

The Thermal and Aerodynamic Development of a Cooling and Heat Resistance Package for a New Hybrid Sports Car

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ABSTRACT

A sports car exhibits many challenges from an aerodynamic point of view: drag that limits top speed, lift - or down force - and balance that affects handling, brake cooling and insuring that the heat exchangers have enough air flowing through them under several vehicle speeds and ambient conditions. All of which must be balanced with a sports car styling and esthetic. Since this sports car applies two electric motors to drive front axle and a high-rev V6 turbo charged engine in series with a 9-speed double-clutch transmission and one electric motor to drive rear axle, additional cooling was required, yielding a total of ten air cooled-heat exchangers. It is also a challenge to introduce cooling air into the rear engine room to protect the car under severe thermal conditions. This paper focuses on the cooling and heat resistance concept. The experimental and computational developments of ten air cooled-heat exchangers are described with the tradeoffs that were required during the development process. Since the cooling and heat resistance package was being developed as the vehicle concept and styling were coming together, CFD played a large role in the heat exchanger size, location, heat resistance package and performance. Specific correlation tests were conducted to gain a greater understanding of the performance of some of the heat exchangers. Ultimately, the flow through all of the heat exchangers was confirmed as meeting all the targets at the first wind tunnel test and also heat resistance package was fixed with significant CFD support.

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INTRODUCTION



Figure 1. Styling Image of the all new NSX

Figure 1 shows the styling image of the all new NSX described in this paper. This sports car has a complicated mixture of multiple heat exchangers, as Figure 2 shows. It was important to set appropriate airflow targets under anticipated vehicle conditions. The biggest challenge for this project, the powertrain and frame development, were started at the same time, but at different R&D centers. The powertrain was developed in

Japan and the frame was developed in the U.S.A. Due to this, the required heat rejection and thermal conditions needed to be predicted by the frame-side development team without the actual powertrain.

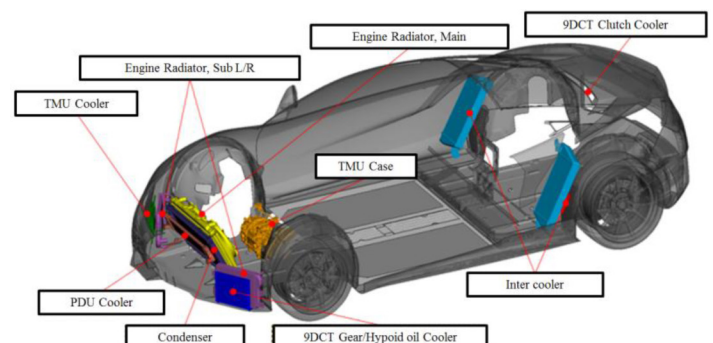


Figure 2. All Heat Exchangers

From a performance point of view, the aerodynamic drag target was set to achieve a maximum speed over 300 kph with balanced front and rear down force. The first key point was to provide enough cooling air flow with adequate down force, especially front down force. Front coolers would require a lot of air flow and it would also be easy to generate front lift from an unfavorable pressure balance by not considering how to

exhaust the high air volume going through the front coolers. Therefore, after setting required heat rejection, CFD was used to predict air flow rate through each heat exchanger and then the cooler specification, layout, grille open area and location were decided by balancing styling and exit opening area. Intercooler and side inlet size were not easy to fix, because the dynamic pressure of external air flow along the side of the car was affected by the upstream cooling package. Additionally, the separation at the upstream edge of side inlet was not predicted with enough accuracy by CFD. After fixing cooler layout, 40% scale model wind tunnel testing was conducted to investigate how to get enough down force by tuning where to exhaust air flow through heat exchangers. Then styling was refined to achieve aero and cooling balance.

