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Structures Webinar

Mark Abotossaway
Blue Origin Engineer and FNL Assistant

ARTEMIS STUDENT CHALLENGES
nasa.gov/stem/artemis.html

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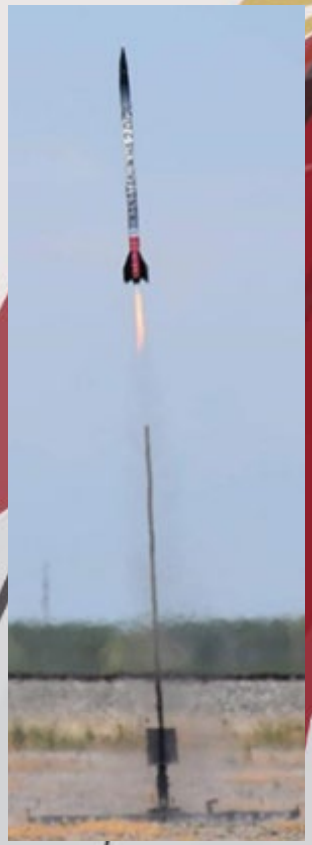
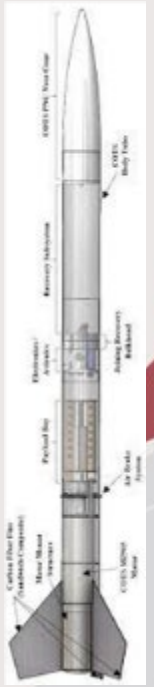
Webinar Overview

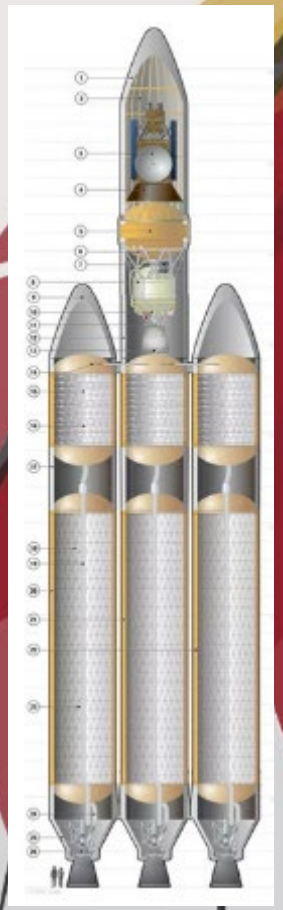
- High Powered Rocket (HPR) Vehicle and Payload Structure
- Structural Design Process
- Materials Overview
- Structural Analysis Process
- Structural Test Process (during Design)
- Assembly / Manufacturing / Integration Process
- Structural Test Process (Post-Fabrication)



High Powered Rocket (HPR) Structures

- Payload / Challenge structure
  - Any combination
- Nosecone - Conics
- Airframe - Cylinder
- Bulkheads - Plates
- Couplers - Cylinder
- Motor Mount Tube - Cylinder
- Centering rings – Rings
- Fins - Plates
- Electronics sleds - Plates





Structural Design Overview

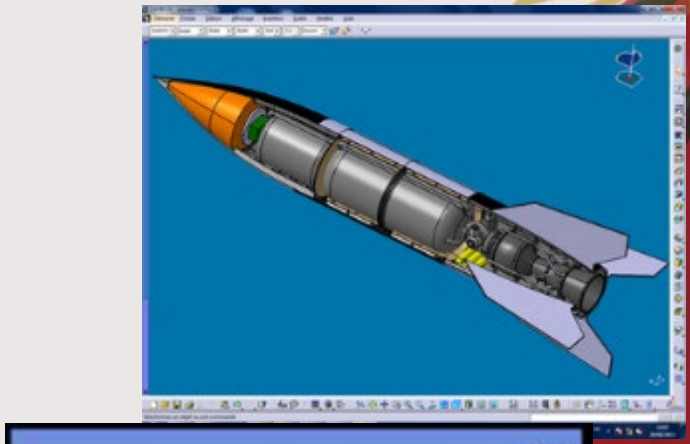
- Could make random selections, and hope it all works in the end…
- **Engineering design** is when you develop a complete product
  - via simulations, calculations, research, trade studies, test, prototyping
    - and you understand the performance of such product
      - via simulations, calculations, research, test
        - prior to building that product
- Designed products need to satisfy a set of criteria or ‘requirements’
  - Set forth by the customer (WSGC FNL is your customer)
  - Tests can verify the product does what its supposed to do, and satisfies the requirements

