A Finite Element Analysis of the behaviour of 3D printing equipment in the event of a constant heat flow

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Abstract. Practising and solving practical problems often require knowledge and sometimes advanced problem-solving skills in several disciplines simultaneously. The issue generated during the research was developed, involves an understanding of the phenomena of fluid flow, knowledge of the principles and methods of solving heat transfer problems, coupled with those of heat stress, a high level of proficiency and solving the problems of advanced technologies, i.e. solving the issues of the state of tensions and micro-and macro-dimensional deformations. Thus, the problem to be solved here, we have structured it, virtually, in three sub-categories of related issues: Finite Element Analysis of the behaviour of the printing equipment in case of a constant heat flow, having as a subject of study the volume of hot air, in stationary flow as well as in non-stationary flow, using COMSOL MULTIPHYSICS®.

1. Introduction

The use of the finite element analysis procedure involves going through some stages, strictly determined by the characteristics pursued and the field of analysis, respectively, the boundary conditions that restrict the analyzed process [1].

The procedure for analyzing this type of problem, generically called Computational Fluids Dynamics (CFD), includes, as a necessary primary step, the construction of the finite element space "$\mathbf{V_h}$", which is a subspace of space V, theoretically defined by [2]. After establishing the volume that constitutes the study Ω domain, the elements that constitute the domain boundary are found. This step is significant, as the correct definition of the boundary, respectively the proper meaning of the boundary conditions eliminates the uncertainties of the system of equations, the ambiguous situations, or the excepted cases, and eliminates the possibilities to generate errors in solving.

COMSOL MULTIPHYSICS® finite element analysis software was used [3]. As an introduction, some parameters and thermal characteristics of some essential components, as necessary, in the economy of heat exchange in the printing equipment, have been retained here. The documentation consists of 191 pages (Annex) containing, in detail, data on geometric and mathematical models. These data were collected during the execution of the analysis. The procedural manoeuvres by which the input parameters of the Finite Element Analysis were set is made available to those interested parties, on digital media, as an integral part of the Annex.

In the first analysis of the heat flow distributed in the characteristic volume, established for study and research, in the stationary flow of an incompressible fluid (air, introduced into the system by the combination of two fans, one for intake, and the other for transfer), the results are materialized in characteristics of the fluid flow through the elementary volume established as a study model, namely: temperature distribution, pressure consistency and velocity field.

Heat transfer in fluids solves, by analysis, the following system of equations:

$$\begin{cases} \rho C_p u \cdot \nabla T + \nabla \cdot q = Q + Q_p + Q_{\text{vd}} \\ q = -k\nabla T \end{cases} \quad (1)$$

where ρ- density, C_p- heat capacity at constant pressure, u- Velocity field, x component; T- Temperature; Q_{vd} - Viscous dissipation, Q_p - a point heat source, q- heat flux; k- Thermal conductivity,

Figure 1 shows the image of the analysis volume, which includes the elements involved in influencing the heat flow and the flow of the fluid in the analysis range, [4], [5]:

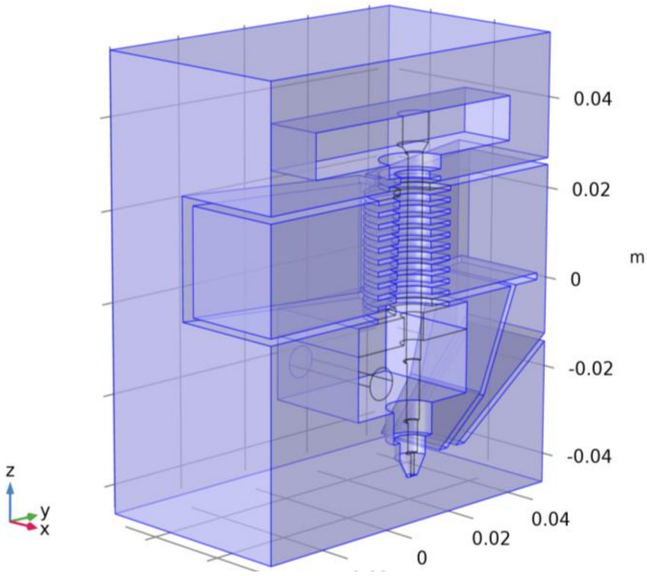


Figure 1. The volume of analysis, as the reference field

The analysis of the air intake system is based on the solution of the following mathematical model:

$$\begin{cases} -n \cdot q = \rho \Delta H u \cdot n \\ \Delta H = \int_{T_{ustr}}^{T} C_p dT + \int_{p_{ustr}}^{p_A} \frac{1}{\rho}(1 - \alpha_p T) dp \end{cases} \quad (2)$$

and figure 2. shows the location of admission air (notation Tustr-temperature of the air at the inlet, (*Upstream temperature*)):

