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TOOL ESTIMATING THE MASS AND SIZING THE STRUCTURE OF A REUSABLE LUNAR LANDER

Presentation Semester 3 - Research Project

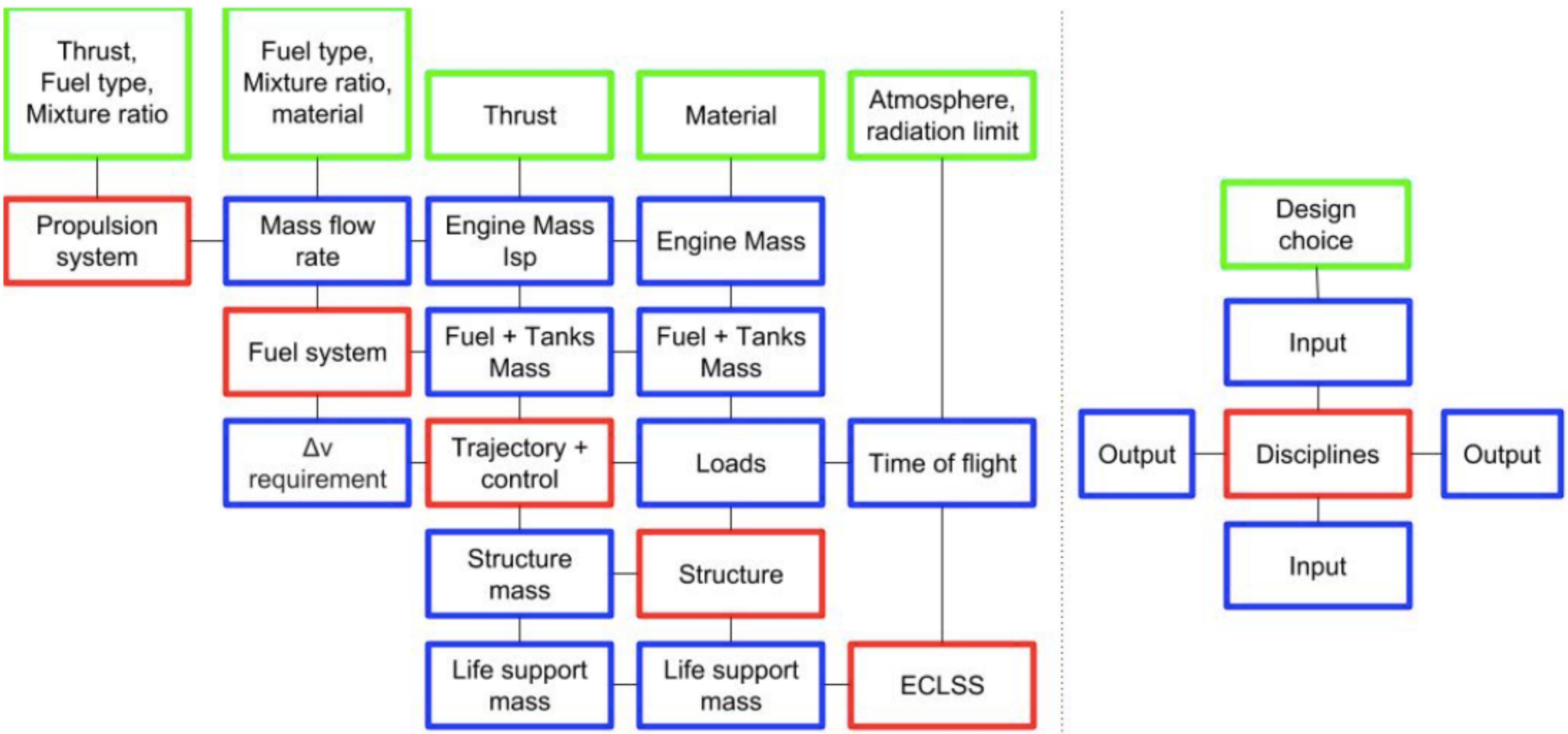
Master of Science in Aerospace Engineering

