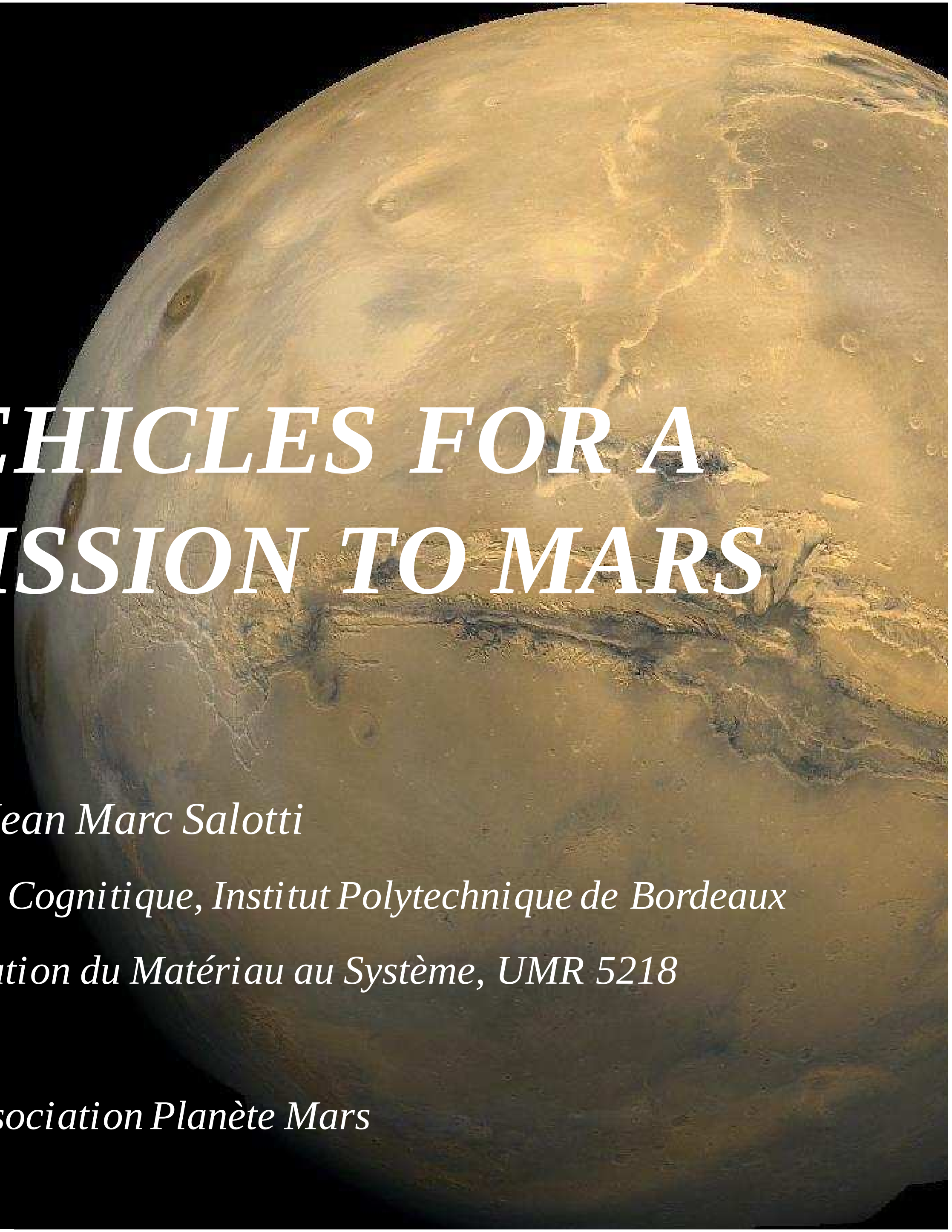

# SMALL VEHICLES FOR A ROBUST MISSION TO MARS

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# *Outline*

Introduction

1. Lessons from NASA DRA 5.0
2. EDL recommendation
3. LEO assembly recommendation
4. Possible scenarios
5. 2-4-2 scenario

