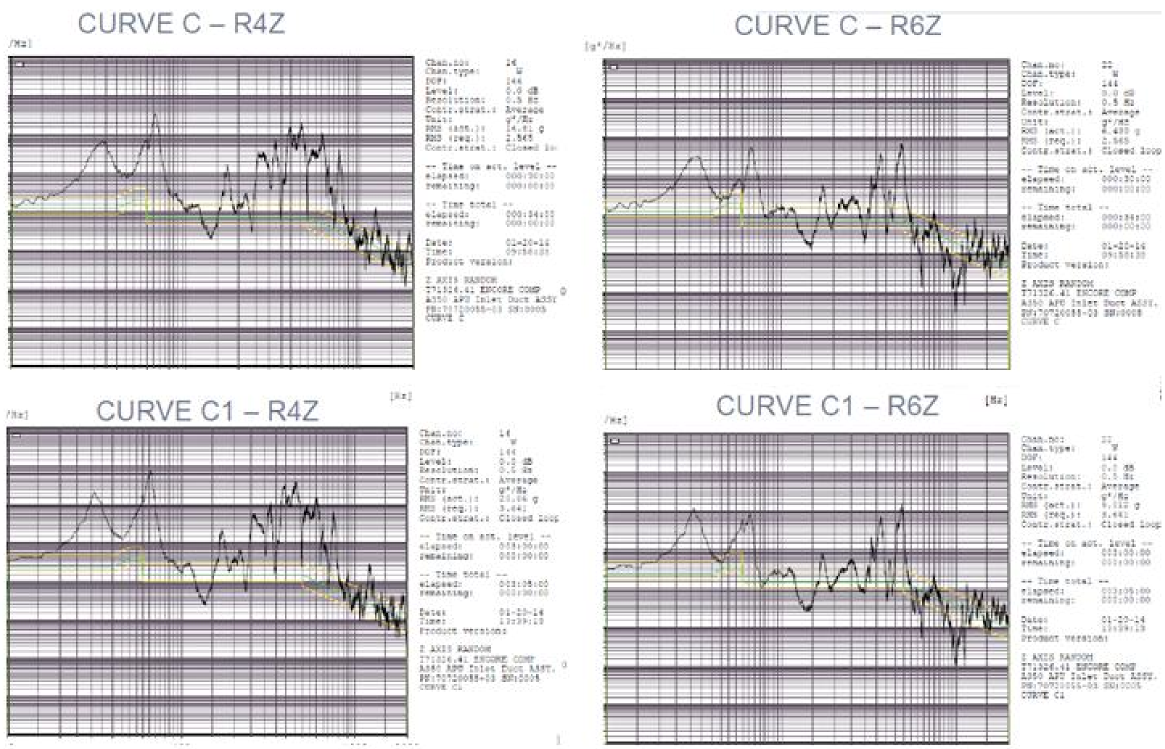



**Figure 3: APU Flap Qualification Test Results**

## 2.2 WIND TUNNEL TEST

Flap door vibrations were identified during design development phase so it was decided to perform further analysis performing Wind Tunnel (WTT) and Flight Tests (FT) in order to minimize the risk of door detachment.

The WTT consisted of simulating the aerodynamic excitation of the flap door in several conditions of the flight envelope of the A/C, and comparing the results with the natural modes of vibration of the structure and FEM results.

### 2.2.1 Equipment Description

The equipment used for this Wind Tunnel Test is composed mainly of accelerometers and unsteady pressure sensors (Kulites). With regards to the accelerometers 6 sensors are needed, installed on internal / external side of the flap door.