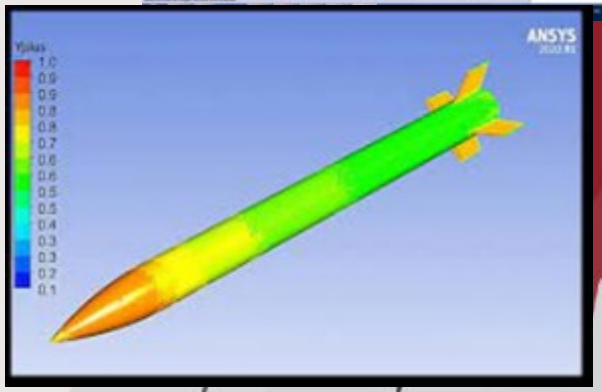
Industry Structural Design

- Industry design tools usual include:
  - 3D CAD Modeler (CATIA, 3DX, Creo, etc.)
  - Computational Fluid Dynamics (CFD) tools
  - Generic sizing tools / calculations

- New design is usually based on
  - Previous design / or similar product
  - Re-use as much as possible in design

- Industry standards simplify design practices
  - Typical design best practices



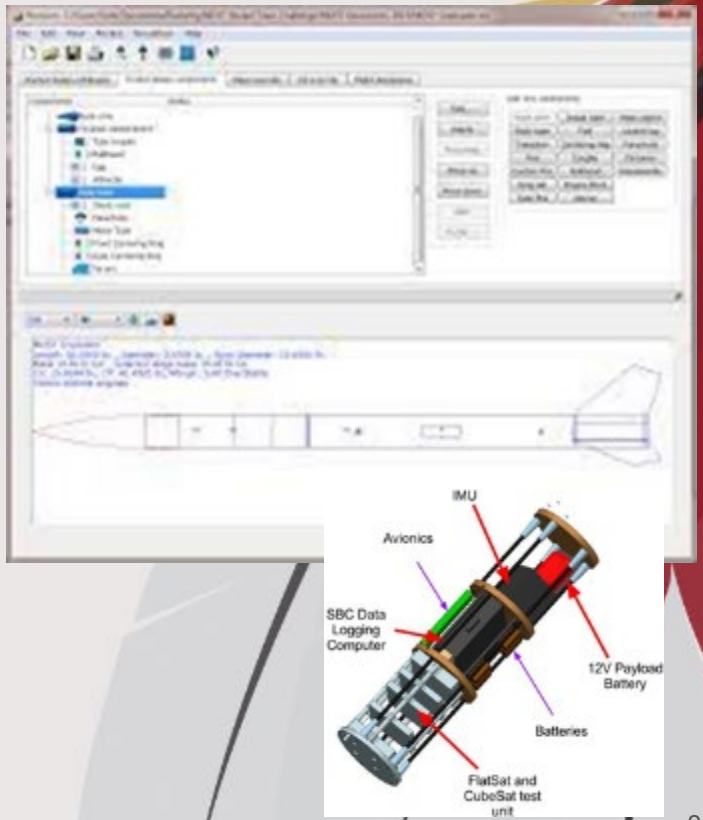


HPR Structural Design

- HPR Design tools will include:
  - Simulation Tool - RockSim
  - 3D CAD Modeler (SolidWorks, AutoCAD, etc.)
  - Hand calculations

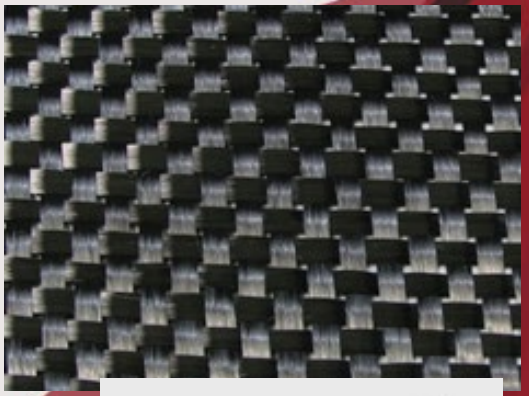
- Design typically starts from a blank sheet
  - Previous experience or data may not be relevant
  - Challenge changes yearly
    - Structure changes to optimize vehicle for that challenge

