Flight Project 2

Wing dynamics

Introduction

This part of the project looks at the problem of wing vibrations. This property determines the *aeroelastic* behaviour of the wing or plane during flight. The simple approach chosen in this task is to investigate the bending vibration of the wing and the corresponding fundamental natural frequency. This very simple model of the wing will be based on the theory of a spring-mass oscillator (see any book on *Mechanics*).

Objectives

The objective is to assess and critically evaluate the dynamics of your wing with particular focus on:

- Stiffness and mass properties of the wing,
- Vibration properties of the wing,
- Assessment of the model quality, assumptions and limitations.

Problem context and suggested approach

In its simplest form, the wing can be modelled as a simple spring-mass oscillator corresponding to the wing moving in its fundamental mode of vibration.

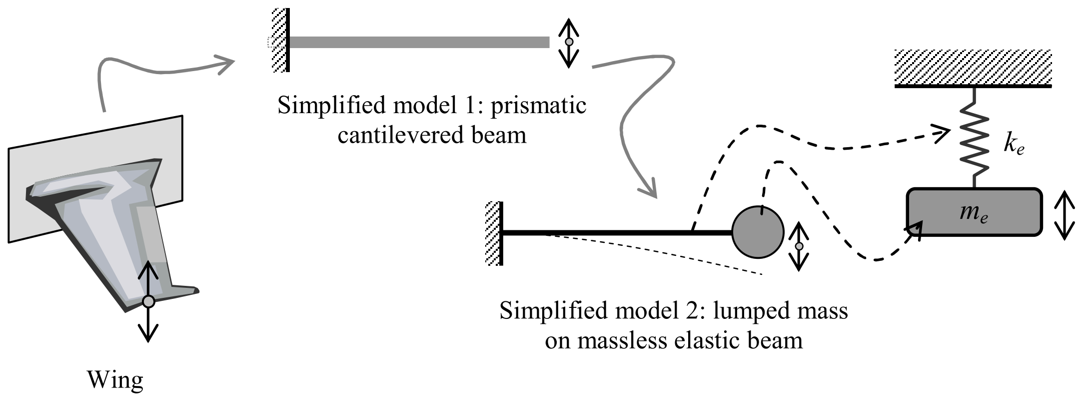

Figure 1 Model of foam wing

This simple spring-mass oscillator has the natural frequency

$$f_0 = \frac{1}{2\pi}\left(\frac{k_e}{m_e}\right)^{1/2} \quad [Hz]$$

where:

- $k_e\ [N/m]$ is the equivalent stiffness of the wing from the **static deflection test** (below),
- $m_e\ [kg]$ is the *equivalent (or effective) mass* of the wing, $m_e = \gamma m_{wing}$, $\gamma \approx 0.24$,
- $m_{wing}\ [kg]$ is the *actual moving mass* of the wing,

Suggested steps for your investigation:

1. *Bending stiffness*: static bending test to determine the *equivalent* stiffness of the wing,
2. *Fundamental natural frequency*: Calculate the fundamental (natural) frequency of the wing using experimentally determined equivalent stiffness k_e and *estimated equivalent* mass of the wing m_e.
3. *Validation and assessment*: experimental validation using your *smart phone* or provided *iPod Touch* and critical assessment of the results. This last exercise will be completed in the BLADE Dynamics Lab with instructor in the pre-arranged time. This exercise will take 15 minutes. Further details (e.g. available time slots for experiments) will be provided via email.

Equivalent stiffness

The basic principle of the test is shown in the following figure.

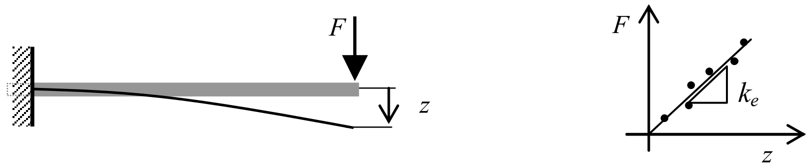

Figure 2 Static test of wing

Loading your wing at the tip of the wing produces a deflection. You can produce a displacement-load diagram and find the equivalent stiffness of the wing valid for this method of loading. A basic definition of stiffness is represented by the following equation: $F = k_e z$.

Suggestions:

- You should use *linear interpolation* (or fit) to determine this quantity for N measured points, where $N > 6$,
- You should estimate this quantity for three different chosen positions close to the tip of the wing to appreciate variability (or uncertainty) of this quantity when determined experimentally.

