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CTU
CZECH TECHNICAL
UNIVERSITY
IN PRAGUE

DIPLOMA THESIS ASSIGNMENT

Student: **Bc. Maude FOUQUET**

Study program: **N2307 Master of Automotive Engineering**

Field of study: **2301T050 Advanced Powertrains**

School year: 2016/2017

Title: **Design of systems used in vehicles for military application**

Assignment:

Compliance review and qualification of an oxygen charging system: Describe the oxygen charging system DO22A. Describe all necessary conditions (needed (requested) documents) for usage of this system in your concrete application you worked on.

Draft of a study process related to the rigging of a vehicle in order to demonstrate its ability to be air dropped: Describe the usage of your proposed system. Describe all necessary conditions which must be fulfilled to assure the possibility of given vehicle to be air dropped. Choose or design needed tray for given vehicle. Find in the model of a given car suitable places at the vehicle where can be taken support (snapping point) for fixing the car to the tray. Describe all necessary conditions which must be fulfilled by hitting the ground. Calculate needed parameters (resistance and necessary quantity) of the Carton shock absorber which will be used for damping in the rigging. Create models of interface parts between the Carton shock absorber and the vehicle to assure that vehicle will not be damaged after the impact on the ground. Create all necessary drawings for all designed parts.Create a tool (MS Excel file) to simplify this whole procedure for other vehicles.

Thesis extent: minimally 55 pages

Graphical extent:

Specialized literature list:

Supervisor: Ing. Ondřej Miláček

Specialist: Bruno Delannoy, Airborne Systems France SAS

Date of thesis assignment: 21 March 2017

Deadline of submission: 21 August 2017

The student acknowledges that he/she must elaborate the project by himself/herself, without any help except consultations with his/her supervisor. A list of used literature, other sources and names of consultants must be listed in the thesis.

I received the assignment on (date):

Student's signature

Doc. Ing. Oldřich VÍTEK, Ph.D.
Head of Department

Prof. Ing. Michael VALÁŠEK, DrSc.
Dean

L.S.

Prague, 10 March 2017

METHOD TO RIG A VEHICLE

By:

Maude Fouquet

Supervised by:

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Ing. Ondřej Miláček

AUGUST 21, 2017

CZECH TECHNICAL UNIVERSITY IN PRAGUE

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TABLE OF CONTENTS

TABLE OF FIGURES

Part 1: Introduction

In the French army, in operation, it's often necessary to drop some equipment (vehicles, munitions, food etc.) to success the mission. These equipments are dropped via a special plane from different height. They cannot be dropped without adding a certain form of protection, via shock absorbers and stowage of the equipment.

In my thesis I particularly pay attention to the dropping of vehicles. Vehicles are installed on platforms which are defined by military documents. The speed of the impact is controlled by the type and number of canopies installed on the vehicle and is included between 6 m/s and 8.5 m/s. As this speed is quite high, the vehicle has to be prepared before the dropping and amortized gradually not to be damaged. So, the organ and all the functions of the vehicle can be preserved.

All the actions which are necessary to prepare the vehicle for landing are called the rigging of the vehicle. They include the choices of the parachutes, the location and volume of shock absorbers, the stowage, and the fixation of parts of the vehicle (they can be dismantled in order to protect them).

My diploma thesis deals with the stowage of the vehicle on the platform and the amortizing. To amortize the vehicle, the French army uses CA14 which is a carton shock absorber with a honey comb structure, disposed under certain part of the vehicle. The aim of my thesis is to describe and implement a sustainable method which will permit my company to rig new vehicles in the simplest way possible, but with a technical guaranty on this rigging. My thesis includes the application of this method for a new French vehicle call VLFS (light vehicle of special forces), which is designed by RTD (Renault trucks Defense).

In another part of my thesis, I realised project management to support my company on the delivery of a system named DO22A (oxygen dispenser autonomous and air-transportable). For this, I wrote some reports concerning the security of the system, and I helped for the corrections on the all the justifications report of the system.

Part 2: The company

Chapter 2.1: Identity card of the company

Name: Airborne Systems France
SASU (Société par actions simplifiée à associé unique)
(Simplified joint-stock company)
Number of salaries: 4
Date of creation: 05-2013
President: Christopher ROWE
CEO: Bruno DELANNOY
Turnover in 2016: 1,684,984 €

Airborne Systems France is a company which has been created less than five years ago. Apart from the group's activities concerning parachutes, there is no activity recognized as specific to the Toulouse (French) site. The design office activity extends to various markets, mainly for defense [1].

Chapter 2.2: History of the company

1919: Leslie Irvin made the first parachute jump in history.

1939: Irvin Air Chute Company partners with GQ parachutes to supply the Royal Air Force. Birth of the X-type Paratroop Parachute Assembly, still used two decades later.

1945-1960: IRVIN-GQ becomes IRVIN Aerospace and participates in the development of the SR-71's first self-contained ejection seat system and brake parachute.

1960-1980: With the space conquest, IRVIN Aerospace gets the parachute markets from several NASA probes such as Pioneer for Venus or Viking for Mars. It is also IRVIN Aerospace that equips the American Space Shuttle with a brake parachute.

2000-2017: the subsidiaries of IRVIN Aerospace are grouped together to form Airborne Systems Group. IRVIN Aerospace is absorbed in Airborne Systems North America. Airborne Systems France was born in 2013 and is part of Airborne Systems Europe, whose activities are mainly concentrated in Llangeinor in Wales.

Chapter 2.3: The company nowadays

Airborne Systems Group today consists of 4 entities: two in North America, one in the United Kingdom and one in France.

Airborne Systems North America
5800 North Magnolia Avenue, Pennsauken, NJ 08109, USA
Tel +1.856.663.1275 | Fax +1.856.663.8146
3701 West Warner Avenue, Santa Ana, CA 92704, USA
Tel +1.714.662.1400 | Fax +1.714.662.1586

Airborne Systems North America Space and Recovery Systems
3000 West Segerstrom Avenue, Santa Ana, CA 92704, USA
Tel +1.714.868.3700 | Fax +1.714.668.0446

Airborne Systems Limited
Llangeinor, Bridgend CF32 8PL, UK
Tel +44 (0) 1656.727000

Airborne Systems France
16 bis rue Paule Raymondis, 31200 Toulouse, FRANCE
Tel +33 (0) 5.61.29.76.05 | Fax +33 (0) 5.61.23.77.04

The group produces several types of airborne and dropping equipment:

- Parachutes T-11 and LLP for infantry, MICROFLY, FIREFLY or DRAGONFLY personnel for loads up to 4.5 t per unit
- Automated GPS guidance system for parcel release
- Packaging accessories (e.g. load release)
- Oxygen distribution for high altitude jumps
- Parachutes for ejector seats
- Helicopter response equipment: suspension ropes, suspension Loads or drops
- Air and sea rescue equipment

The group operates throughout the product cycle: design, production, personnel training and maintenance. Airborne Systems has an ISO 9001:2008 certified center where personnel are trained in the use and handling (e.g. folding) of Airborne products. Located in Eloy Arizona the site is co-located with the largest sports parachuting center in the United States. This allows access to different infrastructures such as jump zones, a vertical wind tunnel, aircraft models etc.

Part 3: Method to rig a vehicle

Chapter 3.1: Prerequisite on dropping

3.1.A - Process of dropping

1. The rigged vehicle is placed into the aircraft. The platform allows the translation of the platform with rigged vehicle in the aircraft during the exit
2. The exit parachute, bonded to the platform, is dropped from the door, falls into the relative wind and opens. It extracts the vehicle out of the aircraft.
3. When the rear part of the platform crosses the floor of the cargo, a pedal rises and releases the exit of the parachute. Then, the main parachutes deploy.
4. The vehicle goes under canopies at a vertical speed included between 6 m/s and 8.5 m/s
5. At impact, the shock absorber, if properly sized will have absorbed all the energy at the moment when the wheels touch the platform
6. The load is released from its rigging and is ready for use.

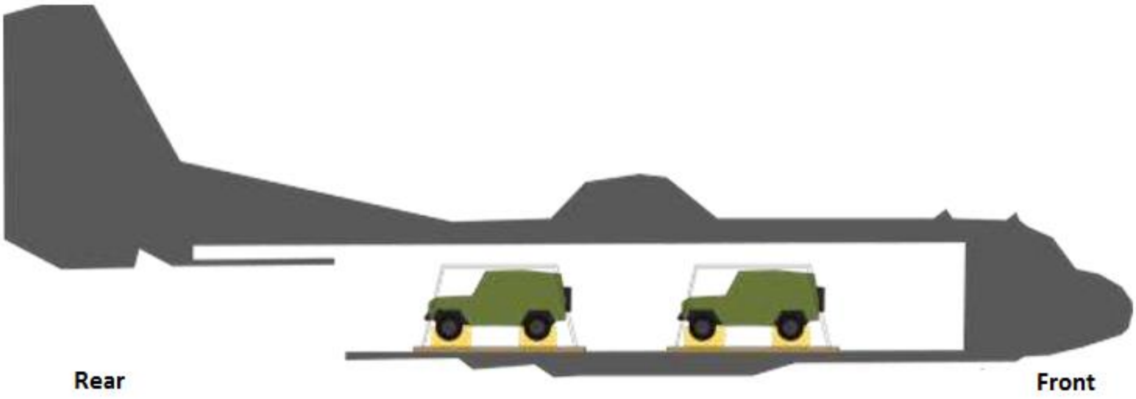


Figure 1: Arrangement of the vehicles in the aircraft

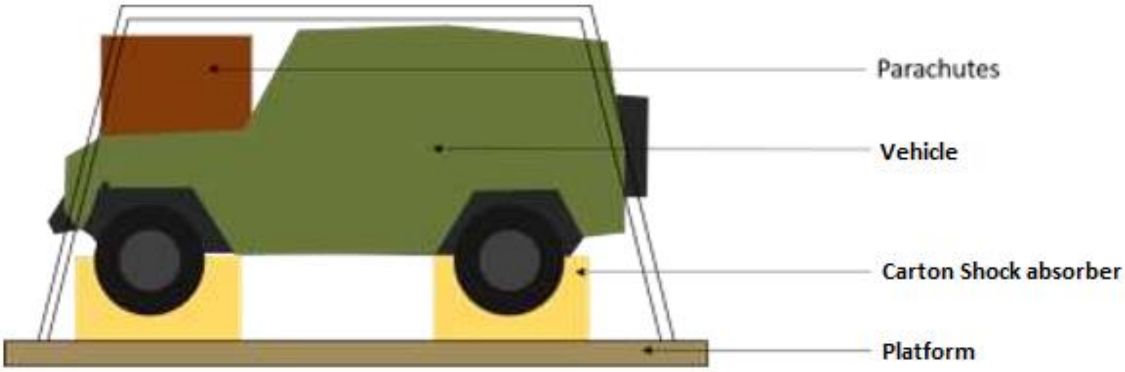


Figure 2: Rigged vehicle

3.1.B - Constrains about dropping

Several constraints have to be taken into account: the load being placed on the CA14, it is raised relative to the platform. In spite of this, it is necessary to fit into a template which will allow the load to be stowed and especially dropped from the aircraft's hold. The gravity center must be within a restricted area: 1 m 20 maximum height from the ground, 20 cm forward and 0 cm rearward from the center of the platform. The risk is to create a nose-up torque at the deployment of the output parachute, leading an uprising of the back of the platform and premature activation of the opening of the main sails, or collision with the upper cargo door.

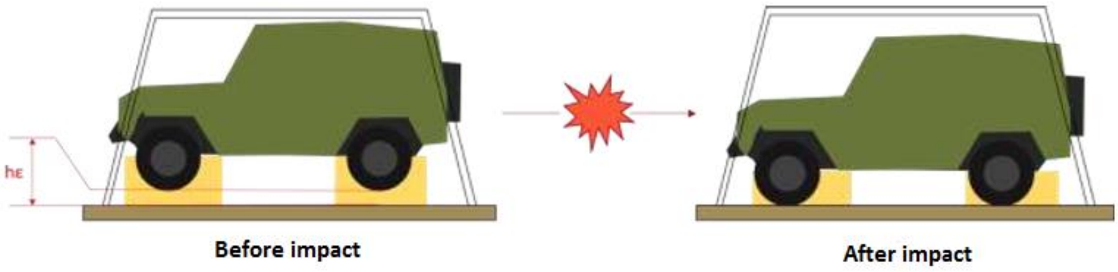


Figure 3: Rigged vehicle before and after impact

Chapter 3.2: Method to realize the rigging of a vehicle

3.2.A - Choices of the parachutes and of the platform

The choice of the parachutes and their number and the platform is the first action to do.

Five different platforms are used by the French military forces. There are constituted by one or several plates, and there are two different plates: PD8 and PD9.

You can find in annex I the description of those two plates. The dropping platforms are the following:

LTCO9: 1 plate PD8

LTCO10: 1 plate PD9

LTCO11: 2 plates PD8

LTCO12: 3 plates PD8 (used for VLFS)

LTCO13: 4 plates PD8

3.2.B - Gravity center and volumetric template

As the vehicle is dropped under parachutes, the center of gravity has to enter in a certain template. This template ensures a correct flight and that the angle that forms the platform when it touches the floor is negligible.

For similar reasons, the vehicle shall enter in a volumetric template. This template ensures that the vehicle is able to enter in the aircraft cargo, and that there will not be any interferences with the shroud linking the platform and the canopies of the parachutes.

As each batch has its own template which varies with different parameters, it's not possible to implement a common method that permits to place the vehicle on the platform. So, the position of the vehicle will be found case by case. However, to optimise the research of the position of the vehicle, the following reasoning can be followed:

Prerequisite: Own a mass balance of the vehicle (furnished by the designer or by the CAO model)

1. Determinate the fragile elements of the vehicle that will be compulsory disassemble
2. Replace those elements in the vehicle and calculate the new gravity center of the system
3. Place the gravity center of the vehicle in the middle of the template. The platform shall not be forgotten, because it creates a moment that makes changes over the centroid
4. Determine the elements of the vehicle that do not enter in the volumetric template
5. Establish a procedure of disassemble of those elements, if it's not possible to simply shift the vehicle to avoid this overtaking
6. Replaced the dissembled elements in the body of the vehicle
7. Calculate the new gravity center with the new position of these elements
8. If the centroid doesn't enter in the template, do again the procedure since the third step; add a ballast if necessary.

3.2.C - Stowage of the vehicle

Stowage requires attaching the load to the platform. To do this, we use straps of 3,500 decanewton (daN) (i.e. the strap resist to a force up to 3,500 daN), attached to specific points of the vehicle (fixing rings fixed to the chassis of the vehicle). Since the functional specifications impose loads factor, it is essential to define the correct stowage plan.

The attachment points of the platform are on the outer side rails, distributed every 12 cm. The strap is fixed to it by means of a link of resistance to the shear force of 5000 daN. Since the straps are doubled, it is this resistance which will be taken into account in the calculations as the limiting element.

For the VLFS, these load values are:

- 4.5 g longitudinal
- 3 g vertical
- 1.5 g lateral

To realize the sizing of the stowage I created an excel table, which is directly linked to the type of platform which is used. You can find in annex II the whole excel table.

The table includes values of the different attachment on the considerate platform. These values, represented by X, Y and Z in meters are the coordinates of the different attachment points in a referential where the center of the platform is the origin.

For example, for the VLFS, this is the LTCO12 (see figure 4) we can find on the excel table:

	longeron gauche (left girder)		
TROU (HOLE)	X (m)	Y (m)	Z (m)
1	2.54	1.33	0.1
2	2.413	1.33	0.1
3	2.286	1.33	0.1
4	2.159	1.33	0.1
5	2.032	1.33	0.1
6	1.905	1.33	0.1
7	1.778	1.33	0.1
8	1.651	1.33	0.1
9	1.524	1.33	0.1
10	1.397	1.33	0.1
11	1.27	1.33	0.1
12	1.143	1.33	0.1
13	1.016	1.33	0.1
14	0.889	1.33	0.1
15	0.762	1.33	0.1
16	0.635	1.33	0.1
17	0.508	1.33	0.1
18	0.381	1.33	0.1
19	0.254	1.33	0.1
20	0.127	1.33	0.1
21	0	1.33	0.1
22	-0.127	1.33	0.1
23	-0.254	1.33	0.1
24	-0.381	1.33	0.1
25	-0.508	1.33	0.1
26	-0.635	1.33	0.1
27	-0.762	1.33	0.1
28	-0.889	1.33	0.1

29	-1.016	1.33	0.1
30	-1.143	1.33	0.1
31	-1.27	1.33	0.1
32	-1.397	1.33	0.1
33	-1.524	1.33	0.1
34	-1.651	1.33	0.1
35	-1.778	1.33	0.1
36	-1.905	1.33	0.1
37	-2.032	1.33	0.1
38	-2.159	1.33	0.1
39	-2.286	1.33	0.1
40	-2.413	1.33	0.1
41	-2.54	1.33	0.1

Figure 4: Coordinates of the attachment points of the LTCO12

The table makes calculations for only one side of the vehicle, this is why only the left attachments are represented in the table. The results are multiplied by two, in order to find the right resistance values.

To use the table, you have first to imagine a coherent way of rigging of the vehicle. For this, a method consists in finding the number of necessary straps in the limiting dimension (the one which need the most important resistance) by multiplying the load value by the mass of the vehicle, then dividing this result by the resistance of one strap [2].

For example, the VLFS mass is 3800 kg, and the longitudinal load factor is 4.5 g. So

$$Nbr_{straps} = \frac{3800 \times 4.5}{5000} = 3.42$$

As this is a longitudinal effort, it can be in both front and rear directions, so we have to multiply by two this value. This give us a number of straps equal to seven to stow the VLFS. However, this includes that the straps are installed with an angle of zero degree, which is really not the case. If we consider in a first approximation an average angle of 45 degrees, we shall multiply this number by 1.41 ($\sqrt{2}$). As we take a certain margin, we will multiply by two again. Finally, we find an approximate number of 14 straps necessary to stow this vehicle.

Note: This first approach permits to determine an **approximate** number of straps. This number permits to realize the first stowage of the vehicle, that will be corrected with the use of the excel table.

The first action that has to be done is to enter the coordinates of the attachments of the vehicle (the vehicle should have been placed on the platform before the stowage is done). On this table, every coordinates are given in meters compared to the center of the platform.

Ring Nbr	Coordinates of vehicle stowage rings		
A1	2.47	0.36	0.74
A2	2.34	0.81	0.77
A3	1.1	0.93	0.59
A4	0.42	0.93	0.59
A5	-0.66	0.93	0.59
A6	-1.9	0.36	0.8

Figure 5: Coordinates of vehicles stowage rings

At each point, you must place one or two straps, which have to be more than one-meter long for practical reasons of establishment.

The table will not give by its own the location of the straps, but is able to verify that with a given configuration, the stowage will fit with the specifications.

After it, you have to place the coordinates of the attachments of the platform that linked the strap to the corresponding vehicle attachment point. If there are two strap on the same attachment point, you enter in the second column the coordinates of the second attachment point on the platform.

Hole Number	Fixing point on the platform			Hole Number	Fixing point on the platform		
	X (m)	Y (m)	Z (m)		X (m)	Y (m)	Z (m)
	2.667	0.98	0				
8	1.651	1.33	0.1				
6	1.905	1.33	0.1	20	0.127	1.33	0.1
11	1.27	1.33	0.1	26	-0.635	1.33	0.1
18	0.381	1.33	0.1	32	-1.397	1.33	0.1
	-2.667	0.98	0				

Figure 6: Coordinates of the attachment point of the platform

The last input data that has to be entered in the file are the mass of the vehicle and the aim of straps resistance.

Then, the vector and its Euclidean norm associated to each strap is calculated. It’s important to verify that each strap has at least approximately a length of 1 meter.

Vector associated to the strap			Length of the strap
X (m)	Y (m)	Z (m)	m
-0.197	-0.62	0.74	0.99
0.689	-0.52	0.67	1.09
-0.805	-0.4	0.49	1.02
-0.85	-0.4	0.49	1.06
-1.041	-0.4	0.49	1.22
0.767	-0.62	0.8	1.27

Figure 7: Calculation of the vector associated to the different straps

If we consider that we apply the maximal effort on each strap (i.e. the effort that correspond to the rupture of the strap), we can find the effort in daN that retain the considerate strap in each direction (X, Y, Z). The formula is: $\frac{Coordinate\ of\ the\ strap\ vector \times 5000}{Standard\ of\ the\ strap\ vector}$.

Maximum resistance of the strap according to direction (daN)		
X	Y	Z
-999.70	-3146.26	3755.22
3152.70	-2379.40	3065.76
-3931.51	-1953.55	2393.09
-4011.22	-1887.63	2312.35
-4273.03	-1641.89	2011.32
3019.88	-2441.10	3149.81

Figure 8: Maximum resistance of the straps in the three directions

When this value has been calculated for each strap in every direction, we can calculate the maximum resistance of the vehicle in four directions.

The first direction is the vertical one. The second direction is the lateral one, the vehicle has to be stowed left and right, but we consider only one side. Indeed, the left straps retain the vehicle in one direction and the right straps in another, and as the stowage of the vehicle is symmetric, it is not useful to do the calculation twice. The third and the fourth direction are the rear and front direction. In contrary to the lateral direction, the longitudinal one has to be calculated for the both sides because the stowage is not symmetric in this direction.

The maximum resistance of the stowage of the vehicle in the lateral and vertical direction is calculated by the sum of the maximum resistance of each strap.

As all the straps retain the vehicle in the vertical direction, you have to multiply by two the found number to find the final resistance of the vehicle.

In the lateral direction, it's not necessary to multiply by two as explained before.

In the longitudinal direction, the straps that are oriented in the front direction are split from the one that are oriented in the rear direction, and the resistance in each direction is multiplied by two because of the symmetry of the stowage.

The final table given in the following picture compare the value given by the functional specifications and the maximum value given by the current stowage. The excel file also give the safety coefficient in each direction.

If the stowage is not sufficient, the problem can be solved by several ways.

If the stowage is too weak in the lateral direction, you have to add some straps. Indeed, even if you displace the attachment point of the straps on the platform, the lateral coordinate will be the same or quite the same, so this will not change the total resistance of the stowage.

If the stowage is too weak in the longitudinal direction and in the vertical direction, you also have to add some straps. Indeed, if you move the location of several straps to increase the vertical direction, you will decrease the longitudinal one and vice versa (see figure 9).

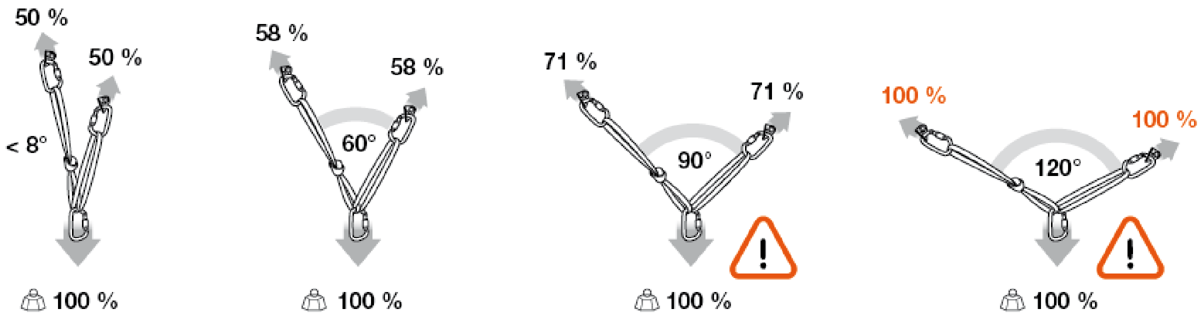


Figure 9: Percentage of effort recuperate by for strap for several angles

But if the coefficient of safety in one of the longitudinal or vertical direction is high enough and the one in the other direction is too weak, you can rearrange the straps to distance or close them in function of the result you want.

