Ground Vibration Testing of a High Aspect Ratio Wing with Revolving Clamp

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Outline

Ground Vibration Testing of a High Aspect Ratio Wing with Revolving Clamp

Main Contributions

1. Design and development of a revolving clamp for High Aspect Ratio wings
2. Extensive Ground Vibration Testing on a High Aspect Ratio wing at different amplitudes and setting angles

Motivation

- Testing and modelling in-flight operations of a High Aspect Ratio (HAR) wing is expensive and time consuming
- Ground Vibration Testing is already part of the design and test phase of an aircraft and could be enhanced to deliver more information
- A variation of the gravitational vector changes the resting shape of the wing
- Investigate the relationship between setting angle, input force, and modal parameters

Background

Ground Vibration Testing

- Finite Element Models (FEMs) are developed as early as the preliminary design stage, but they need validation
- Ground Vibration Testing (GVT) allow to obtain the vibration response of the structure from a given input
- Modal parameters can also be extracted from experimental data and used to validate or update the FEM

Methods

The High Aspect Ratio Wing

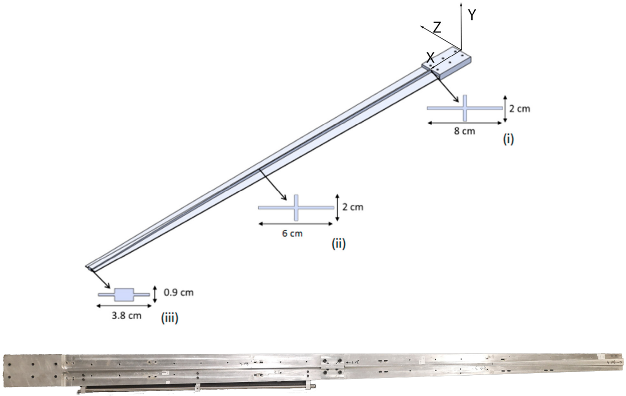
- eXperimental BeaRDS-2 (XB-2) wing is a dynamically scaled model of a A320-like civil airliner wing
- BeaRDS framework was a project from Cranfield University which aimed to create a work flow for the design, testing and modelling of flexible wings based on dynamically scaled prototypes.

Methods

Materials

- 6082-T6 Aluminium
- Stainless Steel
- Digital ABS
- Agilus 30

Property	Details	Unit
Semi span	1.5	m
Root chord	236	mm
Tip chord	83	mm
LE sweep	14.9	°
Mass	3.024	kg



Methods

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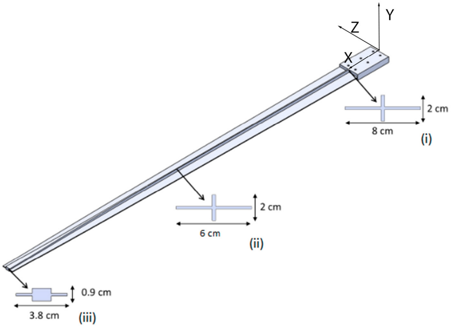
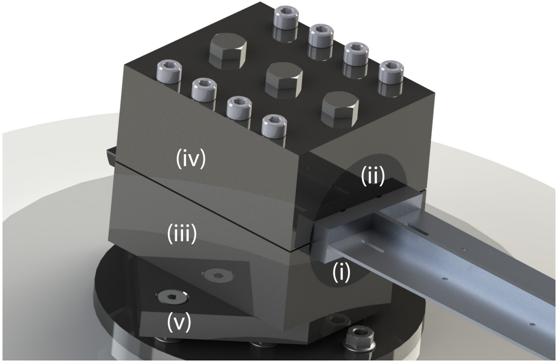


Methods

The Revolving Clamp

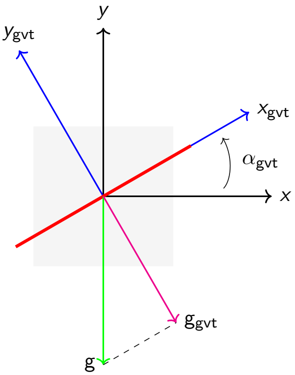
- 5 parts
  1. Lower sock
  2. Upper sock
  3. Lower end
  4. Upper end
  5. Base plate
- Aluminium
- 4.189 kg

