Hydrostatic pressure loads for a tank using "CID Distributed Loads" fields in a PATRAN FEM model

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Abstract: *The purpose of this paper is to present a practical way to introduce distributed loads on the walls of a tank in order to perform a FEM analysis using PATRAN/NASTRAN programs. The problem is generated mainly by the fact that there are gravitational accelerations in the three directions of the moving airplane that produce a great number of combinations of inertial loads and consequently a great number of critical load cases. We compared the performed stress analysis with the loads obtained with this method in different cases for* $n = 1$*. (Different forms of the fuel tanks and different placements of the tank inside the aircraft). The form and the density of the grid do not significantly affect the precision of the real inertia loads. Using the presented method one can reduce the volume of FEM files used in the analysis and can quite accurately reproduce the pressure loads on the fuel of a moving aircraft.*

Key Works: *hydrostatic pressure, finite element simulations, distributed loads, fuel tank for aircrafts, stress analysis*

1. INTRODUCTION

One of the most common problems in the stress analysis of the walls of an airplane tank is to introduce the hydrostatic pressure loads.

The problem is generated mainly by the fact that there are gravitational accelerations in the three directions of the moving airplane that produce a great number of combinations of inertial loads and consequently, a great number of critical load cases.

The hydrostatic pressure on a wall of a tank depends on the height of the column of the liquid considered on the coordinated axis where inertial loads appear.

Because the stress analysis of the airplane tank is performed using a finite element model, hydrostatic pressure loads should be introduced as pressure loads on plane elements (plates).

The FEM evaluation is performed as usual in the aircraft design [1, 2, 3, 4]. In the finite element program PATRAN/ NASTRAN there is an option to apply this type of loads **"CID Distributed Loads''** defined by **"Fields"** force distributed fields on elements.

Using this option, the field forces are defined as vectors in a three-axis coordinate system. Using this option to apply pressure loads on a wall of a tank, one creates fields of "distributed loads" for each inertial load on each coordinate axis for $n = 1$.

For $n \neq 1$ we multiply the field with the corresponding value of the inertial load factor. To simplify the presentation in the following lines we consider only tanks with plane walls and we shall evaluate the influence of the geometry of the walls and of the mesh density on the value of the fuel weight.

2. DEFINING THE LOADS "CID DISTRIBUTED LOADS" USING FIELD EQUATIONS

In PATRAN "CID Distributed Loads" creates a distributed load on an element using the components defined on the three directions of a given coordinate system.

They are the equivalent of a pressure load but are defined as three-component vector in a Cartesian coordinate system.

This vector may be defined in PATRAN using the "Fields" option which introduces a distribution of things on a finite element grid in the following four ways: introducing point values, or using some equations, or in a field window, or using some exterior routines (PCL Function).

Here we use the method of introducing equations in the PATRAN field window.

3. DEFINING THE HYDROSTATIC PRESSURE EQUATIONS

If we consider a tank on the ground full of liquid acted only by the gravitation force, then the hydrostatic pressure on a wall of a liquid column of height h is:

$$p = y * h$$

where: p is the pressure, y is the specific weight of the liquid and h is the height of the column of the liquid above the considered point.

The maximum pressure p_{max} on a wall of a tank of height H full of liquid is:

$$p_{max} = y * H$$

If we shall use in the stress analysis this value, we shall obtain loads 3 or 4 times greater than the real weight of the liquid.

So, it is necessary to introduce a variable hydrostatic pressure on the wall in order to have plausible results.

First we consider a simple tank as presented in figure 1, placed with its base on the horizontal plane and with its height in the vertical direction.

The pressure on the lateral wall is varying from the base to the top, according to the following equation:

$$p = p_{max} - p_{max} * Z/H,$$

where Z is the coordinate in the Oz direction of the considered point where the pressure is calculated and for each wall three components on the coordinate axes are defined and one must take into account that the pressure acts from the interior to the exterior of the tank.