This whole procedure has to be adapted to the vehicle that is being rigged.

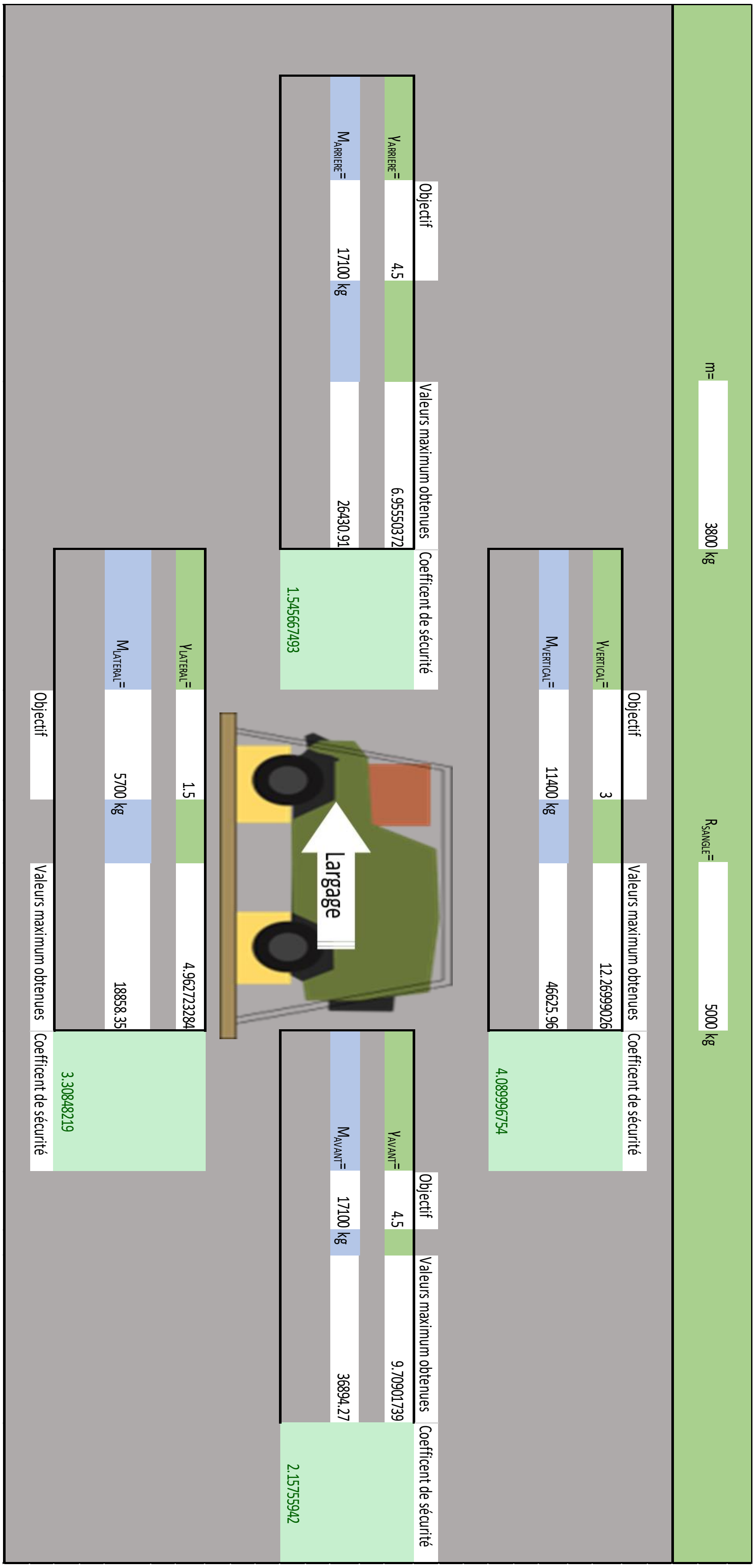


Figure 10: Recapitulation of the strength of the stowage

Before the stowage can be validated, the resistance of the platform attachment points has to be verified. Indeed, if two straps are installed one the same attachment point, as the resistance of a strap (5000 daN) is the same than the resistance of the attachment point, the latter is able to break.

To calculate the maximum resistance of the stowage of the vehicle, we have calculated the maximum resistance of each strap before breaking. Now by the same method, we have to calculate the real effort applied on each strap if the vehicle is submitted to the maximum acceleration given by the specifications. In other words, this calculation gives us the repartition of the effort in the stowage.

The formula for the real force applied on each strap is:

$$\frac{Aimed\ value\ of\ resistance\ for\ the\ vehicle\ \times Maximum\ value\ of\ resistance\ for\ a\ given\ strap}{Maximum\ value\ of\ resistance\ for\ the\ vehicle}.$$

To calculate the effort applied one each attachment point, we have to calculate the Euclidian norm of the vector for each strap and sum two standards if two straps are attached on the same attachment point.

Effort applied to the strap according to the direction (daN)			Effort applied to the strap according to the direction (daN)			Effort take per ring
X	Y	Z	X	Y	Z	(daN)
-646.8	-951.0	918.1	0.0	0.0	0.0	1471.6
1461.2	-719.2	749.6	0.0	0.0	0.0	1792.8
-2543.6	-590.5	585.1	1943.0	-520.9	516.2	2986.2
-2595.1	-570.5	565.4	1987.6	-491.4	487.0	2995.0
-2764.5	-496.3	491.8	1758.6	-622.4	616.8	3181.6
1399.7	-737.8	770.1	0.0	0.0	0.0	1759.7

Figure 11: Calculation of the resistance of the rings

To summarize the function of the excel table presented before, it permits to calculate the resistance of the stowage of the vehicle to given acceleration by entering:

- Mass of the vehicle
- Needed resistance to acceleration
- Coordinates of the straps on the vehicle and on the platform

Before validating the stowage of the vehicle, the last thing to verify is the interfaces between the straps and the vehicle. For this, it’s important to place the straps on the CAO file to verify that any parts of the vehicle are disturbing the disposition of the straps.

3.2.D - Surface of the carton and positioning of the stacks

3.2.D.i. Presentation

The method includes four steps.

- The first step permits to obtain a surface of carton with an average height.
- Then, when the disposition of the carton is done, the second step permits to verify that the repartition of the effort is correct and that the carton crushes nearly homogeneously.
- The third step permits to verify that the deceleration undergone by the vehicle is not too high, otherwise, the vehicle would be damaged.
- The fourth step permits to verify that the support polygon fit with the given template.

The aim of this verification is to ensure that the platform will not break when the vehicle touches the floor.

There are two types of carton shock absorber that exists. The difference is in the structure of the honeycomb meshes. The mesh A is used for the very heavy load, and the mesh B is most commonly used. So the following calculations are realised for the second type. The difference in the calculation is the value of the average pressure under which the carton crashes (P_{moy}). If the calculs wants to be applied for mesh B, the value of this pressure has to be replaced by the right one, but the procedure is the same.

3.2.D.ii. Bibliography

Between 1960 and 1975, the French military forces decided to start researches on new material to improve the capacity of dropping from military aircraft. The aim was to determine the ideal physical and mechanical characteristics of a shock-absorbing material allowing the dropping of loads of several tons. After several attempts, the material selected was the honeycomb structure carton CA14.

This material is:

- Light
- Cheap
- Easily storable
- Easily destroyed
- Able to support loads without sagging
- Capable of damping heavy loads contacting the ground between 6 and 8 m/s ensuring that this load do not undergo a deceleration of more than 40 g for about 20 ms.

Crushing of the carton:

Some tests have been carried out in order to test the mechanical properties of the carton. Fractions of honeycomb block were crushed at the rate of 100 mm/min. The curve giving the variation of the pressure as a function of the crushing has been recorded.

The curve below shows that the pressure necessary to initiate crushing of the carton, p_{max}, by buckling of the meshes, is slightly higher than the one required for the further crushing. The average pressure is obtained when the carton block has crushed for 10 percent of its volume.

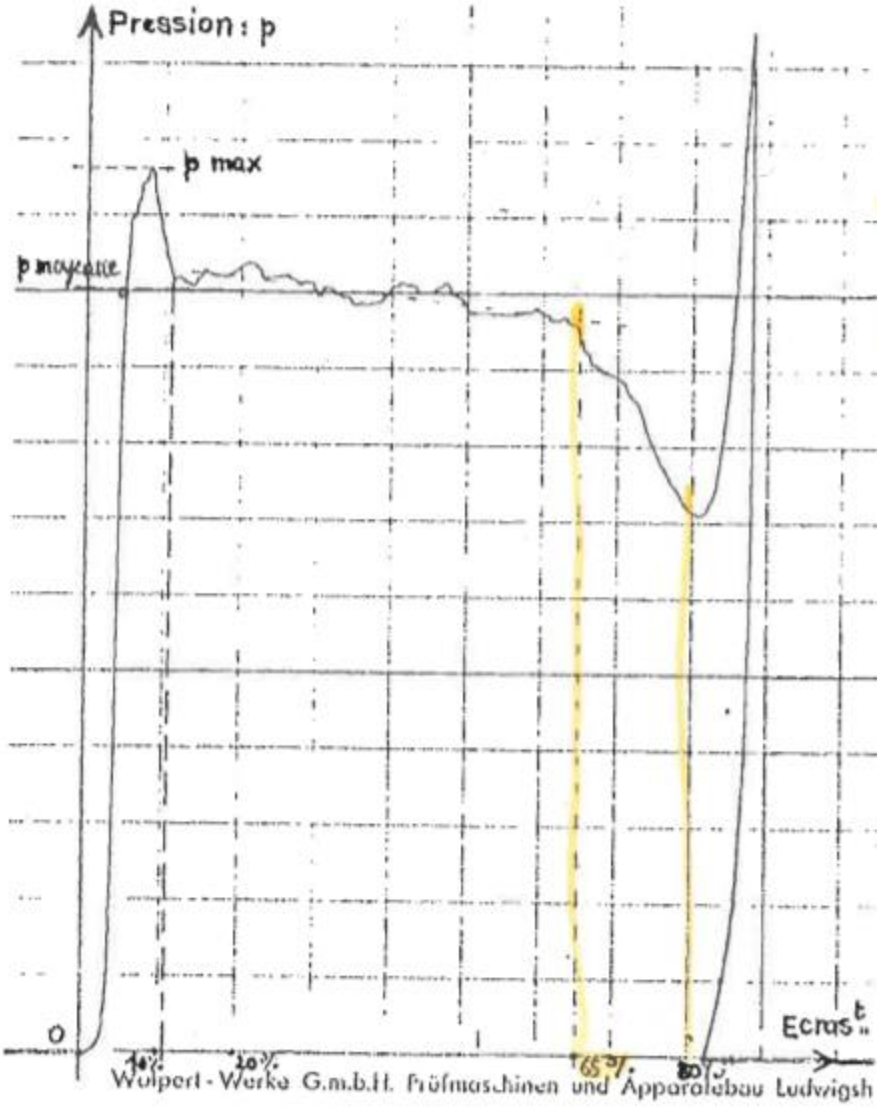


Figure 12: Necessary pressure to crush the carton

Then, the pressure decreases slightly to 65%, it then undergoes a significant decrease and reaches a minimum value for a crushing of 80%.

The meshes are then completely crushed. The shock absorber is then a compact mass of carton and no longer behaves as a shock absorber as such, but as a non-deformable solid. If the pressure is removed from the carton, it relaxes and regains height, in a phenomenon of oscillation and restores a part of the absorbed energy. There is then rebound of the load in case of drop. To avoid this phenomenon, the end of the damping should coincide with a crushing of the stacks of CA14 less than 80%.

These tests made it possible to determine the value of the average pressure under which the carton crushes. The compression was carried out with thirds of blocks placed between two plates ensuring a regular crushing.

The compression rate was 100 mm/min. The table below summarizes the values of the pressure recorded for 50% of crushing of the cartons

2310	2640	2620
2620	2160	2300
1960	2260	2220
2040	2160	1940
1800	2080	1860
1960	2200	2180
2400	2040	Average : 2184 daN

We will consider that the average pressure to crush the carton is named $P_{moy} = 2$ bars.

3.2.D.iii. First step: Determination of the surface of carton

Method to determine the surface of carton

The aim of this step is to theoretically determine the volume of carton required to reduce sufficiently the acceleration due to the shock by dissipating the energy acquired during the fall over a minimum braking distance.

The total energy contained in the platform is given by the equation:

$$E_{total} = \frac{1}{2} \times M \times {V_0}^2 + M \times g \times h_\varepsilon$$

Where:

- M is the mass of the load [kg]
- V_0 the speed of the load when the platform touches the ground [m/s],
- g the gravitational constant [m/s^2],
- h_ε the total displacement (the deformation of the carton) [m].

The efficiency of the damper depends on the working volume (given by h_ε, S, the surface of carton) and the average pressure P_{moy}.

The work of the shock absorber W_a is given by:

$$W_a = P_{moy} \times h_\varepsilon \times S$$

If the carton shock absorber is correctly sized, the whole energy is recuperated by the deformation of the carton, so we have:

$$W_a = E_{total}$$

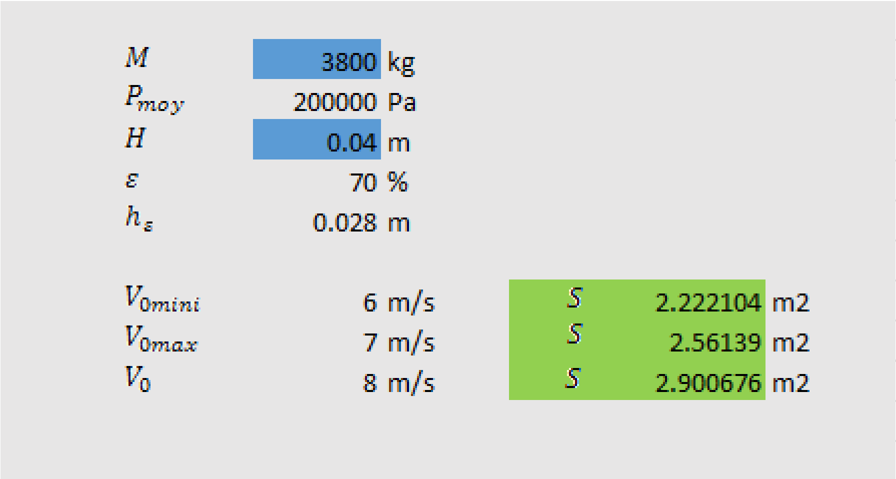
$$P_{moy} \times h_\varepsilon \times S = \frac{1}{2} \times M \times {V_0}^2 + M \times g \times h_\varepsilon$$

So,

$$S = \frac{M}{P_{moy}} \left(\frac{V_0}{2h_\varepsilon} + g \right)$$

As we know the mass, the average pressure, the speed of impact, if we assume that the crushing percentage of the carton is 70%, we can deduct the surface of carton required.

An Excel table has been created to easily permit to enforce this formula.



M	3800	kg			
P_{moy}	200000	Pa			
H	0.04	m			
ε	70	%			
h_ε	0.028	m			
V_{0mini}	6	m/s	S	2.222104	m2
V_{0max}	7	m/s	S	2.56139	m2
V_0	8	m/s	S	2.900676	m2

Figure 13: Excel table calculating the surface of carton

The table gives the surface of carton required for three different speed of landing, 6 m/s, 7 m/s and 8 m/s.

When the surface of the carton has been calculated, the number of loaves needed can be calculated. Indeed, the surface of one block of carton is equal to 0.33 m^2 (0.33 x 1 m).

$$Nbr = \frac{S}{0.33} \times H \times 100$$

$H \times 100$ represents the number of blocks stacked in average.

When the number of blocks required has been determinded, the company that has designed the vehicle will give the location on the car, where carton could be placed.

Verification of the surface calculator

To verify the accuracy of the tool, I used the existing database of rigged vehicle and I compared the surface given by the excel table and the real quantity of carton shock absorber used.

I divided the database in eight categories by realizing an average of vehicle with approximately the same masses.

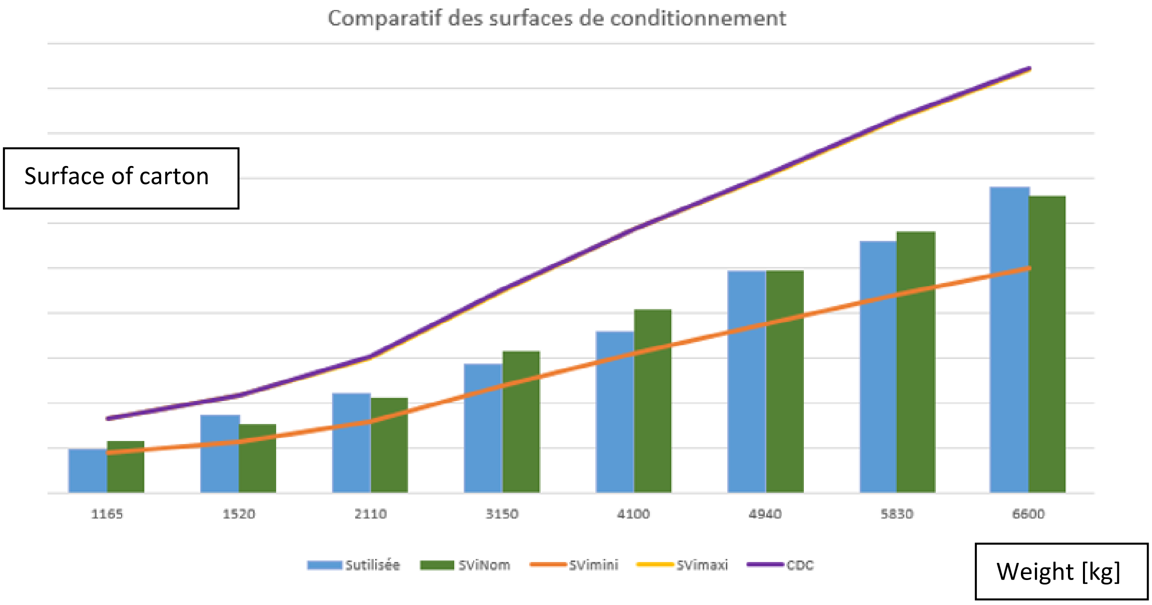


Figure 14: Comparison of surfaces of carton

The graph 13 above shows that the used surface of carton shock absorber (blue stack) is not far away from the surface calculated by the tool (green stack) for a speed of landing of 7 m/s. The orange and the violet curve represent respectively the surface calculated by the tool for the minimal and respectively the maximal speed of landing.

The conclusion of this study is that with differences of less than 10%, we decided to validate the tool. Moreover, the biggest differences are picked up for vehicles with very specific forms (boats, grader).

3.2.D.iv. Second step: Method to verify the positioning of the stacks

First approach

In this work, I assume that the position of the point of gravity in transversal direction is directly (or very close) to the middle of the car and rotation around longitudinal axis can be neglected. So the calculations are only taking in account the rotation around transversal axis (displacement at the right and left side is equal). Thus, I work with a two dimensions (2D) model [3][4].

We consider a mass M, which falls on a stack of carton. The surface of the carton is S_c. We consider that the effort is applied on one point.

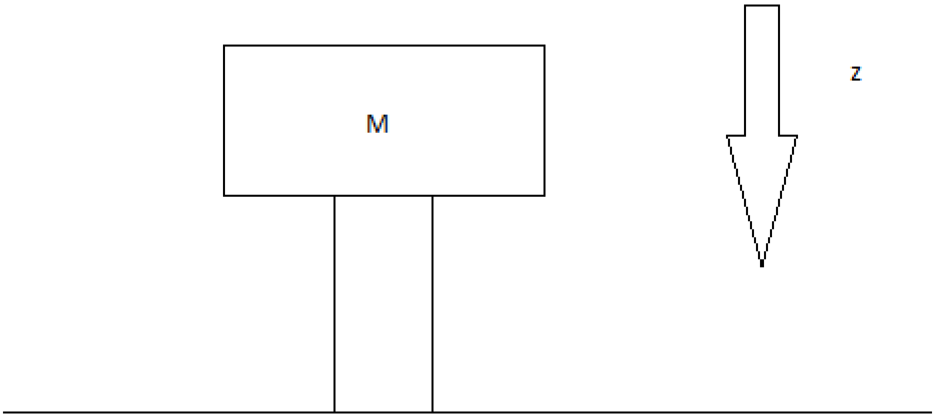


Figure 15: Sketch of a mass on one stack of carton

We consider the displacement u [m].

The derivate of the displacement, $\dot{u}$ [m/s], is the speed of the crushing of the carton.

We consider F_c [N], the strength applied on the carton.

K is the stiffness of the dampers of the vehicle. In the following step, K is equal to zero, so we neglect the impact of the vehicle dampers.

g is the gravitational acceleration [m/s^2].

M represents the mass of the vehicle [m].

$P_{moy}$is the average pressure necessary to crush the carton [Pa].

$$M \times \ddot{u} = M \ \times g - F_c - K \times u$$

$$F_c = S_c \times P_{moy}$$

$$M \times \ddot{u} = M \ \times g - S_c \times P_{moy} - K \times u$$

When $t = 0,\ \dot{u} = \ V_0$

If $K = 0$

$$\dot{u} = \left(g - \frac{S_c}{M} \times P_{moy}\right) \times t + V_0$$

$$u = \frac{1}{2}\left(g - \frac{S_c}{M} \times P_{moy}\right) \times t^2 + V_0 \times t$$

Second approach

Now, we consider that the vehicle is placed on two carton stack. We consider that the vehicle is balanced on the y axis. As the carton shack are quite thin, they are designated by their medium abscissa. G is the gravity center of the vehicle.

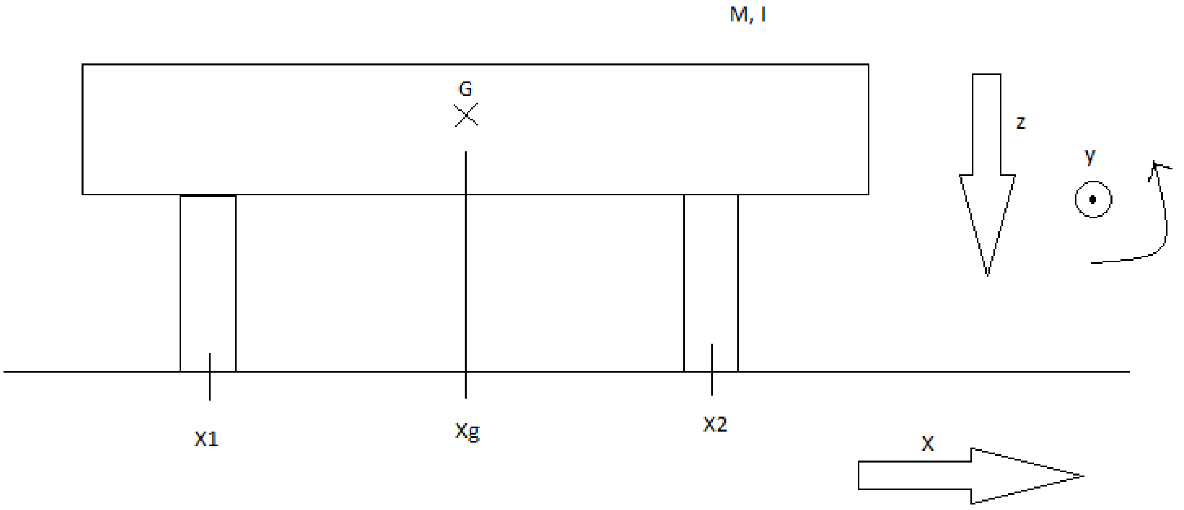


Figure 16: Sketch of a mass on two stack of carton

x_g [m] is the abscissa of the gravity center and $x_i$is the abscissa of the middle of the different carton shack.

