MECHANICAL TESTING ON LARGE AIRCRAFT STRUCTURES POSSIBILITIES - LIMITS - EXAMPLES

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OVERVIEW

Laboratory testing with static and dynamic mechanical loads is a major part in the qualification process for aircraft applications as well as for space applications.
As testing for space equipment has been the forerunner in this area, the respective test equipment and test facilities for static load testing, acceleration testing, vibration testing, shock testing and acoustic testing have been developed to cover the specifications for the whole range of space specimens, from electronic box size up to spacecraft size.
Mechanical testing on aircraft applications now profits from the available space testing technology. Vibration, shock and acceleration testing for small and medium size components is common practice nowadays.
Larger structures, however, are not very often tested in laboratory conditions, although aircrafts are getting bigger and bigger. This may be due to the fact, that there are only a few test facilities for large specimens and that the demanding specifications often meet the limits of these facilities.
This presentation is supposed to improve the mutual understanding on mechanical laboratory testing for large aircraft specimens by giving an overview on what can be achieved with the existing facilities, by explaining which facility limits have to be considered and by showing examples, where successful tests have been executed.

1. INTRODUCTION TO MECHANICAL TESTING

1.1. Purpose

Mechanical testing along with climatic and electromagnetic testing is one of the major areas for the qualification of any newly developed aircraft component.

The main purpose of mechanical testing is to simulate all the loads, which occur to a component during its life cycle, in order to determine, whether:

- the structure of the component can withstand the loads without any degradation and whether
- the mechanical loads cause any functional degradations to the component under test

1.2. Mechanical Load Cases for Aircraft and Spacecraft Applications

Basically aircraft as well as spacecraft applications are subjected to similar mechanical load environments. These loads are either of static/quasi-static, dynamic or transient nature:

Static/Quasi-Static Loads	- Aerodynamic loads - Cabin pressurisation and depressurisation - Acceleration loads during flight manoeuvres
Dynamic Loads	- Aerodynamic loads - Vibration and acoustic noise generated by the engines - Vibration induced by rotating elements
Transient Loads	- Engine ignition impulses - Separation shock events - Aircraft landing shocks

TAB 1. Mechanical Load Cases

Due to this similar load environment the testing approach for both categories (aircraft and spacecraft) is also a similar one.

The most obvious difference in-between the two different applications is the overall duration, the components are subjected to the mechanical loads. While the launch phase for spacecraft lasts only a few minutes, an aircraft is often operated for more than thousand hours of flight.

1.3. Mechanical Test Methods

Simulation of the above mentioned load cases is currently done with the following listed test methods and the corresponding facilities:

Static and Quasi-Static Loads	
Static Tests	Individual test set-ups using for example hydraulic actuators for loading
Quasi-Static Tests	Sinusoidal vibration test in the low frequency range using electrodynamic or hydraulic vibration systems
Acceleration Tests	Centrifuges

Dynamic Loads	
Vibration Tests with Sinusoidal or Random Excitation	Electrodynamic or hydraulic vibration systems
Acoustic Tests	Acoustic reverberation chambers or progressive wave tubes
Transient Loads	
Shock Tests	Electrodynamic vibration systems or special shock and pyroshock facilities

TAB 2. Mechanical Tests and Facilities

2. TESTING PHILOSOPHY FOR LARGE AIRCRAFT APPLICATIONS

2.1. Comparison of the Mechanical Testing Philosophy for Spacecraft and Aircraft Applications

As already mentioned the mechanical testing approach is similar for the two different types of applications.

The comparison shows, that for smaller specimens (component level; specimen dimensions less than 1x1x1m³) the basic testing approach is actually, with the exception of centrifuge testing for aircraft applications, identical.

Test	Aircraft Application	Spacecraft Application
Acceleration	Centrifuge	N/A
Vibration	Sine or Random up to 2000 Hz	Sine or Random up to 2000 Hz
Shock	Pulse or Transient Shock	Transient Pyroshock

TAB 3. Test Philosophy Comparison for Small Specimens

Due to this similarity in test requirements, identical vibration and shock test facilities can be used for aircraft and spacecraft components.

For larger specimens (specimen dimensions more than 1x1x1m³) the spacecraft testing approach differs as shown in the following table. Vibration testing is divided into two parts, a sine vibration test for the lower frequency range and an acoustic noise test for the higher frequency range.

Test	Aircraft Application	Spacecraft Application
Static	TBD	TBD
Quasi-Static	N/A	Low Frequency Sine Vibration
Acceleration	Centrifuge	N/A
Vibration	Sine or Random up to 2,000Hz	Sine up to 100Hz
Acoustic	N/A	Acoustic Noise
Shock	Pulse or Transient Shock	Transient Pyroshock

TAB 4. Test Philosophy Comparison for Larger Specimens

Due to the fact that most of the currently available large vibration test facilities are initially designed for spacecraft testing the aircraft requirement of testing up to 2000Hz is generally not considered for these facilities. An additional factor, which is not considered for the large vibration facilities, is the higher test duration for aircraft tests with its potential impact on fatigue damages to the facility.