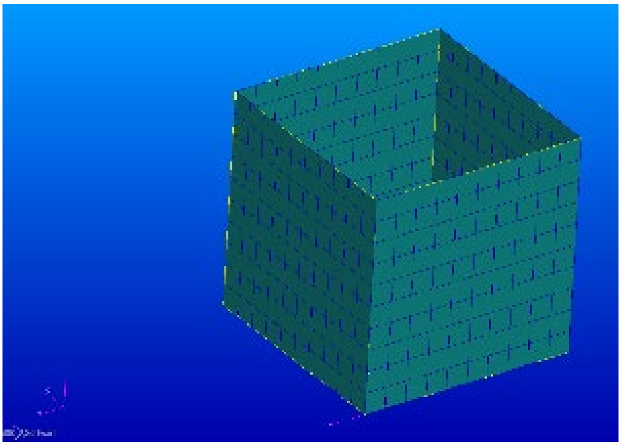


Figure 1. Simple rectangular tank

Therefore, for example, the pressure vector on the front wall of the tank is:

$$p_x = -\left(p_{max} - p_{max} * \frac{Z}{H}\right), p_y = 0, p_z = 0.$$

If the basis of the tank is placed at Z_0, then the equation of the distributed force on a wall is:

$$p = p_{max} - p_{max} * (Z - Z_0)/(Z_{max} - Z_0),$$

where: Z_0 is the coordinate defining the lowest point of the tank and Z_{max} is the coordinate defining the highest point of the wall.

For a tank with oblique walls, as presented in figure 2, the pressure on an oblique wall is:

$$p_x = \pm\left(p_{max} - p_{max}(Z - Z_0)/(Z_{max} - Z_0)\right) * cos(alfax)$$
$$p_y = \pm\left(p_{max} - p_{max}(Z - Z_0)/(Z_{max} - Z_0)\right) * cos(alfay)$$
$$p_{zx} = \pm\left(p_{max} - p_{max}(Z - Z_0)/(Z_{max} - Z_0)\right) * cos(alfaz)$$

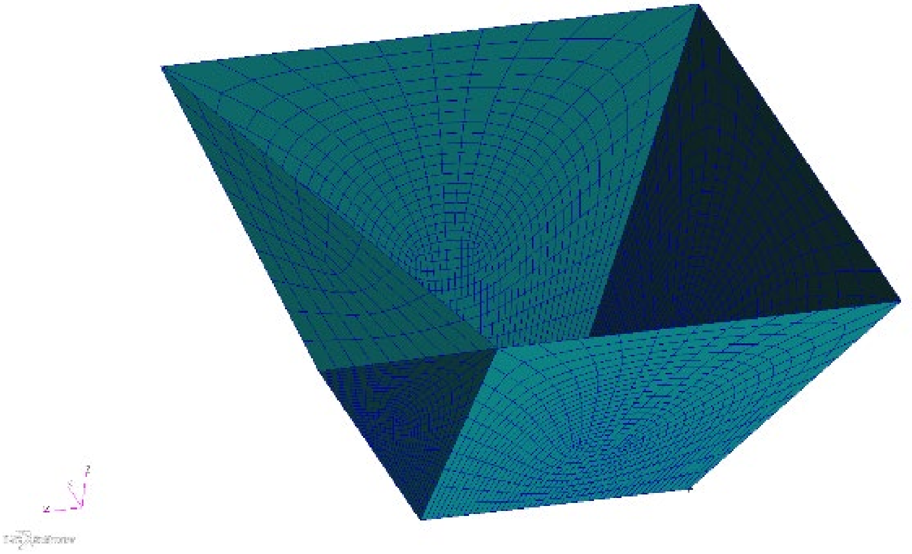


Figure 2. Tank with oblique walls

where $p_x p_y$ and $p_z$are the components of the distributed forces on the three directions of the considered coordinated system and $alfax,\ alfay,\ alfaz$ are the angles of the walls with the three-coordinate system.

In figure 3 we present a PATRAN window used to define the three components of the pressure vector.

