A new methodology for fuel mass computation of an operating aircraft

M Souli[1*], R Messahel[1], B Reynard[2], P Sinou[2]
1. Laboratoire de Mécanique de Lille, University of Lille, France
2. ZODIAC Aerospace PLAISIR, France

ABSTRACT
The paper performs a new computational methodology for an accurate computation of fuel mass inside an aircraft wing during the flight. The computation is carried out using hydrodynamic equations, classically known as Navier-Stokes equations by the CFD community. For this purpose, a computational software is developed, the software computes the fuel mass inside the tank based on experimental data of pressure gages that are inserted in the fuel tank. Actually and for safety reasons, Optical fiber sensor for fluid level sensor detection is used. The optical system consists to an optically controlled acoustic transceiver system which measures the fuel level inside the each compartment of the fuel tank. The system computes fuel volume inside the tank and needs density to compute the total fuel mass. Using optical sensor technique, density measurement inside the tank is required. The method developed in the paper, requires pressure measurements in each tank compartment, the density is then computed based on pressure measurements and hydrostatic assumptions. The methodology is tested using a fuel tank provided by Airbus for time history refueling process.

1. INTRODUCTION

Most aircraft as commercial aircraft have their fuel tank located within the wing. The shape of the tank has a complex geometry, and thus some techniques are required to accurately measure the fuel mass inside the tank. We have to mention, the fact the tank is subdivided into several compartments to attenuate fuel dynamic motion, requires measurements of the fuel height inside each compartment. The measurement of the fuel volume is done using the measurement of the fuel height at several locations where the probes are located. Most methodologies used for aircraft fuel systems measure the fuel height using different techniques. For regular geometry of the tank, a linear relationship can simply relate fuel height to fuel volume. For complex shapes as the ones in commercial aircraft, the relationship between the fuel height measurement and the volume is not anymore linear, which requires sophisticated methods to compute for fuel mass computation. Several techniques have been developed for measurement of the fuel height. Capacitance gauging has been used for decades in aeronautic. The industry has almost universally accepted this method of gauging as the way to gauge fuel quantity accurately. The success of capacitance gauging systems is mainly related to their compatibility and longevity in the relative hostile

*Corresponding Author: mhamed.souli@univ-lille1.fr

aircraft environment. In addition to the complexity of the shape, some allowances due to presence of the internal components such as ribs, stringers, pumps and valves located within the tank. The methodology, based on pressure gauging, presented in this research takes into account internal components when using a very fine computational mesh for the inside tank geometry. Pressure gauging method is a common technology in hydrodynamic analysis, and wind tunnel experimental studies. This technology is widely used in different industries but mainly for static analysis. Adapting this technology to aircraft wing is a great challenge because of complex fluid phenomena linked to the geometry and the dynamic of the tank. Aircrafts usually have several fuel tanks separated by baffles designed to reduce sloshing effects and wave amplitude motion. The size of holes pierced on the baffles are designed to reduce sloshing effects, transfer and distribute fuel mass in a equilibrium concept thought different baffles. Up to now and for some technical reasons, pressure gages build to perform under severe conditions and environment, that are accurate for small to medium pressure measurements, between 10 Pas and 10000 Pas, are not available in industrial instrumentations manufactures. For lack of experimental data for pressure values, that will be provided by Zodiac in the near future, a numerical simulation is performed to provide pressures, that will be used as input parameters in our software package to provide fuel mass inside the tank. To validate our methodology of fuel mass computation, a computational method using FEM (Finite Elements method) is performed to model a fuel filling tank. Numerical pressure values can be extracted at locations where numerical pressure gages are implemented. These pressure values will be used as input data for the developed software package.

In this paper, we first present the hydrodynamic equations governing the dynamic of the fluid during the filling process, where the flow is assumed incompressible and the fuel a viscous fluid. To compute accurately the free surface or the interface between the fuel and the surrounding air in the tank, interface reconstruction technique is performed. Interface reconstruction is a numerical method for interface tracking, a piecewise linear reconstruction of the interface, which provide second order accuracy, developed by Young [1,2]. The numerical simulation provides pressure time history values as input data, and provides also mass fuel time history that will be used as a reference data, to validate fuel mass computed using the methodology developed in the project.

Using a computational finite element mesh inside the tank, the fluid air interface cannot be aligned with the mesh, this lead to a situation where some elements are completely filled with the fluid, and some are partially filled. To accurately compute the volume of the fluid at a specific time during the filling process in this particular case, or during the flight, the element volume intersection with the free surface needs to be geometrically computed.

In the second phase, the method used in the software package, for the computation the volume intersection is presented. This method is based on research work done by Lopez and Hernandez [3].

2. HYDRODYNAMIC EQUATIONS AND LEVEL SET METHOD

The state of the art of computational mechanics consists in developing and solving applied mathematical models to solve practical problems. Numerical methods provide approach solutions to physical problems by solving developed mathematical models. To solve the fuel tank refuelling problem, the fuel can be considered incompressible or nearly incompressible. The choice between these two physical assumptions will lead to a different numerical algorithm, explicit time scheme for nearly incompressible flow and implicit time scheme for incompressible flow, and thus two possible numerical strategies have been used for computing fuel mass in an operating aircraft.

During the last decades, the performance of computers has grown exponentially with the development and expansion of High Performance Computing (HPC). For complex and large finite element method (FEM), we may need to consider computing resource as an input parameter since the size of the model and the physical termination time will directly affect the computational time (CPU) time, the memory storage, but also the accuracy of the solution. Finally, one need to find the best compromise between the accuracy of the solution and the needs in term of computation (CPU time, memory ...).

Fuel dynamic behaviour inside the tank can be modelled using classical CFD (Computational Fluid Dynamics) equations to predict fluid velocity and pressure at any location inside the tank. These equations known as Navier Stokes equations are defined by Equation 1. To accurately determine fuel level at any location inside the tank, these equations need to be completed by level set equation for interface reconstruction, interface defining the level of fluid material inside the tank.

$$\rho\left(\frac{\partial v}{\partial t}+v_i\frac{\partial v_i}{\partial x_j}\right)=-grad(P)+\mu\nabla^2 v+\rho.g$$

$$div(v)=0 \tag{1}$$

where:

v: fluid velocity and, the pressure

ρ: fluid density

μ: dynamic fluid viscosity

g: gravitational vector

The first equation in Equation 1 expresses conservation of momentum and second equation mass conservation for incompressible flow.