Conclusion

# *Introduction*

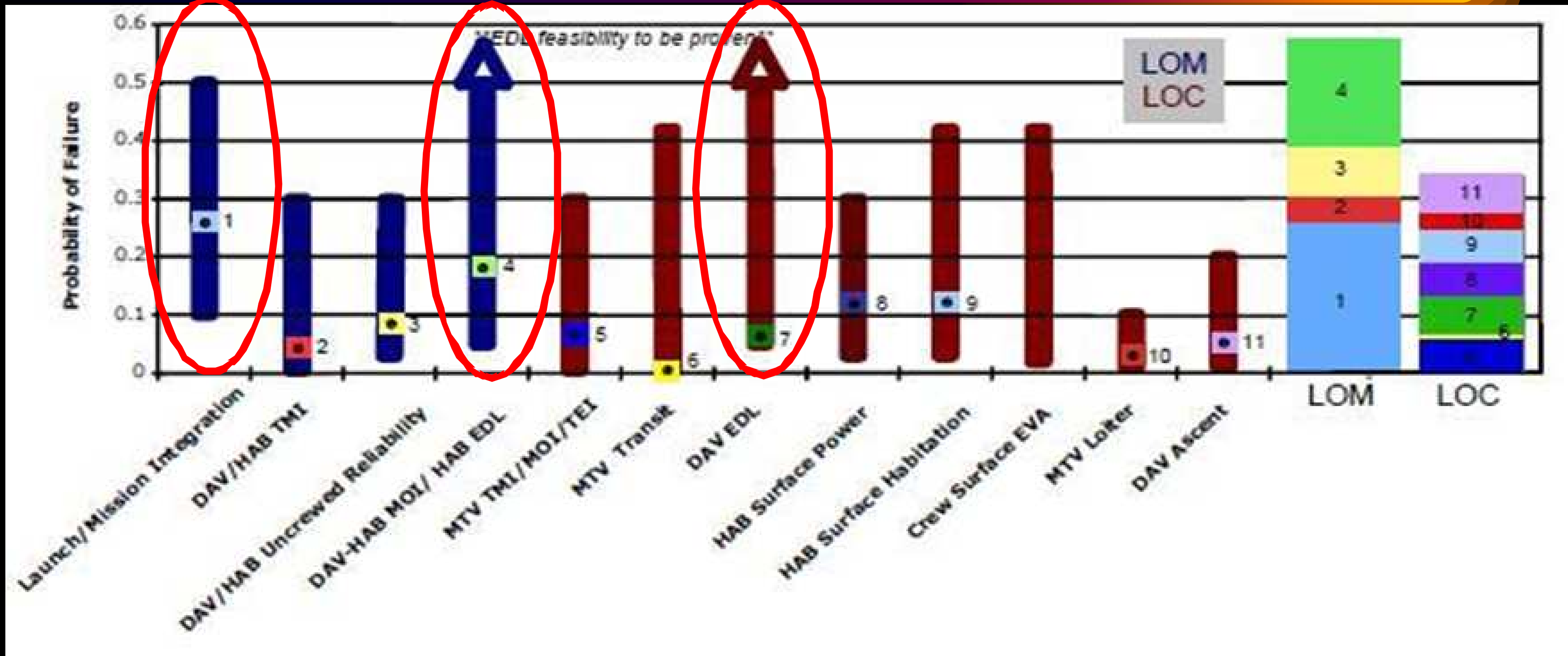
NASA DRA 5.0: Tremendous work but …

"The general story that was constantly reiterated from the individual mission risk analyses was that current design philosophies and technologies would not provide an acceptable level of reliability for a Mars mission."

