LANDER DESIGN AND STRUCTURAL SUBSYSTEM

As the Venus environment is extreme in terms of temperature, pressure and chemical composition, it is mandatory find materials that are able to survive in its environment for long enough. As the past mission toward Venus has shown, the lesson learned is that, oversizing a component sometimes is not enough. Most of the pressure vessel equipping landers successfully landed on Venus, in fact, were able to survive in a 150 atm pressure evniroment. Notwithstanding this, the whole system failed. Handle it, then, is more difficult than what expected as not only every single component must be able to survive on Venus, so is supposed the whole system as well. Regarding the lander, multiple critical components were designed. They are:

1. Parachute
2. Damping system.
3. Legs
4. valves
5. Pressure vessel.
6. Pneumatic tubes.
7. Capsule and tank collecting system.
8. Cupola.
9. Balloon
10. Aerodynamic plate.
11. External skin.

PARACHUTE

The parachute is deployed almost 3 minutes after the entry vehicle has entered in the atmosphere at 90 km altitude, when the vehicle is subsonic (200 m/s). Twenty minutes after, at 70 km altitude the parachute will be jettisoned and the free fall begins. The requirement needed for sizing the parachute is that it must be able to generate a deceleration 4 m/s^2 higher wrt the one that heat shield undergone.

Atmosphere density [kg/m^3]	0.192
Entry velocity [m/s]	200

At a first stage analysis it is supposed a drag coefficient for the lander, the parachute and the heath shield along with other geometrical and physical characteristics that are reported in the following table:

Cd_lander [ADIM]	1
Cd_parachute [ADIM]	0.7
Cd_heat shield [ADIM]	1.2

From the CAD is it possible to evaluate the diameter of the lander.

Diameter of the lander [m]	1.5
Parachute density [kg/m^2]	0.3
Diameter heat shield [m]	2.6

Mass heat shield [kg]	216.353
Density of the heath shield [kg/m^2]	40.75

It is then possible evaluate the deceleration acting on the heat shield and the one that the parachute must generate:

$$D_{heat\ shield} = \frac{1}{2}\rho_{atm} * C_{d\ heat\ shield} * A_{heat\ shield} * V^2$$

Drag force on heat shield after separation [N]	26465
Acceleration acting on heat shield after separation [m/s^2]	113
Acceleration needed on lander [m/s^2]	117

It is important notice that the acceleration acting on heat shield does not depend on the heat shield diameter provided the density per unit of area of the heat shield is constant. It will only depend on velocity, atmospheric density, heat shield density and the drag coefficient of the heat shield. In fact:

$$m = \rho_{heat\ shield} * A$$

$$m = \rho_{heat\ shield} * \pi * \frac{\text{Ø}^2}{4}$$

$$D_{heat\ shield} = \frac{1}{2} * \rho_{atm} * V^2 * C_{d\ heat\ shield} * \pi * \frac{\text{Ø}^2}{4}$$

Using second Newton's law:

$$a = \frac{D_{heat\ shield}}{m} = \frac{1}{2} * \frac{\rho_{atm} * V^2 * C_{d\ heat\ shield}}{\rho_{heat\ shield}}$$

And then, knowing the mass of the lander it is possible to evaluate the drag force that must act on the lander in order to generate a separation:

Mass lander [kg]	371.1634805
Drag force acting on lander necessary for splitting [N]	43455.72921

Knowing $C_{d\ parachute}$ and $C_{d\ lander}$ it is possible to define the area of the parachute inflated:

Cd*a parachute [m^2]	12.36049827
Area parachute inflated [m^2]	17.65785468
Diameter parachute inflated [m^2]	4.741590329

And the constructed diameter that is $\frac{\pi}{2}$ times higher than the one of the parachute inflated:

Parachute constructed diameter [m^2]	7.448072672

Finally one can calculate the parachute effective area and mass as follow:

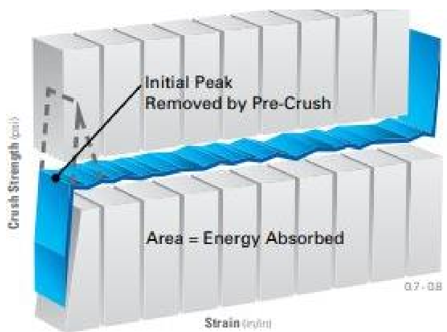
Final parachute area [m^2]	43.56901006
Final parachute mass [kg]	13.07070302

DAMPING SYSTEM

With the aim of designing the legs, it is mandatory design them using a lightweight and resilient material. Honeycomb made materials can suit properly with this necessity. Plascore is a global leader in engineered core, and it developed a material, the Plascore CrushLite, namely an aluminum honeycomb core material which is certified to specific crush strengths for energy absorption applications. CrushLite™ yields at a constant force providing reliable and consistent energy absorption in almost any environment. It presents the following characteristics:

• Predictable energy absorption properties
• High crush strength-to-weight ratio
• Efficient constant force crush curve
• Wide range of strengths available
• Crush stroke in excess of 70%
• Excellent moisture and corrosion resistance
• Elevated use temperatures

In the aerospace field it acts as a single event shock absorber for impact protection without adding significant weight.



CrushLiteTM aluminum honeycomb is available in untrimmed sheets, cut to size, machined, or die cut. Precrushing, load certification, and other operations are available upon request.

Plascore Honeycomb Designation					Crush Properties		
Nominal Density lbs/ft³	Cell Size (Inch)	Foil Gauge (Inch)	Available in Perforated	Foil Alloy	Crush Strength[1] (psi)	Standard Crush Tolerance (+/- psi)	Minimum Stroke[2] (%)
0.6	3/4	.0007	+	5052	7.5	2.5	70
1.0	1	.002	+	3003	10	2	70
1.2	1	.003	+	3003	25	5	70
1.0	3/8	.0007	+	5052	25	5	70
1.0	3/8	.0007	+	5056	35	5	70
1.6	3/8	.001	+	5052	45	4.5	70
1.8	3/4	.003	+	3003	45	4.5	70
1.6	1/4	.0007	+	5056	50	5	70
2.0	3/16	.0007	+	5052	75	7.5	70
2.3	3/8	.0015	+	5052	80	8	70
2.3	1/4	.001	+	5052	90	9	70
2.3	1/4	.001	+	5056	100	10	70
3.0	3/8	.002	+	5052	120	12	70
3.6	3/8	.003	+	3003	120	12	70
3.1	1/8	.0007	+	5052	130	13	70
3.4	1/4	.0015	+	5052	140	14	70
3.1	1/8	.0007	+	5056	170	17	70
3.7	3/8	.0025		5052	180	18	70
4.2	3/8	.003		5052	210	21	70
4.3	1/4	.002	+	5052	230	23	70
5.2	1/4	.003	+	3003	245	24.5	70
4.5	1/8	.001	+	5052	275	27.5	70
4.5	1/8	.001	+	5056	320	32	70
5.2	1/4	.0025		5052	330	33	70
5.4	3/8	.004		5052	350	35	70
5.7	3/16	.002	+	5052	380	38	70
6.0	1/4	.003		5052	420	42	70
5.7	3/16	.002	+	5056	440	44	70
6.1	1/8	.0015	+	5052	450	45	70
6.1	1/8	.0015	+	5056	535	53.5	70
8.1	1/8	.002	+	5052	700	70	70
8.1	1/8	FC	+	5052	750	75	70