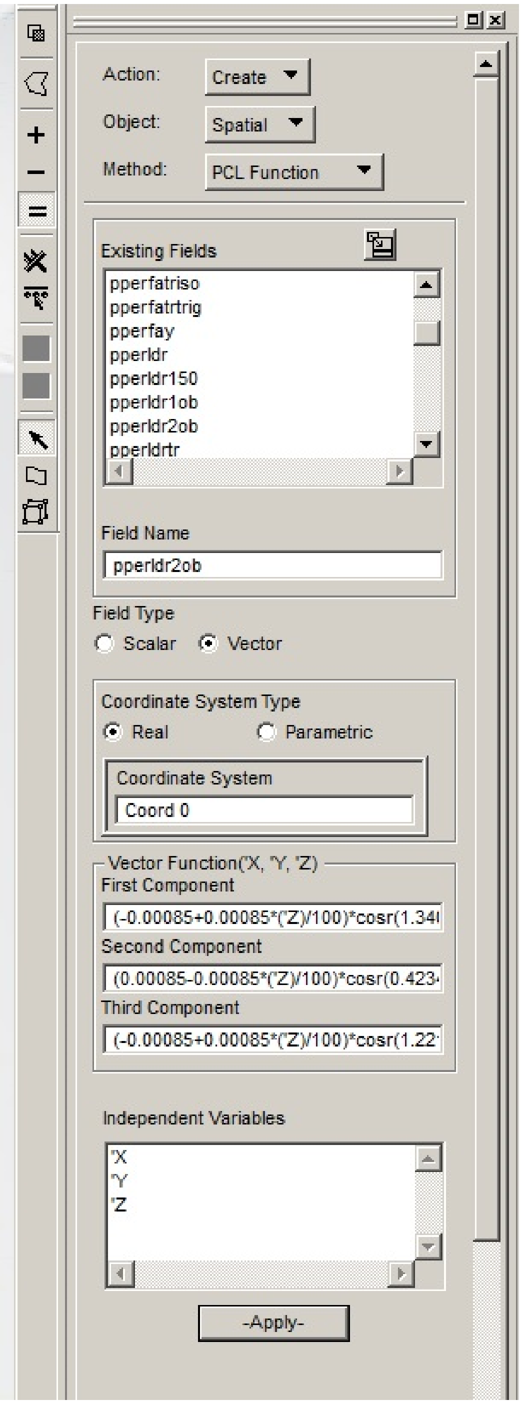
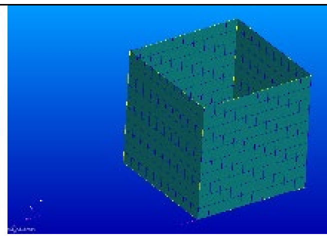
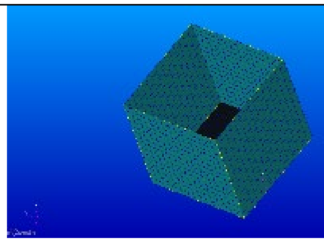
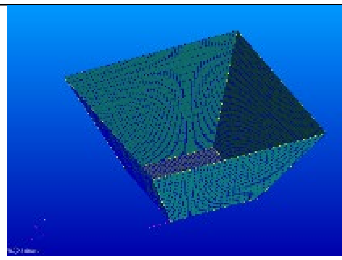
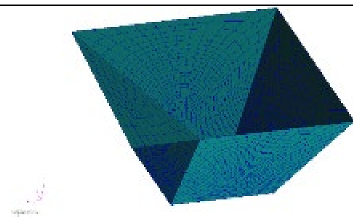


Figure 3. PATRAN window

4. STUDIED CASES AND RESULTS

The studied cases are presented in Table 1.

Table 1. Studied cases

-rectangular tank: 100x100x100mm H=100mm	
-rectangular tank: 150x150x150mm H=150mm	
-Tank with oblique walls: Small base=100x100mm Large base =200x200mm H=100mm	
- Tank with oblique walls, one of which is composed of two planes arranged at an angle Small base=100x100mm Large base=200x200mm H=100mm	

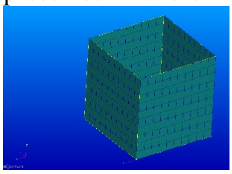
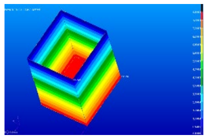
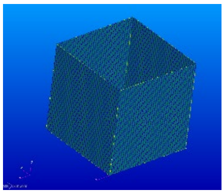
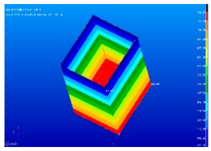
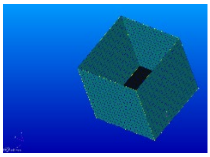
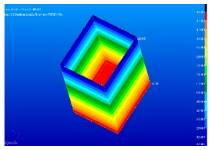
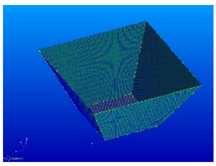
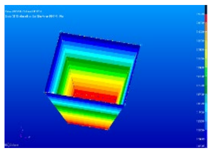
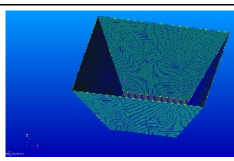
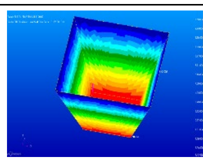
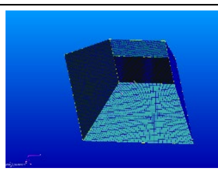
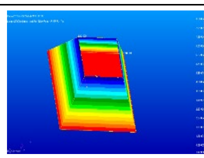
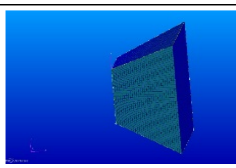
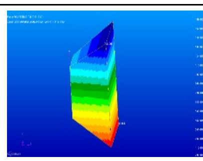
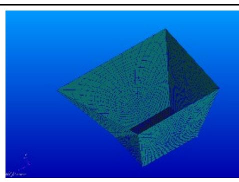
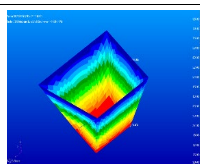
We used three finite element grids: a regular grid, a refined regular grid and an irregular grid.