- Too complex
- Too risky
- Too costly

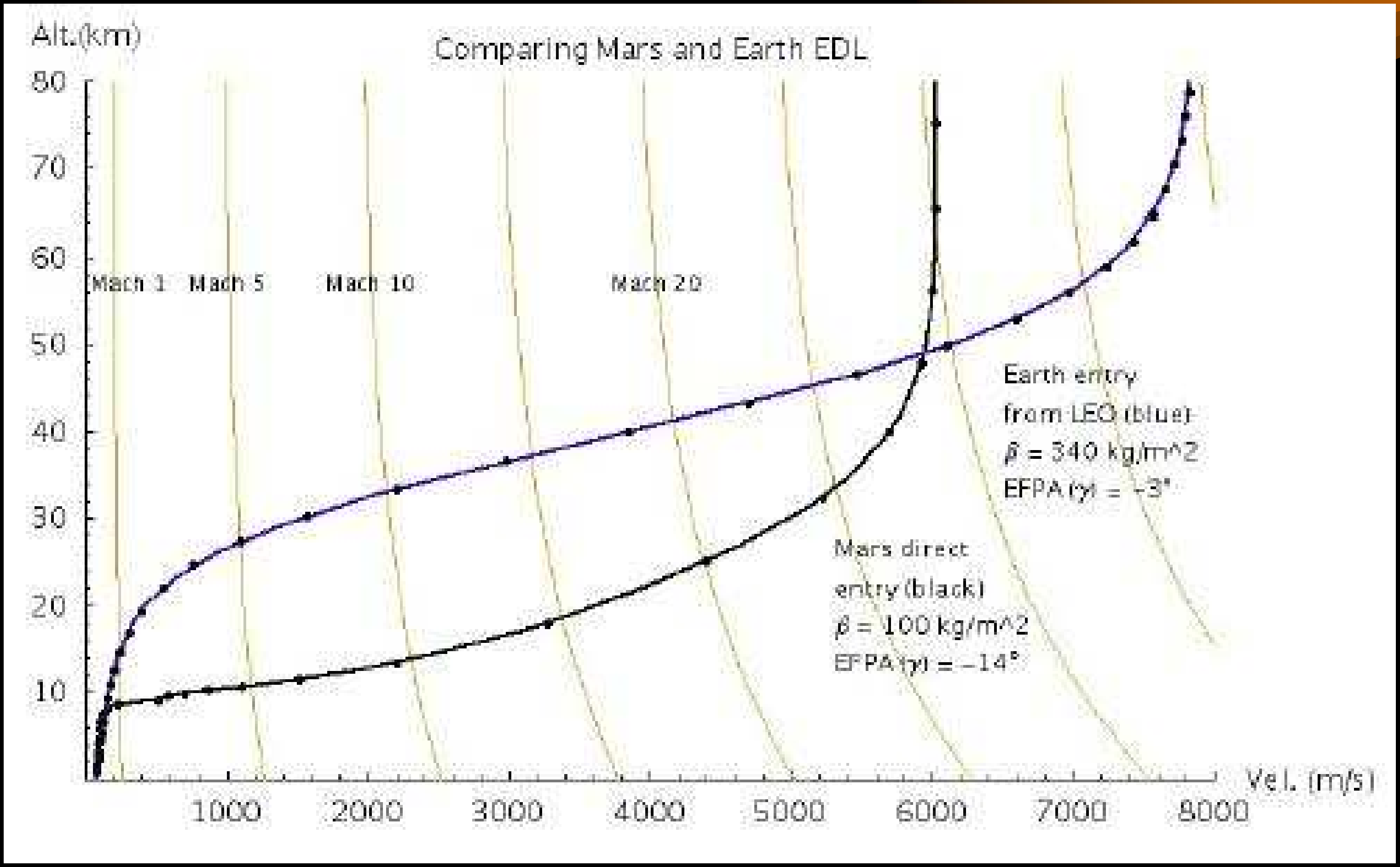
=> Find another destination?

# 1. Lessons from DRA 5.0

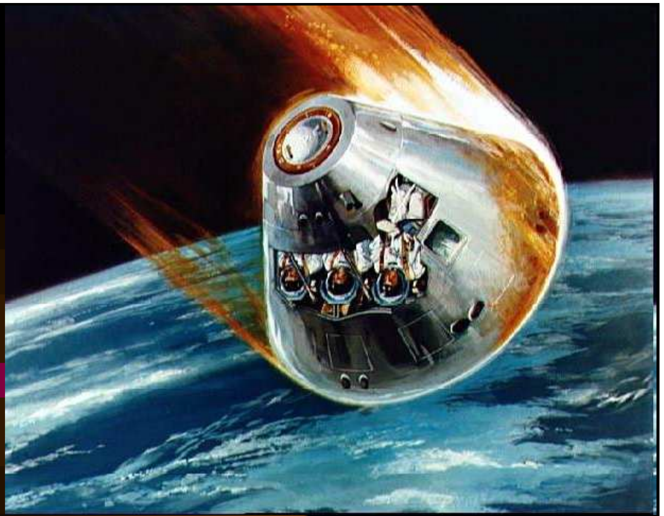



LEO assembly, long, complex, LOM risks> 25%!
"EDL feasibiity to be proven" !!!

