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Predicting Parachute Deployment Performance for upcoming Supersonic Flight Dynamics Tests on the LDSD Program

Michael Contreras & Doug Adams
Jet Propulsion Laboratory, California Institute of Technology

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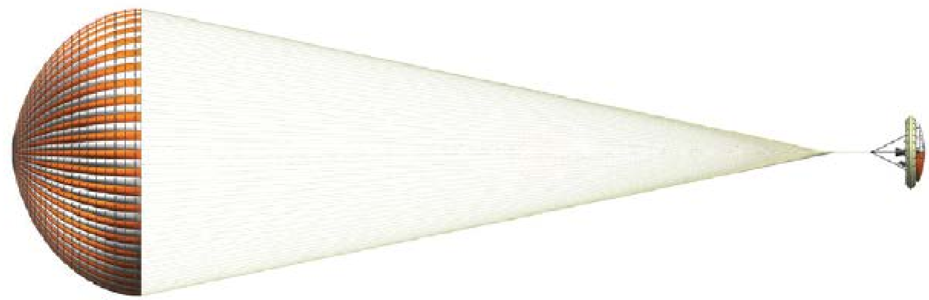
LDSD Tech Demo Mission

- Current deceleration technology ***dates back to NASA's Viking Program*** (1976). The basic Viking parachute design has been re-used through 2012 to deliver the Curiosity rover to Mars.
- ***To land heavier spacecraft*** on Mars, NASA must advance the technology of decelerating large payloads traveling at supersonic speeds in thin atmospheres to a new level of performance.
- These new drag devices are one of the first steps on the technology path ***to potentially landing humans, habitats, and their return rockets safely on Mars.***



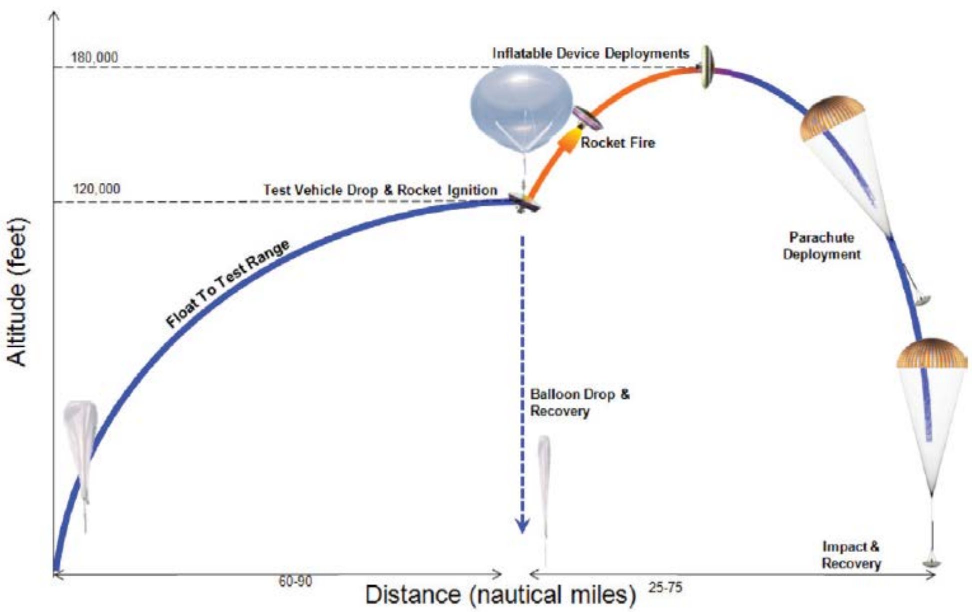
33.5-meter Supersonic Ring Sail Parachute