In Table 2 we present the used models, the distribution of the resulted pressure, the total weight of the liquid, and the computed weight of the liquid with the expression:

$G = \gamma * V$, where G is the weight of the liquid and γ is the specific (unit) weight.

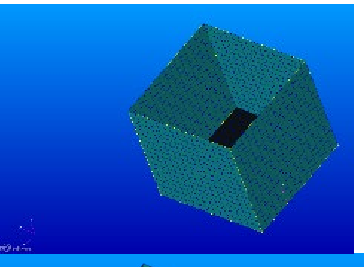
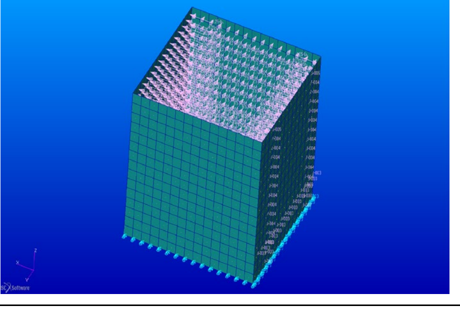
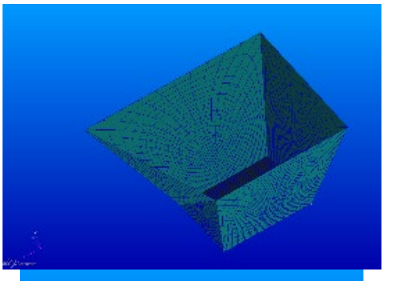
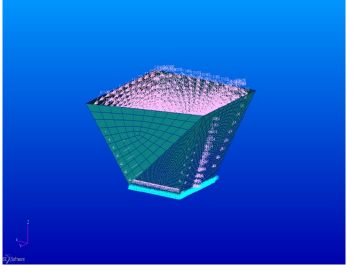
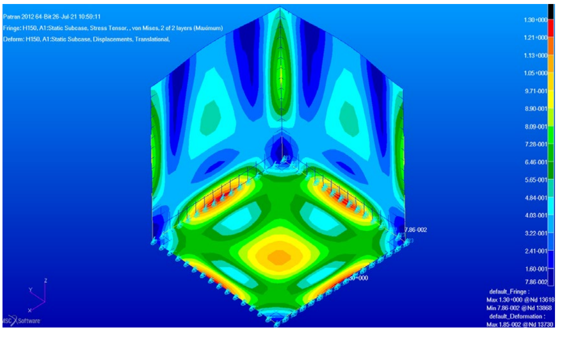
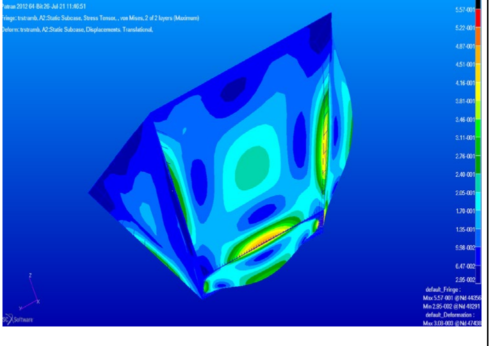
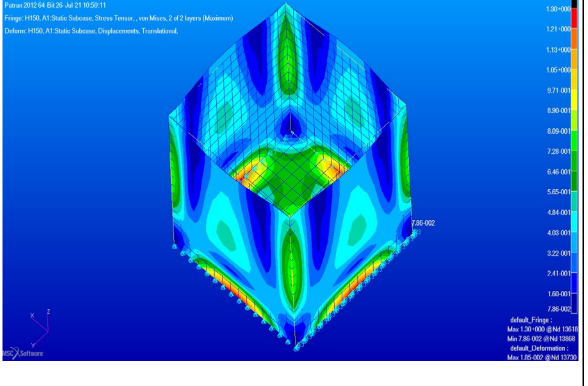
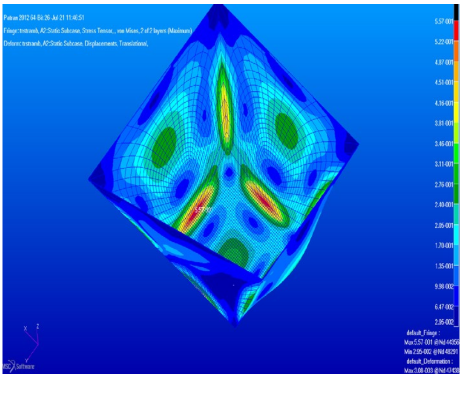
We considered a liquid with γ= 0.85daN/dm^3.