# 2. EDL recommendation



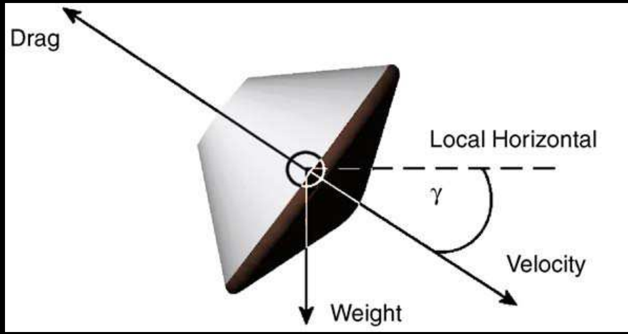
# *EDL parameters*



Ballistic coefficient:

$$\beta = \frac{M}{CS}$$

M: mass
C: drag constant
S: surface facing the flow




Problem:
What happens with bigger vehicles?
For the same shape, M increases faster than S
=> High ballistic coefficients
=> Atmospheric braking not efficient
=> Late braking, high heat peak rate, high peak deceleration value

# *Possible solutions*

Mass of entry vehicle: 70 to 110 tons!

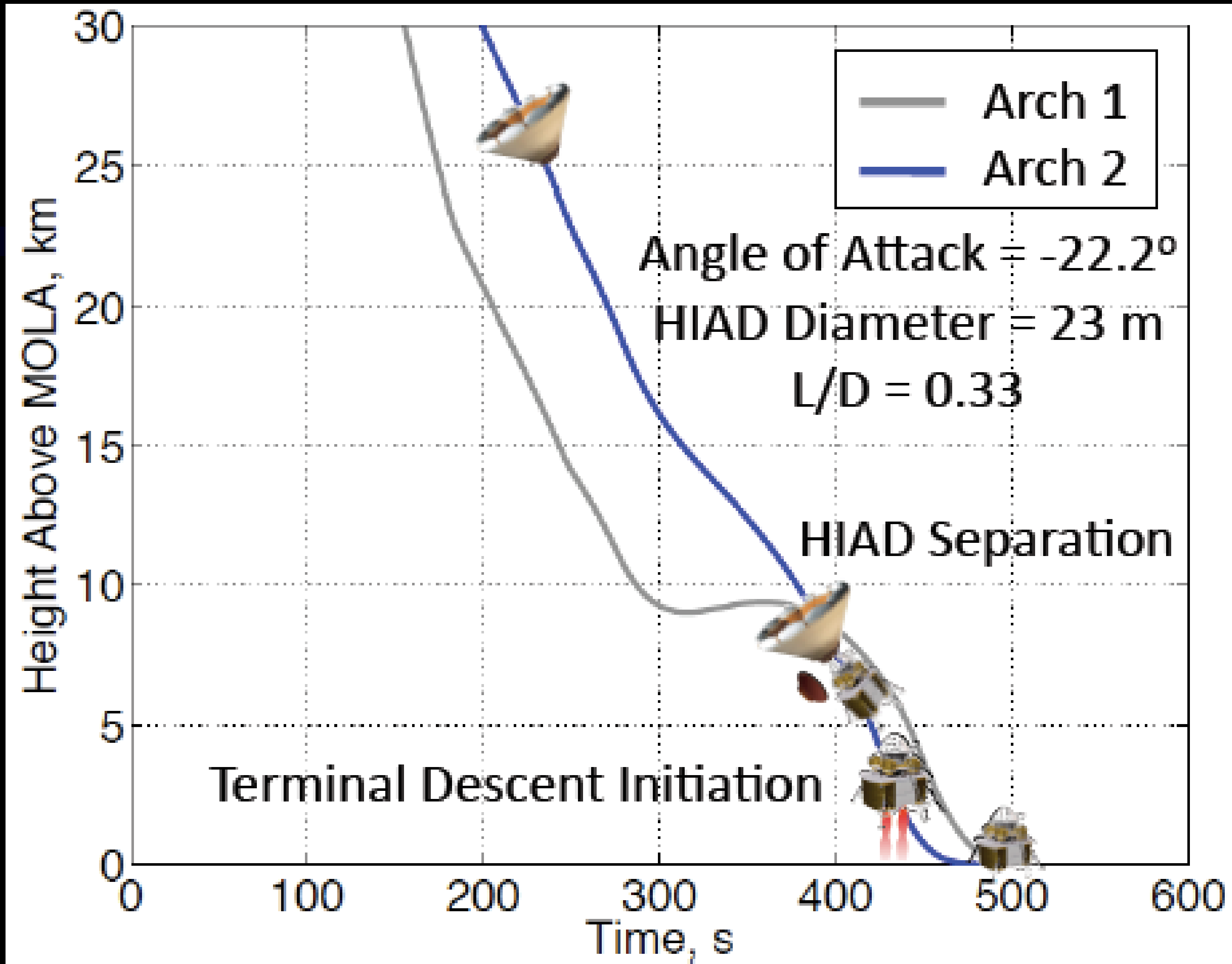
2 solutions (NASA):