6-meter SIAD-R

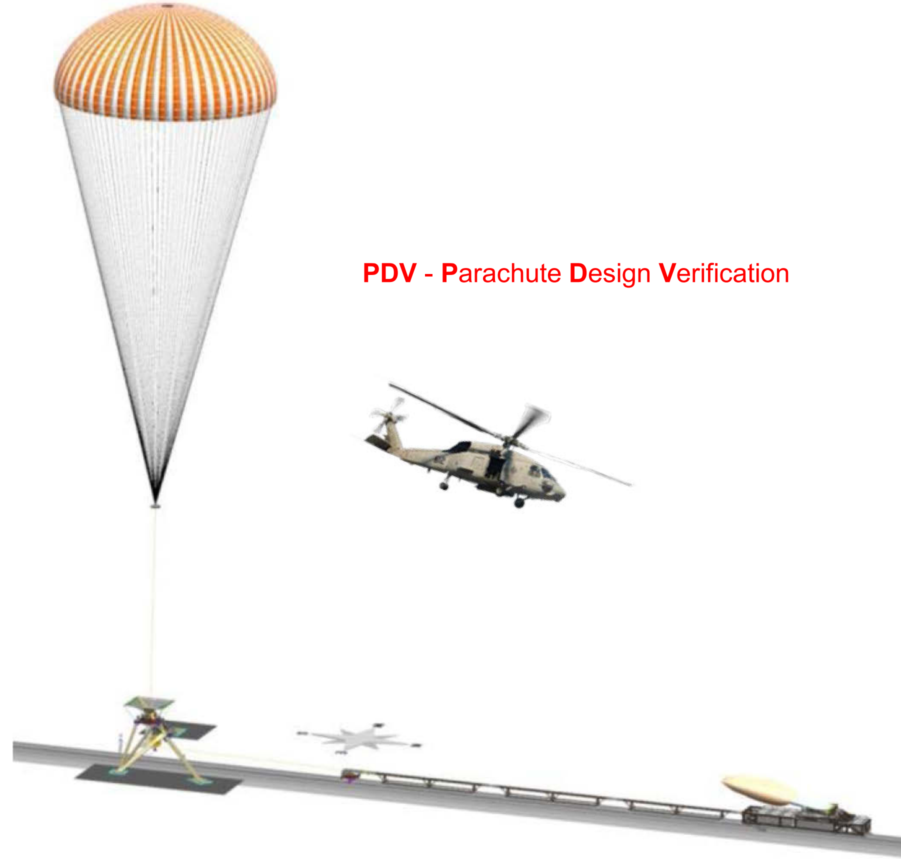
8-meter SIAD-E

Test Program at a Glance

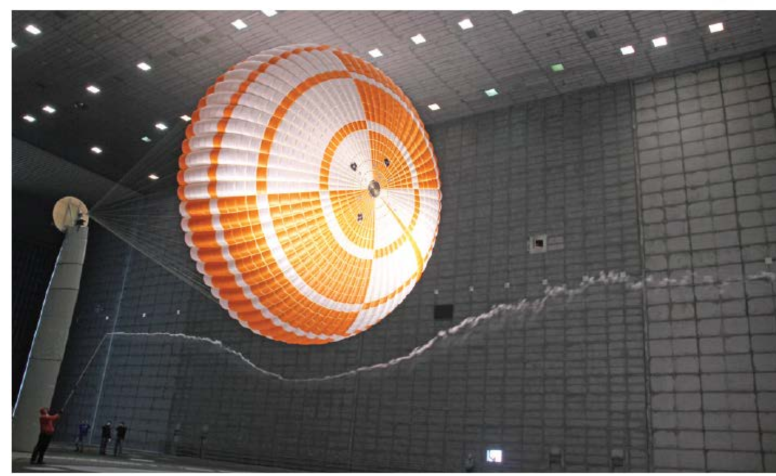
SDV - Supersonic **I**nflatable **A**erodynamic **D**ecelerator (SIAD) **D**esign **V**erification



SFDT – Supersonic **F**light **D**ynamics **T**est

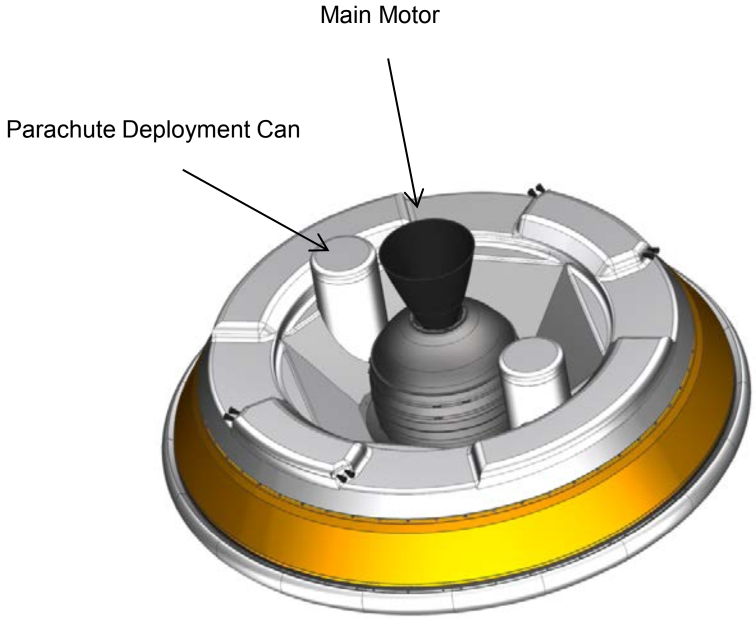


PDV - Parachute **D**esign **V**erification



SFDT Project Concern

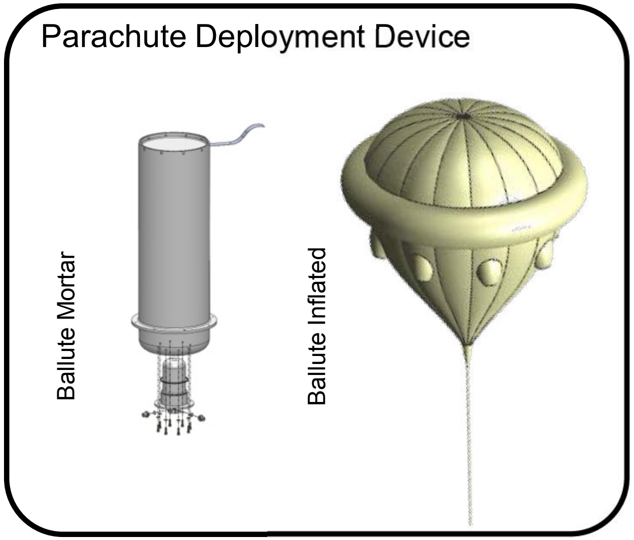
- Main motor is located at center of test vehicle, therefore parachute must be deployed off center line
- Due to size of parachute, mortar fire required to extract parachute bag is not permissible due to vehicle restrictions
  - *An alternative Parachute Deployment Device (PDD) must be used to deploy the parachute rigging and canopy*

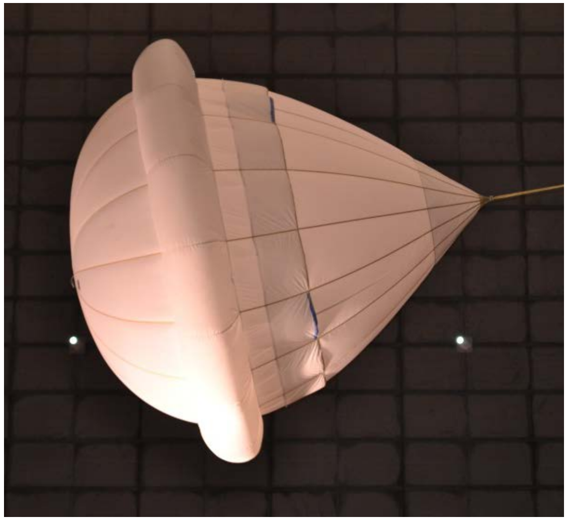


Taken from MSL Open Air Mortar Fire Test

PDD Design Trades

- Select PDD that deploys the parachute pack with sufficient deceleration and drag such that positive tension is maintained in the parachute rigging and suspension lines
- Select PDD such that deployment mortar required does not exceed that required for direct parachute bag mortar fire
  - *Using the developed simulation capability, it was determined that a ballute with diameter 4.4 m was capable of emulating a mortar deployment during the free flight phase - post ballute release*