Once the terminal velocity is obtained thanks to a fluidic simulation, it possible to estimate the peak force acting on the damping system in the simplified case scenario of constant deceleration. Assuming that:

Mass of the lander [kg]	365
Velocity at touchdown [m/s]	6
Space for deceleration [m]	0.1
Base area leg [m^2]	0.0003

$$s = \frac{1}{2}a * t^2 + vo * t$$

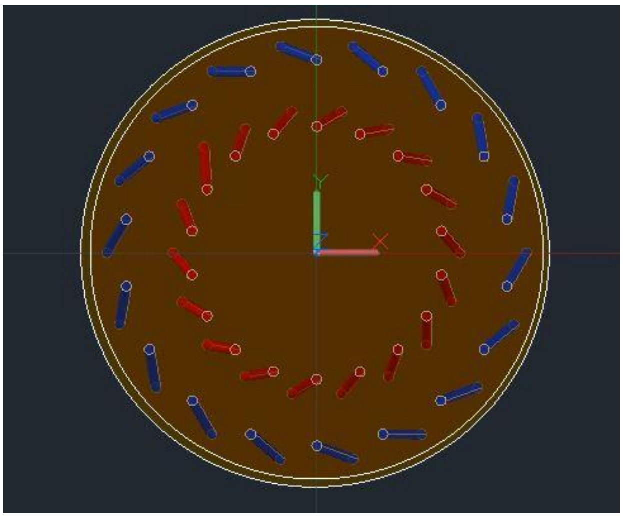
$$V^2 = V_0^2 + 2ax$$

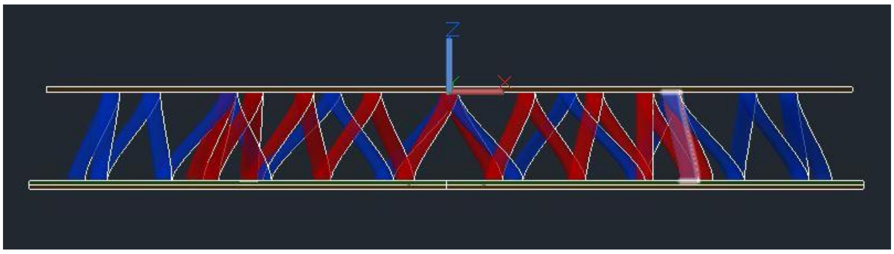
Actual deceleration [m/s^2]	180
Time of deceleration [s]	0.0138
Force experienced [N]	65720

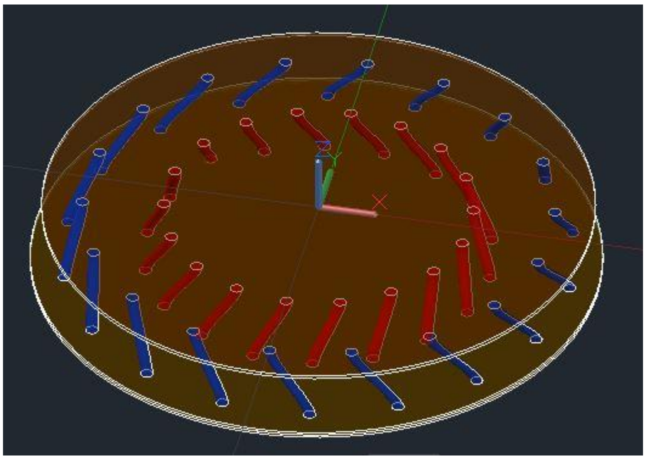
Number of dampers, ADIM	36
Force that every damping leg will experience [N]	1826
Pressure that every damping leg will experience [Pa]	6085167
Pressure that every damping leg will experience [atm]	60.05

The honeycomb material chosen for the legs has the following properties:

- nominal density of $9.72\ lbs/ft^3 = 181\ \ kg/m^3$
- cell size of 1/8 inches
- crush stenght of 750 psi as well as 51 atm (+20%).







The last step involve the determination about the weight of the damping system. Through Auto-CAD it was possible calculate the area of a single leg and the, with the knowledge of the density, assess the total mass.

Total volume [m^3]	0.13
Total mass [kg]	19.5

LEGS

The legs are made up of Alloy X-750 that has good mechanical properties at high temperatures up to 704°C. The alloy was developed from Alloy 600 by adding aluminum and titanium to make the alloy precipitation hardenable. Alloy X-750 offers outstanding performance in highly stressed environments, which is why it is often used in gas turbines, nuclear reactors and aircraft structures. This alloy will extremely well bear the impact force of the landing. In the following table there is a description of the physical properties of this material:

Density [kg/m^3]	8276
Melting range [°C]	1393-1427
Ultimate tensile strength at 538°C [MPa]	650
0.2% yield strength at 538°C [MPa]	310
Coefficient of thermal expansion at 538°C [μm/m°C]	14.94
Thermal conductivity at 538°C [kcal/(hr.m.°C)]	12.1
Modulus of elasticity at 538°C [GPa]	185

The legs designed are 8 and they are intended to guarantee a steepness as much low as possible to the science payload elements. That is why the ALHAAT system will be implemented. This advanced technology is able to lock the ground during the last 20 km of descent analyzing the topography of it and figuring out what is the safest place to land on. As such every single leg is able to adjust its own length according to the information gathered by this technology. The actual time needed to adjust the length of the legs is supposed to be of 60 seconds. Further little adjustment can be performed up until a a few tens of seconds before touchdown.

Every single leg is actually made of 3 parts:

- a larger diameter cylinder.
- a shorter diameter cylinder

- a pentagon base.