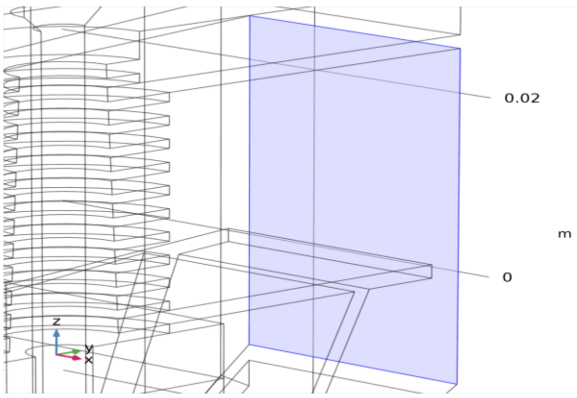


Figure 2. The intake system domain

The sequence in Figure 3. shows the volume of finite elements, the volume of analysis for which possible turbulent flow situations were studied:

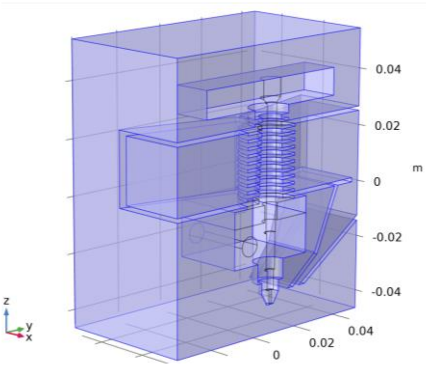
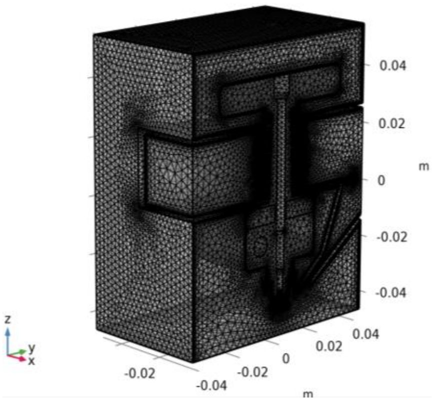
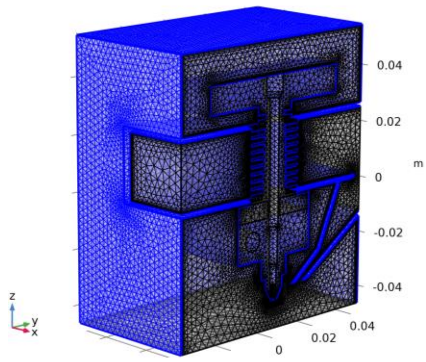


Figure 3.- The domain to be analyzed in case of turbulent (non-Newtonian) flow, [6]

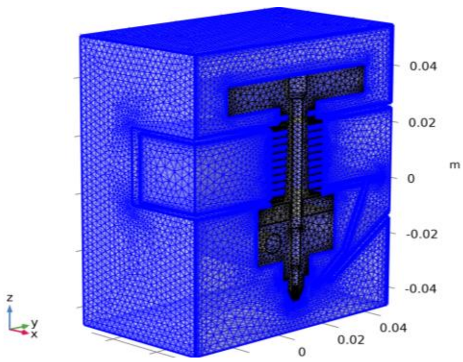
The system of equations related to this state and the properties of the fluid are determined sequentially by solving the set of equations adapted to the same study volume as the one in figure 3.
The discretization of the field of analysis is presented in figure 4:



a)- Tetrahedral finite elements



b)- Prismatic finite elements



c)- Triangular finite elements

Description	Value
Minimum elements quality	3.377E-5
Medium elements quality	0.5944
Tetrahedral finite elements	1689872
Pyramidal finite elements	28107
Prismatic finite elements	339687
Triangular finite elements	107331
Quadratic finite elements	5438
Edge finite elements	6461
Top finite elements	227

d)-Finite elements discretization statistics

Figure 4. The discretization of the analysis domain, [7]

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The temperature distribution, figure 5, shows, no doubt, that, in contrast to the high-temperature values, in the area of the printing nozzle, which is to be expected, in the areas outside the heating block of the printing filament, the temperature falls the limits of a controlled operation of the equipment as a whole.