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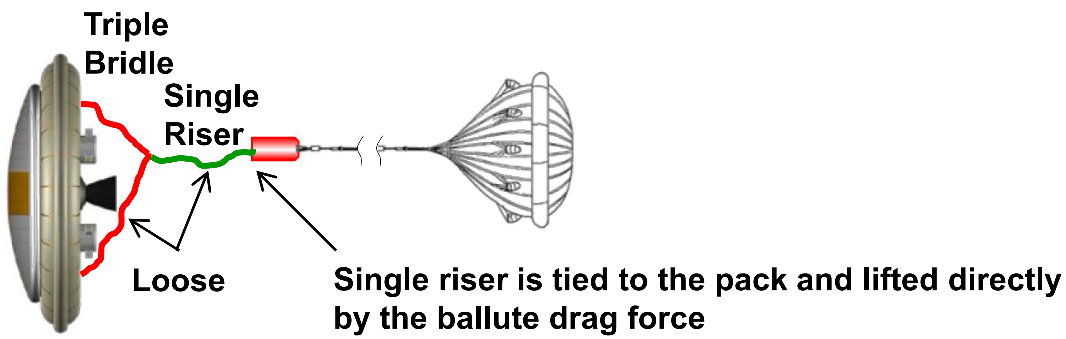
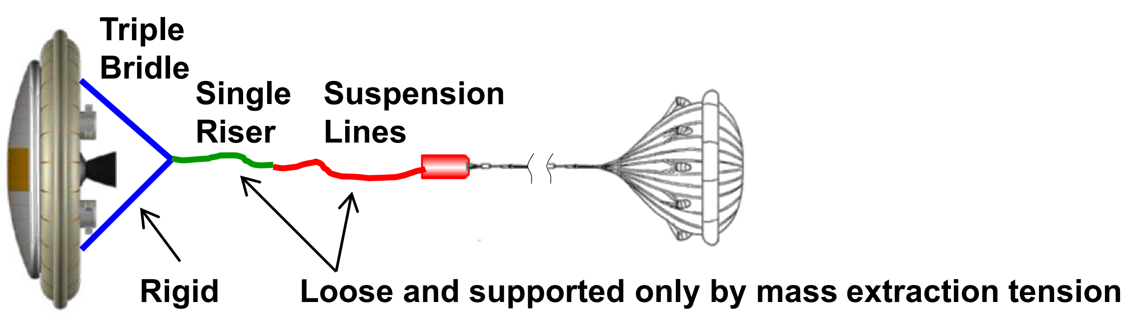
“Stand and Deliver”

- The “stand and deliver” deployment was adopted to eliminate previous reliance on stored rigging momentum and suspension line extraction forces to deploy and maintain the position of the triple bridle
- **Stand** – the single riser is affixed to the bottom of the parachute pack and the assembly is lifted into posn. by direct action of the ballute drag

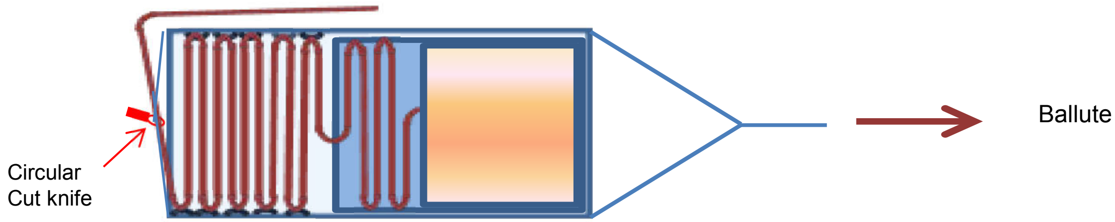


- **Deliver** – the triple bridle is rigidized (no further tension req’d for support) and the pack is opened allowing suspension line extraction

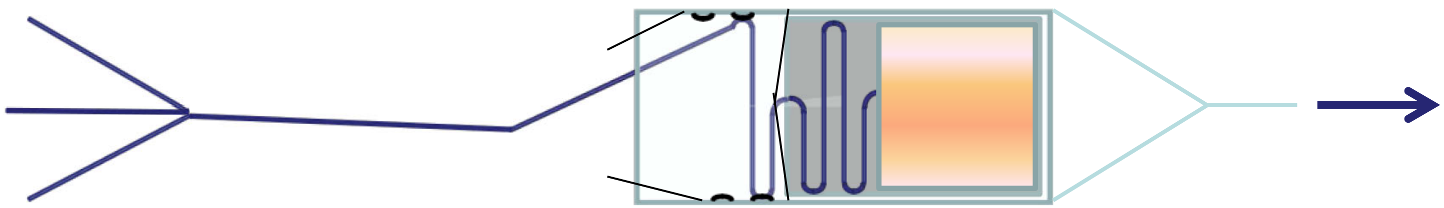


SSRS Deployment Bag

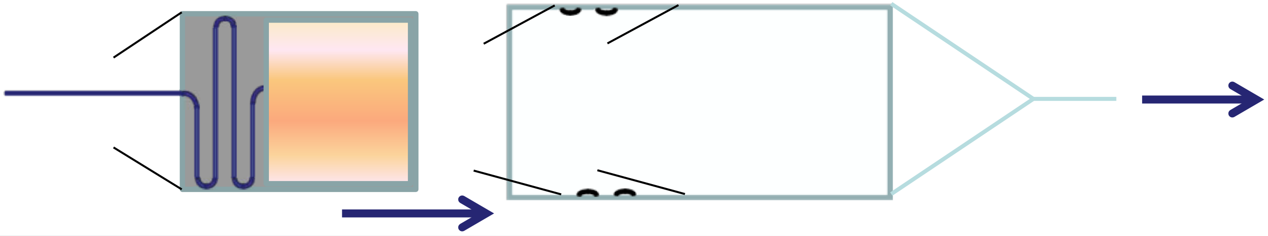
- Outer bag is lifted away from vehicle while riser and bridle legs are stood up



- At time of bridle leg stand up, cutter (on captive lanyard) releases closing flaps, allowing remaining riser and suspension lines contained in outer bag to pay out



- As final line bight on outer bag is released, locking line bight on compartment flaps is released, and outer bag is stripped away from inner bag allowing inner bag with remainder of suspension lines and canopy to continue to deploy on inertia alone.