A general overview of the accelerometers installation is Figure 4:

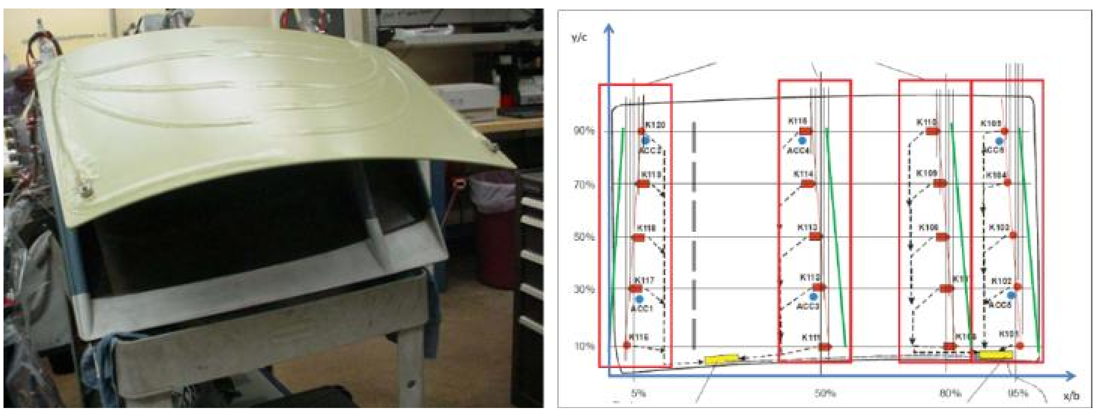



**Figure 4: APU Flap Wind Tunnel Test Instrumentation**

### 2.2.2 Data Processing and Analysis Method

The wind tunnel test was performed in ONERA S2 installation. Real equipment was introduced into the tunnel instead of a mock up with higher safety factors due to the advanced design phase where the vibrations were detected.

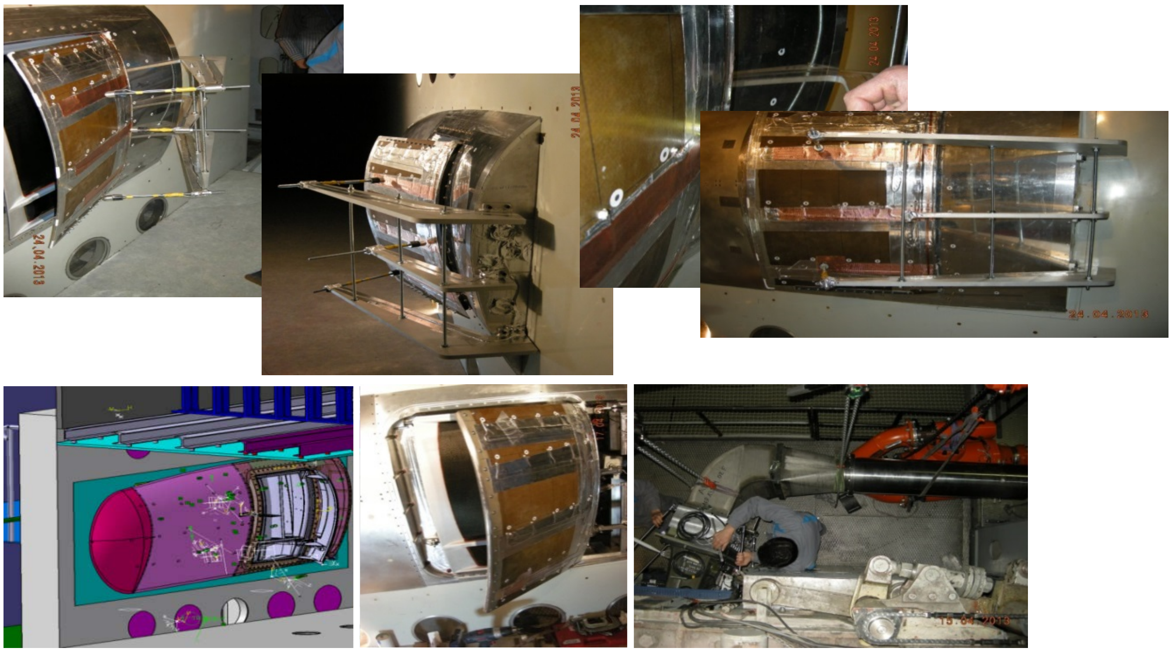
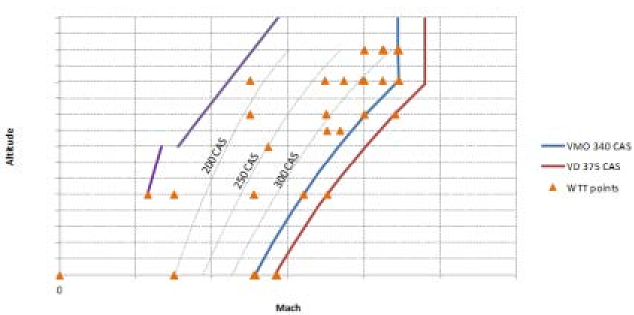