The second key point was to predict thermal boundary conditions and apply heat resistance package to the vehicle without having the actual powertrain. From a customer usage point of view, circuit driving would be a more severe condition than a typical production vehicle driving mode. Therefore, a road course circuit driving test was conducted and thermal conditions were investigated by using competitor vehicles at Virginia international Raceway (VIR) circuit. Then a special test mode was established to evaluate heat resistance performance for chassis-dyno testing. A similar prototype engine was installed in an early prototype car. Heat resistance testing was conducted to get thermal boundary conditions for a thermal CAE model of the car.

In the following section, the aerodynamic and thermal development process of a new hybrid sports car will be described by using CFD, and full scale prototype car wind tunnel testing, and chassis-dyno testing.

Due to tool availability and the maturation of the powertrain, it was decided to model all the engine cooling configurations using CFD. Each separate configuration was solved at various candidate speeds, namely 40kph, 80kph, 160kph, 200kph, and 300kph, which were all associated with the different coolers. While the CFD model conversion, clean up and build processes was accomplished using an common industry standard software package, all the engine cooling CFD modeling was done using open source software, where the setup and post-processing was scripted to be as automated as possible. Over the course of the development, thousands of engine cooling CFD models were setup and solved as the configuration developed and various countermeasures were proposed and feasibility was applied. For example, front bumper and side opening areas and location, heat exchangers layout, ducting, sealing, exit areas and exit opening location, etc. were all evaluated using the engine cooling CFD model.

The role of thermal CAE was critical during the whole vehicle development process mainly because of the dual challenges of hybrid sports car: high heat generation in the rear engine room and the compact layout of the engine room. If the detailed representation of the engine room in 3D thermal model was not challenging enough, there were several sub-system level thermal modeling activities, too. Sub-system level modeling was necessary to protect key components unique to high performance vehicles like this one. Thermal CAE was especially beneficial during the early stage when no hardware prototype was available. One of the key concepts employed throughout the thermal modeling process was 'targeted cooling' of engine room parts using forced convection. Another one was the 'suppression of thermal radiation' at its source.

VEHICLE CONCEPT

This sport car applies two electric motors at the front axle and a high-rev V6 twin- turbo charged engine in series with an electric motor and a 9-speed double-clutch transmission (9DCT) at the rear axle. This three motor hybrid system can be apply superior acceleration and cornering performance by using three motor assist and independently controlled front two motor torque vectoring. This vehicle was designed to be short wheelbase and short rear over hang for styling. Additionally, the cargo trunk was placed at rear over hang for utility. This resulted in the rear engine room being very compact and all powertrain components needed to be arranged efficiently. This new high-rev V6 twin-turbo charged engine and three motors generate over 550hp as the power train system.

OVERALL AIRFLOW CONCEPT FOR COOLING AND HEAT RESISTANCE

Figure 3 and 4 show Front and Rear section cooling airflow concept on this car. Airflow paths were selected in order to get good balance between styling, aerodynamic lift balance, front cooling system, side opening cooling system, and rear powertrain room cooling.

At the front of the car, the center bumper opening was placed at the stagnation point to take advantage of the maximum dynamic pressure and the upper grill opening was placed to balance the air flow distribution on the coolers. (See Figure 4). On the other hand, to reduce front aero lift and get down force for high speed handling and stability, how the cooling air flow exited the front motor room was considered to minimize the interference to the external airflow structure. This was accomplished by optimizing the hood exit slots. At the front fender, a vent was applied to reduce high pressure in the front wheel house and reduce the front aero lift. To avoid the interference to the airflow underneath the underbody and to generate front down force, there was no exit opening under the car. This would also make the diffuser worked more effective for generating aerodynamic down force. The side front openings were also used to get high speed airflow for intercoolers for the twin turbo chargers.