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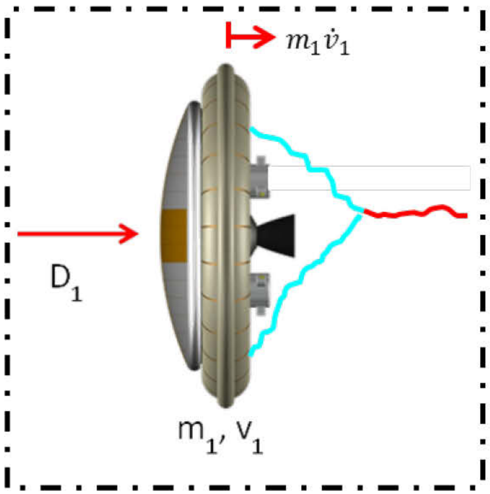
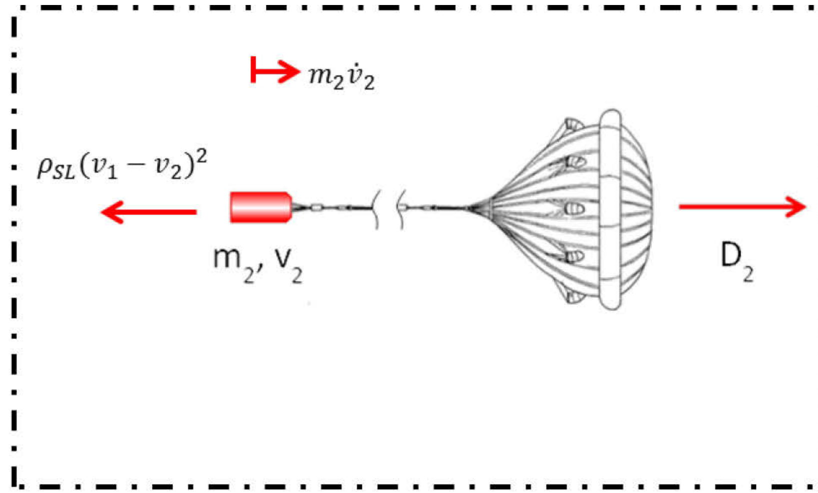
Modeling Rigging Stand Up





(1) $$m_1\dot{v}_1 = -D_1 - F_r$$

(2) $$m_2\dot{v}_2 = -D_2 + F_r + \rho_{SL}(v_1 - v_2)^2$$

(3) $$\dot{m}_1 = -\rho_{SL}(v_1 - v_2)$$

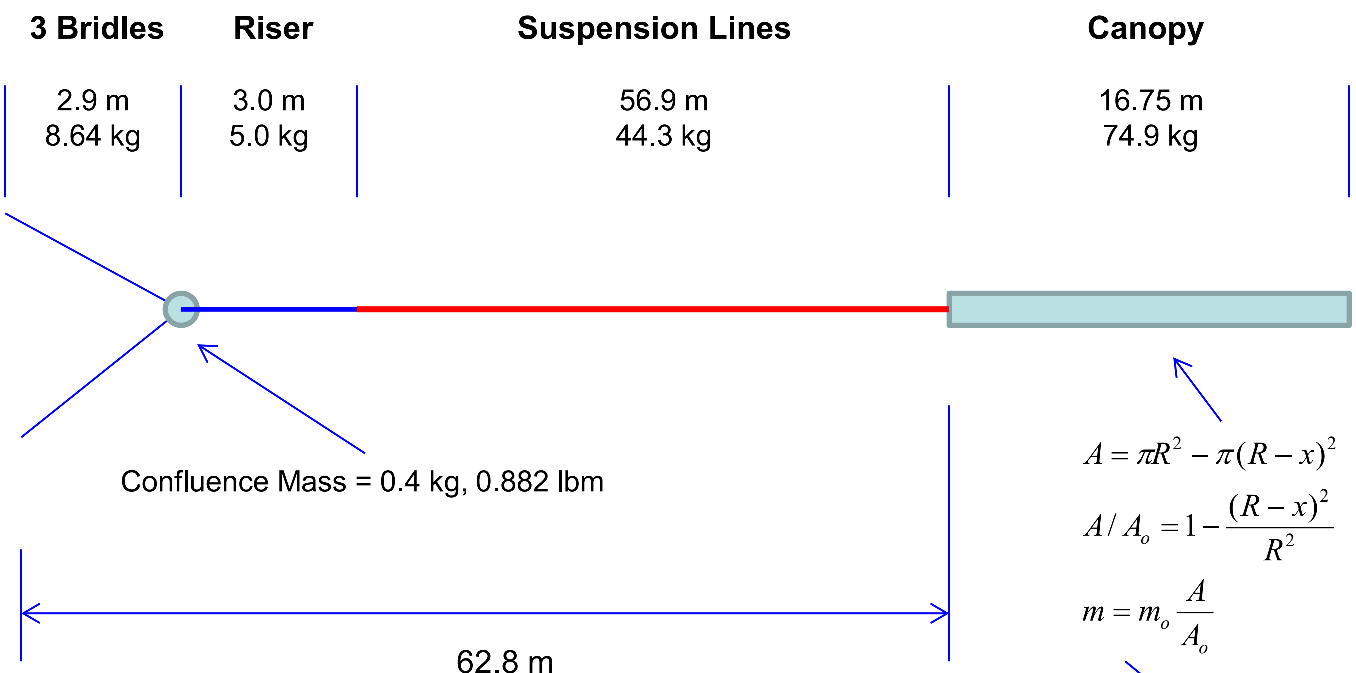
(4) $$\dot{m}_2 = \rho_{SL}(v_1 - v_2)$$

(5) $$\dot{x} = v_1 - v_2$$ ⟶ **Critical for event detection**

References:

1. *Greenwood, D. T., Principles of Dynamics, 2nd ed., Prentice Hall, New York, 1987, pp. 165-171*
2. *Toni, R. A., "Theory on the Dynamics of Bag Strip for a Parachute Deployment Aided by a Pilot Chute," 2nd Aerodynamic Deceleration Systems Conference, El Centro, CA, Sept. 23-25, 1968, AIAA-1968-925*
3. *McVey, D. F., and Wolf, D. F., "Analysis of Deployment and Inflation of Large Ribbon Parachutes," 4th Aerodynamic Deceleration Systems Conference, Palm Springs, CA, May 21-23, 1973, AIAA-1973-451*