To simulate fuel filling process inside the tank, inflow velocity, computed for inflow rate provides by Zodiac Aerospace, is prescribed at a local opening area.

Equation 1 governs the flow velocity and pressure inside a fluid domain given physical boundary conditions. To accurately define the fluid level at each time during the fueling process, Equation 1 need to be completed by level set equation:

$$\frac{\partial \alpha}{\partial t}+v.\nabla\alpha=0 \tag{2}$$

The basis of the Level Set methods has been proposed by Osher and Sethian [4]; and describe in detail in Souli and Benson [5]. The interface function α defines the distance to the fluid interface. The zero level curve of the continuous function α defines by the location of the fluid interface. Equation 2 is known as a transport equation that describes the evolution of the free surface or zero iso-surface.

Numerical computation of Equations (1-2) can induce mass loss in under-resolved regions. This is the main drawback of level set methods. To improve mass conservation, different extensions of the level set method have been developed be developed, as the particle level set (Enright et al. [6]) and a coupling between VOF and level set (Sussman and Puckett [7]; van der Pijl et al. [8]).

3. NUMERICAL SIMULATION OF AIRCRAFT TANK REFUELING

3.1. Problem description

In this work, we are interested in the hydrodynamic effects of the fluid during tank refueling and more precisely in the influence of the dynamics effects on the pressure field and how does it evolve in time for a variation of volume compared to the hydrostatic solution.

Two set of simulations will be performed for a given pitch and roll angle and results will be compared in term of volume-pressure cross plot. A first set of hydrostatic simulations using both LS-DYNA [9] and ZODIAC's analytical tool will be performed in order to validate the LS-DYNA software for simulating hydrostatic pressure when the fuel is at rest but also to have qualitative results and to control the convergence of the results during the computation (crucial step as we need to follow a simulation that takes several days, and one cannot afford to wait for the final results). A second simulation of the full hydrodynamic process respecting the following input parameters:

- Real time simulation: 900 s. Simulation starts at t=0 s and ends at 900s (97% of total volume is filled).
- Ambient temperature: 20 °C.
- Gravity Load: 9.81 m/s² following Z-axis.
- Fuel tank is fixed in space.
- Initially filled with air, the tank is filled with fuel introduced at constant pressure (3400 mbar).
- The structure is considered to be rigid.
- The tank is filled with Jet-A1 kerosene type:
    - o Density: 807 kg/m^3.
    - o Kinematic viscosity: 1.65 cSt.
- Gas pressure: 1013 mbar.
- Outside pressure: 1013 mbar.
- Constant inlet volume flow rate: 3.34.e-3m^3/s.

Results are expressed in term of volume-pressure cross plots at a given sensor location. The CAD model of the fuel Tank has been done by ZODIAC. It includes all the details: Baffles, mice holes, central opening on baffles. Only the vent system is not included in the geometry.

The CAD model of the fuel tank is shown in Figures 1, 2 and 3 local zooms are shown at the inlet and outlet locations, respectively.

3.2. Numerical Simulation

The fuel tank CAD model provided by ZODIAC was modeled excluding the mice holes on the bottom and the top of the baffles. Adding the mice holes would have required smaller elements size and thus may have increased considerably the overall CPU time. Reminding that the main concern of this study is the validation of Fuel mass computation methodology against numerical simulation results in absence of experimental data, the effects of the mice holes can be neglected. The numerical model is composed of 4.536.706 tetrahedron elements. Figure 4 shows the numerical model including baffles with holes separating the different compartments. A local zoom on the mesh is shown in Figure 5 at the inlet location.

