SIMULATION OF THERMAL WING AND MODELISATION OF A THERMOACOUSTIC ENGINES

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ABSTRACT

Any semiconductor component admits a maximum temperature of operation, called maximum temperature of junction, depend on the type of material used and technology of realization. This maximum temperature of junction remains a significant data since it is it which makes it possible to consider the level of cooling necessary to the correct operation of the component.explanation. To cool an electronic component of power, a thermal wing is necessary; in this thesis, initially, one studied the behavior theoretical and physical of this wing and finally of simulations were made by using a model of wing designed with COMSOL Multiphysics 4.3. In the second time, we saw the other techniques of cooling, that is to say directly one changing the physical properties of the component itself, for example in the case of a structure RC - IGBT with bands P+ and NR + alternate by simulating it in 2d on the software Sentaurus™ TCAD, amongst other things, a study by simulation of new structures of cooling containing diamond CVD (Chemical Vapor Deposition) is also possible, simulation it is also possible to make an approach by cooling by thermoacoustic on this our study focuses itself on the difficulties met if one deals with nonlinear wave and with the possibility of reducing on a small scale the thermoacoustic engines.

Keyword : - *thermoacoustics1, processes cooling, thermoacoustic engines.*

1. INTRODUCTION

In many sectors of applications such as the house automation, the car or railway the electronics of power and the electronic components are strongly present. The development of new technologies in the field of the electronics of power allowed the miniaturization of the components, while increasing the densities of power within the components. Thus, one can today consider systems electronic on high level of functional integration, possibly distributed, and combining functions of calculation, measurement and possibly of actuation (microsystems). Different the studies makes until now to cool an electronic device are the thermal wings, the systems of air cooling: forced convection or piezoelectric effect, the liquid cooling, the spray cooling, the cooling by jets, the heat pipes, the drains thermal and the cooling by Peltier effect which can prevent the destruction of an electronic device but the management of the rise of temperature remained a major problem. In this work, one takes account of the regulation of the thermal processes which gathers the whole of the processes implemented to maintain the temperature.

2. THERMAL WING

2.1 Experimental studies

The experimental module is an electronic assembly of circuit abovewhich one placed a wing average length of 20 cm and basic surface E x E = 2.3 cm x 2.3 cm = 5.3 cm^2. The electronic circuit properly is a dimension length L = width l = 22 cm and height H = 7cm. one will take ε = 0.85 because we use black plane sheet (TPN: Tôle Plane Noire).

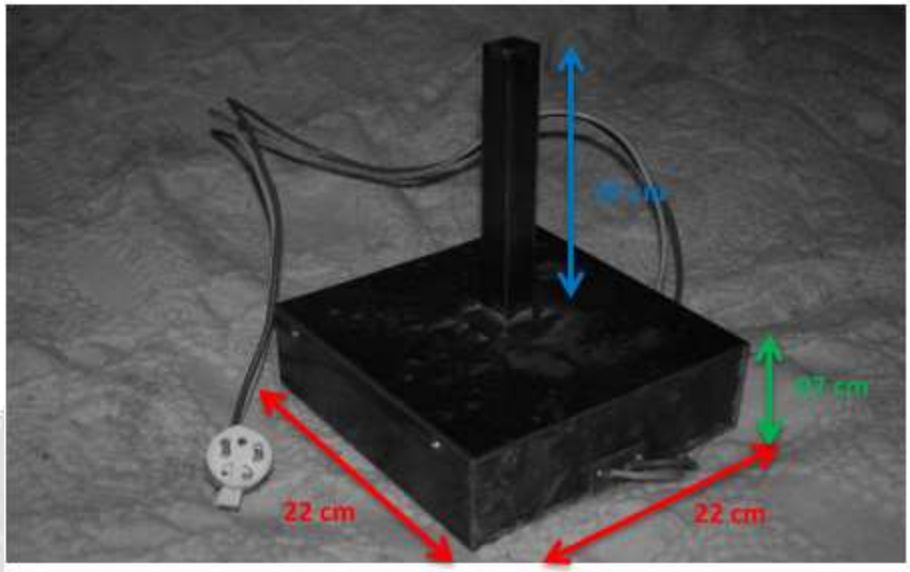

Fig -1 : Diagram of the experimental device n°1

At the beginning of the experiment, we took a resistance of 1000 W right to check if the device functions and at the end of a few minutes only, the temperature of the whole of the case with wing was standardized i.e. all the air contained in our device cannot ensure one natural conduction anymore and that if it were the case of an electronic component it is sure that the latter would be destroyed.
After some modification, the power dissipated by the components with interior of the case is 300 W what one would keep in the continuation.
After 5 mn, the temperature in the neighborhoods of the case is 25 °C and in the case in the neighborhoods 100 °C; the other end of the wing gives T_F = 20 °C :

$$\dot{Q}_{conv} = \varphi_{conv} = h_{conv} * A_S * \Delta T = h_{conv} * A_S(T_S - T_{fluide}) \quad (1)$$

$\dot{Q}_{conv} = \varphi_{conv}$: heat flux

h_{conv} : coefficient of covection

A_S : Heat-transferring surface

ΔT : Difference in temperature

Separately let us calculate the flow of transfer of the natural convection and that of radiation :

- We can consider the 4 sides of the box as being vertical surfaces height 7cm:

$$h_{conv} = 1.42 * \left(\frac{\Delta T}{H}\right)^{0.25} \quad (2)$$

Lc = 0.07 m Ac = ((2*0.22) + (2*0.22))*0.07 = 0.06 m2

$$h_{conv} = 1.42 * \left(\frac{100-25}{0.07}\right)^{0.25} = 8.12\ W/m^2\ °C$$

$$\dot{Q}_c = h_{conv} * A_c * \Delta T = 8.12 * 0.06 * 75 = 36.54\ W$$

- The surface in top is comparable to a horizontal plate heating upwards:

$$\boldsymbol{h_{conv} = 1.32 * \left(\frac{\Delta T}{L_h}\right)^{0.25}} \qquad (3)$$

$$L_h = \frac{4 * A_S}{P} = \frac{4 * 0.22 * 0.22}{2(0.22+0.22)} = 0.22\ m$$

$$A_h = 0.22 * 0.22 = 0.0484\ m^2$$

$$h_{conv,top} = 1.32 * \left(\frac{100-25}{0.22}\right)^{0.25} = 4.30\ W/m^2 °C$$

$$\dot{Q}_{conv,top} = h_{conv,top} * A_h * \Delta T = 4.30 * 0.05 * 75 = 16.12\ W$$

The box being placed in the room, the temperature of its neighborhoods is thus equal to the temperature of the air in the room (i.e. 25°C = 298 °K). The rate of transfer of heat by radiation is :

$$\boldsymbol{\dot{Q}_{rad} = \varepsilon * A * \sigma * \left(T_S^4 - T_{alentours}^4\right)} \qquad (4)$$

$$A = A_c + A_h = 0.05 + 0.06 = 0.11\ m^2$$

$$\dot{Q}_{rad} = 0.85 * 0.11 * 5.67.10^{-8} * (373^4 - 298^4) = 60.81\ W$$

The total flow of heat is :

$$\dot{Q}_{total} = \dot{Q}_{conv} + \dot{Q}_{rad} = 36.54 + 16.12 + 60.81 = 113.5\ W$$

The component is not cools

Remaking our experiment with this time but we will decrease the height of the device of 2.5 cm, that is to say with final dimension length L = width l = 22 cm and height H = 4.5 cm. The value of ε= 0.85 not change. One will always place a wing average length of 20 cm and basic surface E × E = 2.3 cm × 2.3 cm = 5.3 cm 2 above the device and also decreased the power dissipated by the component with approximately 200 W

The temperature with interior of the device reaches the 200 °C and the temperature in the neighborhoods of 150 °C; with the extreme end of the wing, the temperature reaches 40 °C.

