Vibrations 2

Coursework specification
Application of a TVA in an aircraft

Students *must* submit their own individual and independent work. All submitted reports will be checked against plagiarism in all their aspects.

Coursework description

This Vibrations 2 coursework constitutes 100% of the final mark in the unit. The coursework centres around an application example of an aircraft which suffers from excessive vibrations in one of its parts. The coursework is divided into 5 tasks. Each task contributes 20% to the overall mark for the coursework and unit. Each task must be answered on a single page in the final individual report. The final report will consist of a single title page (which should include all relevant ID details, in particular name and *UoB user name*) and five additional pages covering the technical tasks.

AfCh … Amplitude-frequency characteristics

DOF … degree of freedom

EoM … Equation of Motion

FRF … Frequency Response Function

ODE … ordinary differential equation

abc … typed Matlab text

Motivation

"*Fighter aircraft have been designed to fly and maneuver at high angles of attack and at high loading conditions. At these high angles of attack, the flow separates from the sharp leading edges of the wing and leading-edge extension (LEX) forming a strong vortical flow that maintains the stability of the aircraft. However, the leading-edge vortices break down upstream of the vertical tails. The breakdown flow impinges upon the vertical tail surfaces causing severe structural fatigue and has lead to their premature fatigue failure, costing millions of dollars every year for inspections and repairs.*" [Sheta&Huttsell, 2003]

Moses, RW, Active vertical tail buffeting alleviation on a twin-tail fighter configuration in a wind tunnel, CEAS International Forum on Aeroelasticity and Structural Dynamics. 1997.

Sheta, EF, Huttsell, LJ., Characteristics of F/A-18 vertical tail buffeting. Journal of fluids and structures, 2003 Mar 1;17(3):461-77.

Within the context of this coursework, you are a vibration specialist asked to analyse a problem of all-moving vertical stabiliser buffeting on a sixth-generation fighter aircraft. A range of tasks needs to be completed to characterise the system and propose the viable passive vibration control solution based on the application of the tuned vibration absorber concept.

The technical tasks have the following focus (detailed description follows later in this document):

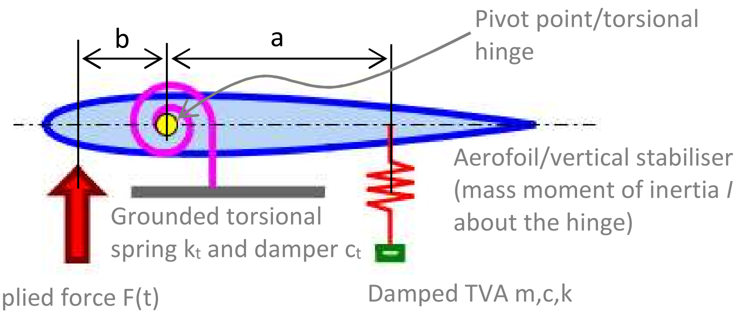
1. *Single DOF analysis* using the provided Matlab model.
2. *Two DOF analysis* using the provided Matlab model and eigenvalue analysis.
3. *Vibration absorber tuning* combined with the use to the provided Matlab model.
4. *Derivation of the equations of motion* for a new two DOF system.
5. *Transient response* using own Matlab simulation with the impulse forcing.

To complete the first three tasks, the provided Matlab application model (called "*app*") will be used as a form of a "*digital twin*" which represents the overall system with the unknown vertical stabiliser properties (later also called "*wing*" or "*aerofoil*"). The last two tasks are independent of the provided Matlab app.