**Figure 5: APU Flap Wind Tunnel Test Installation**

A high number of flight points were tested in the WTT in order to cover the maximum number of the A/C conditions in flight. The most critical response of the flap door was found on NLOT268 with the following test conditions:




| NLOT | AFLAP | M0 | PDYN | MassFlow |
|---|---|---|---|---|
| 268 | 20,9 | 0,58 | 21571 | 8,85 |

**Figure 6: Flight Envelope and WTT tested points. NLOT268 test conditions.**

### 2.2.3 Results

All the accelerometer data were registered in function of time and then PSDs curves were calculated for all the tested conditions.

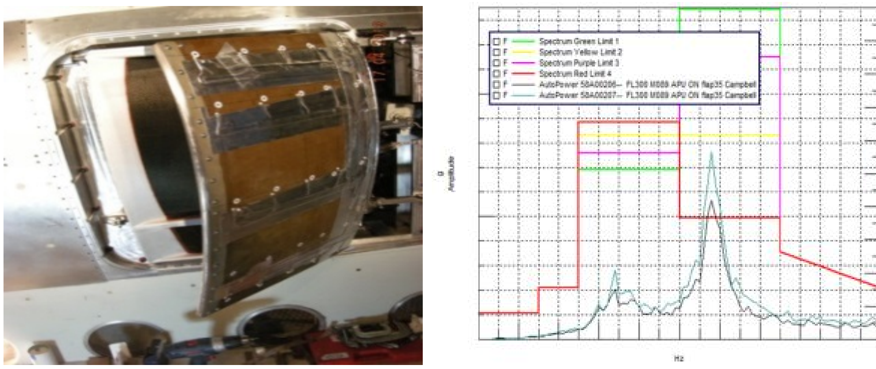


**Figure 7: APU Flap Wind Tunnel Test results (accelerometer / pressure / strain gauge sensors data)**

## 2.3 FLIGHT TEST

The purpose of capturing and processing the flight test data was to determine the APU inlet door response actually seen during flight for a direct comparison to WTT results, qualification test results and conclusions, and to provide supplemental information to assess the door under abnormal conditions (dispatch with door at 20 degrees, door failed open at 35 degrees)

### 2.3.1 Equipment Description

The APU inlet door accelerometer locations for flight are shown in Figure 7.