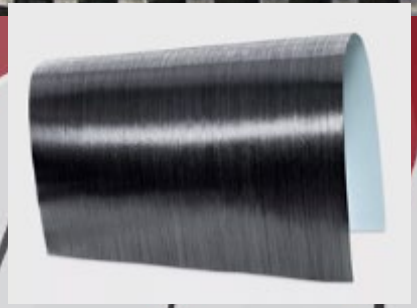
- Rocketry rules confine your choices / design space
  - These are listed as Requirements



Structural Material Overview

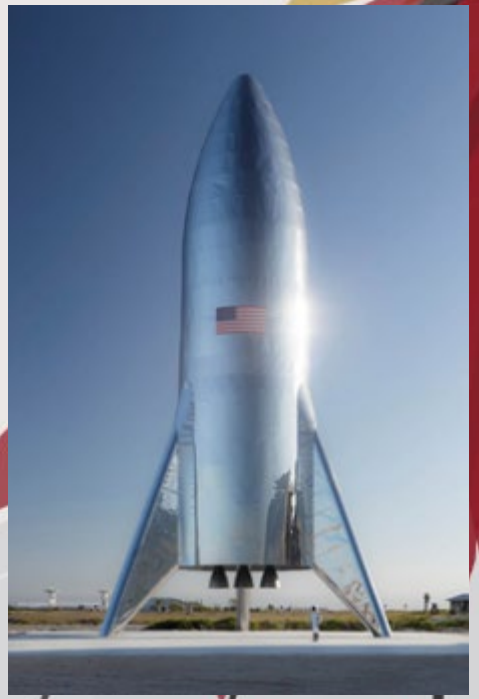
- Choosing the right material
  - Involves an understanding of all possible materials available
- Different materials for interior vs exterior components
- Consider environmental effects when selecting materials
  - Should consider thermal expansion when ‘mixing’ materials
- Customer may limit your material selection
- Commercial-Off-The-Shelf (COTS) materials may be your first choice
  - Opposed to researching and developing new materials





Industry Structural Materials

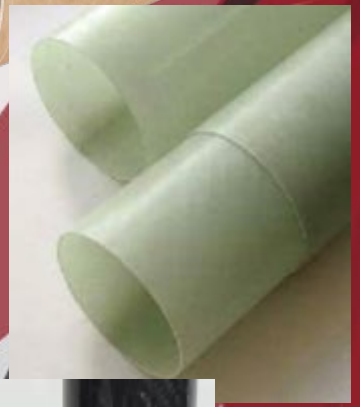
- In industry, material selection is based on a balance of
  - Cost – Performance – Weight
- New materials typically developed early in concept design
  - Carbon fiber plain cloth or tapes, and processes
  - Metallic alloys
- Operating environment is a huge factor in material selection
  - Hot vs cold / dry vs wet / vibration
- Fatigue / damage tolerance are also material selection factors
  - How long does the vehicle need to last for



HPR Structural Materials

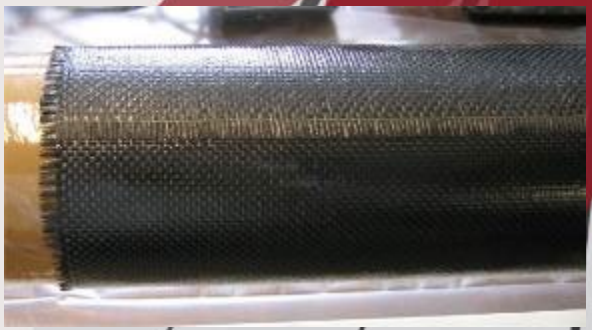
- Commercial-Off-The-Shelf (COTS) materials can be grouped into:
  - Phenolic Cardboard - Airframes
  - Fiberglass - Airframes
  - Carbon Fiber - Airframes
  - Wood (plywood, balsa)

- Suggest you use COTS components mainly (*Unless the Challenge is such that we want you to fabricate)
  - The Challenges are designed to be the focus of your efforts
    - You add unnecessary work by fabricating airframe components
  - Reduces chance of structural failures on Launch Day
    - We cannot ascertain your fabrication / test abilities
  - The weight / cost benefits may outweigh any performance risk however



HPR Structural Materials

- Industry material selection rules may still apply..
- Material selection is a balance of:
  - Cost – Performance – Weight
- Understand your operating environment
  - How will it affect your materials?
- Fatigue and damage tolerance
  - How robust does the vehicle need to be?
- Workability – how easy is it to work with this material
  - Do you have the machining / tooling capabilities?

