



6th INTERNATIONAL CONFERENCE INTEGRITY-RELIABILITY-FAILURE Lisbon/Portugal, 22-26 July 2018



1- INTRODUCTION

Fire events in car parks have been a major problem for buildings, vehicles and humans. The main cause for fire propagation are the combustible materials of the vehicles.

Ceiling jet flow occurs when the fire plume impinges the ceiling and develops in the radial direction.

Both temperature and velocity predictions are decisive for sprinklers positioning, fire alarms positions, detectors (heat, smoke) positions and activation times and back-layering predictions.

2- OBJECTIVES

Investigate the ability of 4 correlative models (Alpert, Cooper, Heskestad & Delichatsios, Motevalli & Marks) on the dynamic and thermal characteristics of the ceiling jet fire (localized fire in open car park), comparing the results to the software CFAST (two zone model) and ANSYS Fluent (field model).

3- MATERIALS AND METHODS

The localized fire event (depends on the class of the vehicle) can be defined by the Heat Release Rate (HRR).

The HRR of the vehicle fire events increases from zero to a maximum value in 25 minutes and decreases to zero at the end of the event.

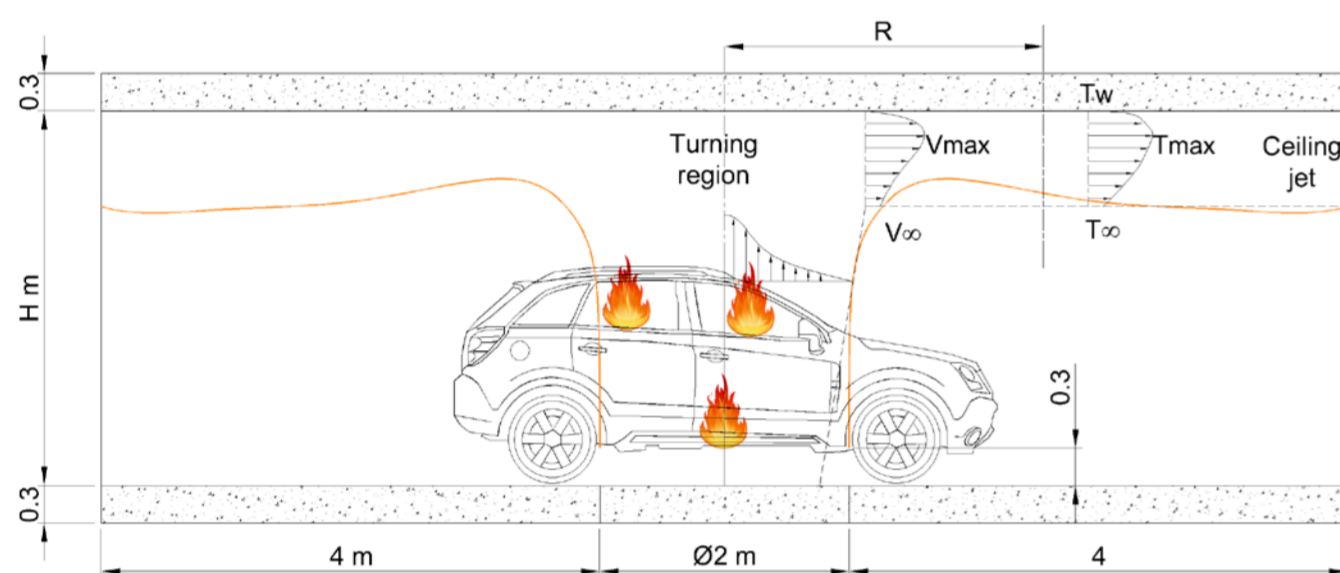


Figure 1 - Localized fire scenario.

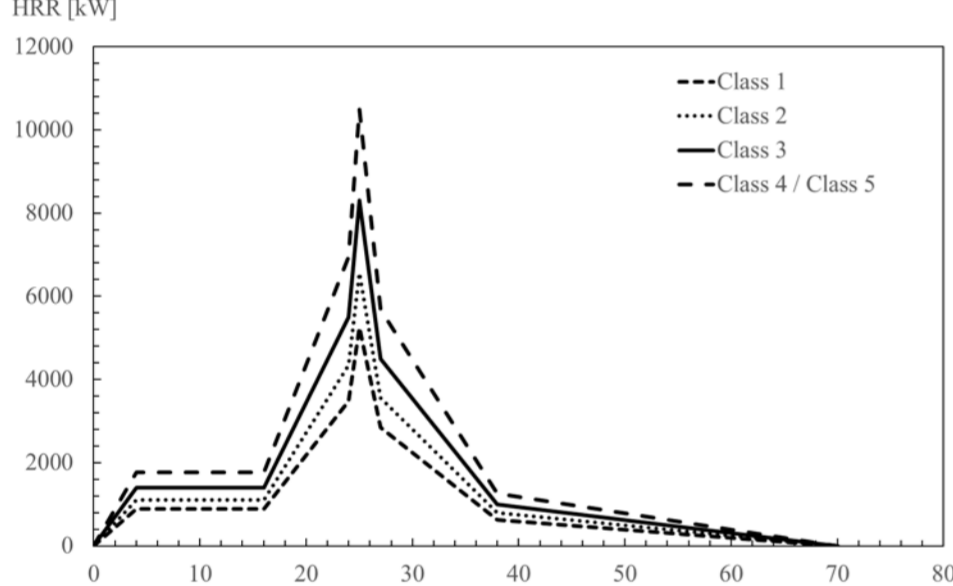


Figure 2 - HRR from different classes of vehicles.