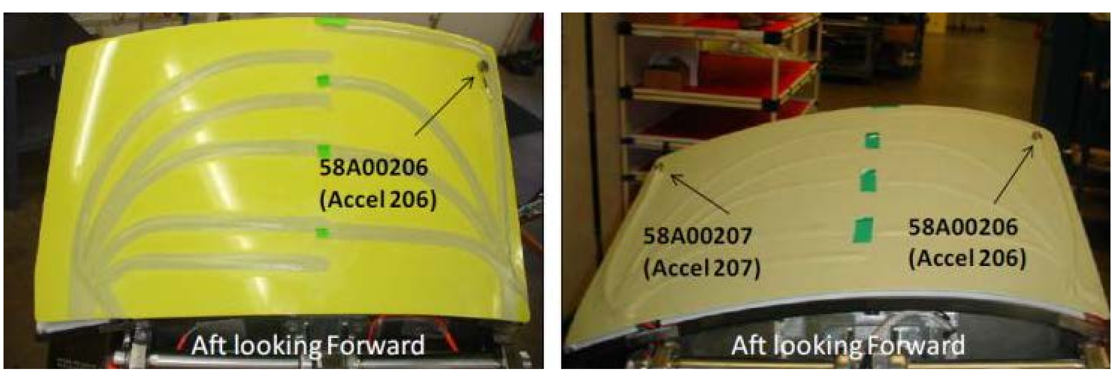



**Figure 8: APU Flap Flight Test instrumentation (accelerometer)**

#### 2.3.2 Data Processing and Analysis Method

In addition to the detailed evaluation of singular points within the flight envelope, there was also data collected at a much lower sampling rate. The lower sampling rate data is good to determine exact conditions for the detailed analysis points (i.e., Mach #, Altitude, etc.), as well as determining the mean actuator loads. This data was collected at a sampling rate of either 1 sample per second or 8 samples per second. Neither of these sampling rates is adequate for evaluating the dynamics, but would still be acceptable for mean actuator loads.

#### 2.3.3 Results

Again, the PSD curves are calculated from accelerometer data in order to evaluate the response of the flap door and to compare with the results from qualification tests, WTT and FEM analysis.

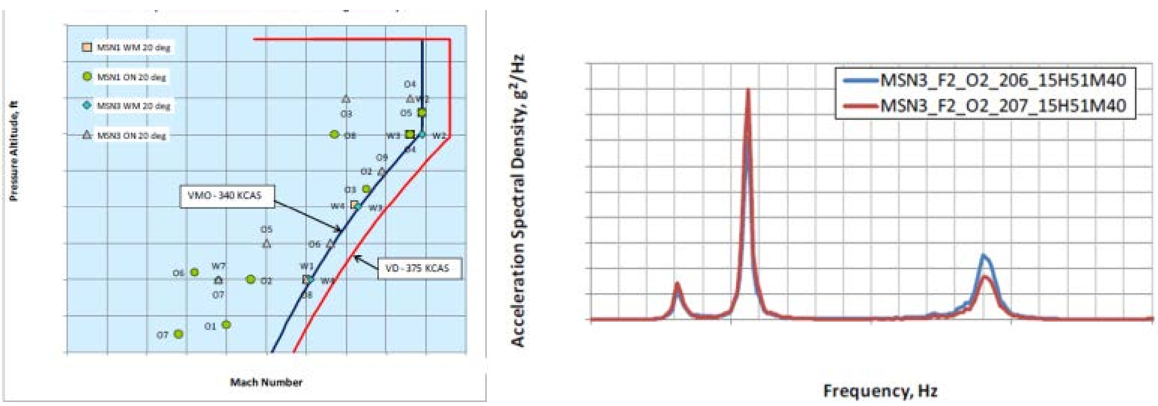



**Figure 9: APU Flap Flight Envelope and Flight Test results (accelerometer PSD)**

The most critical condition were found for Windmilling conditions and flap door open to 20º, similar to these found on WTT results. So this flight point results will be used for comparison in order to keep coherence with the tested conditions.

## 3. THEORETICAL PROCEDURE

Theoretical analysis has been performed using MSC Nastran with its Solution 111 (Dynamic Response Analysis in the Frequency Domain). An overview of the FEM is provided here below:

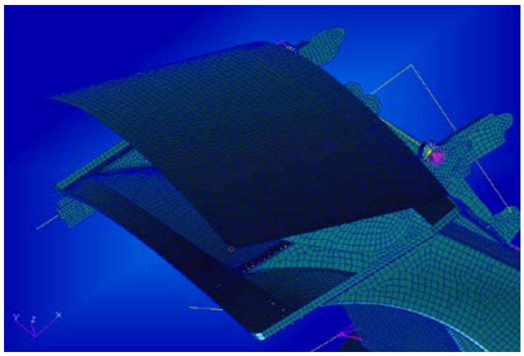


**Figure 10: APU Flap Finite Element Model Overview**

### 3.1 ANALYSIS METHOD

By using MSC Nastran Solution 111 with an unitary excitation the Frequency Response matrix has been obtained for the same points where accelerometers were located at qualification test, Wind Tunnel Test and Flight Test.