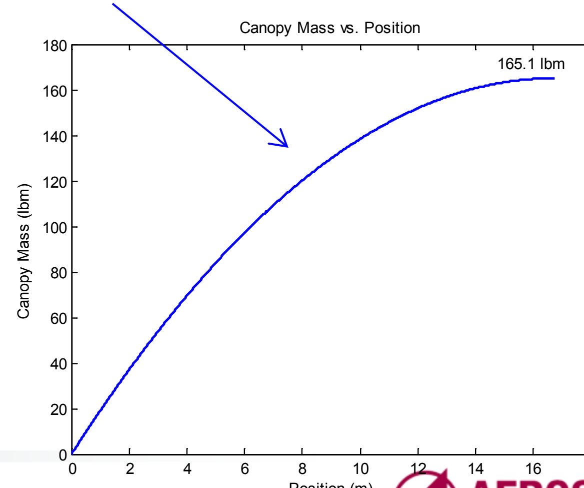
Parachute Mass Model



$$A = \pi R^2 - \pi (R - x)^2 \quad for \quad 0 \le x \le R$$

$$A / A_o = 1 - \frac{(R - x)^2}{R^2}$$

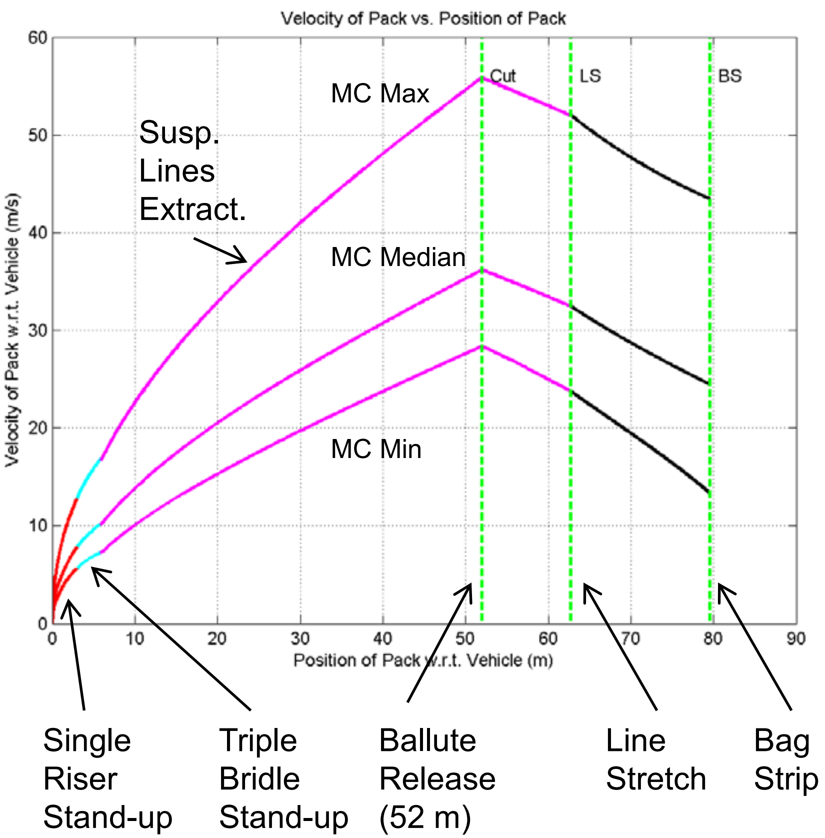
$$m = m_o \frac{A}{A_o}$$



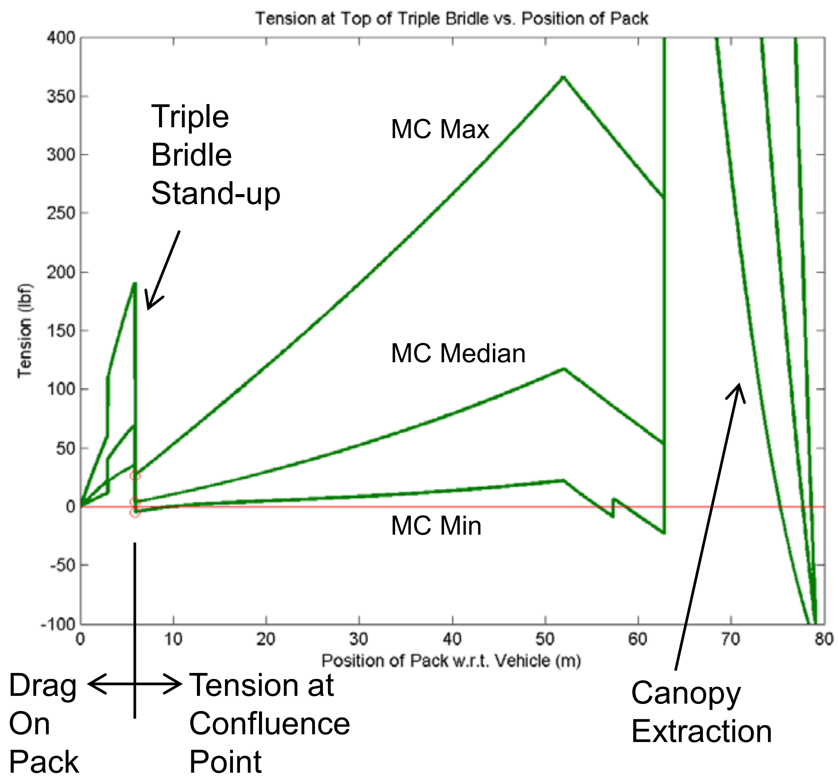
The canopy mass model is based simply on percentage of the circular area that is extracted at position "x" from the skirt of the parachute where 0 < x < Do/2.

SIAD-R Results (Mach 2.25)

- Sample plots of the min, max, and median results using the SIAD-R Monte Carlo initial conditions



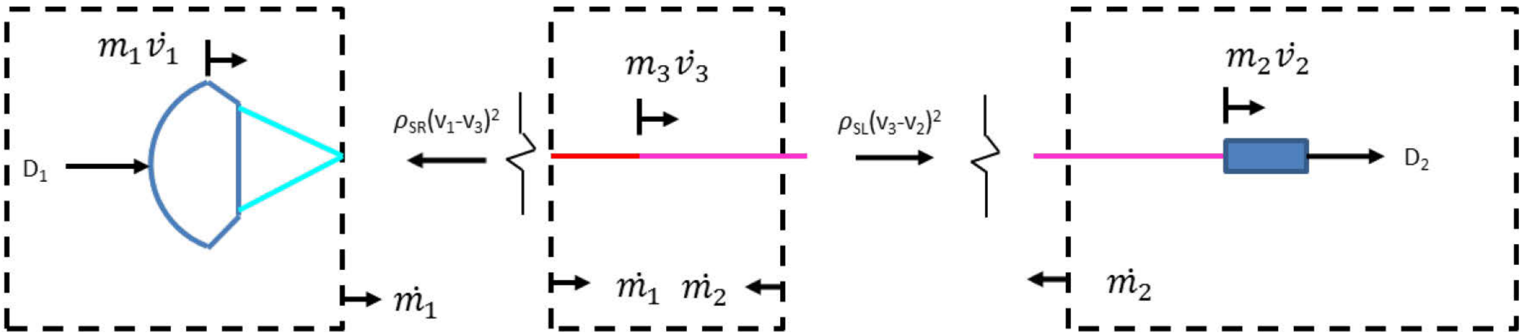
Pack Vel. vs. Pack Posn.