Table 2. Models and results

Tank	Grid	FEM Model	Distributed loads	FEM weight [N]	Computed weight [N]
Cube 100x100x100	Regular grid	The studied cases are presented in Table1 		-8.50E+00	8.5
	Refined regular grid			-8.50E+00	8.5
Cube 150x150x150	Regular grid			-28.6875	28.6875
Oblique walls with small base	Regular grid			-19.83964	19.83333
	Irregular grid			-19.83928	19.83333
Oblique walls with large base	Regular grid			19.8349	19.83333
Oblique walls placed on an edge	Regular grid			-19.83254	19.83333
Tank with oblique walls, one of which is composed of two planes arranged at an angle	Irregular grid			-17.71657	17.70833

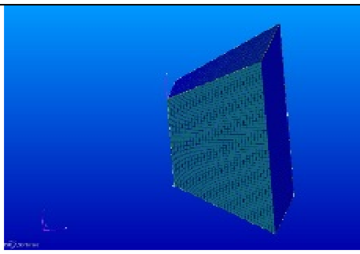
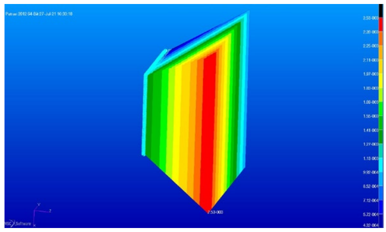
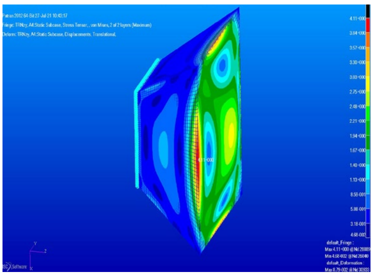
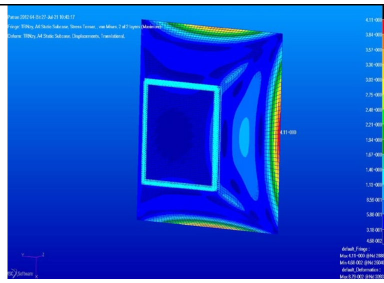
In table 3 Von Mises stresses and deformations are presented in two analyzed cases.

Table 3. Stresses and deformation for an inertial case $n = 1$ and the Oz is down oriented

Cube 150x150x150	Tank with oblique walls, one of which is composed of two planes arranged at an angle
 	 
	
	

In table 4 we present Von Mises stresses and deformations for another tank with oblique walls with inertial forces on the two axes Oy and Oz.

Table 4. Stresses and deformations for a tank with oblique walls placed on an edge

Tank with oblique walls	
	
	

5. CONCLUSIONS

In this paper we presented a practical method used to apply the hydrostatic pressure loads in a finite element model defined in PATRAN, using fields of distributed loads (CID Distributed Loads).

We compared the performed stress analysis obtained with these loads in different cases for $n = 1$. The form and the density of the grid do not significantly affect the precision of the real inertia loads.

This method is very useful to define the critical load cases for an aircraft because it reduces the memory volume of the FEM file.

An alternative way to define these fields is to use external routines.

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