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Passive vs. Parachute System Trade Applied to the Multi-Mission Earth Entry Vehicle Concept

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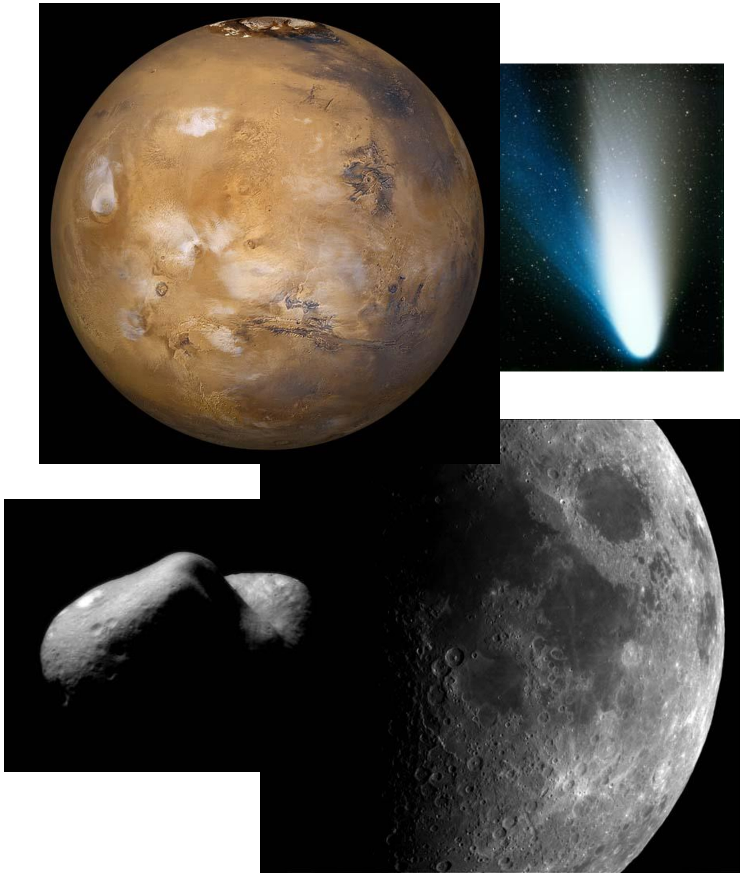
Why MMEEV?

- **The Multi-Mission Earth Entry Vehicle concept was first introduced at the 6th International Planetary Probe workshop in 2008[1-4].**
  - Began as an internal LaRC development in 2006 as a follow-up to the work done in support of the Mars Technology Program.
  - Between 2008-2013, development was directed by NASA's In-Space Propulsion Technology Development Program.
  - Beginning in FY13, NASA has provided focused B&P resources to the development of MMEEV hardware designs, particularly in support of risk mitigation activities, understanding fabrication / manufacturing challenges and limitations, performance verification testing and vehicle integration.
  - This concept has already been applied in various mission studies and mission proposals.
- **The highly reliable MSR EEV concept provides a logical foundation by which any sample return mission can build upon in optimizing an EEV design which meets their specific needs.**
  - By preserving key design elements, the MMEEV concept provides a platform by which key technologies can be identified, designed, developed and flight proven prior to implementation on MSR.
  - By utilizing a common design concept, any sample return mission, particularly MSR, will benefit from significant risk and development cost reductions.
- **The MMEEV provides a flexible platform by which technology development and flight test experience can be applied (either as cross-feeding or feed-forward) to other sample return missions, reducing both risk and cost.**