φ [rad] is the angle of the vehicle compared to the horizontal axis.

I [kg.m2] is the moment of inertia about the y-axis in G

$$M \times \ddot{u_g} = M \ \times g - F_{c1} - F_{c2}$$

$$M \times \ddot{u_g} = M \ \times g - S_{c1} \times P_{moy} - S_{c2} \times P_{moy}$$

$$\dot{u_g} = \left(g - \frac{S_{c1} + S_{c2}}{M} \times P_{moy}\right) \times t + V_0$$

For $\dot{u_g} = 0$, $t_0 = -\frac{V_0}{g - \frac{S_{c1}+S_{c2}}{M} \times P_{moy}}$

t_0 is the time during the impact and the final crushing of the carton.

We are looking for $u_g(t_0)$ which is the final vertical displacement of the gravity center.

$$u_g = \frac{1}{2}\left(g - \frac{S_{c1} + S_{c2}}{M} \times P_{moy}\right) \times t^2 + V_0 \times t$$

Now, we have to obtain the final angle of the platform, to determine the displacement for the first and the second carton stack.

$$I \times \ddot{\varphi} = F_{c2} \times (x_2 - x_g) + F_{c1} \times (x_1 - x_g)$$

$$I \times \ddot{\varphi} = S_{c2} \times P_{moy} \times (x_2 - x_g) + S_{c1} \times P_{moy} \times (x_1 - x_g)$$

$$\dot{\varphi} = \left(\frac{S_{c2} \times (x_2 - x_g) + S_{c1} \times (x_1 - x_g)}{I}\right) \times P_{moy} \times t$$

For now, we consider that the angle of impact is equal to zero.

So, $\varphi = \frac{1}{2}\left(\frac{S_{c2} \times (x_2 - x_g) + S_{c1} \times (x_1 - x_g)}{I}\right) \times P_{moy} \times t^2$

With $\varphi(t_0)$, we can determine the displacement of the first and the second carton stack

Third approach

The hypotheses are the same than in the second approach, but we now consider a number n of carton stack. By the same method than before, we can write the following equations:

$$M \times \ddot{u_g} = M \ \times g - \sum_{i=1}^{n} F_i$$

$$u_g = \frac{1}{2}\left(g - \frac{\sum_{i=1}^{n} S_{ci}}{M} \times P_{moy}\right) \times t^2 + V_0 \times t$$

$$I \times \ddot{\varphi} = \sum_{i=1}^{n} F_{ci} \times \left(x_i - x_g\right)$$

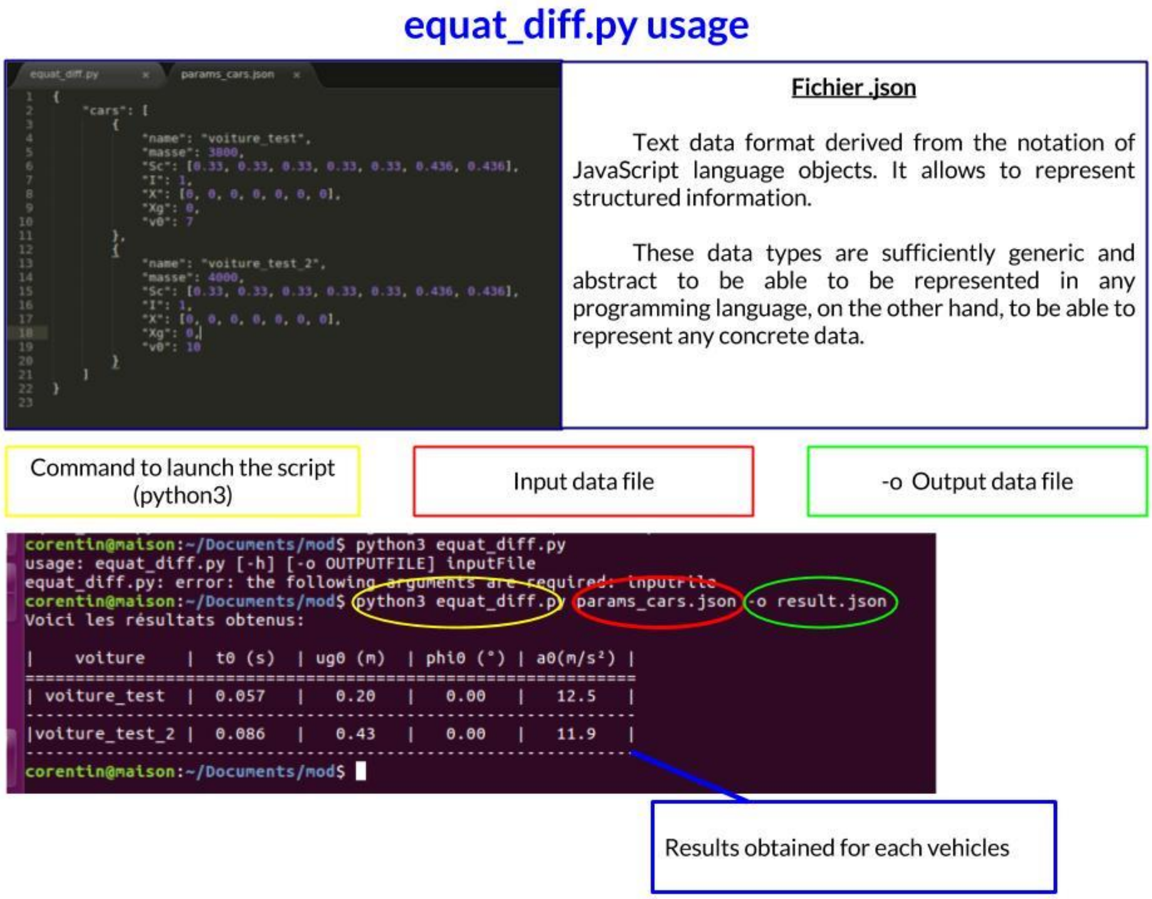
$$\dot{\varphi} = \left(\frac{\sum_{i=1}^{n} S_{ci} \times \left(x_i - x_g\right)}{I}\right) \times P_{moy} \times t$$

$$\varphi = \frac{1}{2}\left(\frac{\sum_{i=1}^{n} S_{ci} \times \left(x_i - x_g\right)}{I}\right) \times P_{moy} \times t^2$$

Implementation of a python program

To simplify the application of the method, I wrote a python program, that permit by creating a json file with the different characteristics of the vehicle to recuperate the behaviour of the vehicle at the end of the impact. You can find in annex III the python code.

It's possible to enter different characteristic for the vehicle in the same json file. This permits to envisage that the vehicle could be dropped with different mass configuration (for example, mass can be added by the transportation of more fire arms or ammunitions)



```
{
    "cars": [
        {
            "name": "voiture_test",
            "masse": 3800,
            "Sc": [0.33, 0.33, 0.33, 0.33, 0.33, 0.436, 0.436],
            "I": 1,
            "X": [0, 0, 0, 0, 0, 0, 0],
            "Xg": 0,
            "v0": 7
        },
        {
            "name": "voiture_test_2",
            "masse": 4000,
            "Sc": [0.33, 0.33, 0.33, 0.33, 0.33, 0.436, 0.436],
            "I": 1,
            "X": [0, 0, 0, 0, 0, 0, 0],
            "Xg": 0,
            "v0": 10
        }
    ]
}
```

Fichier .json

Text data format derived from the notation of JavaScript language objects. It allows to represent structured information.

These data types are sufficiently generic and abstract to be able to be represented in any programming language, on the other hand, to be able to represent any concrete data.

```
corentin@maison:~/Documents/mod$ python3 equat_diff.py
usage: equat_diff.py [-h] [-o OUTPUTFILE] inputFile
equat_diff.py: error: the following arguments are required: inputFile
corentin@maison:~/Documents/mod$ python3 equat_diff.py params_cars.json -o result.json
Voici les résultats obtenus:

|    voiture    |  t0 (s)  | ug0 (m)  | phi0 (°) | a0(m/s²) |
==============================================================
| voiture_test  |  0.057   |   0.20   |   0.00   |   12.5   |
--------------------------------------------------------------
|voiture_test_2 |  0.086   |   0.43   |   0.00   |   11.9   |
--------------------------------------------------------------
corentin@maison:~/Documents/mod$ █
```

Figure 17: Usage of the python program

Verification of the second step

Introduction

To be used in real cases, the analytic method used to determine the positioning of the stack has to be certificated. For this, I imagine two types of verifications.

The first one is to realize elementary trials, to validate the carton behavior. The second one is to apply the method on already existing rigging and to compare the result with the results that were found on these vehicle dropping.

Elementary trials

Presentation

To realize these trials, I collected eight weights of 25 kg each, I also had lots of CA14 that are used for the dropping of materials and a forklift to lead the loads to a certain height to represent a drop.

Figure 18: Realisation of the trials

As it seems quite difficult to drop a load without any parachute ensuring that the load touches the floor with an angle equal to zero, I decided to place the carton shock absorber directly on the floor, to place a distributor (piece of plywood) and to make the load fall on this structure. The distributor ensures that the effort created by the load will be uniformly distributed on the carton.

To realize the trials, we linked four weights with different halyards. First, we put two weights on a piece of plywood, that we cut to the right dimension. Then we drilled six holes on this piece of plywood to maintain the weight on the plywood.

Figure 19: Realisation of the weight

As we don't own any speed sensor, I determined the speed of impact, considering a free fall without any friction forces (as the weight is very dense, they can be neglected).

As we measured for each trial the weight and the height, we determined the speed of impact V_0 [m/s] by the formula:

$$V_0 = \sqrt{2 \times g \times Z_0}$$

Where Z_0 [m] is the initial height of the charge and $g = 9.81$ m/s^2 is the gravitational constant.

NB: The height of the fall has been measured from the top of the weight plywood and the floor. As the carton was still disposed on the floor and that another piece of plywood was on the carton, we have to remove the height of the carton and two times the height of the plywood to determine the speed of impact.

Post treatment

We realized six trials with the previous method. You can find in annex IV the photos of the trials.

The following table present the initial values of each trial.

Number	Weight (kg)	Height (m)	Number of stacks	Surfaces of stack (m^2)
1	103.5	2.57	1	0.11
2	103.5	1.87	1	0.11
3	103.5	2.57	1	0.33
4	103.5	2.57	1	0.22
5	103.5	2.57	1	0.22
6	103.5	2.37	3	0.11

Then, we analytically calculated the speed of impact:

Number	V_0 (m/s)
1	7.1
2	6.05
3	7.1
4	7.1
5	7.1
6	6.88

The aim of the trial is to correlate the analytical way of calculation of the displacement, so for each trial, I calculated the theoretical displacement using the method of the first step. Then I measured on each carton stack the average displacement.

The results are presented on the following table:

Number	u_{theo} (cm)	u_{trial} (cm)	Percentage of mistake (%)
1	12	4.25	64
2	9	3	66
3	4	1.5	62
4	6	2	66
5	6	2.15	66
6	12	5	58

Several conclusions can be reached from these trials.

1. In general, we see that the analytical displacement found is approximately 3 times higher than the one found by trials.

2. For the first trial, the displacement founded is higher than the actual height of the carton (10cm). This is normal, because the carton in the trial has been on one side totally crushed by the fall of the load.
3. These trials give us a tendency, but are not really exploitable because we can see on the picture, that we were unable to distribute the efforts correctly on the carton stack.

However, we know that in the analytical analysis, we considered that the carton was crushing at an average pressure of 200 000 Pa. In the graph (number 11) of the variation of pressure in function of displacement, we see that there is a P_{max}which is higher than P_{moy} which is necessary to initiate the crushing of the carton. This is a potential explanation of the results.

Moreover, the displacement of the carton is measured after the trials. But the carton has a damped behaviour, so it has a tendency to regain volume after the load has been retire from it. This is another reason that give sense to our trials.

Second trials

Before trying to correct my analytical method, I decided to make another tests, on a more equipped test bench, in order to obtain more valid results.

For this I asked an external company, that own that kind of test bench. The bench is constituted of a load, guided in the z axis by two wire cables. The load is two times drilled, and when it is released, it goes down following the cables, that ensure that the load touches the carton with a close to zero angle.

The parameters used for these trials are the following one:

- The falling mass is equal to 122 kg
- The dimension of the carton on the floor is 1*0.33*0.1 m^3 (L*l*h)
- We are looking for a speed of impact of 5 m/s, so with the formula $H = \frac{V^2}{2 \times g}$, with V the speed of impact, and g the gravitational constant, we find a height of fall equal to approximately 1.27m. This speed of impact will be verified at each fall, thanks to the speed sensor located on the test bench.

Figure 20: Calculation of the crushing of the carton

The results found are given in the following table:

Number	Speed of impact (m/s)	Displacement (m)
1	5.03	0,042
2	5.01	0,047
3	5.03	0,045
4	5.01	0,045
5	5.00	0,045
6	5.03	0,059

We can see that the result of the sixth trial is far away from the others, so I will neglect this result for the analysis. However, this result proves that the carton is a delicate material whose properties can be easily modified by external parameters that we don't generally control (for example humidity changes a lot the behaviour of the carton).

If I apply this trial to the analytical method, it gave me a displacement of 7.3 cm, whereas the real displacement is included between 4.2 and 4.7cm. This highlights that the analytical method gives a displacement higher than the real one, but the gap is lower than with the first trials. This can be explained by the fact that the displacements are calculated at the end of the impact but with the load still present on the carton, which consequently can't take back volume, as I explained in the analysis of the first series of trials.

With the video of the trial, I highlight the fact that the carton followed an oscillatory phenomenon. This means that the carton takes back a lot of its volume (approximately 50% of the crush volume). As my analytical method don't take in account this oscillatory phenomenon, I will consider that the analytical method I present above is correct and that it can be used to rig new vehicles.

I talked about the verification with old rigging of vehicles. Unfortunately, the French army wasn't able to furnish me those kind of information, so I couldn't realize this verification.

3.2.D.v. Third step: Deceleration applied to the vehicle

The aim of this step is to calculate the deceleration applied to the vehicle. As we know the duration of the deceleration, and the length of the displacement and the initial speed of landing, the formula is the following one:

$$a = \frac{V_0}{t_0}$$

a is negative, because this is a deceleration and is expressed in m/s^2.

$1\ g = 9.81$ m.s^{-2} so the number of g that the vehicle support is equal to $\frac{a}{9.81}$.

3.2.D.vi. Fourth step: Support polygon

In the specifications, we also have to verify the "polygone d'appui" (support polygon).

This polygon must enter in a template which is described in the following graph:

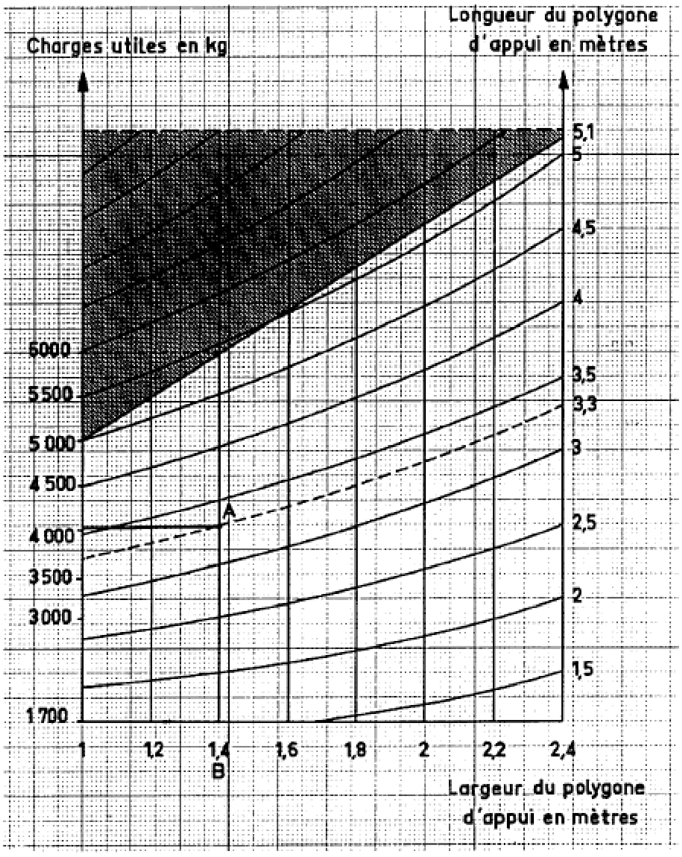


Figure 21: Verification of the support polygon

The departure of this abacus is the weight of the vehicle, for a minimal width of 1 meter, correspond a minimal length, following the curve. If the width is longer, the minimal length decreases and correspond to the intersection between the weight and the width.

3.2.E - Interfaces between the vehicle and the carton

As the chassis of the vehicle is not flat, it's important to realize interfaces between the chassis and the different stack of carton. There is no specific method to realize these interfaces, because it depends on the quantity of carton that has to be placed, the chassis of the vehicle and other parameters.

3.2.F - Application of the method to the VLFS

3.2.F.i. Choices of the parachutes and of the platform

The platform LTCO12 has been chosen by the company that design the car to realize the rigging of the VLFS.

The LTCO12 platform is a basic platform intended for the release by ejection of heavy equipment through the axial door of an aircraft. It is made up of:

- a platform assembly;
- a suspension assembly
- a traction assembly
- a set of lashing
- a parachute liking and holding assembly
- a transport assembly

Packaged for transport and storage, the LTCO12 lot is in the form of a platform, a parachute platform and a box containing all the other components.

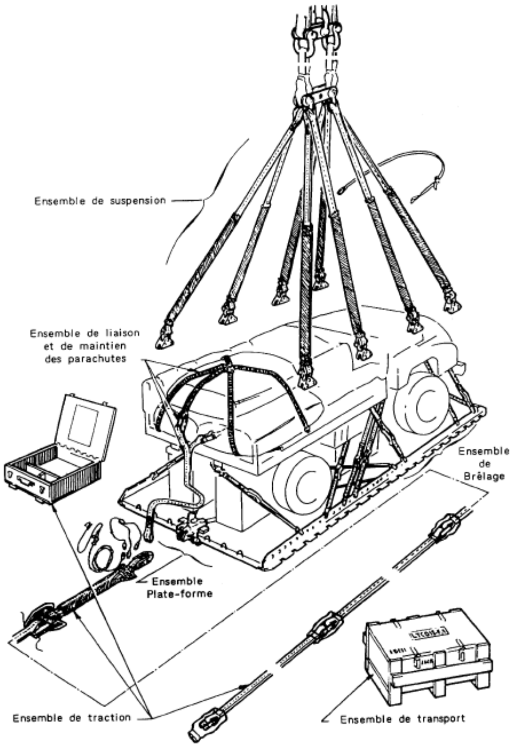


Figure 22: Presentation of the LTCO12

The dimensional characteristics of the VLFS are not yet fixed and the study is based on the information and numerical models transmitted by Renault Truck Defense.

It is retained that the GVWR is 4,200 kg and that the maximum weight of the air-ballistic vehicle is 3,800 kg. However, this mass may be variable and the conditioning must be able to withstand a measured variation.

In view of this mass and the one of the LTCO12 (class 600 kg), it is proposed a configuration of parachutes of load with four PL11, in order to favor a reduced landing speed while having a comfortable margin to take into account the mass of the complementary lot.

3.2.F.ii. Gravity center and volumetric template

In the direction of the height, the volumetric template for the LTCO12 (included parachutes) is:

- 2.40 m for L ≤ 6 m,
- 2.30 m for L > 6m.

In the transversal direction, due to the beam formed by the suspension slings, the width of the loads placed on the platforms must lie within the limits defined by the following figure:

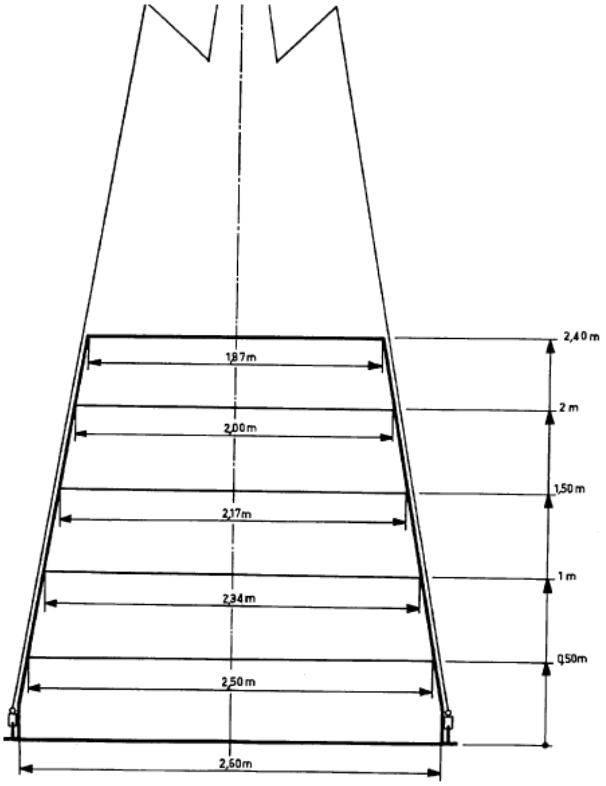


Figure 23: Transversal template of the LTCO12

In the longitudinal direction, the front and rear overhangs are limited to 0.90 m at an angle of 30 °, resulting in a limitation to 2.30 m in height when the overall length exceeds 6 m.

As the considered mass is equal to 3,800 kg, it will therefore be sought to place the vehicle as high as possible (see figure 23), within the limit mentioned above, so as to position a sufficient height of damping carton.

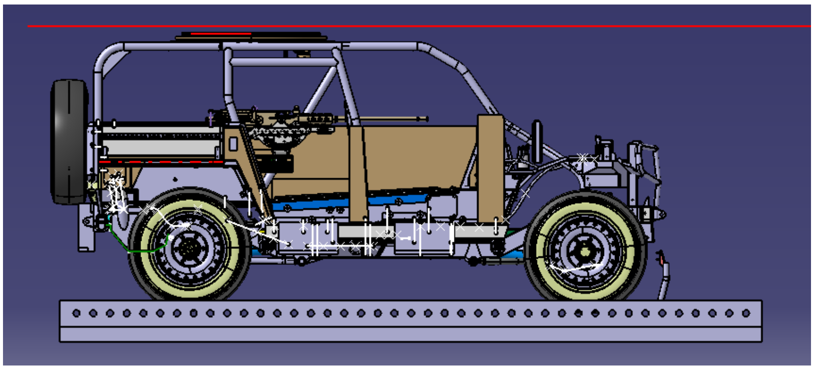


Figure 24: Positioning of the vehicle on the platform

In this configuration, the wheels will be at the limit of contact with the upper part of the platform and the shock absorbers of the VLFS will be relaxed to the maximum. This will allow the carton to be crushed to a maximum height of about 20 cm, parallel to the action of the suspension.