Sensed Tension at the Top of the Triple Bridle

Negative Tension and Pile Up Formulation

- For cases which exhibit negative tension at the top of the triple bridle immediately following triple bridle stand up, it is necessary to ***integrate backward motion*** to capture pile up of single riser
  - *To do this, a 3rd body must be spawned which adds additional equations of motion*



(1) $m_1\dot{v}_1 = -D_1 + \rho_{SR}(v_1 - v_3)^2$

(2) $m_2\dot{v}_2 = -D_2 + F_r$

(3) $m_3\dot{v}_3 = -\rho_{SL}(v_3 - v_2)^2 - F_r$

(4) $\dot{m}_1 = -\rho_{SR}(v_1 - v_3)$

(5) $\dot{m}_2 = -\rho_{SL}(v_3 - v_2)$

(6) $\dot{m}_3 = \rho_{SR}(v_1 - v_3) + \rho_{SL}(v_3 - v_2)$

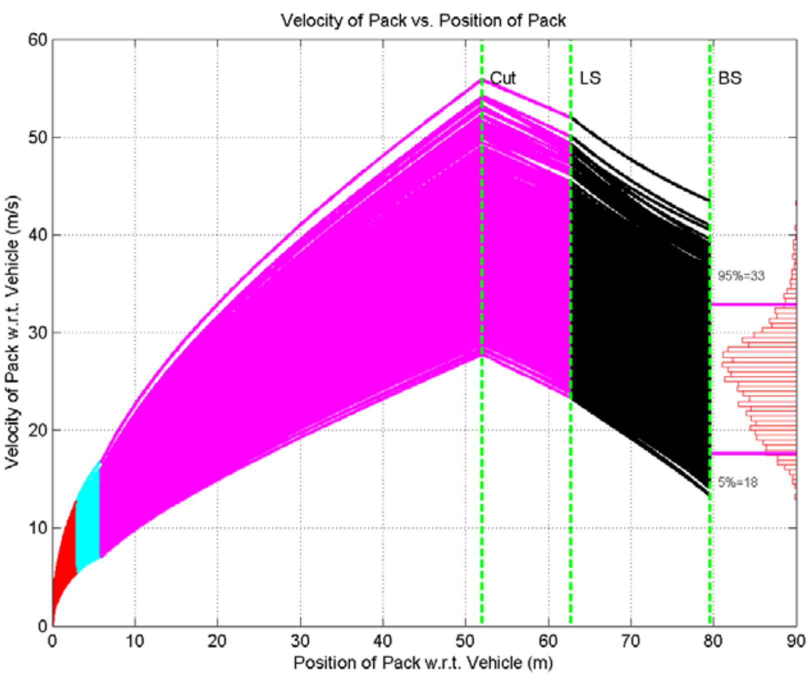
(7) $\dot{x}_{12} = v_1 - v_2$

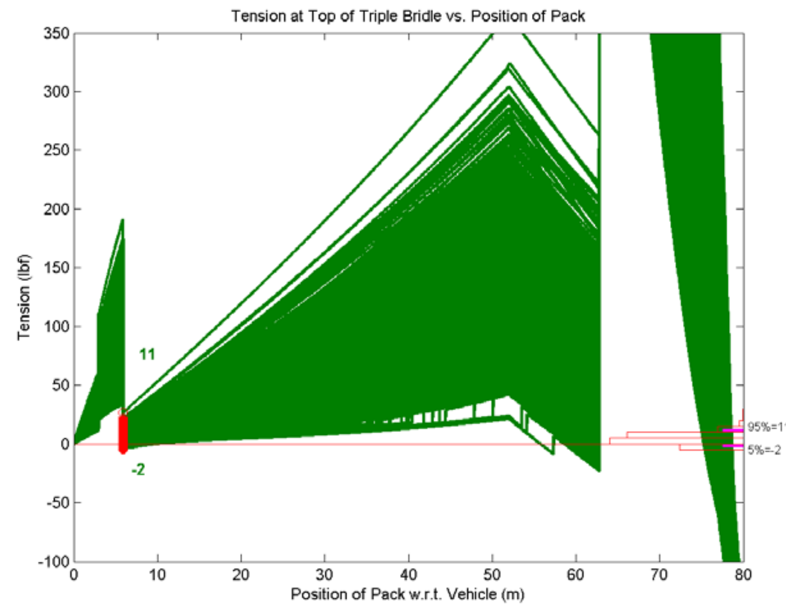
(8) $\dot{x}_{13} = v_1 - v_3$

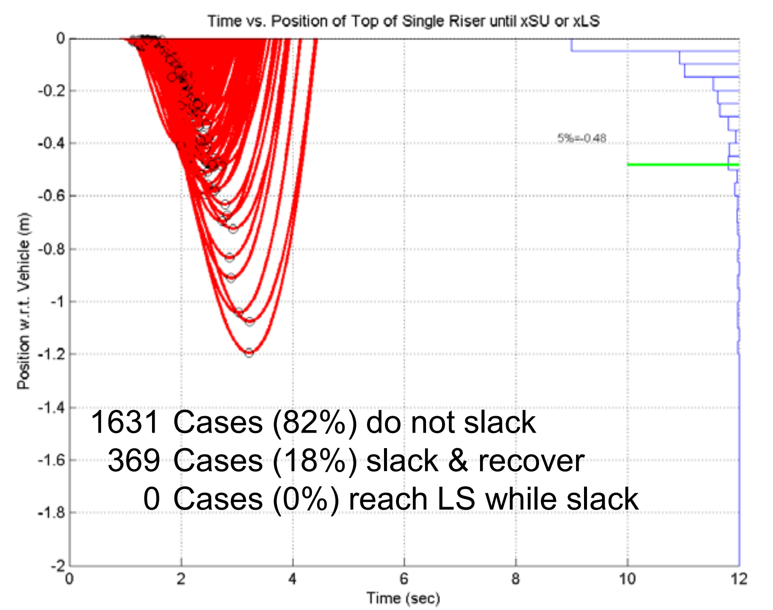
Event detection (equations 7–8)

SIAD-R Pile Up Results

- 4.4 m ballute, 33.5 m parachute
- 52 m ballute release posn.
- All 2000 Monte Carlo cases shown







