Structural test and analysis of aluminum and composite landing gear for small-scale aircraft

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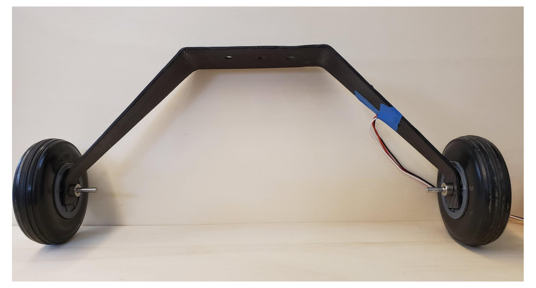
Motivation

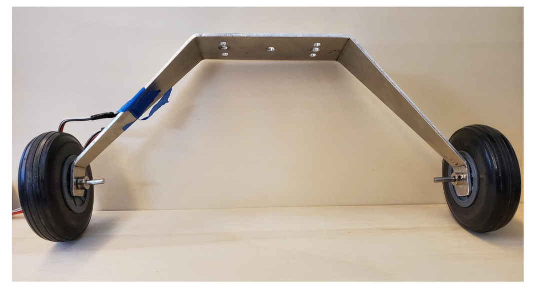
M-Fly is a student design team that designs and builds Radio-Controlled (RC) aircraft and competes annually at the Society of Automotive Engineers (SAE) Design, Build, Fly competition. A common area of structural failure is in the aircraft's main landing gear, which supports most of its weight during landing. M-Fly would like to strengthen its landing gear without increasing its weight, which can result in competition point deductions. As a result, it is investigating using in-house manufactured carbon fiber landing gear as an alternative to its conventional aluminum landing gear.

Objectives and Goals

- To provide a recommendation to M-Fly based on the following hypothesis:
  - Is it possible to use student-manufactured carbon fiber as an alternative to conventional, 6061 aluminum to reduce weight while maintaining landing gear strength?
- To provide M-Fly with a landing gear design recommendation, including:
  - Finite element model (FEM) in Abaqus
  - Material properties of wet lay-up carbon fiber
- To conduct five sets of experiments:
  - Carbon fiber coupon testing
  - Pendulum tests to validate Raspberry Pi
  - Carbon fiber lay-up
  - Drop tests
  - Abaqus analysis

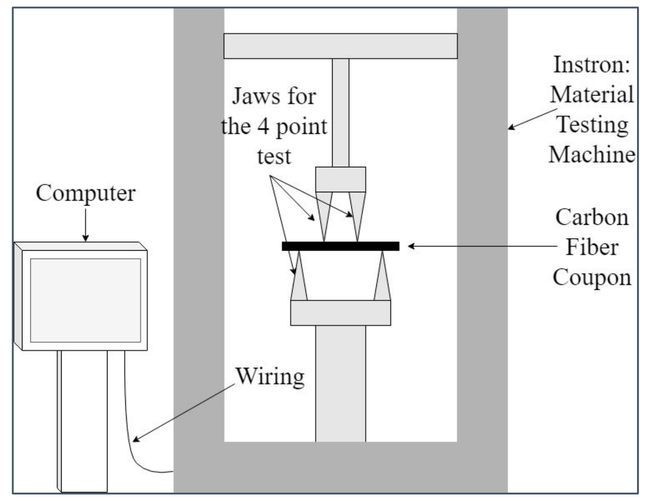


Carbon fiber landing gear

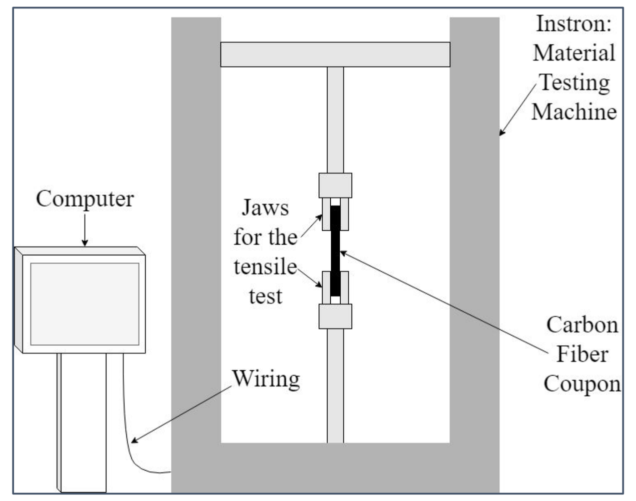


Aluminum landing gear

Methods



Four-point bending diagram



Tensile test diagram

Carbon Fiber Lamination

- Utilizing a [0-45-0-45-0-0-0-0-0-0-0-45-0-45-0] ply pattern for high flexural modulus, based on Classical Lamination Theory (CLT)
- Perform a wet layup using a West System epoxy resin
- Cut with diamond saw for safety and uniformity of specimens
- Carbon fiber landing gear is lighter than aluminum:
  - Carbon fiber mass: 0.76 lbs
  - Aluminum mass: 0.96 lbs

