AE410: Aerospace Structural Dynamics

Fall 2019, Final Project *

Name Student 1: RED ID Student 1:

Name Student 2: RED ID Student 2:

Name Student 3: RED ID Student 3:

Name Student 4: RED ID Student 4:

Name Student 5: RED ID Student 5:

Pledge

We have not obtained/used any help nor provided anyone such help in completing this exam.

Signed (student 1): Date:

Signed (student 2): Date:

Signed (student 3): Date:

Signed (student 4): Date:

Signed (student 5): Date:

Part # 1

Consider the **unswept** wing (defined here as **model # 1**) whose wing box structure is shown in Figure 1. In addition, consider the **swept** wing (defined here as **model # 2**) whose wing box structure is shown in Figure 2. Finally, consider the **swept** wing (defined here as **model # 3**) whose wing box structure is shown in Figure 3.

For all the models # 1, # 2, and # 3, the wing-box structure is symmetric. The top and bottom skins have a constant thickness of $2.5\,mm$. The wing structure has **three spars**, one each at the leading edge, center and trailing edge of the wing-box. The shear webs of the spars have a constant thickness along the

*Due Date: December 12th (5:00PM).

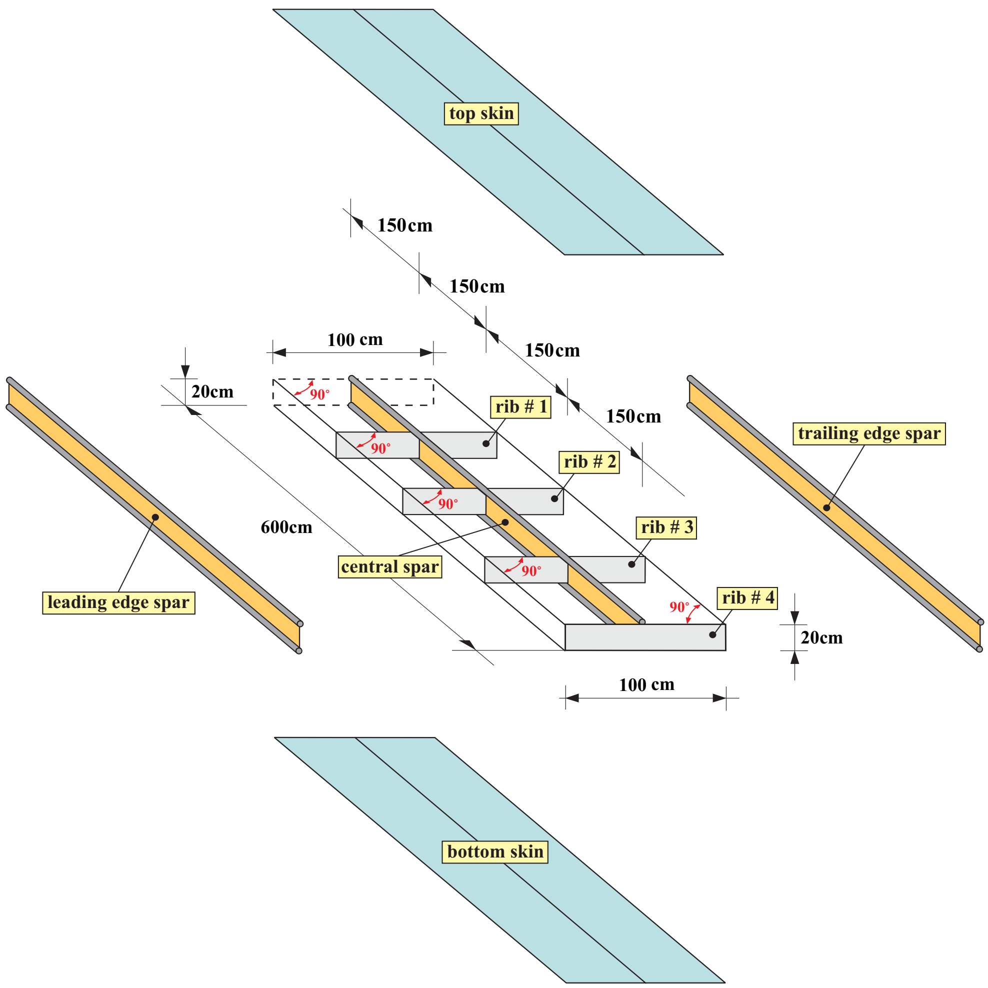

Figure 1. Unswept wing (model # 1): exploded view of the wing box structure showing spars, ribs, and top and bottom cover panels.

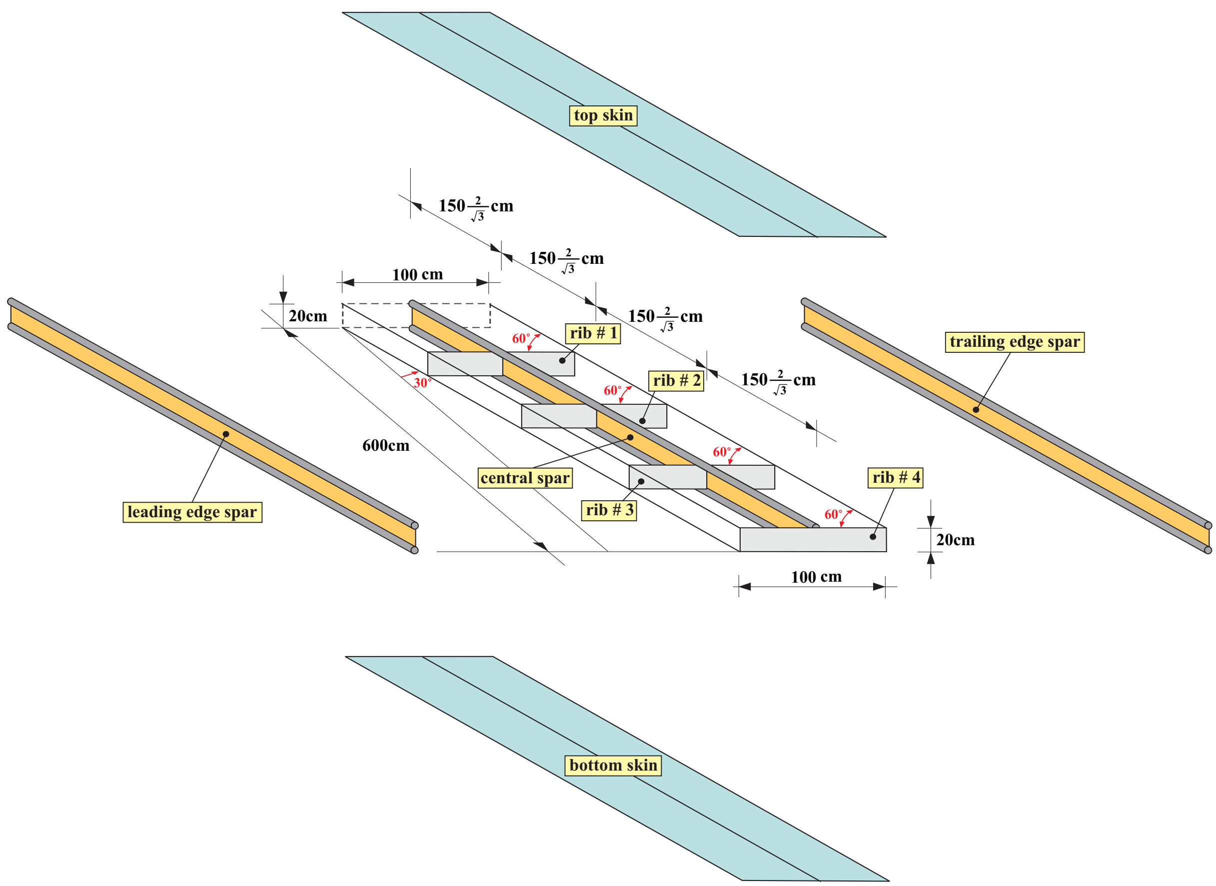

Figure 2. Swept wing (model # 2): exploded view of the wing box structure showing spars, ribs, and top and bottom cover panels.