For the vertical surface :

Lc = 0.04 m

Ac = ((2*0.22) + (2*0.22))*0.04 = 0.03 m2

$$h_{conv} = 1.42 * \left(\frac{200-150}{0.04}\right)^{0.25} = 8.45\ W/m^2\ °C$$

$$\dot{Q}_c = h_{conv} * A_c * \Delta T = 8.45 * 0.03 * 50 = 12.68\ W$$

For the surface in top

$$L_h = \frac{4 * A_S}{P} = \frac{4 * 0.22 * 0.22}{2(0.22 + 0.22)} = \ 0.22\ m$$

$$A_h = 0.22 * 0.22 = 0.0484\ m^2$$

$$h_{conv,top} = 1.32 * \left(\frac{200 - 150}{0.22}\right)^{0.25} = \ 5.12\ W/m^2\,°C$$

$$\dot{Q}_{conv,top} = h_{conv,top} * A_h * \ \Delta T = 5.12 * 0.05 * 50 = 56.98\ W\ \approx 12.8\ \ W$$

The rate of transfer of heat by radiation is :

$$A = A_c + A_h = \ 0.05 + 0.03 = 0.08\ m^2$$

$$\dot{Q}_{rad} = \ 0.85 * 0.08 * 5.67.10^{-8} * (473^4 - 423^4) = \ 69.55\ W$$

$$\dot{Q}_{total} = \dot{Q}_{conv} + \dot{Q}_{rad} = 12.68 + \ \ 12.8 + \ 69.55\ = 95\ W$$

It is noted that the wing done well his work since the difference in temperature between the two end of the wing is of 150 °C - 40 °C = 110 °C

The thermal resistance of our wing is $R_{th} = \frac{150 - 40}{220} \approx 0.5\ °C/W$, it's perfect.

2.2 Simulation by Comsol Multiphysics 4.3

Initially, we choose Model Wizard

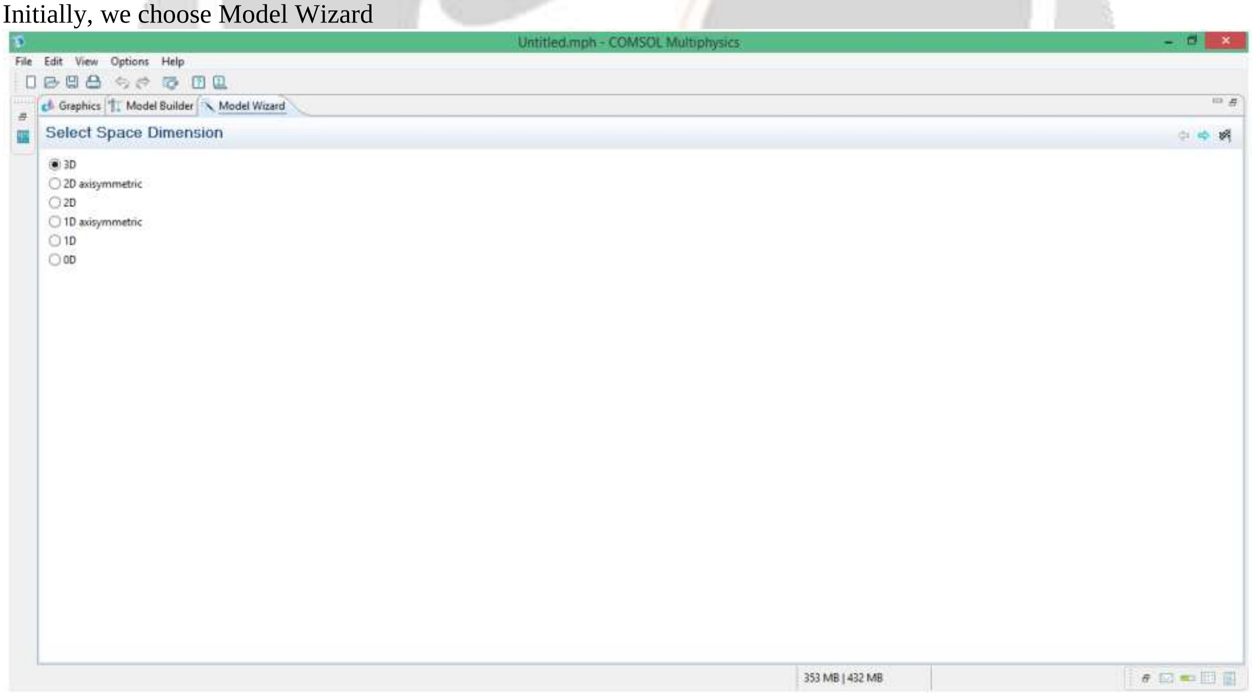

Fig -2 : The Model Wizard

Then according to the patch : Δu Mathematics/ Δu PDE Interfaces/ Δu Coefficient Form PDE(c) and build the result :