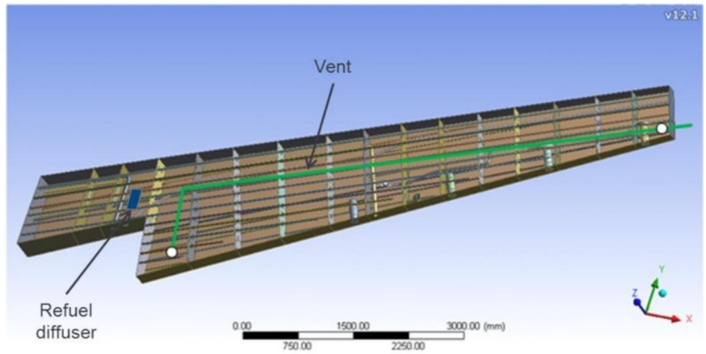

Figure 1: Fuel Tank CAD Model

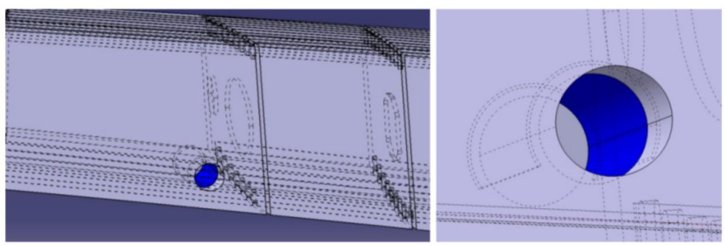

Figure 2: Local Zoom on the Fuel Tank Inlet

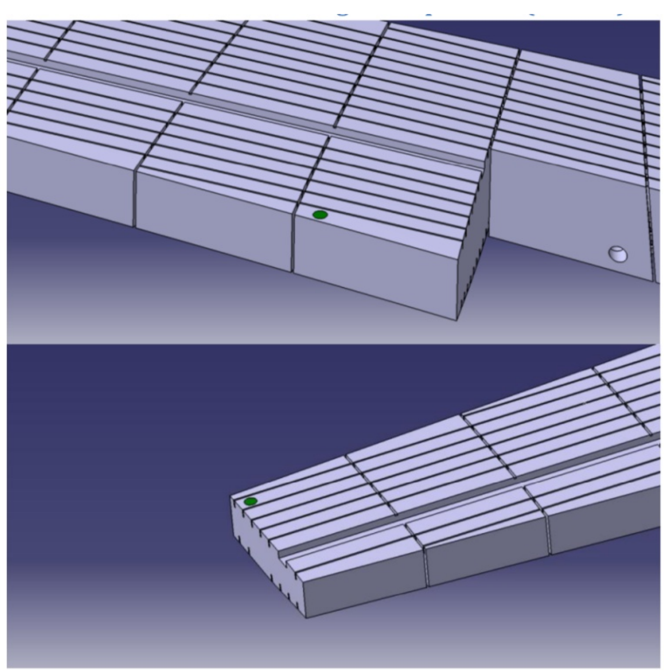

Figure 3: Local Zoom on the Fuel Tank Outlets

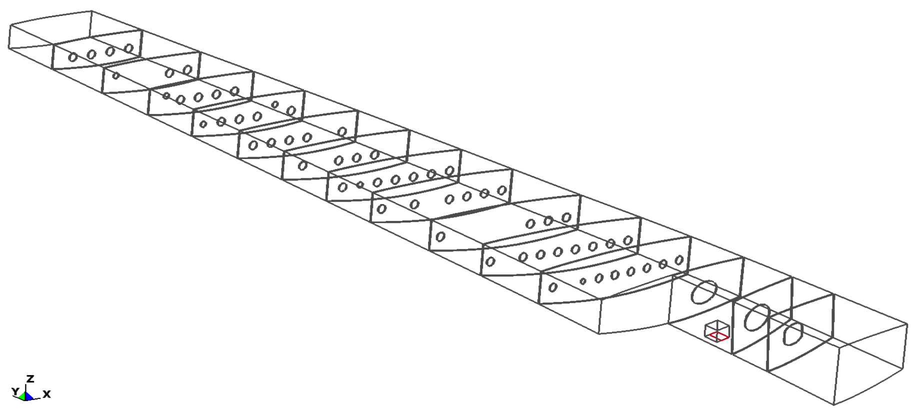

Figure 4: Numerical model of the Fuel Tank model: Baffles and holes.

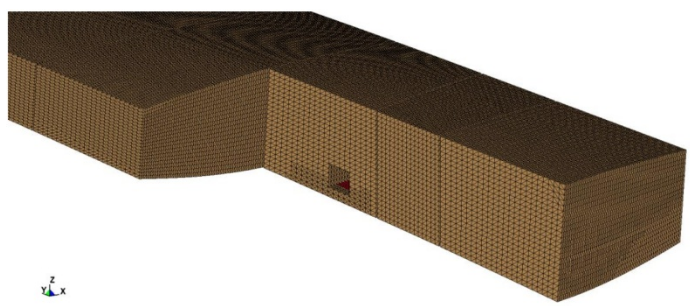

Figure 5: Local zoom of the mesh at the Fuel Tank Inlet location.

Hydrostatic simulation

When the fuel is at rest, we have only one plane fuel free surface in the whole fuel tank and a hydrostatic pressure profile is obtained. Hydrostatic pressure for each material can be simulated in LS-DYNA based on an element depth and with respect to the "reference" pressure P_{top} at the top of the fuel.

For one multi-material formulation that contains two fluids (fuel and air), the hydrostatic pressure is defined by:

$$P = P_{top} + \sum_{i=1}^{Nmat=2} \rho_i g h_i \tag{3}$$

For given pitch and roll angles (θ_x, θ_y), the hydrostatic simulation is repeated for variable height of fuel to obtain the reference volume-pressure cross plot. To do so, an automatic script has been programmed in Linux OS, the different steps of the program are:

- Initialization of the parameters: Fluids properties, minimum Z-coordinate Z_{min} of the tank, maximum Z-coordinate of the tank Z_{max}, the desired number of height levels N_{sub} and the height increment $\Delta h = \frac{Z_{max} - Z_{min}}{N_{sub}}$.
- For $i = 1\ to\ N_{sub}$.

- o Compute the height $h_i = (Z_{min} + \Delta h)_{for\ step\ i}$
- o Initialize the volume fraction by cutting the element with a $X - Y$ plane located at position h_i in Z-axis.
- o For each multi-material, compute in LS-DYNA the hydrostatic pressure using Equation 3.
- o Copy the mass for the material fuel and convert it to volume using the density.
- o Copy the pressure at the location of the sensor (see Figure 6).
- o Since the pressure is computed at the centre of an element in LS-DYNA (one-point quadrature rule), we compute the analytic hydrostatic pressure at the centre of the element (and not at its base).
- o Store in two different files the gathered results (LS-DYNA and analytic pressure).

Relative Pressure contour plots are shown for 25%, 50%, 75% and 100% of the total height $(Z_{max} - Z_{min})$. Figure 7. LS-DYNA and analytic hydrostatic relative pressure are given in Figure 8.

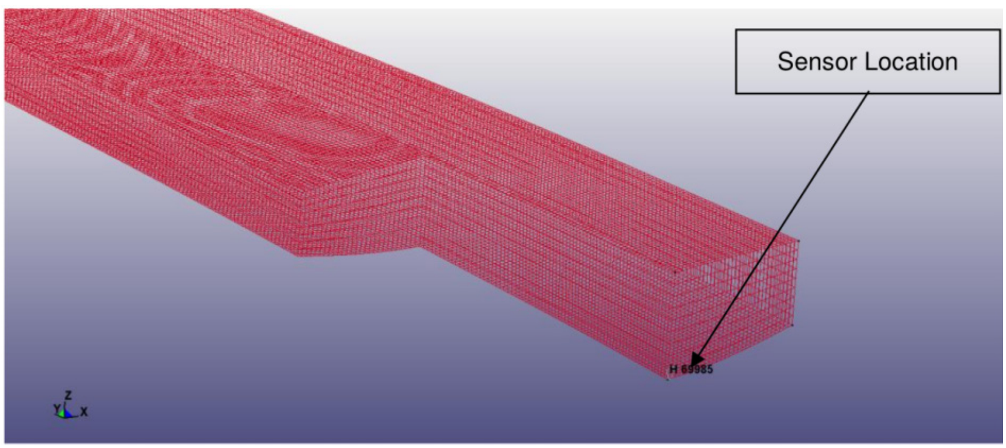

Figure 6: Sensor at the maximum pressure location.