The tool and the modelled system

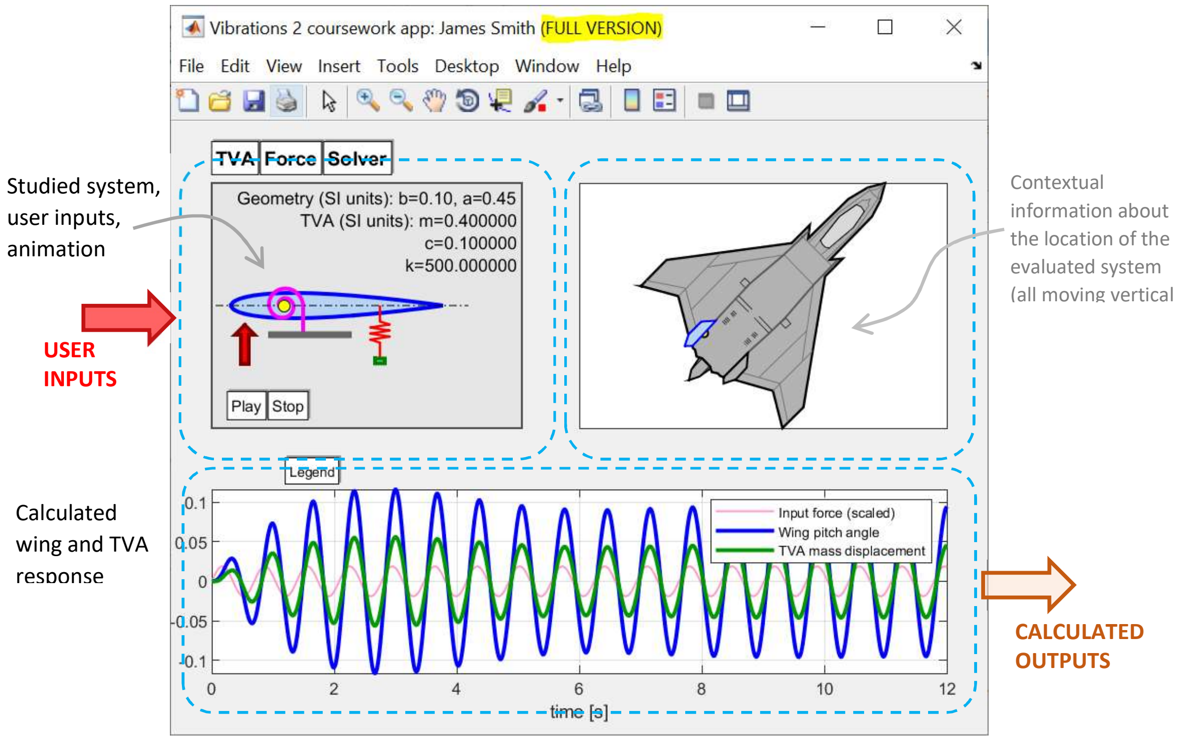
To support the first three tasks of this coursework, a simple *Matlab* app is provided in the P-file format to avoid the necessity or possibility of the source code modification. The app represents a model of the problematic vertical stabiliser with the unknown physical properties which will be determined in **Task 1**.

The system's visual representation is shown in the following figure together with its constituent components, model elements and relevant geometry information (note the offset dimensions).



This is a *two degree-of-freedom* problem where the first DOF is realised by the aerofoil pitching and the second DOF is linked with the vertical motion of the TVA mass.

The application window is shown in the following figure where the main user blocks are identified and described. Further information about the user interface can be found in the recorded live sessions held on 30/4/2021 ("*Vibrations - Coursework Demo*") and on 7/5/2021 ("*Vibrations - Coursework Consultation*").

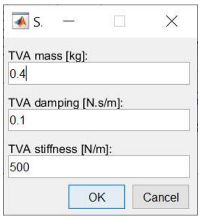


IMPORTANT: You must use the FULL version of the Matlab app which can be downloaded from "***Assessment Information***" folder located in "***Assessment, submission and feedback***" section. Do not use the preliminary version released for learning and demonstration purposes. In FULL version, all students have their own individual aerofoil parameters to work with. This capability is not present in the demo version.

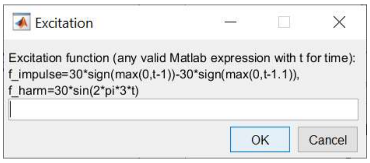
User functionality

After each user-specified parameter update, the system's *vibration response* is automatically updated and shown in the bottom panel. The *user inputs* are applied in the top left panel. The top right panel serves for simple contextual information about the overall system layout.