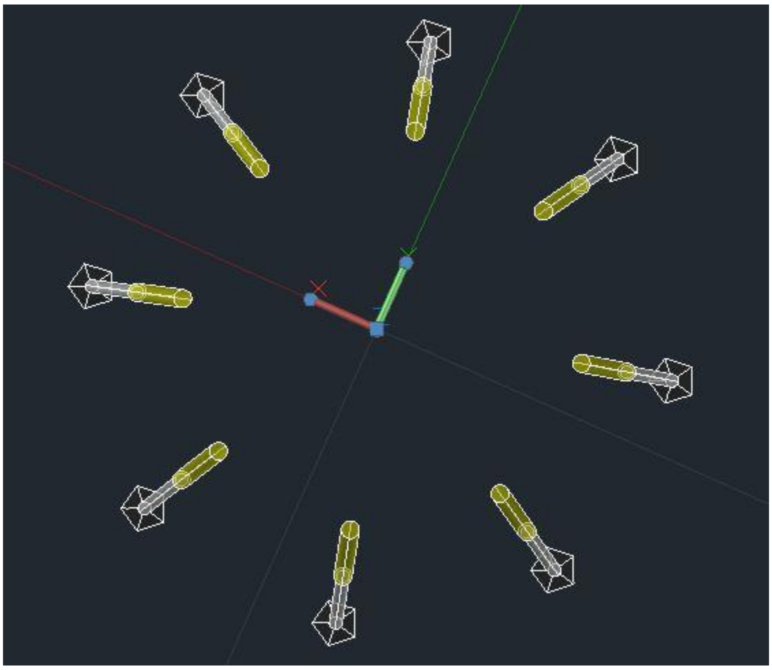
In the following table some geometrical specification are reported:

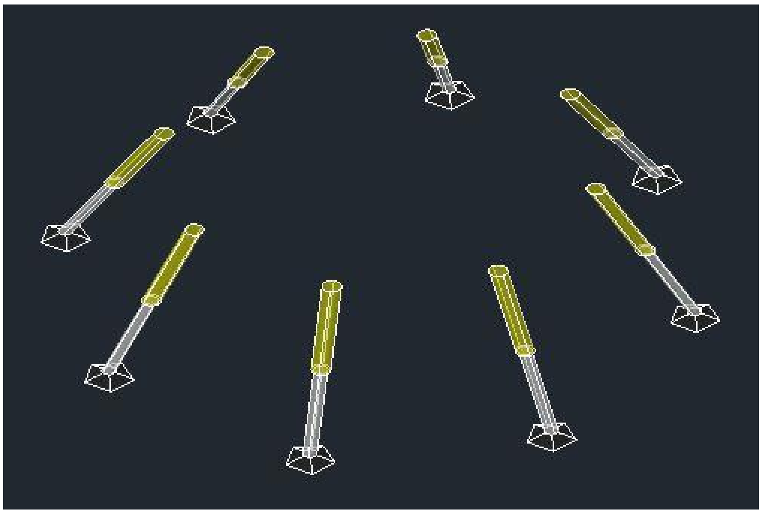
Base area upper cylinder [m^2]	0.0006
Radius upper cylinder [m^2]	0.014
Length upper cylinder [m]	0.12
Base area lower cylinder [m^2]	0.0005
Radius lower cylinder [m^2]	0.012
Length lower cilynder [m]	0.125
Length of pentagon side	0.05
Area pentagon [m^2]	0.00455
Vertical encumbrance of the pentagon [m]	0.045
Volume single leg [m^3]	0.0001

And then the total mass is evaluable:

total mass [kg]	8.276

Three Auto-CAD sketches from three different view of the pressure vessel only are reported below:





VALVES

The valves will be foundamental in the samples pushing process. In particular 3 valves per every pneumatic tube are designed. The company that produces them is Meggitt. Specifically a valve called “sleeve and poppet” will be used: it can bear temperature up to +593°C and its diameter can vary from 0.5 to 2.5 inches. Also it can be made up of aluminum titanium or nickel. The material chosen depend on the coupling with the pneumatic tube.

Sleeve and poppet

In order to figure out which material fits best for venus operations some physical properties of aluminum titanium or nickel are studied. It is noteworthy the fact that the aluminum has a low fusion temperature. Actually creep and softening temperature are the most important parameters that must be taken into account.

The target company is the NeoNickel that is specialized in manufacturing metal alloy with high performance in different shapes and for many customers. Most of this alloy are used in petroleum industry just because they must be able to bear extremely high temperature and pressure as well as chemically degrading environment.

one valve weight [kg]	0.35

SAMPLING SYSTEM

PNEUMATIC TUBES

The lander sampling system consists 4 different tubes. All of them are made up of 602-CA nickel alloy. Exposure to a carbon enriched atmosphere, can cause carburization. Due to its high Nickel content, 602 CA® has an outstanding resistance to carburisation, ensuring prolonged ductility in the face of carbon monoxide (CO) and methane (CH4). Performing well under high pressure and temperature, 602 CA® is extensively used in thermal processing equipment. It has the following properties:

Density [kg/m^3]	7890
Melting range [°C]	1340-1400
Hardness	HRB
Specific heat capacity [J/(kg°C]	450
Electric resistivity [μΩ*m]	1.23
Ultimate tensile strength at 538°C [MPa]	560
0.2 % yeld strength at 538°C [MPa]	180
Minimum creep at 538°C, 0.0001%/hr	NULL
Coefficient of thermal expansion at 538 °C, μm/(m°C)]	14.9
Modulus of elasticity at 538°C [GPa]	189

Their main purpose of the ***pneumatic tubes*** is to ensuring a ***safe*** and ***quick*** path to the samples from the bottom of the drills to the collecting capsules at the top of the lander. They will also must be able to ensure a constant difference in pressure with respect to the external atmosphere during the whole cruise towards Venus until the specific moment in which the one way valves are open.

DESCRIPTION OF THE COLLECTING PROCESS: The dimension of the sample depends on the dimension of the drill's head. In particular the input value for radius and length of the sample are:

Radius of the drill's head [m]	0.019
Length of one sample [m]	0.13
Volume of one sample [m³]	0.00015

Once the three samples are gained a so called "pack" is formed. At this point, the first one way valve located at the bottom of the tubes is open. In doing so, the delta of pressure will push the samples and the net force will push them forcing to travel within the tube. The delta of pressure calculated should be enough even if something wrong happens. In particular the delta of pressure is estimate supposing that:

1. the density of the sample is 6000 kg/m^3 namely 15% higher wrt the medium density of Venus.
2. Eventual leakages present will determine losses so that the actual difference in pressure necessary is 10% higher wrt the minimum value where with the expression "minimum value" is intended the delta of pressure associated to a net force able to balance the weight of the samples only.
3. Not taken into account the bind reaction due to the fact that the tube are inclined of Ɵ and are not perpendicular to the surface.
4. At the minimum pressure value needed to balance the weight of the samples, must be increased of 10% in order to generate a net force that will actually push the samples.