MMEEV Design Trade Space

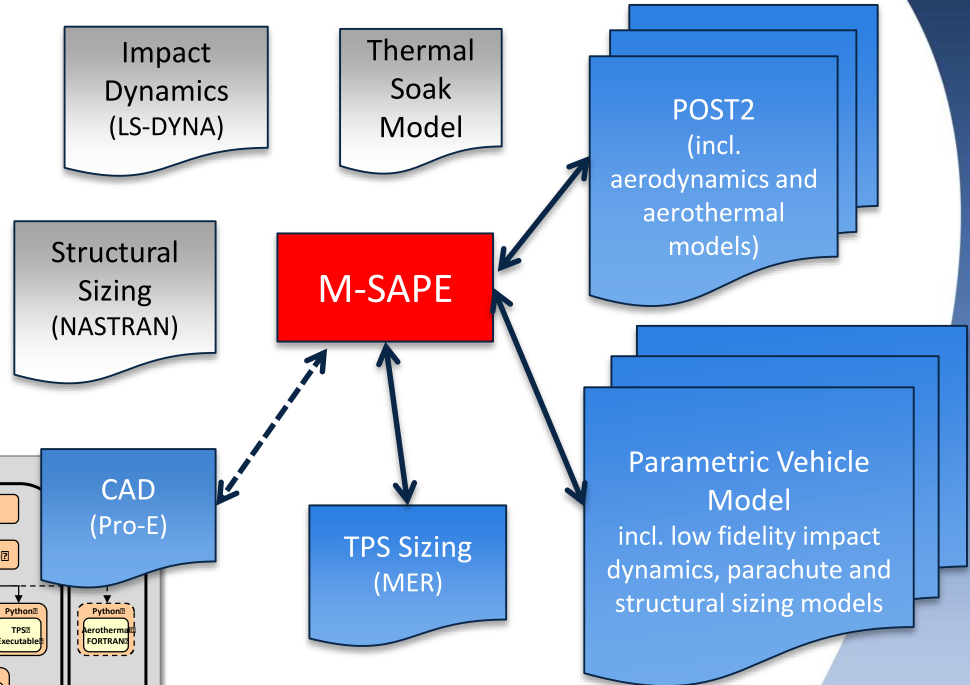


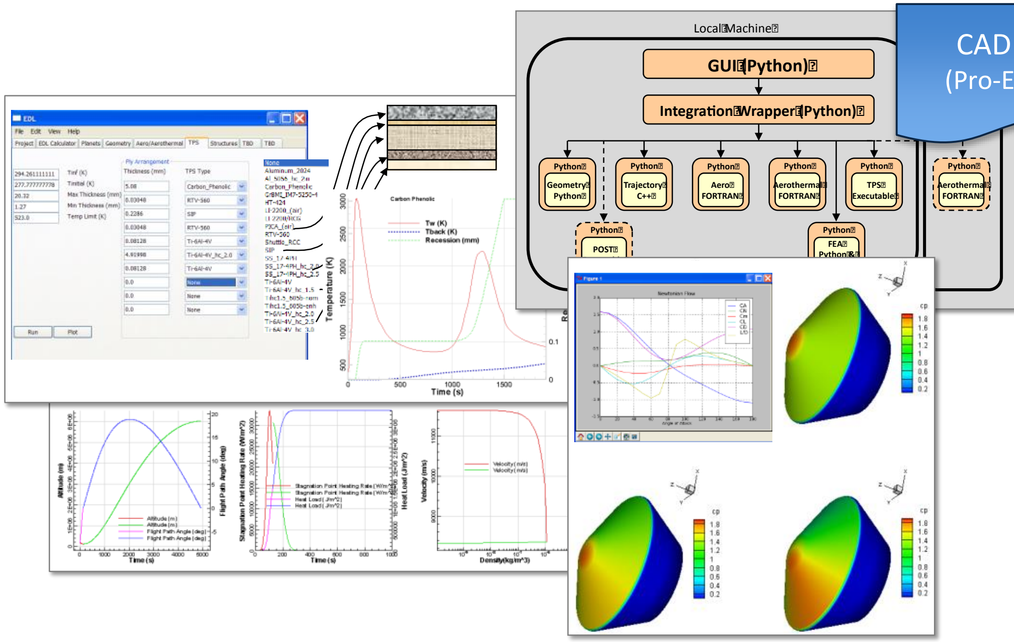
- **MMEEV design requirements can vary greatly across sample return missions.**
  - Payload accommodations :
    - consider payload masses between 5 and 30 kg
    - spherical volume of user specified size or density
    - vary vehicle diameter from 0.5 to 2.0 m
  - Entry conditions (inertial) :
    - entry velocities between 8 and 16 km/s
    - entry flight path angles between -5º and -25º
- **MMEEV performance is characterized across the trade space in several areas of likely interest to sample return missions.**
  - Vehicle (entry) mass and configuration
  - Aerodynamics and Aeroheating
  - Structural loading
  - Impact dynamics
  - Thermal soak

Since each individual sample return mission may have a unique set of performance metrics of highest interest, the goal is to provide a qualitative performance comparison across the specified trade space. From this, each mission can select the most desirable design point from which to begin a more optimized design.

