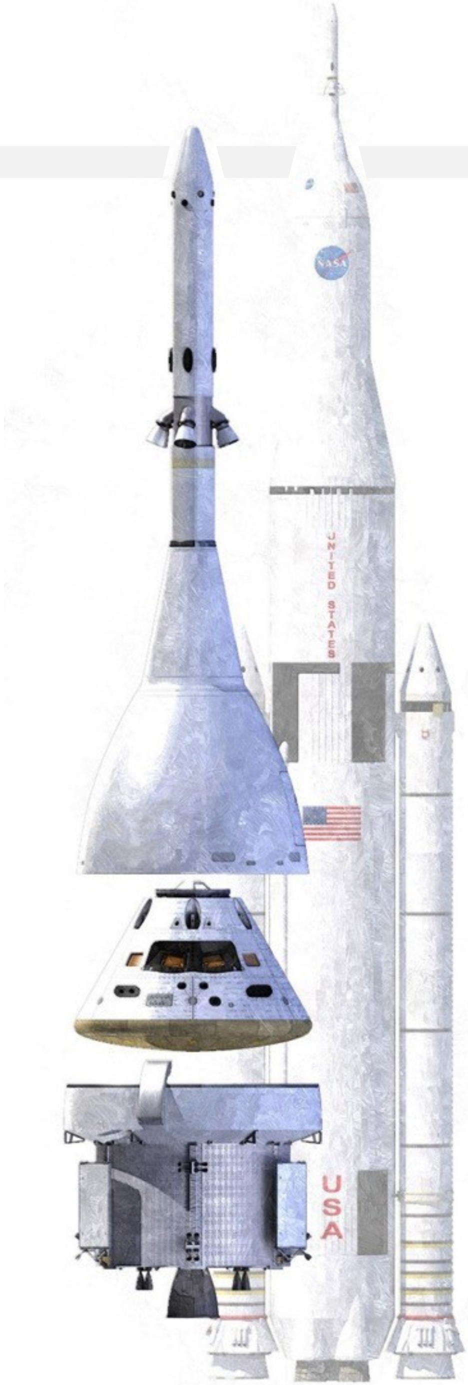

Inflight Parachute Measurement Challenge

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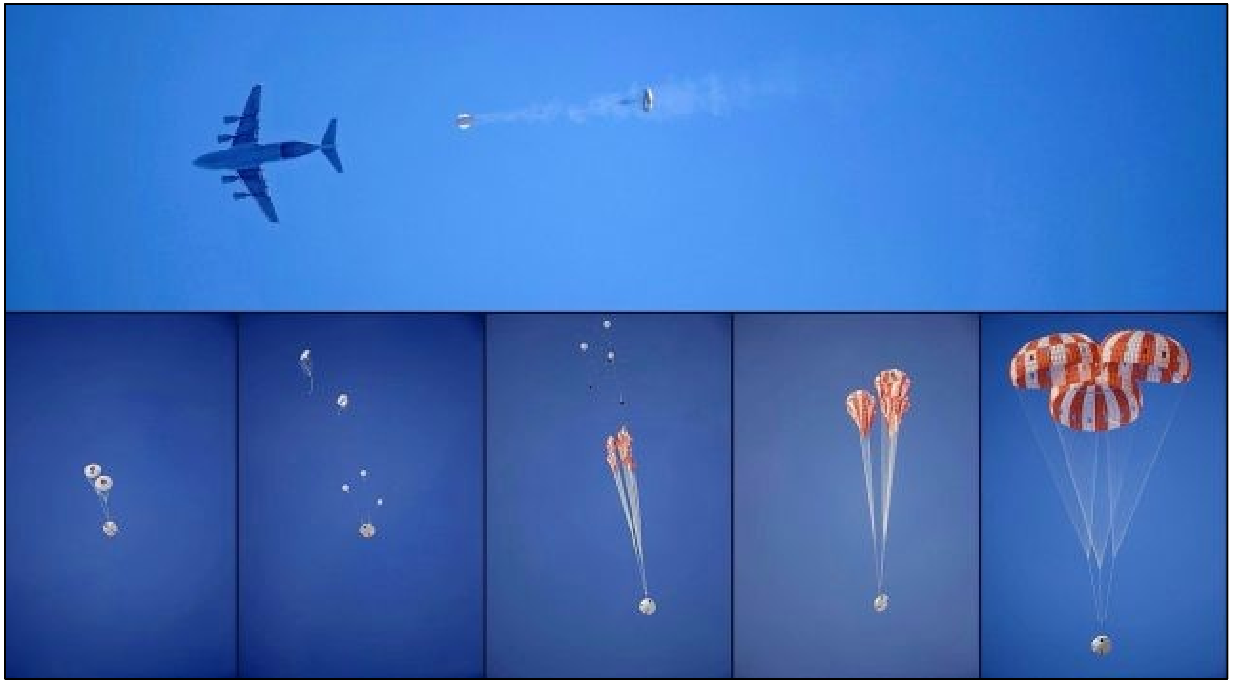
Objective

