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DGT: A NEW METHODOLOGY FOR HIGHSPEED AIRCRAFT GROUND VIBRATION TESTS– IFASD 2019

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Abstract: A Ground Vibration Test (GVT) is a mandatory certification test for all new aircraft series supporting Loads & Aeroelastics model validation and first flight clearance. In recent years, a lot of efforts were provided to optimize the standard GVT procedure. Further reduction in the test's cost and lead time was only possible by introducing alternative testing procedure like the Dynamic Ground Test (DGT) method. The aircraft becomes its own test mean. The test principle lies on the use of the flight control surfaces to perform excitations of the aircraft while the flight test instrumentation records the resulting vibrations. The DGT method was industrialized for the first time on the A350-1000 and it turned out to be a full success. The test duration could be limited to 2 working days, the total cost was significantly reduced and vibration levels needed for proper dynamic identification were sometimes even higher than by using external shakers. All requested test results for certification were provided in time and quality.

1 INTRODUCTION

Over the last few years, Airbus has launched two new derivative aircraft, the A350-1000 and the A330-900neo. They enhanced the aircraft performances or customer experience with new features such as new engines, optimized wing and wingtip profile, or extended fuselage. As mean of compliance for certification, a Ground Vibration Test (GVT) campaign was needed to ensure proper dynamic model correlation, and to deliver clearance activities for first flight. This crucial test was usually performed a few weeks before the first flight with an aircraft in "ready to flight" configuration. Considering the heavy industrial constraints on Final Assembly Line (FAL) activity, and the need for an optimized route to first flight, the former GVT process was challenged when applicable to new derivative aircraft. New test methodology was developed, so-called Dynamic Ground Test (DGT). The primary objective of this new test was to reduce the test duration, and then to perform a complete modal identification of a full aircraft up to 15Hz in a 2-days test slot. As a reminder, testing slot allocated for classical GVT method is more in the range of one to several weeks, depending on the new features introduced on the new aircraft. This paper describes the methodology for DGT selection, the assessment of such method, and finally its performance on A350-1000.

2 INDUSTRIAL CHALLENGES FOR DERIVATIVE AIRCRAFTS

For derivative aircraft, dynamic structural characteristics are derived from the baseline aircraft dynamic behavior which was identified during classical GVT. For example, the dynamic behavior of the A350-1000 is derived from A350-900 dynamic model validated by a full GVT performed on the first A350-900 specimen [1]. For the A350-1000, the industrial challenge was then to shorten the route to the first flight, while maintaining a robust and accurate modal identification to validate the theoretical aircraft model for aero-elastics certification and support first flight clearance. Initial target for the A350-1000 was to achieve this task in a 2-days slot, while the GVT on the A350-900 lasted 9 days. In order to alleviate the testing requirements for derivative aircraft, only 1 mass configuration was targeted, instead of 2 for a classical GVT.
In addition, to shorten the time needed to prepare the aircraft before the test, it was decided to keep the aircraft standing on tires, whereas the aircraft is usually standing on suspension devices during classical GVT. Potential flexible mode coupling with rigid body modes was expected and had to be assessed during test methodology development phase.

For these derivative aircrafts, a modal analysis was requested up to 15Hz, instead of 50Hz for a classical GVT, with a special focus on modes below 6Hz.
For each mode, following parameters had to be identified:

- Eigen-frequency
- Generalized damping
- Mode shape
- Non-linearity plot

The test had to be performed on the first prototype in FAL before first flight. The post-processing and the modal base completion have to be finalized within 10 days after the test.

3 TEST METHODOLOGY SELECTION

Considering the challenge on test duration, a disruptive approach was needed to meet the requirements. An assessment of different test methodologies was performed to select the most appropriate.

3.1 GVT optimization

The first assumption was to start from the actual GVT methodology and identify how to speed up the test. As said before, the test principle is well documented in the literature, the main goal being to excite the aircraft with different shakers connected to the structure. Different excitations are needed to properly excite all the structural modes of the aircraft and extract the dynamics. Phase Separation Method (PSM) is currently the preferably used during the test [2]. The post-processing is thus performed by an Experimental Modal Analysis (EMA) approach which is an input-output method. Phase Resonance Method (PRM) can be used to tune the modes and extract their associated damping with a high accuracy. However, this approach being very time consuming, it is not often used during Airbus GVT anymore.