The parachutes cannot be positioned on the hood due to their volume (1,800 x 1,300 x 900 mm^3).

The maximum length allowed is 6 m, with deportations. The burden will be built using the authorized deportation. For this:

- the VLFS will be positioned as far ahead as possible to allow the shock-absorbing carton to be placed under the rear of the vehicle (the spare wheel is 6 cm above the platform);
- the parachutes will be positioned on a support stowed on the vehicle and the platform. (see figure 24)

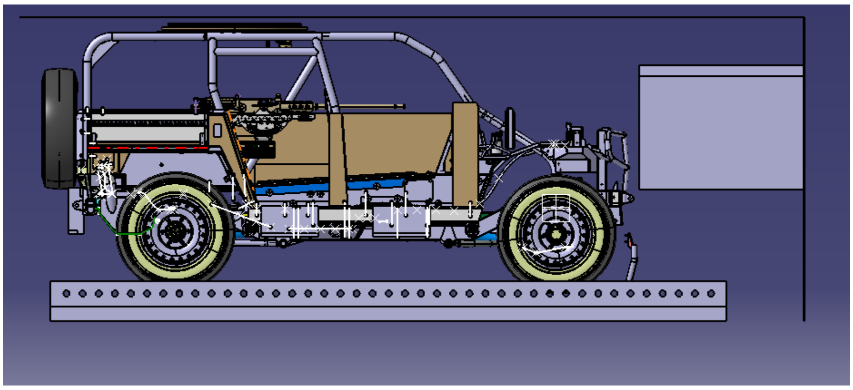


Figure 25: Positioning of the parachutes on the rigging

Due to the identified interference, it will be necessary to remove / fold down the following elements to meet the width requirements (see figure 25):

- wing mirror,

- side panels (interference in open or closed position),
- spare wheel and lateral support.

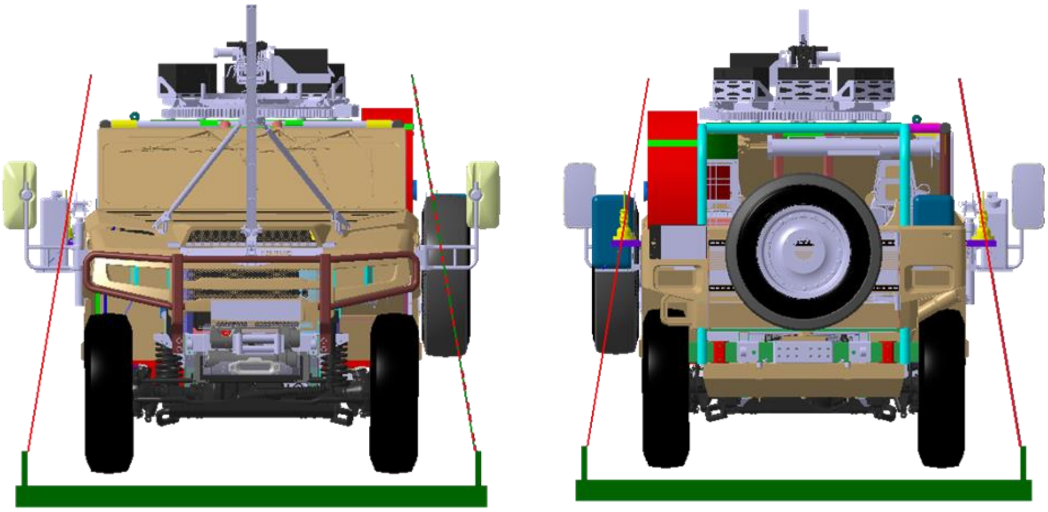


Figure 26: Interferences between the rigging and vehicle equiment

The center of gravity (CoG) of the load (with parachutes) may be offset from the center of the platform by a maximum of:

- 0.20 m forward,
- 1.20 m upwards,
- 0.10 m laterally.
- No offset is allowed backwards.

In height, the COG must be at a lower height or, at most, equal to half the height of the packed load and provided with its load parachutes.

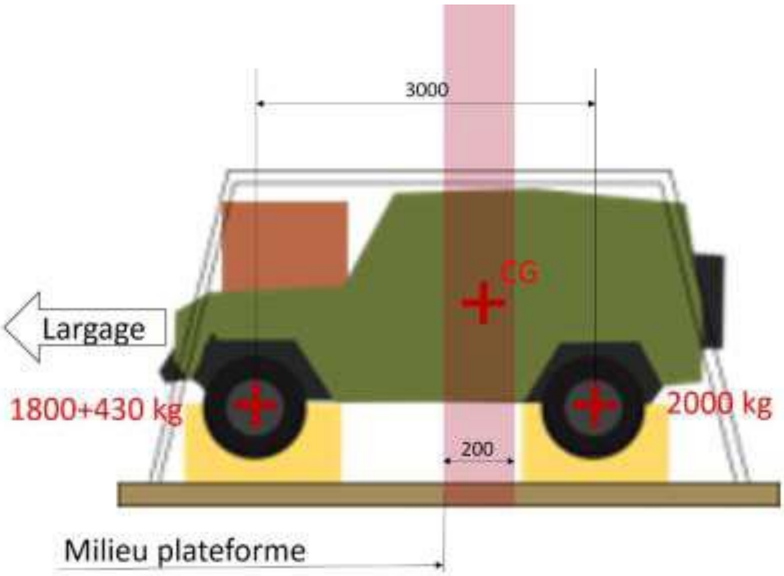


Figure 27: Constrains about Gravity Center

The two schemes following (figure 27) represents the mass balance given by Renault Trucks defense for two different configurations of the VLFS.

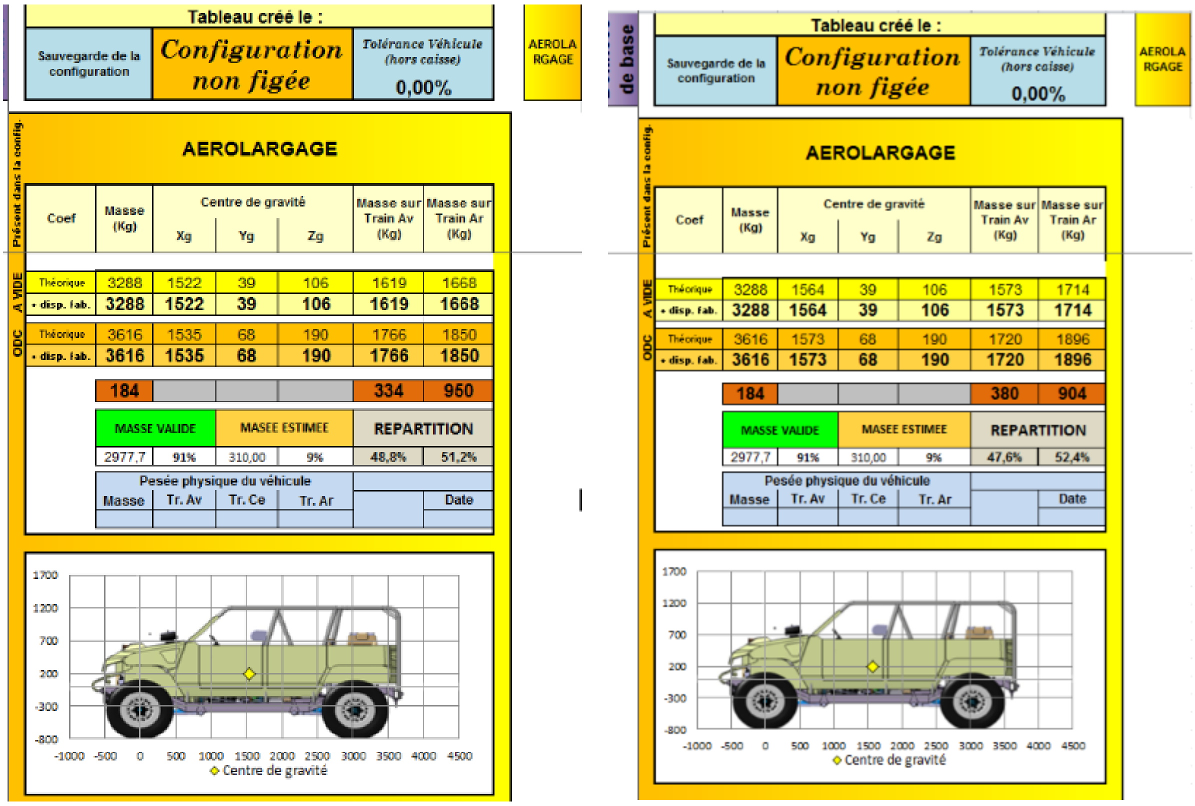


Tableau créé le :

Sauvegarde de la configuration	Configuration non figée	Tolérance Véhicule (hors caisse) 0,00%

AEROLA RGAGE

Présent dans la config.

AEROLARGAGE

	Coef	Masse (Kg)	Centre de gravité Xg	Yg	Zg	Masse sur Train Av (Kg)	Masse sur Train Ar (Kg)
A VIDE	Théorique	3288	1522	39	106	1619	1668
	+ disp. fab.	3288	1522	39	106	1619	1668
ODC	Théorique	3616	1535	68	190	1766	1850
	+ disp. fab.	3616	1536	68	190	1766	1850
		184				334	950

MASSE VALIDE		MASEE ESTIMEE		REPARTITION	
2977,7	91%	310,00	9%	48,8%	51,2%

Pesée physique du véhicule					
Masse	Tr. Av	Tr. Ce	Tr. Ar		Date

de base

Tableau créé le :

Sauvegarde de la configuration	Configuration non figée	Tolérance Véhicule (hors caisse) 0,00%

AEROLA RGAGE

Présent dans la config.

AEROLARGAGE

	Coef	Masse (Kg)	Centre de gravité Xg	Yg	Zg	Masse sur Train Av (Kg)	Masse sur Train Ar (Kg)
A VIDE	Théorique	3288	1564	39	106	1573	1714
	+ disp. fab.	3288	1564	39	106	1573	1714
ODC	Théorique	3616	1573	68	190	1720	1896
	+ disp. fab.	3616	1573	68	190	1720	1896
		184				380	904

MASSE VALIDE		MASEE ESTIMEE		REPARTITION	
2977,7	91%	310,00	9%	47,6%	52,4%

Pesée physique du véhicule					
Masse	Tr. Av	Tr. Ce	Tr. Ar		Date

Figure 28: Mass balance of the VLFS

We have the position of the COG and the mass of each component on the platform. It is necessary to recover the distance with respect to the center of the platform of the COG of each component and to multiply it by its mass. We get the moment of each component. By adding all the moments we get the moment of the set in relation to the center of the platform. Simply divide this moment by the sum of all the masses and we obtain the position of the global COG.

The analysis tool is in the form of an excel table (figure 28 and 29).

The aim is to determine the position of the COG, with and without the parachutes, in order firstly to verify compliance with the condition indicated above and secondly to position the suspension jumpers.

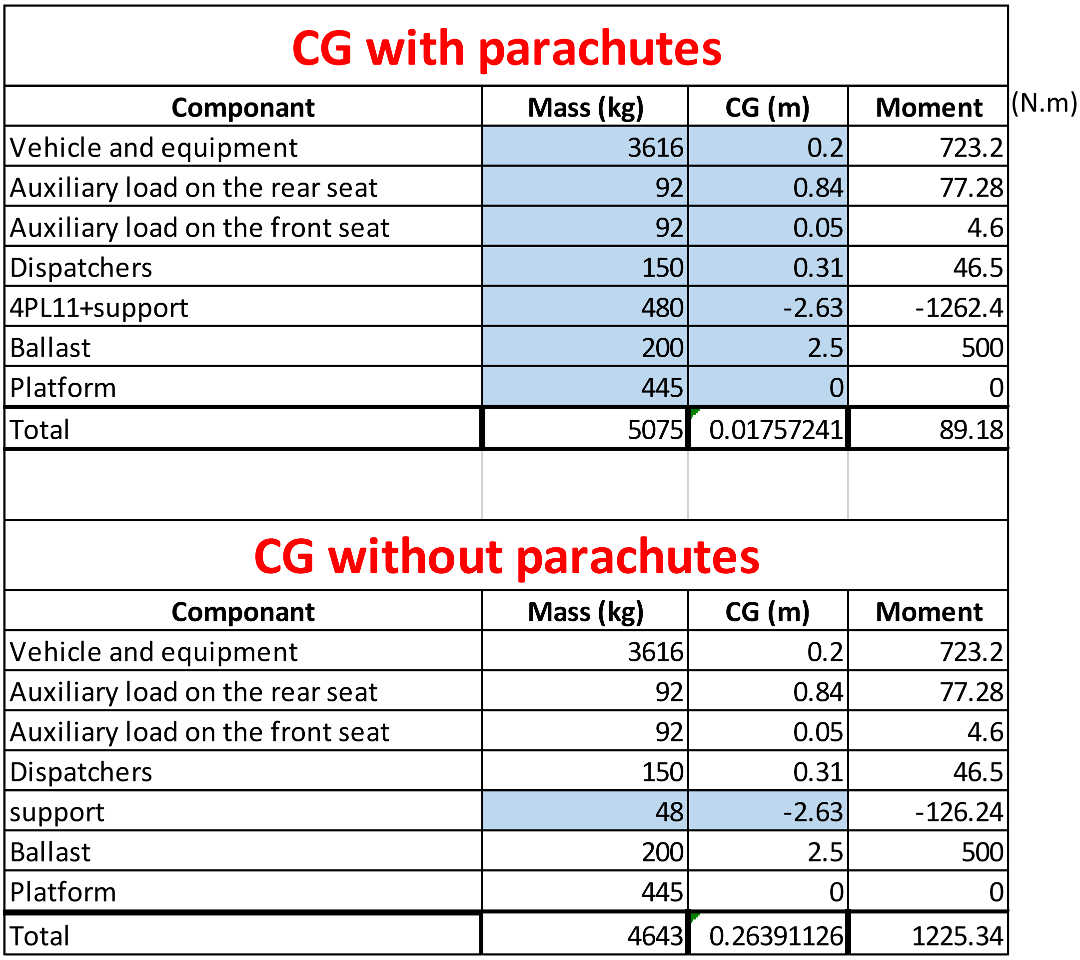
The input data relating to the vehicle in the airdrop configuration, communicated by RTD, is a mass of 3,616 kg. To these 3,616 kg will be added the 184 kg of auxiliary loads distributed in the vehicle.

In cluster of four, each PL11 is equipped with two AP8 extension. This gives a unit weight of 108 kg per parachute. The support is not yet defined but an arbitrary weight of 48 kg is attributed to it, giving a total mass of 480 kg whose COG is positioned 2.63 m at the rear of the center of the platform.

Finally, the overall COG of the interfaces is located at 0.24 m in front of the center of the platform.

To position the COG on the longitudinal axis, we will calculate the moment exerted by each component with respect to the middle of the platform.

The COG will be calculated with and without auxiliary loads.



CG with parachutes

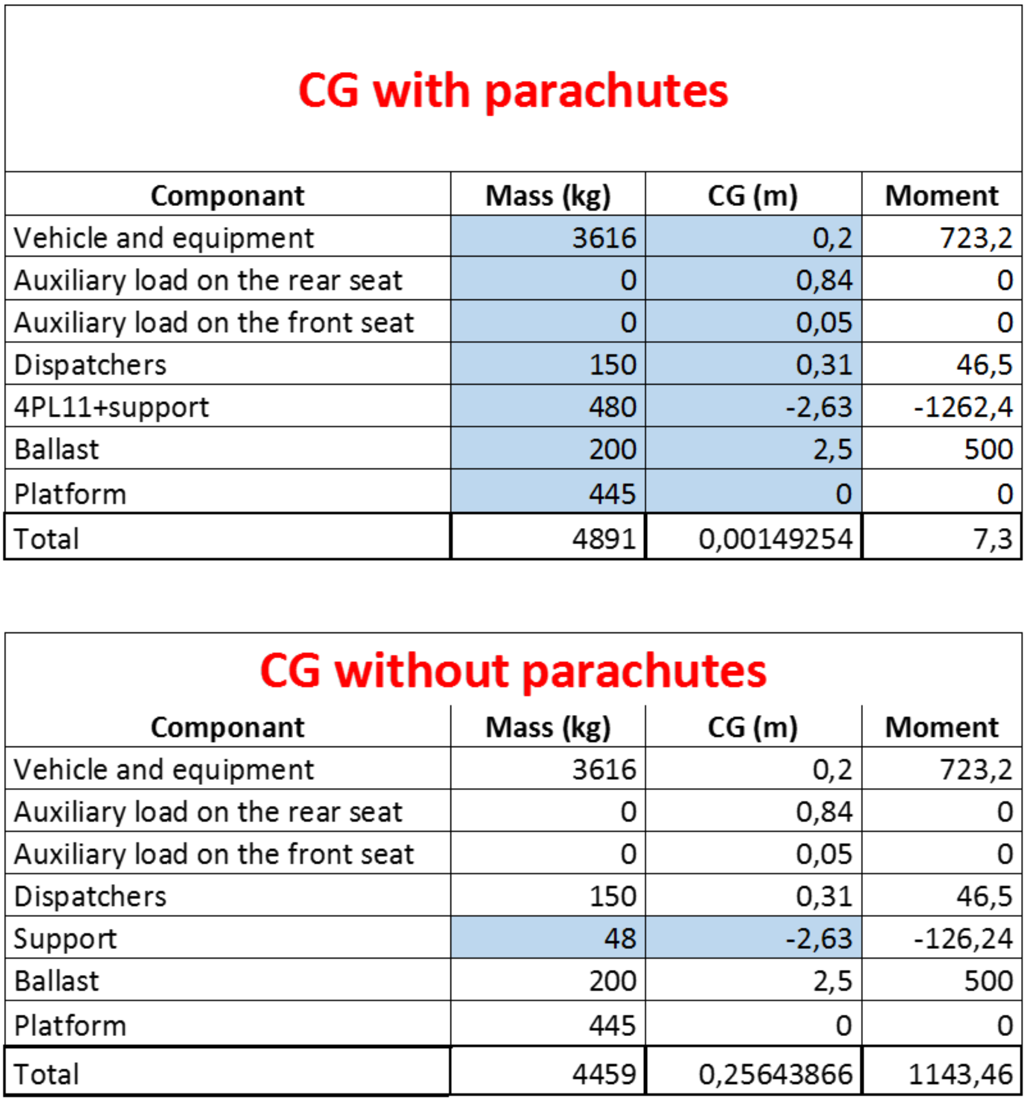
Componant	Mass (kg)	CG (m)	Moment (N.m)
Vehicle and equipment	3616	0.2	723.2
Auxiliary load on the rear seat	92	0.84	77.28
Auxiliary load on the front seat	92	0.05	4.6
Dispatchers	150	0.31	46.5
4PL11+support	480	-2.63	-1262.4
Ballast	200	2.5	500
Platform	445	0	0
Total	5075	0.01757241	89.18

CG without parachutes

Componant	Mass (kg)	CG (m)	Moment
Vehicle and equipment	3616	0.2	723.2
Auxiliary load on the rear seat	92	0.84	77.28
Auxiliary load on the front seat	92	0.05	4.6
Dispatchers	150	0.31	46.5
support	48	-2.63	-126.24
Ballast	200	2.5	500
Platform	445	0	0
Total	4643	0.26391126	1225.34

Figure 29: Gravity center with and without parachutes with auxiliary loads

It appears that it will be necessary to provide a ballast positioned at the front of the platform in order to guarantee compliance with the COG position of the load.



CG with parachutes

Componant	Mass (kg)	CG (m)	Moment
Vehicle and equipment	3616	0,2	723,2
Auxiliary load on the rear seat	0	0,84	0
Auxiliary load on the front seat	0	0,05	0
Dispatchers	150	0,31	46,5
4PL11+support	480	-2,63	-1262,4
Ballast	200	2,5	500
Platform	445	0	0
Total	4891	0,00149254	7,3

CG without parachutes

Componant	Mass (kg)	CG (m)	Moment
Vehicle and equipment	3616	0,2	723,2
Auxiliary load on the rear seat	0	0,84	0
Auxiliary load on the front seat	0	0,05	0
Dispatchers	150	0,31	46,5
Support	48	-2,63	-126,24
Ballast	200	2,5	500
Platform	445	0	0
Total	4459	0,25643866	1143,46

Figure 30: Gravity center with and without parachutes without auxiliary loads

The positioning of the parachutes at the front of the VLFS exerts a significant torque and moves the COG towards the rear of the platform.

It is therefore necessary to place, under the rear interface, a ballast with a mass of 150 to 200 kg to bring the COG of the load within the acceptable limits (between 0 and 20 cm towards the front of the platform).

The precise position will be determined when the mass and COG assumptions have been fixed. However, it is likely that this ballast will be located in the vicinity of the foremost buffer stack. A representation of what this metal ballast (E30) could be is given below:

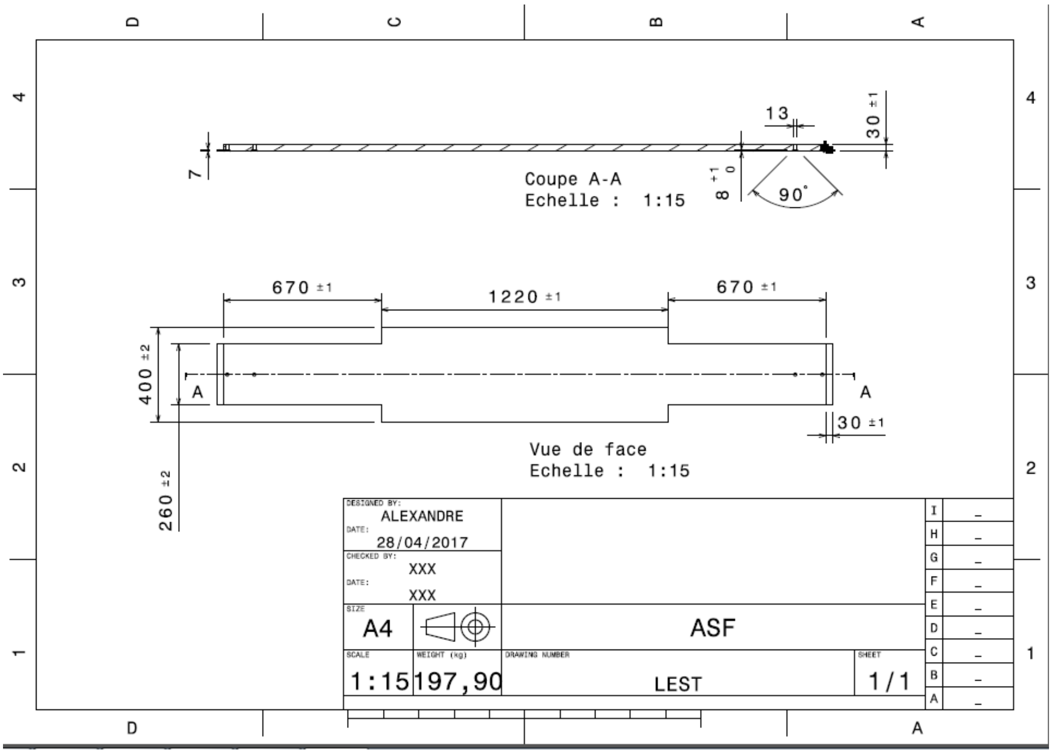


Figure 31: Drawing of the ballast

Finally, modulo the presence of a ballast whose mass will be between 150 and 200 kg, the longitudinal position of the COG of the burden constituted will respect the conditions of use of the LTCO12, whatever the mass of the auxiliary loads.