Carbon Fiber Testing

- Four-point bending test obtains maximum flexural stress and the flexural modulus
- Tensile test obtained maximum tensile stress and Young's modulus

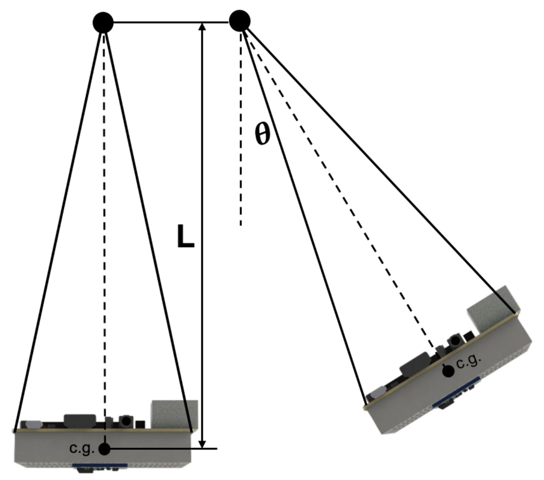
M-Fly landing during competition

Acceleration Data Acquisition

- Raspberry Pi chosen to capture data at a high sample rate of 800 Hz and to store data for later analysis
- Adafruit MMA8451 accelerometer chosen for ease of reading digital output

Acceleration Data Validation

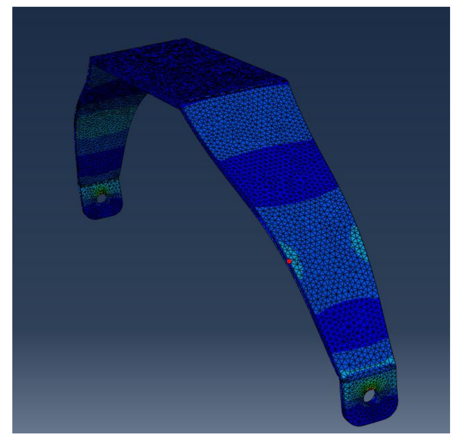
- Pendulum test was performed to validate the acceleration data readings
- The data acquisition process is validated by comparing experimental and theoretical simple pendulum periods at a given pendulum length (L) and angular displacement (Θ)



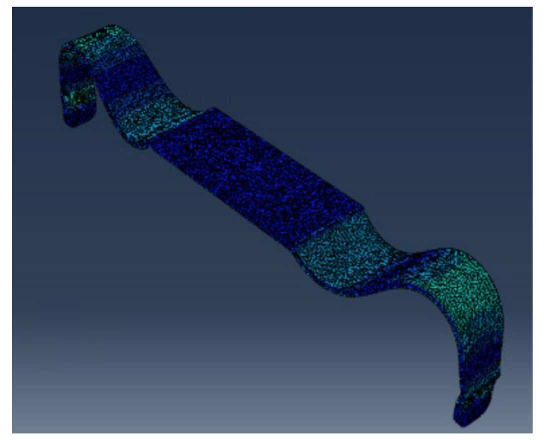
Pendulum Test Setup

Abaqus

- Abaqus FEM used to visualize maximum stress in composite and aluminum landing gears
- Applied boundary conditions instead of modeling loads because of the complexity of the model and the need to solve the equation in a shorter amount of time
- This gives us the location of the maximum stress along the struts given a displacement



Stress on runway



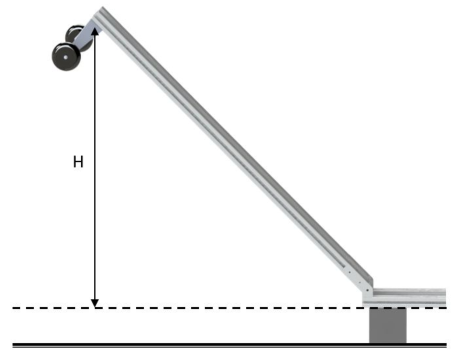
Maximum stress during landing

Drop Test Landing Dynamics Analysis

- Drop tests used to collect peak loads and analyze landing dynamics according to flow chart:

Collect impact duration data from drop test → Calculate peak force on structure → Exert force on structure and collect vertical deflection → Input deflection from peak force into Abaqus as boundary condition → Output maximum stress on structure

- Dynamics during impact for two types of material were compared using the acceleration versus time plots
- Impact time was determined drop test results
  - Composite landing gear showed better dynamic response due to higher flexibility
  - Maximum impact acceleration was difficult to determine due to the sampling rate of the accelerometer



Drop Test Setup

Results and Analysis

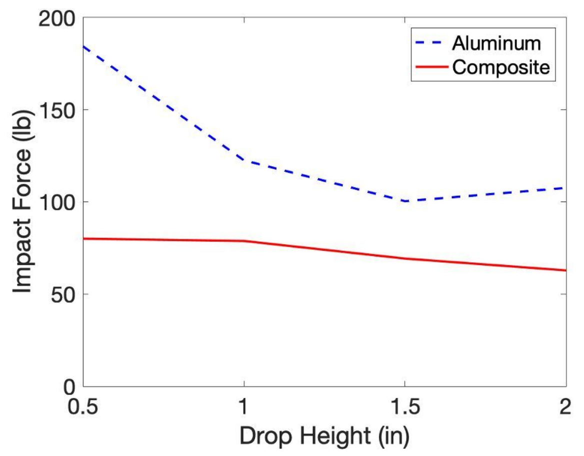
Coupon Testing

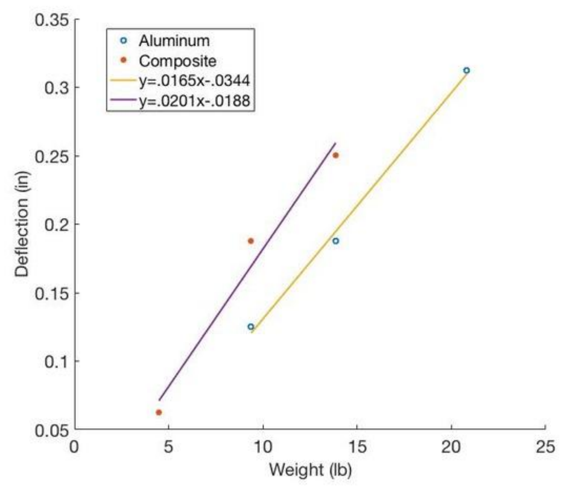
Material Property	Carbon Fiber (tested)	6061 Aluminum (standard)
Maximum Flexural Stress [MPa]	504.24	310.00
Flexural Modulus [GPa]	55.32	68.90
Maximum Tensile Stress [MPa]	560.47	310.00
Young's Modulus [GPa] (tensile test)	6.33	68.90

- Compare strength properties of carbon fiber laminate and 6061 aluminum by assuming approximate isotropy in the multidirectional composite
  - Carbon fiber Young's modulus is 9.18% of aluminum Young's modulus
    - The aluminum landing gear will deflect less than the composite
  - Carbon fiber flexural modulus is 80.30% of aluminum Young's modulus
    - In flexure, carbon fiber maintains stiffness properties of aluminum
  - Carbon fiber maximum flexural stress and maximum tensile stress are 162.66% and 180.80% of ultimate tensile strength of aluminum
    - In flexure and tension, carbon fiber landing gear is stronger than aluminum

Drop Test

- Drop test impact times processed using equations of motion for rigid bodies, resulting in peak impact forces
- Peak force experienced by structure is 180 lb-f
- Maximum deflection experienced by structures determined by deflection vs. weight trendline
  - Carbon fiber is 3.66 inches
  - Aluminum is 2.94 inches
- Maximum deflections input in Abaqus, outputting maximum stress in each structure
  - Carbon fiber is 683 MPa
  - Aluminum is 740 MPa





Caption: Maximum impact force from drop test (top), Carbon fiber and aluminum deflection under weight (bottom)

Conclusions

We recommend that M-Fly use in-house manufactured landing gear because of lower weight and similar structural properties compared to traditional aluminum landing gear. There is a 0.2 lb difference in landing gear. Although the stiffness properties of carbon fiber are less than that of the aluminum, the carbon fiber is stronger and can withstand more stress than the aluminum. M-Fly has expressed interest in building their own carbon fiber landing gear; based on our experimental findings, we recommend that they move forward with this endeavor.