These two aspects as well as the general challenges going along with a test campaign on a large aircraft component may be reasons, why actual laboratory testing is still not performed too often.

This paper will further on concentrate on vibration, shock and acceleration testing, the tests which can be performed on already available large standard facilities.

Static testing as well as acoustic testing are separate topics of their own and will not be addressed here in more detail.

2.2. Test Specifications for Mechanical Testing on Large Aircraft Applications

The most important applicable standards for aircraft component testing are:

- RTCA/DO-160 for all civil aircraft and helicopter applications
- MIL-STD-810 for all military applications
- Company Standards (e.g. ABD0100.1.2 for Airbus)

With respect to vibration, acceleration and shock testing these standards define the following test requirements, which differ in duration and severity, dependent on the actual application and the concerned aircraft type:

- Acceleration
  - 1g - 20g acceleration input
  - Operational and non-operational testing
  - Durations of up to 1 minute per load direction
  - 6 load directions
- Vibration (mostly Random Excitation)
  - 10Hz - 2,000Hz test frequency range
  - $1g_{RMS}$ - $20g_{RMS}$ acceleration input
  - Operational and non-operational testing
  - Durations in-between 1 and 5 hours per test axis
  - 3 test axes (uni-axial testing)

- Shock
  - Transient or pulse (mostly sawtooth shaped) input
  - 6g - 40g peak acceleration
  - Differing transient durations
  - Operational and non-operational testing
  - Up to three shocks per direction
  - 6 load directions

An interesting aspect for large specimens with all those standards is that there is basically no differentiation with respect to the specimen size or mass.

The only consideration in this respect is contained in the RTCA/DO-160 standard, which foresees a test level reduction for vibration tests on specimens with a mass exceeding 22.7kg in the frequency range above 60Hz. The reduction is 0.1dB for each 0.454kg above 22.7kg overall mass. However, this input level reduction is restricted to half the original input level (-6dB), which is reached if the specimen mass equals 50kg. So consequently there is no difference in testing requirements, whether a specimen's mass is 50kg or 500kg.

3. TEST FACILITIES FOR LARGE AIRCRAFT APPLICATIONS

3.1. Test Facility Properties

In the following chapter the properties of some of the currently available large vibration, shock and acceleration test facilities in Western Europe are presented.

For vibration and shock tests hydraulic or electrodynamic vibration systems are used. Acceleration tests are performed with the use of centrifuges.

The respective properties are:

Hydraulic Vibration Systems: HYDRA at ESTEC

- Table Size: Ø5m
- Maximum Specimen Mass: 22.5t
- Maximum Acceleration: 3g
- Frequency Range: 1 - 100Hz
- 6 DOF Excitation

Electrodynamic Vibration Systems: 300kN Shaker at IABG

- Table Size: 3x3m²
- Maximum Specimen Mass: 3t
- Maximum Acceleration: 15g
- Frequency Range: 5 - 2,000Hz
- Single Axis Excitation (vertical or lateral)

FIG 1. 300kN Vibration System (IABG)

Centrifuges: ZARM (University Bremen)

- Table Size: 1x1m²
- Maximum Mass/Acceleration: 15gxt

FIG 2. Centrifuge (ZARM)

3.2. Test Facility Limits

The restrictions for the performance of vibration, shock and acceleration tests on large test facilities are basically given by the facility properties, that means:

- Size of the maximum test set-up (specimen plus adapter)
- Maximum mass of specimen plus adapter
- Maximum input load
- Frequency range (for vibration testing)
- Maximum displacement (for vibration and shock testing)

In addition also aspects, which are generally not considered, have to be respected:

- Centre of gravity location of the test set-up
- Maximum overturning moment
- Input reduction at critical frequency ranges for the test facility

Finally the standard test tolerances for acceleration, vibration and shock testing can no longer be applied with respect to:

- Uniformity of the load input
- Rigidness of facility and test adapter in the whole test frequency range

On the other hand facility limits can in certain occasions also be circumvented, for example by using non standard test adapters, when the specimen size exceeds the standard set-up size.

In summary this paragraph shows that compared to tests on small specimens large ones require a much more detailed investigation of all testing aspects during a test preparation phase.

4. TEST EXAMPLES

In the following a number of examples for tests on large aircraft applications with the already described facilities are given, which have been successfully executed in the past.

FIG 3. Acceleration Test on a Waste Water Tank by AOA on the Centrifuge at ZARM

(In this case the standard facility table was exchanged by a large test adapter, which allowed a direct fixation of the test adapter in the six loading directions for the acceleration test.)