The acceleration acting on the samples, is enough to allow the samples to travel the distance of the tube after taking into account real losses. Supposing for simplicity that the delta in pressure is zeroed in one second, that it is a decreasing linear function of the time and that the valves have just two possible position (fully open or fully closed) it is possible to evaluate the final velocity and the space travelled by the samples.

With this know it is possible to say what follows:

Density of sample [kg/m^3]	6000
Mass of a single sample [kg]	0.8841
Min. Δ pressure needed [pa]	20755.8
Min. Δ pressure needed [atm]	0.20484
Leakage, adim, 10%	1.1
Actual min Δ pressure stored [atm]	0.22533
Actual Δ medium pressure imposed (15%) [atm]	0.259
Net force acting on the samples [N]	4.94
Acceleration of the pack [m/s^2]	1.86
Terminal velocity of the pack [m/s]	1.59
Space travelled by the pack [m]	0.84
Length of the telescopic tube [m]	1.051

As said before, since the pressure decrease linearly during the time the valve is open, the initial pressure is supposed to be the double wrt the medium pressure actually needed.

Δ Pressure at the beginning [atm]	0.518

In the case in which after the first one-way valve is open, the samples will not be able to travel all the way through the tube, a “second attempt mechanism” will allow a second attempt. It consists of a vertical tube in which the vacuum is created. It is connected to the main pneumatic tube thanks to a one way valve and the main difference wrt to the pneumatic tube is that inside it the vacuum is created. In the case in which the samples will not be able to get the top of the pneumatic tube after the first attempt, the connecting valve is open and an isothermal transformation takes place. In doing so the pressure inside the main pneumatic tubes decreases and a second attempt is possible. The procedures for the second attempt are the same of the first one.

In order to figure out what must be the volume of the secondary tank it is possible to use the relation that describe an isothermal expansion.

$$P_1V_1 = P_2V_2$$

Where:

$P_1 = 92\ atm$

$P_2 = P_1 - \Delta P_{beginning}$

With this know it is now possible say what follows:

P1 [atm]	92
R1 [m]	0.016
L1[m]	0.94
V1 [m^3]	0.00075599
P2 [atm]	91.4817
V2 [m^3]	0.00076

And then define radius and length of the secondary tank:

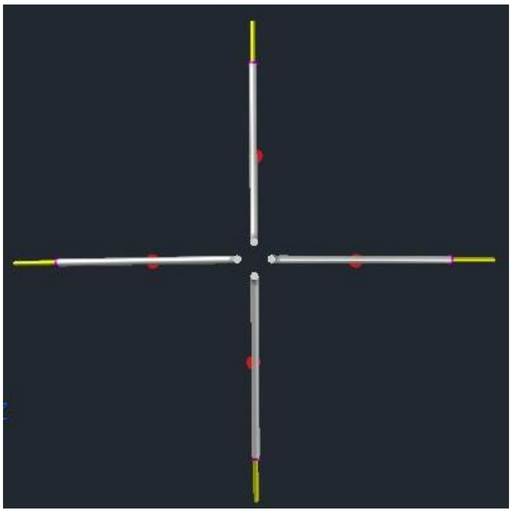
R2 [m]	0.03
L2 [m]	0.2688

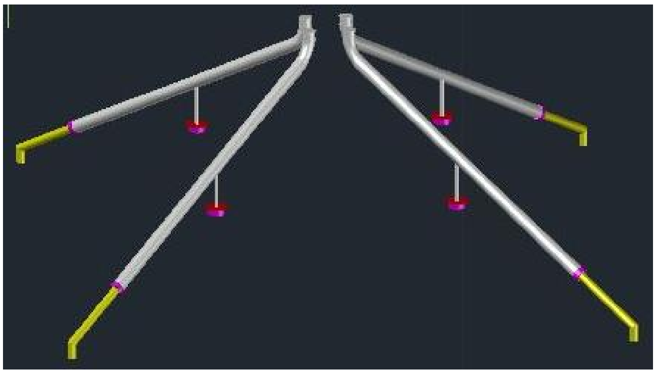
It is also possible to confirm that the mission requirements is satisfied. In fact, the total mass of samples gathered from top 10 cm is:

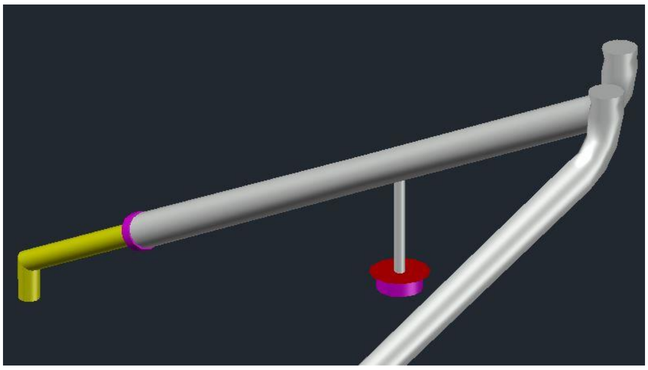
Total mass gathered [kg]	10.615

Every single pneumatic tube is equipped with 4 one-way valves “sleeve and poppet”.

Three Auto-CAD sketches from three different view of the pressure vessel only are reported below:







CAPSULES AND TANK

Once the samples get the top of the pneumatic tube, a valve at the bottom of every capsule opens. Since the samples will be still in motion, the residual kinetic energy will allow them to enter in a hallow that will pick them up. Four main larger capsules are intended to gather the 4 different packs, each of which contains 3 samples. Just after the pack enter in its own capsule the valve at its bottom gets close. At this stage 3 inner cylinder present in every capsule rotate round a common axis and this will allow a mechanical separation of every sample. Twelve different room will be created then.

The volume and general dimension of the capsule is slightly larger (5%) wrt the sample's.