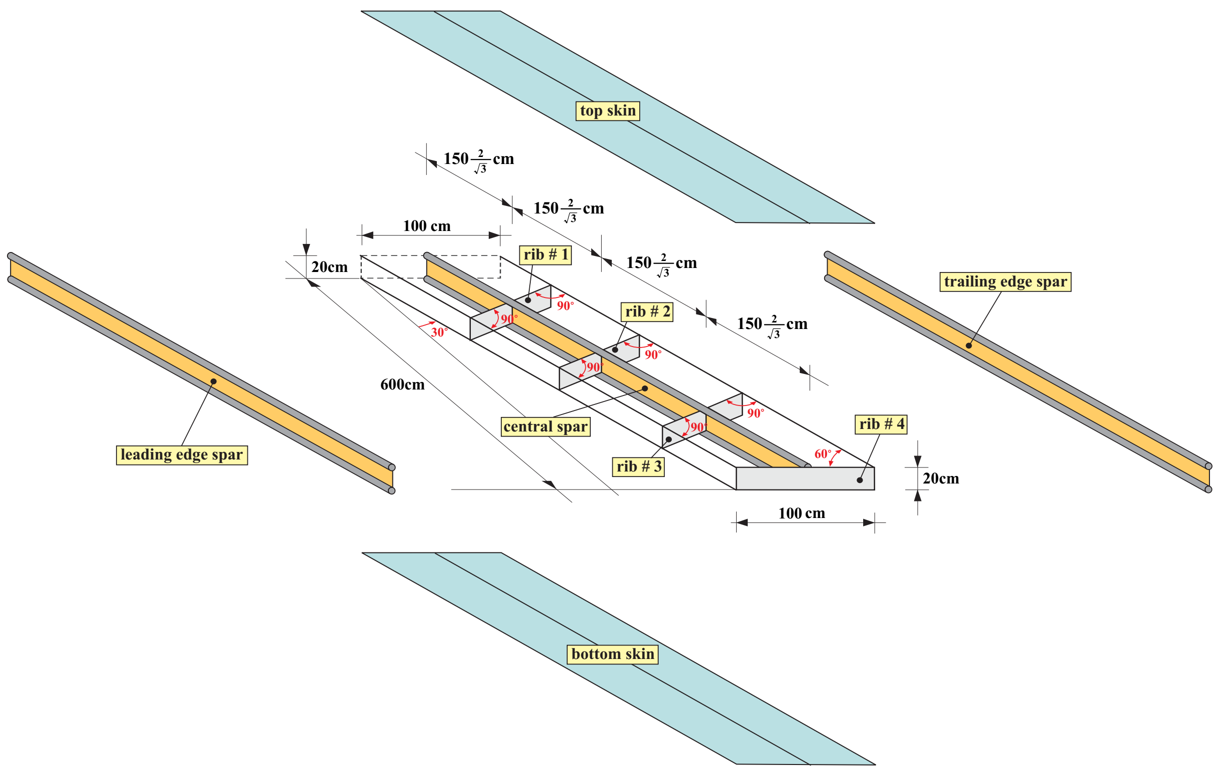

Figure 3. Swept wing (model # 3): exploded view of the wing box structure showing spars, ribs, and top and bottom cover panels.

length of the wing. Their thickness is $2.8\,mm$. The wing-box has **three spars** and **four ribs** (see Figures 1, 2, and 3 for details about the geometry). The thicknesses of the ribs is $t_1 = 2.5mm$. At the top and bottom edges of the shear webs there are spar caps. For simplicity, please **do not model the spar caps**. For all the models # 1, # 2, and # 3, model the wing top and bottom panels, the shear webs of the spars and the ribs with 4-noded quadrilateral (QUAD4) shell elements. Assume **clamped boundary conditions** at the root of the wing. The material properties of **all** the wing components are the following: $E = 72\,GPa$, $\upsilon = 0.30$, $\rho = 2700\,Kg/m^3$. E is the elastic modulus, υ is Poissons's ratio and ρ is the density.