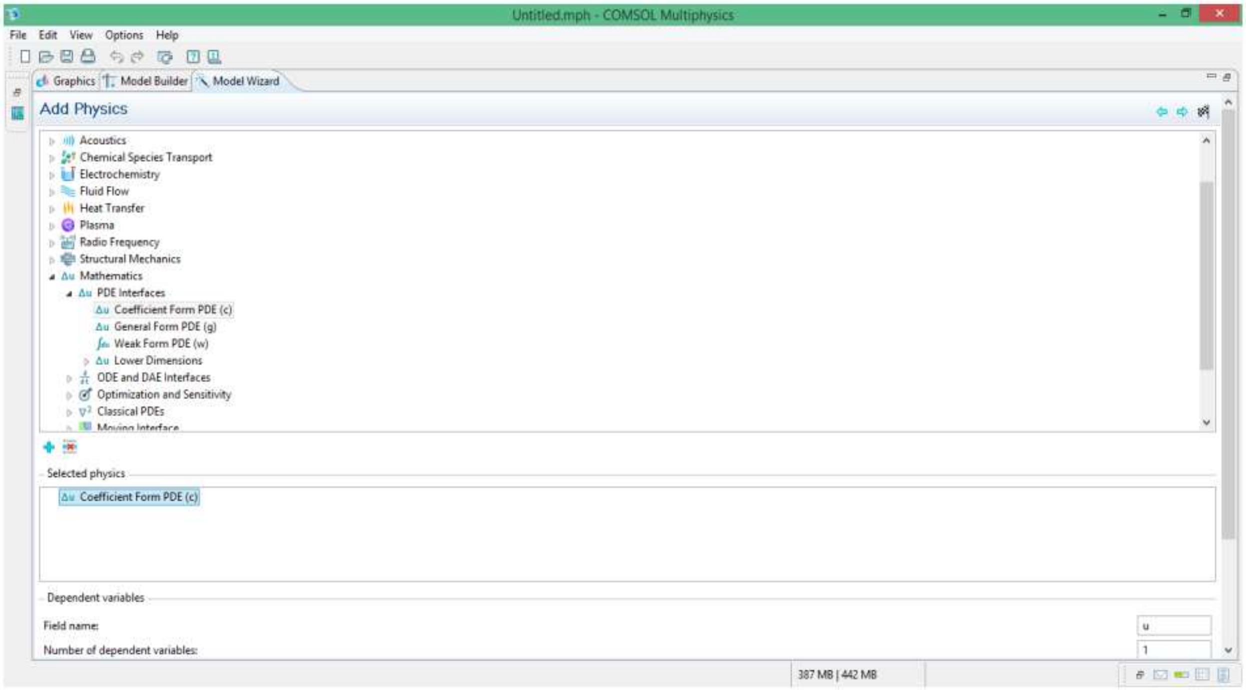

Fig -3 : The Δu Model

After clic to Time Dependent then the draw

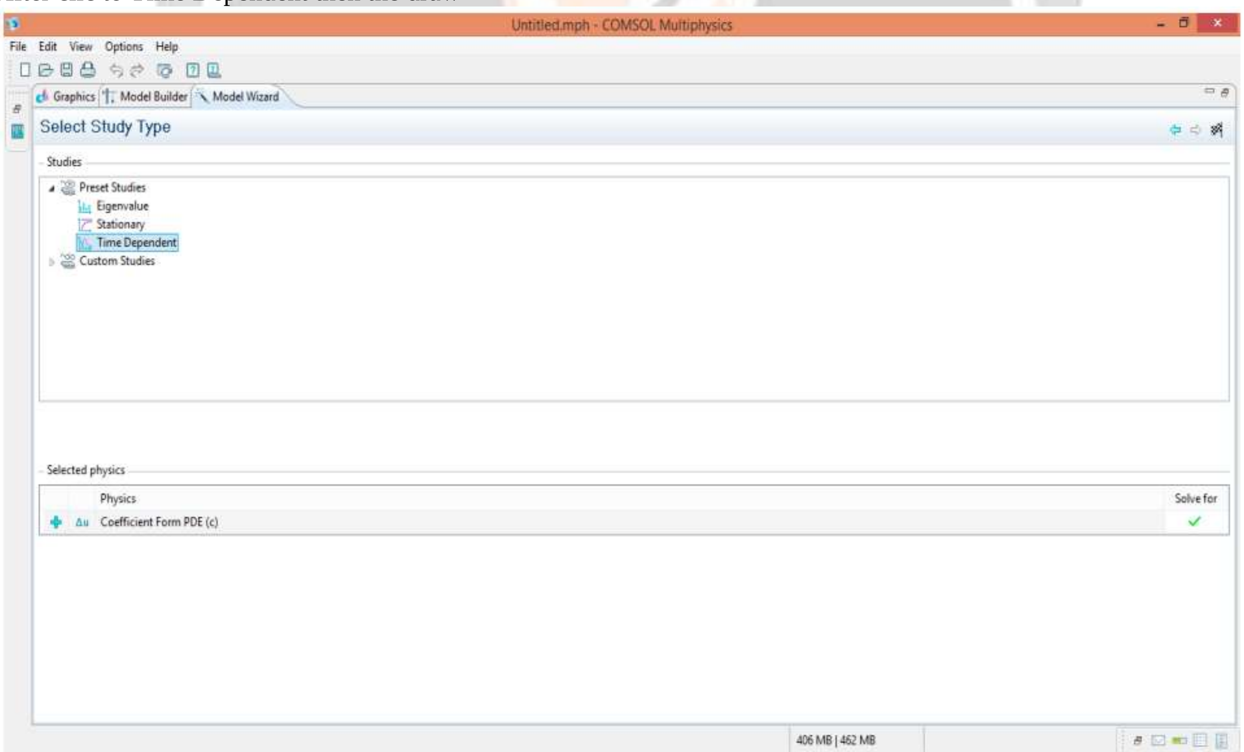

Fig -4 : The Time Dependent Model

Here the Graphics icon is used to visualize our diagram in several dimensions; the icon Model Builder to re-examine the way or patch which one took. Now let us make a clic right on Geometry and then click on Block. Let us parameterize the data to be identical to that of our experimental device :

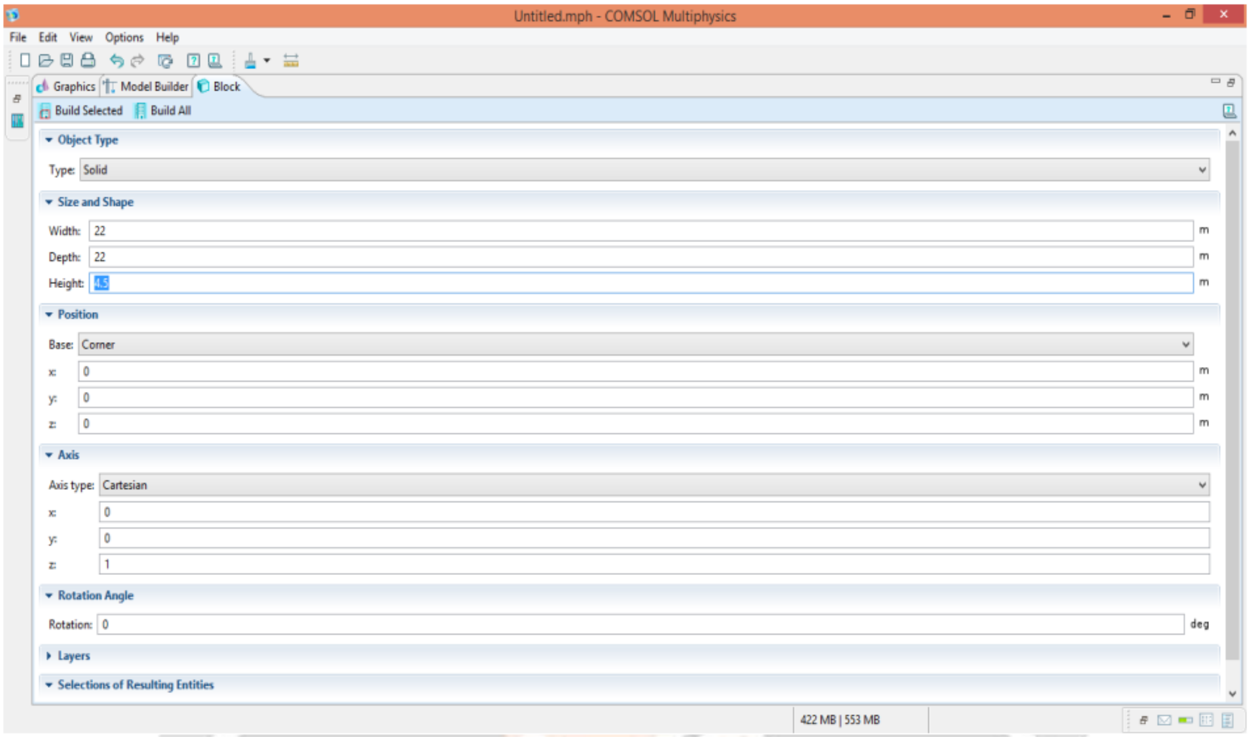

Fig -5 : The Selection and creation of a Block

For validation, one click on Build All and we will have:

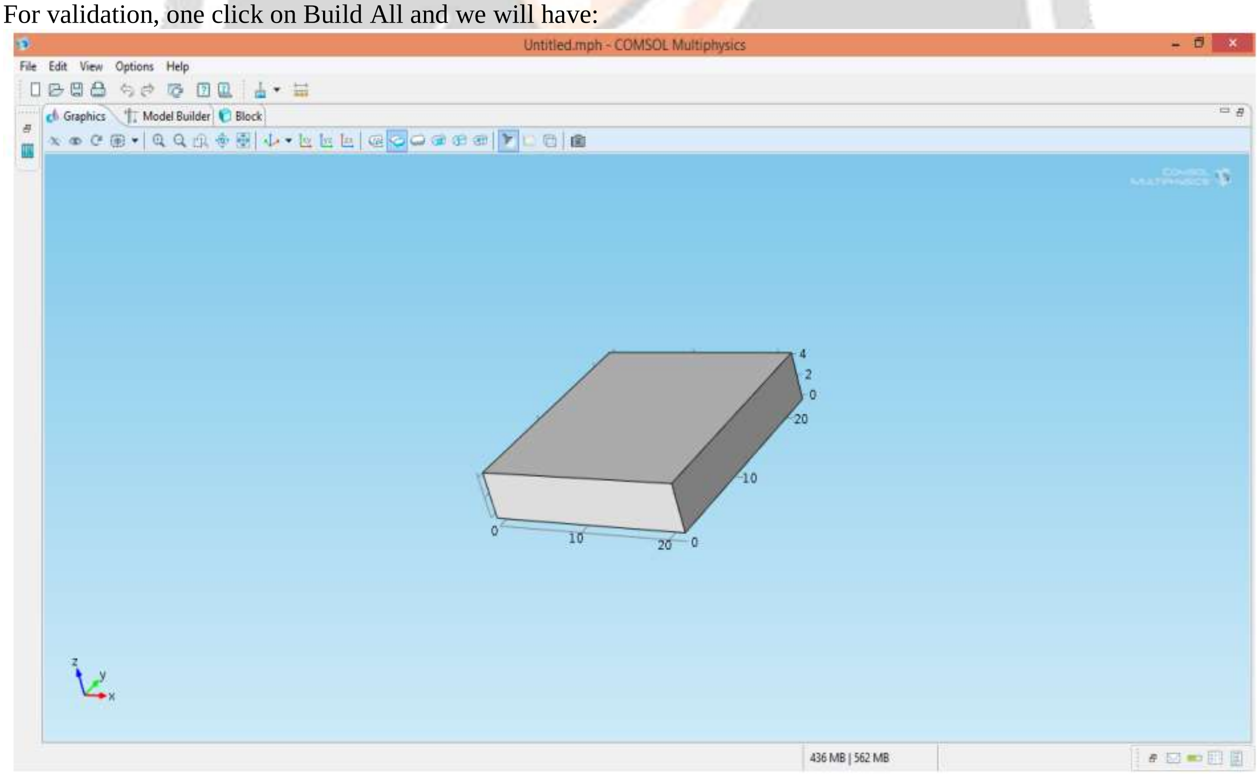

Fig -6 : Creation of a Block

Now we obtained a drawing in 3d rather in conformity with our device. We will remake the same stages to create the model of wing but all by making sure that that would be posed well in the center and above the first block thus we would have the new parameter :