In the following the dimensioning process of for capsules and tank is reported:

Radius (+5% wrt drill) [m]	0.01995
Length (+5% wrt drill) [m]	0.1365
Volume [m³]	0.0001544
Int. pressure [atm]	91.48175
Ext. pressure [atm]	92
Young's modulus (602-ca), e, [pa]	1.89E+11
Thickness, t, [mm]	0.016577
Thickness (+25%), t, [mm]	0.020721

This thickness physically enough for substaining the difference in pressure is mechanically difficult to realize for machines. This is the reason why a wall of 2 mm in thickness was chosen.

With this assumption it is possible to define the total mass of the 12 capsules:

Density of 602-ca [kg/m^3]	7890
Mass 1 capsule [kg]	0.257787
Total mass 12 capsule [kg]	3.093

The same process was done to design the lander. In particular taking into account the mission requirements:

"Return to Earth or Earth vicinity at least one cubic liter of Venus atmosphere from the surface and at least one cubic liter of Venus atmosphere from an altitude of 40 km above the surface."

It was chosen to gather 1.3 L from 0 km altitude and 1.3 L from 40 km altitude.

Defining as input value radius and volume it was possible state what follows:

Volume, v, [m³]	0.0026
Radius, r, [m]	0.05
Length, l, [m]	0.26438
Int. pressure [atm]	0
Ext. pressure [atm]	92
Young's modulus (602-ca), e, [pa]	1.89E+11
Thickness, t, [mm]	0.58
Thickness (+25%), t, [mm]	0.72

This thickness physically enough for substaining the difference in pressure is mechanically difficult to realize for machines. This is the reason why a wall of 2 mm in thickness was chosen.

In doing so:

Density [kg/m^3]	7890
Mass [kg]	1.85

Three Auto-CAD sketches from three different view of the pressure vessel only are reported below:

SPACE RESERVED FOR CAPSULES PICTURES WHEN READY.

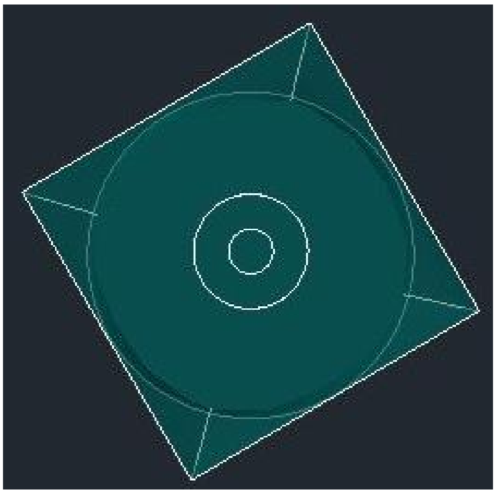
CUPOLA

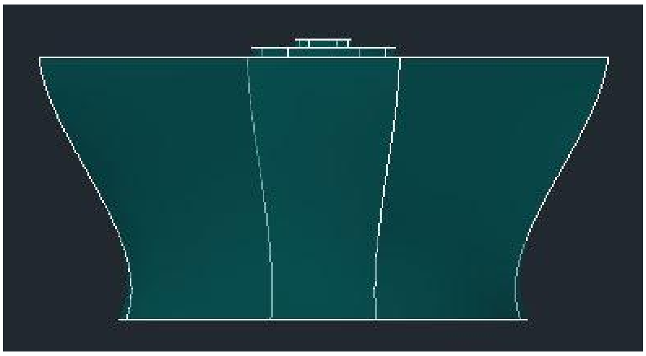
This is the upper part of the lander. It is intended to envelop the gathering system of the samples, the rocket and the ascending balloon. It will be the gate towards the carrier. It is made up of TI-6Al-4V alloy just like the skin, the pressure vessel, the upper and lower drag plate. The mechanism that will allow it to open the roof is fairly simple. Thanks to a one degree of freedom carrucola, the two half of the roof will slide ensuring a fast way to generate a gate.

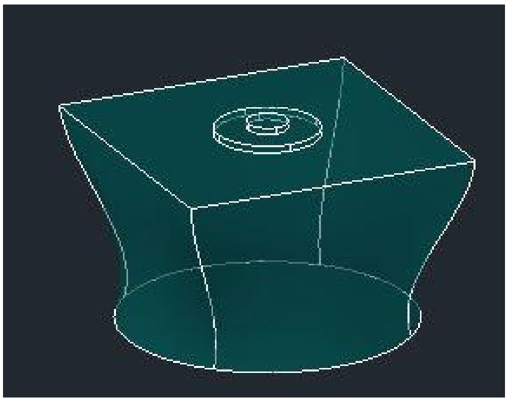
Through the knowledge of the volume, the total mass of the cupola can be calculated:

Density TI-6Al-4V [kg/m^3]	4429
Volume of the cupola [m^3]	0.0144
Mass of the cupola [kg]	9.5666

Three Auto-CAD sketches from three different view of the pressure vessel only are reported below:







BALLOON

The balloon is the component in charge to ascent the Venus atmosphere carrying the samples of surfaces and atmosphere and the rocket that will perform the randezvous with the carrier at an altitude of almost 60 km where temperature and pressure do not put at risk the rocket ignition phase. The balloon must be designed in order to guarantee its survivability throughout a broad spectrum of temperature, pressure and chemical environment. In the following table is summed the delta of temperature and pressure it is supposed to bear:

Delta of temperature [°C]	455
Delta of pressure [°C]	91.5

Also, between 35 and 55 km altitude a layer of sulfuric acid clouds is present and the balloon must not suffer it. For all these reason the balloon is made up of multiple layers coupled each other and having multiple characteristics. The balloon is made up of seven different layers. Starting from the innermost:

1. Polyurethane coating
2. Vectran
3. Mylar
4. Superwool
5. Palladium/Silver or
6. Vacuum deposition of Gold/SiO_2

The layer of polyurethane will enable all the layers to be glued together. The layer made up of vectran is able to provide the necessary strength will prevent the balloon from bursting due to the internal pressure. Just in contact with vectran there is a layer of mylar that is used to prevent from leaking out.

The outer layer is made up of gold or a noble metal that will not suffer the high temperature and the corrosive environment like silver or palladium that are also way more ligher (expecially palladium). The greatest problem of silver is that it is thermally conducted. If silver or gold will be used, a layer of superwool must be put under one of them.

	Thermal conductivity [W/(mK)]	Density [kg/m^3]	Melting point [°C]	Specific heat [J/(kg*K)]
Silver	429	10490	962	232
Gold	317	19320	1064	128
Palladium	71.8	12023	1555	244

Palladium as optimal thermal characteristic better than gold and silver and also is able to resist very well to corrosion. In any case a vacuum deposition of gold can be done in order guarantee a further protection from acid environment. These 6 layers should then be able to guarantee enough chemical and thermal inertia and also guarantee enough mechanical integrity.