Tasks

1. Model the geometry of the wing with FEMAP (suggestion: find the coordinates of the points that identify the surfaces and create the geometry; please note that the caps are not modeled in this assignment). Note that the **only** difference between models # 2, and # 3 is in the ribs # 1, # 2, and # 3. Everything else is identical.

2. For each case define the material properties in FEMAP. Define a plate property that is used to model the **ribs** with thickness t_1. Define a plate property that is used to model the **top skin** panels. Define a plate property that is used to model the **bottom skin** panels. Define a plate property that is used to model the **leading** edge spar. Define a plate property that is used to model the **central** spar. Define a plate property that is used to model the **trailing edge** spar.

   Please use different colors for each property and visualize the elements in FEMAP according to the colors.

3. Mesh the spars, top skin, and bottom skin. **Do not mesh** the ribs (note that if the ribs are not meshed they are not considered in the analysis). Please verify that **no coincident nodes** are present (in FEMAP this is done with the command **Tools→Check→Coincident Nodes**). **Do not** impose the boundary conditions at the root of the wing (so for this analysis the wing is an **unconstrained** structure). **For models # 1, # 2, and # 3**:

   - Calculate the first 10 natural modes and frequencies and **comment about the first six modes.**
   - Identify the shape and frequency relative to the **first elastic mode**.
   - Identify the shape and frequency relative to the **second elastic mode**.
   - Refine the mesh and perform a **convergence test**.

4. Impose the boundary conditions at the root of the wing (all the analyses that follow must be performed with the cantilevered wing so the root is always constrained).

   - Calculate the first 15 natural modes and frequencies and **comment about the first six modes.**
   - Identify the shape and frequency relative to the **first bending mode**.
   - Identify the shape and frequency relative to the **first torsional mode**.
   - Refine the mesh and perform a **convergence test**.

5. In addition to the existing mesh, mesh **rib #4** and verify that in your FEM model there are no coincident nodes. Calculate the modes and natural frequencies and discuss the differences you find with the previous findings (case of wing box with no ribs). What happens to the first torsional mode? What happens to the first bending mode? What happens to the high frequency modes? Please note that **rib #1, rib #2, and rib #3** are not meshed. Thus, it is like they are not there. Thus, models # 2 and # 3 coincide at this stage! (even if the geometry is different because you actually created the geometry for the ribs).

6. In addition to **rib #4**, mesh **rib #1**. Make sure there **are no coincident nodes on the same locations**. Calculate the modes and natural frequencies and discuss the differences you find with the previous findings. What happens to the first torsional mode? What happens to the first bending mode? What happens to the high frequency modes? What is the difference between the 3 models of Figures 1, 2, and 3?

7. In addition to **rib #4** and **rib #1**, mesh **rib #2**. Make sure there **are no coincident nodes on the same locations**. Calculate the modes and natural frequencies and discuss the differences you find with the previous findings. What happens to the first torsional mode? What happens to the first bending mode? What happens to the high frequency modes? What is the difference between the 3 models of Figures 1, 2, and 3?

8. In addition to **rib #4**, **rib #1**, and **rib #2**, mesh **rib #3**. Make sure there **are no coincident nodes on the same locations**. Calculate the modes and natural frequencies and discuss the differences you find with the previous findings. What happens to the first torsional mode? What happens to the first bending mode? What happens to the high frequency modes? What is the difference between the 3 models of Figures 1, 2, and 3?