- Objectives
  - Describe the anatomy and analysis techniques of a generic cluster of spaceflight parachutes
  - Identify measurements of particular interest to the spaceflight parachute design and analysis community
  - Identify additional uses of measurements
- Agenda
  - Spaceflight parachute anatomy
  - Spaceflight parachute loads analysis
  - Current problem statement – asymmetry
  - Existing capabilities
  - Measurements of particular interest
    - Other uses for measurements

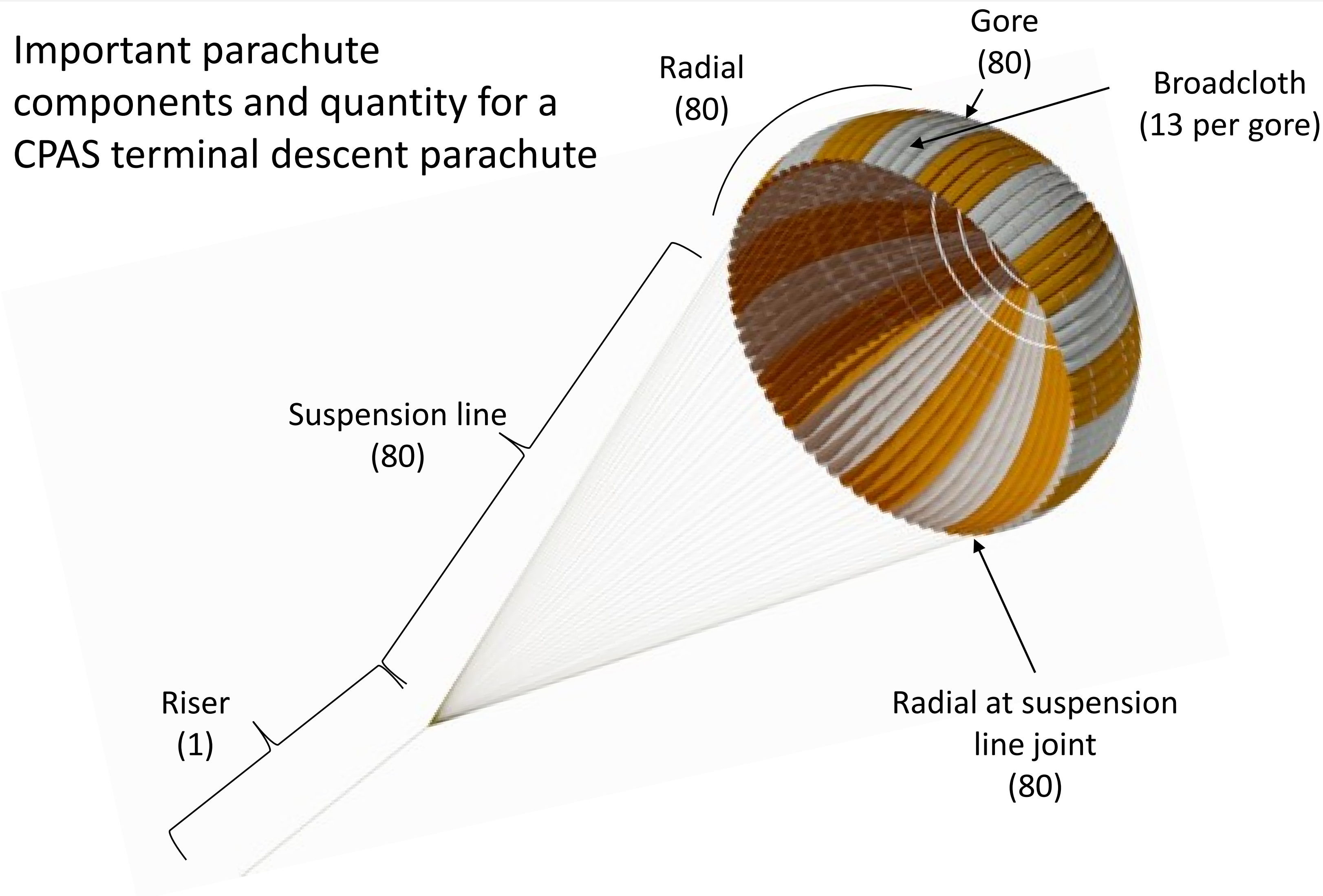
Parachute Anatomy

- Terminal descent spaceflight parachutes are comprised of drag producing elements and textile structural grid elements
- Typical systems (such as Orion and Apollo) use multiple stages and types of parachutes to decelerate the spacecraft to a required velocity for touchdown