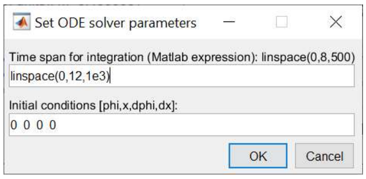
The user input windows can be activated by a mouse click on: "**TVA**" or the spring-mass visualisation of the damped TVA (see figure below) to change the mass, damping and stiffness of the TVA; "**Force**" or the red arrow visualisation of the input force to change the time-dependent excitation function (*see* the figure below); "**Solver**" to adjust the ODE time integration range, discretisation and the initial conditions.



Specify TVA parameters



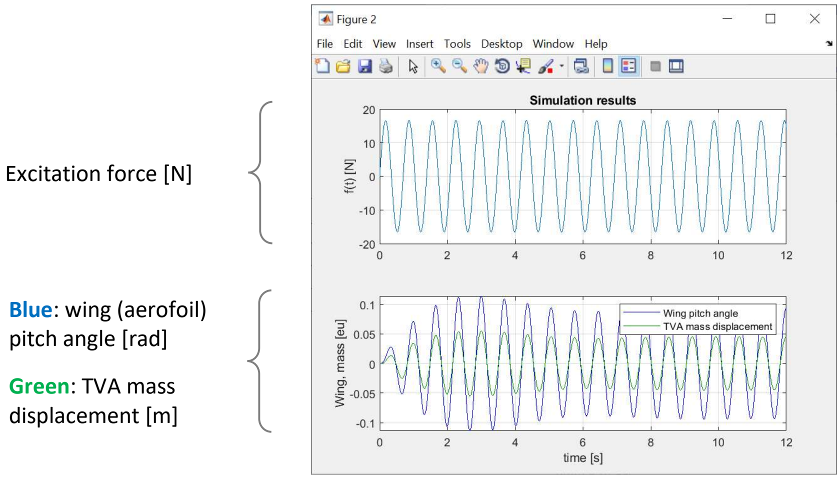
Specify excitation function



Specify ODE integration options

The *time-dependent excitation function* can be any valid Matlab expression with the specific parameter values and a time symbol "t". Examples of suitable functions are: "1" (a constant unit step at t=0 sec), "30*sin(2*pi*3*t)" (a harmonic force at 3 Hz), "0" (a zero-force leading to free vibrations for the non-zero initial conditions), "0.1*t" (a slow ramp function). More complicated function specifications are possible. The *four initial conditions* represent: (**1**) initial aerofoil angular displacement in [rad]; (**2**) vertical TVA displacement in [m]; (**3**) aerofoil angular velocity in [rad/s]; (**4**) vertical TVA velocity in [m/s].

For a precise analysis purposes, the calculated vibration responses can be plotted separately after a mouse click on any of these lines. A separate window will be generated which will show the applied force in [N] (the top subplot). The bottom subplot contains the aerofoil angular displacement (shown in blue) in [rad], and the vertical TVA mass coordinate (shown in green) in [m].



A mouse click on one of the calculated vibration response curves also updates the content of the variable "`var_tvalab`" which is present in the base workspace (i.e., through command line) and can be used for further analysis in or outside of Matlab. The columns in this matrix represent [time,dof1,dof2,force] and the rows represent the time instants for which the responses were calculated.

An animation of the obtained responses can be started (stopped) by clicking on "Play" ("Stop") text fields. A click on "Legend" text field switches on/off a legend in the calculated vibration response panel.

