NUMERICAL AND EXPERIMENTAL ASSESSMENT OF THE AIR-TO-BOIL TEST IN A VEHICLE WITH AIR CONDITIONING

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Abstract. *Since 2000, simulation softwares have been used at Fiat Automobile for several applications. The use of computational tools provides cost reduction in a new development, reducing the time spent on the vehicle design and the number of built prototypes. The use of Flowmaster® software as support tool of developments to cooling system has confirmed the trend of simulations in automotive market. This software uses diagram blocks to simulate parts of the vehicle under specified conditions. This paper presents numerical and experimental ATB (Air-to-Boil) tests in a vehicle with 1.4 liters engine bi-fuel and air conditioning. ATB test is a standard test used to evaluate the maximum efficiency of the cooling system. It is carried out on a climatic chamber with dynamometer roller with controlled temperature, humidity, and solar radiation. The test was simulated using Flowmaster software and the numerical results are compared with the experimental data obtained in the climatic chamber. In the mathematical model, the behavior of each component was determined separately and obtained by experimental tests. The good correlation of the results is attributed mainly to the experimental characterization of the components of the system*

Keywords*: mathematical model, Flowmaster software, Air-to-Boil (ATB) test, internal combustion engine, cooling system.*

1. INTRODUCTION

In the past years, the development of virtual tools in automotive vehicles has increased due to the importance of predict behaviors and physical characteristics of the vehicle without spending time and money with physical prototypes. Nowadays it is crucial to maintain the development process as short and efficient as possible. According to Donath et. al. (2008) and Silva et. al. (2008), one of the most significant advantages of the simulation models in cooling systems is the ability to study only the parameters of the cooling system to determine its influence on the system. These sensitive analyses are important to help to understand the behavior of the thermal control of the engine under several conditions and to help to explain some phenomena and interdependences. These characteristics provide a lower response time on the release of new vehicles and versions and to allow the companies to suit the market demands.
Virtual tools are largely spread on the automotive ambiance due to the several acting areas and possibilities of integration, as aerodynamic studies, acclimatization, handling, structure and cooling systems. Recently, Xuefeng (2008) studied the integrated and synchronized development of simulation technologies in automotive vehicles, obtaining satisfactory results. Nevertheless, the work showed that virtual development does not replace experimental tests.

Recent studies (Donath et. al., 2008; Randazzo, 2004; Ngy, 1999, Silva et. al., 2008) were developed with Flowmaster software to predict the behavior of the automotive cooling system. Once known the behavior of the components, the software was used to predict the radiator inlet and outlet temperatures during standard tests. Austin and Botte (2001) studied the integration of the air conditioning circuit and the cooling system, in order to better understand the behavior of the systems. The study of the system with the air conditioning circuit is very important, because the air conditioning influences the engine thermal rejection. The condenser, responsible for the reduction of the temperature of R-134a, is positioned downstream of the radiator. When the airflow passes through the radiator, the temperature is higher. The airflow temperature has to be altered in order to maintain the temperature of the cooling fluid under the ideal working conditions of the engine. The validation of the integration between the cooling system and the air conditioning circuit takes Fiat to a new level in terms of thermal simulations.

This work presents a comparison between numerical results and experimental data of the Air-to-Boil (ATB) tests in a vehicle equipped with air conditioning. The numerical results were obtained with Flowmaster software, to specified conditions. To compare numerical and experimental data, tests were performed in a climatic chamber, according to Fiat standards (Fiat, 2007). The main purpose of the simulation was the evaluation of a cooling module proposed by an alternative supplier and the prediction of its behavior without physical tests. The virtual tests were used as preliminary tests. The final approval of the proposed module can only be done after experimental tests in the climatic chamber.

2. COOLING SYSTEM

A cooling system can be seen as the storaged energy of the engine, composed by the cooling fluid, engine oil, engine head and engine block (Fig. 1). The energy level can be expressed as a function of the system temperature. There is typically an energy source (combustion chemical energy) in na internal combustion engine, but part of this energy is not used due to several reasons. The air injected in the engine is mixed with the injected fuel and burns inside the engine cylinders. Part of the combustion generates power to the engine; the rest is lost to the environment, engine block and cooling system (Yoo et. al., 2001).

The vehicle cooling system consists of the internal combustion engine, the main heat source, the water pump, the thermostatic valve, the expansion reservoir, the hoses, the cooling fluid and the cooling module, which consists of the condenser, the radiator and the fan. The cooling fluid (a mixture of water and ethylene glycol) is responsible for the transport of the cooled fluid to the engine. The ethylene glycol is usually used in a proportion of 30% to 60%, with additives to avoid the corrosion of the metals it contacts. It reduces the freezing point of the cooling fluid to a temperature below 0°C and increases the boiling point, reducing the risk of the cooling fluid boils, harming the engine components or stopping the vehicle for lack of refrigeration. In duty vehicles, the glycerin has been used as part of the cooling fluid, avoiding the cavitation of the water pump and increasing the solution boiling point. Studies of the use of glycerin in small vehicles are been performed, because the glycerin due to its ecological properties. Since it is a sub product of biodiesel, it is being produced and it is not being so much used.