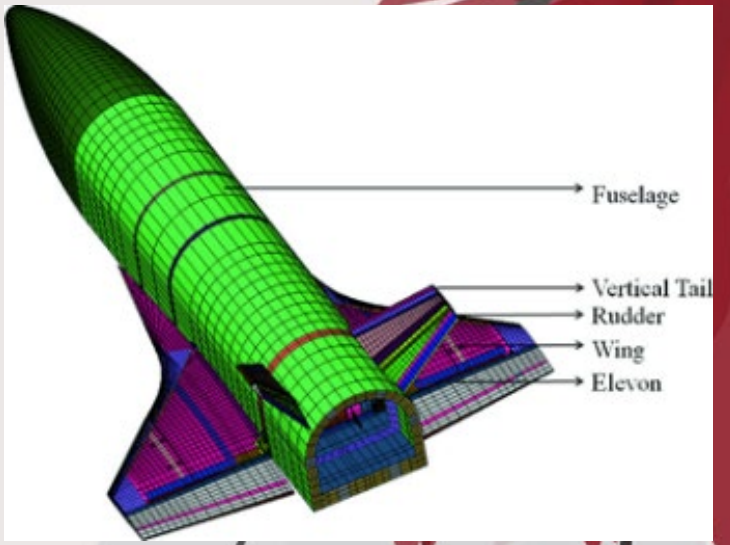


Structural Analysis Overview

- Engineering ensures the vehicle
  - Satisfies the performance parameters
  - Can withstand the expected loads (each component)

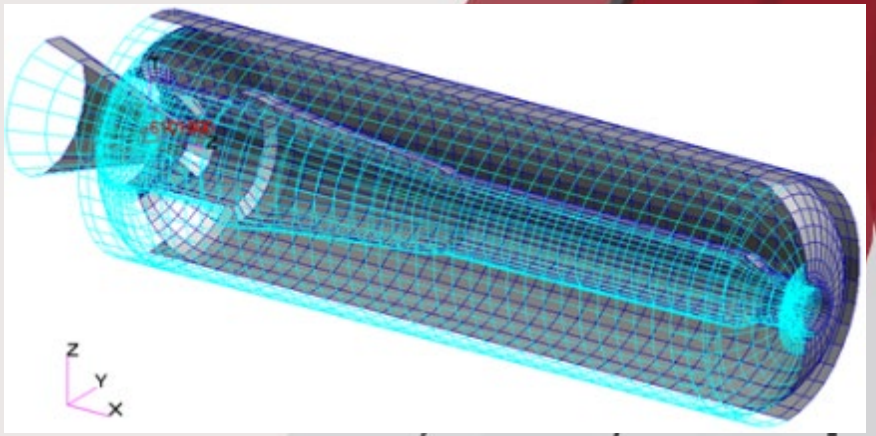
- Analysis achieves this by
  - Simulations
  - Calculations
  - Finite Element Analysis

- If results of a simulation / calculation do not satisfy the performance parameters or loads
  - You must change the design or material
  - Repeat the analysis



Industry Structural Analysis

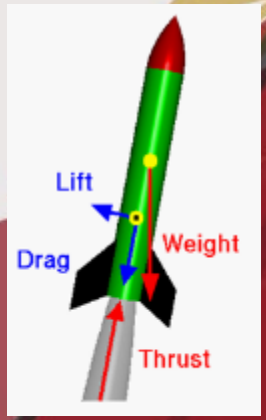
- Structural analysis for launch vehicles is very detailed
  - Human rated also has more stringent requirements
- Loads are developed early from Aero Finite Element Models (FEMs)
  - Internal loads model FEMs distribute load
- Classical analysis methods are used
  - Plates, shells, beams etc.
- Free body diagrams / load paths
- Sizing parts to minimize weight



