Intake System Analysis of the 550 Maranello Using the WAVE code

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Figure 1 - Ferrari 550 Maranello

Abstract

This paper describes the application of the WAVE code to the analysis of the intake system of a 12-cylinder, high output gasoline engine for Grand Touring car application. The work described constitutes the foundation for a Sound Quality application. The approach followed and the modeling techniques employed in this application are reported. The correlation with the available experimental data is also presented and commented.

Introduction

In recent years Sound Quality Engineering has gained more and more importance in many areas of vehicle design. Particular attention has been paid to passenger car design, where many familiar examples can be quoted: the "thump" made by a car door closing (subjectively associated with overall solidity), the "swoosh" made the wiper blade sliding on the windshield and, of course, the noise generated by the engine.

Almost every engine manufacturer claims that their engines have a distinctive, unique sound; this is so important in terms of product identification that some even tried to patented it! Most of the interior noise is due to the engine noise radiated through the intake and the exhaust systems. Since Ferrari cars are characterized by their performance and their engine sound (the "roar" of a Ferrari is legendary) it is natural that Ferrari is using state-of-the-art simulation techniques in order to design their intake and exhaust systems.

In order to provide a useful tool to the Noise, Vibration and Harshness (NVH) and Sound Quality (SQ) engineers, Ricardo Software has developed WAVE, a 1-dimensional engine cycle simulation program. In addition to calculating engine performance, WAVE can simultaneously predict the radiated noise from the intake and exhaust orifice/s using a versatile acoustic post-processing package. Moreover, WAVE gives the SQ engineer the ability to generate audio files in order to subjectively assess many iterations of intake and exhaust systems and allows the engineer to build prototypes of the pre-optimized systems only. The intake and exhaust orifice noise can then be filtered through a Noise Transfer Function in order to simulate interior noise.

This paper presents the construction and calibration of a WAVE model of the Ferrari 550 engine. This is the first part of an advanced project investigating the possibility of changing sound quality with no influence on overall engine noise and performance.

Background

What has made the success and reputation of Ferrari Grand Touring cars is their close ties with the racing cars that have been winning on racetracks all over the world for the past 50 years. Racing is the ideal proving ground for new technical ideas, particularly Formula 1 racing where the strenuous competition that has always existed has produced the most advanced race cars in the world. Ferrari is the only manufacturer that simultaneously builds Formula 1 cars and Grand Touring cars for the road. Not only technical innovations filter from the Formula 1 racing cars through to the production cars, but also CAE tools and techniques used in order to achieve the required high-quality design in the shortest turn-around time possible (which is simply indispensable to stay competitive).

Figure 2 - Ferrari 550 Maranello engine

This whole Ferrari approach and philosophy has produced the 550 Maranello, one of the most outstanding super cars on the market today (see Figure 1).

Engine description

Engine

The engine that powers the Ferrari 550 Maranello is a 4-valve per cylinder, 5.4 l unit with 12 cylinders in a 65 ° V (Figure 2). Please find some significant performance data in the following table.

Displacement [cm^3]	Max Power [HP] @ rpm	Max Torque [Nm] @ rpm	Bore [mm]	Stroke [mm]	Compression Ratio
5473	485 @ 7000 rpm	568@5000 rpm	87.9	74.9	10.8:1

Courtesy of **Ferrari SpA**

Intake System

Ferrari developed a particular type of variable geometry intake manifold for the 550 Maranello engine to enhance torque and power features. The system, patented by Ferrari, includes a third volume added to the intake manifold, which changes its resonant characteristics. This additional volume is connected to the manifold by 12 throttle valves with electro-pneumatic servo control mechanisms, driven by the engine management control units (Figure 3).

The additional volume is closed at engine speeds lower than 6000 rev/min, so that the cylinder can breathe through long primary runners favoring the mid-speed torque; at speeds higher than 6000 rev/min, the throttle valves are open. This translates into an optimized engine performance across the complete speed range.

Additionally, the intake system is characterized by 2 quarter-wave pipes (one for each bank) upstream of the 2 airboxes. These resonators were tuned in order to reduce the overall intake noise level.