FIG 4. Vibration Test on a Cooling Pack by Liebherr on the Multi-Axis Hydraulic Vibration System at IABG

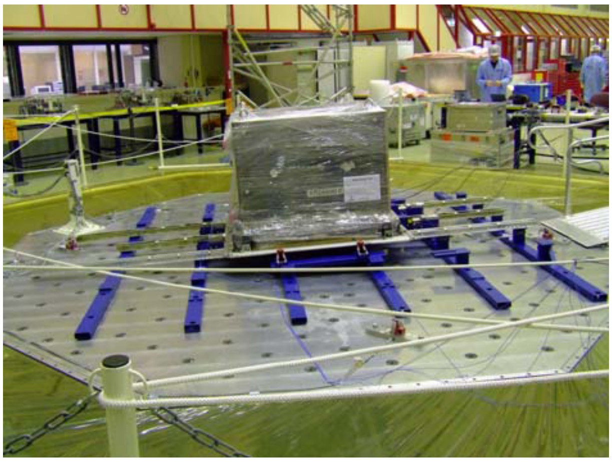

FIG 5. Vibration Test on Cargo Loading Equipment by Airbus on the HYDRA Facility at ESTEC

FIG 6. Vibration Test on a RAP Container Unicooler by DoKaSch on the 300kN Vibration System at IABG

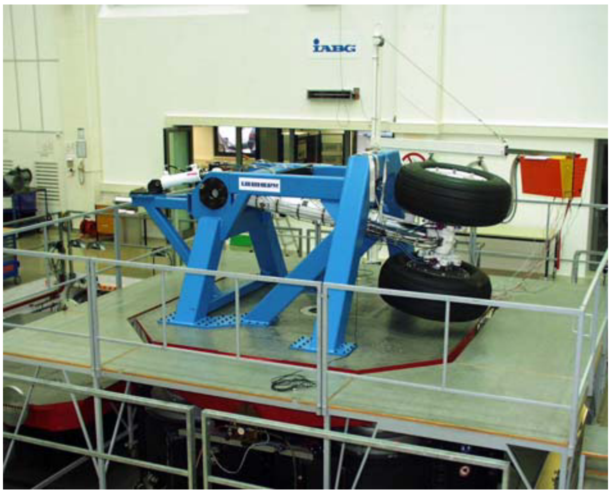

FIG 7. Vibration Test on a Main Landing Gear for a Commuter Aircraft by Liebherr on the 300kN Vibration System at IABG

5. TESTING ALTERNATIVES

In this final paragraph two aspects shall be addressed, which are already practised in space equipment testing and which may also be beneficial, if applied for large aircraft applications.

5.1. Replacement of the Acceleration Test by a Quasi-Static Vibration Test

If specimen dimensions exceed the maximum capacity of the available centrifuges, there is no other comparable way of applying a static load to the specimen interfaces. Consequently the validation is often only done by analysis.

For spacecraft applications this task is solved by performance of a so called quasi-static sinusoidal vibration tests. Using the already available vibration set-up, a sinusoidal input is applied in the frequency range, where there is no relevant dynamic amplification on the specimen (as shown in FIG 8. below) in order to apply the required loads on the specimen interfaces.

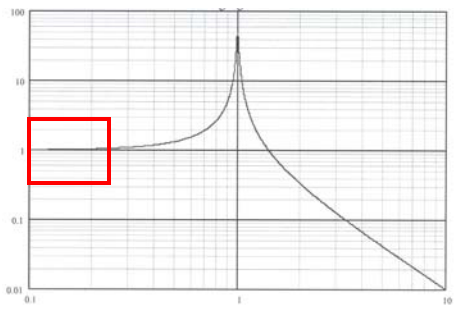

FIG 8. Quasi-Static Vibration Frequency Range

This procedure is not used for aircraft applications yet. One main reason for this may be the fact that there is no generally accepted formula for deriving quasi-static vibration parameters from an acceleration specification.

5.2. Force Limited Vibration Testing

Vibration testing on the standard laboratory facilities has the tendency to be too severe in the frequency range of the main specimen resonances. This is due to the fact that the interface stiffness is different in test compared with the actual aircraft environment.

While vibration test interfaces are supposed to be as rigid as possible, the actual interface in the aircraft is most of the times less rigid, with the consequence that the test interface enables the introduction of a higher force to the specimen during test.

This difference is well known and for space applications often an input reduction is applied during test, in order to protect the specimen from an excessive force application. The actual input limitation is done by interface force limitation or by limitation of response accelerations on the specimen, if the respective values are known.

This technique has not yet been introduced for aircraft applications. However, especially for large and expensive specimens such an approach would be beneficial, if specimen damages by overtesting could be avoided.

6. SUMMARY

This presentation does not claim to be a complete compendium in the topic of mechanical testing on large aircraft structures.

It was supposed to give an insight in the not every-day field of large specimen testing by

- Giving an overview of the available facilities and their properties
- Indicating testing limitations to be considered
- Showing examples of successfully performed tests and
- Identifying areas of possible improvements

Thus the common knowledge and the mutual understanding in this special area of testing is supposed to get enhanced.

7. ACKNOWLEDGEMENTS

I would like to conclude this paper by thanking the involved test houses and specimen manufacturers for their generous contribution by providing information about their facilities, their specimens and the respective tests.

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