Light Weight Structural Designs via Dynamic Properties

Mass Mitigation Project

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Background and Objective

- Objective: Develop a new or modified method to size hardware that results in lighter structural designs
- This MMP is focused on leveraging the "frequency dependency of strain"
  - This is applicable to those structural designs that are driven by dynamic loads
  - Based on our long-standing engineering assumption that dynamic loads are static in structural/stress analyses that dictate the weight of a structural design
    - For a given acceleration, as one goes up in vibrational frequency associated displacement goes down exponentially and in general strain is a very small fraction of that

Loads don't break hardware, strain does

For harmonic motion, displacement is $X = \ddot{X}/\omega^2$

Strain, $\varepsilon \ll X$

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Background and Objective

- Efforts and resources to date
  - Prior to FY11, less "formal" efforts were exerted
  - Up to FY 22, efforts were via TE (FY11, FY19, & FY20) resources (no FTE) and "down time"/personal time
  - In FY22 & FY23 HLS provided FTE & ODC
  - FY24 resources will be requested from HLS and TRENCHWURKS

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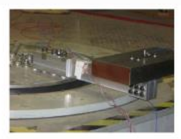
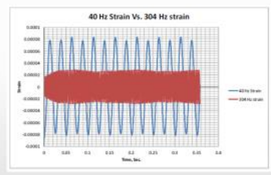
Accomplishments

- 2011 TE efforts were presented at Spacecraft and Launch Vehicle Dynamic Environments Working Group (SCLV) June 2012

Configuration 1 – Beam without the mass
f≈300 Hz, M= 6.5 Lb., M_{CL}≈ 4 Lb.



Configuration 2 - Beam with added mass
f≈40 Hz, M= 48.5 Lb., M_{CL}≈ 46 Lb.



≈ 24.5 g (≈98 Lb.) Input ≈ 2 g (≈92 Lb.) Input Results

- ***Take away: For practically an equivalent dynamic loading condition, approximately 3X more strain was measured at 40 Hz than at 300 Hz***

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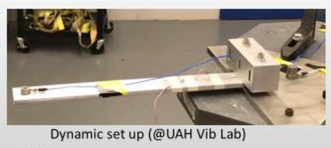
Accomplishments

- 2019 TE – Free Vibration Tests
  - Designed a cantilever beam Test Article (TA)
    - 16"X2"X0.375"
    - AL 6063
  - Performed static and dynamic test

Static set up



Dynamic set up (@UAH Vib Lab)

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Accomplishments

- 2019 TE efforts – Free vibration test

- Static test:
  - The Predicted load to failure was applied (≈80Lb.)
  - ≈ 1" was tip displacement observed while loaded
  - Plastic deformation was visible after unloaded

- Dynamic test:
  - Sine dwell at the fundamental mode (≈43Hz)
  - +/- 6" deformation was observed
  - > 2X ultimate strain was measured
  - NO plastic deformation was visible

- ***Most noteworthy take away: The beam sustained ≈ +/-6" displacement and > 2X ultimate strain dynamically but 1" statically failed the beam***

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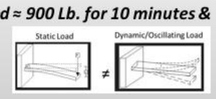
Accomplishments

- 2020 TE efforts – Forced Vibration
  - Kinematic Test Support Structure (KTSS) was designed to use a shaker table to load/move the end of a TA
    - KTSS included 3 load cells to measure the applied loads
    - Vib test were controlled to the average of three measured forces
    - Test were run from 20 Hz to 300 Hz at specified levels
    - Test were run for 10 minutes

Kinematic interface - bearings

Shaker Table Fixed End

- ***Most noteworthy take away: At 40 Hz, the beam sustained ≈ 900 Lb. for 10 minutes & from our static test we know 80 Lb. failed the beam***



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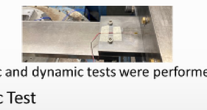
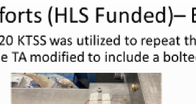
Accomplishments

- 2022 Efforts (HLS Funded)– Bolted Joints
  - The 2020 KTSS was utilized to repeat the 2020 tests but with the TA modified to include a bolted joint





  - Static and dynamic tests were performed
- Dynamic Test
  - Again, tests were performed from 20 – 300 Hz
  - Dynamic loads were specified up 2,000 Lb.
- Static set up
  - Bolt failure occurred at ≈ 400 Lb.
  - Predicted failure @ ≈ 380 Lb.

- ***Most noteworthy take away: The TA sustained ≈ 2,000 Lb. at frequencies as low as 150 Hz and failure was experienced at ≈ 400 Lb. statically***

Dynamic set up

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Current and Future Efforts

- Current,2023, Efforts (HLS Funded)
  - Welded joints
  - First cut modified methodology
- Repeating 2022 efforts but using a welded TA instead of bolted is underway
  - At the completion of this it will have been demonstrated that material (at least the one tested), bolted systems and welded systems can sustain notably higher loads dynamically that statically
    - This equates to our stress/structural analyses that dictate the weight of a structural design are not giving the material enough credit which results in unnecessary robustness
- Design of a simple box via a heritage method and a modification of that is underway
  - Static and dynamic tests are planned
  - This will demonstrate how much mass might be saved in a box design that leverages the subject
- Note: All of this is eye opening and cool to a structures geek but without a modified methodology then it has no utility. Initiating this and it evolving to result in lighter structural designs being the norm is the target end game.

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Current and Future Efforts

- Our CAN with California State University at Northridge (CSUN) was also kicked off in 2023
  - Their focus is to perform tests in an effort to characterize the "dynamic strength" of a selected alloy at different frequencies
  - This is prompted by the fact that in the 2019 test we measured strain much (>2X) higher than published ultimate
    - That was pleasantly unexpected ☺
- Future plans
  - Current interns complete the box design/fab/test and the welded joint this semester
  - The summer intern (Michelle Quinones is returning) continue working any component related lose ends
  - Initiate efforts on larger things
    - More representative of primary structure
  - Fall and beyond: Continue working primary structure …