GRID FINS

Grid fins are four separated aerodynamic surfaces that will help the lander to actively control its descent toward the surface. They are mounted on the side faces of the cupola in order to guarantee an high static margin to the lander. In doing so static equilibrium is ensure.

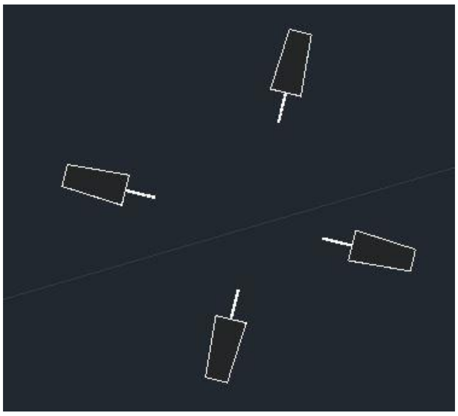
Grid-finds will have a limited authority throughout the super rotating zone and will actually be able to govern the descent during the last 20 km (30' almost). In this amount of time, in fact, they will be able to implement the information gathered by ALHAAT system in order to allow the lander to land on the most suitable tesserae region.

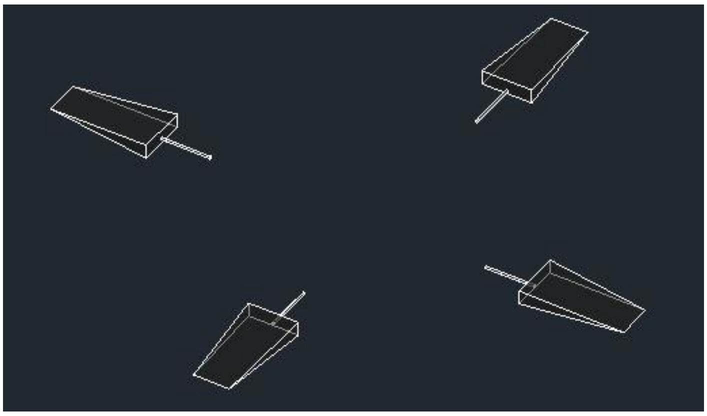
Generally they will be able to control the lateral movement: every fin is able to rotate round its main axis in order to change the magnitude and the direction of the lift.

They are the only moving parts of the whole structure that will operate in a broad spectrum of chemical and physical conditions. This is the reason why a particular alloy was chosen for their realization: WASPALOY.

Density WASPALOY [kg/m^3]	8163
Volume of the grid fins [m^3]	0.0002
Mass of the grid fins [kg]	1.6326

Two Auto-CAD sketches from two different view of the pressure vessel only are reported below:





PRESSURE VESSEL

The pressure vessel is probably the most important structural component of the whole lander. It must undergone the extremely high pressure and temperature on Venus and guarantee Earth-like condition inside it, where all the science payload, sensors, batteries, cabling, active and passive temperature control system etc are embedded. In the past space missions, pressure vessels failure caused the flop of the mission due to the impossibility to keep contact with the lander or to the internal rising of pressure and temperature. This is why once of the main requirements for the pressure vessel is that its ultimate tensile strength must be 150 atm.

The pressur vessel is an hemisphere made up of a titanium alloy: titanium 6Al-4V (Grade 5)

Ti 6Al-4V (Grade 5) is the most widely used of all the alpha-beta titanium alloys. The alloy was originally developed for the aerospace market and widely used in aerospace structural components. More recently the alloy has seen extensive use in the oil & gas market where a combination of high strength, corrosion resistance and low weight is essential. The density of Ti 6Al-4V (Grade 5) is 50% that of nickel-based alloys and stainless steels. It is therefore used extensively in various applications due to its high strength-to-weight ratio. It is typically used in the annealed condition, at service temperatures up to 400°C. However it may be heat treated for high strength in sections under 4" thick.

Its properties are reported in the following table:

Density [kg/m^3]	4429
Melting range [°C]	1609-1660
Hardness	HRB
Thermal conductivity at 316°C [kcal/(hr*m°C]	9.08
Coefficient of thermal expansion at 316 °C, [µm/(m°C)]	9.9
Modulus of elasticity at 316°C [x10^5 MPa]	9.65

A double hemispheric shell will be manufacture as a crawl space will be fundamental for hosting insulating materials (see thermal control system chapter). The crawl space will be internal to the main surface of the pressure vessel. It occupies almost 10% of the total diameter of the hemisphere. This is the reason why the radius used in the formula below is augmented of 10%.

In order to figure out the diameter of the pressure vessel it was evaluated the total volume of the component that will be allocate inside it.

VOLUME COMPONENTS [L]	
Payload	111.43
Primary batteries	12.114
PCM	22.3865
Cabling	1.947
Cartrdge heaters	1
Fixing platform	2.229
Pressure sensors	0.3
Temperature sensors	0.3
Minimum pressure vessel total volume	151.71

Once the properties of the material and the minimum total volume (and then radius) are known, it was possible to evaluate the minimum thickness that the pressure vessel must have in order to bear the difference of pressure imposed by the requirements, and then its mass.

Ti-6Al-4V	
External pressure [atm]	150
Internal pressure [atm]	1.2
Radius of the hemisphere [m]	0.480

Using the relation for evaluating the minimum thickness for preventing the bucking:

$$P = \frac{0{,}365 * E * t^2}{r^2}$$

It was possible calculate the final mass of the pressure vessel without insulating:

Thickness [mm]	9.012
mass [kg]	24.166

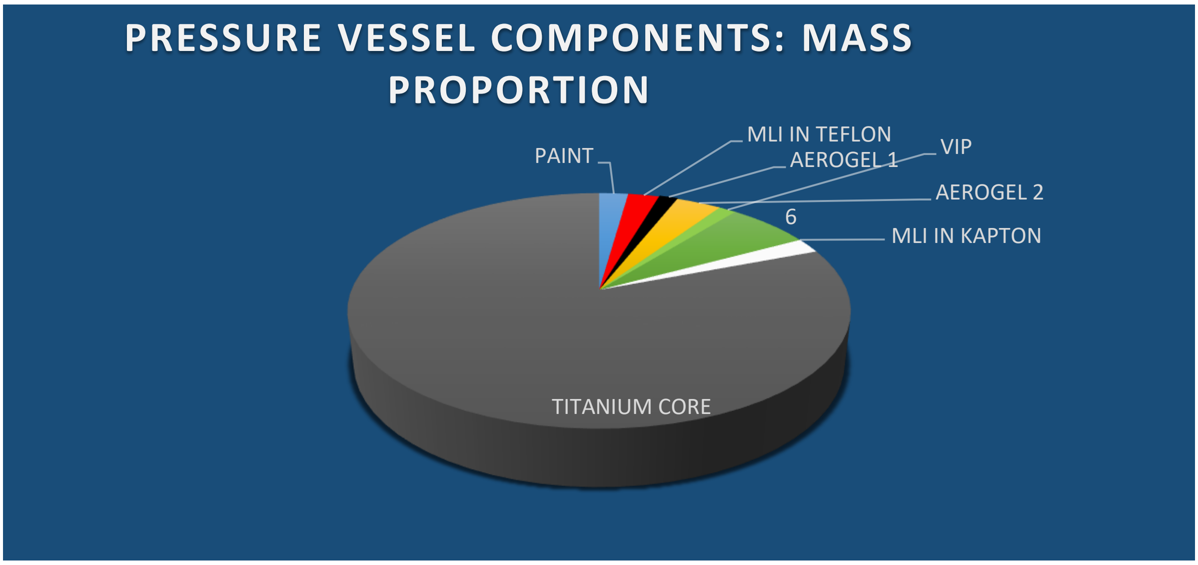
At this stage it is interesting notice the proportion between the mass of the pressure vessel and the mass of the insulations:

Mass [PV/ insulator]	0.346123

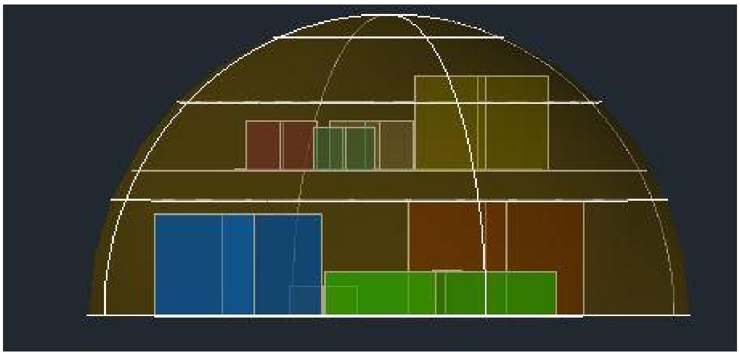
This means that every almost 3.5 kg of titanium 1 kg of insulation material is necessary. But if one looks at the ratio of the density can easy note that the ratio is higher:

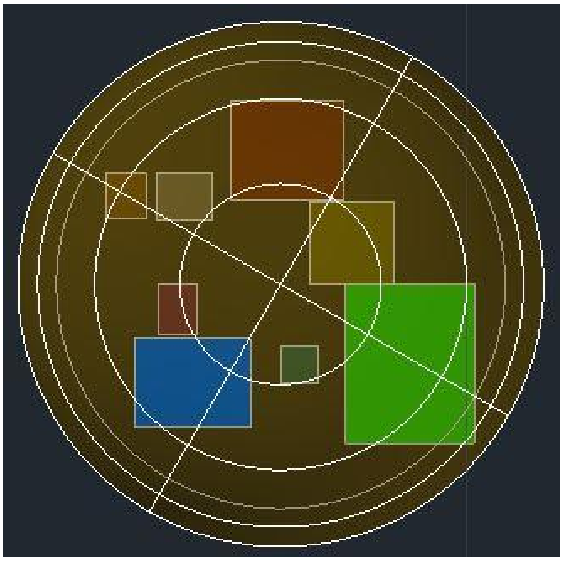
Density [PV/insulator]	14.37987

This means that the volume of the insulator is low and then that its encumbrance is low. In a space design process the encumbrance as well as the mass are critical drivers. The ratio $\frac{\text{Density [PV/insulator]}}{\text{Mass [PV/ insulator]}} = 41.55$ is an index of how well is the insulator saving space.



Once all the measures were known, it was possible to drawing the pressure vessel. Two Auto-CAD sketches from two different view of the pressure vessel only are reported below:





DRAG PLATE

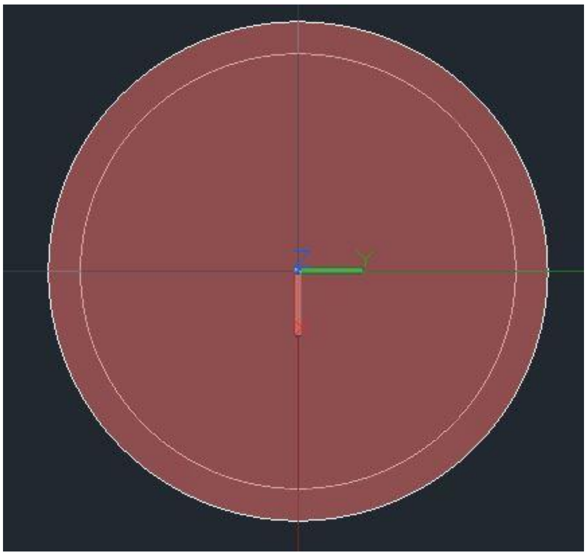
This part of the lander has a very important role. Along with the grid fins, they can be considered as the two real aerodynamic components. In particular the drag plate will help the lander to slow down once the parachute will be jettisoned. The drag plate rules the actual encumbrance on the lander as it is its wider part. It measure 1.5 m in diameter and is supposed to give the most relevant contribute to the deceleration during the final part of the descent, namely from 90 km altitude circa, up to the touchdown.