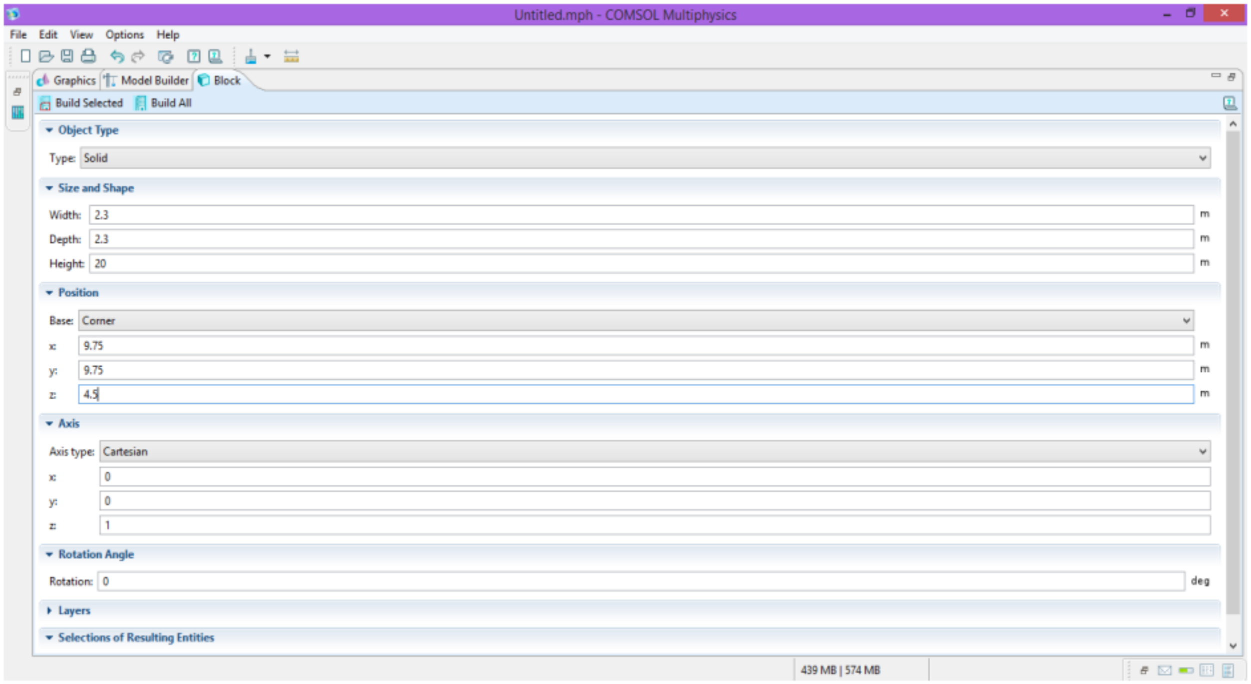

Fig -7 : Creation of a Second Block

We will validate these data then to see the result:

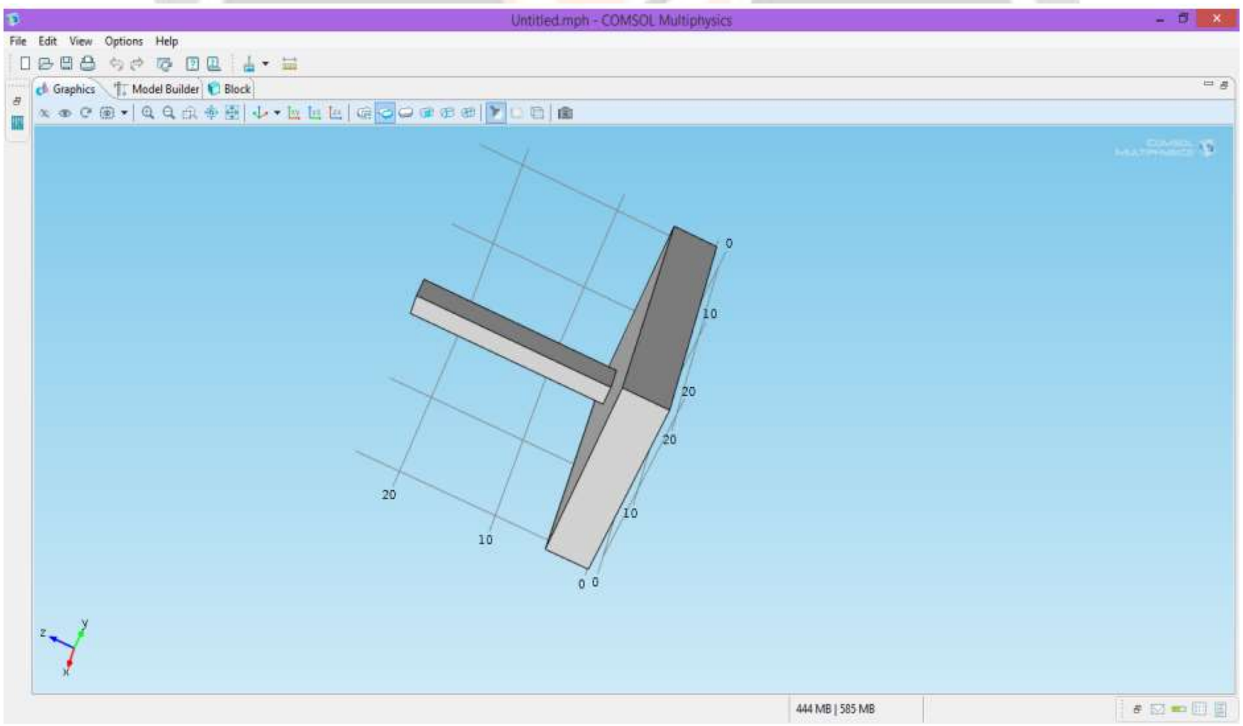

Fig -8 : Unification of two Blocks

Now that the blocks are plain; we could finally simulate the thermal behavior of our device by knowing that the hot source is the basic circuit. After having parameterized and enter some data.

The result is good, since it is in conformity with our experimental study and besides, we sees very well the difference in temperature enters on several parts of our device.