3.2 TVT test

The TVT (Taxi Vibration Test) [3] was originally developed by DLR (Deutsches Zentrum für Luft-und Raumfahrt). The purpose is to taxi the aircraft on calibrated bumps to excite the structure. The bumps location can be tuned to excite symmetrical and unsymmetrical modes. The resulting vibrations are measured by dedicated recorders located into the aircraft. The extraction of modal parameters is performed by using output only modal analysis algorithm (OMA, for Operational Modal Analysis).

3.3 DGT test

DGT methodology is reproducing a flutter flight testing techniques on ground. The aircraft structure is excited through its flight control surfaces. Different kinds of excitation signals (sweeps, random) can be generated by a computer located inside the aircraft. The deflections of such surfaces and the induced vibrations on the aircraft structure are captured by the Flight Test Instrumentation (FTI).

3.4 Test selection

The GVT classical process appeared as already highly optimized with respect to test duration. Limiting the test to only one configuration would not have led to meet expectations in terms of duration. Objective of modes extraction up to 15Hz was not allowing a reduction of shakers locations to be tested. Besides, at least four levels of excitations were still requested for linearity plots. Considering the challenge of significant test lead time reduction, optimizing the existing GVT workflow was not deemed sufficient, and a need of a disruptive approach was underlined.

TVT testing technique was evaluated but some uncertainties remained on the capability to generate enough vibrations for some key aircraft modes identification. In addition, it turned out to be difficult to control the level of excitation on the aircraft to properly address the different domains of the linearity curves.

Due to large flight control surfaces available on Airbus aircraft and high capabilities of associated actuators, significant deflections can be reached which induces important levels of energy into aircraft structure. The type of vibration excitations can also be selected among random excitations, sine sweeps or even pulses. In addition, the level of excitation can be accurately monitored and adjusted by changing flight control surfaces deflection level. Using these flight control surfaces would significantly decrease the time needed to prepare the test, avoiding the use of scaffoldings to handle the different shakers.
Considering the advanced capabilities of the flight-test onboard computer managing the flight control surfaces used on aircraft and the expected testing requirements, DGT testing technique appeared as the best candidate.

One common way to reduce test preparation time was to decrease the number of acceleration channels installed on the aircraft structure by using the FTI installation which was normally dedicated to flight vibration tests.

In order to validate this choice, a complete validation process was performed to confirm the new test methodology would meet the expected requirements in terms on time and quality.

4 DGT METHODOLOGY VALIDATION

4.1 Optimized Ground Test

Once the methodology chosen, different investigations had to be led. The first one was to assess the capability of the flight control surfaces to properly excite the aircraft modes. In addition, OMA was also tested with this new way of excitation as EMA was not suitable anymore to perform the post-processing.

This first validation step was performed during a test called by Airbus "Optimized Ground Test" (OGT). This was a research test performed in 2011 by Airbus, ONERA and DLR on A340-600 flight test aircraft.

For this test, the aircraft was fitted with a full GVT sensor chain of 510 acceleration channels. Classical GVT was performed to get a modal database which was used as a reference. In addition, various flight control surfaces excitations were performed and aircraft dynamic response was recorded through the same GVT instrumentation.
The following flight control surfaces were excited:

- Rudder
- Elevators
- Outer Ailerons
- Inner Ailerons.

Symmetrical and anti-symmetrical sweeps were performed to extract the maximum number of modes between 0.5Hz and 13Hz.

Classical GVT identification is made using EMA method based on Frequency Response Functions (FRF) computed between force inputs at shaker location and structural accelerations. During a DGT, forces generated by the flight control surfaces cannot be directly measured, and only acceleration is measured. An OMA method has then to be used. The validation process between a GVT and a DGT, as explained by Figure 1, can be decomposed into three steps between four different tests.