App start and initial configuration

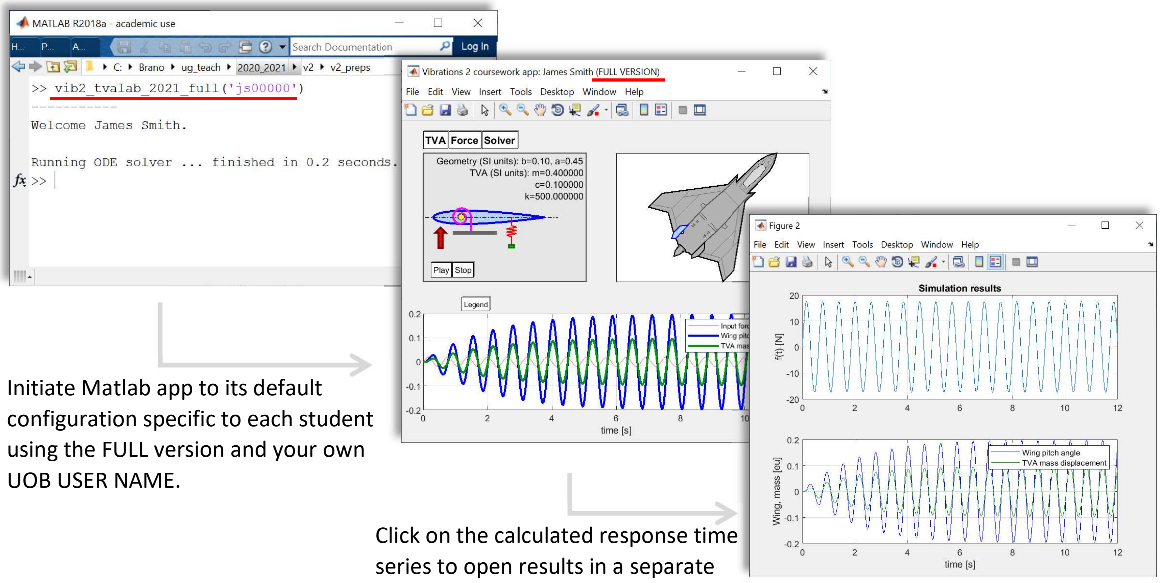
Each student must download their own FULL version from the "*Assessment Information*" folder located in the "*Assessment, submission and feedback*" section of the unit to be able to work with their own problem specification. In other words, every student has their own specific aerofoil parameters values to determine in **Task 1**.

The FULL version of Matlab app must be started using a single input argument which represents the student's "UOB USER NAME" typed in lower case on the Matlab command line. The P-file must be located in the directory visible to Matlab, e.g., current working directory.

Example:

```
vib2_tvalab_2021_full('js00000') % use your own UOB USER NAME
```

After this, the application starts and is ready to be used for further analysis:



Initiate Matlab app to its default configuration specific to each student using the FULL version and your own UOB USER NAME.

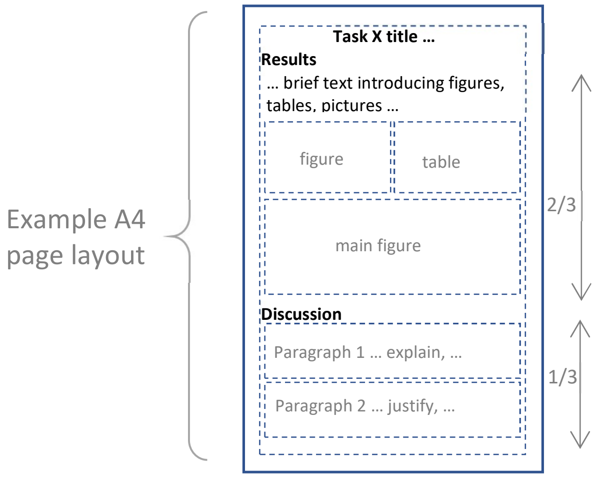
Click on the calculated response time series to open results in a separate window for further analysis.

The default initial state of the app is represented by the student's specific aerofoil parameters, the identical and adjustable TVA parameters, and semi-randomised harmonic excitation force. The force and TVA parameters can be changed. The aerofoil parameters are fixed and specific to each student.

Final remarks: It is recommended to run the app on your own machines, assuming you have a Matlab installation. However, in case of problems of any kind on your local machines, you can work with this app on your own UOB remote desktops. This option was assessed and was found to be a feasible option for the use of this tool. This Matlab app does not assume or require the use of any special toolbox, only the core Matlab functionality is used.

Coursework specification

Each task is specified in terms of its technical objective and the expected delivery format. All tasks should have page layout consistent with the following example. Each task specification offers further detail on what are the recommended proportions between the *compulsory* Results and Discussion sections.