Correlative models are used to estimate temperatures and velocities of the hot gases in a ceiling jet flow.

Alpert (1972) developed correlations for the maximum gas velocity and temperature in jet flows induced by large-scale fires.

$$V_{max} = 0,197 \frac{\dot{Q}^{1/3} H^{1/2}}{R^{5/6}}, \quad \text{if } R/H > 0,15$$

$$V_{max} = 0,96 \left(\frac{\dot{Q}}{H}\right)^{1/3}, \quad \text{if } R/H \leq 0,15$$

$$T_{max} = T_{\infty} + 5,38 \frac{(\dot{Q}/R)^{2/3}}{H}, \quad \text{if } R/H > 0,18$$

$$T_{max} = T_{\infty} + 16,9 \frac{\dot{Q}^{2/3}}{H^{5/3}}, \quad \text{if } R/H \leq 0,18$$

Alpert (2011) correlative model: based on the knowledge of the flame virtual origin.

$$V_{max} = 0,215 \frac{(\dot{Q}_c/H)^{1/3}}{(R/H)^{1,003}}, \quad \text{if } R/H > 0,15$$

$$V_{max} = 0,2526 \frac{\dot{Q}_c^{1/3}}{(H-z_0)^{1/3}} \left(\frac{R}{H-z_0}\right)^{-1,0739}, \quad \text{if } \frac{R}{H-z_0} > 0,246$$

$$T_{max} = T_{\infty} + 5,289 \frac{\dot{Q}_c^{1/3}}{(R/H)^{0,611} H^{5/3}}, \quad \text{if } R/H > 0,18$$

$$T_{max} = T_{\infty} + 6,721 \frac{\dot{Q}_c^{2/3}}{(H-z_0)^{5/3}} \left(\frac{R}{H-z_0}\right)^{-0,6545}, \quad \text{if } \frac{R}{H-z_0} > 0,134$$

Cooper correlative model.

$$V_{max} = 0,26 \left(\frac{R}{H}\right)^{-1,1} H^{-1/3} \dot{Q}^{1/3}, \quad \text{if } 0,2 \leq R/H \leq 4$$

$$T_{max} = T_{\infty} + 28,1 \dot{Q}^{2/3} H^{-5/3} \exp\left(-1,77 \frac{R}{H}\right), \quad \text{if } 0 \leq R/H \leq 0,75$$

$$T_{max} = T_{\infty} + 5,77 \dot{Q}^{2/3} H^{-5/3} \left(\frac{R}{H}\right)^{-0,88}, \quad \text{if } 0,75 \leq R/H$$

Heskestad & Delichatsios correlative model:

$$V_{max} = 0,197 \left(\frac{R}{H}\right)^{-0,63} \left(0,188 + 0,313 \frac{R}{H}\right)^{-2/3} \dot{Q}^{1/3} H^{-1/3}, \quad \text{if } 0,4 < R/H \leq 8$$

$$V_{max} = \left(\frac{\dot{Q}_c}{H-z_0}\right)^{1/3}, \quad \text{centre line speed}$$

$$T_{max} = T_{\infty} + 2,75 \left(0,188 + 0,313 \frac{R}{H}\right)^{-4/3} \dot{Q}^{2/3} H^{-5/3}, \quad \text{if } 0 < R/H \leq 8$$

$$T_{max} = T_{\infty} + 25 \left(\frac{\dot{Q}_c^{2/5}}{H-z_0}\right)^{5/3}, \quad \text{centre line temperature}$$

Motevalli & Marks correlative model:

$$V_{max} = 0,0415 \left(\frac{R}{H}\right)^{-2} \dot{Q}^{1/3} H^{-1/3} + 0,427 \left(\frac{R}{H}\right)^{-1} \dot{Q}^{1/3} H^{-1/3} + 0,281 \dot{Q}^{1/3} H^{-1/3}, \quad \text{if } 0,26 \leq R/H \leq 2$$

$$T_{max} = T_{\infty} + 0,23 \left(\frac{R}{H}\right)^{-2} \dot{Q}^{2/3} H^{-5/3} + 5,2 \left(\frac{R}{H}\right)^{-1} \dot{Q}^{2/3} H^{-5/3} + 2,7 \dot{Q}^{2/3} H^{-5/3}, \quad \text{if } 0,26 \leq R/H \leq 2,0$$

CFAST is a two-zone fire model that predicts the thermal environment caused by a fire within a compartment. The grid was defined with 50 divisions for both compartments, after a convergence test.