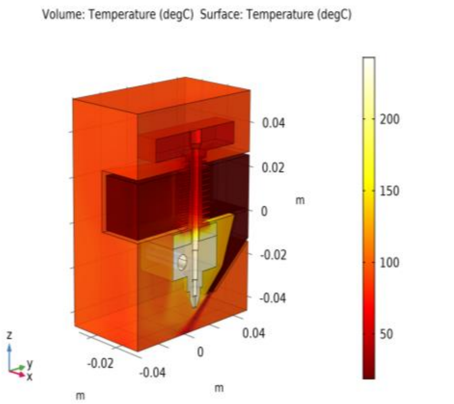


Figure 5. Temperature distribution (ht)

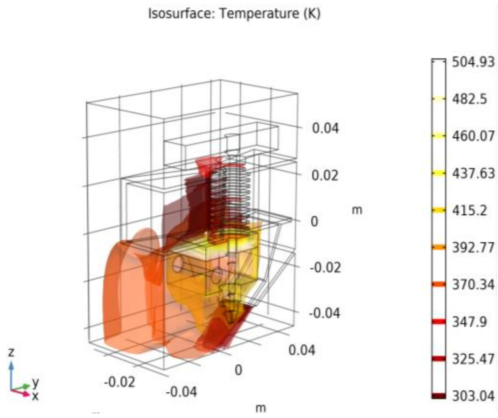


Figure 6. Isothermal surfaces (ht)

Figure 7 shows the air velocity field as it passes through the components of the printing equipment, which contributes to the cooling in the radiator areas and the area of the part being cooled.

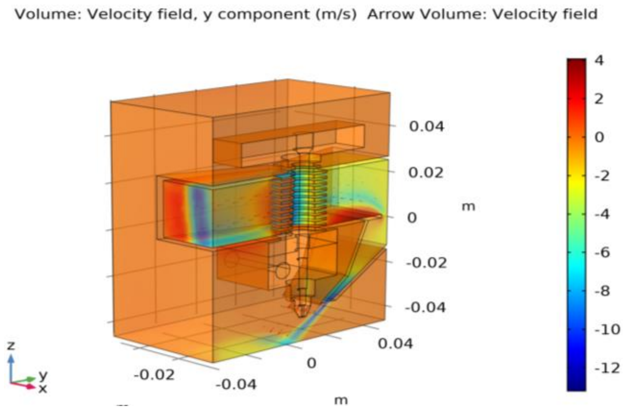


Figure 7. Velocity field distribution

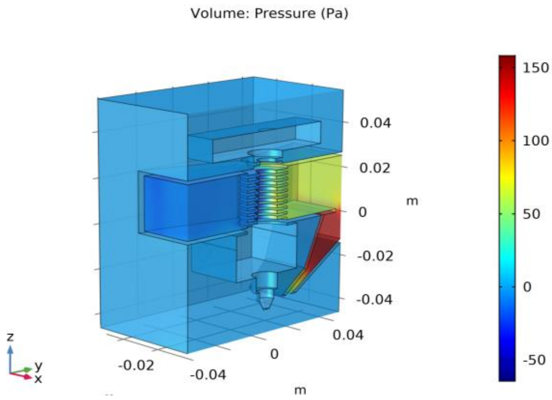


Figure 8. Pressure distribution (spf)

Figures 9 to 11 graphically represent the evolutions of three measurable quantities: temperature, pressure and airflow velocity (the last two are defined as a function of the coordinates on the Oy axis) [8], [9].