Writing recommendations and page formatting:

- A4 page size, all page margins minimum 2 cm and maximum 2.5 cm wide.
- Font size 11pt, Single line spacing.
- Use figure captions, include and use SI units, label or annotate where appropriate, use legends.
- Introduce all figures and tables with a brief description to navigate the reader through results.
- Use variety of line styles, data markers, choose suitable font size, ensure visibility.
- Use formal language style, avoid the use of the first person in discussions or elsewhere.
- Avoid the use of photographed hand-drawn sketches.
- Cover between one to three points in each discussion piece.
- Avoid trivial, obvious, repetitive, or irrelevant discussion points.
- "*briefly*" means two, three or maximum four lines of text, more text is seen as the inability to offer a succinct observation or discussion point.

Marking:

- Each task contributes 20% to the total 100%.
- In each task, 70% of the mark is derived from the technical elements in terms of their degree of completion (in line with the following specs) and their quality.
- In each task, 30% of the mark is derived from the organisation (e.g., layout, flow, clarity), technical delivery (e.g., figures, tables, schematics, equations) and style (e.g., spelling, grammar).
- Every report is checked against plagiarism at multiple levels.
- Do not use parts of this coursework document or graphics in your reports.

Task 1: Single degree-of-freedom analysis (20% of 100%)

Specification: Use the provided Matlab app to find the physical parameters of the aerofoil (mass moment of inertia of the aerofoil about its hinge, torsional damping, torsional stiffness). Present the following *Results* and *Discussion* points:

- The main figure (graph) in *Results* should contain (**1**) the 1DOF FRF obtained using the harmonic excitation in Matlab app, overlayed with (**2**) the FRF calculated analytical using the physical parameters, further combined with the information indicating (**3**) the 1DOF undamped natural frequency.
- The other shown *Results* should represent the summary table with the found parameters and one additional auxiliary figure illustrating (any) one of the methods used during parameter identification.
- One paragraph in your *Discussion* should summarise briefly the methods or approach used for parameter identification.
- One paragraph in your *Discussion* should briefly summarise the assumptions or criteria used during the parameter identification stage.

Guidance, suggestions, hints:

- Recommended layout: Results section 2/3 A4 page, Discussion 1/3 A4 page.
- The default system in Matlab app, after its start, is 2DOF and needs to be modified to approximate the 1DOF aerofoil system by reducing, suitably, the significance of the TVA part in the system.
- Use suitable input conditions (forced, free vibrations) to obtain such responses that can be used to calculate the parameters, e.g., LogDec, static or slow deformation, very high frequency excitation.
- Useful resources: lectures 3, 4, 7, 8.

Task 2: General two degree-of-freedom analysis (20% of 100%)

Specification: Use the provided Matlab app to calculate 2DOF system AfCh and present the following *Results* and *Discussion* points:

- The single main figure (graph) in *Results* should contain the following information identified with the help of the Matlab app: (**1**) the initial 2DOF AfCh for the aerofoil DOF and (**2**) 2DOF AfCh for the TVA DOF (calculated for the initial values of the aerofoil and TVA parameter values); (**3**) 1DOF AfCh for the aerofoil DOF; (**4**) the information indicating the 2DOF undamped natural frequencies (e.g., labelled vertical lines).
- The other shown *Results* should represent the summary table with the values of the undamped natural frequencies (also visualised in the main figure).
- One paragraph in your *Discussion* should comment briefly on the mutual relationship between the two calculated 2DOF AfCh functions for the aerofoil and TVA DOFs.
- One paragraph in your *Discussion* should comment briefly on the relationship between the 2DOF AfCh functions and the two calculated undamped natural frequencies.
- One paragraph in your *Discussion* should briefly discuss the role of the aerofoil and TVA damping on the shape of the two AfCh functions and other results presented in the main figure.

Guidance, suggestions, hints:

- Recommended layout: Results section 2/3 A4 page, Discussion 1/3 A4 page
- Use your own initial (default) 2DOF system configuration in Matlab app, in combination with the suitable range of harmonic inputs, to calculate the amplitude frequency characteristics (AfCh functions) such that both resonance regions are well described.
- Use 1DOF approximation from **Task 1** to calculate the corresponding 1DOF AfCh. Think about the relationship between the AfCh (2DOF lectures) and FRF (1DOF lectures) functions.
- If interested to support your damping discussion, consider recalculating the relevant AfCh function(s) for the changed damping value.
- To calculate the 2DOF undamped natural frequencies, you need to derive the EoMs for the 2DOF problem (e.g., using Newton), determine the mass and stiffness matrices, and perform the eigenvalue analysis.
- In your discussions, focus on similarities and differences, characteristic features, trends, root cause of the behaviour of interest, significance, etc.
- Useful resources: lectures 12, 14, 15, 16.