9. Consider now the entire structure you previously meshed. Delete the constraint set and calculate the first 10 modes. Comment the differences between the different cases. What do you notice?

10. Write a technical report with the discussion of this study (including the convergence tests you performed). The technical report **must** comply with the following guidlines:

    - It has to be written in **WORD** (if you are a LaTeX user you are allowed to use it as long as you use the AIAA style). Please use the template posted on blackboard (it is the AIAA journal template). The maximum number of pages is 40. **reports exceeding this page constraint or with a character size less than 11pt or with wrong page margins will receive a 25% penalty. If you do not use the template or you modify the style of the template a penalty of 50% will be applied to your work**. Make sure you know how to use the template (if you are not sure please ask the instructor...)
    - An Abstract should be present (notice that it is in bold).
    - An Introduction should be present.
    - Technical discussions and results must be presented. These are crucial parts in the determination of the final grade.
    - A section with the conclusions must be included.
    - Provide citations to all reference you use at the end of your report.
    - In your report, do not provide raw data from simulation results (e.g. f06 file outputs).
    - single-space document has to be used.
    - Reports containing handwritten parts/figures/equations or scanned parts from handwritten derivations will receive the grade of **zero**.
    - Make sure you know how to use the template (if you are not sure please ask the instructor...)

Suggestions

You will need to run several times NASTRAN to generate the required results. Is is convenient to **store** all the NASTRAN analysis files (including the FEMAP file) in a separate folder (i.e., a different folder is created for a different case). If a previous set of results is still loaded in FEMAP and a new set of results has to be imported, it is convenient to delete the current set of outputs before importing a new one. This is important to avoid errors in the interpretation of the results.
For an optimal visualization of the modes with FEMAP please go to *view* → *Options* → *Deformed Style* and select 3%. It is convenient to mesh everything (including the all 4 ribs) and the delete the mesh of the not utilized ribs (please save the FEMAP models so you will have a model with all the 4 ribs meshed, a model with no ribs and so on).

Part # 2

Consider the system reported in Figure 4. The following should be observed:

- The system is hinged at point A

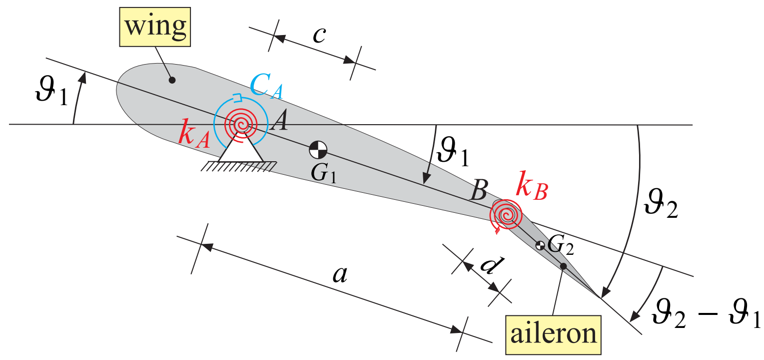

Figure 4. Simplified two-degree-of-freedom model of a wing-aileron system.

- The **generalized coordinates** used to describe the motion are ϑ_1 and ϑ_2. Other generalized coordinates will not be accepted.
- There is an **internal hinge** at point B, allowing the **relative rotation** of the aileron with respect to the wing.
- G_1 is the center of mass of the **wing**, which has mass m_1 and **mass moment of inertia with respect to the center of mass of the wing** $I^{w}_{G_1}$.
- G_2 is the center of mass of the **aileron**, which has mass m_2 and **mass moment of inertia with respect to the center of mass of the aileron** $I^{\mathrm{ail}}_{G_2}$.
- c is the distance between A and G_1. d is the distance between B and G_2
- The spring k_A is not stretched when $\vartheta_1 = 0$. The spring k_B is not stretched when $\vartheta_2 = \vartheta_1$. C_A is the rotational dashpot positioned at A.
- The **gravity is not considered**.