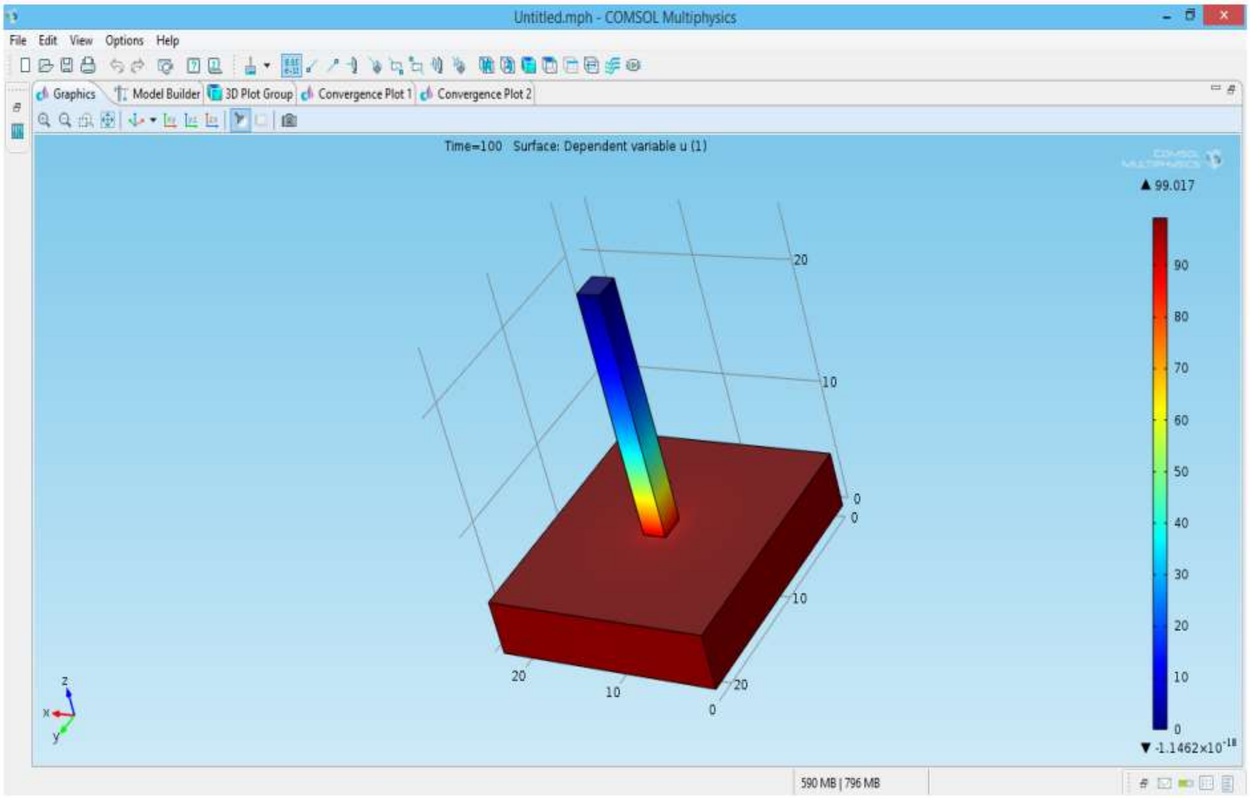

Fig -8 : Final result of the thermal behavior of our experimental device

The result is very good and we could even create a device with several wings on the face which would support the speed of cooling.

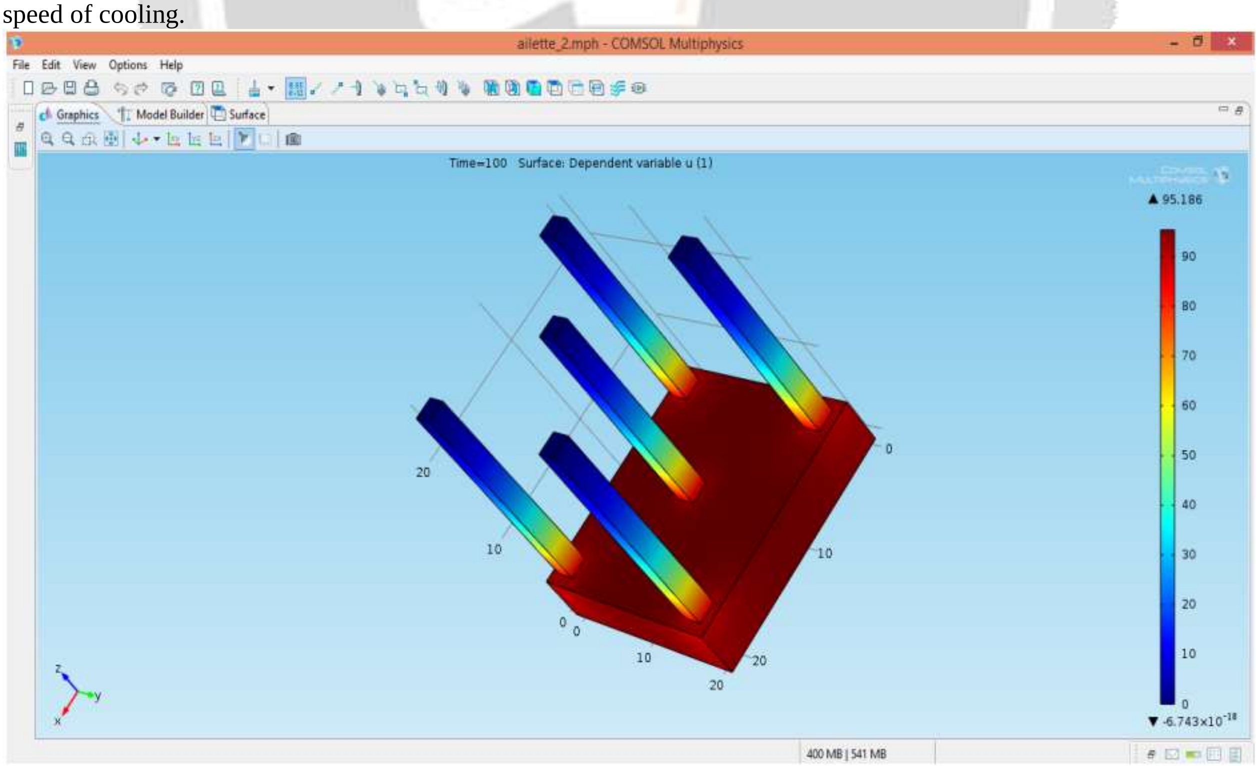

Fig -9 : Result obtained with five wings

3. MODELISATION OF A THERMOACOUSTIC ENGINES

The " thermoacoustic effect " finds its origin on the level of the processes of interaction between a fluid, in which oscillates an acoustic wave, and solid walls, which thus generates a transformation energy between energies acoustic and thermal (or vice versa). These are the modifications of pressure related to the axial displacement of the fluid imposed by the wave which will generate several thermodynamic transformations. The presence of the walls adds a temporal dephasing to heat exchange which takes seat in the vicinity of those.
In the boundary layer thermal, close to the walls, when those present a variation in temperature Δt, the oscillation of the amplitude of temperature is more reduced than in the center of the flow where it has a character closer to an adiabatic behavior. With the scale of the gas particle, this phenomenon remains very weak; it is then advisable to amplify it in order to obtain levels sufficiently powerful. To implement this "thermoacoustic effect ", several conditions (of geometry in particular) are to be respected. Thus the most accessible systems (generally of the systems with standing waves) consist of an acoustic resonator (i.e. a tube lengthened preferably closed) filled with inert gas and inside whose a porous environment provided with two exchangers of heat at its ends. These exchangers of heat make it possible to ensure heat exchange with the mediums external with the resonator (source and well). In the case of a refrigerator, a loudspeaker emitting the wave inside the resonator is also present.

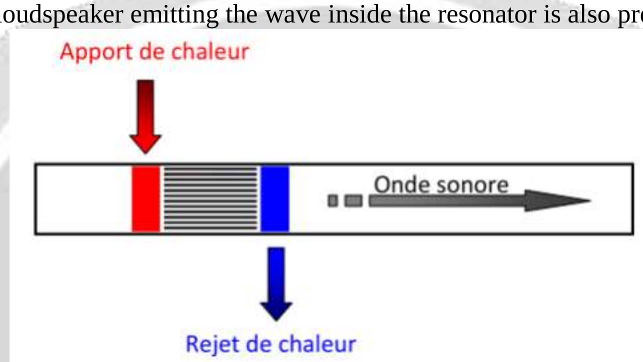

Fig -10 : Principle of operation of thermoacoustic engine with stationary waves

3.1 Nonlinear effect at the thermoacoustic engine

When we seeks to define a scale speed, in particular in acoustics, the number without characteristic dimension is the Mach number. It is related to the approximation of linear acoustics. Indeed we point out that this approximation bases its assumption that acoustic speed is very small in front of the speed of sound. The Mach number being defined as follows :

$$M = \frac{U_a}{c} = \frac{U_a}{\sqrt{\gamma R_s T_0}} \approx \frac{|P_a|}{P_0} \quad (5)$$

$$u_a = U_a \sin(kx)\cos(\omega t) \quad (6)$$

It results from this that this approximation is valid for Mach number very small in front of the unit. For M~1, this assumption is not valid any more because nonlinearities are too present.
The second number without dimension in is the Reynolds number largely used in the traditional cases of a flow in a tube. Then according to whether one is interested in the effects in the boundary layers or the body of the fluid, the Reynolds number will take several forms. Menguy and Gilbert use the Reynolds number acoustic:

$$Re_a = \frac{\rho_0 c^2}{\mu\omega} \quad (7)$$

It compares the wavelength and the viscous boundary layer.
for the non-linearity of the phenomena, it is judged according to the value of the Reynolds number " nonlinear " definite also by :

$$Re_{NL} = \left(\frac{U_a}{c}\right)^2 \left(\sqrt{\frac{\omega}{2V}}r\right)^2 \quad (8)$$

The Reynolds number nonlinear relates to the inertia of the fluid in the zone of streaming.