Rated as Satisfactory

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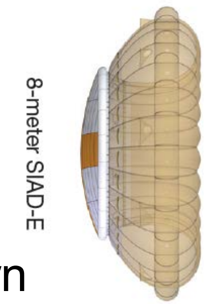
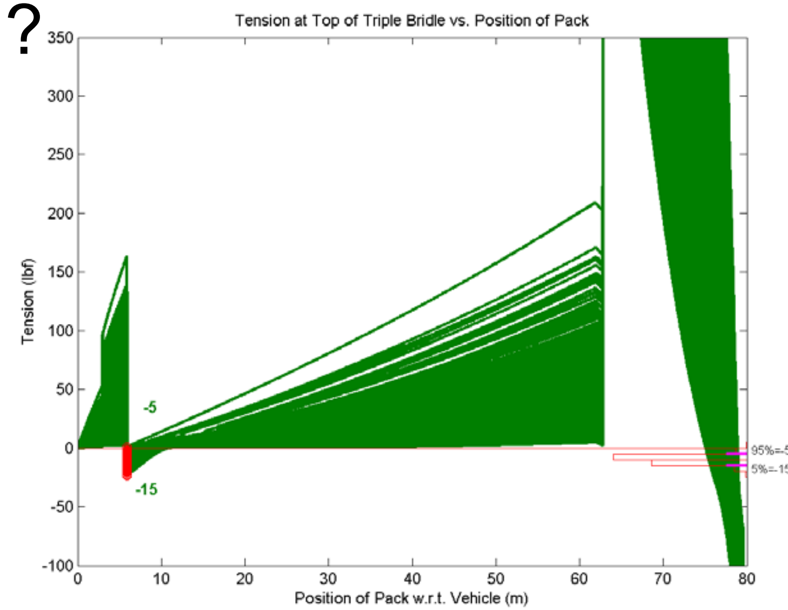
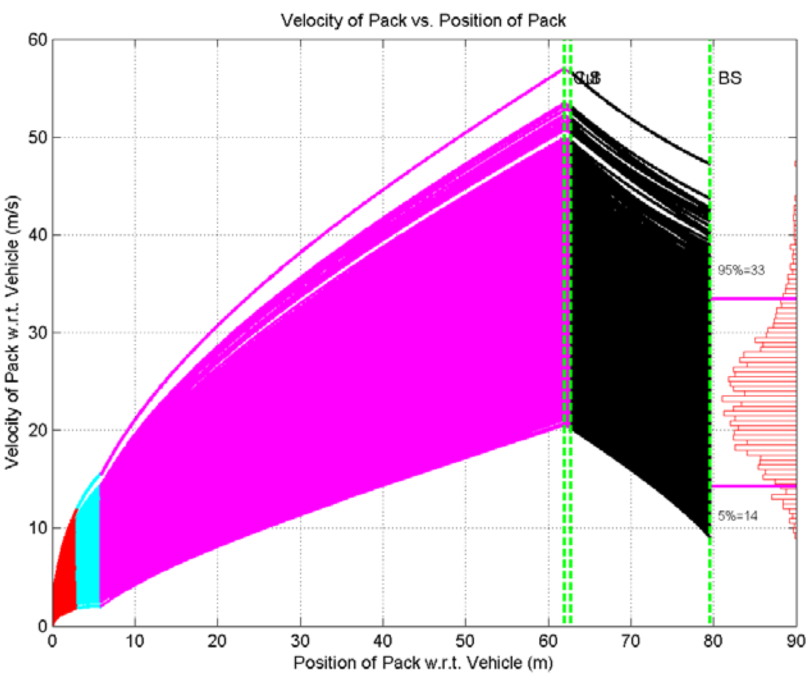
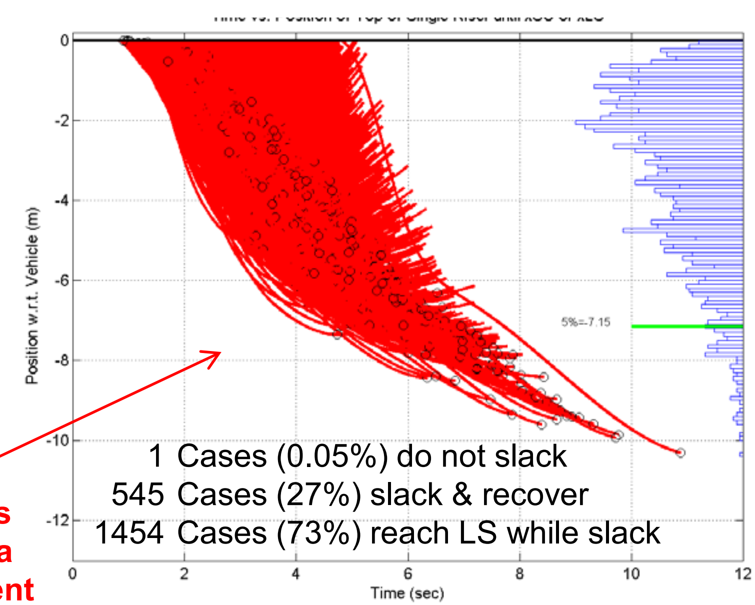
What about SIAD-E (Mach 2.25) ?

- 4.4 m ballute, 33.5 m parachute
- 62 m ballute release posn.
  - *- 2/3 suspension line mass (reefed)*
- All 2000 Monte Carlo cases shown