Task 3: Tuned Vibration Absorber (20% of 100%)

Specification: Tune the TVA such that it absorbs or suppresses the resonance in your own 1DOF system. Present the following *Results* and *Discussion* points:

- The first figure in *Results* should contain the following information identified with the help of the Matlab app: (**1**) 1DOF AfCh (reused from **Task 2**); (**2**) 2DOF aerofoil AfCh for the case with the arbitrary tuned TVA (i.e., without any additional constraints) and zero TVA damping; (**3**) 2DOF aerofoil AfCh for the case where the TVA mass is 5% of the *equivalent mass* of the aerofoil (*see* hints) and 1% TVA damping (*see* hints); (**4**) 2DOF aerofoil AfCh for the case where the TVA mass is 5% of the *equivalent mass* of the aerofoil (*see* hints) and 20% TVA damping (*see* hints).
- The second figure in *Results* should compare the TVA configurations described above in (**3**) and (**4**) by additionally including, in each case, the AfCh functions for the aerofoil DOF and TVA DOF.
- One paragraph in your *Discussion* should comment briefly on the characteristic features observed in the *first* figure, particularly the effect of the TVA mass constraints and TVA damping.
- One paragraph in your *Discussion* should comment briefly on the characteristic features observed in the *second* figure, particularly the effect of the TVA damping on the behaviour of the primary system (aerofoil) and secondary system (TVA) relative to each other.

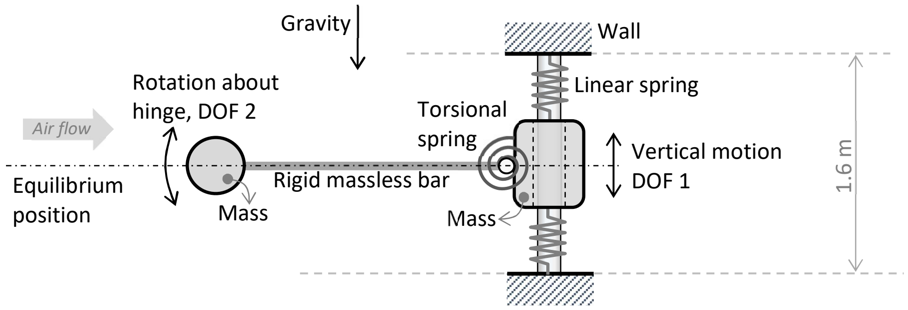
Guidance, suggestions, hints:

- Recommended layout: Results section 2/3 A4 page, Discussion 1/3 A4 page.
- Use harmonic inputs and appropriate frequency domain sampling to recover the required AfCh functions.
- To determine the *equivalent mass* of the aerofoil, use the concept of "*radius of gyration*" from Mechanics formulated between the aerofoil hinge and the TVA attachment point.
- The "%-value TVA damping" represents the damping ratio of the TVA spring-damper-mass system when in isolation from the primary system (aerofoil) and acting as a 1DOF system.
- Useful resources: lectures 15, 16.

Task 4: Equations of motion for 2 DOF system (20% of 100%)

Context: An advanced 7’×5’ wind tunnel test rig with a long “stinger” for an upstream positioning the scaled aircraft models suffers from excessive resonant vibrations due to harmonic excitation which originates from the wind tunnel rotor fans. This task focuses on the analysis of the simplified model of this test rig.

Specification: Derive the equations of motion about the equilibrium position of the system below using the Lagrange’s approach and evaluate the influence of the torsional stiffness on the undamped natural frequencies. Define all required parameters, a coordinate system, generalised coordinates, positive orientations, etc. For the parametric study, define the suitable and meaningful parameter values.