An important factor of the loss of efficacity of the thermoacoustic engines is the existence of phenomena of " streaming " within the acoustic circuit of the engine, i.e. the existence of local or total average flows permanent in fluids with dominant oscillatory.
The secondary flows described above can affect the flow of energy and the fields of temperature in the systems thermoacoustic.

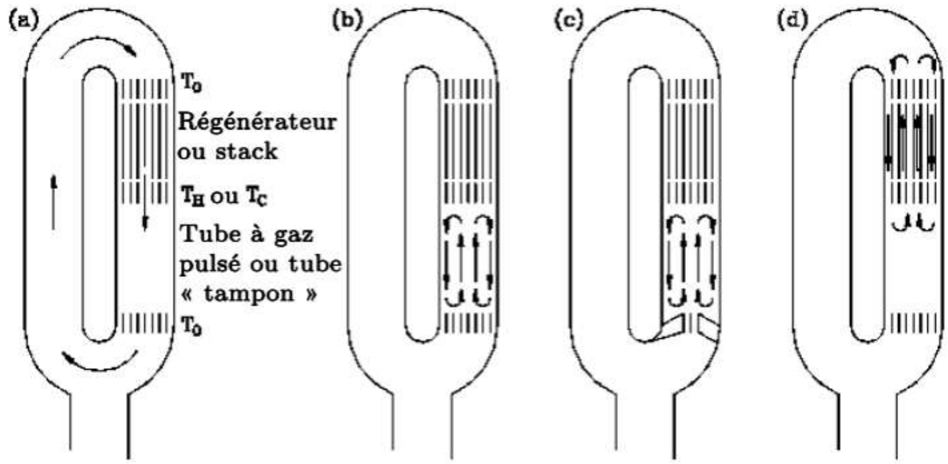

Fig -11 : The different streaming within thermoacoustic engine : a- streaming of Gideon; b- streaming of Rayleigh; c- streaming of jets; d-streaming in the regenerator

3.2 Caracteristic of TAET

The ThermoAcoustoElectric Transducer (TAET) is a prototype dimensioned and installed at the Laboratory of Acoustics of the University of Maine. It is built on the basis of engine thermoacoustic of Stirling coupled to a load mechanic-acoustics.

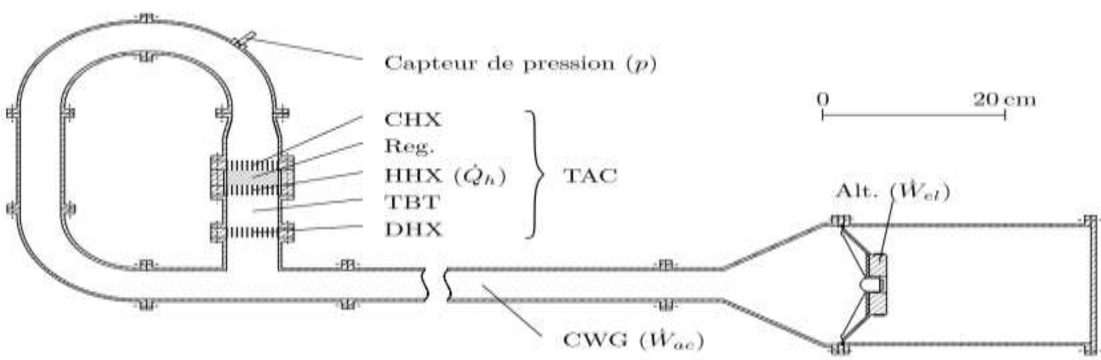

Fig -12 : The ThermoAcoustoElectric Transducer

An auto-oscillation is established in the engine because the difference in temperature between the ends of the regenerator is sufficiently significant so that the thermoacoustic amplification of the core compensates for the viscothermic and mechanical losses in the system.
The only parameter of control of the system after release is the power injected into the exchanger. The evaluation of the power acoustique˙ in the resonator and the drive ratio DR. allows to quantify thermoacoustic conversion.

$$\dot{W}_{ac} = \frac{\pi r_0^2}{2\omega\rho\Delta x}\left[\left(1-\frac{\delta_\nu}{r_0}\right)|p_1||p_2|\sin\psi + \frac{\delta_\nu}{2r_0}\left(|p_1|^2-|p_2|^2\right)\right], \quad (9)$$

r_0 indicate the internal ray of the resonator and δv the viscous thickness of boundary layer with de pulsation ω :

$$\eta_{reg} = \frac{\dot{W}_{ac}}{\dot{Q}_h} \qquad (10)$$

3.3 Performance of the TAET with a loop of feedback electoacoustic

The performances of thermoacoustic conversion are controlled by the interaction between the sound field and the distribution of temperature in the regenerator and the TBT (Thermal Buffer Tubes).
The electrical power who supplies the auxiliary source is noted. Three parameters of controls are then available : the power of heating; the voltage amplification and the déphasage :

$$\eta(\dot{Q}_h, \Phi, G) = \frac{\dot{W}_{el}}{\dot{Q}_h + \dot{W}_{AS}}. \qquad (11)$$

Two configurations are studied for the incorporation of the auxiliary source

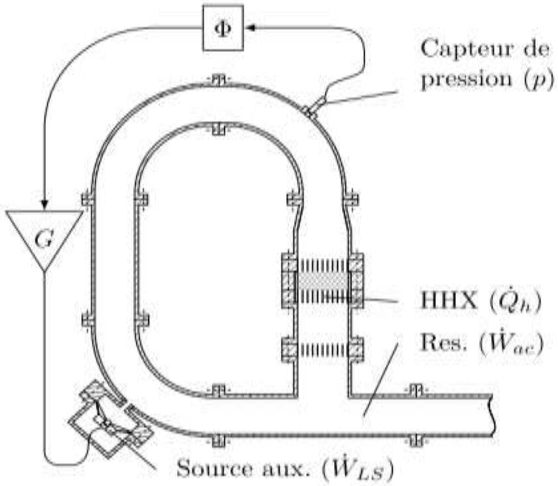

Fig -13 : Two configurations of auxiliary source controlled by a loop of feedback . (a) External source in a cavity, coupled by a capillary. (b) Internal Source positioned in the guide of wave, above the core.

On the basis of work of Desjouy and coll on the acoustic control of the sound field in an annular thermoacoustic engine, an auxiliary source is added on the annular resonator, in the shape of a loudspeaker in a cavity and is coupled by a capillary.