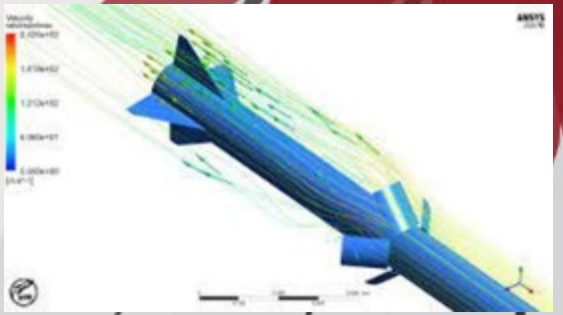
HPR Structural Analysis

- Mainly use RockSim for COTS component selection
  - Use RockSim to verify vehicle performance satisfied
  - May use other calculation methods to verify RockSim

$$F = m\,a$$



- You should understand the maximum load / force on each component
  - What components experience highest loading?
  - When is max loading?
  - Component selection based on load type experienced (axial, shear)
  - Especially useful if fabricating your own components
  - ‘Size’ your parts appropriately!



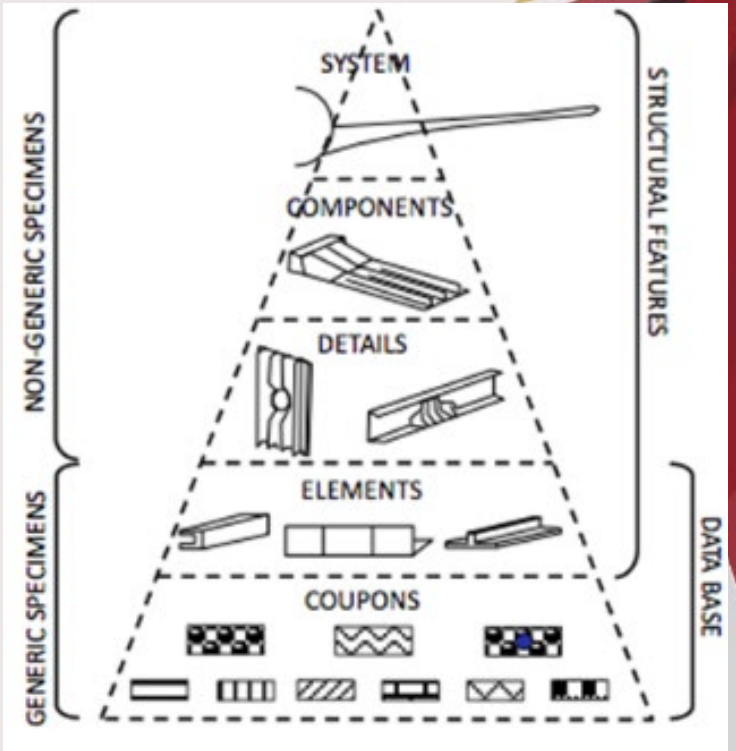
- May use Computational Fluid Dynamics (CFD) or FEM
  - To characterize your performance, to see stresses and loads

Structural Test Overview

- During design / analysis phases
  - Test small components to determine suitability
  - Especially true if you are fabricating parts (3D printed, composite)
- Not required but encouraged (for HPR)
  - Know the strength / properties of your materials
  - Test your bonded materials and bond strength
- Structural tests can include
  - Shear strength - Tension / compression - hoop strength - bending / deflection / buckling
- Tests should be conducted early in a program
  - Results validate material selections / configurations

Industry Structural Testing

- Uses a ‘test pyramid’ approach
  - Starts at coupon level - bottom
  - Culminates in full scale vehicle testing - top
- New *materials* are developed with this approach
  - Coupon and element tests for materials
  - Configured tests for the specific design
- Testing is conducted alongside design
  - Testing can reveal bad design choices as well
  - Testing should validate analysis
- Fatigue and damage tolerance tests
  - Projectile testing / impact / damage



HPR Structural Testing

- COTS structures should not require test (usually overdesigned)
- May be interested in ascertaining the limits of the material
  - Do sample testing to failure
  - Helps develop understanding of testing, if you fabricate parts
- If you fabricate your own components
  - 3D print materials - FG or carbon fiber layups - FG or carbon sandwich panel
- HIGHLY recommend you do structural testing
  - Shear-tension-compression strength, hoop strength, bending / deflection
- You may want to use a similar test pyramid as industry
  - Update your TEST PLANs in your Reports!