All the components are not defined, so there will surely be modifications to bring to the mass and the position of certain parts.

At this stage of the study, the packaging is designed symmetrically with respect to the longitudinal axis of the platform. Consequently, a possible offset of the COG in the transverse direction could only come from the position of the COG of the VLFS with these auxiliary loads.

If necessary, several additional options could be envisaged to compensate for an excessive lag:

- ballast asymmetrical,
- positioning instructions for auxiliary loads,
- lateral positioning displacement of the vehicle (within the limit allowed by the burden template).

In order to decide on this point, it is necessary to have the position of the VLFS gravity center.

Considering a height of the load of 2.40 m, the height of the COG must be less than 1.20 m.

The LTCO12, ballast and distributors representing a mass of approximately 970 kg have a COG that is well below this limit.

The parachutes and their support, representing a mass of about 480 kg, have a COG above this limit.

The final position of the COG of the load on the vertical axis is thus mainly conditioned by the position of the COG of the vehicle with its associated loads. This is to be clarified by RTD.

3.2.F.iii. Stowage of the vehicle

In annex II, you can find the entire excel file with the example of VLFS.

It shows that to stow the VLFS, we use 18 straps, and that the security coefficients are the following:

- Longitudinal direction:
  - Rear: 1.55
  - Front: 2.16
- Vertical direction: 4.08
- Lateral direction: 3.3

Before validating the stowage of the vehicle, the last thing to verify is the interfaces between the straps and the vehicle. For this, it's important to place the straps on the CAO file to verify that any parts of the vehicle are disturbing the disposition of the straps.

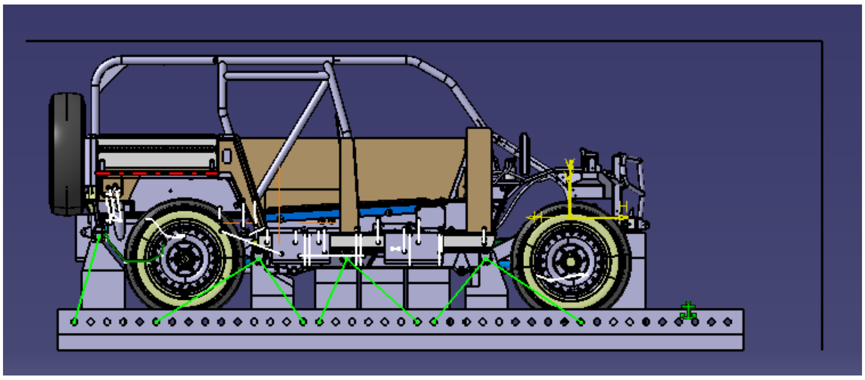


Figure 32: Side view of the stowage

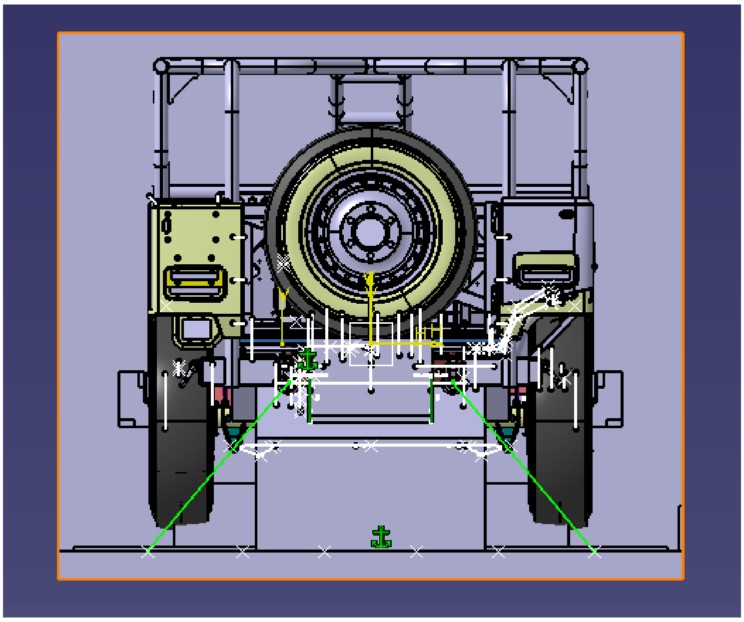


Figure 33: Rear view of the stowage

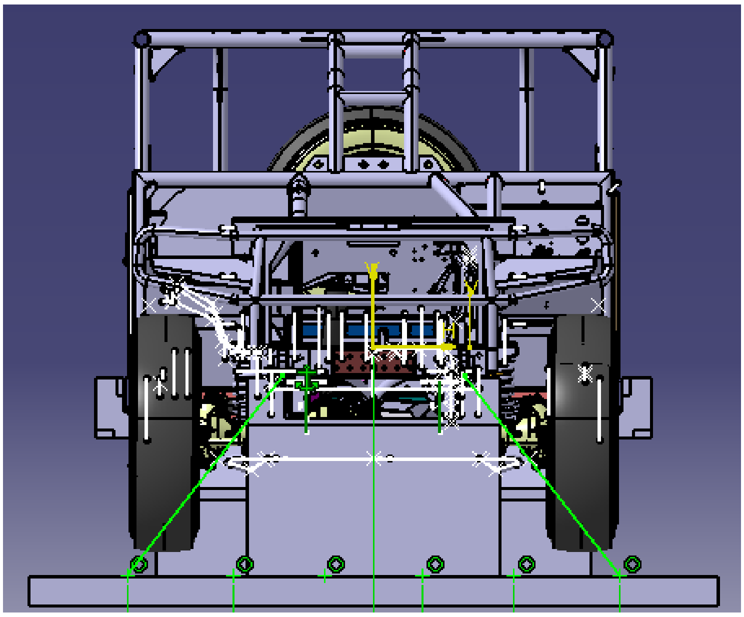
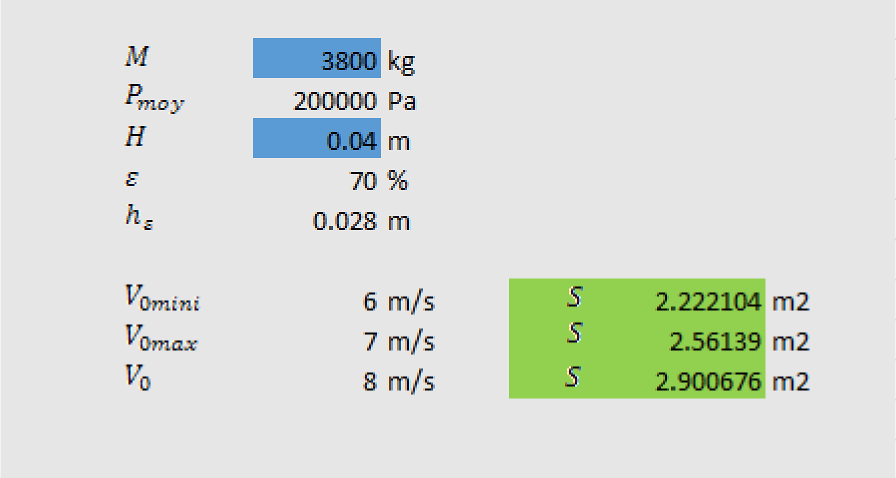


Figure 34: Front view of the stowage

For the VLFS, I verified (cf. pictures 31, 32 and 33) and there are no interferences, so the stowage of the VLFS is validated

3.2.F.iv. Surface of the carton and positioning of the stacks

The mass of the VLFS is approximately 3,800 kg, if we consider an average height of carton of 40 cm, the table give the following result:



M	3800	kg			
P_{moy}	200000	Pa			
H	0.04	m			
ε	70	%			
h_{ε}	0.028	m			
V_{0mini}	6	m/s	S	2.222104	m2
V_{0max}	7	m/s	S	2.56139	m2
V_0	8	m/s	S	2.900676	m2

Figure 35: Surface of carton calculated for VLFS

$$\frac{2.22}{0.33} \times 0.04 \times 100 < Nbr < \frac{2.90}{0.33} \times 0.04 \times 100$$

$$26 < Nbr < 36$$

The number of carton blocks we have to install below the VLFS is included between 26 and 36.

After having discussed with Renault Trucks defence, the designer of the vehicle, we decided to divide the stacks in the following way:

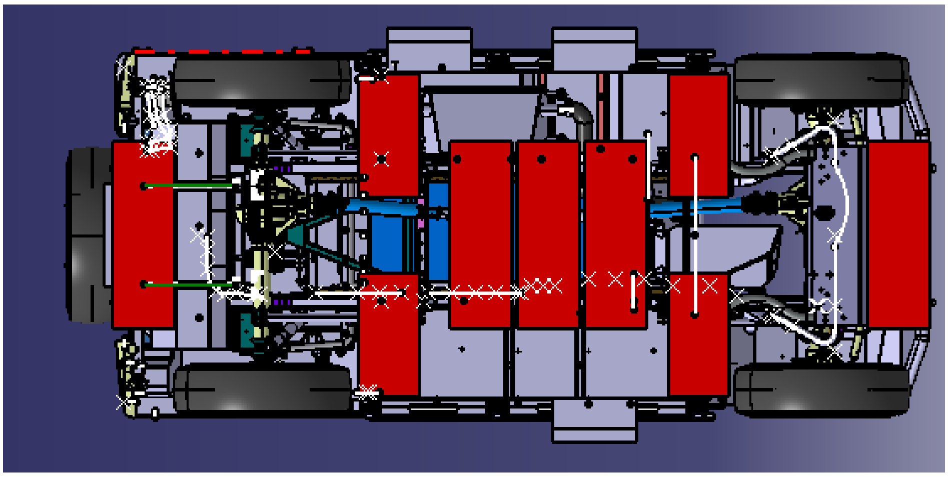


Figure 36: Disposition of the stack of carton for VLFS

There are five stacks whose size are 1 x 0.33 m^2 and four stacks whose size are 0.66 x 0.33 m^2.

Obviously, we calculated the number of required blocks with an average height, but this height has to be adapted to the architecture of the vehicle.

There are seven different abscissas for the stack of carton for the VLFS. So $n = 7$.

$$M = 3800\ kg\ ;\ \ g = 9.81$$

$$S_1 = S_3 = S_4 = S_5 = S_7 = 0.33\ m^2$$

$$S_2 = S_6 = 0.436\ m^2$$

In the literature, we find that $P_{moy} = 200000\ Pa$

We are looking for the duration of the deformation, so we have to resolve $\dot{u}_g = 0$

For a speed of landing equal to 7m/s, we find, with the formula $t_1 = -\frac{V_0}{g - \frac{\sum_{i=1}^{7} S_i}{M} \times P_{moy}}$ that the value of time of the deceleration is. $t_1 = 57\ ms$. This is coherent with the value found on the literature, included between 14 ms and 70 ms.

Now, we are looking for the displacement of the gravity center at the end of the impact.

$$u_g(t_1) = \frac{1}{2}\left(g - \frac{\sum_{i=1}^{7} S_i}{M} \times P_{moy}\right) \times {t_1}^2 + V_0 \times t_1 = 20\ cm$$

If we consider that the speed of landing is equal to 7m/s, as we know that the duration of the deceleration is equal to 57 ms, we deduct that the vehicle support

$$a = \frac{7}{9.81\ \times 0.057} = 12g$$

So we have to verify with the designer that the vehicle is able to support such a deceleration, otherwise we should change the number and the configuration of the carton shock absorbers in order to fit with the vehicle constraints. For the VLFS, Renault Trucks defense confirm that this deceleration was acceptable for the vehicle.

As the final model of the VLFS is not clear, I was not able to apply the method to look for the angle of the vehicle after the drop.

Concerning the support polygon, for the VLFS, the width and the length between the stacks of carton are represented on the following pictures (figure 36):

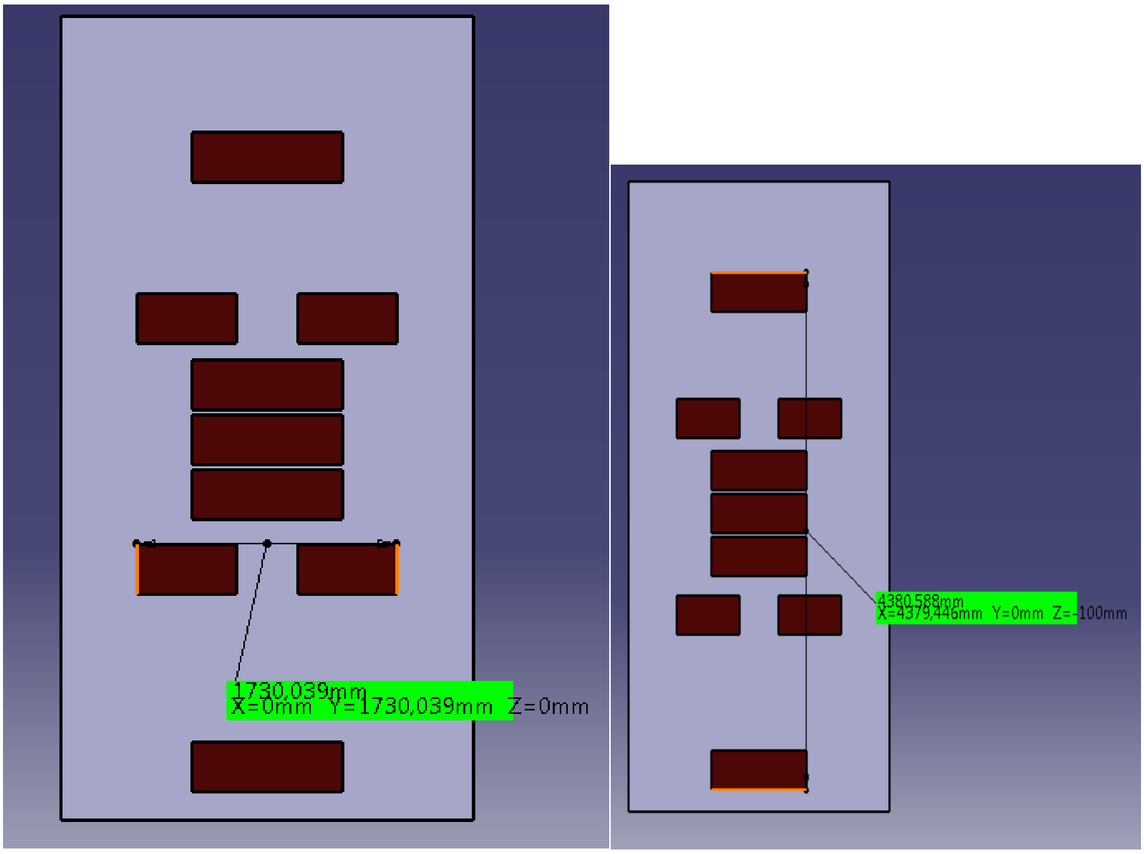
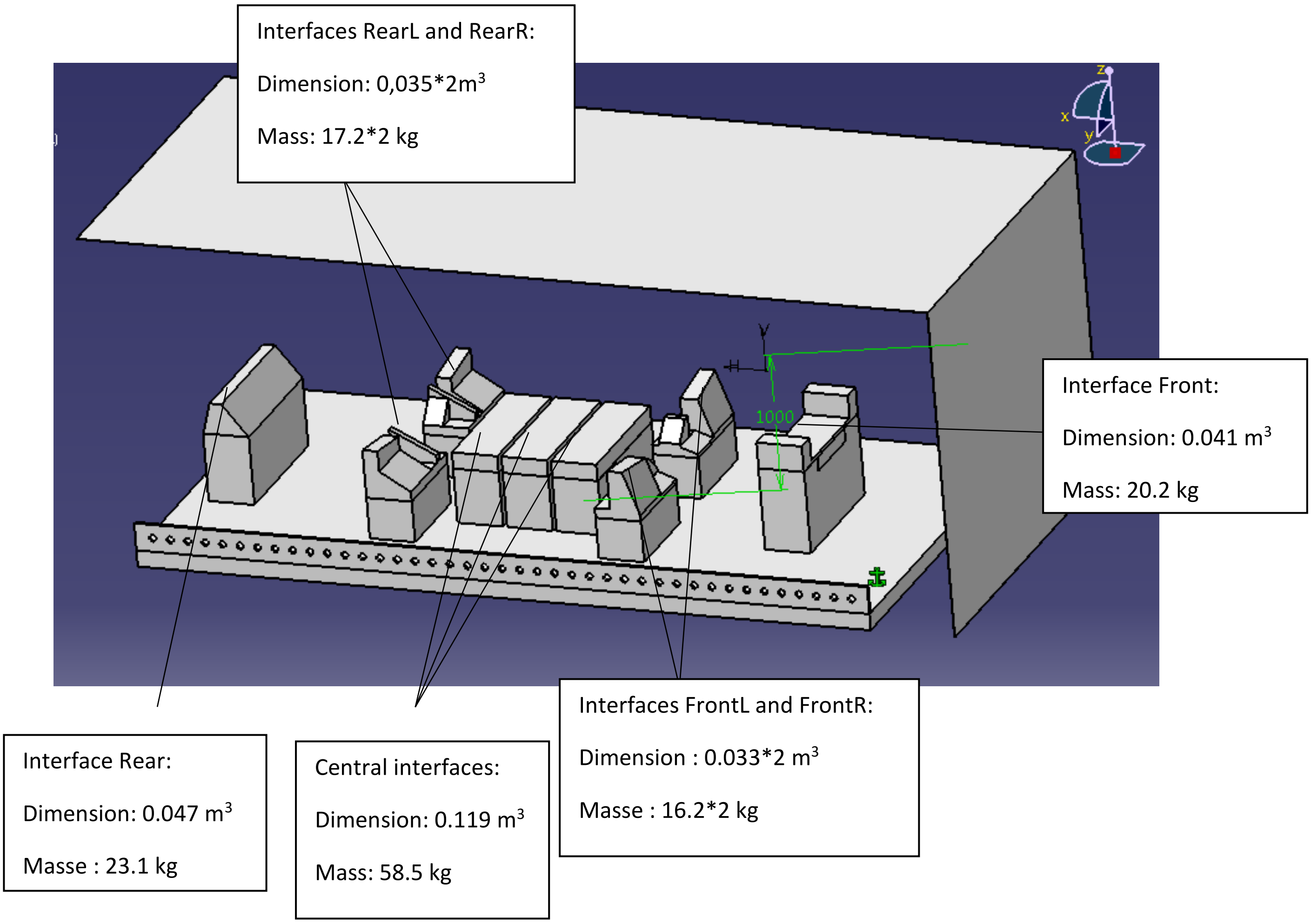


Figure 37: Verification of the support polygon

The width is equal to 1.73 meters and the weight of the vehicle is 3,800 kg. The minimal length to respect the support polygon is so less included between 2.5 and 3 meters. As the current length is equal to 4.79 meters, there is no issue with the support polygon.

3.2.F.v. Interfaces between the vehicle and the carton

For the VLFS, in accord with the disposition of carton stacks that is presented above, I realized interfaces that are on the below scheme.



Interfaces RearL and RearR:

Dimension: 0,035*2m^3

Mass: 17.2*2 kg

Interface Front:

Dimension: 0.041 m^3

Mass: 20.2 kg

Interfaces FrontL and FrontR:

Dimension : 0.033*2 m^3

Masse : 16.2*2 kg

Interface Rear:

Dimension: 0.047 m^3

Masse : 23.1 kg

Central interfaces:

Dimension: 0.119 m^3

Mass: 58.5 kg

Figure 38: Sketch of the interfaces

You can find in annex V the plans of all the interfaces that had been realized.

Part 4: DO22A

Chapter 4.1: Introduction

The DO22A (distributeur d'oxygène autonome et aérotransportable) is an autonomous oxygen distributor which is also air-transportable.

This system has been ordered by French army to obtain a better capacity to fill oxygen bottles for parachutists.

Chapter 4.2: Description of the system

The system is constituted of a principal system and an additional rack (bottles of oxygen). The principal system is itself constituted of several parts:

- A generator
- A compressor
- The distribution system
- The storage of oxygen
- Several boxes containing the tools

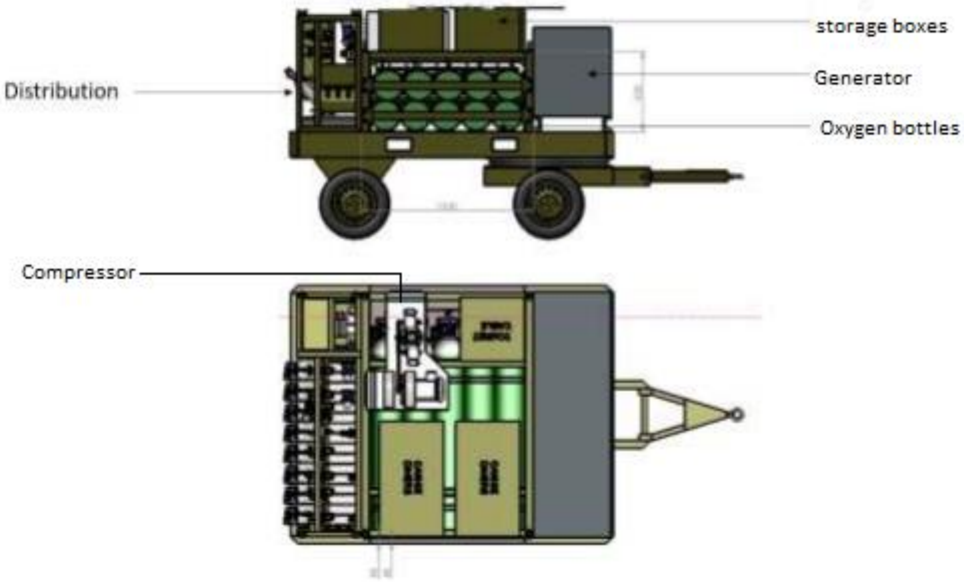


Figure 39: Presentation of the DO22A

The air under high pressure is contained in the storage capacity, when the DO22A is operating, the air leaves the bottles and fills the smaller one, first by balancing the pressure then when the pressure in the mother bottles are not enough pressurised, the compressor starts to operate and continue the work.

All this system is electrically powered by the generator, and can also be powered by the sector.

As the DO22A has the ability of being carried by the road, on a boat and in an aircraft cargo, all the system has been sized to resist to high constrains of acceleration. Besides, the air-transportable capacity implies that the system shall answer to several standards.

Chapter 4.3: Security study

I realized a security study, to ensure the consumer that the system was safe and that all the precaution to guaranty safety of the user has been taken.

The contract specified that the security report has to contain (the following paragraph is the translation of a part of the contract):

- The regulatory framework applicable to the delivered components constituting DO22A,
- The state of regulatory compliance (especially EC conformity),
- The measures taken to control the identified risks (carrying additional adapted fire extinguishers, regular inspection by an observer in the cargo zone during the flight, etc.)
- The list of dangerous substances, together with the quantities, within the meaning of the IATA regulations,
- The contractor's commitment to compliance with the manufacturing standards for pressure capacities (construction, packaging, maintenance, marking, etc.) given in the regulations:
    - General of the Class 2 packing instruction of the IATA regulations,
    - Particulars of packing instruction 200 of this same regulation.