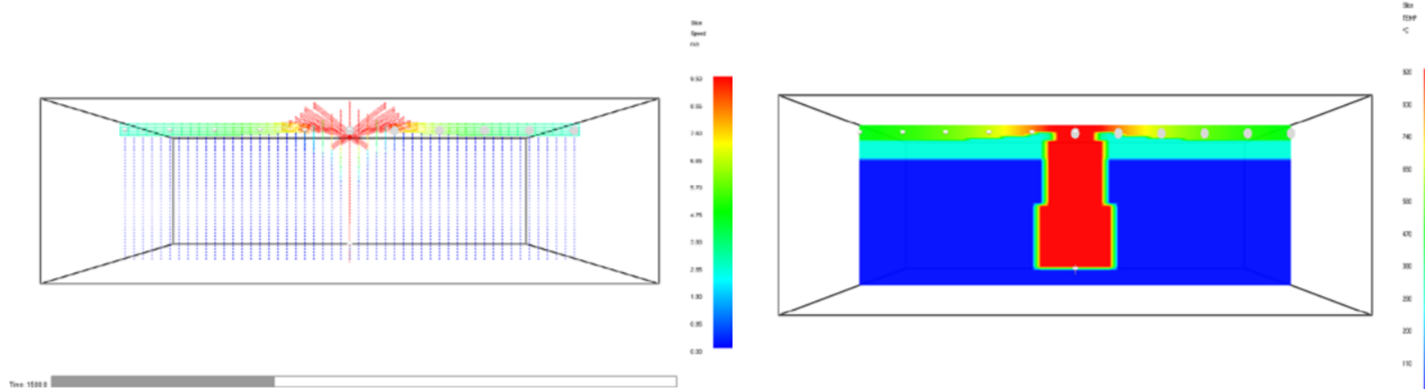


Figure 3 - Velocity and Temperature of class 3 vehicle (time 1500s, compartment 1 (H=3m)).

Geometry:

Compartment 1: 10x10x3 m high (openings left and right side).

Compartment 2: 10x10x5 m high (openings left and right side).

Concrete slab with a thickness of 0.3m.

Boundary conditions:

The ambient temperature was assumed to be 20°C.

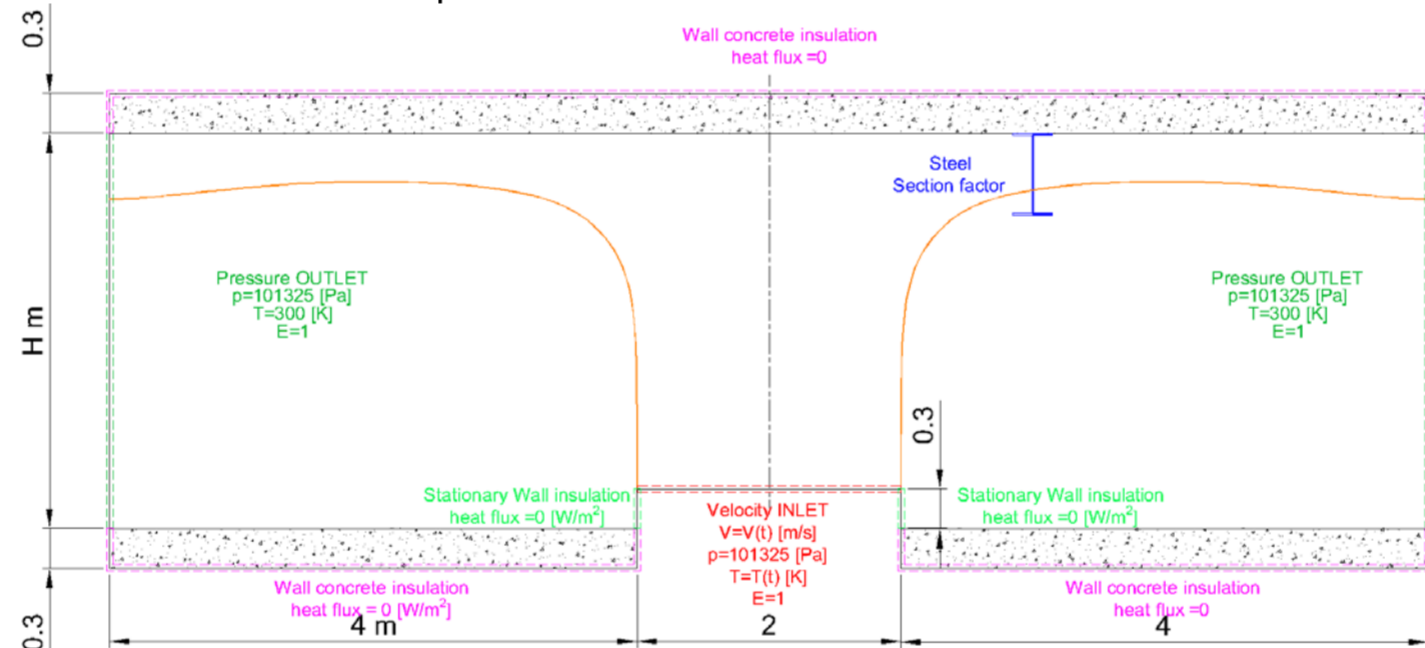


Figure 4 - Boundary conditions in ANSYS Fluent.