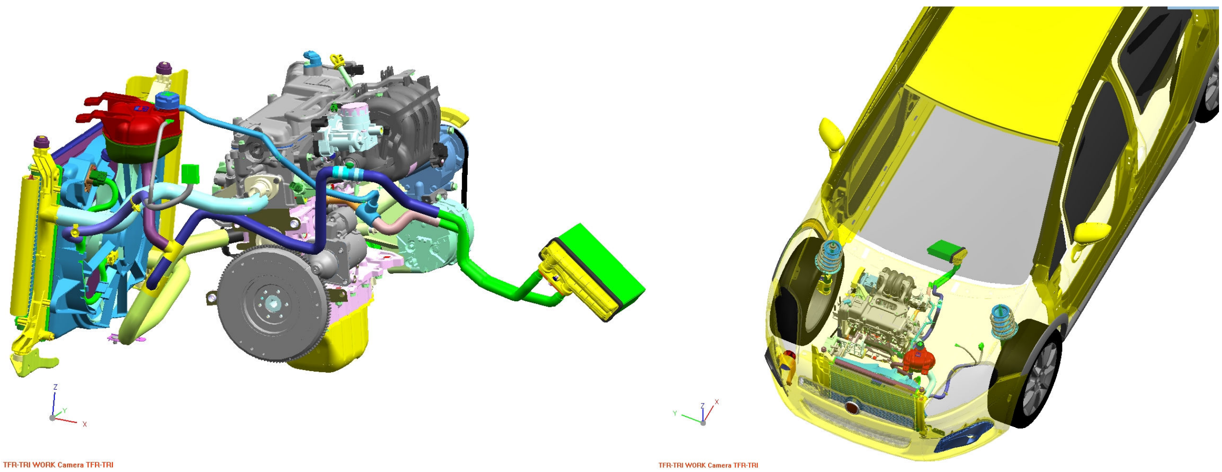

Figure 1 – Vehicle cooling system and 1.4 Fire Flex engine

According to Kargilis (2003), the ATB index is based on the guarantee, durability and competitiveness of the vehicle performance. It represents the ambient temperature in which the cooling fluid on the radiator inlet will boil. The ATB test should be performed in a acclimatized environment. The test conditions are subject to the standards of the automotive companies, taking into account mainly gear ratios, ability to climb a hill and total load towable. The ATB test performed to this paper was done according to Fiat standard 7-T0010 (Fiat, 2007).

3. EXPERIMENTAL ANALYSIS

The experimental results on this study were performed in a climatic chamber with roller dynamometer (Fig. 2) with wind speed up to 200 km/h, ambient temperature from -18°C to 50°C, solar panels with solar radiation up to 1200 W/m² and air relative humidity up to 80%. The ATB test consists of the full characterization of the engine related to power, torque and heat rejection, cooling module including the head losses on both sides (water and air) passing through the radiator, mass flow rate curve of the fan, condenser’s heat rejection, mass flow rate curve of the water pump and the thermostatic valve, possible existence of frontal air, weight, shaft ratios and fuel.

Figure 2 – Climatic chamber with roller dynamometer

The sensors used on the test are:

- Pressure transducers of 1.5 bar with analog output, installed on the expansion reservoir, radiator inlet and outlet (uncertainty of 10%);
- Pressure transducers on the high pressure and low pressure air conditioning tubes;
- K type thermocouples, on the radiator inlet and outlet, engine head, engine oil, gear box, air filter inlet, throttle and air conditioning diffuser;

The ATB index is defined by:

$$ATB = T_v - T_u + T_a \tag{1}$$

where:
T_v = Boiling temperature of the cooling fluid
T_u = Temperature of the cooling fluid at the radiator inlet
T_a = Ambient temperature

The ATB index evaluates the maximum efficiency of the cooling module under specified conditions. If this limit is reached, the cooling system, the shaft ratio or the maximum load the vehicle can handle must be redesigned.

4. NUMERICAL ANALYSIS

It was used the Flowmaster V7™ software to numerically evaluate the temperature of the cooling fluid at the radiator inlet. The software performs an one-dimensional modeling of CAE/CFD virtual systems, determining effects of fluid flows and thermal effects trough empirical and mathematical expressions of pressure, mass flow and temperature.

The software uses a block diagram methodology. The blocks represent the cooling system components. The suppliers of the components perform tests of the components, according to Fiat specifications. The characteristic curves of head losses (air side and fluid side) are generated as result of these tests. The characteristic curves are set on the software as input data, together with another data, as coolant mass flow rate on the radiator, velocity and frontal opening area of the vehicle.

The experimental data obtained with the usual cooling module (Supplier 1) were used to validate the numerical model. Once validated the model, the blocks of the components of Supplier 2 (condenser, radiator and fan) were changed.