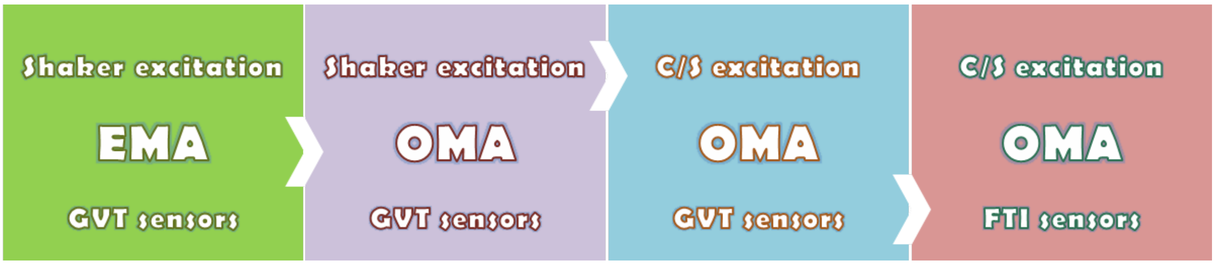

Figure 1: Validation process from GVT to DGT

From the data sets collected during the OGT, first modal identification based on flight control surfaces excitations and GVT instrumentation was performed. Comparing the modal base extracted from the GVT (first box) to the modal results obtained from control surfaces excitations (third box) underlined two different phenomena: the use of control surfaces to excite the modes, and the use of OMA method to post-process the data.
Several publications have shown the possibility to extract high quality modal results with OMA method. A preliminary study was implemented on other test results to validate the capability to extract the aircraft dynamics from shakers excitations with OMA method versus EMA. Results showed good agreement. The first step of the validation process, from first box to second box, was considered as validated. As a result, instead of validating step one from the first to the second box, then step two from the second box to the third one, only one comparison was made between results from box one and three. It was equivalent to compare a GVT to a DGT acquired through a GVT sensor chain.

Focus was made on aircraft modes below 6 Hz. The deviations in frequency remained very low for most of the modes (less than 1%). Damping assessment comparison was considered as acceptable. However it was identified that the flight control surfaces excitations method was not necessarily suitable to get proper identification of some specific modes. As the main outputs of this investigation provided satisfactory results, the combination of flight control surfaces excitations to excite the aircraft and OMA method and extract its dynamics was validated.

The last validation step from the third to the fourth box was to assess the capability of using a reduced instrumentation to correctly capture the modes. Indeed, as said at the beginning of the paragraph, post-processing of third box was achieved with full GVT instrumentation (reminder: 510 acceleration channels). During this OGT, 118 FTI sensors were also available. Usually number of FTI sensors used for flutter tests is around 150 accelerometers.
Results have highlighted the need to keep a sufficient number of sensors on the aircraft to extract the modes with the expected quality. 118 channels was not enough to get good matching in terms of MAC between modes from FEM and modes from the test. It was concluded that a target of 200 acceleration sensors shall be implemented for DGT on A350-1000.

The OGT confirmed the technical feasibility to perform a DGT to extract the dynamics of a full aircraft by strongly reducing the time dedicated to such test and without decreasing the quality of the results. The decision was made to investigate further the test process.

4.2 Dry run on A350-900

In 2016 a dry-run was performed on the first A350-900 specimen. This test was aiming to assess the influence of aircraft boundary conditions and to identify potential technical showstoppers to de-risk the first industrial use of DGT for the A350-1000. Another goal of this dry-run was to prepare the test matrix of the future DGT.

Prior to this test, virtual testing was performed on A350-900 Finite Element Model (FEM) to optimize excitation levels and assess the different suspension conditions to be tested.

Concerning aircraft boundary conditions different tire pressures were tested. Main goal was to find the best configuration to properly extract the rigid body modes on one side, and the flexible modes on the other side. At the end of the dry-run, one pressure configuration was chosen to perform the future DGT.

One of the main outcomes of this dry-run was to collect data to build the test matrix of the future DGT. The first point was to define for each mode the most appropriate flight control surface leading to the best qualitative extraction. Synchronized excitations with different flight control surfaces were also tested to optimize targeted modes excitability.

Various excitation signals were tested using flight control surfaces capabilities such as random signals and sine sweeps. Random signals were identified as relevant for a first assessment of the modal characteristics. Finally sine sweeps were selected as the most efficient way to refine the aircraft modal identification.

Different levels of amplitudes were tested to assess the capability to collect sufficient measured data to build linearity curves. The main difficulty was to define the sweeps to be tested by keeping in mind the necessity to reach high levels of vibration on the different modes but without exceeding aircraft structural monitoring thresholds. This task is usually addressed by a force notching strategy during classical GVT. Unfortunately the onboard computer managing the flight control surface cannot offer the same real-time capability. As a consequence this dry-run was absolutely necessary to define different sweeps addressing various frequency bands and deflection levels to remain agile and efficient during the DGT.