Materials:

All the materials properties were considered temperature dependent for the CFD simulation, including the solid part and the fluid part. Figure 5 represents the main thermal properties involved in simulation.

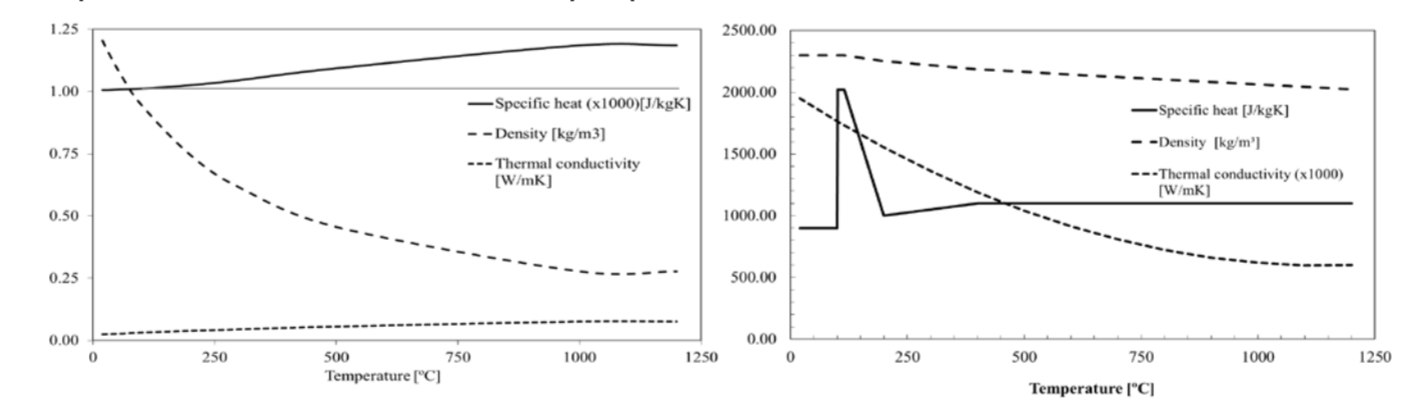


Figure 5 - Thermal properties for air and concrete.

ANSYS Fluent software is CFD software which includes well-validated physical modelling and is capable of deliver fast and accurate results.

Part of the boundary conditions were obtained from the software CFAST for both compartments at a point located on the floor of the vehicle see velocity and temperature field depicted in Figure 3.

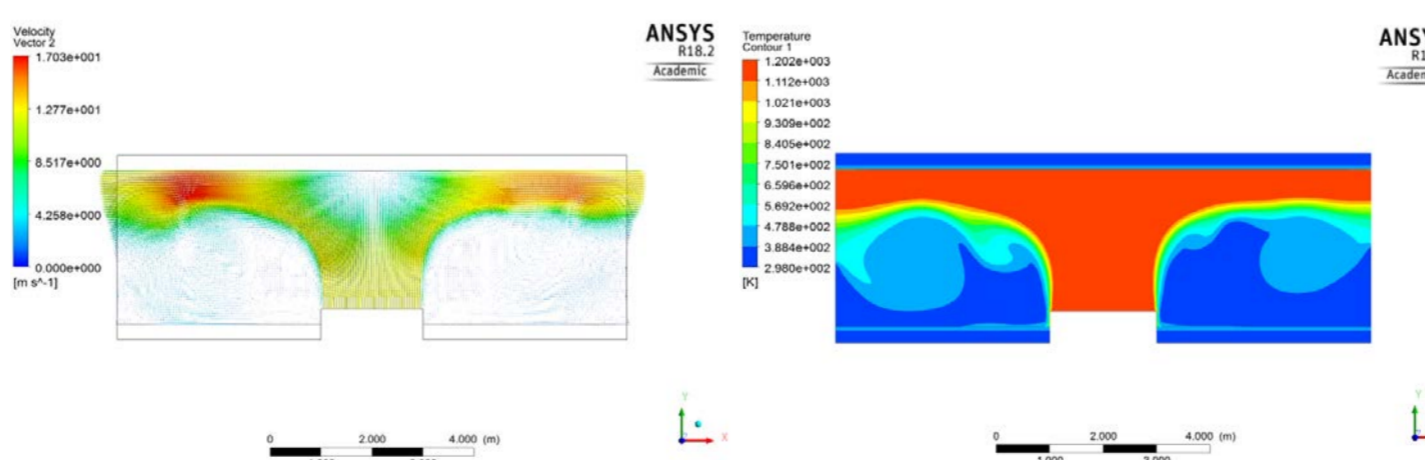


Figure 6 - Velocity and Temperature of class 3 (time 1500s for compartment 1 (H=3m)).