Figures 2 and 3 present the thermal efficiency curves as function of the coolant and air mass flow rates of the radiators evaluated in this paper. Figure 2 is related to Supplier 1 (usual module) and Fig. 3, to Supplier 2 (proposed module).

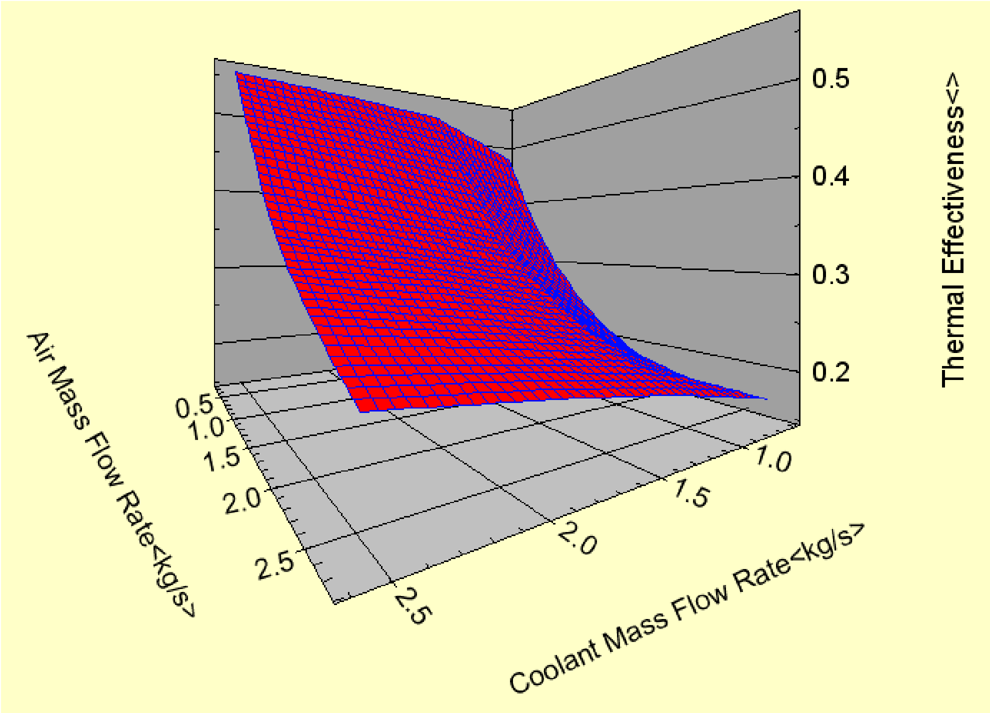

Figure 2 – Thermal efficiency of the usual radiator

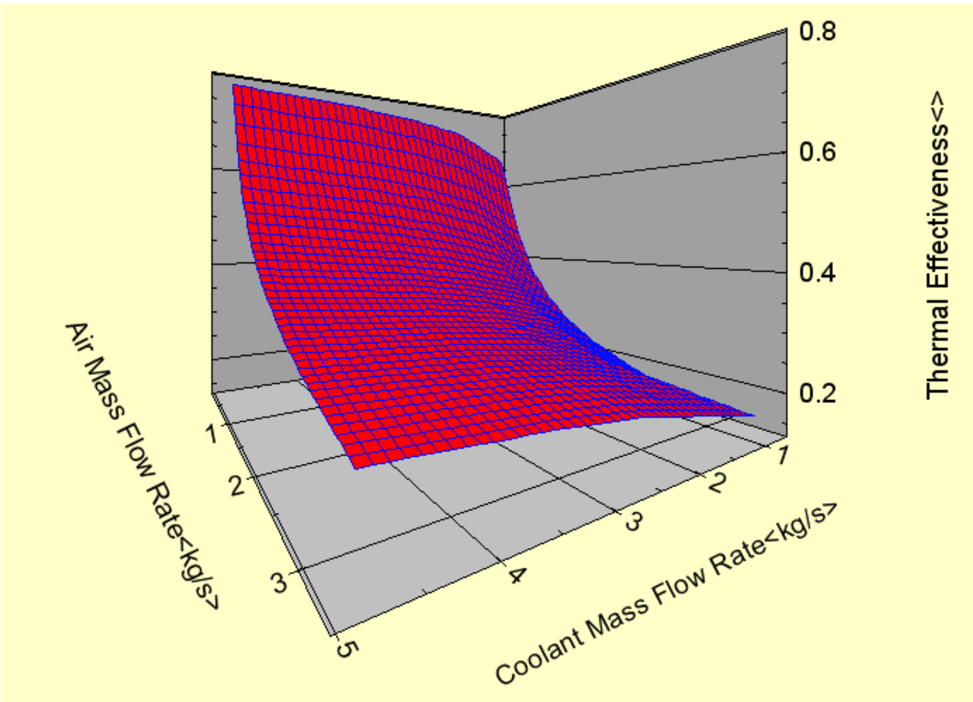

Figure 3 – Thermal efficiency of the proposed radiator

Figures 4 and 5 present a comparison between the head losses on the air side of the radiator and on the liquid side of the radiator, respectively.