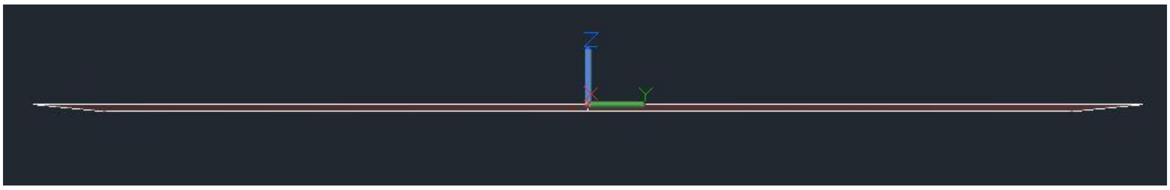
It is designed in order to survive the extreme environment and the deleterious acid enviroment between 55 km and 35 km altitude where acid sulfuric clouds are present. This is the main reason why the material chosen for the external film was the nickel alloy RA-333. The internal part is instead made up of rigid aluminium. RA-333 alloy is reliable in corrosive and high temperature environments. Not only is RA333® resistant to carburisation and thermal shock, this ultra-tough alloy also holds its strength over long period of time at temperature up to 1204°C. It presents the following characteristics:

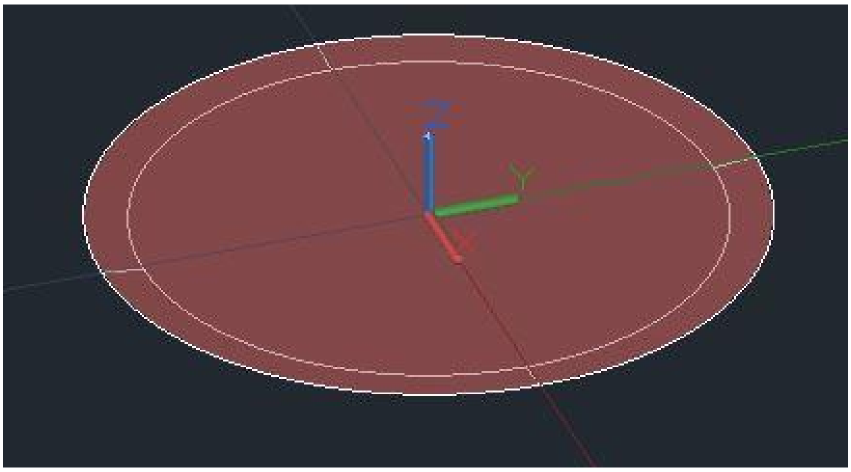
Density [kg/m^3]	8140
Melting range [°C]	1245-1300
Hardness [HRC]	94
Specific heat capacity [J/kg°C]	300
Ultimate tensile strength at 538°C [MPa]	589
0.2% yield strength at 538°C [MPa]	212
Minimum creep 0.0001%/hr at 538°C	NULL

Coefficient of thermal expansion at 538°C [µm/m°C]	15.48
Thermal conductivity at 538°C [kcal/(hr.m.°C)]	16.81
Modulus of elasticity at 538°C [GPa]	170

Three Auto-CAD sketches from three different view of the Drag plate only are reported below:







Using data from Auto-CAD it is then possible evaluate its mass:

RA-333 Density [kg/m^3]	8140
% of RA-333	5
Aluminium density [kg/m^3]	2700

% of aluminium	95
actual density	2972
Volume [m^3]	0.01
mass [kg]	29.72

EXTERNAL SKIN

This part of the lander was designed with the purpose of:

- protecting the sampling system and the pressure vessel from the ***oxidative enviroment***.
- ***damping the extreme external temperature*** during the science operation phase.
- ***give aerodynamics integrity*** to the lander during the descent phase.

It is made up of TI-6Al-4V alloy and the inner part is coated with 3 layers of kapton MLI. In doing so, pressure vessel, sampling system and sensors will not experience the actual temperature and oxidative enviroment present on Venus surface or they will, but for a shorten amount of time. Even though the temperature will increase this won't be a major problem.

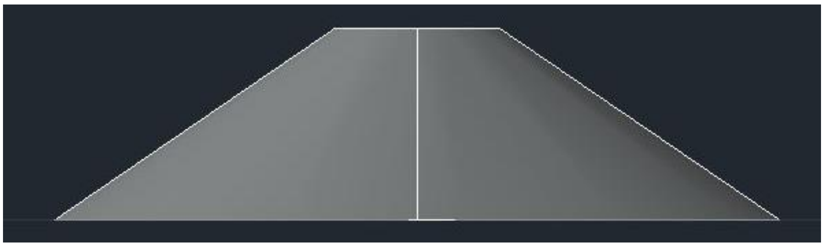
density [kg/m^3]	4429
melting range [°C]	1609-1660
hardness	HRB
Coefficient of thermal expansion at 316 °C, [µm/(m°C)]	9.9
Modulus of elasticity at 316°C [x10^5 MPa]	9.65

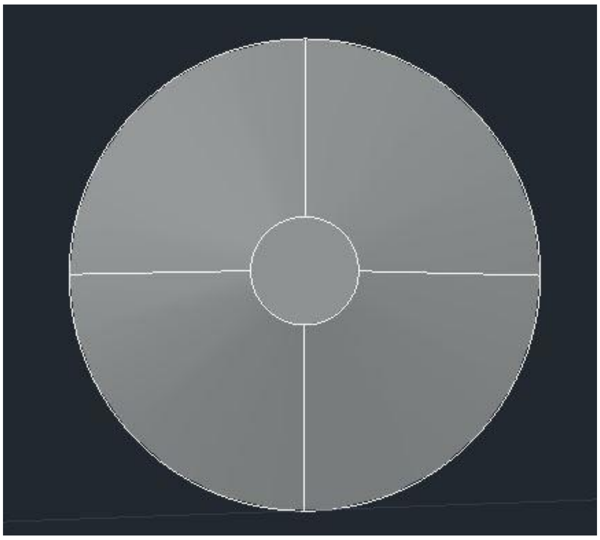
The TI-6Al-4V, in this case, was actually chosen for two main reasons:

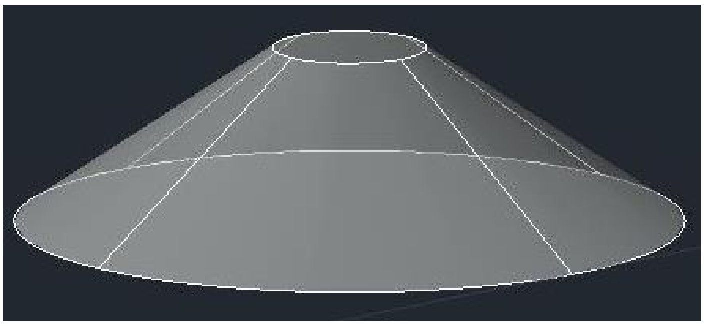
Specific heat capacity [J/kg°C]	526.3
Coefficient of thermal expansion at 538°C [µm/m°C]	9

These are two very good value.

Three Auto-CAD sketches from three different view of the Drag plate only are reported below:







Using data from Auto-CAD it is then possible evaluate its mass:

Density [kg/m^3]	4429
Volume [m^3]	0.1946
Actual % of material	5
mass [kg]	43.09417