Keeping aircraft standing on tires as boundary conditions, it was confirmed that the first wing flexion was coupled with vertical rigid body modes, heave and pitch. But, this was considered as acceptable for future test on derivative aircraft for FEM update and flutter computations by adjusting tires pressure.

This dry-run confirmed the need to keep some shaker excitations for some modes to meet similar excitation levels than from classical GVT. Nonetheless, it was frequently identified that the level of force induced by flight control surfaces could be higher than the one from classical external shakers (e.g. Rudder).

This test was also a fruitful experience to enhance the skills of the testing team and secure the test preparation activities for the A350-1000.

5 TOOLS FOR DGT PERFORMANCE

In order to cope with data processing phase and the expected test efficiency a software suite development was launched. Main tools were results database software, force notching solution for optimum level shaker excitation. In addition, the need for synchronizing FTI and external chain sensors led to the development of a software named Synchrotool and described as follows.

One of the key enablers to reduce test lead time was minimize the time slot allocated to external sensors installation. Indeed more than 500 sensors were used for a classical GVT on former Airbus programs.
It was then decided to rely mainly of the aircraft FTI accelerometers used for flight vibration tests. The challenge is that a typical Airbus prototype is fitted with approx. 150 accelerometers for flight test campaign.
Following OGT test and virtual testing using FEM, a target of 200 sensors was identified to support robust modal identification and mode naming.
A dedicated tool was then needed to complement FTI sensors chain with external sensors. Acquiring both data flows, one from FTI and one from LMS SCADAS III front end, and synchronizing them in slightly differed time was the main difficulty to address.
A consistent time history throughput file must be available within few minutes after test run completion and transmitted to the team working on spectral function computations.
The workflow and the targeted test productivity excluded a non-automated solution to be repeated at the end of each run.
A fully automated solution was then developed with LMS-SIEMENS and Airbus teams.
At the end of each excitation run, external measurement platform (SIEMENS TestLab) was requesting data by FTP protocol to the flight test recorders installed onboard the aircraft. Data from FTI were then retrieved by a dedicated PC.
One dataset was available from FTI on one side and from SIEMENS SCADAS III on the other side.

Both datasets need then:

- To be synchronized in the time domain.
- To be aligned in the frequency domain to cope with the different sensor technologies used: DC-capable accelerometers on FTI and ICP sensors on SCADAS III.

FTI sensors were capable of measuring DC acceleration without phase shift at low frequency. They were considered as the reference for the spectral alignment process. ICP sensors, acquired by SCADAS III, due to the embedded technology, showed phase shift in low frequency. Prior to the test, the transfer function between both kinds of sensor was measured in a laboratory, and it was then virtually applied to the sensors during the time synchronization process.

As a result a consistent dataset was available at the end of each run to perform modal analysis.

Development of this Synchrotool device was a corner stone for the test performance. It allowed quick duplication of any failed FTI sensor in a short time with an autonomous sensor. It also enhanced post-processing activities to overcome some potential FTI sensors maturity issues.

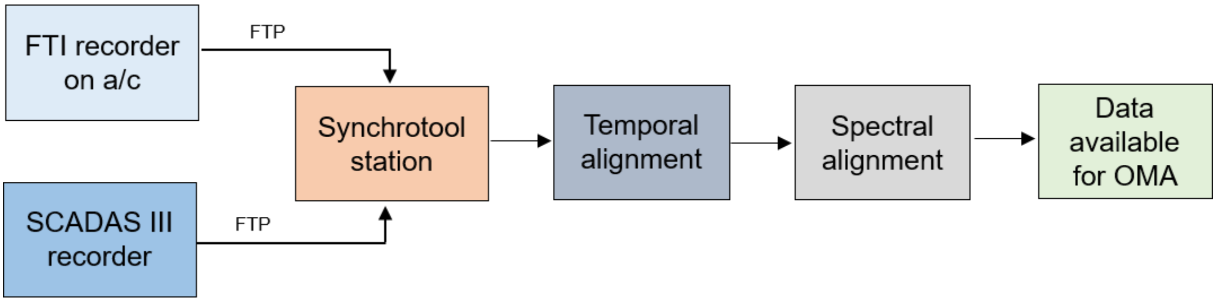

Figure 2: Synchrotool workflow

6 DGT TEST ON A350-1000

Considering the lessons learnt and the experience of the dry run test performed on A350-900, DGT testing techniques were selected as industrial test means for the A350-1000 program. Testing slot was scheduled during the Final Assembly Line just after painting on the first A350-1000 specimen MSN0059.