M-SAPE Trade Space Analysis Environment

- M-SAPE (MMEEV – System Analysis for Planetary Entry)[5] is based on a prototype EDL system analysis tool which has been developed for missions to celestial bodies with atmosphere.
- Python, a platform independent language, is used for tool integration as well as Graphical User Interface.





- Individual MMEEV system / sub-system models are integrated with M-SAPE.
- M-SAPE is then be used as the centralized data flow manager and project requirements interface to MMEEV concept studies.

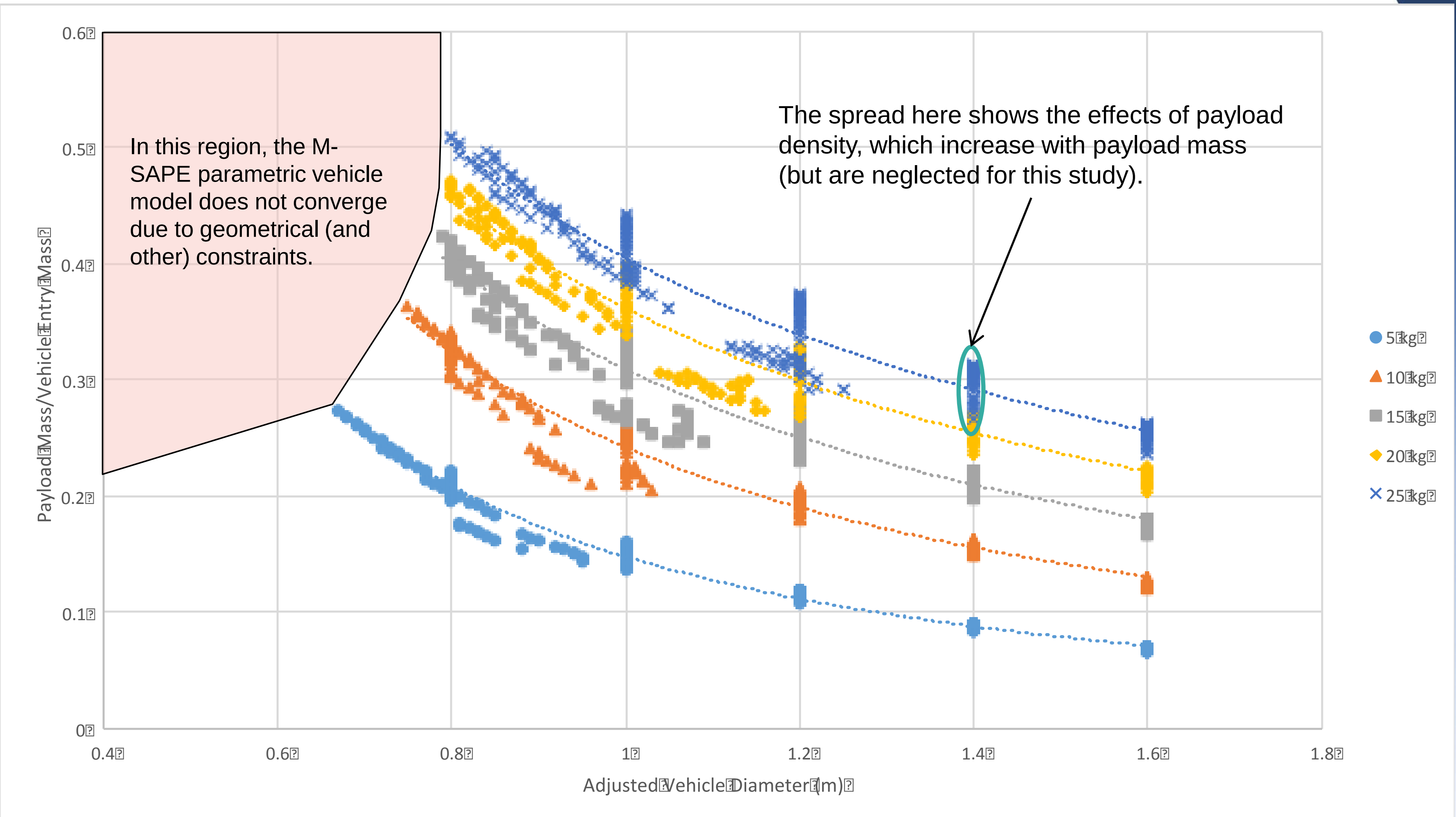
Passive vs. Parachute Trade Study Objective and Background