1. PROJECT'S GOAL

A NEW NEED

- Design a reusable launcher which will act as a shuttle

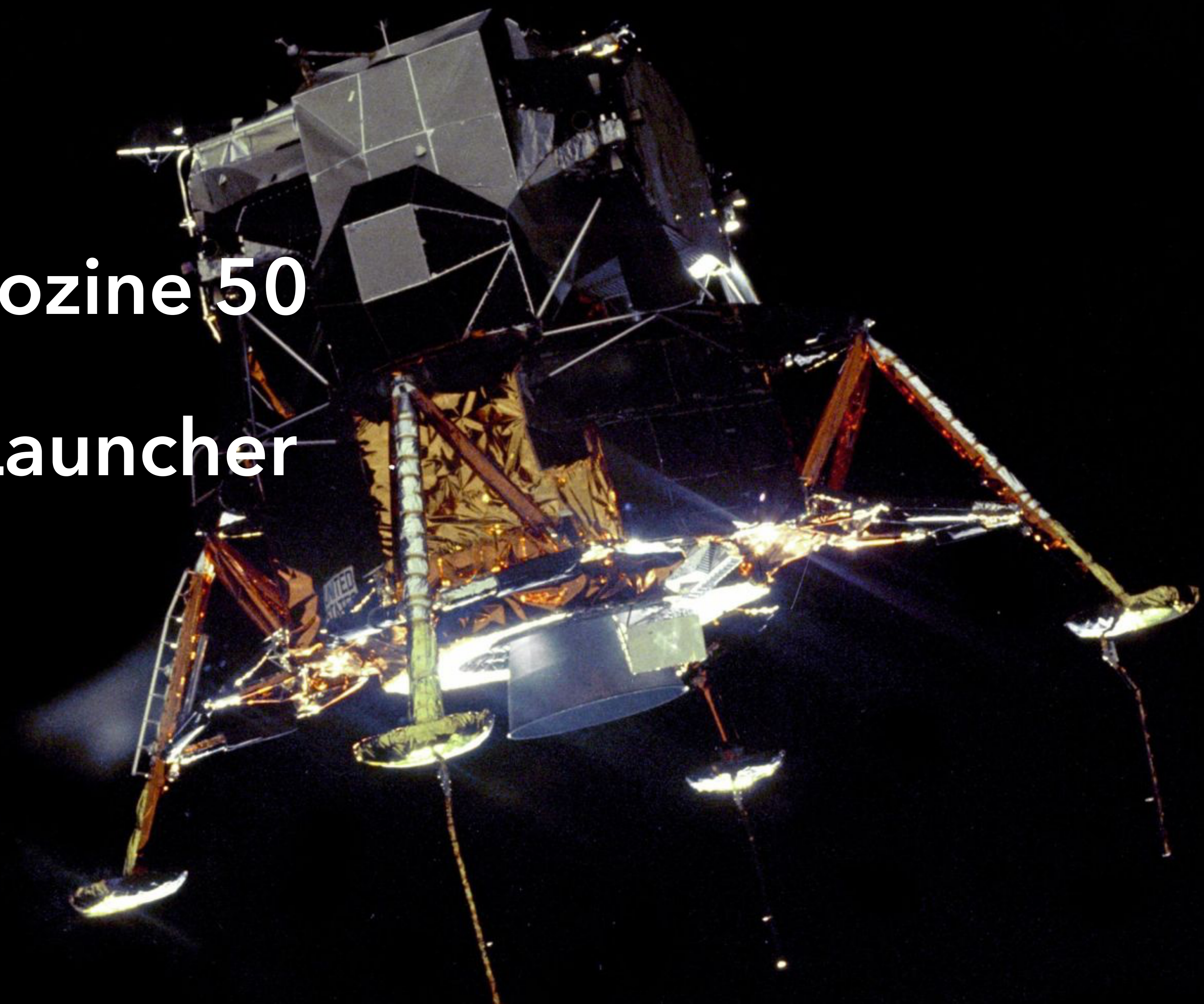
MDO STRUCTURE



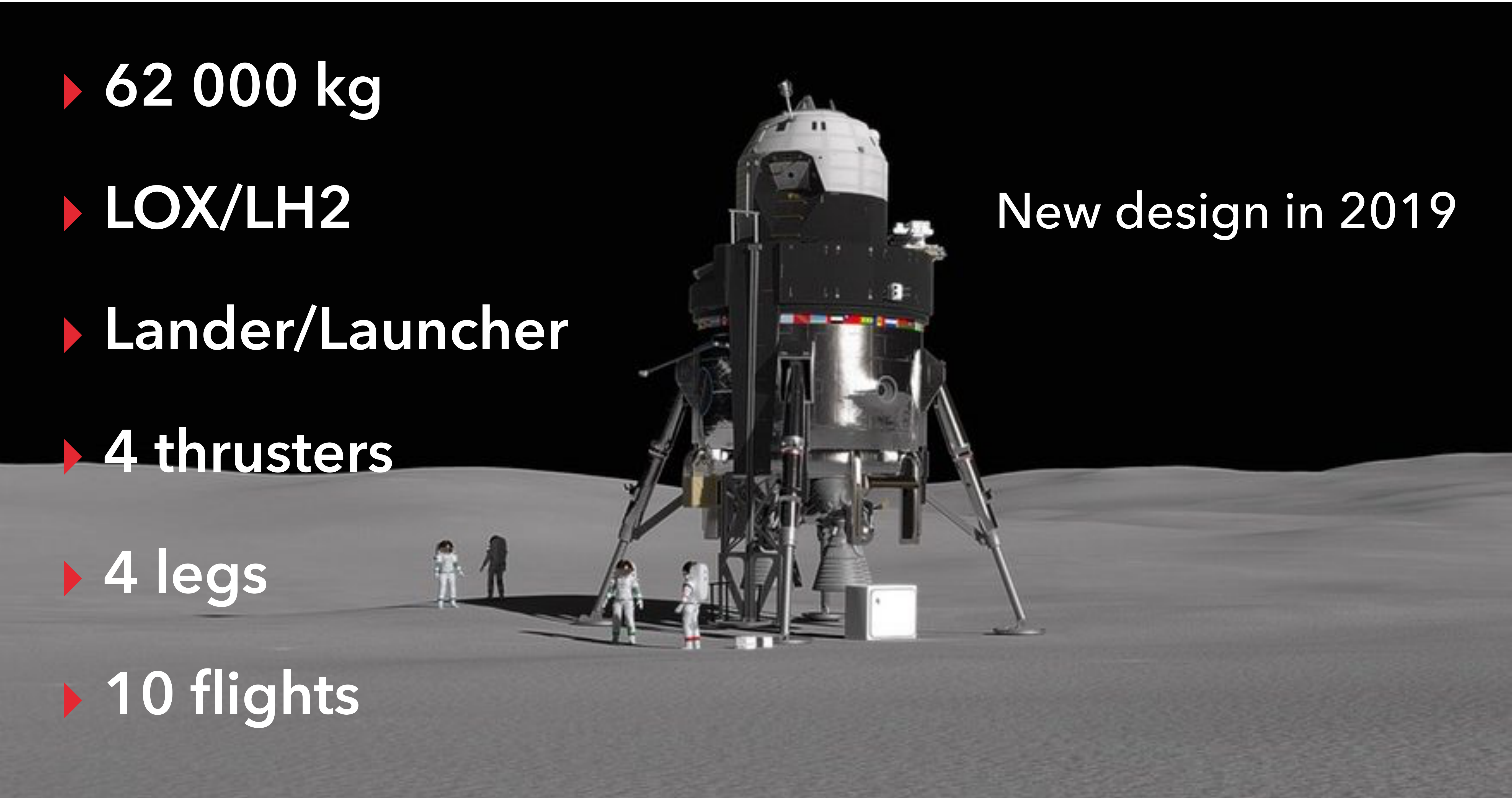
2. DESIGN

NASA – APOLLO LUNAR MODULE (1969)

- 15 200 kg
- N2O4/Aerozine 50
- Lander & Launcher
- 1 thruster
- 4 legs



LOCKHEED MARTIN (2018)