Once obtained the frequency response matrix the structural response of the door has been obtained, both against RTCA_DO160 and against MIL-STD input signals, from 0 to 2500 Hz.

### 3.2 RESULTS

Results of the theoretical analysis show the response at the flap. As is shown in Figures 10 and 11, there are three eigenmodes of this flap below 100 Hz (~35Hz, ~55Hz, ~90Hz)

Plots show the response accelerations at the forward left corner in the three main directions. This point shows the most critical response and higher accelerations.

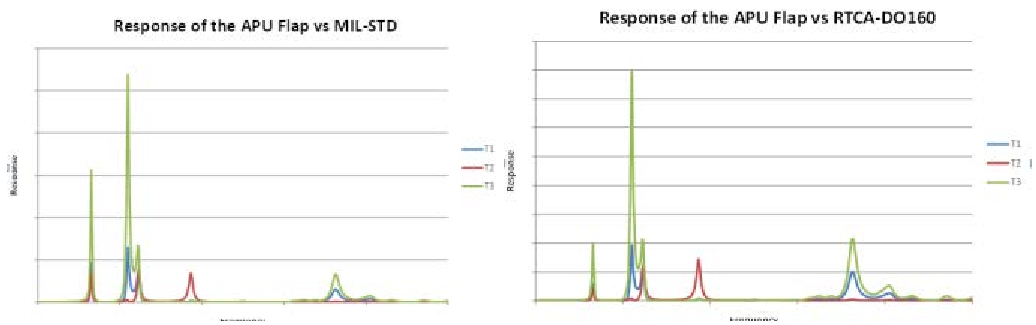



**Figure 11: APU Flap Theoretical Response to MIL-STD810 and RTCA-DO 160**

## 4. COMPARISON

Figures 12 and 13 show all three sources of data that have been used for this analysis: theoretical analysis, qualification test, flight test and wind tunnel test results. The following curves are compared

- R4Z acceleration PSD response to Curve C1 – RTCA – DO160 test
- Acceleration PSD of Accelerometers 206 and 207 for MSN003 Flight 110
- Random Vibration Analysis (SOL111) Acceleration PSD response to RTCA and MIL-STD excitation curves (node 121712 from FE Model) (MSC Nastran)
- Acceleration PSD of Accelerometers 4 and 6 from WTT-NLOT268