4- RESULTS

A total of 16 simulation results were obtained taking into consideration 2 different heights for the compartment (H=3 m and H=5 m), 4 different car classes (fire events), 6 radial positions (R).

The ratio for the first compartment are R/H= 0, 0.37, 0.74, 1.11, 1.48 and 1.85 and for the second compartment are R/H= 0, 0.21, 0.42, 0.64, 0.85 and 1.06, which corresponds to all the radial positions evaluated (R=1,2,3,4 and 5 m).

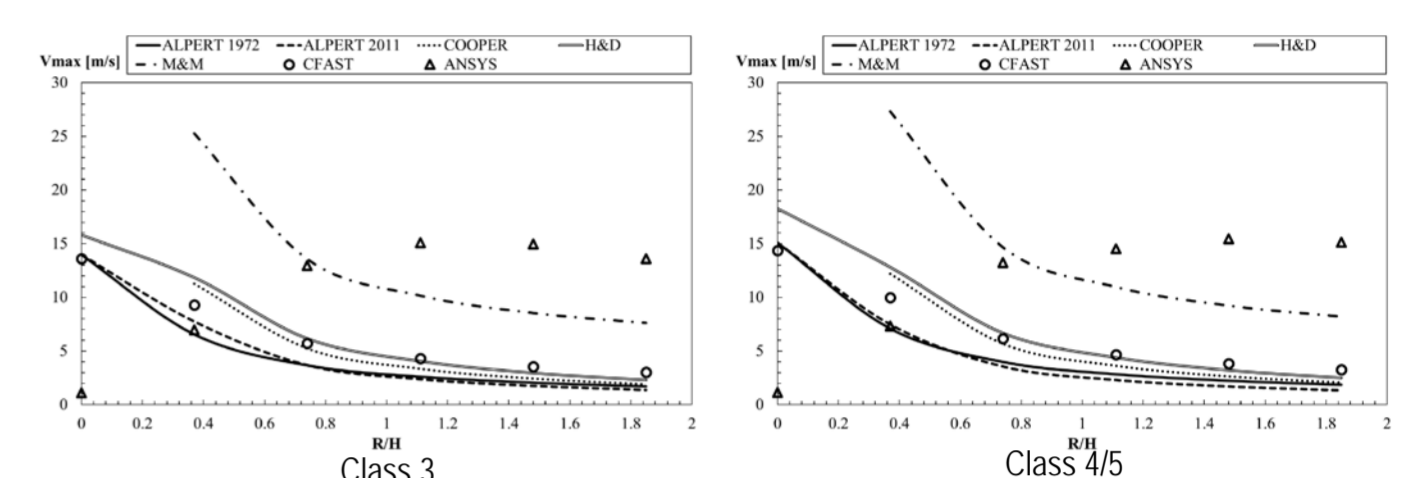
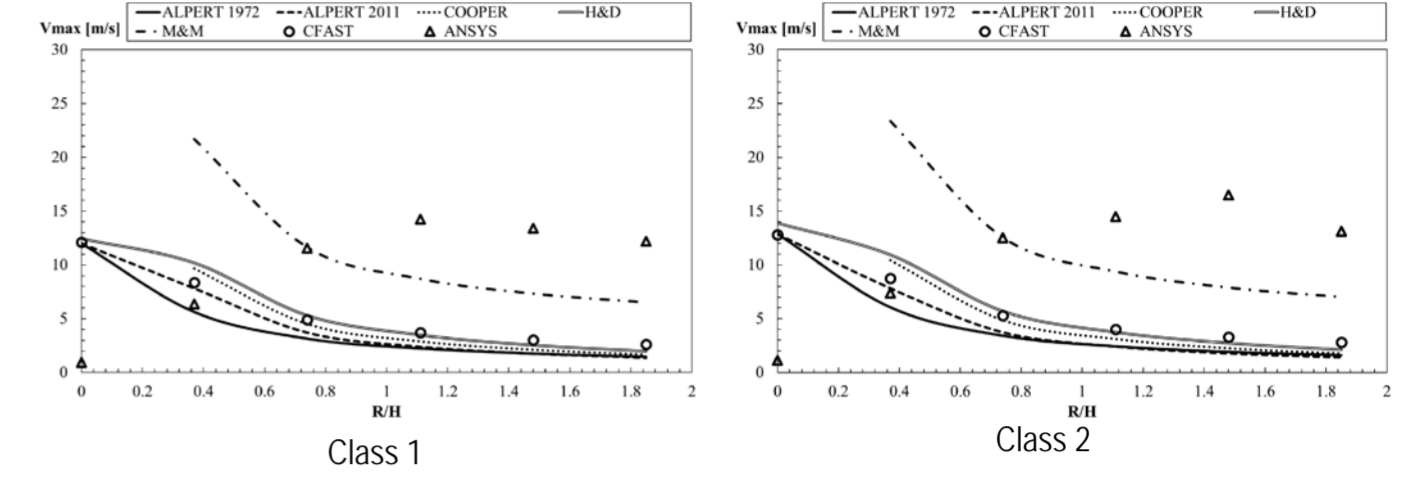


Figure 7 - Maximum velocity for the compartment 1.