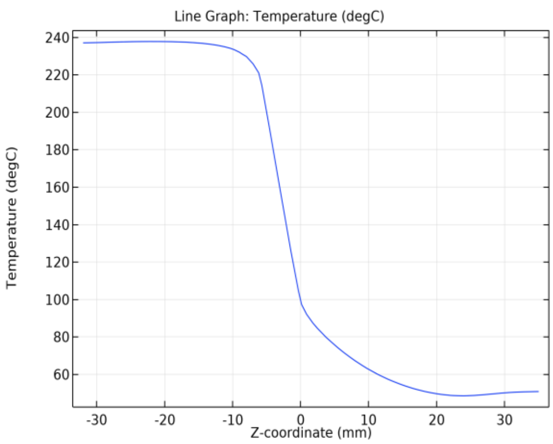


Figure 9. Temperature variation graph

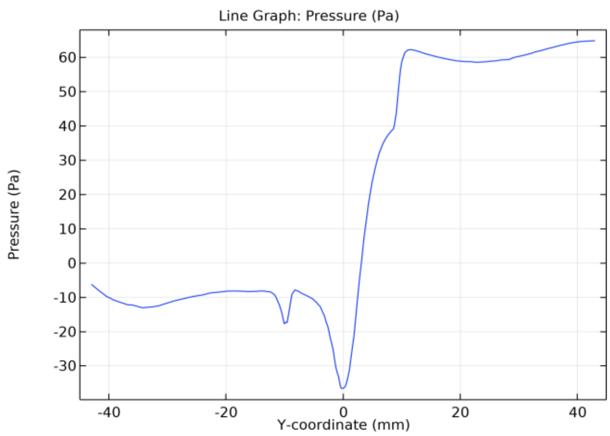


Figure 10. Graph of pressure evolution, on the axis Oy

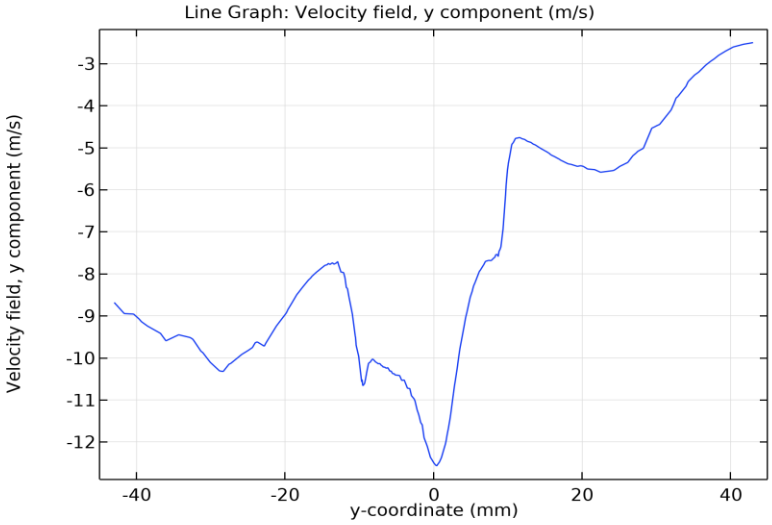


Figure 11. Graph of velocity evolution, on the axis Oy

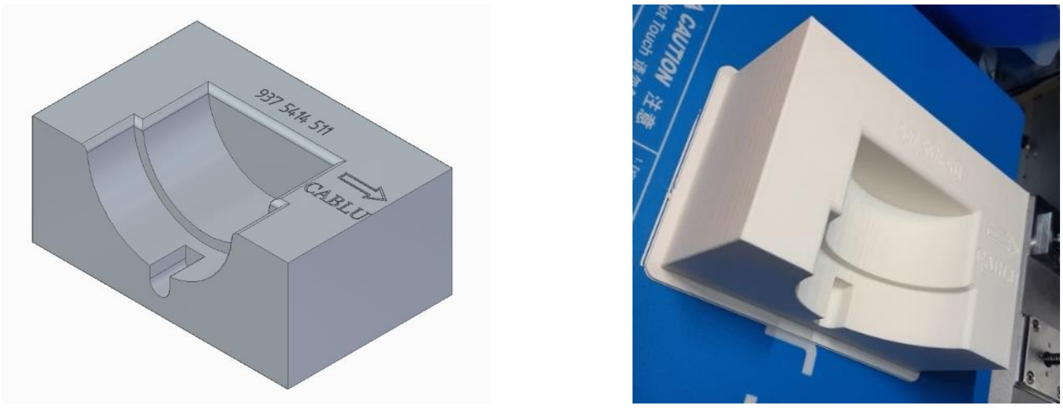
Conclusion

There are cases in practice where critical situations require the use of emerging, revolutionary technologies, namely to manufacture parts using 3D printers, and for finishing surfaces that require high dimensional accuracy as well as a surface condition superior to 3D printing [2], [10], [11], to subsequent cutting operations such as turning [12] and milling are used.

The decision to adopt as a solution the implementation of 3D printing as well as the success achieved based on the case above presented (figure 11) and combining the advantages of the two methods (additive and subtractive) to obtain a part that meets the requirements to which this part will be subjected. New devices have been designed to facilitate the assembly and verification of the various components.

Figure 12. Device fixed in the equipment

The above figure (figure 12) shows the 3D model of brushless motor support from a local company, the support used in the production process of an electric motor [6]. The engine mount is a device that needs to be made of plastic to prevent it from being scratched during the assembly process, figure 13.



a) 3D model engine mount b) 3D printed engine support

Figure 13.-Brushless motor support
- two-dimensional variants

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