Assignment # 1

Assume large displacements, but assume that dashpot and springs behave linearly.

1. Draw the **free body diagram (FBD1) of the aileron only**. Include the **inertial forces and moment of inertial forces**
2. Draw the **free body diagram (FBD2) of the aileron-wing system** (i.e., you must not cut the system at the junction located in B). Include the **inertial forces and moment of inertial forces**
3. Using the moment equation about B and FBD1, obtain the first equation of motion
4. Using the moment equation about A and FBD2, and taking into account the equation of motion just obtained from FBD1, obtain the second equation of motion

Assignment # 2

1. Assume **small perturbations** about the condition at rest (generalized coordinates and their time derivatives equal to zero) and **linearize the equations of motion**. You need to **justify all the derivations**
2. Write the system of equations in matrix form and identify **mass, damping, and stiffness** matrices

Assignment # 3

Assume the system is linear (the linearized equations must be used). Assume the data below:

$$k_A = \alpha k_B \equiv \alpha k \qquad a = \beta d \qquad I_{G_2} = \gamma m_2 d^2 \qquad I^w_{G_1} = \varphi I^{\text{ail}}_{G_2} \tag{1}$$

Take the following value for the parameters:

$$\frac{k}{m_2 d^2} = 25 \qquad \alpha = 10 \qquad \beta = 4 \qquad \gamma = 2 \qquad \varphi = 5 \tag{2}$$

1. Calculate the **natural frequencies**
2. Calculate the **modes** and **comment your findings**
3. Normalize **mode 1** so that its modulus is equal to $\sqrt{3}$
4. Normalize **mode 2** so that its modulus is equal to $\sqrt{5}$
5. Write the analytical expression of the **actual free vibration solution** by assuming the following initial conditions:

$$\begin{aligned} &\vartheta_1\,(t=0) \equiv \vartheta_{10} = \tfrac{2}{180}\pi \text{ rad} \qquad &&\dot{\vartheta}_1\,(t=0) \equiv \dot{\vartheta}_{10} = -\tfrac{3}{2\cdot 180}\pi \text{ rad}/s \\ &\vartheta_2\,(t=0) \equiv \vartheta_{20} = \tfrac{1}{180}\pi \text{ rad} \qquad &&\dot{\vartheta}_2\,(t=0) \equiv \dot{\vartheta}_{20} = -\tfrac{5}{180}\pi \text{ rad}/s \end{aligned} \tag{3}$$

6. Using MATLAB **plot the solution** $\vartheta_1\,(t)$ and $\vartheta_2\,(t)$. Plot the solution up to a meaningful time you select by using **engineering judgment**.

Assignment # 4

Assume the system is linear (the linearized equations must be used). Assume the data below:

$$k_A \equiv k \qquad k_B = 0 \qquad a = \beta d \qquad I_{G_2} = \gamma m_2 d^2 \qquad I^w_{G_1} = \varphi I^{\text{ail}}_{G_2} \tag{4}$$

Take the following value for the parameters:

$$\frac{k}{m_2 d^2} = 25 \qquad \beta = 4 \qquad \gamma = 2 \qquad \varphi = 5 \tag{5}$$

1. Calculate the **natural frequencies**
2. Calculate the **modes** and **comment your findings**
3. Normalize **mode 1** so that its modulus is equal to $\sqrt{3}$
4. Normalize **mode 2** so that its modulus is equal to $\sqrt{5}$

Assignment # 5

Program in MATLAB (**no other language will be accepted**) the calculation of natural modes and frequencies for a **two-degree-of-freedom** system. The program must be able to find the modes and frequencies of a problem of the following type:

$$\boldsymbol{M} \cdot \ddot{\boldsymbol{x}} + \boldsymbol{K} \cdot \boldsymbol{x} = \boldsymbol{0} \tag{6}$$

Where $\boldsymbol{x}$ is a vector of generalized coordinates, $\boldsymbol{M}$ is the mass matrix (provided by the user in the m file), $\boldsymbol{K}$ is the stiffness matrix (provided by the user in the m file).
The program must have the following features:

- The user assigns the mass and stiffness matrices (via m file).
- The frequencies and associated modes are sorted, so that the lowest value frequency has identity equal to 1
- The entire code and inputs must be included in a single m file.