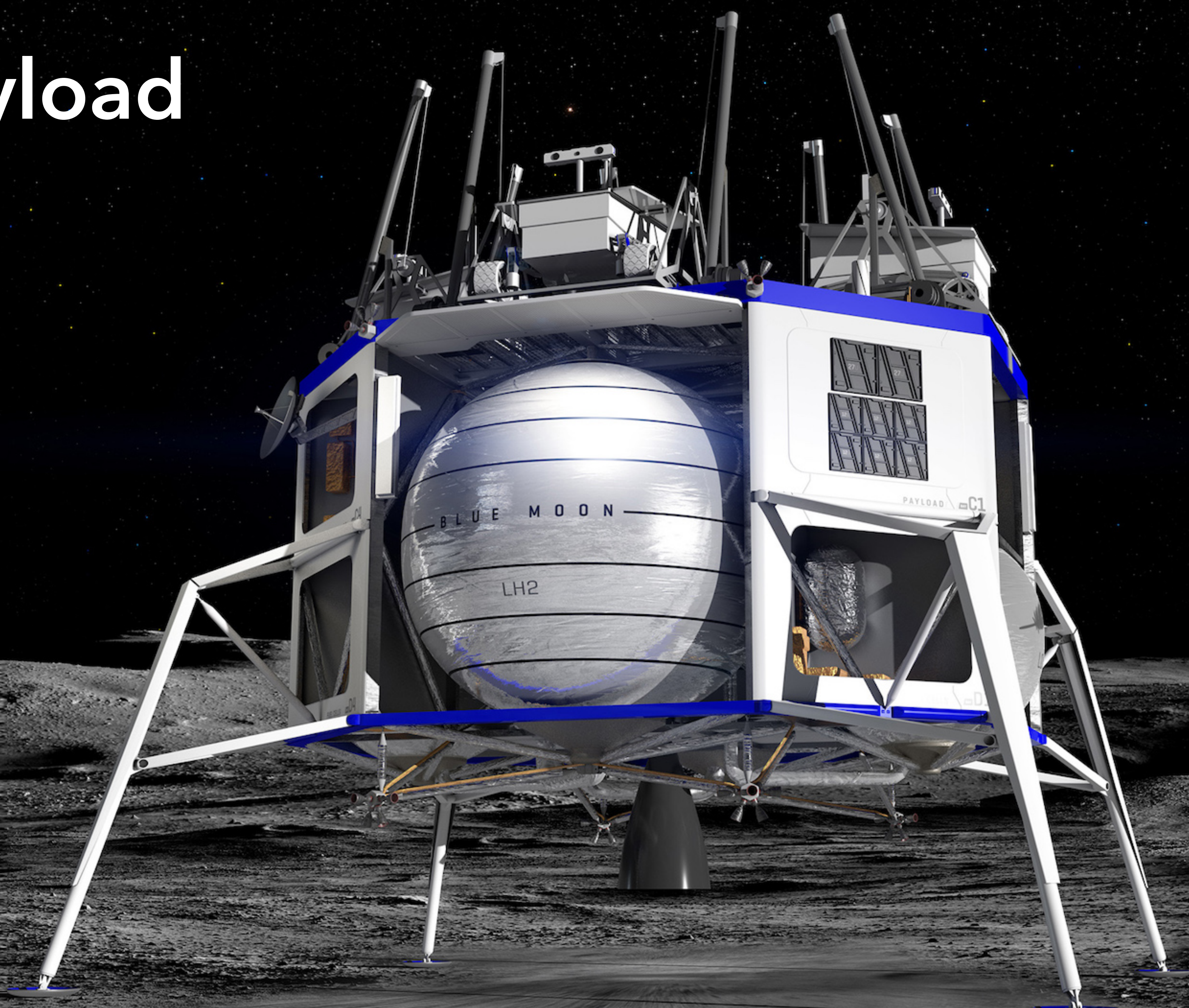


- 62 000 kg
- LOX/LH2
- Lander/Launcher
- 4 thrusters
- 4 legs
- 10 flights

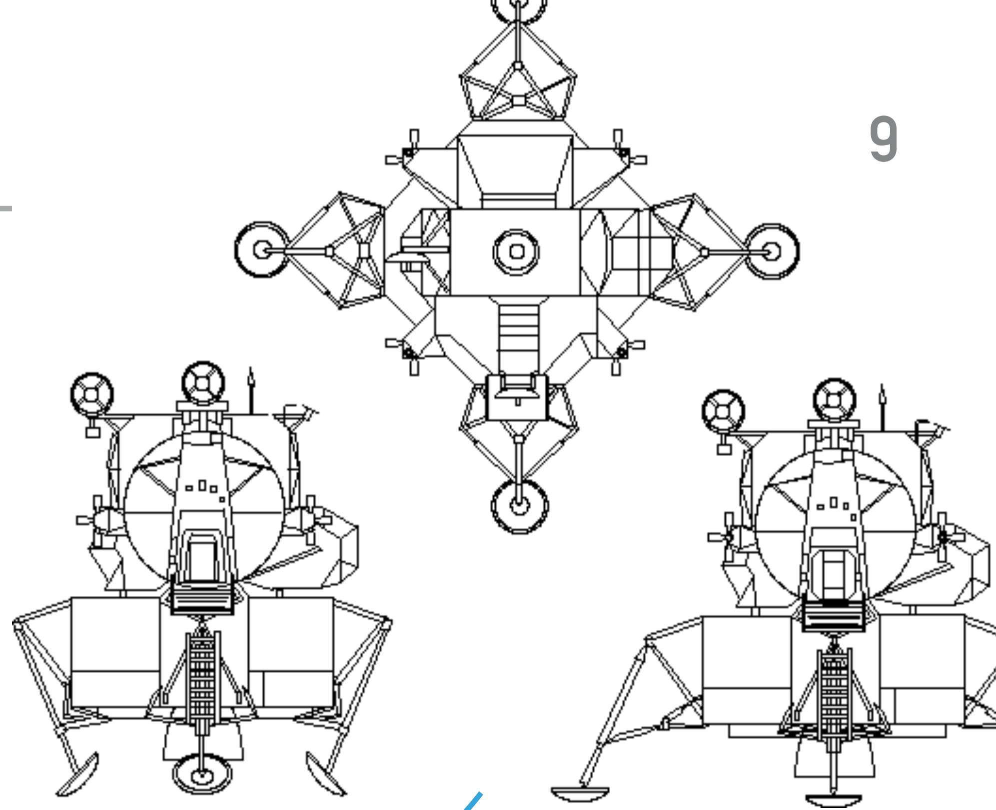
New design in 2019

BLUE ORIGIN – BLUE MOON (2019)

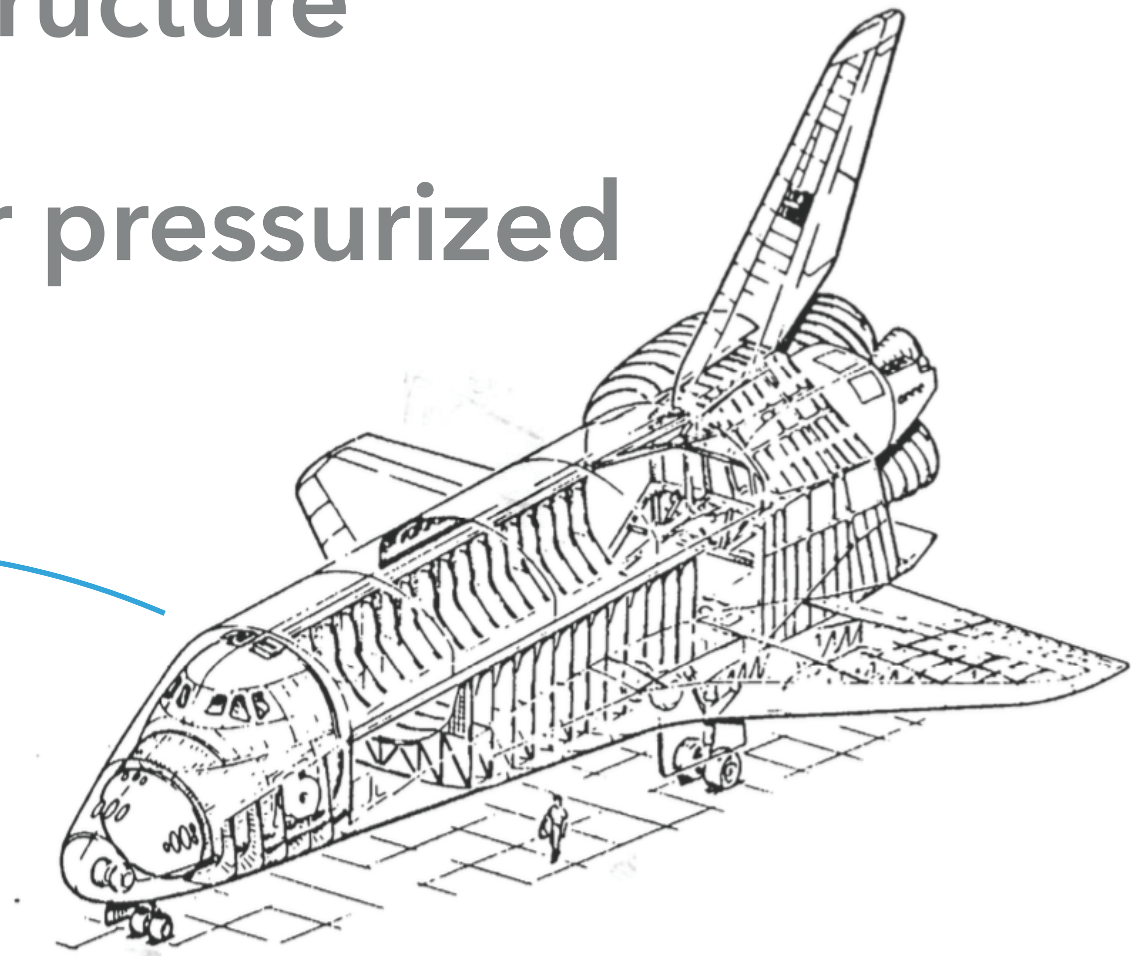
- adaptable payload
- LOX/LH2
- 1 thruster
- 4 legs