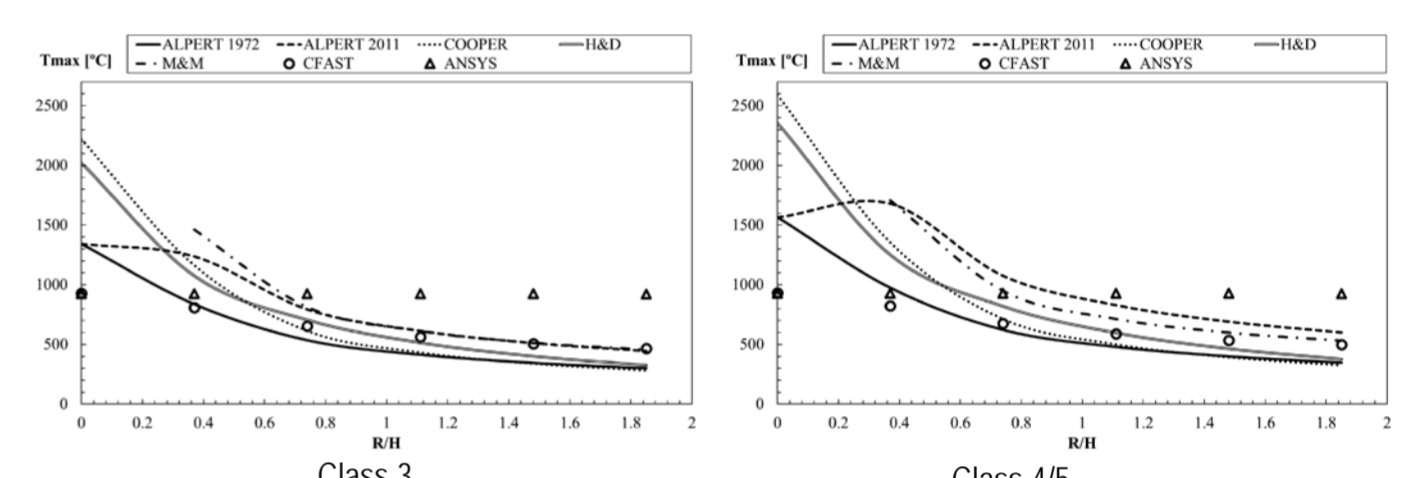
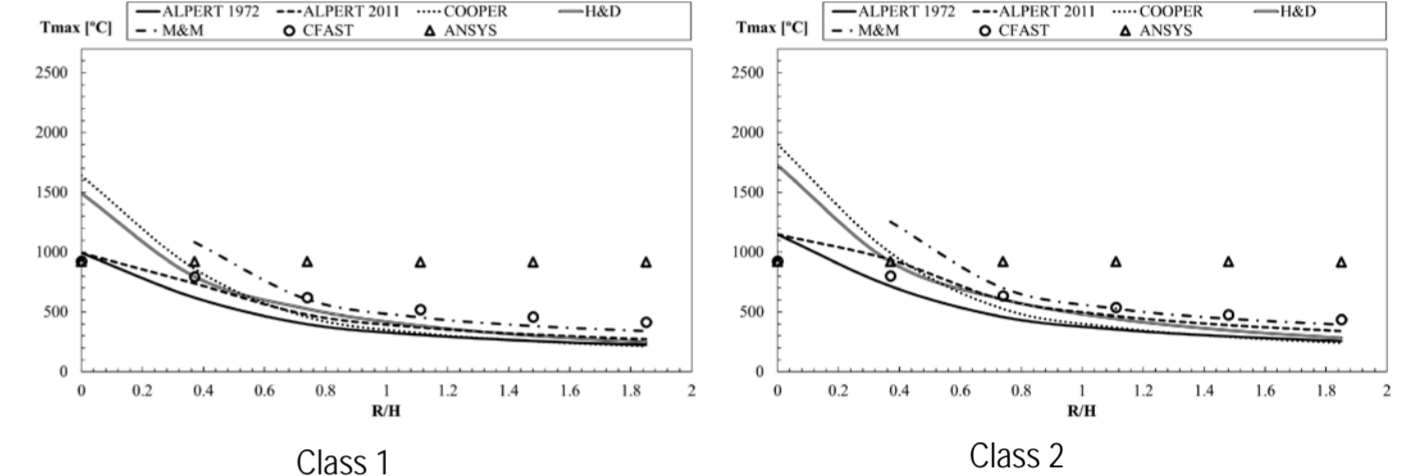


Figure 8 - Maximum temperature for the compartment 1.