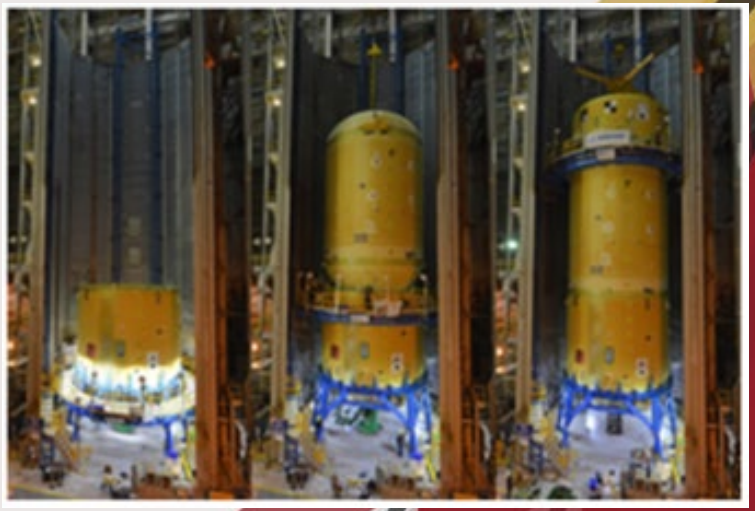
Manufacturing and Integration Overview

- Structures should be designed for ease of manufacture, assembly and integration

- Keep manufacturing in mind when you make part / material selections
  - Will this part be difficult to manufacture?
  - Will this part be difficult to integrate?
  - Is this material easy to work with? Difficult to modify?

- Good designs become terrible products when changes must be made because assembly / integration aren't taken into consideration
  - Changes to parts for integration is usually evident upon inspection

Industry Integration



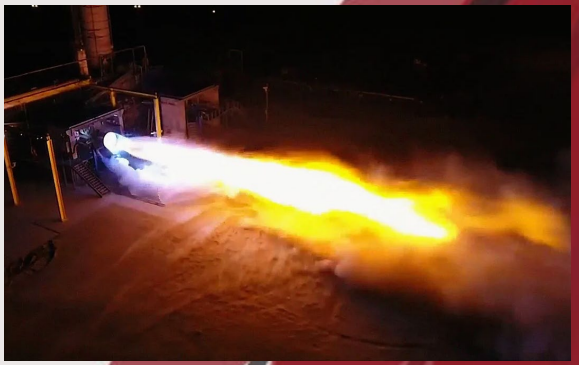
- Fabrication begins as design finishes
  - First few units are slow to fabricate
  - Usually more than 1 unit (less than 10 – 1000s)
- Various supplier parts must all fit together
  - Tolerance stack-ups / GD&T
  - Geometric Dimensioning & Tolerancing is important!
- Tooling usually begins during design
  - These may be long lead items (need to start before design complete)
- Design / analysis may need to change if assembly / manufacturing can’t meet the drawing
  - Manufacturing engineers work with design team
  - Liaison engineering supports production

HPR Integration

- COTS components should integrate easily (good tolerance)
  - A HUGE benefit of using COTS components
- Fabricating components / mixing parts
  - Integration will be a concern (varying tolerances)
  - Ensure you leave time for fabrication (and to fix tolerance issues)
- Payload / Challenge components must have an integration plan
  - Use CAD models to ensure
    - Parts will fit in an assembly, and assembly will fit into rocket
    - May need to CAD up the entire rocket / all parts
  - Ensure your RockSim matches your CAD models matches Hardware
    - Simulate what you are building

Structural Testing (Post-Production)

- Products undergo rigorous testing following production
  - Used to verify that the design satisfies the requirements
- Human rated vehicles require much more testing
  - Must demonstrate a complete autonomous flight
  - Aircraft complete a series of flight tests, complete envelope
- Testing also used to ensure the product is safe
  - A structural failure in safe environment is better than in public environment
  - If all design considerations were followed, it is unlikely there will be a structural failure