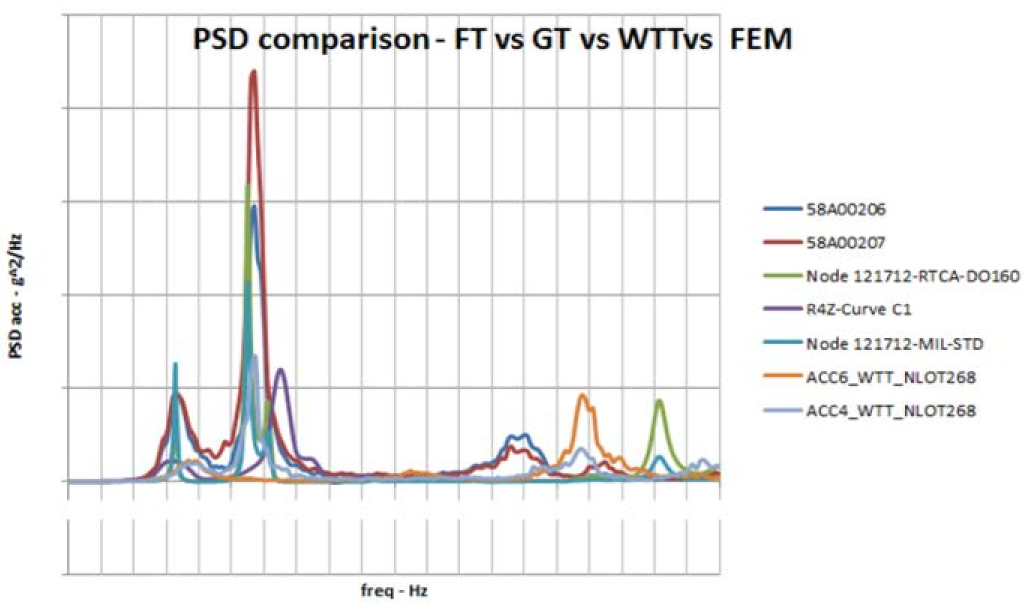



**Figure 12: APU Flap Comparisons between RTCA / MIL-STD / Flight Test**

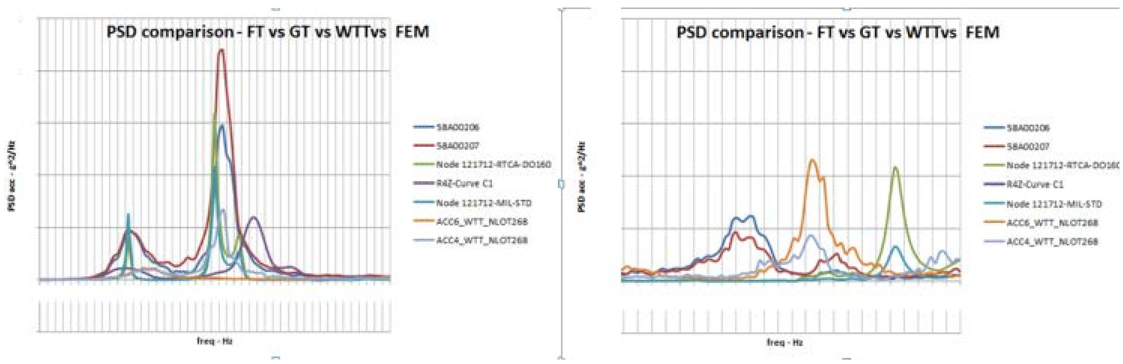



**Figure 13: APU Flap Comparisons details [0-100Hz] and [100-200Hz]**

As can be observed in the above figures, aerodynamic excitation is more critical in frequencies over 50 Hz. This is the root cause of the non-conservatism of this methodology, since it is not meant to be used with systems embedded into high speed airflow.

## 5. CONCLUSIONS

It is an extended practice to justify vibrations requirements (CS-25.301, CS-25.305 and CS-25.1309) for design by means of qualifying the system vs a standard spectrum as RTCA-DO160 or MIL-STD810.

This methodology can be compliant for non-aerodynamic structures, but when the mechanical system is embedded into high speed airflow, physic changes due to the effect of fluid-structure coupling and the vibration spectrum could be not conservative: real responses of the structures can be higher than the responses obtained in the shaker tests.

Although some differences can be identified between the tested conditions and analysis (Ground Test orientation, excitation input location…), they will not impact in the final conclusion:

"*The APU air intake flap door responses confirms that real responses of the structure during flight test and wind tunnel test, simulating real operational conditions, are higher than the measurements obtained from the currently used qualification tests*"

## 6. RECOMMENDATIONS & FUTURE WORK

New qualification spectrum definition for ground vibration test should be developed in order to justify strength and fatigue systems of equipment embedded in an aerodynamic air flow.

Some work is being done by internal departments in Airbus in order to particularize the qualification spectrums for every equipment.

## 7. REFERENCES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