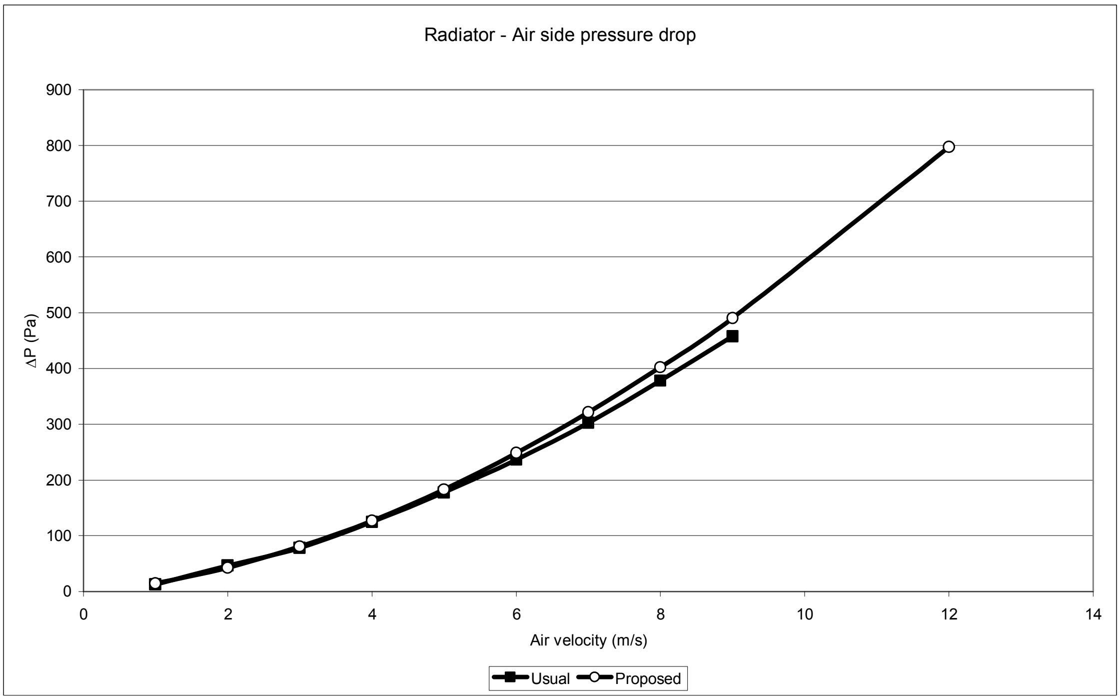

Figure 4 – Comparison of the head losses on the air side of the radiator

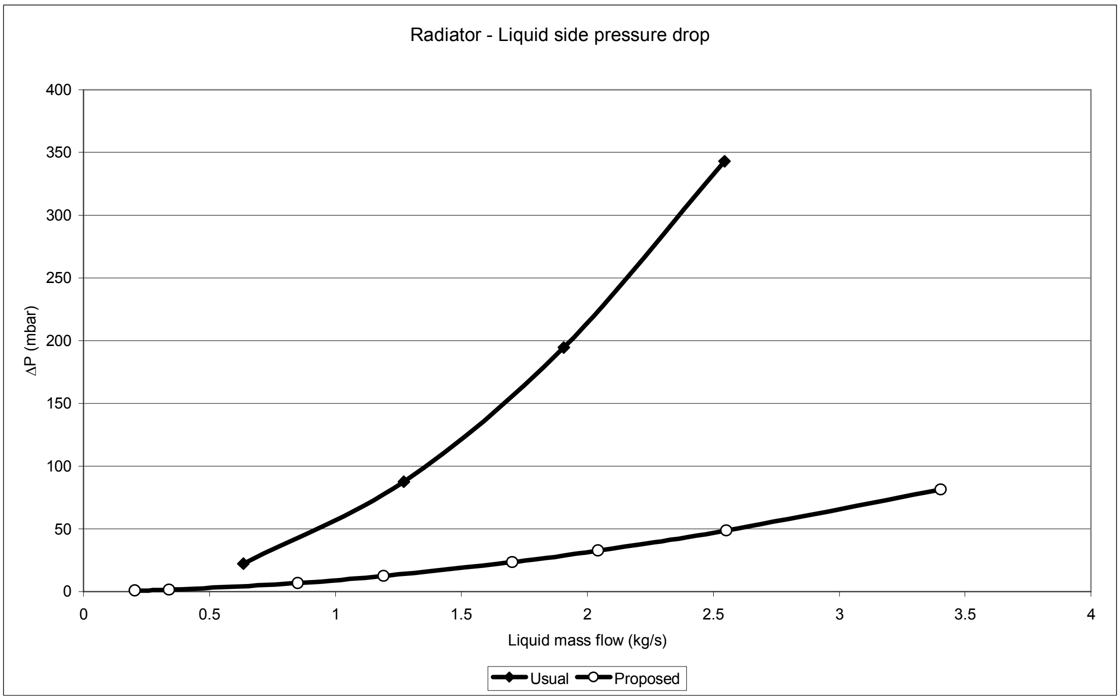

Figure 5 – Comparison of the head losses on the liquid side of the radiator

Figure 6 presents a comparison between the head losses on the air side of the condenser. Figure 7 represents the characteristic curves of the fan used on the evaluated cooling modules.