Equivalent mass and natural frequency

The equivalent mass $m_e = \gamma m_{wing}$, $\gamma \approx 0.24$ is the result of the assumption that the wing vibrates in the particular shape similar to the one shown in Figure 2. Different sources recommend different γ, typically in the range $\gamma \in [0.23, 0.33]$!

Suggestions:

- Calculate f_0 for the indicated range of γ and for different estimated k_e.
- Assess variability (or uncertainty) of the resulting f_0.
- Use *relative* differences to express your observations.

Validation and assessment

The previous results will be assessed experimentally using a *vibration experiment*. This can be accomplished using smart phones (iPhone, Android, or provided iPod Touch etc.) as they contain *accelerometers* – sensors for the measurement of acceleration. An example provided in this note is based on a free app downloaded from Apple Store called "iSeismometer" *. This app allows the acquisition, processing and emailing of the measured accelerations. These data can be further processed in *Matlab* or *Excel* or any other suitable tool. Two suggested experimental setups are indicated in Figure 3.

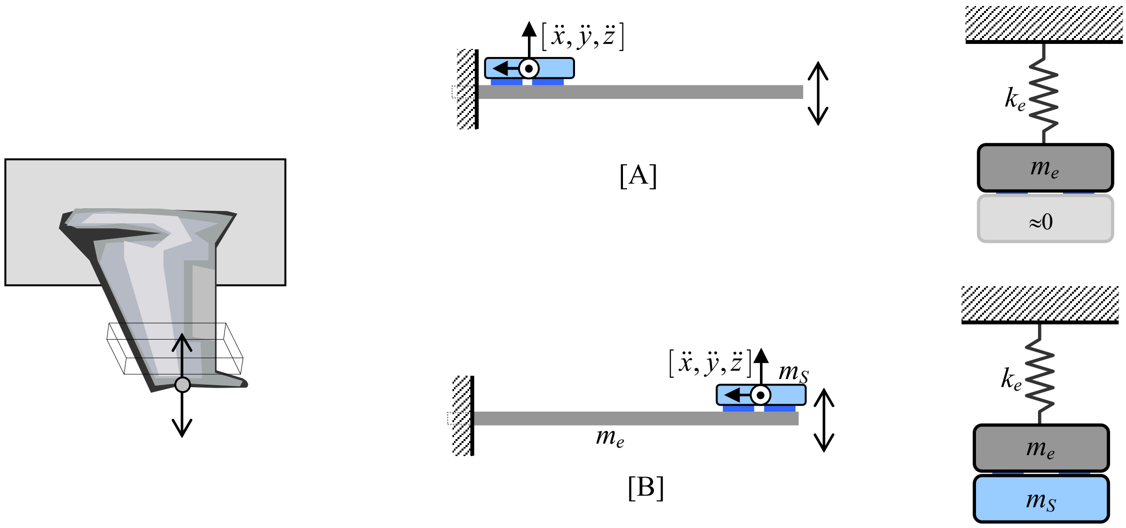

Figure 3 Wing and its models for stiffness and bending vibrations

Each configuration has its own advantages and disadvantages. The influence of the instrument's mass is minimized (indicated by "≈0") in configuration [A] and the resulting recorded signals should give a good indication of the fundamental natural frequency of the wing. Alternatively, configuration [B] can be used together with the modified spring-mass model (shown in Figure 3) and the formula for f_0 adjusted correspondingly. In each case, the acquired signals can be used to infer the frequency of motion (e.g. determining the distance between the two neighboring peaks on the recorded waveform, using signal processing techniques).

Suggestions:

* www.iseismometer.com

- Locate your "sensor" according to [A] or [B] → start your app → wait until your structure reaches its static equilibrium position → gently tap your wing close to the tip → wait and observe free response of the wing → store or email your data for further processing. This process emulates aspects of so called "*impact vibration testing*" – an experimental technique used in aerospace for design, assessment, monitoring and maintenance of planes, wings, blades, propellers, fuselages, missiles, electrical equipment etc. etc.
- Repeat the suggested *dynamic test* (choosing configuration [A] *or* [B]) for small changes of the position of your sensor around its reference position on the wing (root or tip) and comment on what you can observe, i.e. trends and changes in measured f_0.
- Use the data obtained in this section to assess the quality of your previous models. What are the limitations of both the experiments and the models?

Conclusion

Summarize your observations, results, procedures, insights, graphs, tables and conclusions in a suitable engineering format reflecting on the provided suggestions.

Appendix: Selected examples of the results