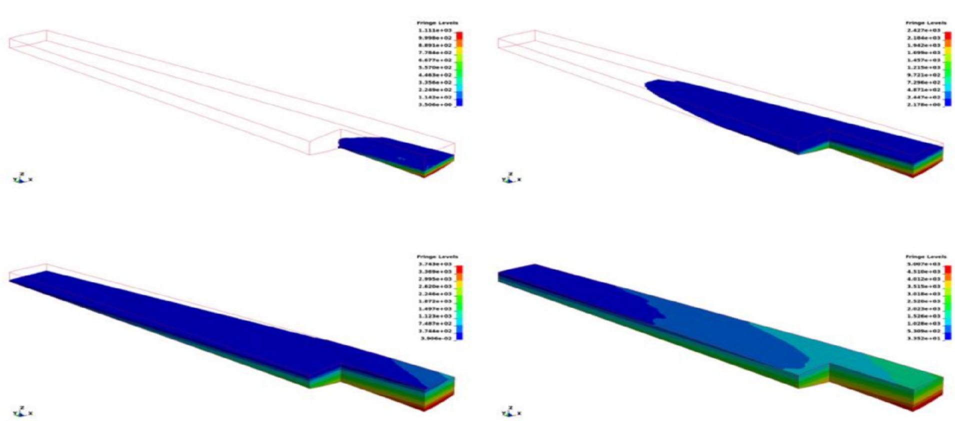

Figure 7: Jet A-1 fuel hydrostatic pressure contour for various heights (25%, 50%, 75% and 100%).

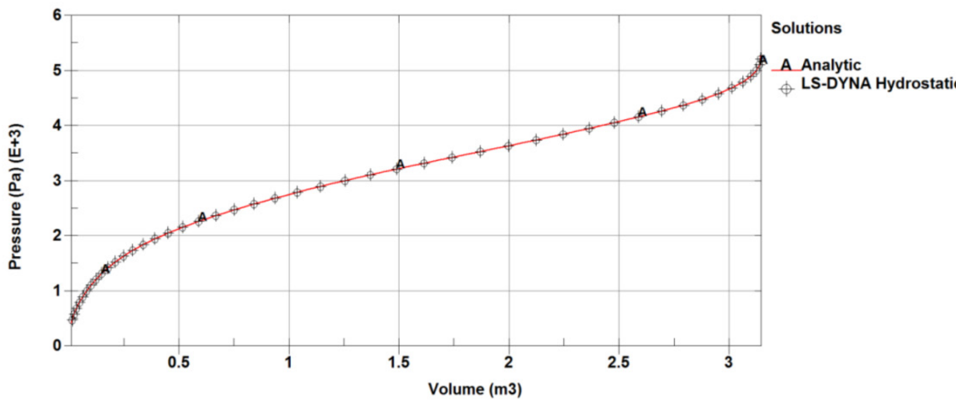

Figure 8: Hydrostatic Volume-Pressure (Relative Pressure) Cross Plot where the pressure is the maximum (Sensor A).

Hydrodynamic simulation

Between the hydrostatic and hydrodynamic analysis, we can notice the two following changes:

- Free Surface is no more one perfectly flat free surface in the whole Fuel tank. Thus, at a given time the fuel height might be different from one compartment to another as the fuel flows through the holes of the baffles.
- A priori, the hydrodynamic pressure should not be neglected. The total pressure is the sum of the hydrostatic and the hydrodynamic pressures.

After post-processing the hydrodynamic numerical results, it was observed that the refueling process is so slow (15 minutes in real time) that the obtained total pressure is mainly hydrostatic.

Although, the hydrostatic pressure is dominant, it can be seen from Figure 9 that in each compartment the fuel height is not the same. The pressure at the sensor location (see Figure 6) for both hydrostatic and hydrodynamic simulation is shown in Figure 10.

Let us comment the different stages highlighted in Figure 10:

1. At time t1 = 80s, the fuel reaches the sensor A location.
2. Between t1 and t2 = 120s, the first compartment is filled linearly.
3. Between t2 and t3 = 200s, the fuel level of the four first compartment is the same. Thus, the increase of the total height is slower (change of slope in Figure 10).
4. Few time step later; the fuel is leaking from the fourth to the fifth compartment. Thus, the fuel height is increasing slower. This explains the short decrease in Figure 10 just before the linear increase between t3 and t4 = 400s.
5. The different stages are repeated sd the fuel tank is getting filled.

At time t5 = 660s, t6 = 800s and t7 = 870s numerical noise is observed in the pressure variable when the fuel tank is almost filled.

4. FUEL MASS COMPUTATION BASED ON PRESSURE GAUGING

4.1. Physical Assumptions

From the different numerical simulations presented in the previous subsection, we can assume the following assumptions:

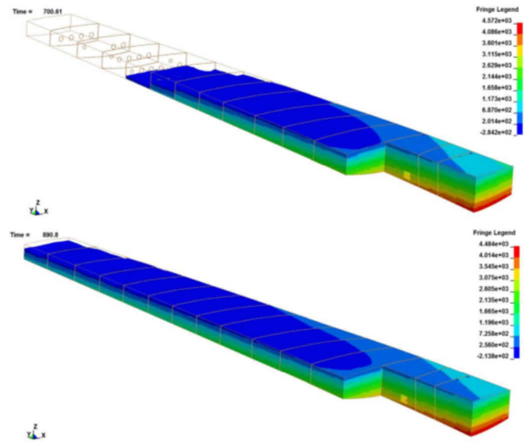

Figure 9: Fuel Tank filling (Fuel Pressure Contour is displayed).