- The large, terminal descent parachutes of the Orion Capsule Parachute Assembly System (CPAS) will be used as an example, but the principles and needs discussed are applicable to all types of parachutes



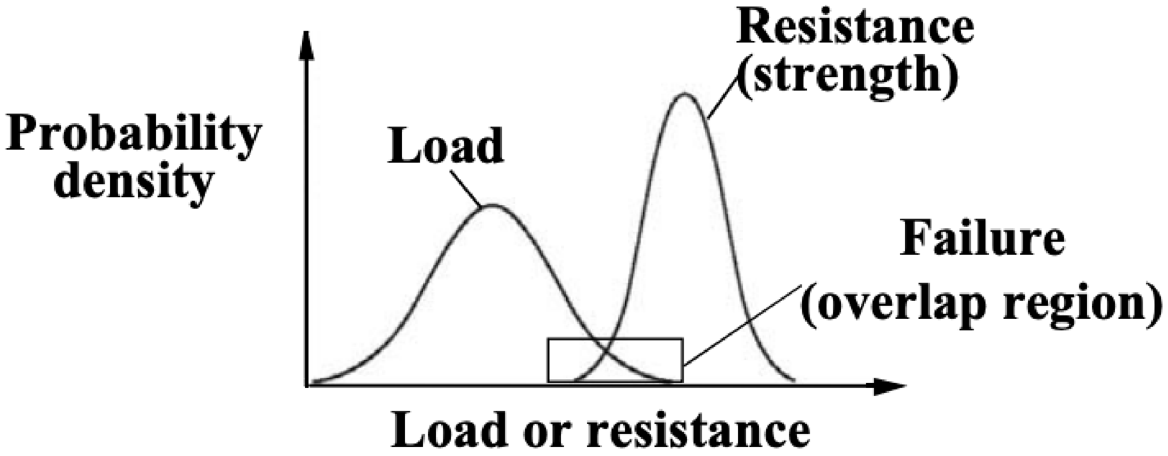
Parachute Anatomy

- Important parachute components and quantity for a CPAS terminal descent parachute



Parachute Loads Analysis

- Parachute loads analysis is the comparison between estimated parachute element strength and the load applied to that element
- To minimize the risk of parachute failure, the distribution of predicted element strength should be separated from the distribution of predicted load by some amount (known as the safety factor)
- As parachutes are complex textile systems deployed in a dynamic environment, the prediction of both the element strength and parachute load have inherent uncertainties which introduce risk to the system

