Guided wave tests with structural vibrations

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1. Introduction

1.1. Context of data

The data refers to ultrasonic guided wave (GW) measurements on a full-scale composite torsion box stiffened panel subjected to realistic high-amplitude low-frequency vibrations (LFV) audible machinery sound waves (SW). The purpose of the study was to gain knowledge about the effects of structural LFV and machinery SW on ultrasonic GW propagation.

The data in this dataset was collected in the Netherlands Aerospace Centre – NLR, located in Marknesse (Netherlands), between May and June 2017., as part of the PhD project of Pedro Ochôa. The research conducted for the PhD project of Pedro Ochôa was integrated in the Thermoplastic Affordable Primary Aircraft Structure 2 (TAPAS 2) project, financed by the Netherlands Enterprise Agency of the Ministry of Economic Affairs.

It is made public both to act as supplementary data for the doctoral dissertation of Pedro Ochôa and publications, and to allow other researchers to use this data in their own work.

1.2. Structure of the dataset

The dataset contains the following file groups:

- Guided wave test data
    - Without LFV or SW
    - With LFV
    - With SW
- Guided wave test results
- Vibration spectra data

1.2.1. Guided wave test data: Without LFV or SW

This file group contains raw ultrasonic signals from GW tests performed on a full-scale composite torsion box stiffened panel at rest.

- File format: MATLAB formatted data (.mat)
- Naming convention : `D_T_Area_St_FkHz_Act_2Pico.mat`
    - `D` = testing date
    - `T` = testing time
    - `Area` = monitored area
    - `St` = state of the monitored area
    - `F` = GW excitation frequency
    - `Act` = actuator number

1.2.2. *Guided wave test data: With LFV*

This file group contains raw ultrasonic signals from GW tests performed on a full-scale composite torsion box stiffened panel subjected to realistic high-amplitude low-frequency vibrations (LFV).

- File format: MATLAB formatted data (.mat)
- Naming convention : `D_T_Area_St_FkHz_durLFV_Act_Si_to_Sf_n.mat`
    - `D` = testing date
    - `T` = testing time
    - `Area` = monitored area
    - `St` = state of the monitored area
    - `F` = GW excitation frequency
    - `Act` = actuator number
    - `Si` = first sensor number
    - `Sf` = last sensor number
    - `n` = data recording number in the same conditions (not always applicable)

1.2.3. *Guided wave test data: With SW*

This file group contains raw ultrasonic signals from GW tests performed on a full-scale composite torsion box stiffened panel subjected to audible machinery sound waves (SW).

- File format: MATLAB formatted data (.mat)
- Naming convention : `D_Area_St_FkHz_Act_Si_to_Sf_cooling_system_n.mat`
    - `D` = testing date
    - `Area` = monitored area
    - `St` = state of the monitored area
    - `F` = GW excitation frequency
    - `Act` = actuator number
    - `Si` = first sensor number
    - `Sf` = last sensor number
    - `n` = data recording number in the same conditions

1.2.4. *Guided wave test results*

This file group contains the results obtained by processing the raw GW test data along with the MATLAB scripts for that purpose.

The script files are:

- `GW_LFV_Exper.m`
- `cwtGWfilter.m` (called by the above scripts)
- `downsampsig.m` (called by the above scripts)
- `findFmain.m` (called by the above scripts)
- `get_comb_data.m` (called by the above scripts)
- `get_filename_info.m` (called by the above scripts)
- `get_pico_data.m` (called by the above scripts)
- `GetSenNum.m` (called by the above scripts)

The result files are:

- `LFV_effect_results.mat` where extracted signal features are stored;
- `Feature_variations.xlsx` where the feature variations are computed and stored.