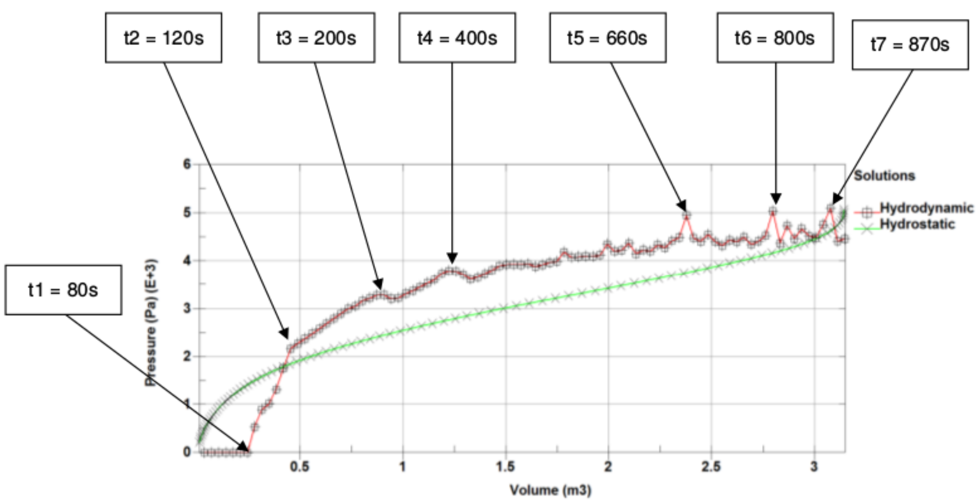

Figure 10: Volume-Pressure (Relative Pressure) Cross Plot where the pressure is the maximum (Sensor A, see Figure 6).

- The free surface in each compartment can be approximated by a linear flat surface, but cannot be assumed to be one linear flat surface for the whole tank. This assumption has been observed during the hydrodynamic simulation (see Figure 9) of the fuel tank filling phase. Thus, the fuel height in the tank varies from one compartment to another.
- Hydrostatic pressure is dominant, and thus we can neglect hydrodynamic pressure due to fuel motion.

In order to fulfill the first assumption, we need to have at least one flooded pressure gauge in each compartment, and thus the fuel mass needs to be computed separately on each compartment and summed up on all compartments afterward.

Considering the second assumption, for a given pressure P and density ρ (obtained by gauging) the fuel height level h_k within each compartment k is computed according to the simple hydrostatic pressure formula:

$$p = \rho g h_k \tag{4}$$

4.2. Fuel Mass Computation

For given pitch and roll angles, this algorithm computes the fuel mass within the tank based on a finite element mesh (composed of eight nodes solid elements) and advanced geometrical tools that compute, for each element, the intersecting volume between the finite element and the free surface plane limiting the fuel level.

Why FE mesh?

Using the divergence-flux theorem (also called Green-Ostrogradski theorem) the computation of the volume of a domain can be reduced to a surface integral computation:

$$V = \iiint_A dV = \frac{1}{3} \iiint_{\partial A} (x, y, z).\vec{n} dS \tag{5}$$

Where ∂A is the boundary of the domain A and $\vec{n}$ is the unit normal vector of dS facing to the outer domain of A.

In order to use Equation 5 to compute the volume, one may know the parametric equation of the boundary surface in order to compute plane tangent to surface and the unit normal vector.

Since the surface of the fuel tank is curved and not flat, the parametric non-linear equation of the boundary surface is unknown. To tackle the complexity of the normal vectors computation, a finite element mesh composed of eight node solid elements (see Figure 11) is used as a first order linear polynomial interpolation of the boundary surface. Each finite element is composed of six flat faces.

Considering the physical assumption that the fuel free surface is flat on each compartment, we can use the finite element mesh to compute the fuel volume inside each compartment. Indeed, the finite element mesh is a partition of the fuel tank. By processing through the finite elements, we can deduce if an element is below, upper or intersected by the free surface plane.

The equation of the plane corresponding to the fuel level, can be solely described by a unit vector normal $\vec{n}$ to the plane and a point $\vec{x}_p$ located on the plane.

The point $\vec{x}_p$ located on the free surface is determined using Equation 4 that gives us the distance from a pressure probe to the free surface based on the pressure and the density (obtained by gauging).

In summary, the main advantages of using a FE mesh are the followings:

- Computation of the unit normal vectors.
- Computation of the surface integral.
- Computation of the intersected elements by the free surface plane to determine the fuel volume.

Volume intersecting algorithm [3]

In this paper, we used the analytical and geometrical tools developed by Lopez and Hernandez [3] for 3D volume of fluid methods (VOF) in general grids.

The VOF method consists in constructing the discontinuous material interface within the element using its volume and the volume of the surrounding neighbors. Such methods are

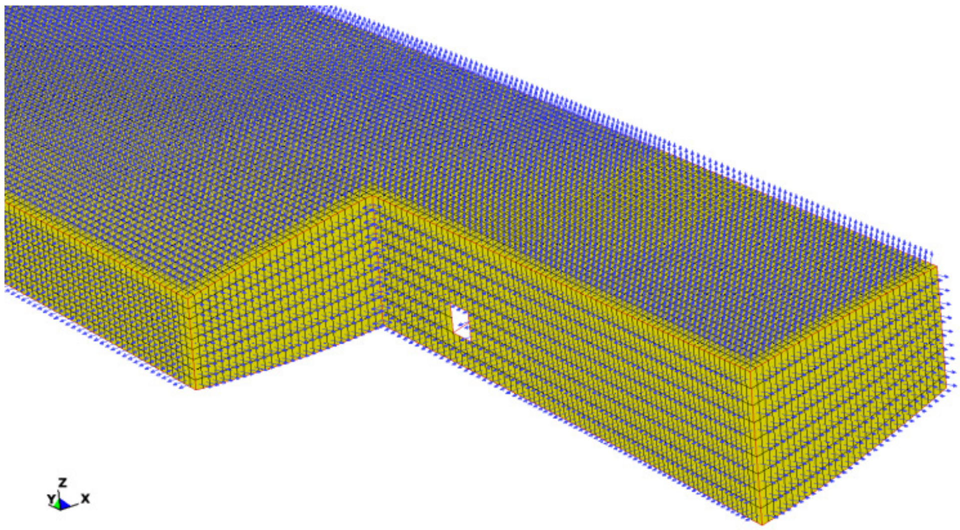

Figure 11: Local Zoom on the outward normal vectors in blue

implemented in many commercial software. The technique implemented in LS-DYNA [9] is the Piecewise Linear Interface Construction (PLIC) proposed by Youngs (see [1] and [2]) for 2D and 3D problems, respectively). The PLIC method follows the early Simple Line Interface Calculation (SLIC) method proposed by Noh and Woodward [10].