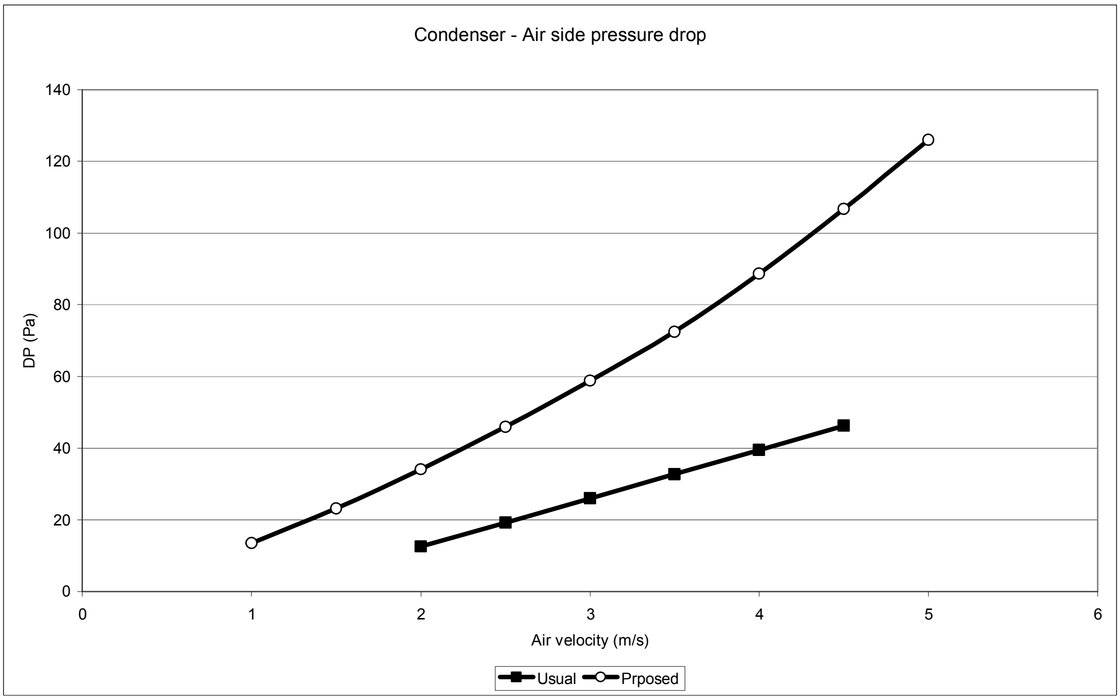

Figure 6 – Comparison of the head losses on the air side of the condenser

The characteristic curves show lower head losses on the proposed module, indicating that the coolant mass flow rate should be lower in this module, increasing the component performance. Nevertheless, its condenser imposes a higher resistance to the airflow, which has to be compensated by the fan in order to not reduce the airflow enough to harm the thermal exchanges.

The use of the Flowmaster V7™ software is important to help to determine the most suitable configuration of the cooling system, reducing the number of tests due to failures for lack of knowledge of some components characteristics. This determination is done using data from the components suppliers and the tests performed at Fiat.

5. RESULTS

In this paper, it was evaluated a new proposal of a cooling module, using Flowmaster V7T™. The numerical model was validated with the usual module. Once validated the model, the software was used to software to predict the ATB test results of the proposed module. Table 1 presents the values of the test conditions, according to Fiat (2007).

Table 1. Tests and environment conditions in the climatic chamber.

Phase	1	2	3	4
Velocity (km/h)	21,6	42,0	40,6	140,0
Relative humidity	60,0	60,0	60,0	60,0
Solar radiation (W/m^2)	700,0	700,0	700,0	700,0
Ambient temperature (°C)	30,0	30,0	30,0	30,0
Voltage in the fan (V)	12,0	12,0	12,0	12,0

Figure 7 shows the speed conditions the vehicle must attend on ATB tests. All conditions are related to drag force, gear ratios and tires. In the first condition, the air conditioning is turned off and the speed is 21,6km/h. In the second condition, the air conditioning is off and the speed is 42,0km/h, the third condition is the same as second condition, but the air conditioning is turned on. For this reason, there is a decrease on the speed, to around 41,6km/h. The fourth and last condition simulates a flat road on 140km/h and air conditioning. With these conditions the vehicle can reach almost every condition that a normal customer could use. The test allows one to evaluate each important condition.