Consider the case analyzed in Assignment # 3. Take now the MATLAB code previously developed and calculate the **frequency and modes** and demonstrate that MATLAB and the analytical derivations coincide. **Send to the instructor the MATLAB code (with necessary input data to run this case). Send only m file not PDF, WORD or other formats (the instructor needs to be able to run the code).**

Assignment # 6

Write a technical report with the discussion of this study (including the analytical derivations with the details; please use professional presentation).

The technical report **must** comply with the following guidelines:

- It has to be written in **WORD** (if you are a LaTeX user you are allowed to use it as long as you use the AIAA style). Please use the template posted on blackboard (it is the AIAA journal template). The maximum number of pages is 40. **Reports exceeding this page constraint or with a character size less than 11pt or with wrong page margins will receive a 25% penalty. If you do not use the template or you modify the style of the template a penalty of 50% will be applied to your work**.
- An Abstract should be present.
- An Introduction should be present (notice that it is in bold).
- Technical discussions and results must be presented. These are crucial parts in the determination of the final grade.
- A section with the conclusions must be included.
- Provide citations to all reference you use at the end of your report.
- Attach the MATLAB code as an appendix to the document. The MATLAB code of the appendix **does not count** in the forty-page limit.
- Single-space document has to be used.
- Reports containing handwritten parts/figures/equations or scanned parts from handwritten derivations will receive the grade of **zero**.
- Make sure you know how to use the template (if you are not sure please ask the instructor...)

How this exam will be Graded

The grades will be assigned according to the following criteria:

- Correctness and completeness of the results/responses.
- **Quality of the presentation of the results** (e.g., clear, easy to follow, etc.).

Important Information

The exam must be given to the instructor in BOTH electronic format (PDF generated from WORD) and hardcopy by December 12^{th} 5:00PM. In this case there are 2 reports that need to be electronically sent. MATLAB code and reports must be sent with a single message by the leader of each group. In the email the team members must be listed by the leader. In the same email the leader needs to write the exact contributions each member did and Cc in the email sent to the instructor all the team's members. This is an exam and no exceptions will be allowed. It is the students' responsibility to make sure that the exam is received by the instructor before the deadline.

The hardcopy must physically contain all the 2 reports together and have the students' names with their signatures (please fill first page of the project). This is a group project: the students have to be part of a **five-student group**. All students of the group will be considered responsible (to the extent the instructor will assess based on the documentation provided) of the technical parts. **This means that the poor performance of a student will impact the other students. Thus, it is strongly encouraged that all students check the work of the peers in the same group to make sure that everything is well presented and correct.**

If there are complaint from one of the partners about unequal contribution to the work or there are issues in the group, an **oral exam** will take place in the instructor's office at the project deadline. **Groups with the number of students different than 5 will not be accepted.**

Academic honesty

All students admitted to SDSU have signed a statement of academic honesty committing themselves to be honest in all academic work and understanding that failure to comply with this commitment will result in disciplinary action. This statement is a reminder to uphold your obligation as a student at SDSU and to be **honest in all work submitted** and exams taken in this class and all others.

Plagiarism

Plagiarism consists of passing off as yours the work that belongs to someone else. As such, **you will be committing plagiarism if <u>you present someone else's work</u> as your own**, even with the other person's consent.

Miscellaneous

.... No late work will be accepted. **Submitting copy of an exam prepared by somebody else is considered cheating**.

Submitting an exam which is copied in full or in part from other students' work is considered plagiarism.

Collaboration outside the group is not allowed.