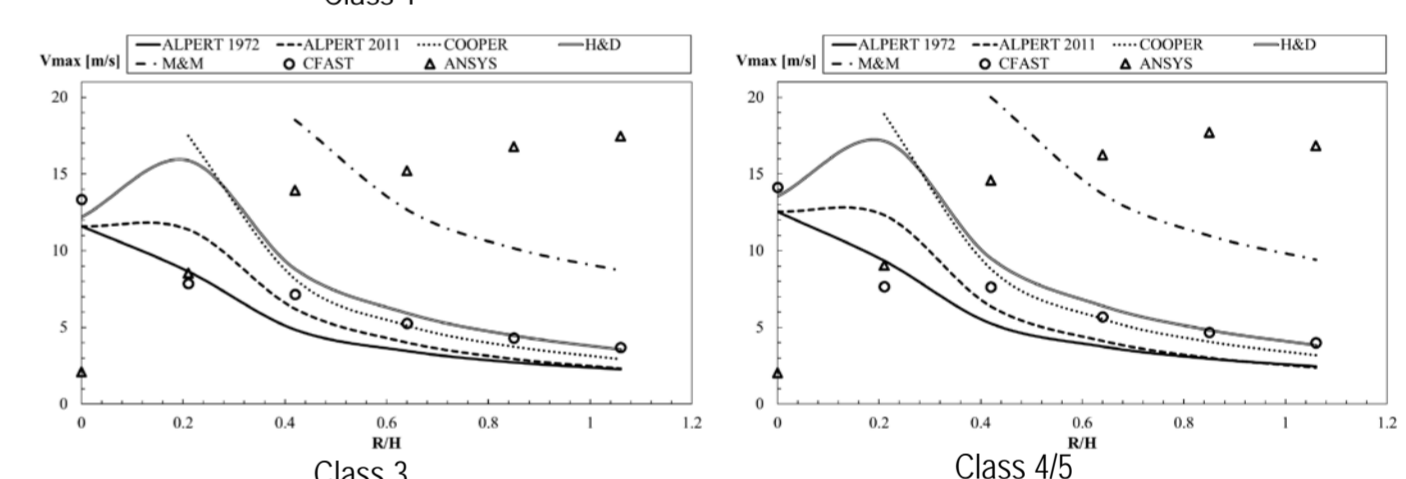
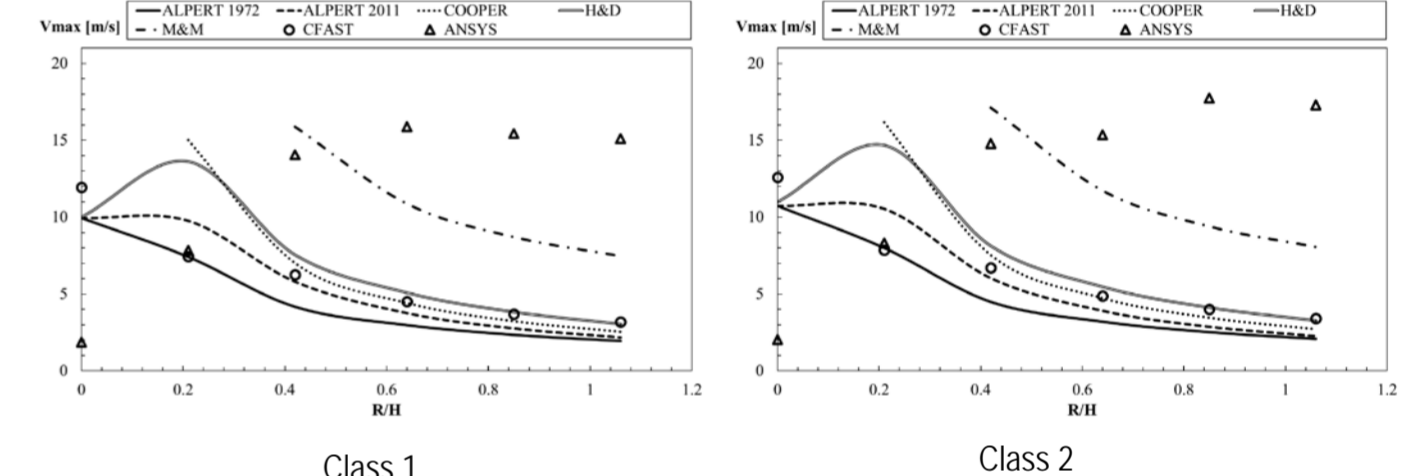


Figure 9 - Maximum velocity for the compartment 2.