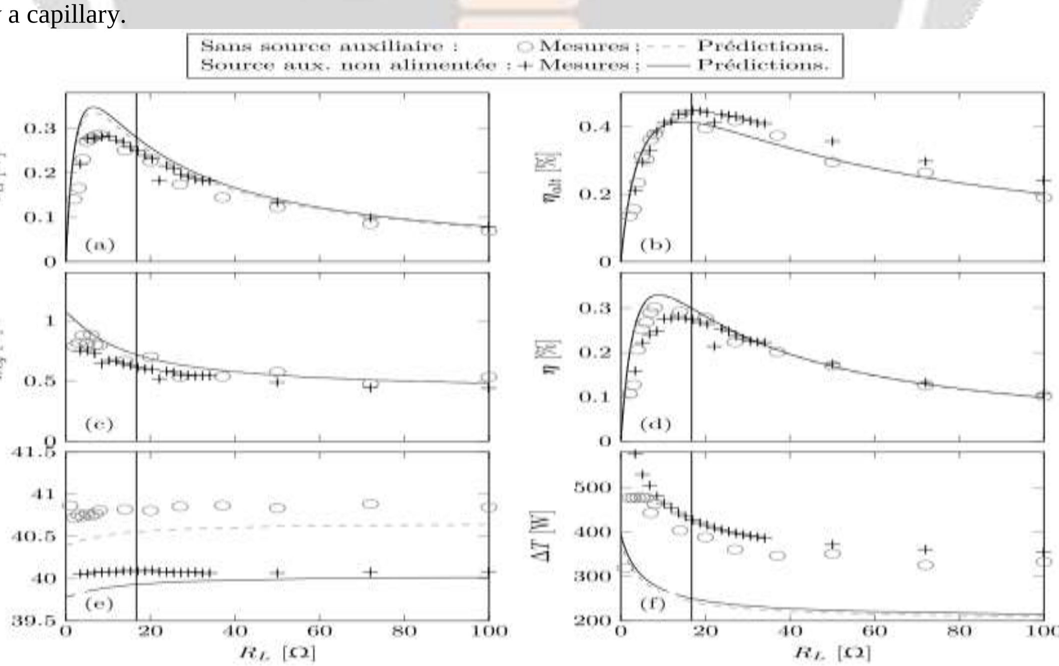

Fig -14 : Performances of the engine without auxiliary source and with the not fed auxiliary source (a) acoustic power, (b) efficacity of thermoacoustic conversion, (c) global efficacity, (d) difference of temperature in the exchanger .

4. MODEL REDUCED OF TRANSDUCER THERMOACOUSTIC

Models reduced are sometimes used to modeling thermoacoustic engine; usually the models for Sterling make analogies of electroacoustic.

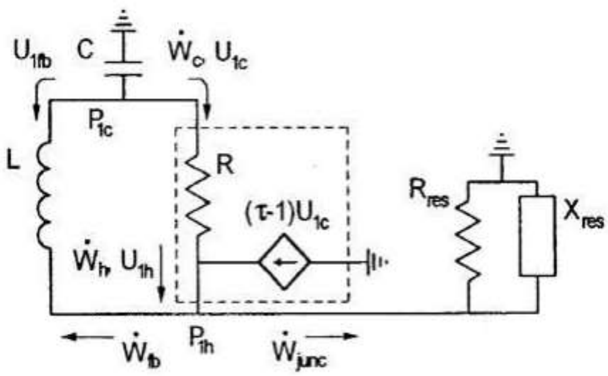

Fig -15 : Electric diagram equivalent simplified of TASHE

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This electric diagram makes it possible to visualize the distribution of the flow of sound power W, and to connect the pressures Pi and the flows U_J acoustic in various points of the acoustic resonator.
Here the representation simplified of a transducer thermo-acousto-mechanic :

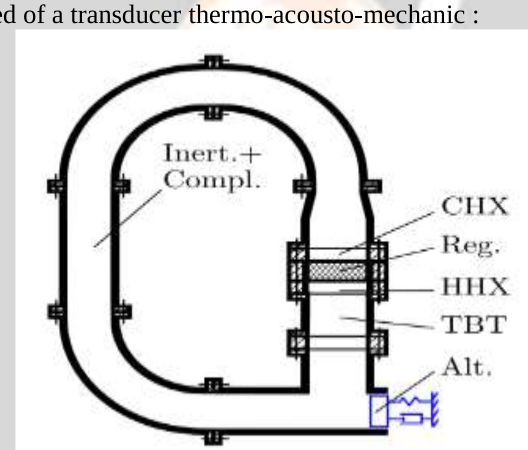

Fig -16 : The representation simplified of a transducer thermo-acousto-mechanics

CHX : Cold Heat Exchanger
HHX : Hot Heat Exchanger
TBT : Thermal Buffer Tubes

The relation between average acoustic speed on the transverse section and the acoustic pressure gives access directly a relation between the differential of pressure dp on the elementary length dx and the acoustic flow $\tilde{u} = S_{\emptyset}\tilde{v}$ through this element of porosity Φ and the pulsation ω :

$$\mathrm{d}\tilde{p} = \frac{i\omega\rho_0 \mathrm{d}x}{\phi S} \frac{1}{1-f_\nu} \tilde{u}. \qquad (12)$$

With ρ0 is the density of the fluid
The expression of the variation of flow along the same elementary segment is

$$\mathrm{d}\tilde{u} = \frac{i\omega\phi S \mathrm{d}x}{\gamma P_0} \left(1 + (\gamma - 1) f_\kappa\right) \tilde{p} + \frac{f_\kappa - f_\nu}{(1-f_\nu)(1-\sigma)} \frac{\mathrm{d}T_0}{T_0} \tilde{u}, \qquad (13)$$

These two expressions (12) and (13) can be rewritten to separate their real and imaginary parts.

$$\mathrm{d}\tilde{p} = (i\omega m + R^{\nu})\tilde{u}, \tag{14}$$

$$\mathrm{d}\tilde{u} = (i\omega C + 1/R^{\kappa})\tilde{p} + g\tilde{u}, \tag{15}$$

The parameters are :

$$\begin{aligned} m &= \frac{\rho_0 \mathrm{d}x}{\phi S}\frac{1-\Re[f_\nu]}{|1-f_\nu|^2}, & R^{\nu} &= \frac{\omega\rho_0 \mathrm{d}x}{\phi S}\frac{\Im[f_\nu]}{|1-f_\nu|^2}, \\ C &= \frac{\phi S \mathrm{d}x}{\gamma P_0}\left(1+(\gamma-1)\Re[f_\kappa]\right), & \frac{1}{R^{\kappa}} &= \frac{\gamma-1}{\gamma}\frac{\omega\phi S \mathrm{d}x \Im[-f_\kappa]}{P_0}, \\ g &= \frac{f_\kappa - f_\nu}{(1-f_\nu)(1-\sigma)}\frac{\mathrm{d}T_0}{T_0}. \end{aligned} \tag{16}$$

The electric Circuit equivalent to the elementary segment of core thermoacoustic is :

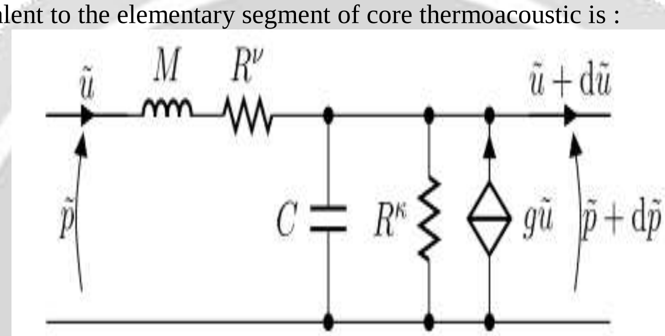

Fig -17 : The electric Circuit equivalent to the elementary segment of core thermoacoustic

Acousto-electric equivalences allow the establishment of an equivalent model for a segment of generic guide of wave. We have :