6.1 A350-1000 presentation

Measuring nearly 74 metres long, the A350-1000 XWB is a new generation mid-size, medium-long range passenger aircraft seating 369 passengers (versus 315 passengers for the baseline -900 version).
The Extra Wide cabin measuring 220 inches across allows increased flexibility for cabin configurations and enables between 7-abreast regional business class up to 10-abreast economy class layouts. The wider cabin gives an opportunity for more comfortable passenger seat layouts versus previous products. Cabin pressure altitude is maintained at or below 6000 feet for improved passenger comfort.
It is powered exclusively by 2 Rolls-Royce Trent XWB engines developed from the RR-Trent engine family with 118” wide-chord fan blades and delivering 97k lbs thrust.

The aircraft entered into service in February 2018.

Figure 3 : view of the A350-1000 in the testing hall

6.2 Excitation Procedures

6.2.1 Flight Control Surfaces Excitations

Elevators, inner ailerons and rudder flight control surfaces were used. Both yellow and green hydraulics circuits were supplied by external ground cards to activate these flight control surfaces.

Figure 4 : view of rotating surfaces

Sine sweep excitations, from 0.5Hz to 15Hz, were used during this test since they are the best trade-off between the excitation level and the testing time. They were performed for different frequency bandwidths and levels. To assess the non-linearity of the structure, runs with different excitation levels and different sweep directions were performed to monitor the evolution of the frequency and the damping as a function of the excitation level.

The Phase Separation Method (PSM) was used as evaluation method. PSM is based on swept-sine excitation signals applied to one, or simultaneously to different control surfaces (symmetrical and anti-symmetrical excitations). In addition, random signals were simultaneously performed on all aircraft flight control surfaces at test start. This step allowed measuring first modal data to obtain a first assessment of the dynamic behaviour of the aircraft.

6.2.2 Shakers Excitations

In addition to flight control surfaces excitations, shaker excitations were performed for a couple of specific aircraft modes identification at sufficient level as per classical GVT methods.

For all the excitations, the level of force injected by each shaker was monitored and controlled by a force sensor which was screwed at the end of the rod linking the shaker to the aircraft.

6.3 Test Instrumentation

For this test, 178 acceleration channels have been installed on all major components of the aircraft to properly capture full dynamic response.

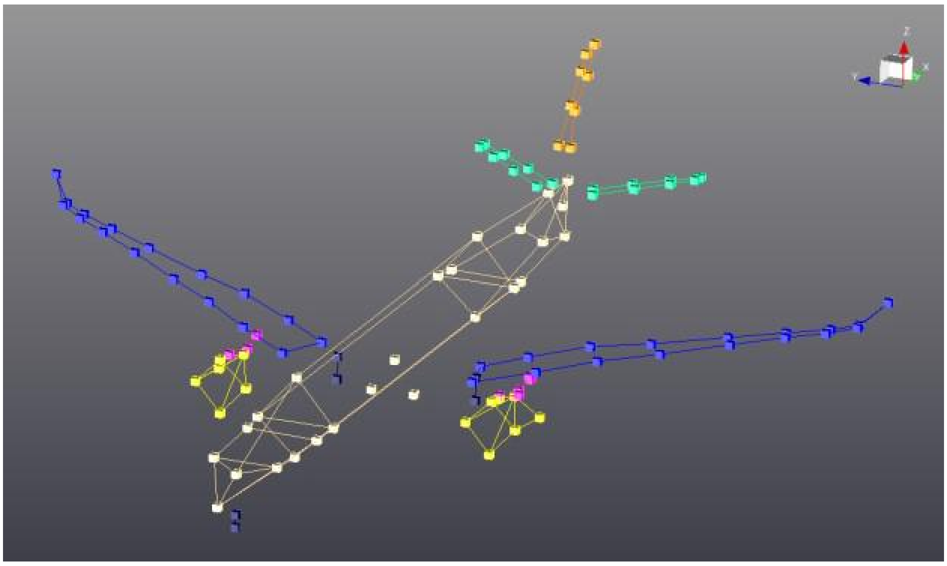

Figure 5 : sensor meshing used for A350-1000 DGT

This sensor set was made of 70% of FTI sensors and 30% of additional accelerometers acquired by SCADAS III front-end.

The synchro tool developed in collaboration with SIEMENS was used all along the test to synchronize FTI accelerometers and external sensors. Another advantage of using the FTI accelerometers was the capability to check maturity of the test installation before first flight.