The PLIC method approximate the interface by a linear plane (segment in 2D and planes in 3D). This approach is adopted in this paper where the linear plan represents the fuel free surface in each compartment. The parametric equation of the plane at the free surface interface is defined by:

$$\vec{x}_p.\vec{n} + C = 0 \tag{6}$$

Where:

1. The normal $\vec{n}$ to the plane is given by $\vec{n} = (0,0,1)$ (Load body in Z-direction).
2. The position vector $\vec{x}_p$ located on the free surface plane is computed from the gauged pressure and Equation 2.
3. The constant C is given by. $C = -\vec{x}_p.\vec{n}$

Let us consider the eight-node hexahedron polygon of six faces and the intersecting plane P shown in Figure 12. For a given node i, the signed distance ϕ_i from the node i to the plane P is defined by:

$$\phi_i = \vec{x}_p.\vec{n} + C \tag{7}$$

If the signed distance ϕ_i is positive, then the normal vector $\vec{n}$ points to the node i and the node i is above the free surface (because$\vec{n} = (0,0,1)$). Else if the signed distance ϕ_i is negative then the node i is below the free surface. Thus:

- If the signed distance is positive for all the nodes of the eight-node hexahedron element then the element is up to the free surface and it is not filled with fuel.

- Else if the signed distance is negative for all the nodes of the eight-node hexahedron element then the element is below the free surface and it is totally filled with fuel.
- Else, the eight-node hexahedron element is intersected by the free surface plan and it is partially filled with fuel.

In the case where the eight-node hexahedron element is intersected by the plan P, the volume filled with fuel is determined by constructing the two new polygons and computing its volume using Equation 5.

The nodes of intersection are created along the edges of the parent element if the signed distances ϕ_i and ϕ_j of the edge's two nodes i and j are of opposite signs. Thus the new node k position vector is given by:

$$x_k = \frac{\phi_i}{\phi_i - \phi_j}(\vec{x}_j - \vec{x}_i) \tag{8}$$

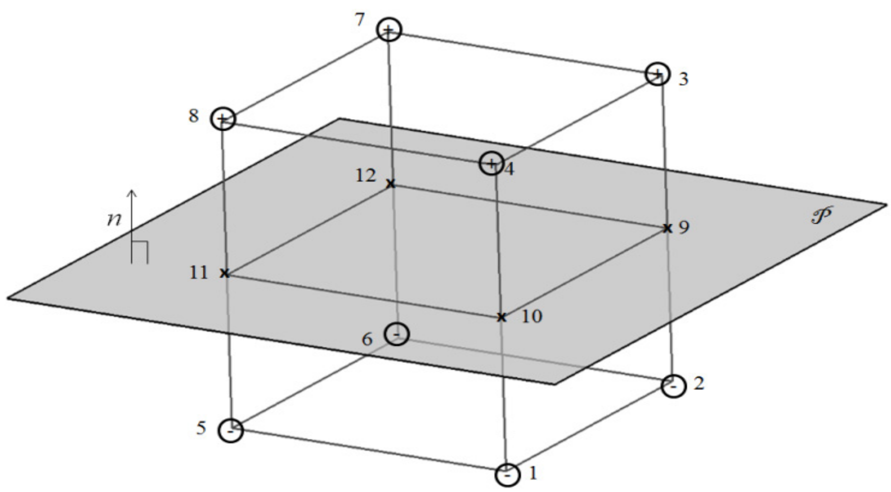

Figure 12: Intersection of the eight-node hexahedron finite element by a plane P. Symbols + and - denote nodes with positive and negative signed distances, respectively. The intersection nodes between the finite element and the plan P is denoted by the symbol x.

4.3. Algorithm description

As assumed, the fuel free surface level is different from one compartment to another (observed from numerical simulation, see Figure 10). Thus, each compartment needs to be processed separately. The computed mass in each compartment is summed up at the end to obtain the total fuel mass.

Let us consider the compartment k denoted by $Comp_k$. For each probe k_i located in the compartment k, we convert the measured pressure P_{k_i} to a local fuel height h_{k_i} using Equation 4. From all the computed local fuel heightsh_{k_i}, we determine the averaged fuel height H_k of the compartment k.

Considering the average height H_k, the position vector of the point $\vec{x}_p$ located on the fuel free surface is determined, then the parametric equation of the fuel free surface plan P using

Equation 6.

Once the parametric equation of the plan P is obtained, we sequentially loop over all the finite element EI_k within the compartment $Comp_k$ and compute the fuel volume within the elements using the intersecting volume procedure described earlier.

Finally the volume of fuel contained in the compartment $Comp_k$ is the sum of the fuel volume in each element EI_k of $Comp_k$. The volume of fuel within $Comp_k$ is converted to mass $Mass_k$ using the fuel density.

The process for the computation of the fuel mass is described in the Figure 13:

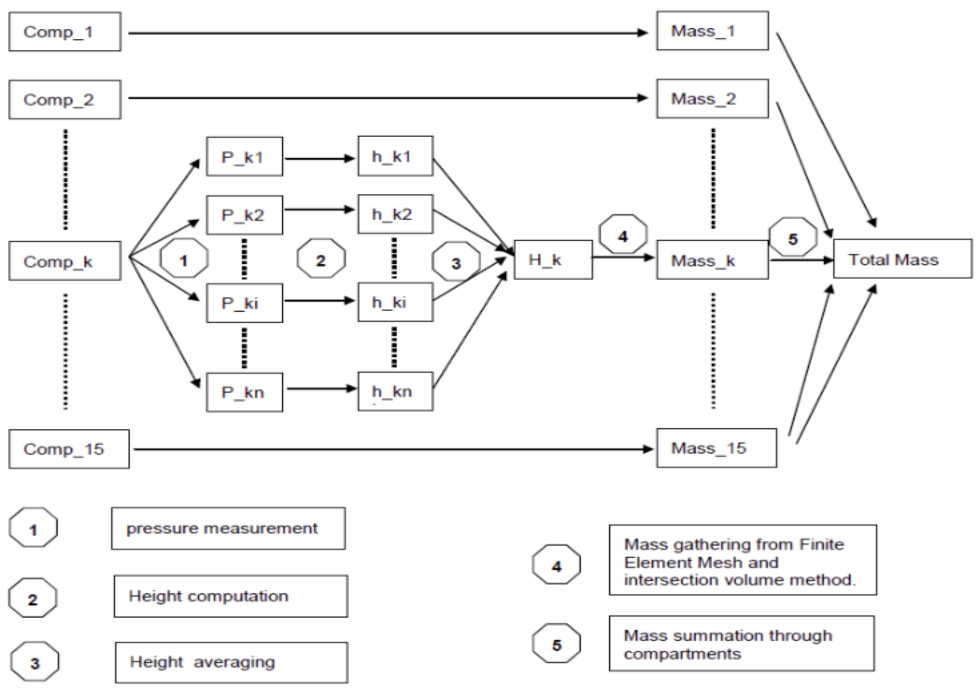

Figure 13: Description of the Fuel mass computation algorithm processing.