In the rear section of the car there are three openings to introduce fresh air flow in the rear engine room. Two are placed inside C-pillar, which was split between the intercooler cooling and a rear powertrain duct that directs the air to the hot turbo charger. The third opening was placed in front of trunk deck for additional rear powertrain room cooling. How the rear powertrain room cooling air flow was to be exhausted was also considered and the exit openings were placed to minimize the interference to the external airflow structure and recover negative pressure behind the car. There were four exit openings: a slot beside rear glass, slots above the tail lights, and center and side openings in the rear bumper. During typical driving, the negative pressure generated by C-pillar vortex, pulls the hot air from powertrain room though the rear glass slot as wells as from the slots above the tail lights. The hot air that would escape from the rear powertrain room would also reduce aero drag and rear lift by changing the longitudinal vortex structure. Also, this hot air from the center and side rear bumper openings, as well as the tail slight slots, would also recover the negative pressure behind the vehicle. All cooling exit area were designed to be larger than opening area to allow the air to flow efficiently.

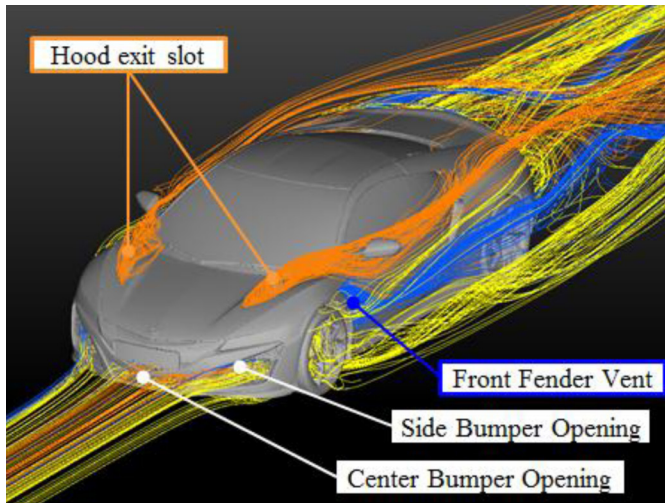


Figure 3. Front Section Cooling Airflow Concept

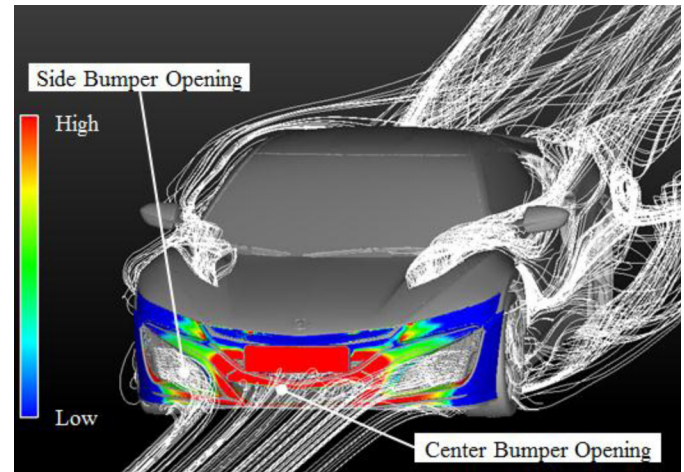


Figure 4. Pressure distributions on Front Bumper fascia

COOLING SYSTEM DEVELOPMENT

Target Heat Rejection Setting and Ten Cooler Requirements

When this project started and the concept was defined, the powertrain had not been developed yet and so it was required to develop the powertrain and frame at the same time. Therefore, the cooling system specification and layout needed to be designed without the actual engine heat rejection data. Honda did not have high power turbo charged production engine at the time and it was assumed the highest required heat rejection would be under maximum speed driving at 300 kph. Required heat rejection can be estimated roughly from the ratio between engine power and heat rejection based general engine design principles, but to confirm this trend on high horse power engine, high power competitor vehicles were investigated to estimate the appropriate relationship between power and heat rejection (see Figure 4). Based on this investigation result, a target heat rejection was assumed, and then heat exchanger specification and airflow optimization were started. Once the actual engine heat rejection data was measured, the target heat rejection and air flow target were updated. All other required heat rejections were also assumed based on the prototype testing and overall cooling system specification and a layout study were conducted.

