Lab 2: Frame Design, Materials, and Structural Integrity

For the MATLAB-based lab session that complements Lecture 3 on Frame Design, Materials, and Structural Integrity, we can create a hands-on experiment where students build, test, and evaluate the structural integrity of a quadcopter frame. The lab will be divided into sections that align with the theoretical concepts covered in the lecture.

MATLAB Lab Session Outline:

Objective:

- To simulate the stresses and strains experienced by a quadcopter frame under load using MATLAB.
- To build a basic quadcopter frame using provided materials.
- To test the structural integrity of the frame and compare performance under different material choices and configurations.

1. Introduction to MATLAB Simulation (15 minutes)

- **Goal:** Teach students how to use MATLAB for simulating the mechanical properties of different materials and designs for the quadcopter frame.
- **Content:**
    - Review how MATLAB can be used for structural analysis (using functions like bendingStress, vonMisesStress, etc.).
    - Provide a brief overview of the finite element method (FEM) for analyzing stress and deformation in the frame components.

2. Lab Exercise: Material Properties Simulation (45 minutes)

Objective:

The goal of this lab exercise is to simulate how different materials (carbon fiber, aluminum, plastic, etc.) behave under stress and observe the resulting deformation of a simple beam structure when subjected to an applied load. You will use a provided MATLAB script to define material properties, apply forces, and visualize stress and deformation in a 2D beam model.

Procedure:

1. **Material Properties Definition:**
    - The provided MATLAB code defines key material properties for different materials:
        - **Density** (kg/m^3)
        - **Young's Modulus** (Pa)

    - **Tensile Strength** (Pa)
  - The materials included in the simulation are:
    - **Carbon Fiber**
    - **Aluminum**
    - **Plastic (ABS)**
2. **Frame Model:**
   - The beam model used for the simulation is a simplified 2D structure with user-defined dimensions:
     - **Length (m)**
     - **Width (m)**
     - **Thickness (m)**
   - You can modify these dimensions within the script to observe their impact on the stress and deformation of the beam under load.
3. **Force Application:**
   - A force is applied at the center of the beam to simulate loads from motors, electronics, or payloads. The applied force can be modified in the MATLAB script.
   - The script calculates the following based on the material properties and applied load:
     - **Stress** (Pa)
     - **Strain** (dimensionless)
     - **Deformation** (m)
4. **Visualization:**
   - The MATLAB script will generate:
     - A plot showing the original shape of the beam and the deformed shape after applying the force.
     - A bar chart comparing the tensile strength of the different materials (Carbon Fiber, Aluminum, Plastic).
5. **Experimentation:**
   - **Step 1:** Run the MATLAB script MaterialPropertiesSimulation as provided.
   - **Step 2:** Modify the following variables in the script to observe their effect on the results:

        - **Material selection:** Switch between Carbon Fiber, Aluminum, and Plastic by changing the material definition in the code.
        - **Applied force:** Modify the force value to simulate different loading conditions.
        - **Beam dimensions:** Adjust the length, width, and thickness to explore how design changes affect stress and deformation.
    - **Step 3:** Re-run the script after making changes to see how the new values affect the beam's stress, strain, and deformation.

Analysis Questions:

1. How does increasing the **Young's Modulus** (stiffer material) affect the beam's deformation?
2. What impact does increasing the **applied force** have on the stress and deformation?
3. Compare the deformation of the beam when using **Carbon Fiber** versus **Plastic**. Which material deforms less, and why?
4. How does changing the beam's **thickness** or **width** influence the stress distribution and overall structural behavior?

Deliverables:

1. Run the MATLAB code with different material properties and design configurations.
2. Record the stress, strain, and deformation values for each scenario.
3. Provide answers to the analysis questions based on your observations from the simulation results.
4. Include screenshots or plots from the MATLAB outputs in your report.

3. Lab Exercise: Frame Design and Simulation (60 minutes)

Objective:

The objective of this lab exercise is to design and simulate the mechanical response of different quadcopter frame configurations (e.g., X-frame, H-frame) under applied motor forces. You will use a provided MATLAB script to create frame models, apply forces simulating flight conditions, and observe the structural behavior and deformation.

Procedure:

1. **Frame Configuration:**
   - The provided MATLAB script FrameDesignAndSimulation allows you to choose between different frame configurations:
     - **X-frame**: Symmetrical arms at 45-degree angles, often used for balanced flight characteristics.
     - **H-frame**: Horizontal and vertical arms, which offer more payload stability but may introduce additional drag.
   - You can modify the frame configuration by changing the frame_type variable in the script.
2. **Force Application:**
   - A force representing the thrust from each motor is applied to the ends of the arms. This simulates the conditions a quadcopter frame would experience during flight.
   - The default motor force is set to **20 N**, but you can adjust this in the script to explore how different thrust levels affect the frame's structural integrity.
3. **Deformation Simulation:**
   - The script calculates the displacement (deformation) of the frame at the motor attachment points based on the applied forces and frame configuration.
   - Both the original and deformed frame structures are visualized in MATLAB using plot functions to illustrate how the frame responds to the motor loads.
4. **Visualization:**
   - MATLAB will generate:
     - A plot of the **original frame** structure.
     - A plot of the **deformed frame** after forces are applied.
   - These plots allow you to compare how the X-frame and H-frame configurations respond to the same applied forces.
5. **Experimentation:**

- **Step 1:** Run the MATLAB script FrameDesignAndSimulation with the default settings for both the X-frame and H-frame configurations.
- **Step 2:** Modify the following variables in the script to observe their effect on the frame's structural behavior:
  - **Frame Type**: Switch between 'X-frame' and 'H-frame' by adjusting the frame_type variable.
  - **Motor Force**: Modify the motor_force variable to simulate different thrust levels.
  - **Frame Dimensions**: Adjust the arm_length and width to explore how changes in frame design affect deformation.
- **Step 3:** Re-run the script FrameDesignAndSimulation after making changes and observe how the frame's deformation varies based on the configuration, applied forces, and dimensions.

Analysis Questions:

1. **Frame Type Comparison:**
   - How does the X-frame compare to the H-frame in terms of deformation under the same applied forces? Which configuration appears to be more stable, and why?
2. **Effect of Motor Force:**
   - What happens to the deformation of the frame when you increase the motor force? At what point do you think the structural integrity of the frame could be compromised?
3. **Impact of Frame Dimensions:**
   - How do changes in the arm length or width of the frame impact the load distribution and deformation? Which design choices minimize deformation while maintaining structural strength?
4. **Design Recommendation:**
   - Based on your observations, which frame type and dimensions would you recommend for a quadcopter design that prioritizes stability and minimal deformation? Explain your reasoning using the results from the simulations.

Deliverables:

1. Run the MATLAB code FrameDesignAndSimulation with different frame configurations, motor forces, and dimensions.
2. Record the results for both the X-frame and H-frame configurations, including the displacements observed at the motor points.

3. Provide answers to the analysis questions based on your simulation results.
4. Include screenshots of the original and deformed frame plots in your report.