4.4. Density computation vs density probing

The described algorithm computes fuel masses in two steps:

- Computation of fuel volume using the Volume Intersecting algorithm [3].
- Conversion of fuel volume into fuel mass using the fuel density.

In the actual aircraft gauging systems, the density is provided by a density probing system. Thus the density is assumed to be known and it is an input parameter to the fuel mass computation algorithm. Considering the physical assumptions in subsection 4.1 and Equation 4, we can take advantage of pressure gauging to determine the density instead of using density probes.

Let us consider two pressure probes i and j located in the same compartment $Comp_k$. We define by $h_{i,j} = Z_j - Z_i$ the vertical distance (Z-direction) between the two probes i and j and by $\Delta P_{i,j} = P_i - P_j$ the pressure difference. For constant density (incompressible fluid), the density is given by:

$$\rho = \frac{\Delta P_{i,j}}{g h_{i,j}} \tag{9}$$

We denote by $nprb_k$ the number of probes present in the compartment $Comp_k$. There is a combination of $n = \frac{(nprb_k)(nprb_k-1)}{2}$, i and j pairs of probes for the computation of the density. For constant density, the n pairs must verify Equation 4 and thus:

$$Y = \begin{bmatrix} \Delta P_{1,2} \\ \Delta P_{1,3} \\ \vdots \\ \Delta P_{nprb_k-1,nprb_k} \end{bmatrix} = \beta \begin{bmatrix} h_{1,2} \\ h_{1,3} \\ \vdots \\ h_{nprb_k-1,nprb_k} \end{bmatrix} = \beta X \tag{10}$$

Where $\beta = \rho g$.

Three methods are tested to compute the density (i.e β in Equation 10):

1. Maximum height $h_{i,j}$:

In this approach, we consider the maximum distance between two flooded probes to compute the density:

$$\beta = \rho g = \frac{Y(k)}{X(k)} \tag{11}$$

Where the index k of the vectors X and Y is taken such that:

$$X(k) = \max_{i,j}(h_{i,j}) \tag{12}$$

2. Linear regression:

$$\beta = \rho g = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{13}$$

Where $\bar{x} = \frac{1}{n} x_i$ and $\bar{y} = \frac{1}{n} y_i$

3. Orthogonal regression:

$$\beta = \rho g = \frac{\sum_{i=1}^{n}(x_i^2 - y_i^2) + \sqrt{(\sum_{i=1}^{n}(x_i^2 - y_i^2))^2 + 4(\sum_{i=1}^{n}(x_i y_i)\,)^2}}{2\sum_{i=1}^{n}(x_i y_i)} \tag{13}$$

4.5. Validation

In absence of experimental data, the numerical simulation of the hydrodynamic fuel tank filling phase is considered instead. Input pressure records from experimental gauging are replaced by pressure time history at the nodes located at the expected position of the pressure probes (see Figure 14).

Using the presented methodology based on pressure gauging and input pressure records from the numerical simulation the fuel mass is computed according to the algorithm described in previous subsection and the different density computation methods.

The computed fuel mass is compared to the reference fuel mass from the numerical simulation for the validation of the methodology. The results for density computations are shown in Figures (15-17) and for the fuel mass computation in Figure 18. Good correlations are observed between the computed and reference fuel masses.

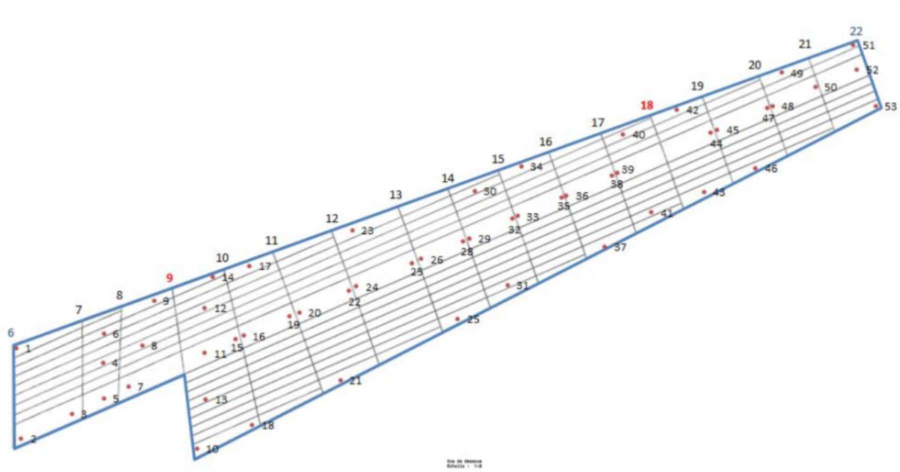

Figure 14: Position of the pressure probes located at the bottom of the fuel tank.

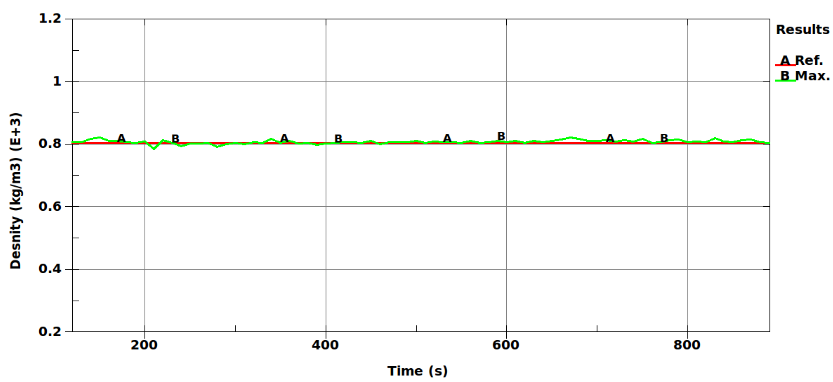

Figure 15: Comparison between the reference constant density and the density computed using the “Maximum Height method” (method 1).

