Vehicle Structural Considerations for Human Exploration Missions

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Crewed Spacecraft for missions beyond LEO will most likely:

- **Be assembled in Deep Space with both pressurized and unpressurized elements**
- **Have large appendages (e.g. solar arrays and radiators)**
- **Have very strict stiffness and leakage requirements**
- **Require radiation protection of habitable areas**

- **Employ a variety of microgravity adaptive countermeasures such as:**
  - **Treadmills**
  - **Resistive Exercise Devices**
  - **Cardio-pulmonary exercise equipment**
  - **Artificial gravity (achieved by rotating all or a portion of the spacecraft)**

What can be learned from ISS that can inform future vehicle structural concepts?

- Large, assembled spacecraft will have many low frequency structural modes (less than 5 Hz).
- Appendages will be especially susceptible to dynamic loads.
- Structural joints between elements have the greatest effect on overall vehicle stiffness.
- Instrumentation need to be pre-integrated on the vehicle to monitor in-space loads and develop structural life predictions.

- Radiation and micrometeoroid protection will have considerable mass impacts based on the acceptable risk to crew health and vehicle safety.

- ISS on-orbit structural lifetime was 15 years by design.
  - Subsequent tests and analyses have extended the structural life to 2028.

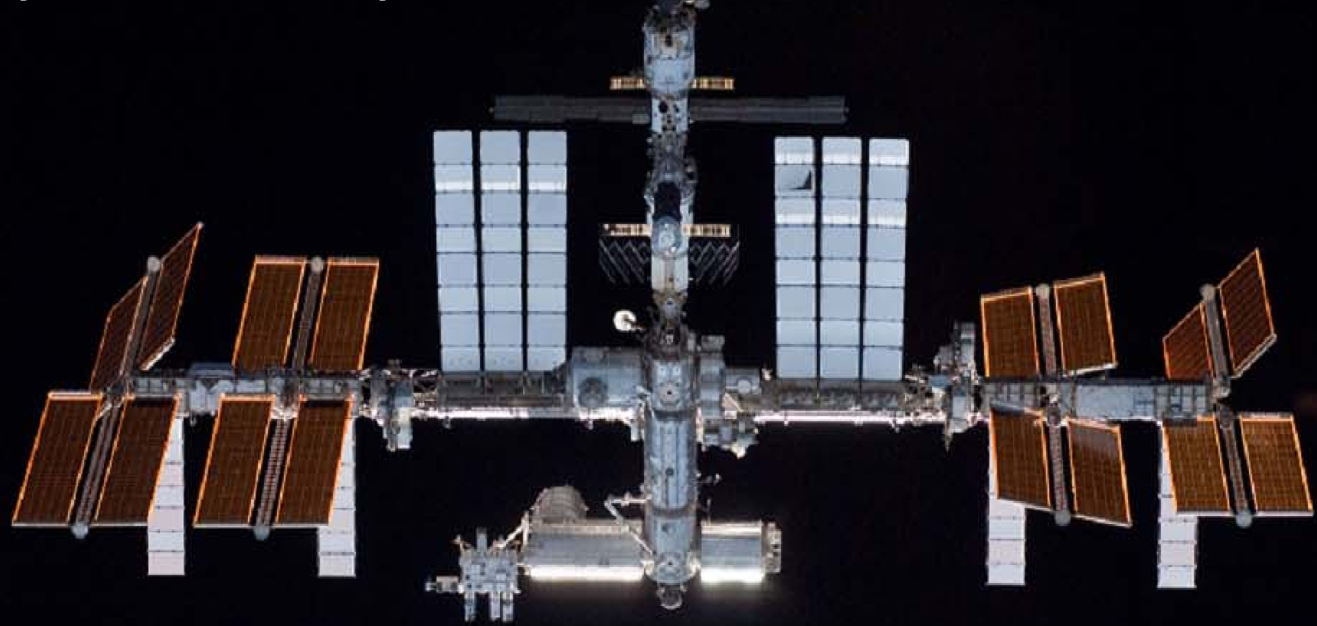
- To conserve the structural lifetime of future exploration vehicles:
  - Vibration Isolation will be required on all crew exercise equipment
  - Appendages will be feathered to mitigate loads from visiting vehicles

- Accelerometer data gathered during operations will be used to track actual structural loading during operations.
- Close co-ordination with GN&C to avoid tuning of jet firings with structural natural frequencies.

http://www.nbcnews.com/id/28998876/ns/technology_and_science-space/t/shaking-space-station-rattles-nasa/

January 14, 2009 anamolous reboost using the ISS Service Module engines.