Present the following *Results* and *Discussion* points:

- In first figure shown in *Results*, include a picture of the system in the deformed configuration with the suitable coordinate frame of reference and positive orientations of the generalised coordinates which you use to form the system Lagrangian. Annotate the figure to make these decisions clear.
- In *Results*, provide the derived and complete Lagrangian (without linearisation) and, briefly, describe the individual energy terms.
- In *Results*, provide the mass and stiffness matrix formulas of the linearised system.
- In the second figure shown in *Results*, include the visual representation of the mode shapes for the specific choice of the parameter values. Include the mode shape vector values too.
- In the third *main* figure shown in *Results*, include the graph which shows the changes of the undamped natural frequencies of the system when varying the torsional spring stiffness between the 0 value and infinity (i.e., rigid connection approximated by a very high value of the spring stiffness).
- One paragraph in your *Discussion* should comment briefly on the influence of gravity and linearisation on the final form of the resulting EoMs.
- One paragraph in your *Discussion* should aim to interpret or explain the changes and trends in the natural frequencies when varying the torsional stiffness.

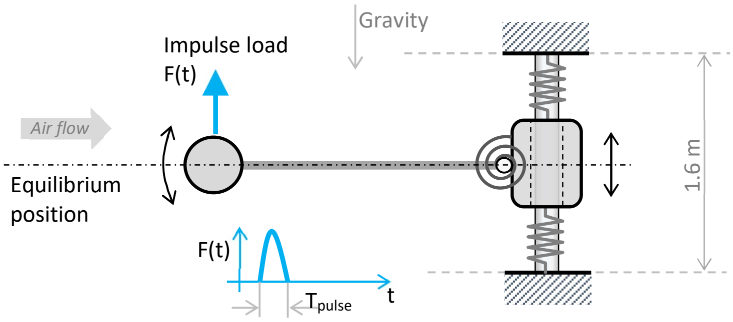
Guidance, suggestions, hints:

- Recommended layout: Results section 3/4 A4 page, Discussion 1/4 A4 page
- Apply the Lagrange’s method, later assume small angles, linearise, obtain matrices, perform eigenvalue analysis using the characteristic equation or `eig` function in Matlab.
- Consider the use of a logarithm scale when plotting the parametric graph.
- Useful resources: lectures 12,17, “*Matlab and vibrations - … revision note*”, example sheets.

Task 5: Transient Matlab simulation of 2 DOF system (20% of 100%)

Context: Previous problem, **Task 4**, is now investigated in the transient context which represents gust load effects on the scaled model of the aircraft placed at the tip of the rig's "stinger" element.

Specification: Perform the transient time domain analysis in Matlab on the 2DOF model derived in **Task 4** and find the total maximum loads transmitted to the walls for a range of the impulse force F(t) cases. Where necessary, choose the specific parameter values used in **Task 4**.



Present the following *Results* and *Discussion* points:

- In *Results*, show the process of the derivation of the generalised loads due to F(t).
- In *Results*, using Matlab formalism, choose and provide the F(t) function specification.
- In *Results*, using the formula(s) or a picture, explain the process of the transmitted load calculation.
- In the first figure shown in *Results*, provide an example transient response and the applied F(t).
- In the second figure shown in *Results*, present the relationship between the maximum force transmitted to the wall and the pulse duration T_{pulse}, where $0.01\times(2\pi/\omega_{02}) < T_{pulse} < 1.5\times(2\pi/\omega_{01})$ and ω_{0i} are the undamped natural frequencies of the 2DOF system.
- In *Discussion*, discuss the trends observed in the second figure with particular focus on the relationship between the natural periods and the conditions under which the maximum transmitted load to the wall is observed.

Guidance, suggestions, hints:

- Recommended layout: Results section 3/4 A4 page, Discussion 1/4 A4 page
- Apply the Lagrange's approach to determine the generalised loads arising from F(t).
- Candidate impulse load shapes: Heaviside-based pulse, 1-cosine, parabolic, triangular, etc.
- To obtain the meaningful transient responses, include the additional damping effects. The equation for the vertical motion DOF should contain the additional term "$c\dot{y}$", the equation for the torsional DOF should contain the additional term "$c_t\dot{\theta}$", where c and c_t are the chosen damping parameters.
- Useful resources: lectures 4, 9, 10, 17, "*Matlab and vibrations - … revision note*", M-files in "*Matlab*" folder.

End of the document.