To create this document (you can find the document in annex VI), I first made an inventory of the different norms that are applicable to the DO22A. These norms are:

- Directive 73/23/EEC on low voltage,
- the IATA (international air transport association) standard, UN 1072 Class 5.1
- the paragraph 1.1.3.6.3 of ADR (The European Agreement concerning the International Carriage of Dangerous Goods by Road)
- the Labor Code, Article R.4541-5
- the standard NF EN 1089-3 relating to the identification of gas bottles.

Then, I made an inventory of all the justification that shall appear in the document. After doing the list of dangerous substances according to the IATA norm, I cut the document into two main parts. The first part is the risk management at the design state, the second one is the risk management at the use state.

At the design state, I highlighted the risks linked to the mechanical resistance of the DO22A in case of transport. These risks had already been erased by the calculation notes furnished by one of our subcontractor. The notes are calculation in finite elements of the resistance of the trailer and of the interfaces between the different parts of the DO22A.

The other major design risks were the interferences between:

- Fuel
- Lubricating grease
- Oxygen
- Electricity.

To establish the security of the DO22A, I made a study on all the interferences between these different elements, proving that every precaution had been taken to avoid every kind of accidents (ex.: electric and antistatic grounding, implementation of auto-test functions and emergency stops).

At the use state, I separate different parts of the use of the DO22A:

- Preparation phase for transport
- Preparation phase for use
- Use phase.

For these three phases, I collected all the situation of nuisances and risks and explained how they were acceptable and managed. This part is presented in the document as the following table (translation of an extract of the security document):

Nuisance situation	**Risk for the user**	**Considered solution**
Loading and unloading of storage boxes	Handling, dorso-lumbar risks	Respect of maximum unit load
	Finger Sticking	Wear of gloves
	Fall of elements on the feet	Recommended safety shoes
	Fall of boxes during unloading	Supply of a large sized walk-in
	Shock at the head of the operator	Very low risk. Caution when using. Recommended Protective Cap Port
Unloading of the generator	Circulation of a forklift truck	Compliance with the rules of use and circulation of the forklift truck

Part 5: Conclusion

The rigging of a vehicle is primary to maintain proper functioning of the latter. It's a complete work that asks a job on several points to respect the associated constrains.

This thesis tries to implement as best as possible a method to realize the rigging. The choice of the platform and of the parachutes are not the critical aspect of the thesis.

The method that I implement to realize the stowage of the vehicle is efficient and probably sufficient, even if a method that proposes by itself a stowage (in contrary to the current one, which verifies the resistance of a given stowage) could have been better.

The principal issues are more on the CA14, carton shock absorber used to damp the vehicle whose properties are still poorly know. Indeed, despite the trials I has realized and the analytical method I implement, lots of imprecisions remains. The documents I used to start this work were talking about an uncertainty of 30 % which can be explicated by the weather situation (humidity in air). Today we are not able to take in account those variations and it could be a way to start further research.

Bibliography

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ANNEX I: PD8 AND PD9 PLATE

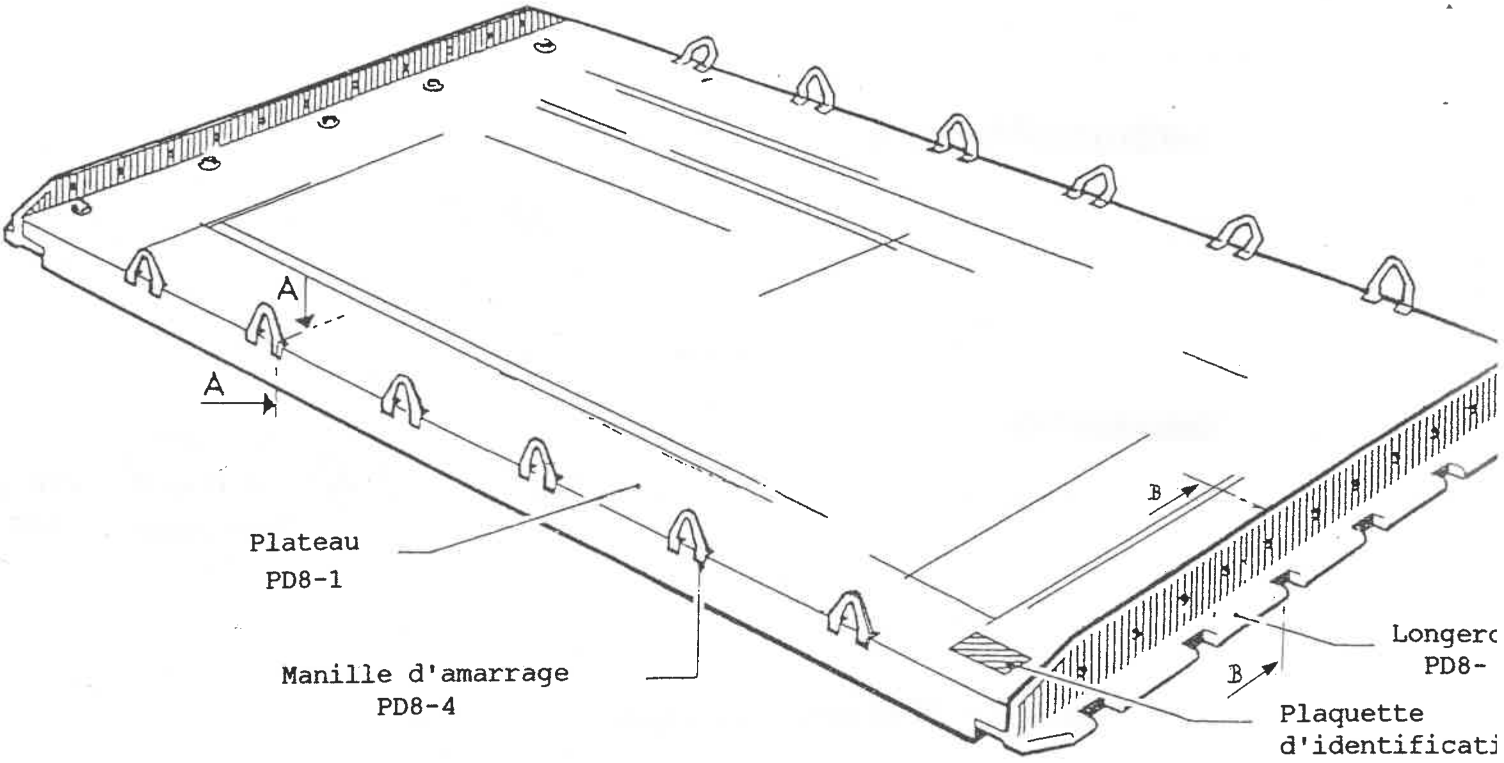
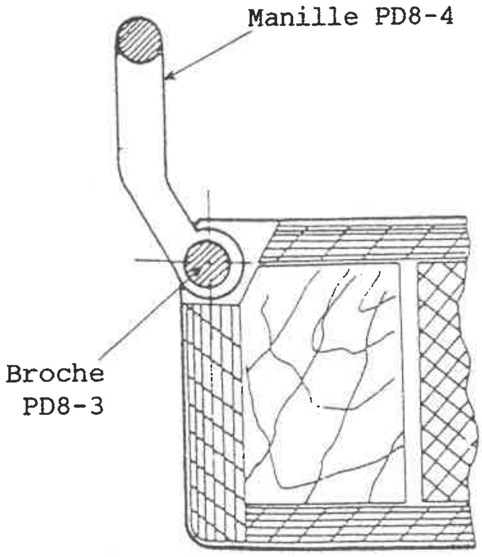
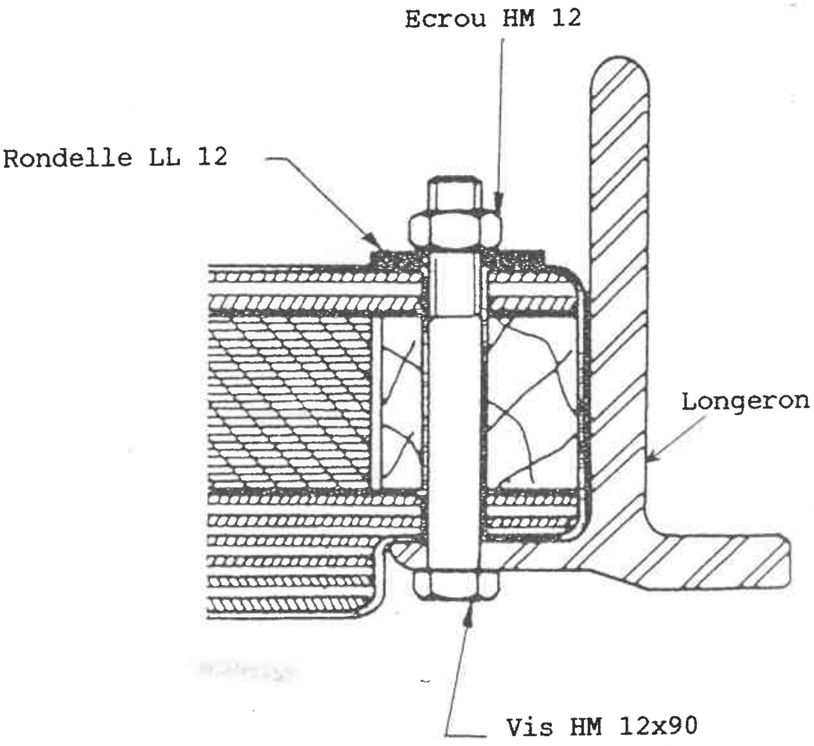


PLATE-FORME PORTEE PD 8



COUPE AA



COUPE BB

II - DESCRIPTION

21 - PLATE-FORME PORTEE PD 8

La plate-forme supporte les deux gaines pendant toutes les phases de manutention et de largage, arrivée au sol comprise; elle assure le contact entre les gaines conditionnées et la surface d'appui au cours de la manutention au sol, de la translation dans l'avion et de l'arrivée au sol; elle assure la liaison entre les gaines conditionnées et le système d'arrimage automatique de l'avion constitué par des taquets qui se prennent dans les crans des longerons de la plate-forme.

211 - PLATEAU PD 8-1

Le plateau est constitué par des panneaux de polystyrène expansé, enrobés de tissu de verre et de résine mélangée à un durcisseur et serrés entre des plaques de contre-plaqué et des traverses de bois, l'ensemble étant à son tour enrobé de tissu de verre.

Le long de chaque petit côté des trous permettent le passage des boulons de fixation des longerons.

Dans l'angle supérieur de chaque grand côté est noyé un tube en alliage d'aluminium destiné au passage d'une broche de fixation des manilles d'amarrage.

Des évidements excavations faites sur les angles supérieurs des grands côtés permettent la mise en place des manilles d'amarrage.

Une plaquette d'identification est fixée dans un angle de la face supérieur du plateau.

212 - LONGERONS PD 8-2

En alliage d'aluminium tréfilé, ils sont montés sur chaque petit côté du plateau au moyen de cinq boulons.

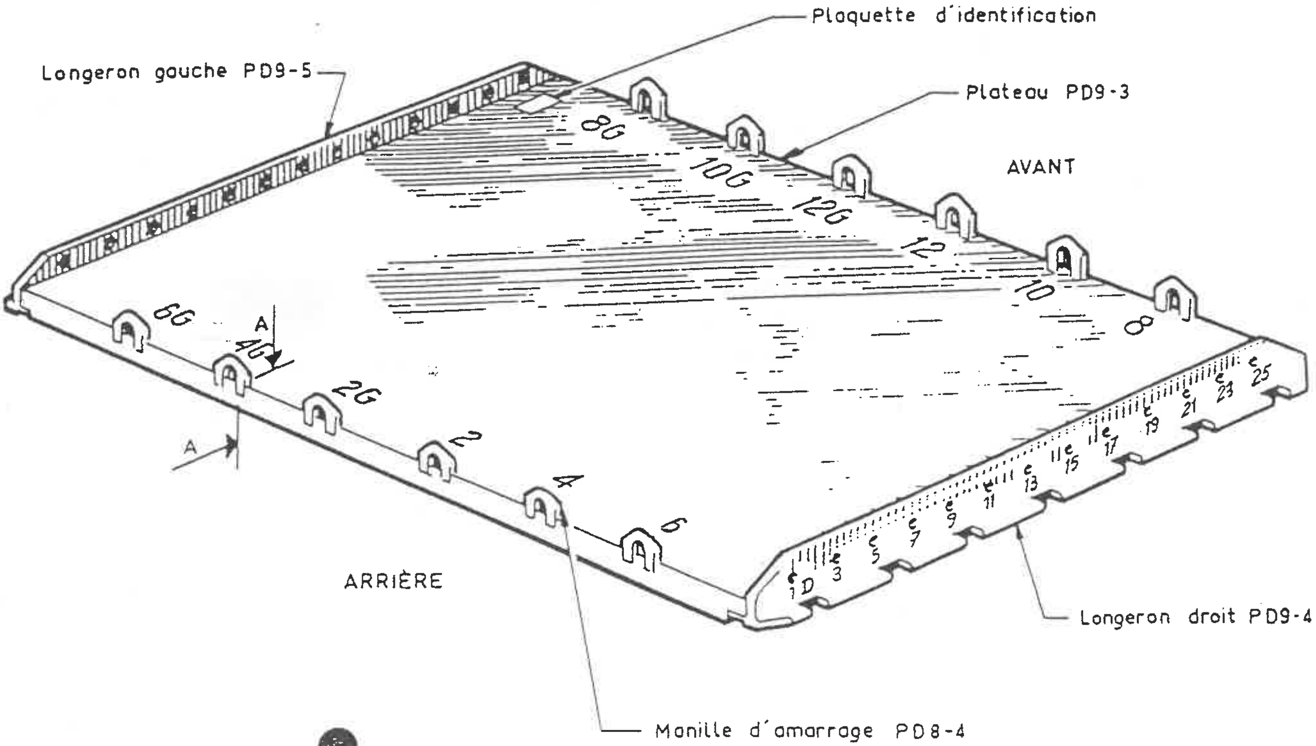
Ils présentent trois ailes; l'une, horizontale intérieure, sert à la fixation du longeron sur l'élément; l'autre, horizontale extérieure, porte les crans nécessaires à l'engagement de la plate-forme sur le dispositif d'arrimage; la troisième, verticale, porte onze trous destinés au passage des pièces de fixation du système de brêlage des charges.

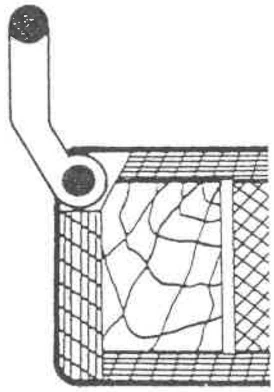
213 - BROCHES PD 8-3

Les broches sont des tiges cylindriques en acier étiré, traversant chaque plateau de part en part à travers les deux tubes d'alliage d'aluminium. Elles fixent les manilles d'amarrage et sont arrêtées par les longerons.

214 - MANILLES D'AMARRAGE PD 8-4

En acier estompé, elles sont en forme de chape et présentent à l'extrémité de chacune de leur branche un trou destiné à leur montage et à leur articulation sur les broches de fixation.. Elles sont montées six sur chaque grand côté au moyen de deux broches traversant le plateau de part en part à travers les tubes en alliage d'aluminium.





Coupe AA

PLATE-FORME PORTEUSE PD9

II - DESCRIPTION

21 - PLATE FORME PORTEUSE PD 9

La plate forme supporte le matériel conditionné pendant toutes les phases de manutention au sol, de translation dans l'avion et de largage, arrivée au sol comprise, elle offre des points d'accrochage aux brêlages de fixation de la charge, elle assure la liaison entre le matériel conditionné et le système d'arrimage automatique de l'avion constitué par des taquets qui se prennent dans les crans des longerons de la plate forme.

211 - PLATEAU PD 9-3

Bien qu'ayant des dimensions différente du plateau PD 8, le plateau PD 9-3 est de conception identique.

212 - LONGERONS PD 9-4 ET PD 9-5

De conception identique aux longerons PD 8-2, ils se différencient par leurs longueur et la présence de six trous de fixation au plateau.

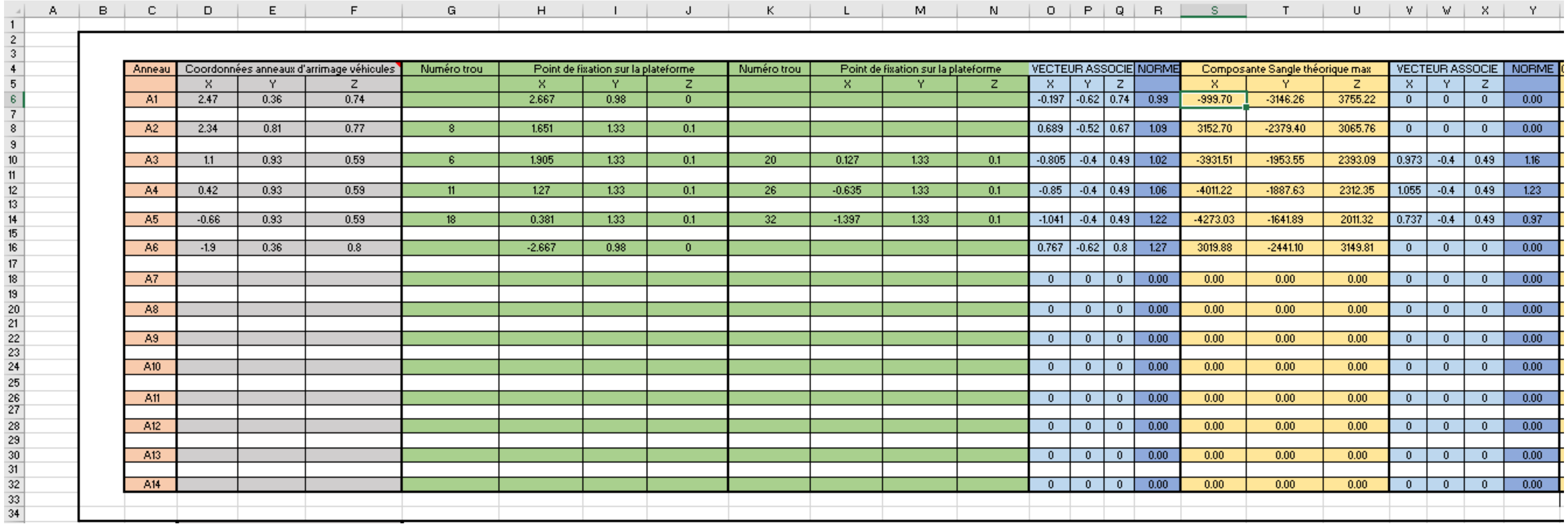
L'aile verticale de chaque longeron porte treize trous, numérotés de 1 à 25 et destinés au passage des pièces de fixation du système de brêlagedes charges et de l'ensemble de suspension; enfin les deux longerons sont différenciés par le numérotage du premier trou:

- 1 D sur le longeron droit,
- 1 G sur le longeron gauche.

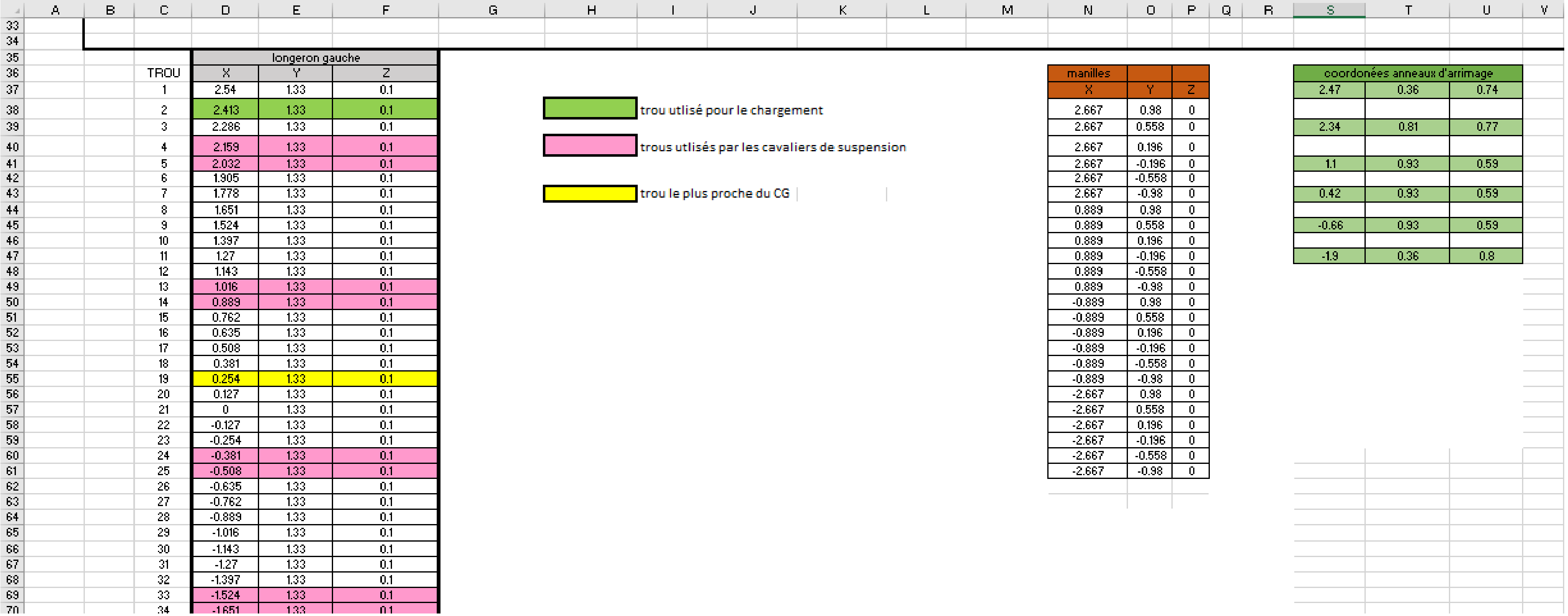
213 - BROCHE PD 8-3, MANILLES D'AMARRAGE PD 8-4

Identiques à celles contenues dans l'unité collective du lot de conditionnement LTCO 9.