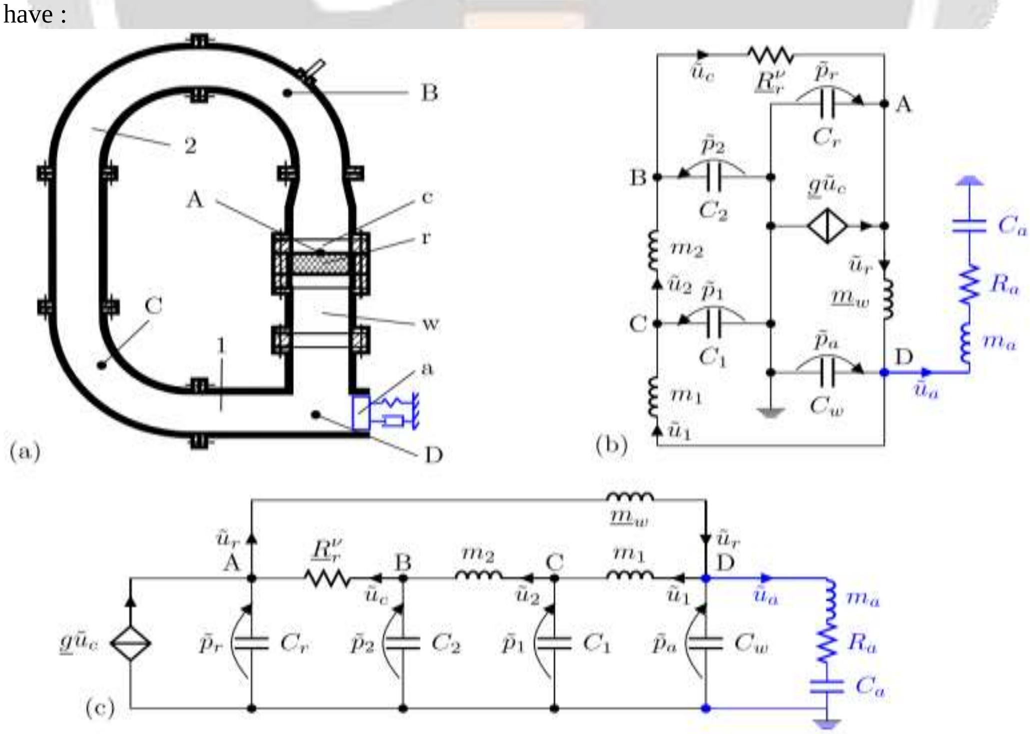

Fig -18 : Electric diagram equivalent of the system thermoacoustic

The expression of the relations between the pressures and acoustic flows in various points of the circuit is given in the temporal field in the form of a system of ten differential equations :

$$
\begin{cases}
\mathrm{d}_t u_a = a_a, & (17)\\
\mathrm{d}_t p_a = \dfrac{1}{C_w}\left(u_r - u_1 - u_a\right), & (18)\\
\mathrm{d}_t u_r = \dfrac{1}{\underline{m}_w}\left(p_r - p_a\right), & (19)\\
\mathrm{d}_t u_c = \dfrac{1}{\underline{R}_r^{\nu}}\left(\dfrac{1}{C_2}(u_2 - u_c) - \dfrac{\underline{g}+1}{C_r}u_c + \dfrac{1}{C_r}u_r\right), & (20)\\
\mathrm{d}_t u_1 = \dfrac{1}{m_1}\left(p_a - p_1\right), & (21)\\
\mathrm{d}_t p_r = \dfrac{1}{C_r}\left((\underline{g}+1)u_c - u_r\right), & (22)\\
\mathrm{d}_t a_a = \dfrac{1}{m_a}\left[\dfrac{1}{C_w}\left(u_r - u_1\right) - \left(\dfrac{1}{C_w} + \dfrac{1}{C_a}\right)u_a - R_a a_a\right], & (23)\\
\mathrm{d}_t u_2 = \dfrac{1}{m_2}\left(p_1 - p_2\right), & (24)\\
\mathrm{d}_t p_1 = \dfrac{1}{C_1}\left(u_1 - u_2\right), & (25)\\
\mathrm{d}_t p_2 = \dfrac{1}{C_2}\left(u_2 - u_c\right). & (26)
\end{cases}
$$

The Model electroacoustic of the discretized core is :

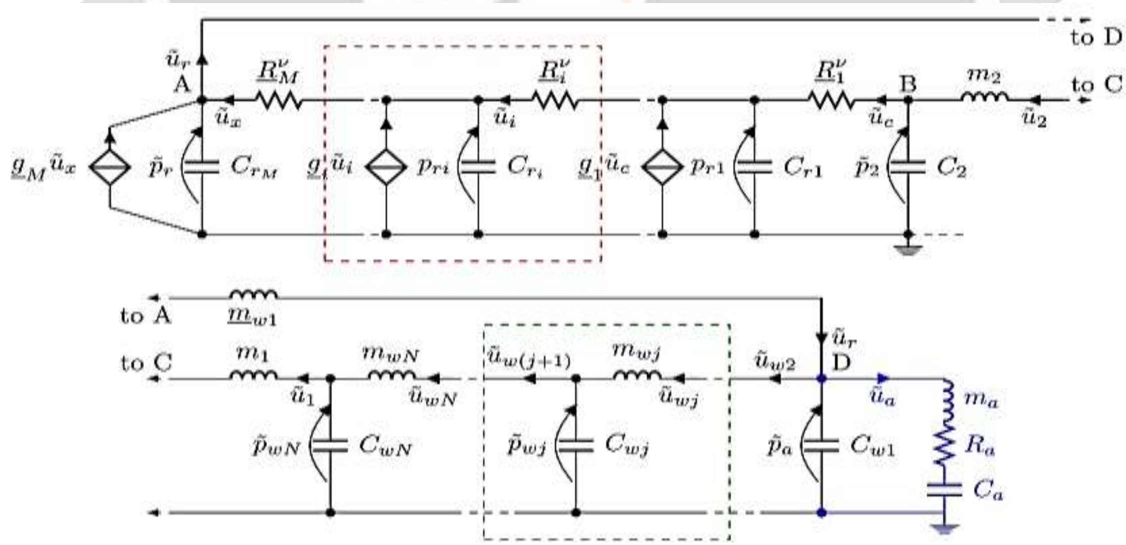

Fig -19 : The Model electroacoustic of the discretized core

The temperature is then supposed to follow a linear distribution on each one of these segments, bringing to the expression of the three elements which compose them, with T m = (T | i+1 + T | i /2) :

$$
\underline{g}_i = \frac{\mathbf{T}|_{i+1}}{\mathbf{T}|_i} - 1, \qquad C_{ri} = \frac{Sl_r}{MP_0}, \qquad \underline{R}_i^{\nu} = \frac{2b\nu_r(T_m)l_r}{MSr_h^2},
$$

The final modeling is:

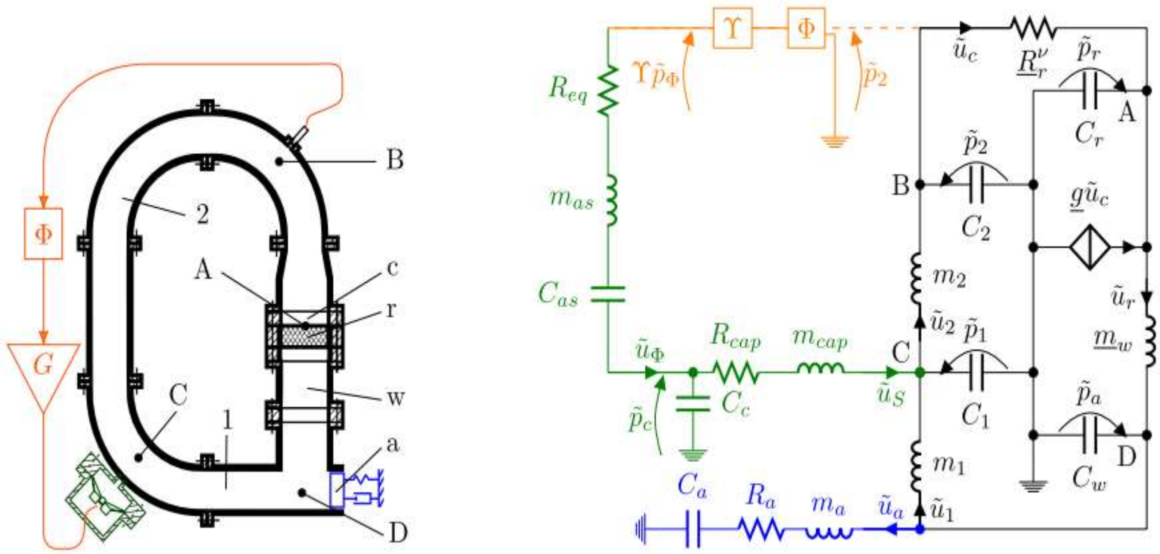

Fig -19 : The final Model electroacoustic equivalent of TAE

5. CONCLUSIONS

The thermal wings can be enough some time to cool an electronic component and besides, one can make a simulation of this mechanism via ComSol Metaphysic. Any time the means of cooling by thermoacoustic is of topicality and in this work the thermoacoustic engines can be to model electrically what facilitates the miniaturization. In the next stage,we will modeling on ComSol Metaphysic the TAE

6. REFERENCES

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