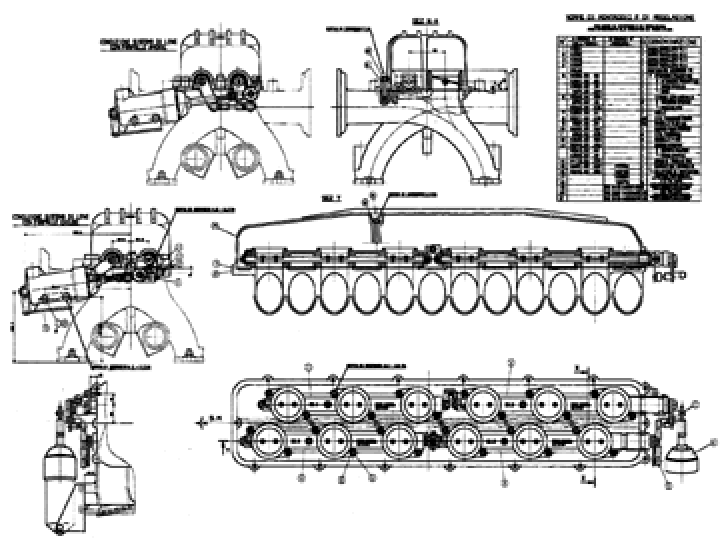

Figure 3 - **Intake System** Courtesy of **Ferrari SpA**

Exhaust System

The exhaust system is also characterized by its variable geometry. Two by-pass valves, located on the rear silencers, are governed by an electro-pneumatic servo mechanism governed by the engine management system based on sensor inputs for engine speed and throttle position.

The possibility of modifying the back pressure of the exhaust system makes it possible to optimize engine efficiency in the various engine operating conditions. Greater back pressure, with the valve closed, allows the torque to be improved at light loads, while a smaller back pressure achieved by opening the by-pass valves enhances engine efficiency at high speeds and full load. The twelve-into-four-into-two exhaust manifold is made of stainless steel with an insulation layer to minimize catalyst light-off time.

WAVE model

A WAVE model of the entire engine was created. Since the analysis focused on the radiated intake noise, a very detailed model of the intake system was built. Particular attention was paid to the unique intake manifold and to the air filter boxes. As can be seen in the schematic representation (Figure 4), the model is fairly complex.

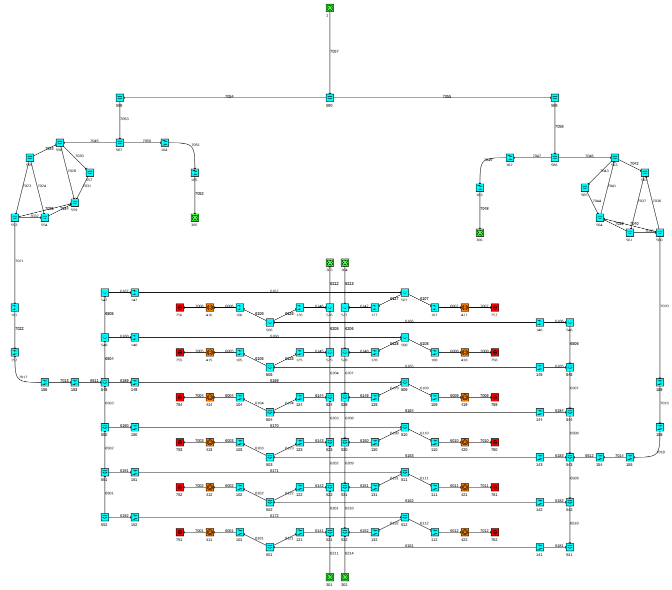

Figure 4: Schematic representation of intake system

A simpler representation of the exhaust system was chosen in order to achieve the quickest run time possible. The (12-4-2) exhaust manifold was modeled completely and a calibrated orifice plate was placed in order to re-create the backpressure generated by the (missing) catalysts and mufflers. This simplified representation proved to be sufficient in the past in order to take into account the effects of the exhaust system on engine performance. The exhaust system can be seen in Figure 5 and was built into an separate include file in order to isolate the intake system thus allowing a better visualization of the animation results.