ANNEX II: STOWAGE EXCEL TABLE



Anneau	Coordonnées anneaux d'arrimage véhicules			Numéro trou	Point de fixation sur la plateforme			Numéro trou	Point de fixation sur la plateforme			VECTEUR ASSOCIE			NORME	Composante Sangle théorique max			VECTEUR ASSOCIE			NORME
	X	Y	Z		X	Y	Z		X	Y	Z	X	Y	Z		X	Y	Z	X	Y	Z	
A1	2.47	0.36	0.74		2.667	0.98	0					-0.197	-0.62	0.74	0.99	-999.70	-3146.26	3755.22	0	0	0	0.00
A2	2.34	0.81	0.77	8	1.651	1.33	0.1					0.689	-0.52	0.67	1.09	3152.70	-2379.40	3065.76	0	0	0	0.00
A3	1.1	0.93	0.59	6	1.905	1.33	0.1	20	0.127	1.33	0.1	-0.805	-0.4	0.49	1.02	-3931.51	-1953.55	2393.09	0.973	-0.4	0.49	1.16
A4	0.42	0.93	0.59	11	1.27	1.33	0.1	26	-0.635	1.33	0.1	-0.85	-0.4	0.49	1.06	-4011.22	-1887.63	2312.35	1.055	-0.4	0.49	1.23
A5	-0.66	0.93	0.59	18	0.381	1.33	0.1	32	-1.397	1.33	0.1	-1.041	-0.4	0.49	1.22	-4273.03	-1641.89	2011.32	0.737	-0.4	0.49	0.97
A6	-1.9	0.36	0.8		-2.667	0.98	0					0.767	-0.62	0.8	1.27	3019.88	-2441.10	3149.81	0	0	0	0.00
A7												0	0	0	0.00	0.00	0.00	0.00	0	0	0	0.00
A8												0	0	0	0.00	0.00	0.00	0.00	0	0	0	0.00
A9												0	0	0	0.00	0.00	0.00	0.00	0	0	0	0.00
A10												0	0	0	0.00	0.00	0.00	0.00	0	0	0	0.00
A11												0	0	0	0.00	0.00	0.00	0.00	0	0	0	0.00
A12												0	0	0	0.00	0.00	0.00	0.00	0	0	0	0.00
A13												0	0	0	0.00	0.00	0.00	0.00	0	0	0	0.00
A14												0	0	0	0.00	0.00	0.00	0.00	0	0	0	0.00



	longeron gauche		
TROU	X	Y	Z
1	2.54	1.33	0.1
2	2.413	1.33	0.1
3	2.286	1.33	0.1
4	2.159	1.33	0.1
5	2.032	1.33	0.1
6	1.905	1.33	0.1
7	1.778	1.33	0.1
8	1.651	1.33	0.1
9	1.524	1.33	0.1
10	1.397	1.33	0.1
11	1.27	1.33	0.1
12	1.143	1.33	0.1
13	1.016	1.33	0.1
14	0.889	1.33	0.1
15	0.762	1.33	0.1
16	0.635	1.33	0.1
17	0.508	1.33	0.1
18	0.381	1.33	0.1
19	0.254	1.33	0.1
20	0.127	1.33	0.1
21	0	1.33	0.1
22	-0.127	1.33	0.1
23	-0.254	1.33	0.1
24	-0.381	1.33	0.1
25	-0.508	1.33	0.1
26	-0.635	1.33	0.1
27	-0.762	1.33	0.1
28	-0.889	1.33	0.1
29	-1.016	1.33	0.1
30	-1.143	1.33	0.1
31	-1.27	1.33	0.1
32	-1.397	1.33	0.1
33	-1.524	1.33	0.1
34	-1.651	1.33	0.1

🟩 trou utlisé pour le chargement

🟪 trous utlisés par les cavaliers de suspension

🟨 trou le plus proche du CG

manilles		
X	Y	Z
2.667	0.98	0
2.667	0.558	0
2.667	0.196	0
2.667	-0.196	0
2.667	-0.558	0
2.667	-0.98	0
0.889	0.98	0
0.889	0.558	0
0.889	0.196	0
0.889	-0.196	0
0.889	-0.558	0
0.889	-0.98	0
-0.889	0.98	0
-0.889	0.558	0
-0.889	0.196	0
-0.889	-0.196	0
-0.889	-0.558	0
-0.889	-0.98	0
-2.667	0.98	0
-2.667	0.558	0
-2.667	0.196	0
-2.667	-0.196	0
-2.667	-0.558	0
-2.667	-0.98	0

coordonées anneaux d'arrimage		
2.47	0.36	0.74
2.34	0.81	0.77
1.1	0.93	0.59
0.42	0.93	0.59
-0.66	0.93	0.59
-1.9	0.36	0.8

AC	AD	AE	AF	AG	AH	AI
Effort réel appliqué sur la sangle			Effort réel appliqué sur la sangle			effort par anneau
X	Y	Z	X	Y	Z	
-646.8	-951.0	918.1	0.0	0.0	0.0	1471.6
1461.2	-719.2	749.6	0.0	0.0	0.0	1792.8
-2543.6	-590.5	585.1	1943.0	-520.9	516.2	2986.2
-2595.1	-570.5	565.4	1987.6	-491.4	487.0	2995.0
-2764.5	-496.3	491.8	1758.6	-622.4	616.8	3181.6
1399.7	-737.8	770.1	0.0	0.0	0.0	1759.7
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

Y	Z	AA	AB
NORME	Composante Sangle théorique ma		
	X	Y	Z
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
1.16	4192.05	-1723.35	2111.11
1.23	4288.30	-1625.90	1991.72
0.97	3794.20	-2059.26	2522.60
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00

AC AD AE AF AG AH AI AJ AK AL AM AN AO AP

m= 3800 kg

R_{SANGLE}= 5000 kg

	Objectif		Valeurs maximum obtenue	Coefficent de sécurité
$\gamma_{VERTICAL}$=	3		12.26999026	
$M_{VERTICAL}$=	11400	kg	46625.96	4.089996754

	Objectif		Valeurs maximum obtenue	Coefficent de sécurité
$\gamma_{ARRIERE}$=	4.5		6.95550372	
$M_{ARRIERE}$=	17100	kg	26430.91	1.545667493

	Objectif		Valeurs maximum obtenue	Coefficent de sécurité
γ_{AVANT}=	4.5		9.70901739	
M_{AVANT}=	17100	kg	36894.27	2.15755942

	Objectif		Valeurs maximum obtenue	Coefficent de sécurité
$\gamma_{LATERAL}$=	1.5		4.962723284	
$M_{LATERAL}$=	5700	kg	18858.35	3.30848219

ANNEX III: PYTHON CODE

```
# -*- coding: utf-8 -*-
import json


# variable globale
G = 9.81
PMOY = 200000


def ss_ssx(car):
    """
    return somme des surfaces (SS) et somme des Sci * (xi - xg) (SSX)
    """
    Sc = car["Sc"]
    X = car["X"]
    Xg = car["Xg"]

    SS = sum(Sc)
    SSX = 0
    for i in X:
        SSX += Sc[i] * (X[i] - Xg)

    return SS, SSX


def get_t0(SS, M, v0):
    return -v0 / (G - (SS * PMOY)/ M)


def ug(SS, M, t, v):
    """ fonction distance """
    return 0.5 * (G - (SS * PMOY)/ M) * t * t + v * t


def phi(SSX, I, t):
    """ fonction d'angle """
    return 0.5 * (SSX / I) * PMOY * t * t


def a(v, t):
    """ return l'accelération """
    return v / (t * G)


if __name__ == "__main__":
    import argparse
    parser = argparse.ArgumentParser()
    parser.add_argument("inputFile", help="file from which to obtain data
(json)")
    parser.add_argument("-o", "--outputFile", help="file from which to
obtain data (json)")
    args = parser.parse_args()

    # on récupère les données issuees du Json
    with open(args.inputFile) as f:
        params_cars = json.load(f)

    cars = params_cars["cars"]
```

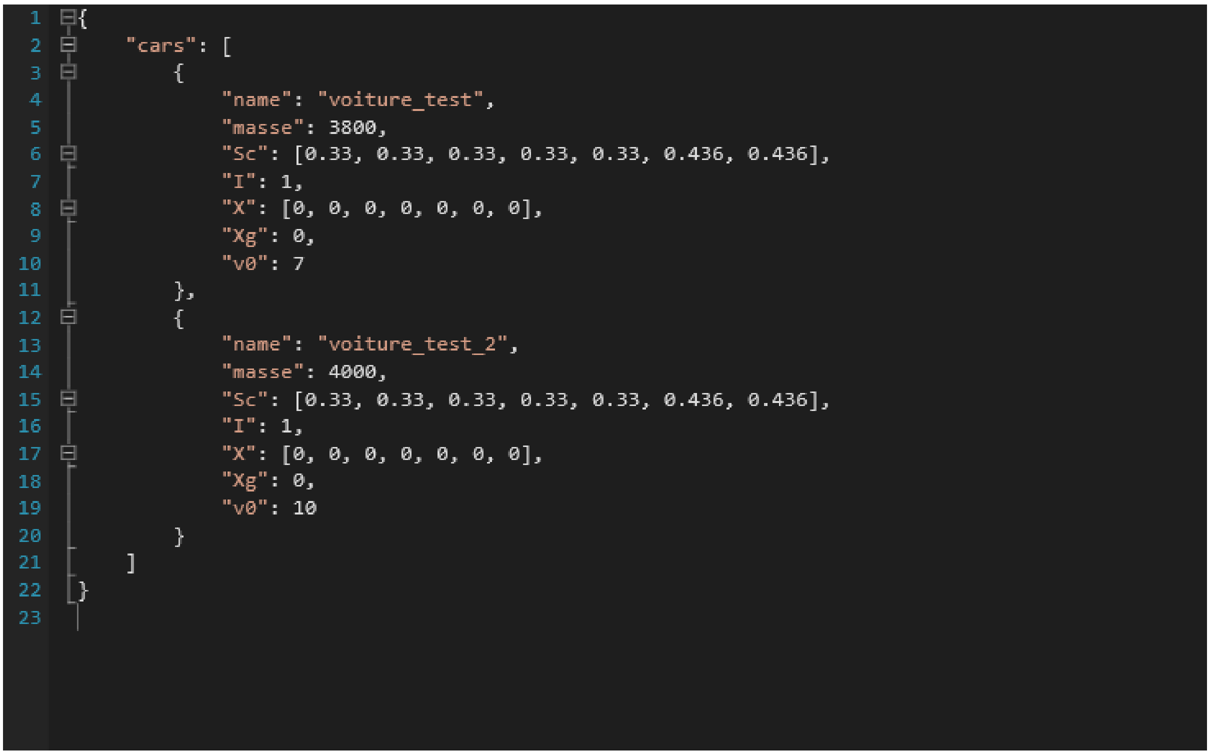
```
    result = { "cars": [] }

    print("Voici les résultats obtenus:\n")
    print("|{:^15}|{:^10}|{:^10}|{:^10}|{:^10}|\n".format("voiture", "t0
(s)", "ug0 (m)", "phi0 (°)", "a0(m/s²)") + "=" * 61)

    for car in cars:
        SS, SSX = ss_ssx(car)
        v0 = car["v0"]
        t0 = get_t0(SS, car["masse"], v0)
        ug0 = ug(SS, car["masse"], t0, v0)
        phi0 = phi(SSX, car["I"], t0)
        a0 = a(v0, t0)
        # on affiche les résultats et on les écrit dans un fichier

print("|{:^15}|{:^10.3f}|{:^10.2f}|{:^10.2f}|{:^10.1f}|\n".format(car["name
"], t0, ug0, phi0, a0) + 61 * "-")
        result["cars"].append({"name": car["name"], "t0": t0, "ug0": ug0,
"phi0": phi0, "a0": a0})

    if args.outputFile:
        with open(args.outputFile, 'w') as f:
            json.dump(result, f)
```



```
{
    "cars": [
        {
            "name": "voiture_test",
            "masse": 3800,
            "Sc": [0.33, 0.33, 0.33, 0.33, 0.33, 0.436, 0.436],
            "I": 1,
            "X": [0, 0, 0, 0, 0, 0, 0],
            "Xg": 0,
            "v0": 7
        },
        {
            "name": "voiture_test_2",
            "masse": 4000,
            "Sc": [0.33, 0.33, 0.33, 0.33, 0.33, 0.436, 0.436],
            "I": 1,
            "X": [0, 0, 0, 0, 0, 0, 0],
            "Xg": 0,
            "v0": 10
        }
    ]
}
```

Figure 1: json file

ANNEX IV: TRIALS

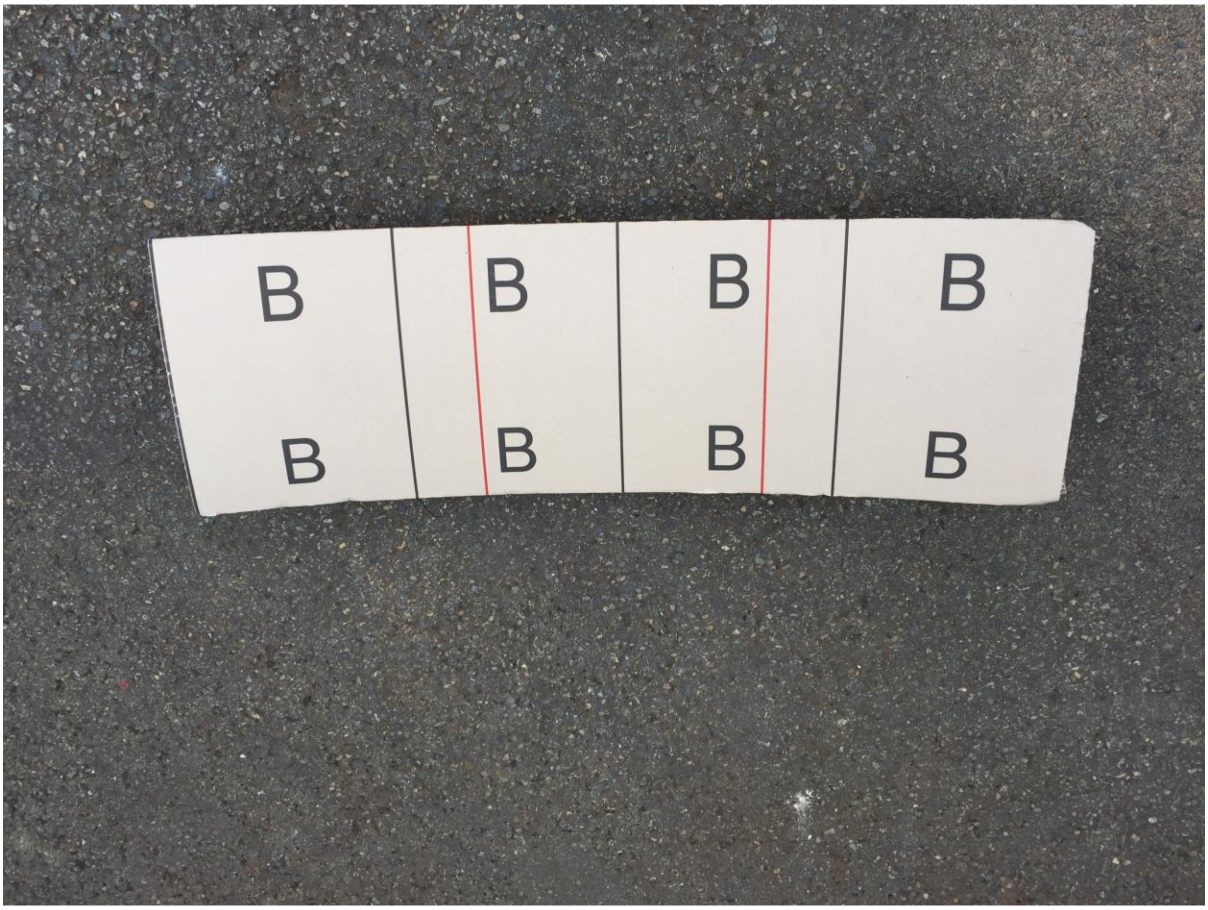
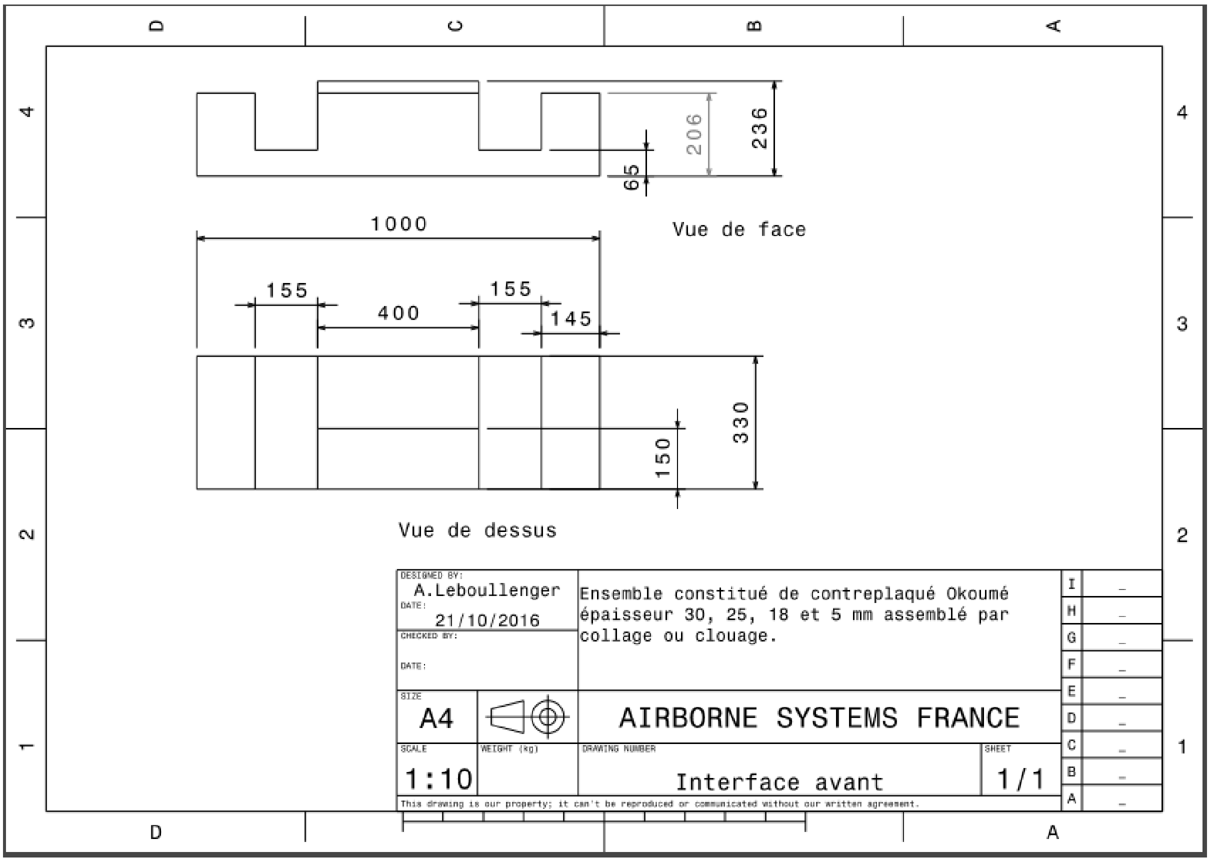


Figure 2: CA14

Figure 3:Trials with the forklift

Figure 43: Plywood and its load

ANNEX V: INTERFACE PLANS



DESIGNED BY: A.Leboullenger
DATE: 21/10/2016
CHECKED BY:
DATE:
Ensemble constitué de contreplaqué Okoumé épaisseur 30, 25, 18 et 5 mm assemblé par collage ou clouage.
SIZE: A4
AIRBORNE SYSTEMS FRANCE
SCALE: 1:10
WEIGHT (kg):
DRAWING NUMBER: Interface avant
SHEET: 1/1
This drawing is our property; it can't be reproduced or communicated without our written agreement.

I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	_

Figure 4: Front interface

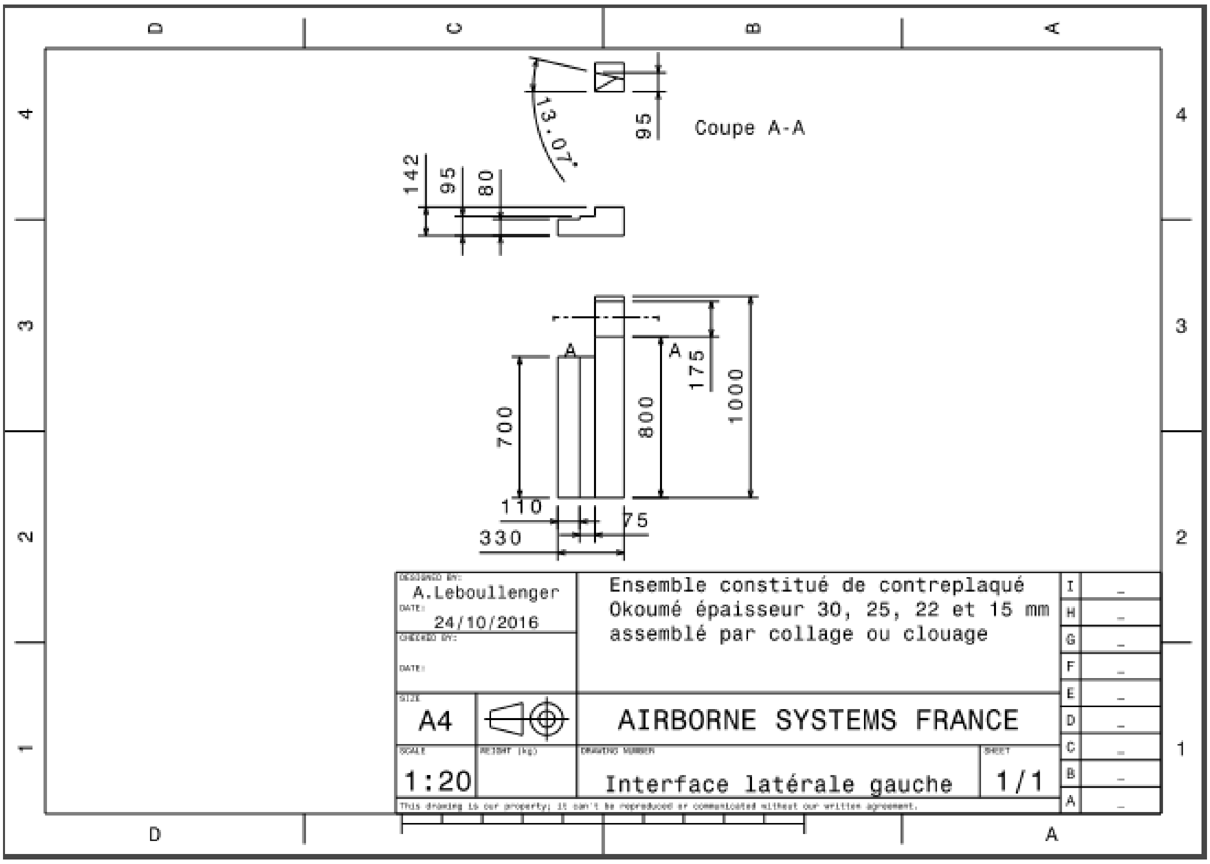


Figure 45: Left Interface

ANNEX VI: SECURITY DOCUMENT

DOSSIER DE SECURITE DU DO22A

TRASE2412 EDITION 1

Date :16 Juin 2017

Rédigé par	Maude Fouquet Ingénieur Dossier Sécurité
Vérifié par	Philippe Brochain STAR ENGINEERING
Validé par	Martyn Jones Directeur de l'Ingénierie

Accréditation DAOS et ISO 9001

Airborne Systems Limited
Registered Office: Bettws Road, Llangeinor, Bridgend CF32 8PL, UNITED KINGDOM | Tel +44 (0) 1656 727000 | airborne-sys.com
Registered Number 2524190 in England and Wales

HISTORIQUE DES REVISIONS

Version	**Synthèse des changements**	**Date**
Initiale	Version initiale niveau RDP	07/04/16
0	Version Projet – Edition 0	30/03/17
1	Version Projet Corrigé	22/06/17

LISTE DE DIFFUSION

Destinataire	Organisme et adresse	N° de copie
Q Pulse	Airborne Systems Ltd Llangeinor, Bridgend, CF32 8PL	Copie électronique originale
DGA/DO/UM-TER Antenne de Toulouse	47 rue Saint-Jean - BP n° 93123 31131 BALMA Cedex	2 ex. papier 1 copie électronique
ASF	16 bis rue Paule Raymondis, 31200 Toulouse	1 copie électronique
ASL	Llangeinor, Bridgend, CF32 8PL	1 copie électronique
FTP DO22A		1 copie électronique

SOMMAIRE

LISTE DES ABRÉVIATIONS / ACRONYMES

Abréviation / Acronyme	Signification
ADR	European Agreement concerning the international carriage of Dangerous goods by Road
DGA	Direction Générale de l’Armement
DO22A	Distributeur d’Oxygène Autonome et Aérotransportable
GE	Groupe Electrogène
IATA	International Air Transport Association
NTI	Niveau Technique d’Intervention
STB	Spécification Technique du Besoin
IMDG	International Maritime Dangerous Goods Code
MT	Manuel Technique
GT	Guide technique
TPED	Transportable Pressure Equipment Directive

1 INTRODUCTION

Dans le cadre du marché n° 2014 92 0016 – Fourniture et soutien de distributeurs d'oxygène autonomes et aérotransportables (DO22A), Airborne Systems Europe, Airborne Systems North America, Sis Novam et Aeronet ont conjointement développé une solution permettant de répondre au besoin exprimé par la Direction Générale de l'Armement (DGA).