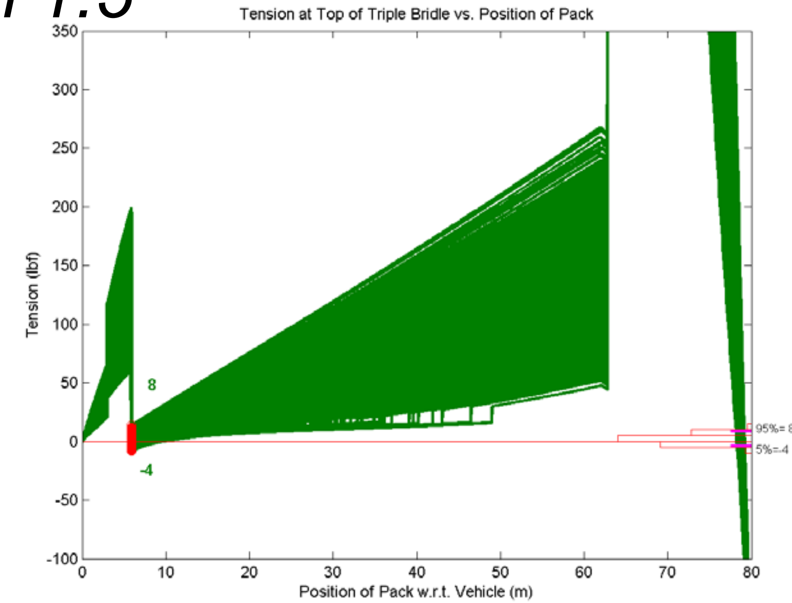


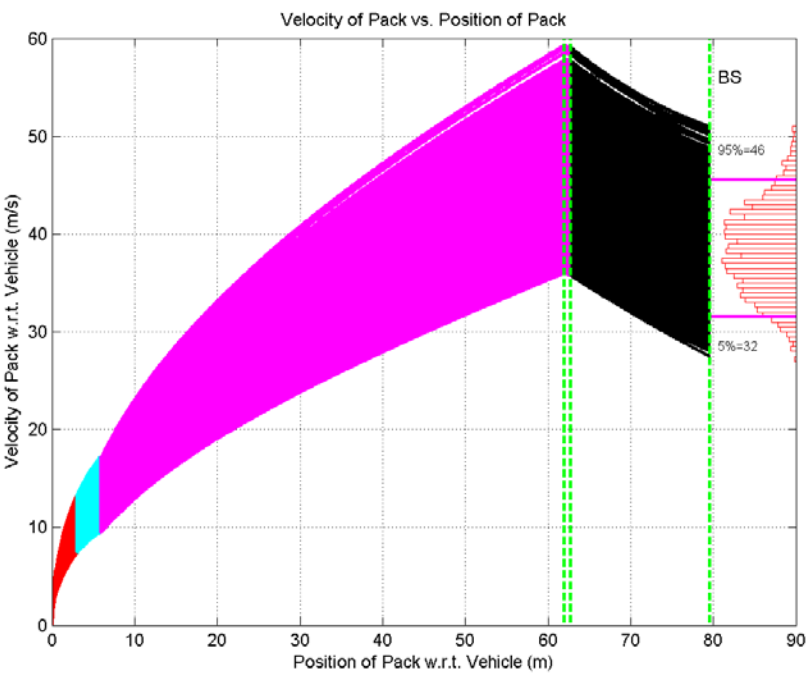
Rated as Unsatisfactory

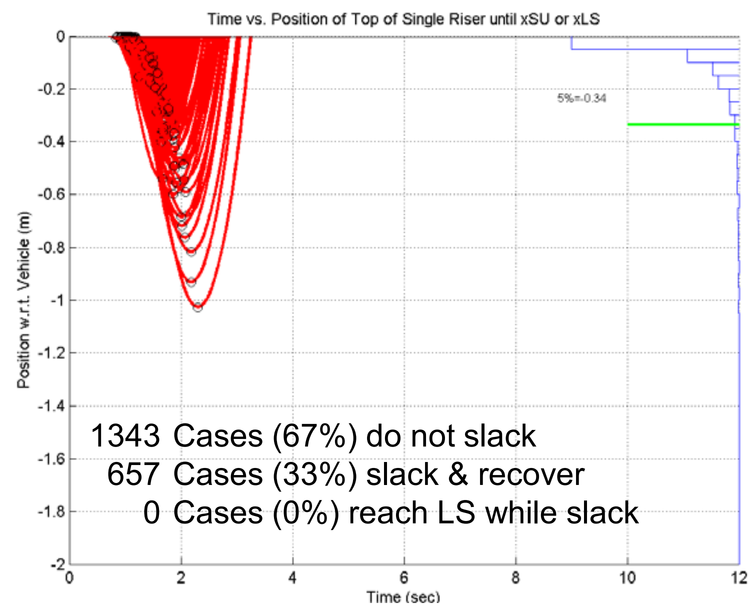
Excessive slacking indicates insufficient ballute drag for a Mach 2.25 SIAD-E Deployment

SIAD-E Solution: *Deploy at Mach 1.5*

- 4.4 m ballute, 33.5 m parachute
- 62 m ballute release posn.
  - *2/3 suspension line mass (reefed)*
- All 2000 Monte Carlo cases shown



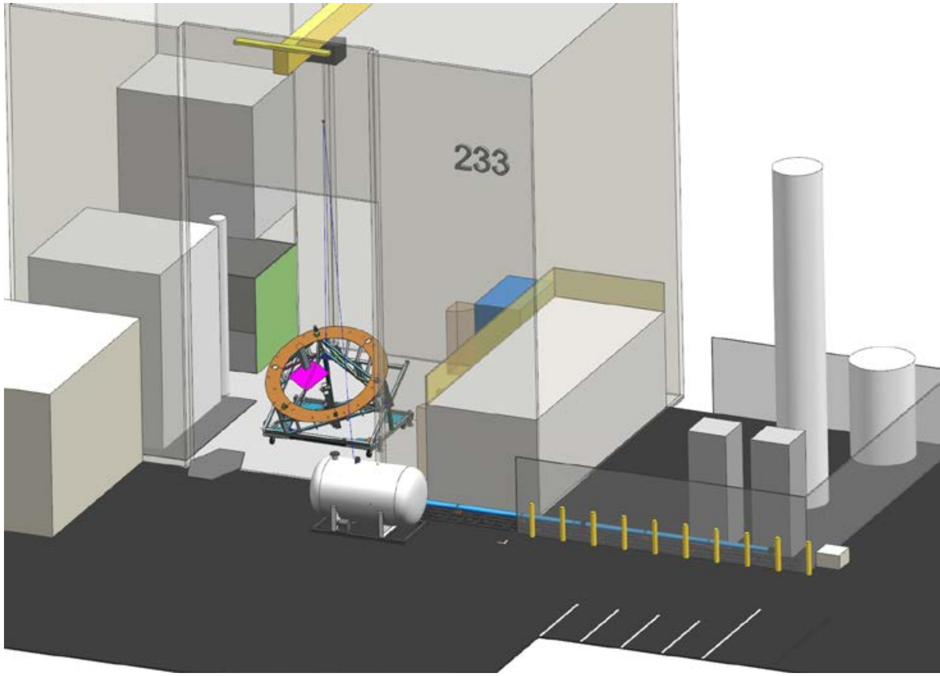




Rated as Satisfactory

Conclusions and Future Work

- A pilot ballute is shown to be an effective deployment solution
- A "stand and deliver" deployment eases pressure on the ballute drag
- The large SIAD-E diameter makes it difficult to achieve the necessary difference in ballistic coefficient between the vehicle and the ballute
  - *Lowering the target Mach number to 1.5 enhances the difference in the forebody and ballute drag coefficients*
- The Rigging Test Bed (shown right) will enable correlation and validation of the simulation
  - *Preliminary tests are under way . .*



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Michael.T.Contreras@jpl.nasa.gov
(818)354-4283

Thank you