DESIGN CHOICES

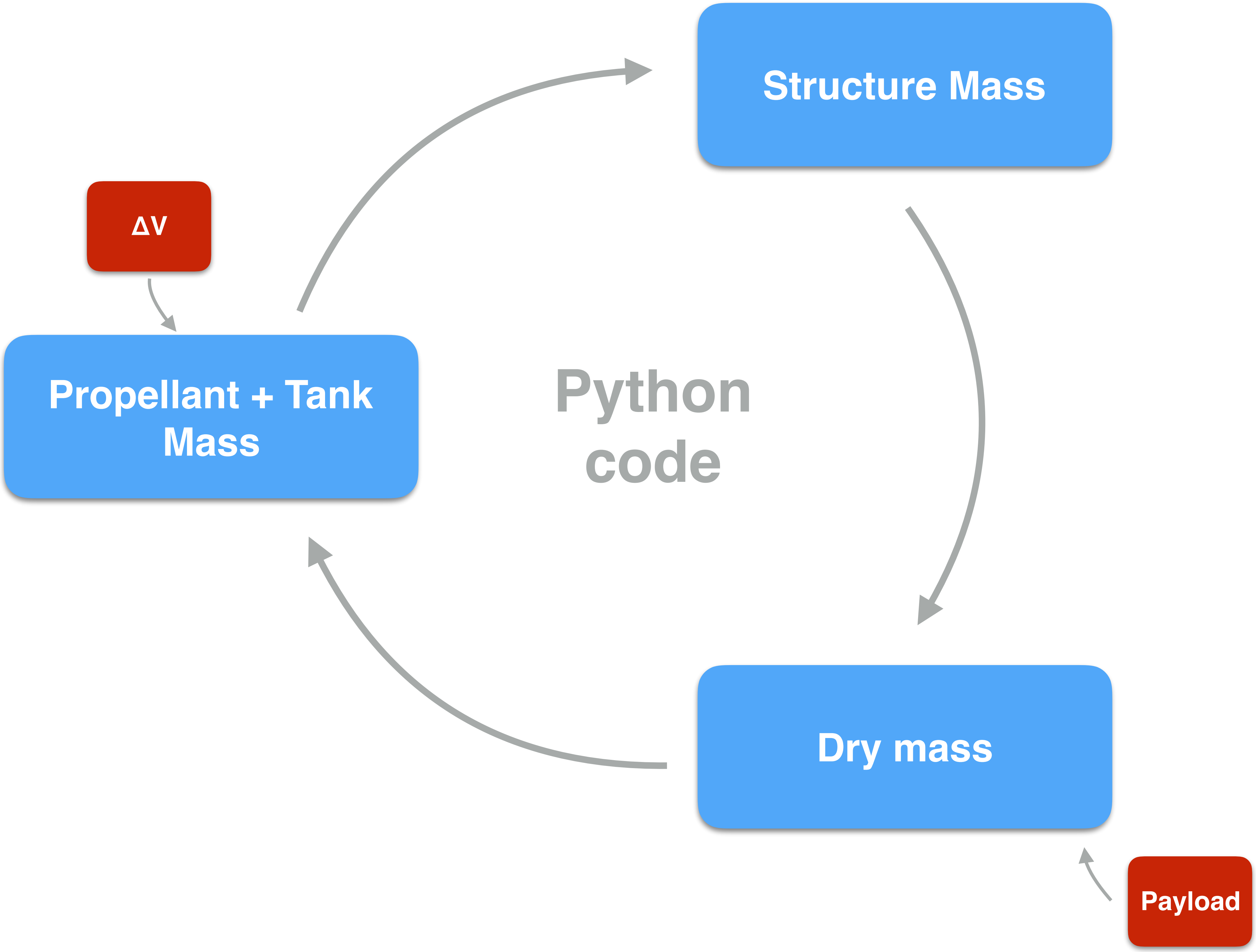


- LOX/LH2
- 4 legs with truss configuration
- Aluminium 7075-T6 for structure
- Aluminium 2019-T851 for pressurized volume



3. MASS ESTIMATION

HOW DOES THE TOOL WORK



FUEL & TANKS MASS

$$\Delta v = I_{sp} g_0 \ln\left(\frac{M_{tot}}{M_{inert}}\right) \quad \longrightarrow \quad \frac{M_{tot}}{M_{inert}} = \exp\left(\frac{\Delta v}{I_{sp} g_0}\right)$$

FUEL & TANKS MASS

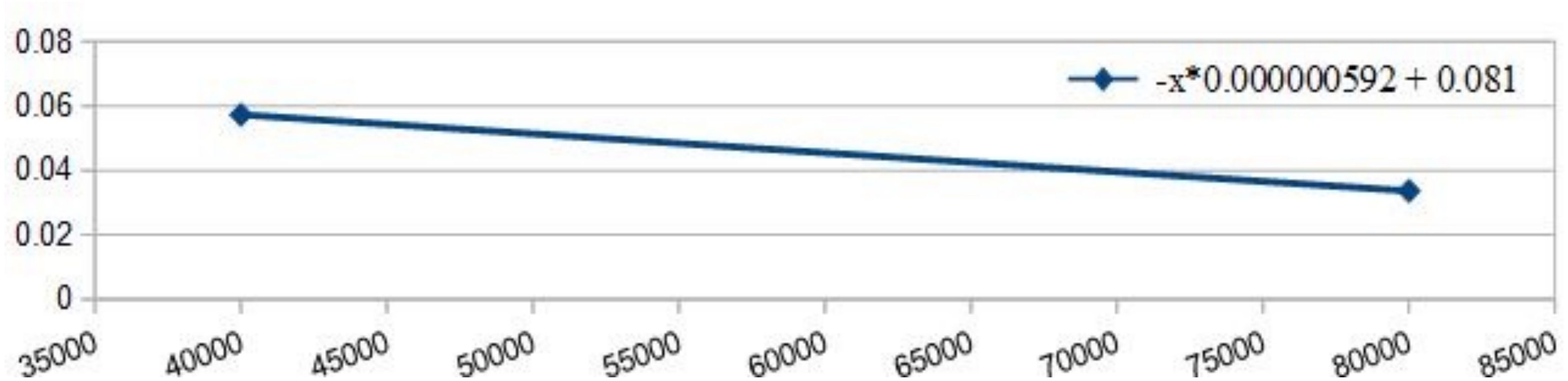
```
def propellant_and_tank(deltav, M_tot, M_dry):

    # rocket equation
    R = exp(deltav / (I_sp * g))

    M_tot = M_dry * R
    M_prop = M_tot - M_dry

    M_prop = M_prop * 1.07 # 4% for FPR Propellant, 3% for Unusable Propellant

    # mixture ratio LOX/LH2, 6:1
    M_LH2 = M_prop / 7
    M_LOX = 6 * (M_prop / 7)
    M_LH2_1 = M_LH2 / 2  # 2 tanks for mass distribution
    M_LOX_1 = M_LOX / 2  # 2 tanks for mass distribution

    # LOX Tank
    M_LOX_Tank = 0.00152 * M_LOX_1 + 318
    V_LOX_Tank = M_LOX_1 / rho_LOX
    r_LOX_Tank = (V_LOX_Tank / (4 * pi /3))**(1 / 3)  # radius of LOX tank
    A_LOX_Tank = 4 * pi * (r_LOX_Tank**2)  # Area LOX Tank
    M_LOX_Insu = 1.123 * A_LOX_Tank  # Mass LOX insulation
    M_LOX_Tanks = 2 * M_LOX_Tank
    M_LOX_Insus = 2 * M_LOX_Insu

    # LH2 Tank
    M_LH2_Tank = 0.0694 * M_LH2_1 + 363
    V_LH2_Tank = M_LH2_1 / rho_LH2
    r_LH2_Tank = (V_LH2_Tank / (4 * pi  /3))**(1 / 3)  # radius of LH2 tank
    A_LH2_Tank = 4 * pi * (r_LH2_Tank**2)  # Area LH2 Tank
    M_LH2_Insu = 2.88 * A_LH2_Tank  # Mass LH2 insulation
    M_LH2_Tanks = 2 * M_LH2_Tank
    M_LH2_Insus = 2 * M_LH2_Insu
```