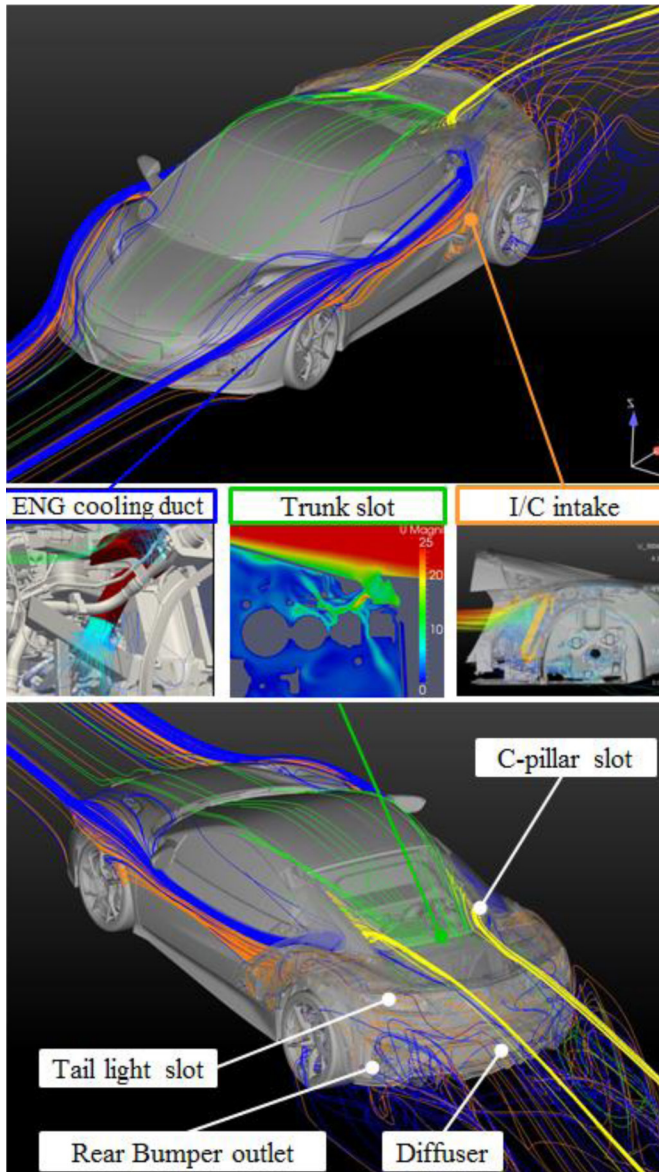


Figure 4. Rear Section Cooling Airflow Concept

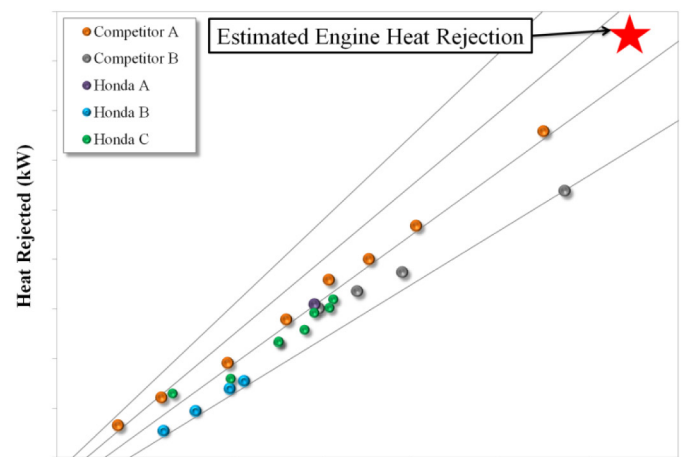


Figure 4. Engine Heat Rejection

Engine Power (kW)

Heat Rejected (kW)

Competitor A

Competitor B

Honda A

Honda B

Honda C

Estimated Engine Heat Rejection

Documents

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