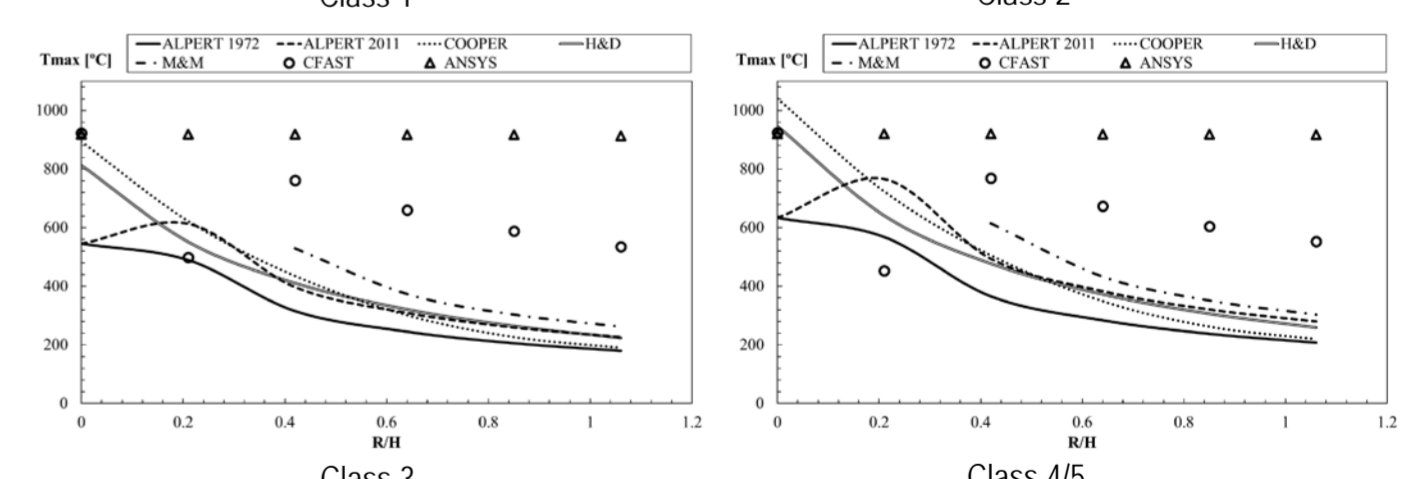
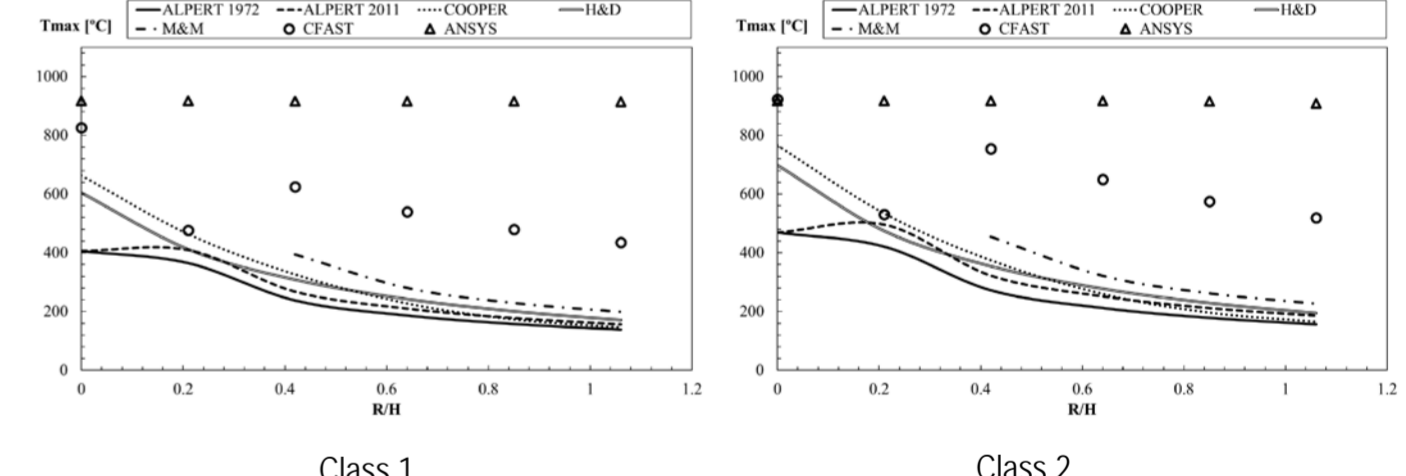


Figure 10 - Maximum temperature for the compartment 2

5- CONCLUSIONS

The maximum velocity and temperature values increase with the class of the cars. The model proposed by Motevalli & Marks presents higher maximum temperatures and velocity for all calculated R/H scenarios. When the R/H ratio increases, the results for the maximum temperatures obtained from all correlative models get closer.

The velocity values obtained by the software CFAST are consistent with the results of the correlative models. The results of CFAST for temperatures are close to the results of the correlative models for a compartment of H=3 m and generally higher for a compartment of H=5 m. The results of ANSYS Fluent differ from the correlative models and the software CFAST due to a low-pressure area formed near the ceiling, the velocity when R=0 is close to zero. The temperatures remain almost constant in time for all the radial positions and they are usually higher than those obtained in correlative models and CFAST.