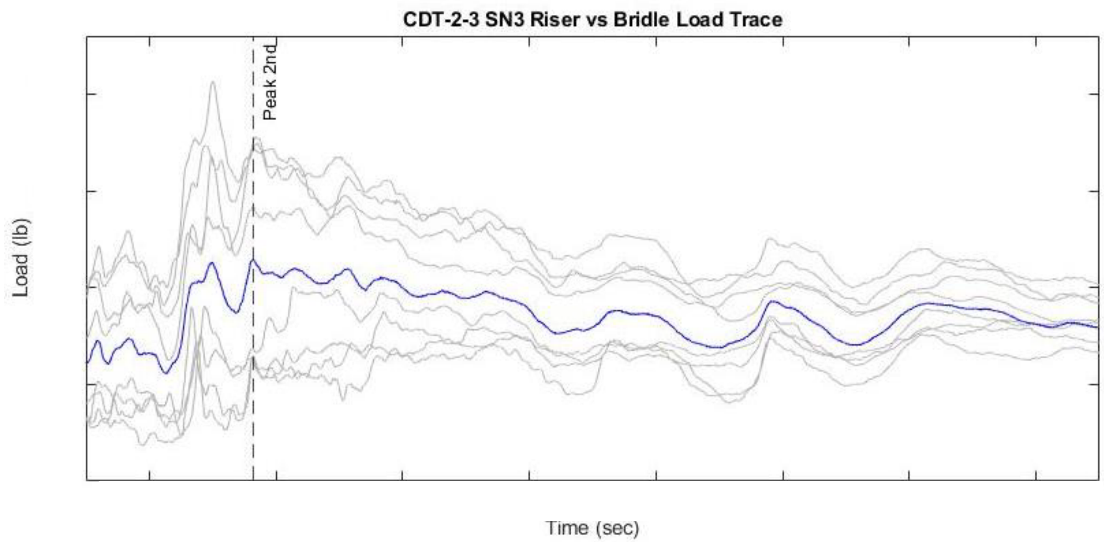


Parachute Loads Analysis

- Current state of the art involves measuring the total parachute load at the riser
  - After sufficient drop tests with measured riser loads, a model can be developed and this value can be predicted in simulation with a reasonable level of confidence
- The predicted riser load is then decomposed into element level loads with basic assumptions
  - E.g. – The CPAS suspension line load = (riser load) / 80
- Traditional parachute design and analysis accounts for textile behavior and dynamic environments by using element level amplification and degradation factors
  - Amplification factors increase the load analyzed for each element
    - Asymmetry, Dynamic, Convergence
  - Degradation factors decrease the strength of the element
    - Abrasion, Fatigue, Aging, Contamination, Thermal, Joint Reduction
- These amplification and degradation factors are ideally tested and measured in the system, but often heritage values are assumed when data is not available

Current Problem Statement - Asymmetry

- **The parachute community currently lacks sufficient inflight data to validate assumptions in applied load predictions**
- A primary contributor to uncertainties in applied load predictions is the asymmetric distribution of load throughout like elements
  - Many possible contributing factors which include interference between parachutes, asymmetrical canopy pressurization, geometry, etc.
- Traditional parachute loads analysis suggests that peak asymmetric parachute loads are approximately 10% higher than ideal, symmetric calculations
- Initial measurements indicate that this asymmetric load amplification on the suspension lines is actually on the order of 100%