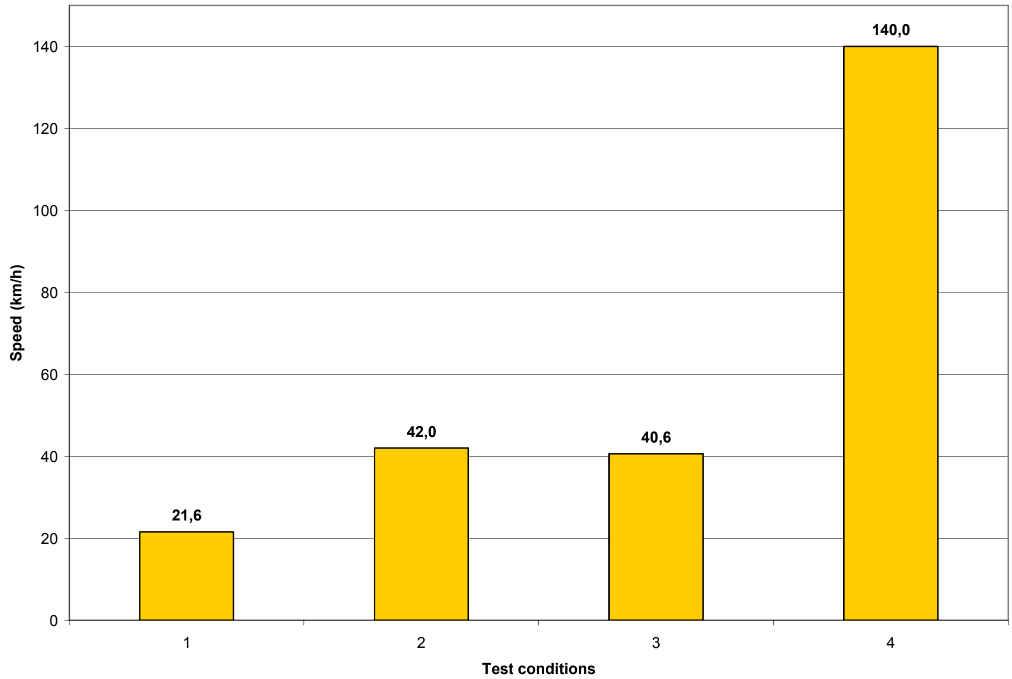

Figure 7 – Speed conditions tests

The most important analysis of ATB test is the inlet radiator, because from this information the ATB result will be evaluated according to formula (1), and then it can be determined if the cooling system is suitable to the car or if it needs improvements.

The inlet radiator temperature is show in the Fig 8. The first simulation was validated with experimental results. Once validated the model to Supplier 1 data, the simulation with Supplier 2 data would be correct.

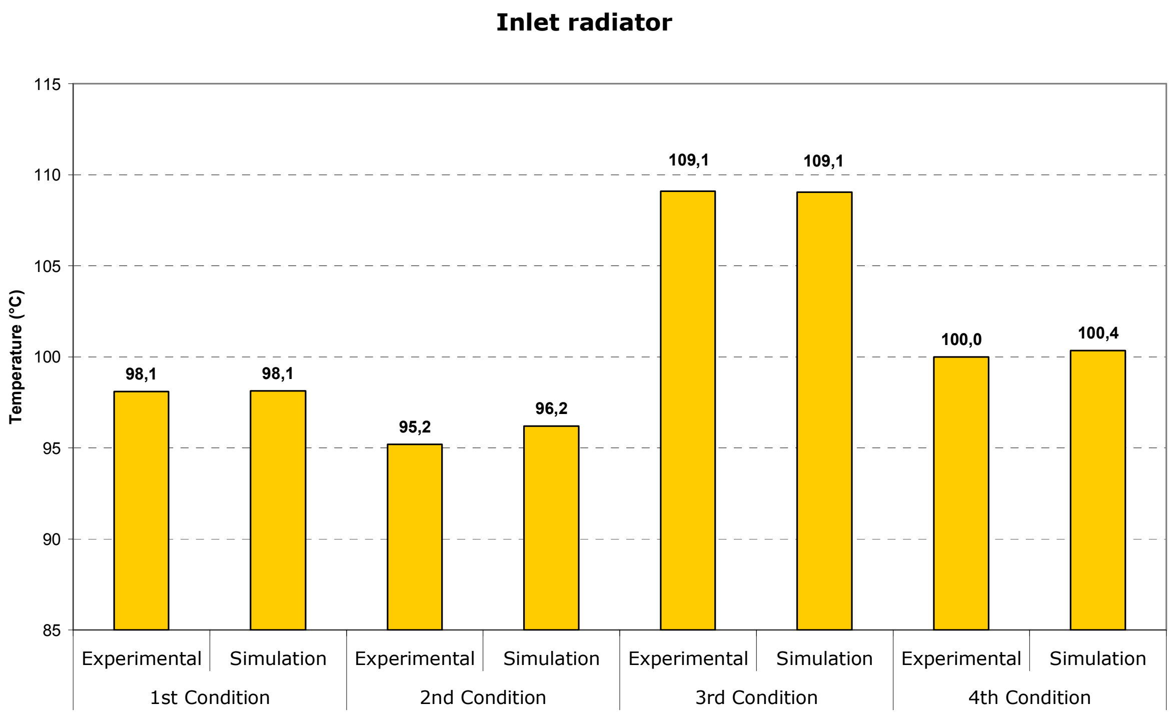

Figure 8 – Simulated and experimental inlet radiator temperature

After validated the numerical method, the tests with Supplier 2 can be evaluated and guarantee the results using head losses in the air and water sides and in the fan. Figure 9 presents the inlet radiator results comparing the usual module and the proposed module. The results show that the radiator performance of the proposed module is better than the usual module, because it kept the temperature in lower levels and the air conditioning performance will be a little bit better. Nevertheless both radiators results are in accordance to the ideal engine conditions. The biggest difference between radiators performance is under 7%, in the first condition (Fig. 10).