- **The objective of this trade study is to determine under what circumstances would a passive EEV be more *beneficial* to one which utilizes a parachute system.**
  - For the purposes of this study, the metric assumed of highest merit is the payload mass efficiency (ratio of payload mass to overall EEV entry mass).
  - This provides an illustration of the "bang for the buck" provided and is also indicative of the magnitude of the possible science return.
- **The analysis utilizes the parametric EEV model developed under the Multi-Mission Earth Entry Vehicle activity and implemented in the M-SAPE environment.**
- **The core work was completed by Allen Henning in support of the Langley Aerospace Research Summer Scholars (LARSS) program.**

Passive Vehicle Model Dimensional Analysis

- **The M-SAPE tool was first used to generate a data set which covers the desired vehicle trade space.**
  - Impact G Limit: 500 g's to 1500 g's
  - Payload Mass (m_{pay}): 5 kg to 25 kg
  - Payload Density: 2000 kg/m^3 to 6000 kg/m^3
  - Vehicle Diameter (D_v): 0.6 m to 1.6 m
  - All cases assumed:
    - 12 km/s entry velocity @ -8º EFPA
    - "non-MSR" vehicle option
    - PICA forebody TPS option
    - $R_{nose}/R_{vehicle}$ = 0.782
    - $R_{shoulder}/R_{vehicle}$ = 0.05
    - 30% mass margin

Passive Vehicle Model Dimensional Analysis
(continued)



Passive Vehicle Model Dimensional Analysis (continued)

- **A dimensional analysis of the M-SAPE results was then completed in order to determine the relationship between the vehicle entry mass and these input parameters.**

  $m_{entry} = A\, D_v^2 + B\, D_v$, where

  $A = C\, m_{pay}^2 + D\, m_{pay} + E$, $B = F\, m_{pay}^2 + G\, m_{pay} + H$, and

  C, D, E, F, G and H are functions of the impact G limit (e.g. $C = a\, G^b$)

- **Similar relationships were identified to estimate the mass of the impact system across this same data set.**

  $m_{is} = A\, m_{entry}^{-B}$, where

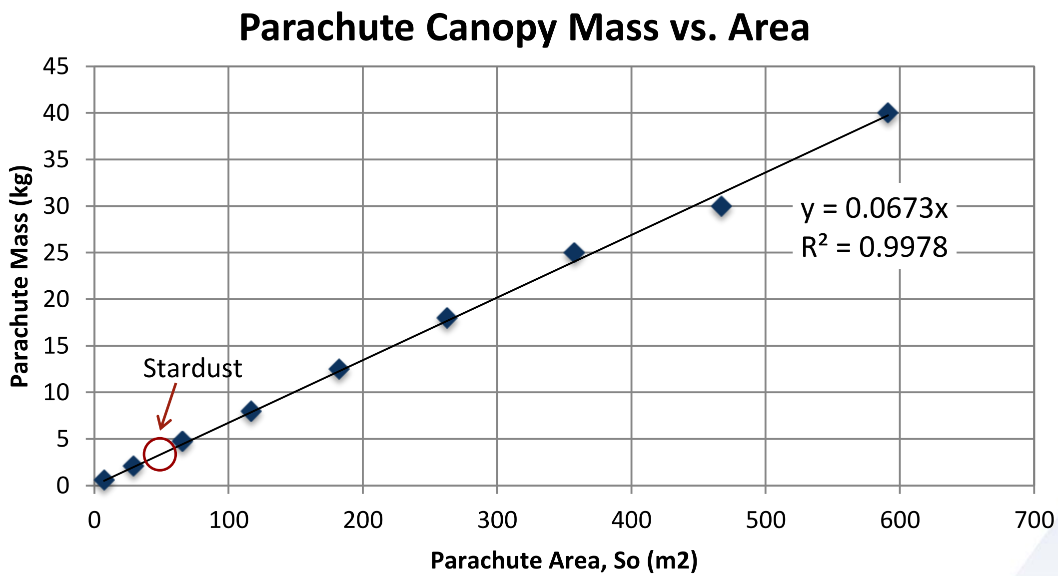
  $A = C\, e^{(D*mpay)}$, $B = E\, m_{pay}\, F$, and

  C, D, E, F, G and H are functions of the impact G limit

- **This impact system mass is replaced by a parachute system mass when assessing low velocity landing options.**

Parachute Model

- A simplified parachute sizing model was developed in order to assess low velocity (1 to 20 m/s) landing cases.
- This model was developed based on data provided by Knacke[6] for nylon recovery parachutes (Type I).
- The main parachute (canopy) mass can then be estimated as a function of the parachute reference area.