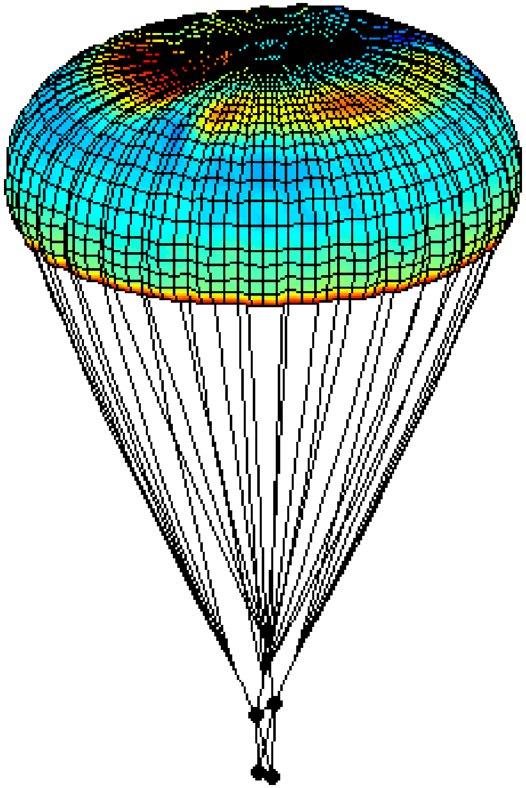


Existing Capabilities

- Riser loads can be measured and predicted in simulation
  - Sufficient measurement capability exists to measure the total force from each individual parachute, but not each component in the parachute
- Wind tunnel testing does not provide data of sufficient quality
  - Deployment and inflation
  - Cluster interaction
  - Dynamic pressure time history
  - Scaling
- Incorporating traditional instrumentation is challenging during flight
  - Desire to maintain configuration
  - Pressure packing
  - Long term storage
  - Initiation
  - Deployment and flight environment
  - Quantity of required measurements

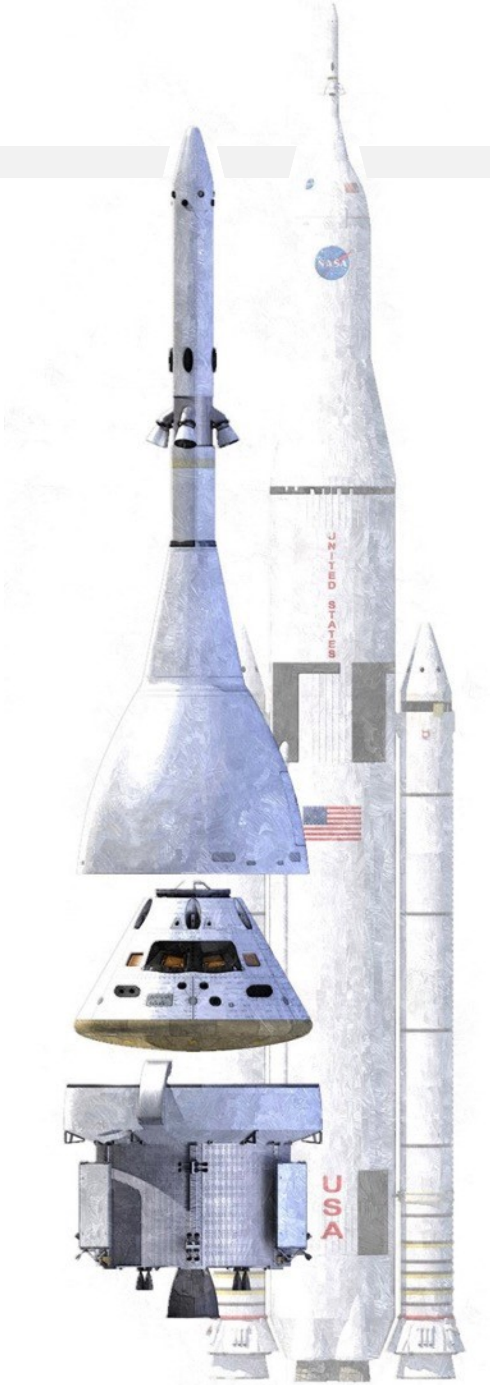
Measurements of Particular Interest

- Suspension line elements are highly susceptible to asymmetric loading
  - Suspension lines are a significant percentage of the total weight and volume of the parachute and thus cannot be significantly overdesigned
  - Individual suspension line loading is the resultant of chaotic loading of canopy elements
- Other measurements will aid in existing analyses, along with validation of Fluid-Structure Interaction (FSI) models
  - Canopy pressurization
  - Broadcloth tension
  - Reefing line tension
  - Radial tension along length
  - Canopy shape
- Other measurements could be used real-time to actuate functions of the parachute based on current conditions



Conclusion

- Parachutes are complex textile systems deployed in dynamic and varying conditions
- Various measurements throughout an inflight system are desired to validate structural analysis assumptions and computer models
- Collecting relevant data has proven difficult due to wind tunnel limitations, inflight environments, and quantity of required measurements
- **The parachute community is seeking solutions to increase the quality and quantity of inflight parachute element-level measurements**



BACKUP

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