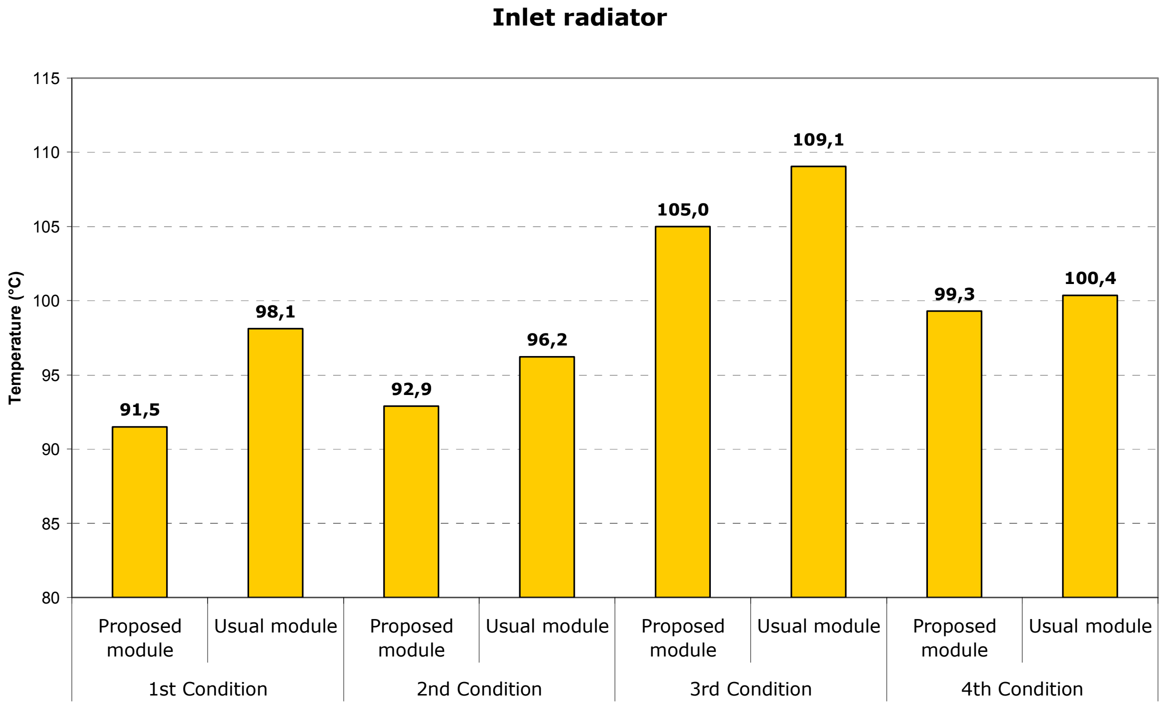

Figure 9 – Proposed and usual module inlet radiator temperature results

The comparison between both suppliers modules on ATB results presented good conditions to approve Supplier 2 on these conditions. After this test Supplier 2 received an order to keep in the way to further tests until final approve.