Parachute Model (cont.)

- **A parachute C_d of 0.85 was selected as being representative of (and average across) likely parachute geometries[7].**
- **The parachute is sized for terminal velocity ONLY.**
  - It is assumed that the parachute and vehicle reach terminal velocity well before landing, thus, terminal velocity equals landing velocity.
  - Sizing for opening loads is NOT considered in this analysis. Instead, an estimate of the mass of a drogue parachute (used for transonic stability as well as a pilot for the main parachute) and it's deployment system (mortar) is used[8].

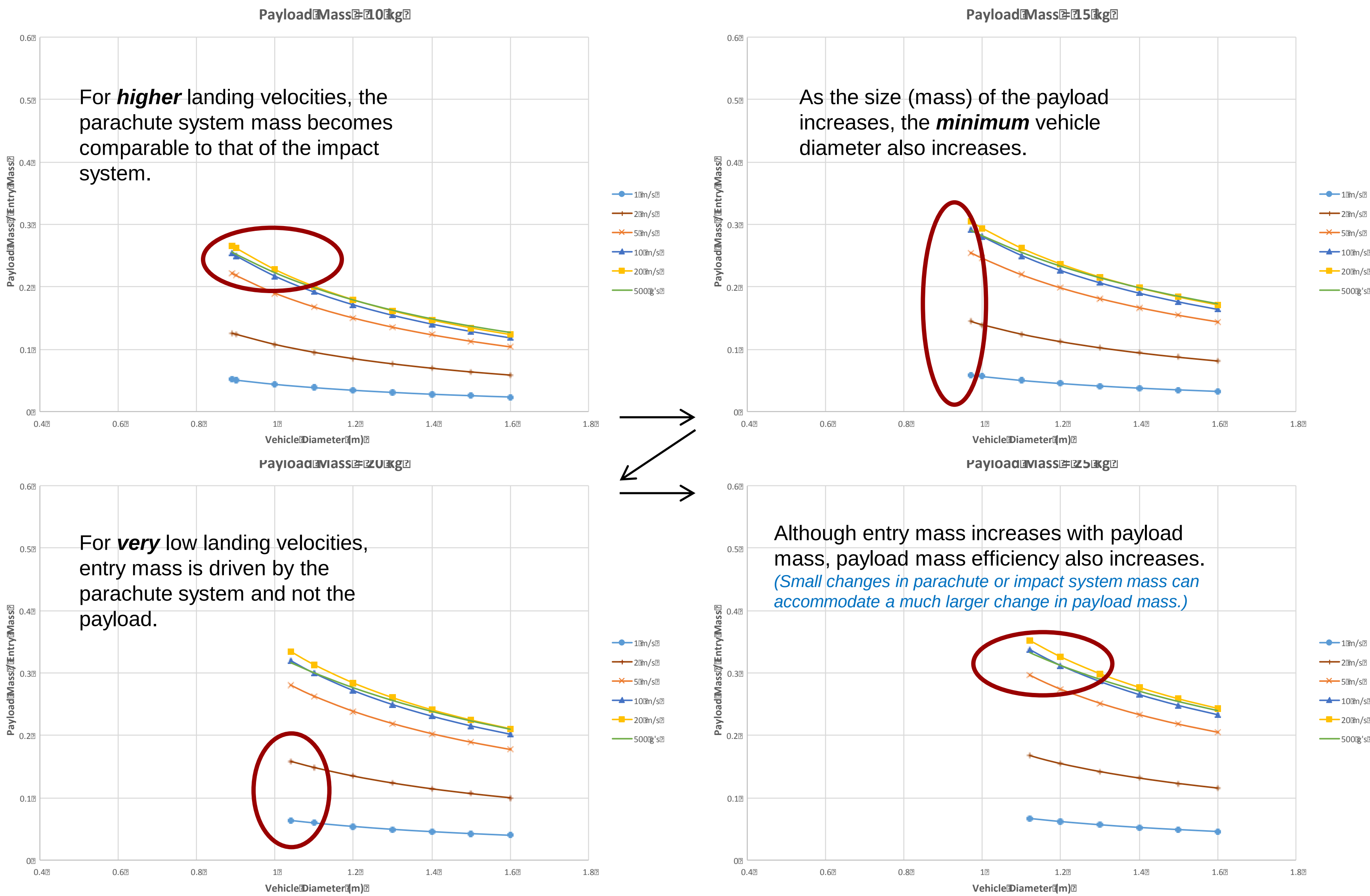
$$m_{drogue} = 0.25\, m_{chute},\ m_{mortar} = 2.677\, m_{drogue}^{0.39} + 2.1$$