STRUCTURAL MASS

- First, a mass « M_ » corresponding to the blackbox + the fuel + the tanks is computed (i.e. total mass without structure).
  Then, the structural mass is computed as a percentage of this mass « M_ » and added to it. Which gives the total mass.

- During preliminary phases the mass of a spacecraft is found empirically regarding already built spacecrafts.
  This method has been used to build the linear curve followed by the structural mass percentage.

```
def structure(M_):
y = -M_*5.92E-07 + 0.081
M_Struct = M_ * y
return M_Struct
```



RESULTS

	NASA concept (kg)	Code results (kg)
Dry Mass	15,823	14,561
Structure	2,465	2,314
Tanks Mass	3,025	1,914
Blackbox	10,333	10,333
Prop. Mass	32,395	28,413
Total Mass	48,218	42,974

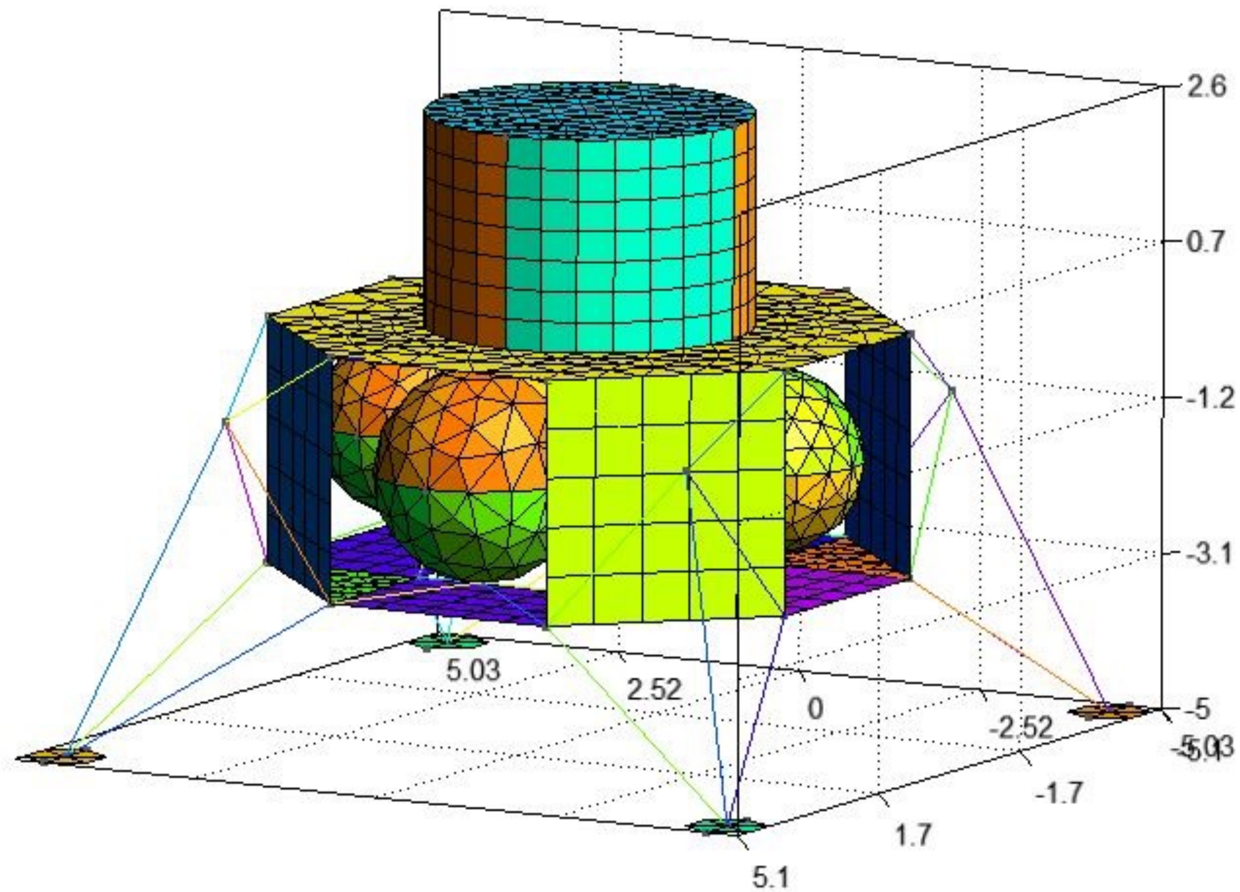
  Difference of 12.1%

- Lockheed's Lander mass : 62,000 kg
  Code results : 70,000 kg

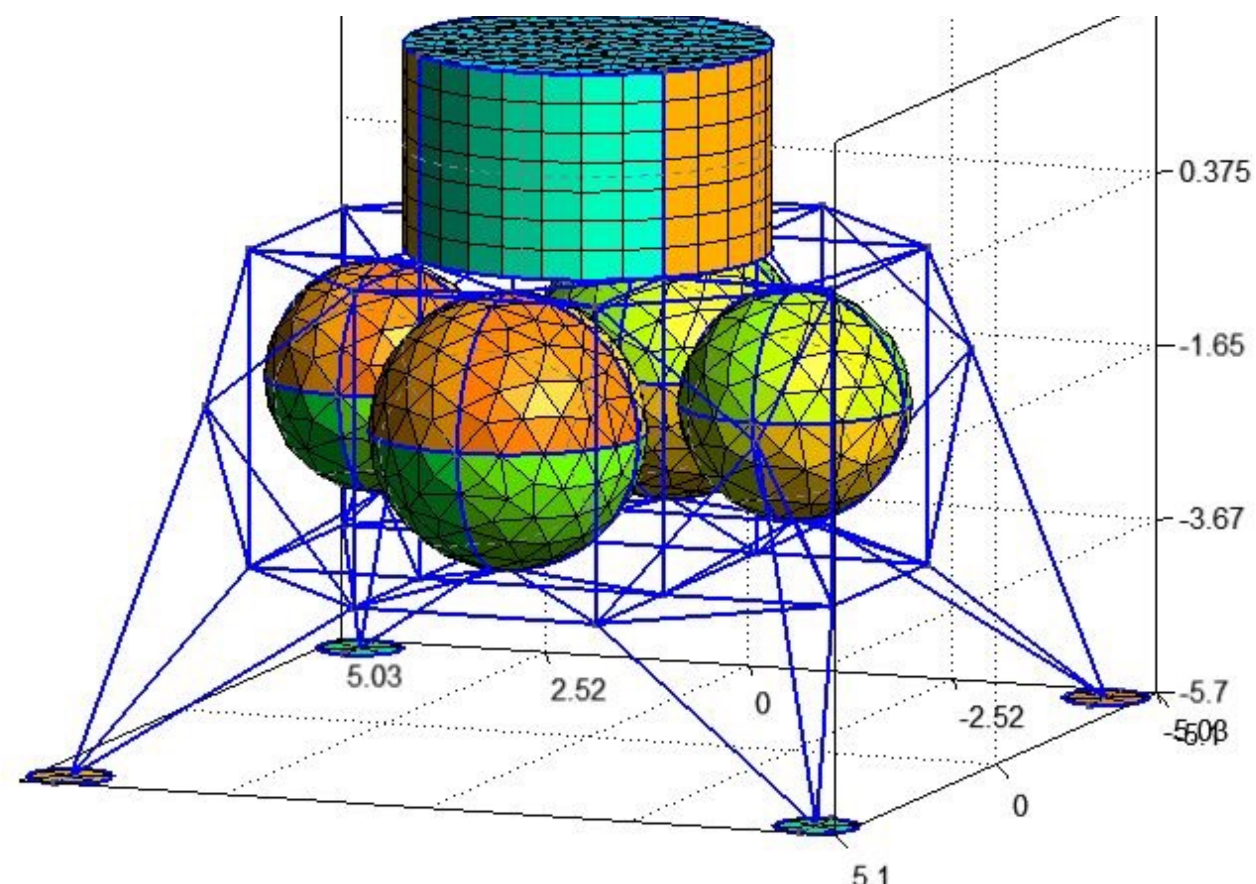
  Difference of 11.5%

4. STRUCTURAL ANALYSIS

THE MODEL

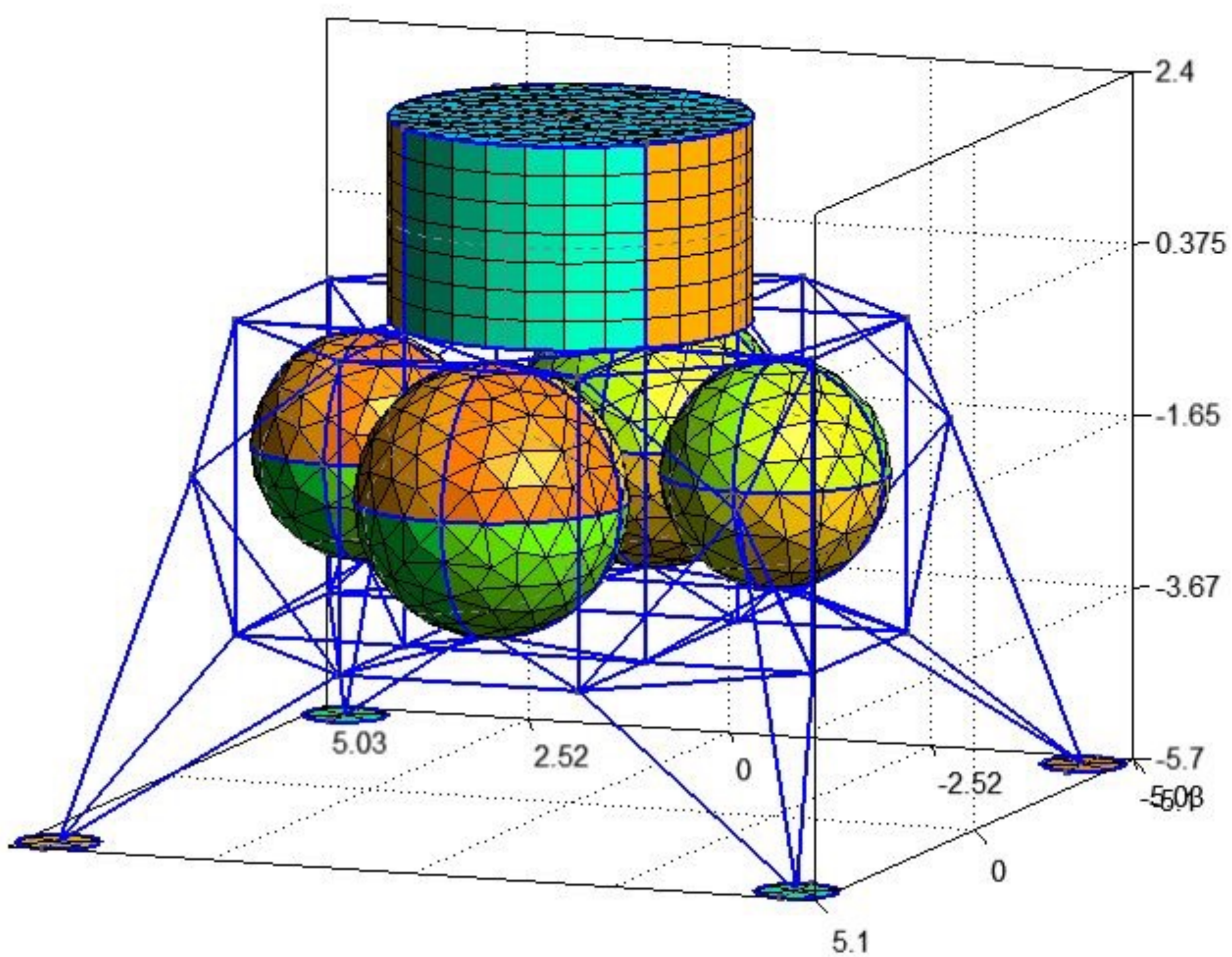


- Several changes since last model (new model below)
- Before : SHELLs and RODs
- Now : RODs and BARs for the structure, SHELLs for pressurized volume