a) increase lift (like planes or shuttles)

b) increase surface

or both.

hypersonic regime ≠ supersonic regime




Hypersonic Inflatable Aerodynamic Decelerators (HIAD)
(From Zang et al, AIAA 2011)

# *Best solution (NASA, 2012)*

Entry vehicle (total): 87 tons
HIAD mass: 10.6 tons
Propellant : 12 tons
Payload: 40 tons

Problems:

- Lower TRL compared to rigid aeroshells
- Critical technology (risks = loss of crew!)
- Reduced timeline margin
- Guidance?

# *Another solution exists!*

Only 2 solutions???

a) increase lift (like planes or shuttles)
b) increase surface

3rd solution!!!

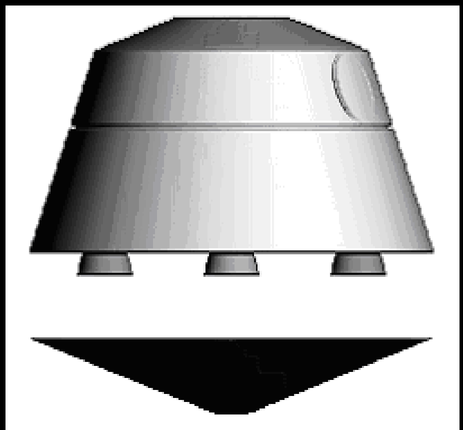
What about reducing the mass by splitting the payload in 2 parts?