- **The total entry mass is then determined by removing the impact system mass from the entry vehicle mass for the specified impact load case and replacing it with the new parachute system mass.**

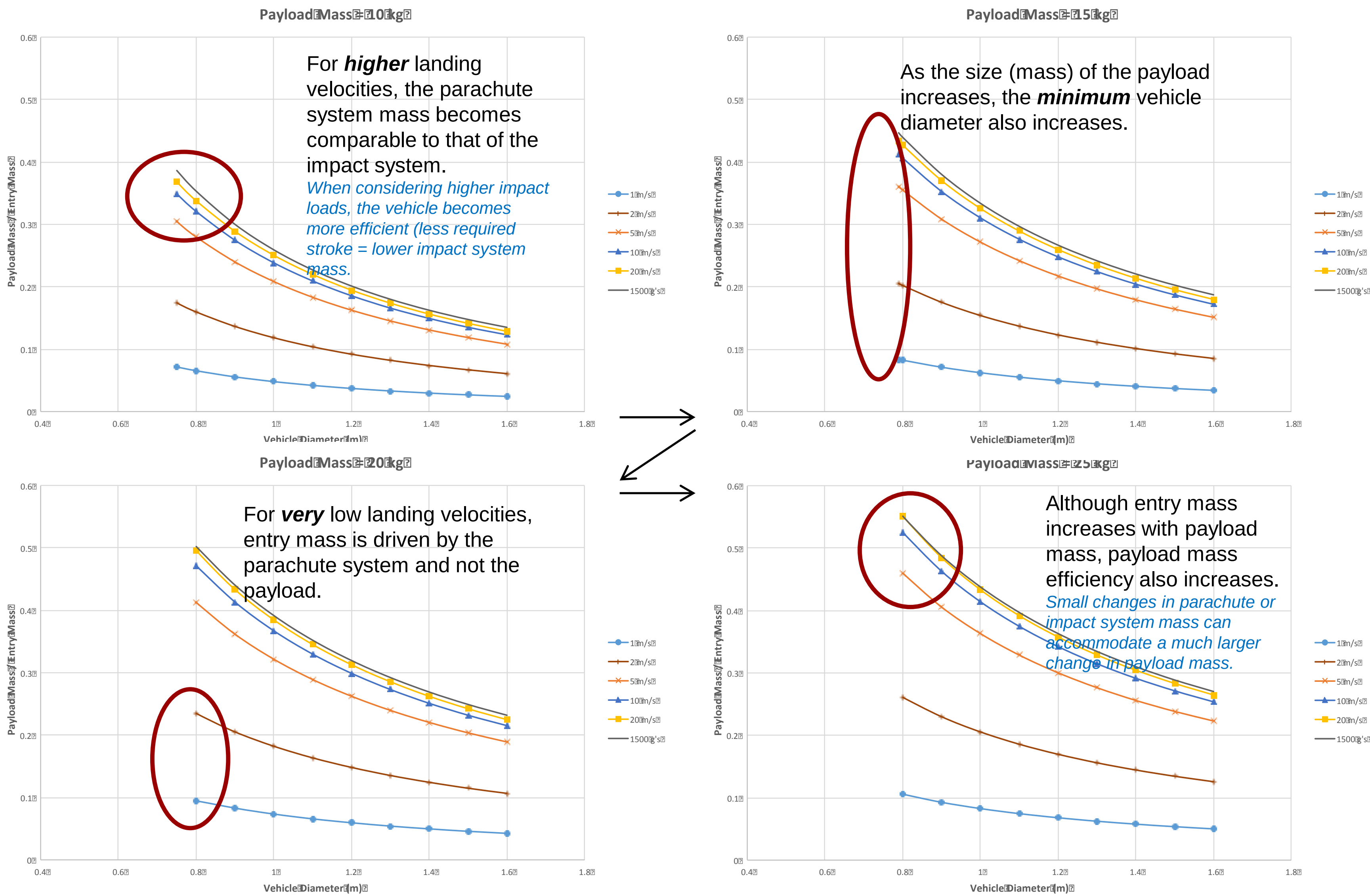
$$(m_{entry})_{chute} = (m_{entry} - m_{is})_{passive} + (m_{chute} + m_{drogue} + m_{mortar})$$