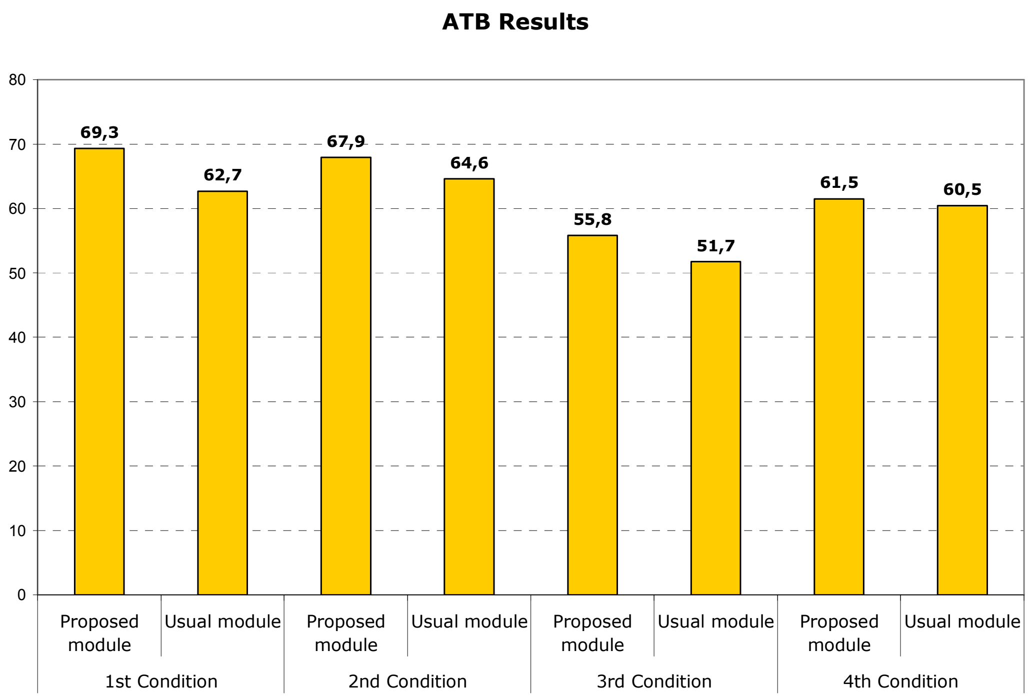

Figure 10 – ATB results

The final analysis is due to Experimental and Simulation method with Supplier 2. This concern to validate numerical method to Supplier 2 and shows that the results obtained is in accordance to climatic chamber test.

To have an idea good correlation between experimental and numerical are above 10%, but the simulation in this study keep the difference under 3% of error (Fig. 11).

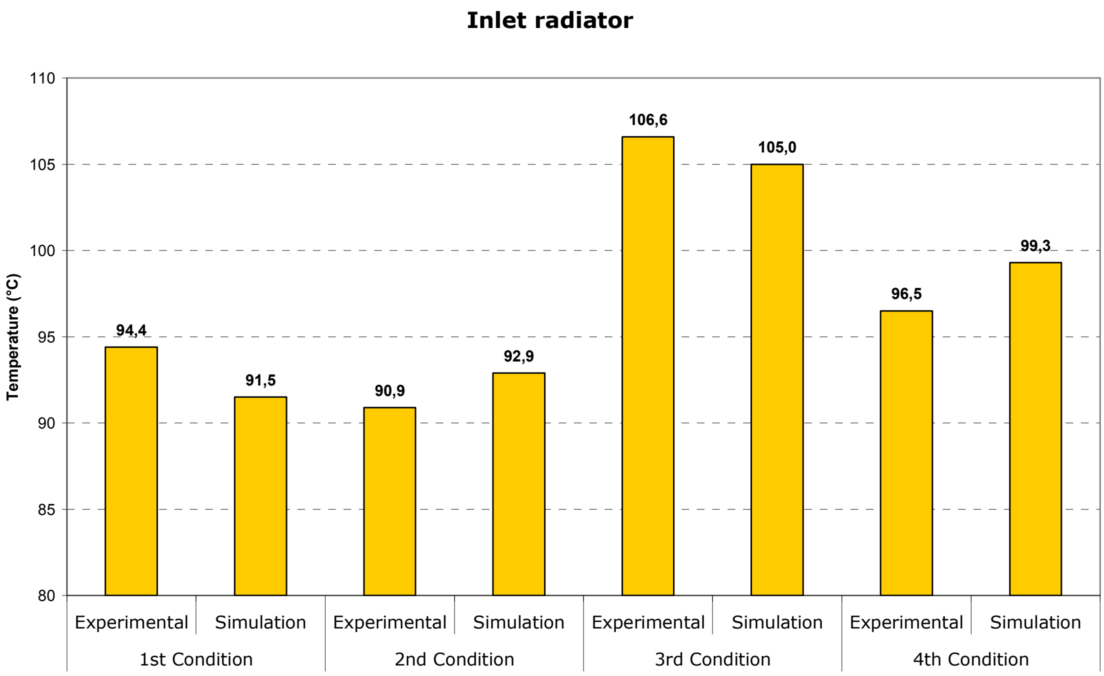

Figure 11 – Experimental and numerical inlet radiator temperature results.

The results are comparison between both suppliers modules on ATB results presented good conditions to approve Supplier 2 on these conditions. After this test Supplier 2 received an order to keep in the way to further tests until final approve.

6. CONCLUSIONS

The prediction of the inlet radiator temperature and the ATB results was performed to a Fiat vehicle using Flowmaster software. The vehicle was tested in several different conditions in a climatic chamber, according to Fiat standards. Two cooling modules were evaluated: the usual one, for which experimental results were performed (in order to validate the model) and a proposed new module. The maximum difference between numerical and experimental results data was about 7%.

From now, any studies can be done on cooling system altering radiator, fan and condenser characteristics curves.

The use of air conditioning in the simulation was developed, becoming a big step for new developments in Brazil, putting Fiat Brazil in a higher level of simulations methods. The cost reduction on experimental tests is very important nowadays and this study reduces time and great amount of money to Fiat. Even the use of simulation is getting bigger importance, it will never stop the experimental tests as important tool to evaluate the customers uses condition.

7. ACKNOWLEDGEMENTS

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