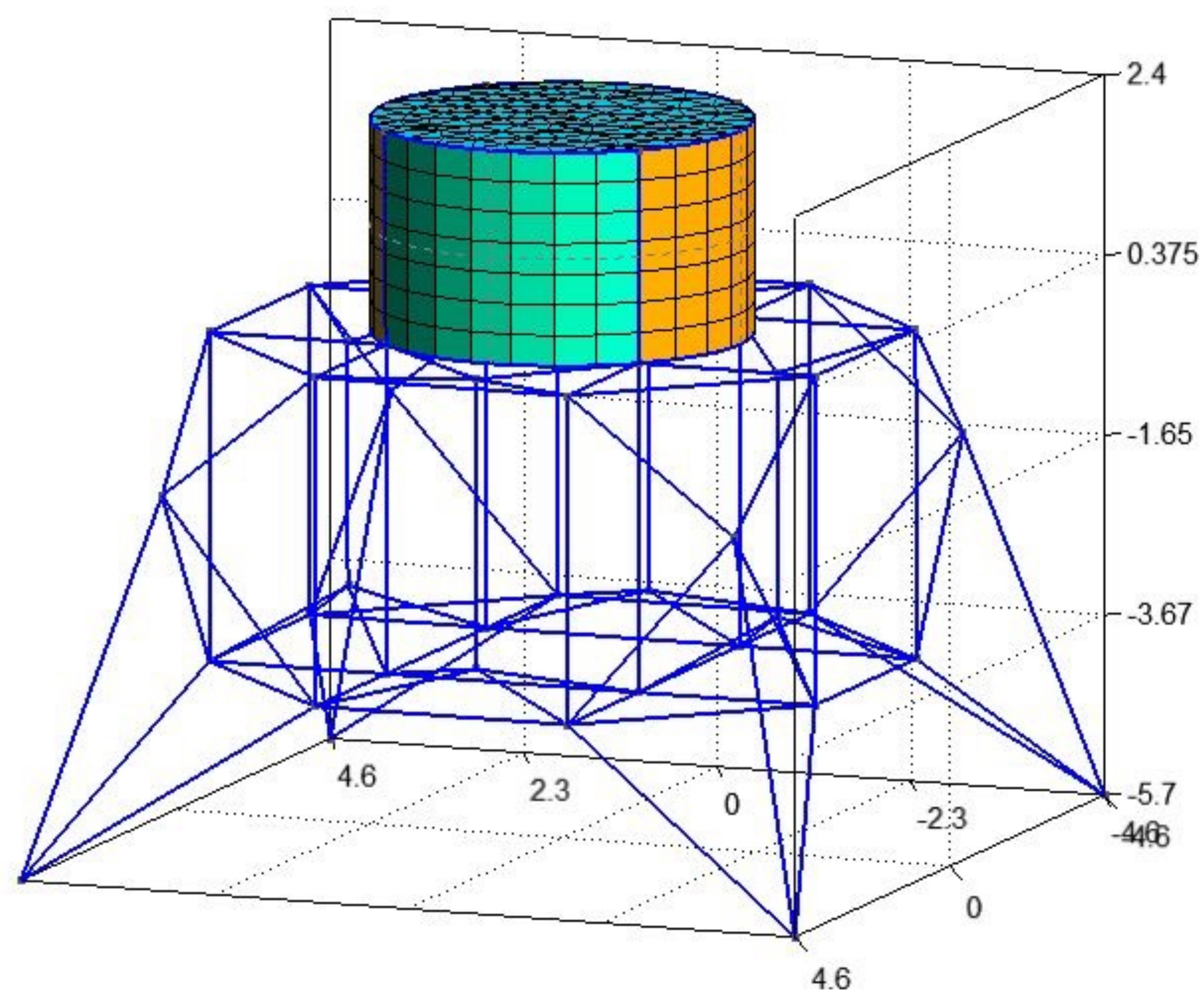


TWO DIFFERENT MODELS

Visualization model

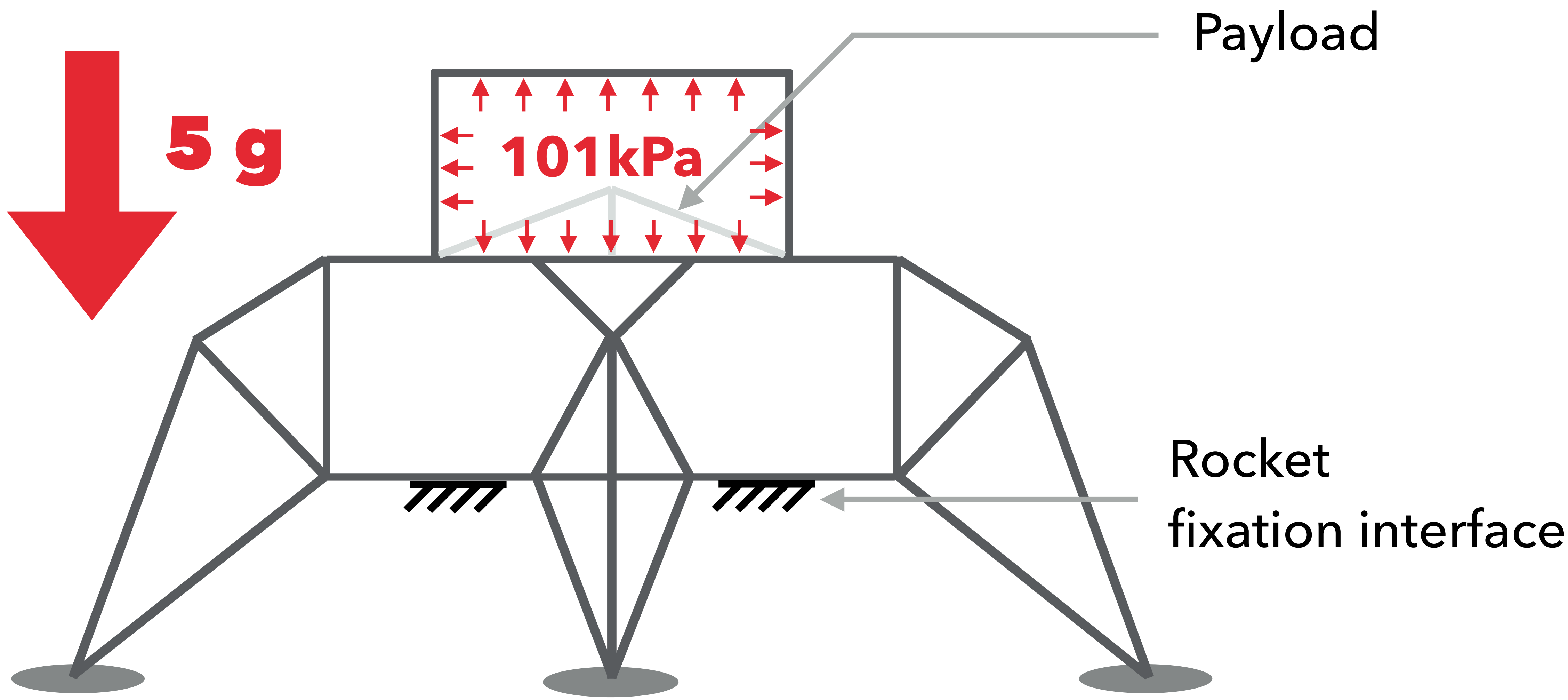


Analysis model

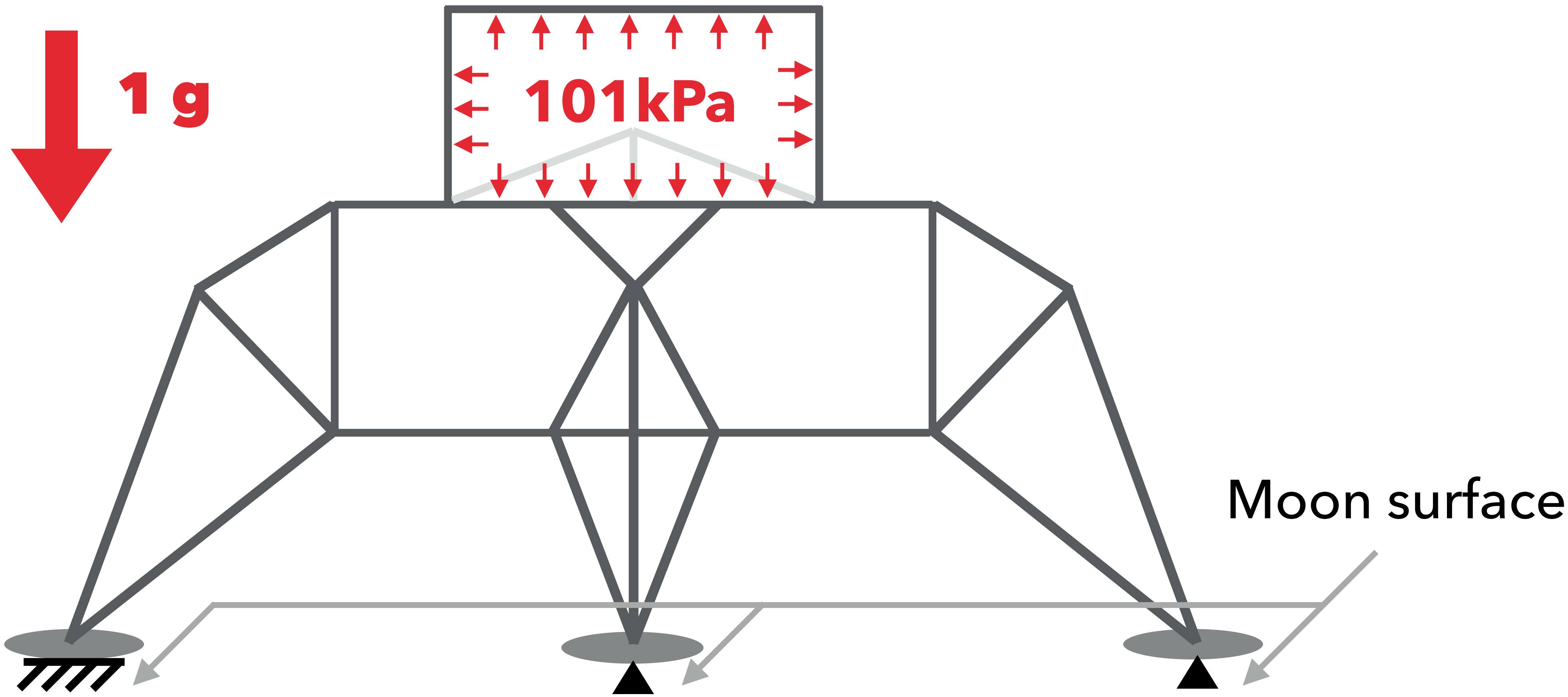


- Tanks as RODs for analysis
- No pads for analysis

SUBCASE 1 – LAUNCH FROM EARTH



SUBCASE 2 – LANDING ON THE MOON



OPTIMIZATION

- To optimize, two solutions were possible :
  - build an external optimizer
  - use the POPT function of nastran95
- Given the time remaining to finish the project, it has been decided to use the POPT function
- This function uses the fully-stressed design method
- Nastran will make the stresses tend toward the stress limits found in the table below :

	Yield Stress (MPa)	Factor of Safety	Stress limit (MPa)
Aluminium 7075-T6	503	1.25	402
Aluminium 2219-T851	352	1.5	235

MASS RESULTS

- Using the same NASA lander inputs as in the mass estimation. The first mass found by nastran is 5,618 kg. And after optimization it is 2,282 kg

	NASA concept	Code result	Nastran result
Structure mass (kg)	2,465	2,314	2,282