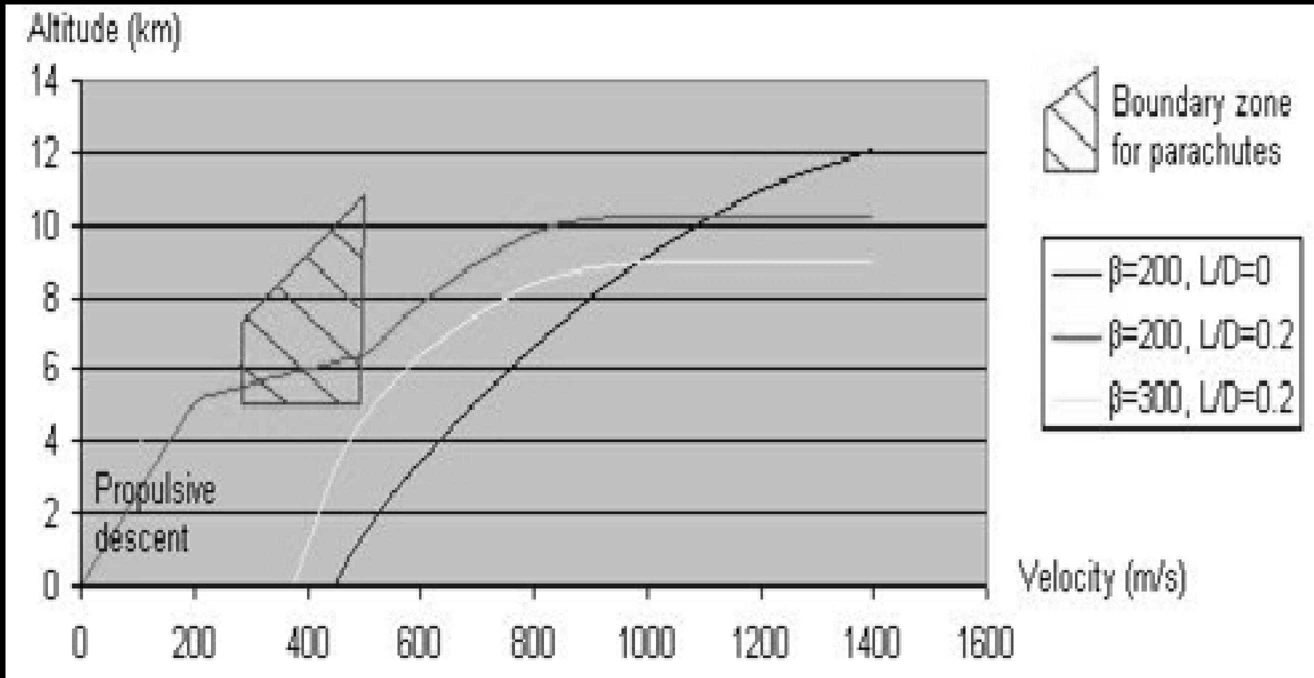
# *How small is needed?*

Objective: most simple EDL, similar to robotic landers

⇒ rigid 70° sphere cone heat shield + parachutes

⇒ low ballistic coefficient, low lift





# *EDL recommendation*

Assumed maximum diameter: 12 meters

Assumed maximum ballistic coefficient: 200 $kg/m^2$

Assumed maximum L/D: 0.2 (some lift remains for guidance)

⇒ Maximum mass = 33 tons (total at Mars entry)

(Ref. : Salotti, Acta Astronautica, 2012)

Recommendation for EDL:

Try to design vehicles < 33 tons!

# *3. LEO assembly recommendation*

It is possible to avoid LEO assembly?

$\Rightarrow$ Maximum mass for direct TMI?

Assumptions:

$\Delta V$ = 3.6 km/s from LEO to Mars

ISP = 450s for the propulsion system (chemical)

2 stages

Structural mass to propellant mass ratio = 12%

10% for fairing

# *LEO assembly recommendation*

Tsiolkovky equation

$$\Delta V = ISP \cdot g \cdot \ln\left(\frac{M_u + (1+r)M_p}{M_u + rM_p}\right)$$

Maximum 130 metric tons in LEO (NASA SLS capabilities)
=> Maximum mass for TMI: 46 tons

Recommendation to avoid LEO assembly:
Try to design interplanetary vehicles < 46 tons

# *4. Possible scenarios*

Recommendation 1: < 33 tons at Mars entry

Recommendation 2 : < 46 tons interplanetary

- Idea 1: reduce the size of the crew
- Idea 2: aerocapture for all vehicles
- Idea 3: several small vehicles and rendezvous on the surface or in Mars orbit

Feasibility?