1.2.5. Vibration spectrum data

This file group contains raw time-force signal of the structural high-amplitude LFV applied to the full-scale composite torsion box stiffened panel

- File format: Comma-separated values (.csv)
- Naming convention: `D_ForceSignal_n.csv`
    - `D` = testing date
    - `n` = data recording number in similar conditions

2. Methodological information

2.1. Guided wave test data

The test specimen was selected as a full-scale horizontal stabilizer torsion box panel entirely made of carbon fibre reinforced thermoplastic, as depicted in Figure 1. Areas 1 and 2 (near stringer run-outs) were GW tested in pristine condition (ND) and after a 50 J impact along the stringers. The impacts were on the outer side of the skin, at the stringer run-outs of areas 1 and 2 (damage conditions D1 and D2, respectively).

The piezoelectric (PZT) transducer network for GW measurement in Areas 1 and 2 is depicted in Figure 2. The setup can be seen in Figure 3. The ultrasonic excitation was produced by an Agilent 33500B waveform generator, amplified by a TTi WA301 wideband amplifier and transmitted to the structure by thin PZT actuator discs. The ultrasonic response was sensed by thin PZT sensor discs and acquired by two digital oscilloscopes, PicoScope 4424 and PicoScope 6402A, both connected to a computer. All the PZT discs were made of APC 850 material (supplied by APC International, Ltd.), had a thickness of 0.4 mm and a diameter of 20 mm. Ultrasonic GW were excited at 123, 213 and 335 kHz, using a 10-cycle sinusoidal tone-burst with the amplitude modulated by a Hanning window.

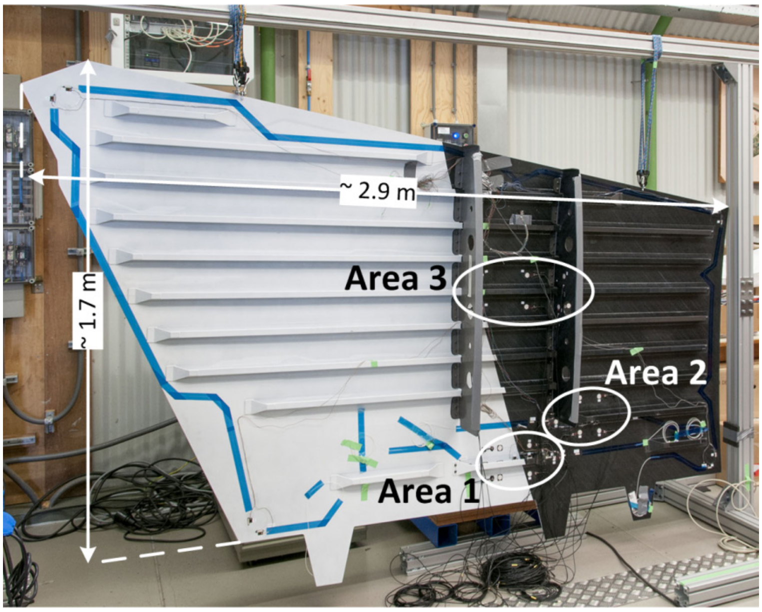

Figure 1. General view of the torsion box panel with critical areas highlighted.

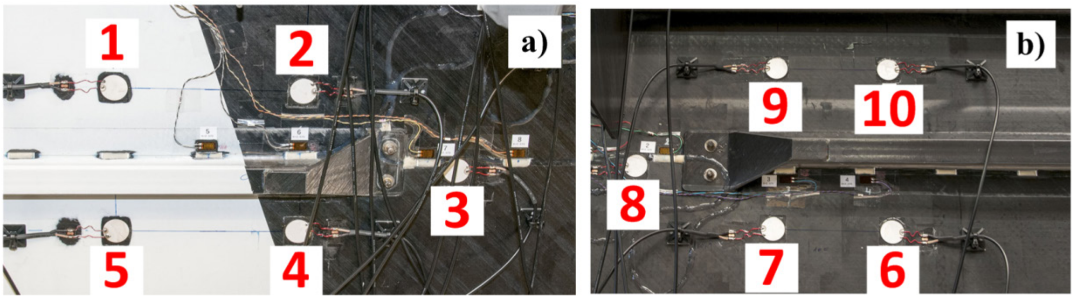

Figure 2. Detailed view of Area 1 (a) and Area 2 (b) with the numbered PZT transducer locations.