Industry Structural Testing

- Rockets - full scale flight tests
  - Autonomous
  - Shows the vehicles can perform safely

- Aircraft – full scale tests
  - Full scale static test to failure
  - Full scale fatigue test for DSO
  - Fleet perform flight tests

HPR Structural Testing

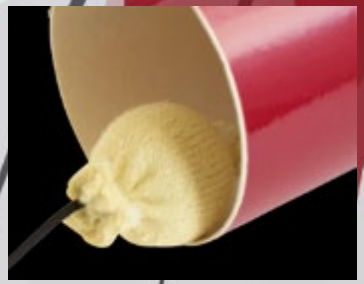
- (Not required) - Recommend a full-scale flight test be built into your schedule and performed prior to Competition Launch
  - Could be empty vehicle flight
    - Don’t risk damage to the challenge payload, or it is not flight ready
  - Good idea to have spare airframes if possible
  - Proper component design and testing increase odds of success
  - Could use a scale model to test components

- (For Flight Tests) – Ensure your Rocketry Mentor helps facilitate your test launch for you
  - Follow all proper procedures, laws and regulations for safe, proper flight

HPR Structural Failures - Tips

- Eyebolts / Bulkheads
  - If not sized properly eyebolts/bulkheads can yield
  - Use washers to distribute load
  - Use closed (forged) eyebolts
  - Use u-bolts, which distributes the load better

- Zipper Event (Phenolic Airframes)
  - Zipper - shock cord tears into the airframe during the parachute deployment
  - Strengthen the airframe area if there are concerns (cloth wrap)
  - Size the shock cords properly (or ‘pad’ the shock cord where it meets the airframe at full deployment)



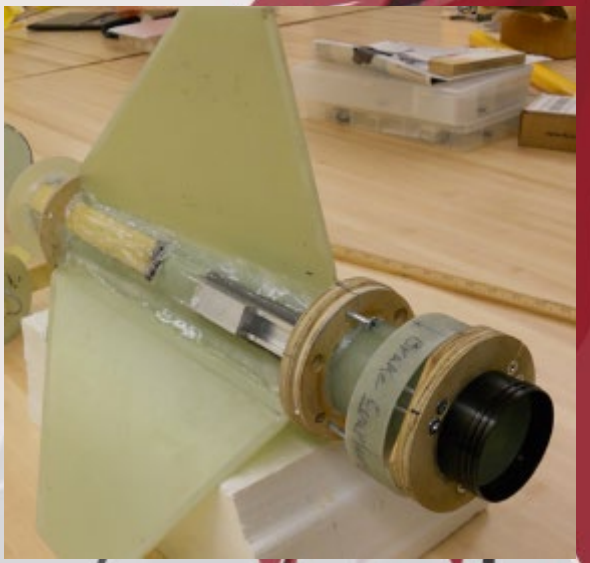
HPR Structural Failures - Tips

- Catastrophe at Take Off (CATO)
  - The motor (mount) is not restrained properly
  - Ensure the centering rings and motor mount tubes are substantially bonded and secure
- Fin flutter or divergence
  - Fins may flex / oscillate under aerodynamic loads in flight – divergence
  - Ensure you size your fins properly, use rigid material, and they are bonded substantially
- Premature / late separation
  - Pressure differentials may cause the airframe sections to separate in flight
  - The use of plastic shear pins will remedy this
  - Too many shear pins and the airframe may not separate

HPR Component Sizing - Tips

- Typically size your payload first, then select the airframe (vehicle) based on the payload criteria
  - In your Challenge, addressing the payload should be your priority
  - Challenge constrains diameter of the payload airframe ONLY

- Most COTS components are already sized for their flight envelope
  - Motor mount tubes, fin thickness, centering ring thickness etc.
  - Modifying the kit to your ‘challenge’ may mean component sizes are vehicle performance are outside of its design envelope



HPR Component Sizing - Tips

- Swap out or modify components if they are sized incorrectly (modify the kit to accommodate your payload)
  - Expected load and type of loading of components
  - Carbon wrap components (if capable) to add strength

- Select the recovery hardware based on the expected amount of load
  - Eyebolts, quick links, shock cord etc. are all sized on load capability
  - Use simulations to find the expected loads

Questions?