  - *Note that as the vehicle landing velocity increases, the landing load begins to become non-insignificant. Since the passive impact system mass has been removed in this case, any additional impact attenuation mass MUST be considered part of the payload mass (reducing the "usable" payload mass).*

Passive (500 g's) vs. Parachute Summary



Passive (1500 g's) vs. Parachute Summary



Case Study

- As a case study, consider a scenario where the where an MMEEV vehicle diameter is restricted to D_v = 1.2 m and the desired payload mass is provided as m_{pay} = 25 kg.

	Passive	Parachute	Stardust (D_v = 0.8 m, m_{pay} = 13 kg*)
Landing Conditions	1500 g's	3 m/s	4.6 m/s
Payload Mass Efficiency	0.36	0.29	0.28*
Entry Mass	68.7 kg	87.1 kg	45.8 kg
Impact or Parachute System Mass	2.5 kg	20.9 kg	4.2 kg
Entry Ballistic Coefficient	β	1.26 β	1.5 β

** Estimated based on SRC total mechanism mass (17.2 kg).*

- This means that the ***"cost"*** of a low velocity landing is an increase in entry mass / ballistic coefficient of more than 25%, which can lead to a significant increase in the aero-thermal environments.
- ***IF*** there was a desire to maintain both the entry:
  - vehicle diameter and ballistic coefficient, then the payload mass would need to be reduced by ~ 25%
  - ballistic coefficient and the payload mass, the vehicle diameter must grow to at least 1.35 m, resulting in a decrease of the payload mass efficiency to ~0.25

Conclusions

- **For any sample return mission, the ultimate determination of the payload landing requirement will be driven by science considerations (e.g. sample preservation).**
- **In some cases, particularly for landing velocities ≥ 10 m/s, there is little difference in the payload mass efficiency between a passive and parachuted vehicle.**
  - As landing velocity increases, parachute mass decreases and eventually becomes comparable to the impact system mass.
- **However, as the payload landing load requirement is allowed to increase, a passive EEV becomes more payload mass efficient than a vehicle which utilizes a parachute.**
- **The trade study described here does not include a multitude of additional considerations which also must be well understood before deciding between a passive or parachuted vehicle.**
  - overall system risk, reliability, complexity, cost, etc.
  - packaging and payload access considerations

Next Steps

- **Look closer at the effect of payload density.**
- **Extend data set to 30 kg payloads and 2000 g impacts.**
- **Consider the impacts on other design elements:**
  - structural re-sizing / load implications
  - volume / packaging / configuration
  - landing ellipse
  - thermal soak
  - landing site (ground conditions)
- **In what is likely to be a significant driver in choosing between a fully passive vehicle and one with a parachute system, summarize the trade space in terms of cost, system complexity, risk and reliability.**

References

[1] Maddock R. W. et al. (2008) Multi-Mission Earth Entry Vehicle Design Trade Space and Concept Development Strategy, IPPW6 (presentation).

[2] Maddock R. W. et al. (2010) Multi-Mission Earth Entry Vehicle Design Trade Space and Concept Development Status, IPPW7 (presentation).

[3] Maddock R. W. et al. (2010) An Application of the Multi-Mission Earth Entry Vehicle : Galahad – An Asteroid Sample Return Mission, IPPW7 (poster session).

[4] Maddock R. W. et al. (2011) Multi-Mission Earth Entry Vehicle Design Trade Space and Concept Development Status Version 2.0, IPPW8 (poster session).

[5] Samareh J. A. et al. (2014), Multi-Mission System Analysis for Planetary Entry (M-SAPE) Version 1, NASA/TM-2014-218507

[6] T W Knacke, Parachute Recovery Systems Design Manual, pg. 6-95, Table 6-2

[7] T W Knacke, Parachute Recovery Systems Design Manual, pg. 5-3, Table 5-1

[8] mortar/drouge sizing reference (slide 10)?