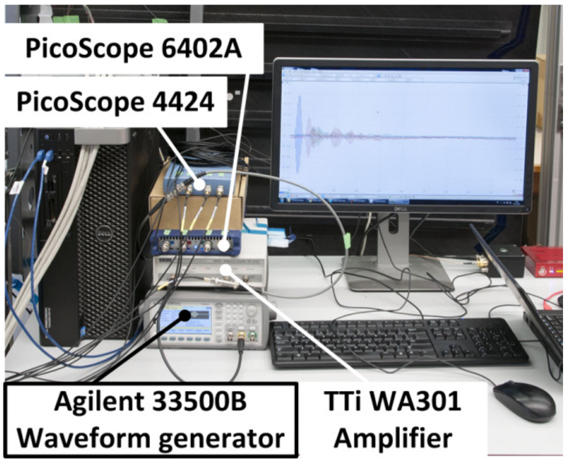

Figure 3. Guided wave measurement setup.

2.2. Guided wave test results

The GW test results in `LFV_effect_results.mat` were generated by running the script `GW_LFV_Exper.m`.
The GW test results in `Feature_variations.xlsx` were generated by copying the values in `LFV_effect_results.mat` to columns E to L and implementing Excel formulas for calculating the variations in columns R to V.

The version of MATLAB used was 2016b.
The version of Excel used was 2010.

2.3. Vibration spectrum data

A TIRAvib 50350 mechanical shaker was connected to the torsion box panel (see Figure 4) in order to apply a single-axis, out-of-plane, high-amplitude LFV with frequency randomly varying between 20Hz and 1000 Hz. The amplitude randomly varied between 5 and 10 G_{RMS}, and the duration was approximately 5 min, during which GW data was also acquired. The signal of the applied LFV was measured by a PCB 208A03 force transducer mounted on the connecting spigot.

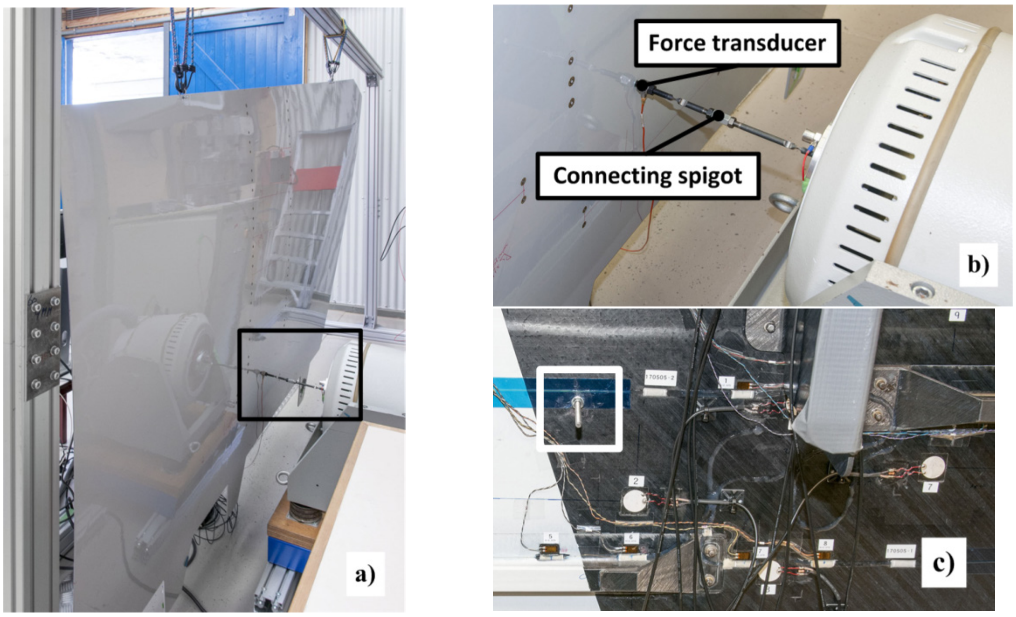

Figure 4. Connection of the mechanical shaker to the torsion box panel: a) general view of the relative positions, b) detailed view of connecting spigot, and c) detailed view of the bolted connection on the inner side of the panel.