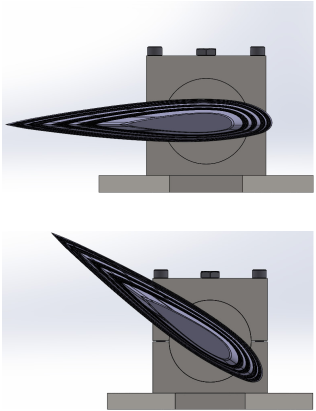


Methods

- Increase in the wing's inclination angle (α_{gvt})
- decreases g_{gvt}
- $\Uparrow \alpha_{gvt} \Downarrow g_{gvt}$ and the wing's deflection

$$g_{\alpha_{gvt}} = g \times \cos(\alpha_{gvt}) \qquad (1)$$

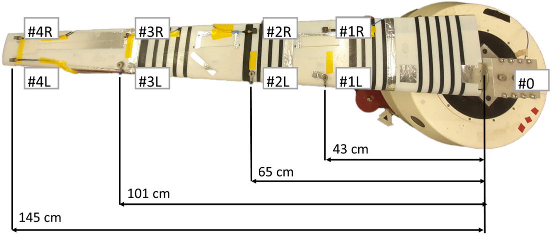




Methods

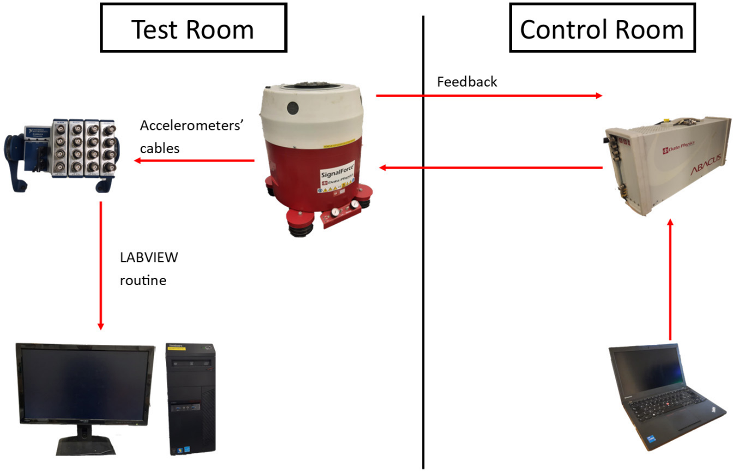
Experimental Setup

- Accelerometers position:
  - Genetic Algorithm-based technique using the cross-correlation of adjacent modes [1]
- 4 accelerometers rows
- 8 total
- Vertical and rotational displacements



Note that the accelerometers do not appear aligned due to the optical effect of the camera lens.

Methods


Test Room
Control Room
Feedback
Accelerometers' cables
LABVIEW routine

Methods

- Band-limited random vibration for 20 min
- 3 different setting angles
- 3 input amplitude (0.649, 0.919, 1.590 RMS ms^{-2})
- 9 total cases
- 5 realisation for each case (45 total tests)

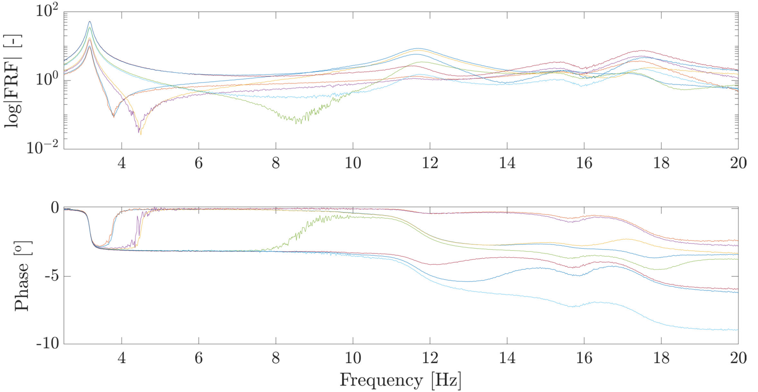
Test Matrix

Case	**Input**	α_{gvt} [°]
1	Low	0
2	Medium	0
3	High	0
4	Low	5
5	Medium	5
6	High	5
7	Low	10
8	Medium	10
9	High	10

Methods

Experimental Data

- Desampling (5120 Hz to 256 Hz)
- Frequency domain conversion (via FFT)
- Frequency Response Functions (FRF) filtered with MATLAB `smoothdata`

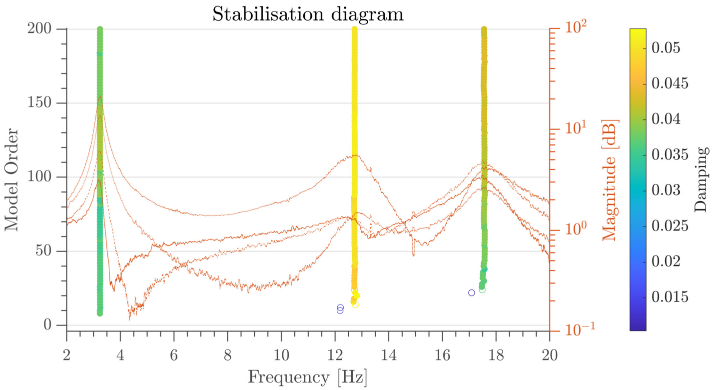


Case 1 - Low input, $\alpha_{gvt} = 0°$, first realisation

Results

Stabilisation diagram

- 4 peaks from FRF plot
- Third mode disregarded as lagging dominant [2]
- $\Delta f = 1\%$, $\Delta\zeta = 10\%$ and MAC $= 0.95$
- Identification method: the Loewner Framework [3]