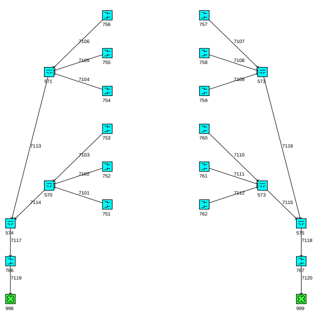

Figure 5: exhaust system

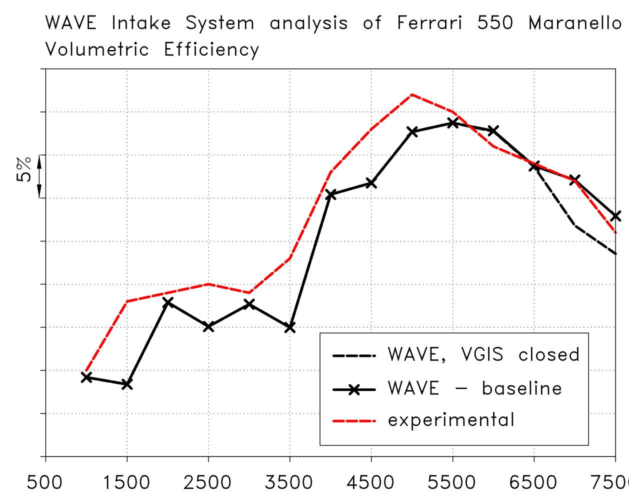

Figure 6

Simulation results

Performance

First, the model was calibrated to match available experimental engine data. The volumetric efficiency prediction (Figure 6) is fairly close to the experimental data, with WAVE slightly underpredicting at lower engine speeds. However, the model captured very well the volumetric efficiency peak and the switch-over point at 6000 rev/min, giving the authors confidence that the main acoustic behavior of the intake system was well captured. The losses in the intake system were fine-tuned in order to produce an as close as possible correlation with the experimental data. Figure 7 shows

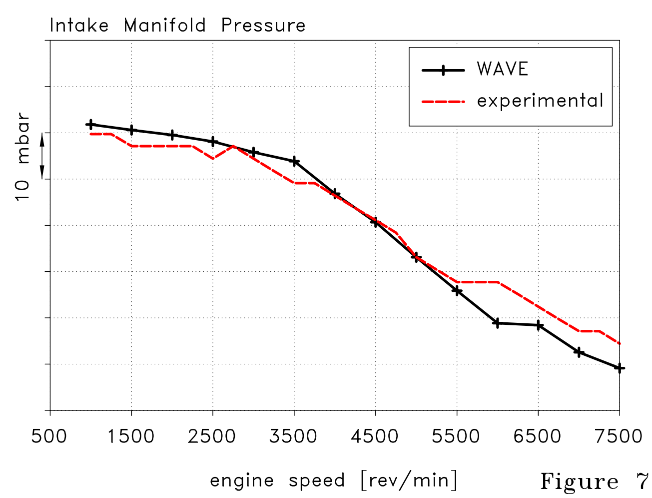

Figure 7

the comparison between measured and predicted intake manifold pressure.

Then, combustion heat release curves were imposed for each engine speed as Wiebe functions based on in-cylinder pressure data and previous simulation work. The resulting maximum cylinder pressure in cylinder 1 (Figure 8) shows a very good agreement with experimental data, indicating that in-cylinder wall temperatures are correctly set.

As mentioned earlier, the exhaust system was modeled up to the end of the exhaust manifold; the rest was represented using an orifice plate which was calibrated in order to produce the correct backpressure (Figure 9).