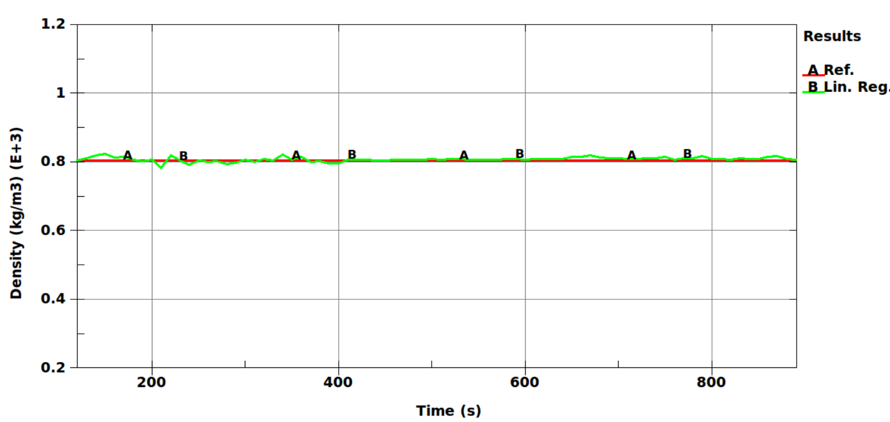

Figure 16: Comparison between the reference constant density and the density computed using the “Linear Regression method” (method 2).

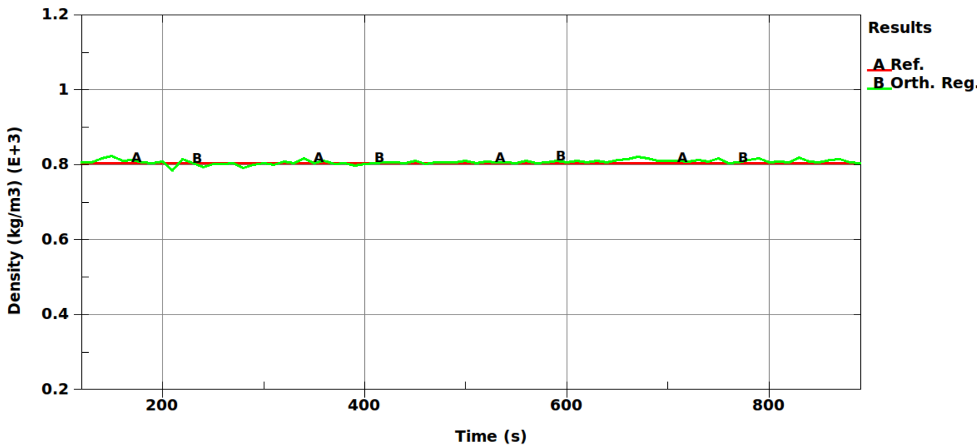

Figure 17: Comparison between the reference constant density and the density computed using the “Orthogonal Regression method” (method 3).

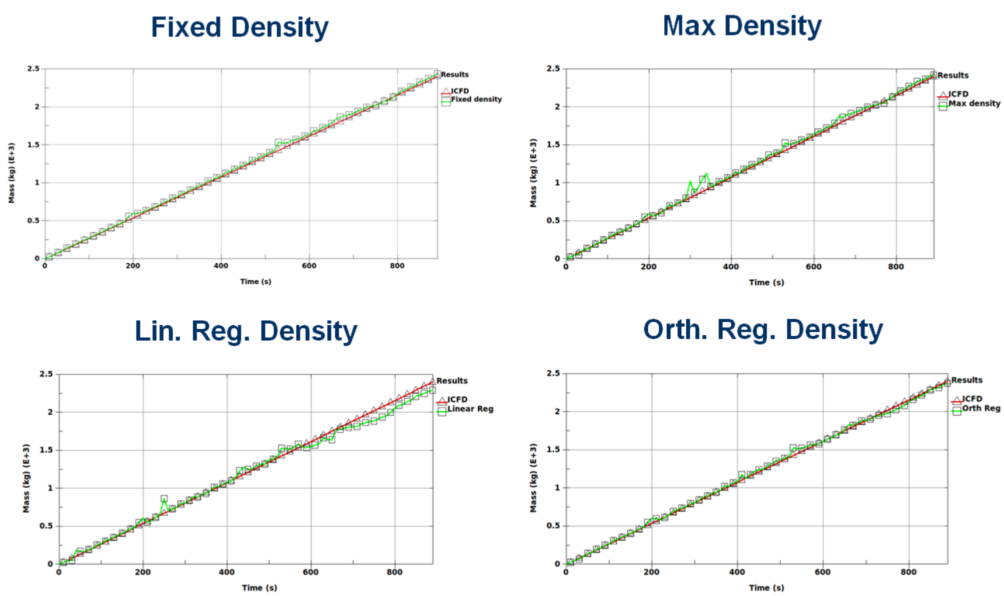

Figure 18: Comparison between the reference fuel mass time history obtained from LS-DYNA simulation and the fuel mass computed.

5. CONCLUSION

In this paper a new numerical methodology is developed to predict fuel mass inside an operation aircraft. This method is only based on pressure measurements in each compartment of fuel tank. Unlike other experimental methods that require fuel density to measure the total fuel mass, the developed method computes fuel density based on ressure measurements and the height of the fuel level inside the compartment fuel tank. Density evaluation is based on classical hydrostatic statement. To validate the methodology a numerical simulation is performed to provide pressures, that will be used as input parameters in the software package that provides fuel mass inside the tank. A computational method using CFD capabilities is performed to model a fuel filling tank up to 900 seconds. During the simulation pressure time history at different gage locations are stored and used as input data for the software package. Mass fuel is computed at each time the pressure is provided from simulation. We observe good correlation between reference density and the density computed out of pressure gages. We also observe good correlation between reference injected fuel mass and the one from the numerical simulation. The next step validation will be using experimental pressure values that will be provided by Zodiac Aerospace in the near future.

6. ACKNOWLEDGEMENT

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