# *Detailed analysis (Salotti 2012)*

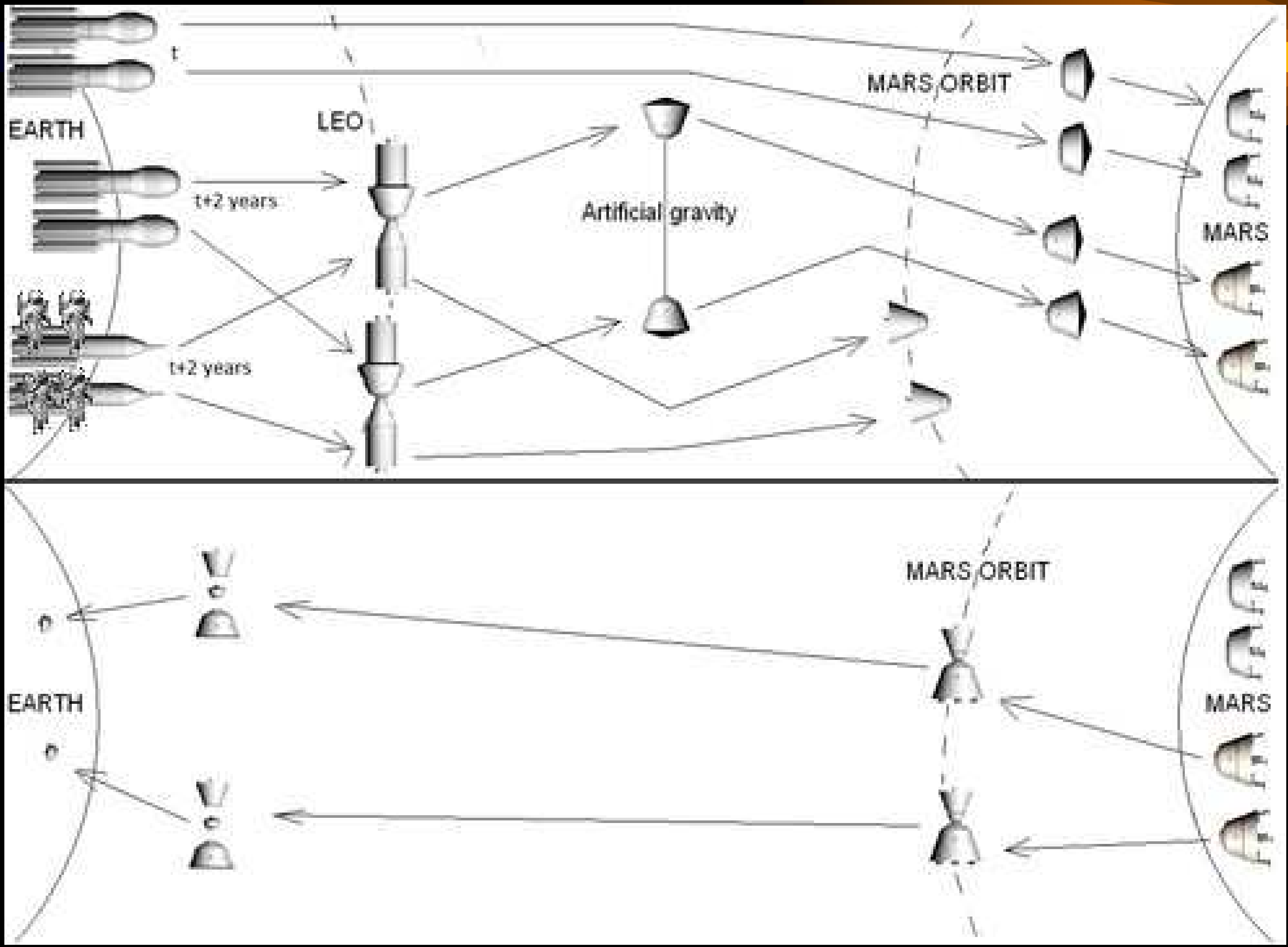
| | Subsystem | Mass estimation (kg) |
|---|---|---|
| **Habitat** | Life Support System (kg) | **3500** |
| | EVA equipment (kg) | **200** |
| | Comm/info management (kg) | **320** |
| | Power prod. 30 kWe P.V.A. (kg) | **1200** |
| | Thermal control system (kg) | **400** |
| | Structure (kg) | **2000** |
| | Consumables for Mars surface (kg) (3100 kg also in cargo) | **3100** |
| | Small rovers (x2) (kg) | **380** |
| | EVA consumables (kg) | **400** |
| | Subtotal for Mars surface (kg) | **11500** |
| | Margin 20% | **2300** |
| | Total for Mars surface (kg) | **13800** |
| **EDL systems (for sizing, see 1)** | Propulsion system, engines (kg) | **1500** |
| | Propellant, 15% of entry mass (kg) | **4200** |
| | Structure, tanks and other systems, 10% (kg) | **2800** |
| | Heat shield, 12% of entry mass (kg) | **3400** |
| | Subtotal (kg) | **11900** |
| | Margin 20% (kg) | **2380** |
| | Total EDL standard option (kg) + add. tanks and str. | **14280 + 3000** |
| **Total, rounded (kg)** | | **31000** |