- The nastran result must be compared to the code result, because it uses its fuel mass input
- With a difference of 1.4 %, this result validates the geometric model

DIMENSIONS & STRESSES RESULTS

- Here the inputs are : ΔV = 5000 m/s, blackbox/payload = 10000 kg, launch g-force = 5 g, landing g-force = 1 g

	section (m2)	Iz (m4)	Iy (m4)	J (m4)
Main landing legs	0.0028	-	-	-
After optimization	0.00045	-	-	-
One beam	0.0046	1.348E-5	6.953E-6	1.381E-5
After optimization	0.00157	4.604E-6	2.375E-6	4.717E-6

- Regarding the stress, the values are good and are below the limits chosen. However, as the POPT function does not provide control over displacement, a few displacements of 1 and 2 decimeters are found

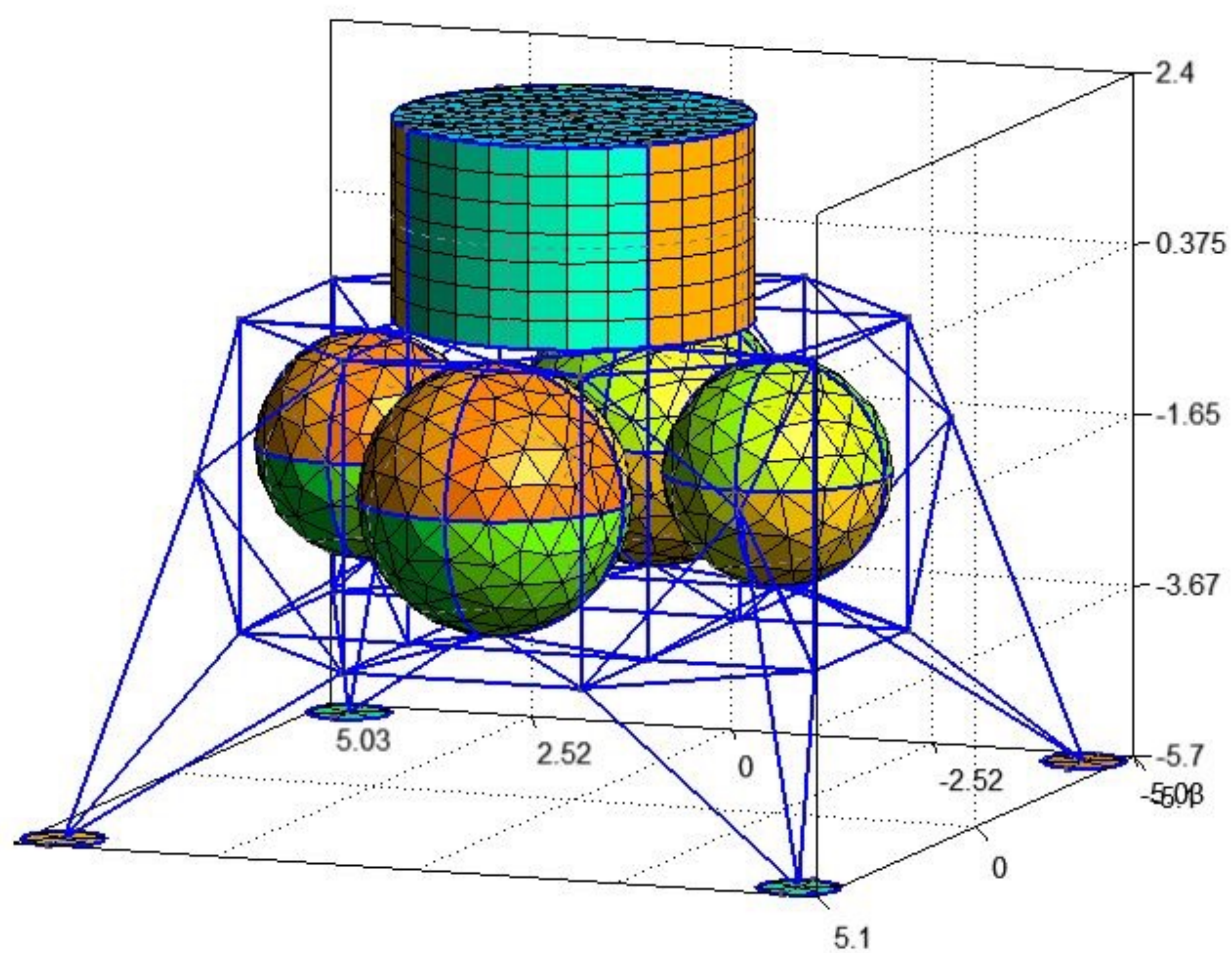
5. DEMO

Tool demonstration

Play the demonstration.mp4 file

6. CONCLUSION

- Consistent mass estimation
- Consistent structural mass from FEM model and tool calculus
- An external optimizer would offer more accurate results and more control over optimization parameters



Thank you
for your attention.

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