3. Data specific information

3.1. <u>Guided wave test data</u>

3.1.1. *Guided wave test data: Without LFV or SW*

Each data file contains a MATLAB structure named **`test_data`** where the signals acquired by the two oscilloscope are stored. Each row of the structure corresponds to one oscilloscope. The structure has the following fields:

- **`Tstart`** field, which contains a double with the reference start instant for the measurements;
- **`Tinterval`** field, which contains a double with the sampling interval;
- **`ChLength`** field, which contains a double with the number of data points in the signals;
- **`NumChannels`** field, which contains a double with the number of channels acquired;
- **`Actuator`** field, which contains a double with the number of the transducer used as actuator;
- the **`Sensors`** field, which contains an array of doubles with the numbers of the transducers used as sensors;
- **`Signals`** field, which contains a 1-by4 cell array with information from all oscilloscope channels (actuator and sensors). If a channel was used, the corresponding element in the cell array is formed by a cell array containing a string with the name of the channel and an array of doubles with the actual signal. If the a channel was not used, the corresponding element in the cell array by an empty array. The excitation signal is stored in the first element of the cell array of the **`Signals`** field, in the first row of **`test_data`**.

3.1.2. Guided wave test data: With LFV

Each data file contains the excitation signal in variable **`A`** and the sensed signals in variables **`B`**, **`C`** and **`D`**. The size of all signals is identified by variable **`RequestedLength`**, which contains the number of useful data points. The sampling interval is given in variable **`Tinterval`**. The reference start instant for the measurements is stored in variable **`Tstart`**.

3.1.3. Guided wave test data: With SW

Each data file contains the excitation signal in variable **`A`** and the sensed signals in variables **`B`**, **`C`** and **`D`**. The size of all signals is identified by variable **`RequestedLength`**, which contains the number of useful data points. The sampling interval is given in variable **`Tinterval`**. The reference start instant for the measurements is stored in variable **`Tstart`**.

3.1.4. Measurement units

Signals: volt (V)
Time: second (s)

3.2. Guided wave test results

The file `Feature_variations.xlsx` contains the results in the **`All_channels`** worksheet. The results of interest are in columns F to I, N and P, which have the physical units defined below. The values in columns V to Z have the relative variations (i.e. expressed in percentage) of the quantities in columns F to I and P.
For analysing the results in `Feature_variations.xlsx` it is important to know that the headings "Act #" and "Sen #" mean actuator number and sensor number, respectively; that "Ex Freq" stands for excitation frequency; and that "Case" represents the monitored state of the structure: "ND" means "Not damaged", "D1" means "Damage in area 1", "D2" means "Damage in area 2", "+ LFV" means "with LFV", and "+ SW" means "with SW".

3.2.1. Measurement units

T10%, 10%-duration time: micro second (μs)
ToF, Time-of-Flight: second (μs)
A_{FN}, area of the normalised signal frequency spectrum curve: non-dimensional
Fch, characteristic frequency: kilohertz (kHz)
DI 19a, damage indicator 19a: non-dimensional
SBR, signal-to-background ratio: decibel (dB)

3.3. Vibration spectrum data

The file contains time and force data. When opened in MATLAB (through the **`importdata`** function), the data is organized in two columns, the first one being time and the second one being force.

3.3.1. Measurement units

Time: second (s)
Force: newton (N)

4. Sharing and Access information