La société Airborne systems France a fait appel à un cabinet externe et indépendant (STAR ENGINEERING) afin de valider ce dossier de sécurité conformément aux exigences du cahier des charges (§ 2.6.1 du CCTP [1]).

Ce dossier est construit en application de :

- la directive 73/23/CEE relative à la basse tension,
- la norme IATA, UN 1072 Classe 5.1
- du 1.1.3.6.3 de la norme ADR
- le code du travail, Article R.4541-5
- la norme NF EN 1089-3 relative à l'identification des bouteilles de gaz

L'objet de ce document est de présenter les risques identifiés et associés à l'utilisation de l'ensemble DO22A, ainsi que les moyens mis en œuvre pour minimiser ces risques (Cf. § 4 et 5 - Maîtrise des risques). Ce rapport présente aussi les justifications des EX_SYS_119, EX_SYS_125 et EX_SYS_126 de la spécification technique du besoin [2]. Ces justifications sont détaillées soit dans le présent document, soit dans le DJD, soit dans le Dossier de définition, soit dans les manuels utilisateurs. Enfin ce document a pour objectif d'obtenir la déclaration de conformité du DO22A.

Le tableau 1 ci-dessous rappelle les différentes exigences contractuelles auxquelles répond ce document.

Document de référence	**Exigence**	**Enoncé**	**Référence de la justification**
Spécification technique du besoin (STB)	EX_SYS_119	Pour respecter la réglementation relative au transport des marchandises dangereuses, les marchandises entrant dans la constitution de la charge transportée doivent être identifiées et la sécurité du transport terrestre et	§ 3.1

		maritime de ces marchandises dans les configurations de mission doit être démontrée.	
Spécification technique du besoin (STB)	EX_SYS_125	L'aérotransport en soute d'avion du DO22A est possible sans contrainte spécifique à la cohabitation des bouteilles du sous-ensemble de stockage d'oxygène pleines et des personnels en soute.	§ 3.2
Spécification technique du besoin (STB)	EX_SYS_126	Pour respecter la réglementation relative au transport des marchandises dangereuses IATA, les marchandises entrant dans la constitution de la charge transportée doivent être identifiées et la sécurité du transport aérien de ces marchandises dans les configurations de mission doit être démontrée.	§ 3.3
Cahier des Clauses Techniques Particulières, § 2.6	Listes des matières dangereuses		§ 2
CCTP, § 2.6	Conformité CE		§ 6
CCTP, § 2.6	Dossier de maîtrise des risques		§ 4 & 5

Tableau 1 – Exigences démontrées

2 LISTES DES MATIERES DANGEREUSES IATA

Conformément au paragraphe 2.6 du CCTP, une liste des matières dangereuses selon la norme IATA devra être fournie.

L'ensemble remorque équipée du DO22A possède 10 bouteilles d'oxygène d'une capacité unitaire de 50 litres, soit un total de 500 litres pour ce sous-ensemble. De plus, chacun des deux racks additionnels est constitué de 12 bouteilles identiques à celles présentes sur la remorque. On compte donc un emport total d'oxygène sous pression de 1 700 litres pour un DO22A complet.

Gonflées à 250 bars, les bouteilles auront un poids d'oxygène de 16,7 kg chacune. La liste des matières dangereuses selon la norme IATA est donc, pour le transport du DO22A et de ses deux racks additionnels, de 34 bouteilles comportant 16,7 kg d'oxygène chacune.

Le gaz transporté étant de l'oxygène sous pression, qui a une propriété de comburant, le DO22A comportera les étiquettes 2.2 et 5.1 (cf. § 3.1) concernant le transport de matières dangereuses.

Compte tenu de la définition du DO22A et des justifications fournies, les différentes configurations d'utilisation et de transport envisagées ne présentent pas de criticité au regard de la matière dangereuse identifiée ci-dessus.

Il est signalé que les conditions de stockage du DO22A sur le site de l'exploitant doivent respecter les règles en vigueur pour le stockage de l'oxygène et sont hors du périmètre de la fourniture Airborne Systems.

3 EXIGENCES DE LA STB

3.1 EX_SYS_119 : Pour respecter la réglementation relative au transport des marchandises dangereuses, les marchandises entrant dans la constitution de la charge transportée doivent être identifiées et la sécurité du transport terrestre et maritime de ces marchandises dans les configurations de mission doit être démontrée.

Le transport de matières dangereuses provient de l'emport d'oxygène. Il est signalé directement sur les bouteilles mères ainsi que sur les bouteilles des racks additionnels qui sont munies d'une ogive blanche afin de signaler la présence d'oxygène sous-pression (cf. guide technique [3]).

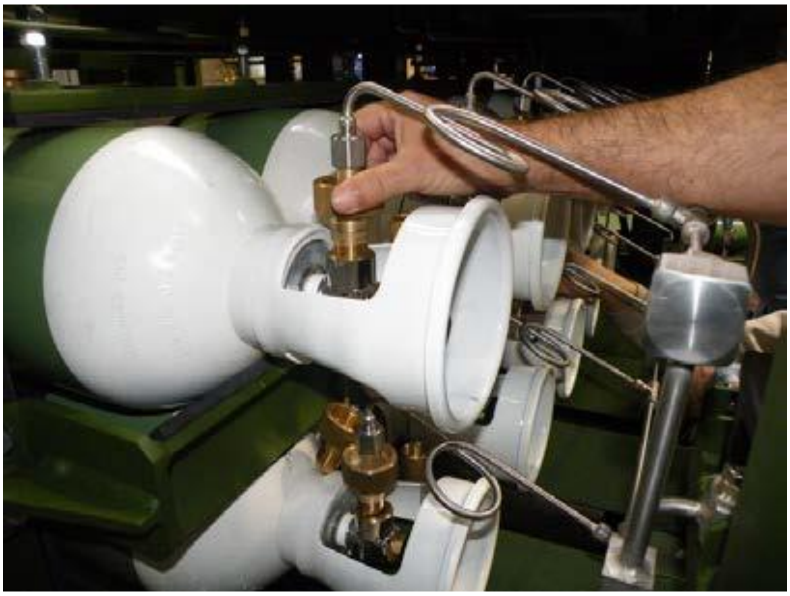


Figure 2 – Ogive blanche bouteille d'oxygène

En configuration transport, le DO22A sera identifié avec des plaques de signalisation transport matières dangereuses. Il comportera sur la bâche recouvrant chaque capacité d'oxygène (capacité fixe et racks additionnels) les panneaux de signalisation « gaz inflammable non toxique » et « comburant », conformément à la classe 5.1 et 2.2 du transport de matières dangereuses.

Figure 2 – Signalisation transport matières dangereuses

Pour le transport terrestre, le référentiel de l'ADR (Agreement for Dangerous goods by Road) devra être appliqué. Si le DO22A est transporté avec ses racks additionnels, l'emport total d'oxygène dépassera les 1 000 litres. Le transporteur devra alors être titulaire du permis transport matières dangereuses (TMD) et respecter le cadre de l'ADR.

Pour le transport maritime, dans la mesure où, d'une part, les bouteilles sont certifiées pour le transport d'oxygène sous pression, et où, d'autre part, la nature de la cargaison est identifiée, il n'a pas été relevé de limitations particulières dans l'IMDG (International Maritime Dangerous Goods). Par contre, l'exécution d'un transport maritime nécessitera le respect des règles de stockage à bord, applicables aux gaz sous pression classifiés 2.2 et 5.1.

3.2 EX_SYS_125 : L'aérotransport en soute d'avion du DO22A est possible sans contrainte spécifique à la cohabitation des bouteilles du sous-ensemble de stockage d'oxygène pleines et des personnels en soute.

Lors des opérations d'aérotransport, comme indiqué dans la STB, le lyrage sera déconnecté des bouteilles afin que la quantité totale d'oxygène présente en soute soit divisée par 10 dans les dix bouteilles de la capacité fixe.

Chaque bouteille, gonflée à 250 bars, contient 16,7 kg d'oxygène. La norme IATA prévoit une charge unitaire maximale de 75 kg d'oxygène pour permettre la cohabitation des personnels et des bouteilles dans les soutes des aéronefs.

Ainsi, la cohabitation de l'ensemble DO22A et des personnels dans les soutes est possible sans contrainte supplémentaire.

Il convient de rappeler que l'aptitude à l'aérotransport n'a été établie par Airborne Systems que pour les aéronefs suivants : C160, C130, A400M, Iliouchine 76 et Antonov 124. La configuration aérotransport prévoit la dépose du GE qui est à arrimer sur une palette.

3.3 EX_SYS_126 : Pour respecter la réglementation relative au transport des marchandises dangereuses IATA, les marchandises entrant dans la constitution de la charge transportée doivent être identifiées et la sécurité du transport aérien de ces marchandises dans les configurations de mission doit être démontrée.

Le transport de matières dangereuses provient de l'emport d'oxygène. Il est signalé directement sur les bouteilles mères ainsi que sur les bouteilles des racks additionnels qui sont munies d'une ogive blanche afin de signaler la présence d'oxygène sous-pression.

En configuration aérotransport, le lyrage du DO22A sera déconnecté, afin de séparer la quantité d'oxygène en plusieurs compartiments individuels de 16.7 kg, soit une quantité inférieure à la limite de 75 kg donnée par le IATA. Il est rappelé que le DO22A sera identifié avec des plaques de signalisation transport matières dangereuses. Il comportera sur la bâche recouvrant chaque capacité d'oxygène (capacité fixe et racks additionnels) les panneaux de signalisation « gaz inflammable non toxique » et « comburant », conformément à la classe 5.1 et 2.2 du transport de matières dangereuses.

4 MAITRISE DES RISQUES A LA CONCEPTION

Cette section regroupe les différents moyens mis en œuvre à la conception du DO22A pour réduire les risques associés à l'environnement d'emploi du système.

Le DO22A regroupe l'utilisation d'oxygène sous-pression, d'électricité et de carburant/graisse. Avant de se servir du DO22A, tout utilisateur devra avoir suivi une formation précise sur le matériel. Cette formation s'adresse à des personnels ayant préalablement suivi une formation interne au ministère de la défense sur l'utilisation d'oxygène sous pression.

Hormis cette formation, la seule habilitation requise pour utiliser le DO22A est l'habilitation B0 ou BR nécessaire à toute intervention sur l'armoire électrique.

L'utilisation du DO22A n'est soumis à aucune restriction particulière relative au travail en hauteur.

Il convient de rappeler que le guide technique (GT) détaille les opérations nécessaires au bon fonctionnement du DO22A et nécessaires à la sécurité. Le respect des prescriptions de ce guide est la meilleure garantie de sécurité lors de l'utilisation du DO22A.

4.1 Risques généraux

Les risques liés à la résistance mécanique du DO22A ont été traités selon les exigences de la spécification technique du besoin et le respect de la sécurité a été pris en compte. Ainsi, le DO22A résiste à l'environnement vibratoire d'un bateau ou d'un Camion (0-10 Hz 1g), et aux accélérations suivantes : 3 g vers l'avant, le haut et en latéral, 1.5 g vers l'arrière et 6 g vers le bas. Les notes de calcul se trouvent dans le rapport transport (TRASE2410) du DJD [4]. Seuls les interfaces d'arrimage prévus sont à utiliser.

De plus, afin d'éviter tout risque de coupure, les arêtes vives et les bavures ont été éliminées à la conception.

Enfin, afin de respecter la charge maximale unitaire dans le cadre du code du travail, les caisses du DO22A ont été chargées de manière à entrer dans le domaine de validité de cette norme.

4.2 Utilisation de carburant/graisse en présence d'oxygène sous pression

Le pétrole et la graisse sont particulièrement dangereux en présence d'oxygène pur car ils peuvent se consumer spontanément et brûler avec une violence explosive.

Le circuit de distribution/compression ne contient aucun lubrifiant de ce type. Cela a d'ailleurs été démontré au travers des mesures de qualité d'oxygène en sortie de circuit de gonflage.

Par ailleurs, afin de réduire le risque d'inflammation dû à la présence de carburant/graisse, il a été convenu que pour toute utilisation du DO22A, le groupe électrogène sera déposé et placé à distance de la remorque équipée (pas de norme spécifique applicable). Ainsi la présence de carburant/graisse ne cause pas de risque pour l'utilisateur.

Enfin les parties mobiles de la remorque sont graissées en usine et ne nécessitent aucune maintenance spécifique au niveau des utilisateurs. En outre, les manuels techniques précisent qu'il ne faut jamais graisser ou huiler l'orifice des bouteilles et des lyres.

En conclusion, le système ne présente aucune zone de cohabitation entre l'oxygène et les graisses lubrifiantes.

4.3 Utilisation d'oxygène sous-pression

Le DO22A comporte une partie distribution permettant à l'utilisateur de charger plusieurs bouteilles individuelles ou collectives à partir des bouteilles mères (capacité fixe) présentes sur la remorque DO22A. Le système utilisera un surpresseur lorsque la pression des bouteilles mères ne sera plus suffisante pour charger les bouteilles.

Afin de garantir la sécurité liée à la présence de l'oxygène, des bouteilles adaptées ont été utilisées (Confère dossier de définition [5]).

Par ailleurs, le sous-ensemble de distribution a été conçu et fabriqué par la société Sis Novam concepteur et fabricant d'équipements Haute pression validés en compression adiabatique Oxygène. La conception a été validée par Airborne Systems au travers des différentes revues menées pendant la phase de développement. La fabrication a été validée par l'application des procédures internes à Sis Novam, matérialisée par l'émission de leur certificat de conformité.

Les risques identifiés liés à la compression de gaz sont les suivants :

- Une montée trop importante de la température qui engendre un risque de dégradation des éléments non métalliques du surpresseur pouvant générer une pollution des bouteilles gonflées ;
- Une déconnexion des interfaces à cause de l'effort du à la pression et la création d'un effet coup de fouet par les tuyauteries flexibles ;
- Fuites.

Afin de compenser ces risques, différents dispositifs de sécurité ont été implantés sur le DO22A :

- le surpresseur montant en température lorsqu'il est en fonctionnement, un ventilateur actif en permanence dès la mise sous tension a été placé dans le sous-ensemble de compression. Cette première précaution est complétée par un thermocouple limitant l'élévation de température (seuil 110° C, définit à partir des caractéristiques des matériaux utilisés, mesuré sur la tête de compression). Si ce seuil devait être atteint, ce thermocouple déclencherait un arrêt de la compression. De même, une défaillance du thermocouple sera rendue évidente à l'opérateur au travers du tableau électrique ;
- des dispositifs anti coup de fouet ont été placés sur les différentes parties flexibles de l'ensemble distribution. Ainsi, même en cas de déconnexion accidentelle des interfaces, l'utilisateur ne pourra pas être blessé pas un tel phénomène. Cela permet de garantir la sécurité de l'utilisateur lors du gonflage des bouteilles

d'oxygène. De plus, il est rappelé que la qualification initiale et spécifique de l'opérateur ainsi que les règles d'utilisation précisées dans le GT éliminent ce risque.

S'agissant des fuites, leur absence est garantie par l'utilisation de composants dédiés à des installations de gaz sous pression. Il convient de noter que le DO22A étant utilisé dans un espace ventilé et isolé, une fuite en utilisation n'est pas un risque en soi. Cela dégraderait simplement la performance du DO22A. En transport, le risque éventuel généré par une fuite en milieu fermé (soute d'avion) est traité par les limitations d'emport du IATA.

Enfin, si malgré les protections mises en œuvre ou en cas de cause externe inconnue, il s'avérait nécessaire de stopper le fonctionnement du DO22A, un arrêt d'urgence présent sur le panneau de commande permettrait, s'il est pressé par l'utilisateur, d'arrêter tous les flux d'oxygène dans l'ensemble distribution. Il devra être réarmé avec une clef fournie avec l'ensemble DO22A afin de permettre la reprise du fonctionnement. Il convient de préciser que l'action de l'arrêt d'urgence n'entraîne pas une purge du circuit et que les consignes de déconnexion des flexibles et du lyrage restent applicables.

Ce dernier dispositif, demandé de surcroît dans le cahier des charges contribue à renforcer la sécurité d'emploi du DO22A.

4.4 Utilisation d'électricité

Le DO22A pourra être alimenté en énergie électrique de plusieurs manières. Le GE pourra fournir de l'électricité au système ou ce dernier pourra être directement relié au réseau électrique présent lors de l'emploi du DO22A.

Les câbles ont été choisis de manière à permettre à la puissance nécessaire au bon fonctionnement du DO22A, de circuler sans risque pour l'utilisateur (Cf. Dossier de définition).

De plus, afin d'écarter tout risque d'électrocution, différentes mises à la terre ont été prévues.

Les éléments métalliques étant tous au contact les uns des autres au travers de leurs éléments de fixation, une mise à la terre antistatique a été prévue pour l'ensemble de la remorque équipée du DO22A. Elle sera réalisée grâce à un câble métallique muni de pinces-crocodile reliant un élément métallique non-peint de la remorque (accroche présente à l'arrière de la remorque) et un élément métallique présent directement sur le site d'utilisation du DO22A. Dans le cas où il n'y aurait pas d'élément métallique accessible à proximité, l'utilisateur utilisera le piquet de masse en forme de T présent dans le lot de bord du DO22A.

En cas d'utilisation du GE, la mise à la terre est assurée selon le même principe en se reprenant sur l'accroche spécifique du GE. En cas de raccordement au réseau électrique, la mise à la terre est assurée par la prise (norme CEI 60309).

A chaque utilisation, le guide technique précise que l'utilisateur vérifiera le bon fonctionnement du circuit électrique. Une fonction auto test, présente sur le panneau électrique, permet de vérifier que les LEDs de contrôle sont en bon état, ce test sera mis en œuvre avant toute utilisation du DO22A. Si un défaut électrique apparait en cours d'utilisation, une des LEDs s'allumera et sera accompagnée d'un signal sonore afin de prévenir l'utilisateur de ce disfonctionnement.

Enfin afin de pouvoir arrêter le système pendant son utilisation dans le cas où un disfonctionnement apparaitrait, le GE est également muni de plusieurs capteurs permettant son arrêt automatique et d'un arrêt d'urgence manuel.

5 MAITRISE DES RISQUES A L'UTILISATION

5.1 Phase de préparation au transport

Situation de nuisance	Risque pour l'utilisateur	Solution envisagée
Manipulation du timon et de la remorque	Coincement des doigts	Port des gants mis en place dans le lot de bord

Tableau 2 – Nuisances et risques pour la phase de préparation au transport

5.2 Phase de préparation à l'utilisation

Situation de nuisance	Risque pour l'utilisateur	Solution envisagée
Chargement et déchargement des caisses	Manutention, risques dorso-lombaires	Respect de la charge maximale unitaire
	Coincement des doigts	Port de gants
	Chute d'éléments sur les pieds	Port de chaussures de sécurité recommandé
	Chute des caisses lors du déchargement	Marche-pied de grande taille fourni
	Choc à la tête de l'opérateur	Risque très faible. Précaution lors de l'utilisation. Port de casquette de protection recommandé
Déchargement du GE	Circulation d'un chariot élévateur	Respect des règles d'utilisation et de circulation du chariot élévateur

Tableau 3 – Nuisances et risques pour la phase de préparation à l'utilisation

5.3 Phase d'utilisation

Situation de nuisance	Risque pour l'utilisateur	Solution envisagée
Allumage du GE	Coincement des doigts dans les armoires	
Chargement des bouteilles	Fuite d'oxygène	Utilisation d'une bouteille « snoop 2oz » en NTI1 pour vérifier les fuites d'oxygène.

Tableau 4 – Nuisances et risques pour la phase d'utilisation

5.4 Phase de maintenance

Le paragraphe 5.2 du Manuel Technique (MT) [6] liste les opérations de maintenances périodiques qui permettent de garantir le bon état des différents éléments assurant la sécurité de l'utilisateur.

Ces opérations de maintenance sont principalement des opérations de contrôle et d'échanges standards.

Aucune de ces opérations n'est dangereuse. Le risque associé à une mauvaise exécution est principalement une fuite dont le cas est traité au paragraphe précédent.

Les opérations de maintenance effectuées par l'utilisateur et l'exploitant du DO22A seront complétées par une visite annuelle de sécurité effectuée par Airborne Sytems France afin de procéder à la vérification obligatoire de certains matériels (exemples : extincteurs, cric). A cette occasion, une inspection visuelle sera effectuée afin d'identifier les dégradations éventuelles. Sauf criticité identifiée, ces dégradations seront traitées au titre de la révision générale prévue tous les 5 ans.

6 CONFORMITE CE

L'article 11.1 du CCAP [7] demande à ce que le système soit livré avec une déclaration CE de conformité. Or, il n'existe pas de référentiel applicable au système complet. Par conséquent l'approche de la « conformité CE » a été faite par sous-ensemble.

Pour ce faire, soit un sous-ensemble possède sa propre déclaration CE, soit une déclaration issue de l'analyse de sa conception et de son utilisation est fournie pour acceptation.

Le tableau 2 ci-dessous regroupe les références des différentes déclarations fabricant.

Sous-ensemble	**Référence**
Groupe électrogène	Déclaration de conformité. Réf C03-026-218
Remorque du DO22A	Déclaration de conformité. Réf AVX1180040001
Distribution du DO22A	Déclaration de conformité Sis Novam du 3 mars 2017
Compression du DO22A	Déclaration de conformité du moteur DOC-BEZ-FS-501-E-EN

Bouteilles mères	Bouteilles conformes à la réglementation ADR / TPED / IATA
Rack additionnels	Déclaration de conformité Sis Novam du 3 mars 2017

Tableau 5 – Documents référençant les déclarations CE

DOCUMENTS APPLICABLES

[1] Cahier de clauses techniques particulières DO22A2014920016CCTP1.0.20131105

[2] Spécification technique de besoin DO22A2014920016STB1.0 20131126

[3] Guide technique

[4] TRASE2410 – DO22A – DJD – Rapport transport

[5] TRASE2343 – DO22A – Dossier de Définition

[6] Manuel Technique

[7] Cahier des clauses administratives particulières CCAP 2014 92 0016