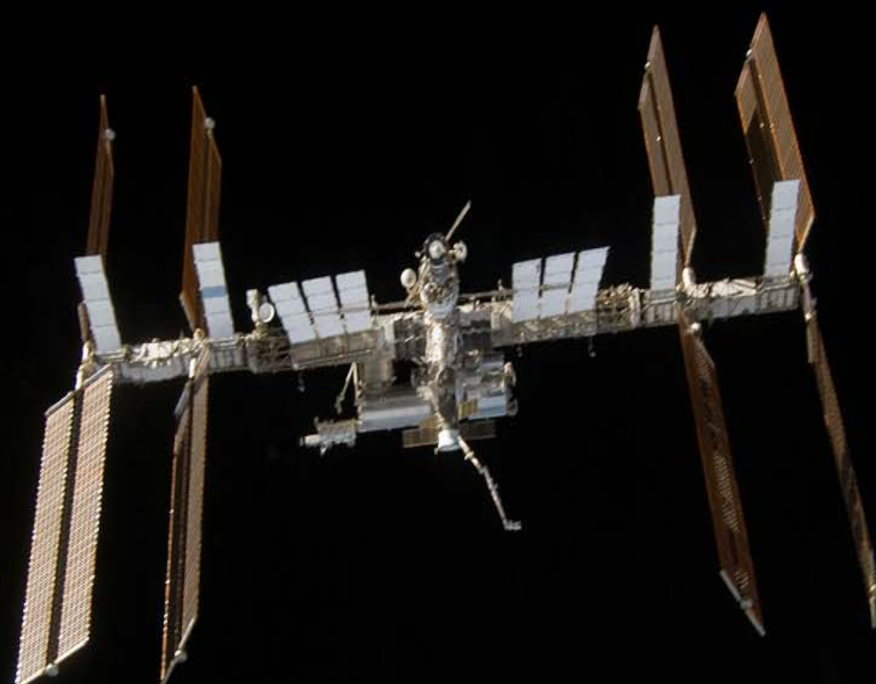
- **The ISS weighs approximately 1,000,000 lbs, began development in 1984 and assembly took about 13 years.**



- **Future spacecraft will weigh less and be composed of a few large pieces.**
  - **Configuration is constrained by SLS lift capability, shroud size and flight rate.**
- **Deep space vehicles should not spend time in LEO because of Orbital Debris.**
  - **Only meteoroid shielding is needed for deep space. LEO loiter will impose a significant parasitic mass penalty for debris shielding on the spacecraft.**

If artificial gravity is considered as an adaptive countermeasure, trade studies to determine whether a local portion of the spacecraft or the entire vehicle needs to rotate as well as the g-level required and exposure duration to be effective must be performed.

- These trade studies will develop a significant array of configurations based on the g-level and portion of the spacecraft required to generate artificial gravity.



- These configurations will also have a wide range of complexity and structural mass.
    - ISS considered adding a centrifuge module for primate research.

Summary of Structural Considerations for future manned spacecraft

- Reduce in-space assembly and EVA.
- Minimize the number of launches from Earth.
- Shorten or eliminate appendages.
- Avoid loiter time in LEO because of Orbital Debris.
- Include instrumentation to monitor operational loads and structural health.
- Use Vibration isolation on all crew-exercise equipment.
- Determine the minimum level, duration and area of the spacecraft that requires artificial gravity if it is used as an adaptive countermeasure in order to reduce the complexity of the vehicle configuration.
- Some level of risk will have to be accepted in order to implement meteroroid and radiation protection due to launch mass constraints.

- Next Steps:
  - Perform vehicle conceptual design studies for a range of g-levels, durations and portions of a crewed spacecraft using artificial gravity to understand the ranges of overall vehicle size, mass, complexity, power and launch vehicle requirements.