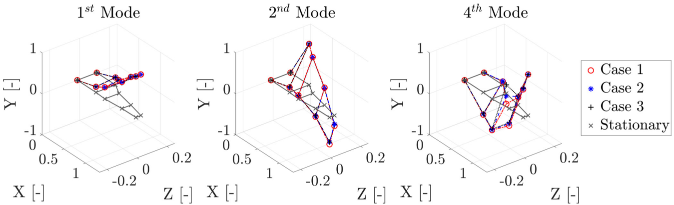
Case 1 - Low input, $\alpha_{gvt} = 0°$, first realisation

Results

Modal Parameters

- Cases 1, 2, 3 - Low, Medium, and High input, $\alpha_{\text{gvt}} = 0°$
- Average over five realisations
- Slight decrease (softening) in all modes
- Less for the 1^{st} mode

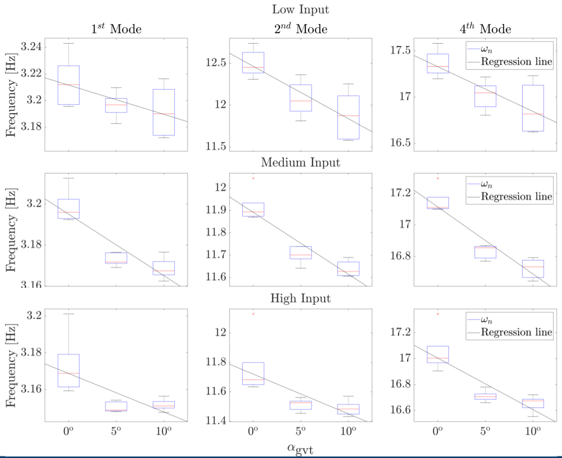
Case	***1***		***2***		***3***	
Mode	ω_n [Hz]	ζ_n [-]	ω_n [Hz]	ζ_n [-]	ω_n [Hz]	ζ_n [-]
1^{st} Bending	3.21	0.035	3.20	0.023	3.17	0.018
2^{nd} Coupled	12.50	0.053	11.92	0.053	11.76	0.055
4^{th} Coupled	17.36	0.045	17.15	0.045	17.05	0.057



Results

Natural Frequencies

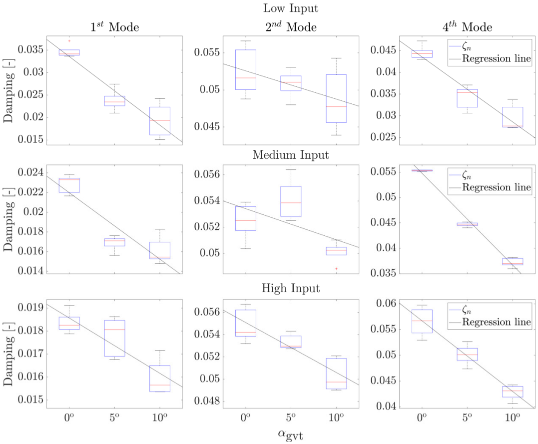
- α_{gvt} influence on natural frequencies
- Global trend: $\Downarrow \propto \alpha_{\text{gvt}}$
- Some spurious occurrences



Results

Damping Ratio

- α_{gvt} influence on damping ratios
- Global trend: $\Downarrow \propto \alpha_{\text{gvt}}$
- Some spurious occurrences



Conclusions and Future Works

- A clear linear relationship between inclination angle and modal parameters is established over a range of input amplitude
- The frequencies and damping ratios are found to decrease with changes in the inclination angle
- The modelling of wing's FEM that takes into consideration these changes is left for future works

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[2] G. Dessena, D. I. Ignatyev, J. F. Whidborne, A. Pontillo, and L. Zanotti Fragonara, "Ground Vibration Testing of a Flexible Wing: A Benchmark and Case Study," *Aerospace*, vol. 9, no. 8, p. 438, Aug. 2022, ISSN: 2226-4310. DOI: 10.3390/aerospace9080438. [Online]. Available: https://www.mdpi.com/2226-4310/9/8/438.

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Questions

If you have any suggestions or further questions then please contact me via email at `Gabriele.Dessena@cranfield.ac.uk`.

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