6.4 Test performance

The test took place on 24 and 25th of August, 2016. A merged team of Airbus Design Office and Flight Test engineers was settled.

Following activities were handled by the test team during the whole campaign:

- Control Surface excitation selection and activation from the aircraft
- Level monitoring
- Acquisition and synchronization of all measured parameters

- Shaker operation
- Spectral calculation
- Modal identification using OMA method
- Database creation and populating

Test team was shared in three main groups:

- The first one, inside the aircraft, was launching control surface excitations at the flight test engineer station, and monitoring vibration levels to ensure structural limits were not exceeded. Measured accelerations remained within the thresholds during the whole test.
- The second group, in a mobile lab truck located close to the aircraft, was managing the acquisition.
- The third group was also monitoring vibration levels, confirming the quality measurement and finally post-processing the acquired data, as described in the following paragraph.

The test duration was 36 hours within 2 days, working two shifts a day with two different test teams.

In total, more than fifty runs were performed with flight control surfaces, more than twenty were achieved with shakers.

6.5 Test processing

As a consequence of mixed flight control surfaces and shaker excitations, modal identification was carried out using either input-output modal analysis for shaker or output-only modal analysis for control surfaces. More than 350 individual modes were extracted from the data using SIEMENS TestLab, by the third group.

Modes were then named, selected on quality criteria and grouped per family to generate the linearity plots.

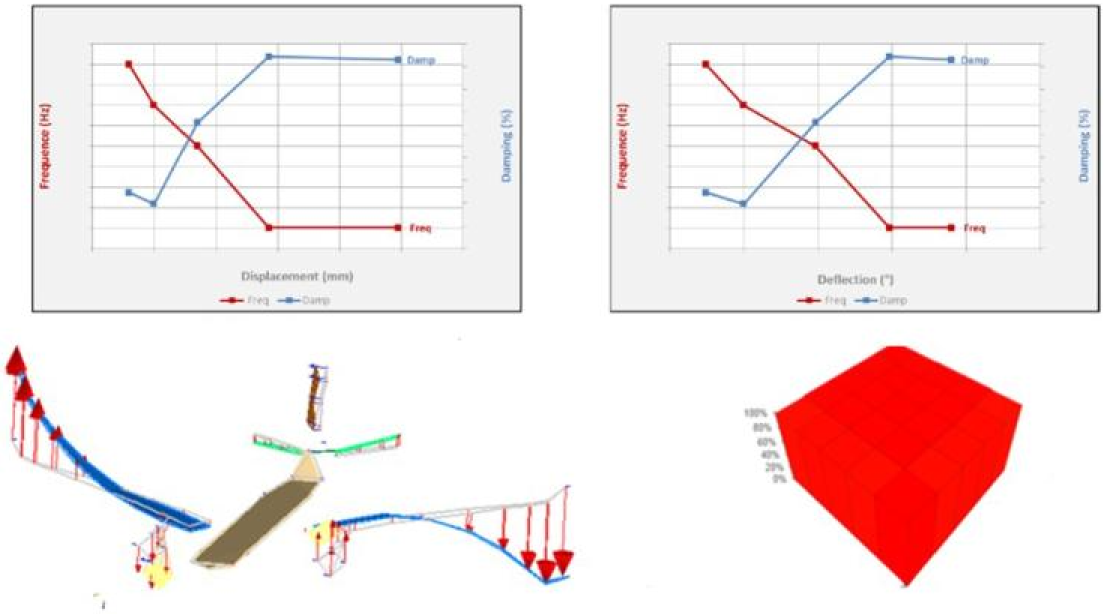

Figure 6 : typical linearity plot with associated cross-MAC

Master mode was then defined as the most representative mode for each family. Consequently, forty master modes were identified up to 15Hz.

7 CONCLUSION

Considering the heavy industrial constraints on Final Assembly Line (FAL) activity and the need for an optimized route to first flight, alternative testing techniques were considered for aircraft derivatives. Main objective was to perform a full modal identification of aircraft dynamic characteristics up to 15Hz within a 2-days test slot.

An optimized testing methodology, so-called the Dynamic Ground Test (DGT) was successfully implemented for A350-1000 aircraft to support first flight clearance activities and fulfil aircraft certification requirements.

Similar process was successfully applied to A330-900neo, latest A330 family derivative.

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