1: J.A. Christian, K. Manyapu, G.W. Wells, J.M. Lafleur, A.M. Verges and R.D Braun, Sizing of an Entry, Descent, and Landing System for Human Mars Exploration, Journal of Spacecraft and Rockets, Vol. 45, No. 1, pp. 130–141, Jan-Feb, 2008

# *Small interplanetary vehicles? Yes we can!!!*

| | | Standard option | Single hab A | Single hab B |
|---|---|---|---|---|
| **ERV** | Payload | 53000 | 39000 | 45000 |
| | 1st stage | 50900 | 37500 | 43200 |
| | 2nd stage | 31800 | 23400 | 27000 |
| | Total (kg) | 136000 | 100000 | 115000 |
| **Cargo lander** | Payload | 23000 | 31000 | 24000 |
| | 1st stage | 22100 | 29800 | 23000 |
| | 2nd stage | 13800 | 18600 | 14400 |
| | Total (kg) | 59000 | 79000 | 60000 |
| **Habitat lander** | Payload | 28000 | 37000 | 39000 |
| | 1st stage | 26900 | 35500 | 37400 |
| | 2nd stage | 16800 | 22200 | 23400 |
| | Total (kg) | 72000 | 95000 | 100000 |
| **IMLEO total** | | **264 tons x2** | **274 tons x2** | **269 tons x2** |

# 5. Preferred scenario =2-4-2



# *Earth return vehicle: 41 tons*

| | | |
|---|---|---|
| **Command module** | Command module dry mass (Earth re-entry capsule) | **4200** |
| | Consumables for the return | **3100** |
| **Subtotal command module (margin not included)** | | **7300** |
| **Service module** | Propulsion system, engines and tanks (kg) | **2900** |
| | Propellant (kg) | **24000** |
| | Heat shield for aerocapture (kg) | **2000** |
| **Subtotal service module** | | **28900** |
| **Subtotal (kg)** | | **36200** |
| **Margin 20%** | | **7240** |
| **Total for TMI, rounded (kg)** | | **43400** |
| **Transfer in LEO (exchange between the astronauts and the return consumables)** | | **-3100** |
| **Launch escape system** | | **1000** |
| **Total at launch from Earth (kg)** | | **41300** |

# *Cargo vehicle: 31 tons*

| | | |
|---|---|---|
| **Payload** | Excavation systems (kg) | 3000 |
| | Water extraction systems (kg) | **1100** |
| | Sabatier reactor and electrolysis unit (kg) | **2810** |
| | Power systems (kg) | **3850** |
| | Structure and packaging (kg) | **1000** |
| | Backup consumables (kg) | **3100** |
| | Science equipment (kg) | **600** |
| | Total payload, margin included (kg) | **15460** |
| **EDL systems** | Propulsion system, 1.5 MN engines (kg) | **1500** |
| | Propellant, 15% of entry mass (kg) | **4600** |
| | Structure, tanks and other systems, 10% (kg) | **3100** |
| | Heat shield, 12% of entry mass (kg) | **3700** |
| | Subtotal (kg) | **12900** |
| | Margin 20% (kg) | **2580** |
| | Total EDL (kg) | **15480** |
| **Total at Mars entry, rounded (kg)** | | **31000** |

# *Launch escape system?*

Astronauts must be launched in a capsule, not directly in the habitat

$\Rightarrow$ Use Earth return capsule!!

# Conclusion

There are options for a simplified human mission to Mars. The main recommendation is to design the architecture of the mission with small landers (<33 tons) and small interplanetary vehicles (<46 tons).

⇒Let us investigate these options in more details

⇒ Let us work on a sustainable roadmap that will lead us to the first mission

Remark: this work is a contribution to an IAA study