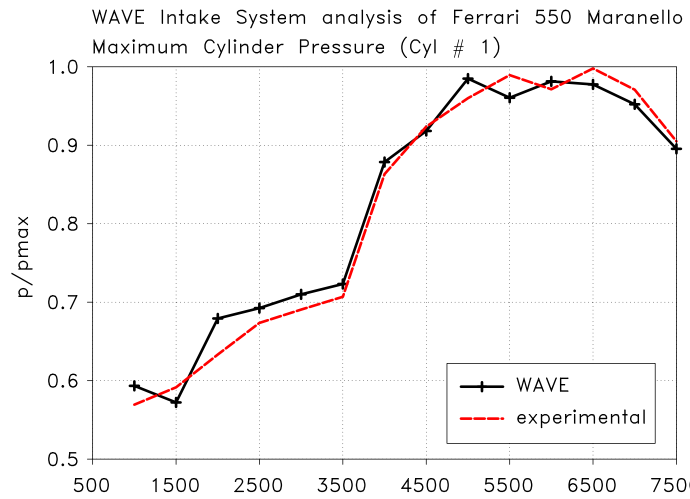

Figure 8

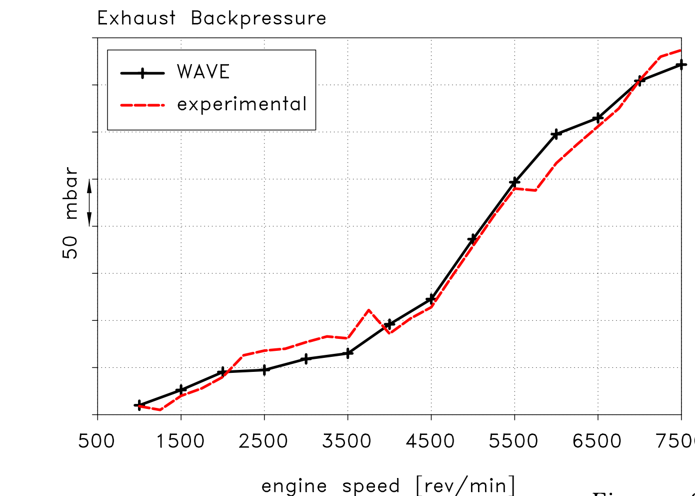

Figure 9

Noise

Using the acoustic post-processor WNOISE to process the WAVE velocity output at the intake orifice, the intake noise sound pressure levels of the calibrated model radiated at 100 mm from the orifice were generated. Analyzing the intake noise prediction using a waterfall plot (Figure 10), 2 resonances clearly appear: the main at 560 Hz and the second at 250 Hz.

Compared to experimental data (Figure 11), WAVE is able to capture very well the main engine orders (3, 5, **6**, 7 & 10) and fairly well the

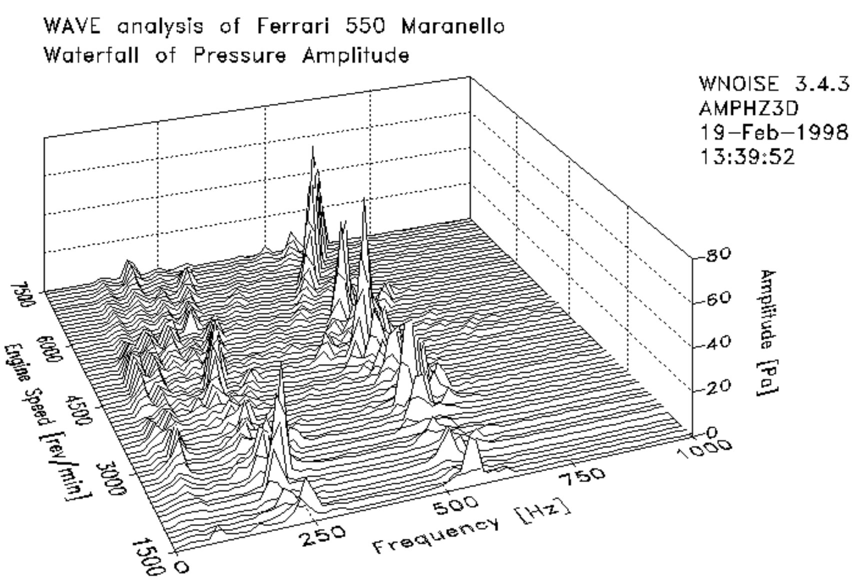

Figure 10

magnitude, with WAVE slightly overpredicting the maximum peaks. The predictions could be improved with further calibration work involving the soft-rubber joints, the wall friction coefficients and the discharge coefficients.

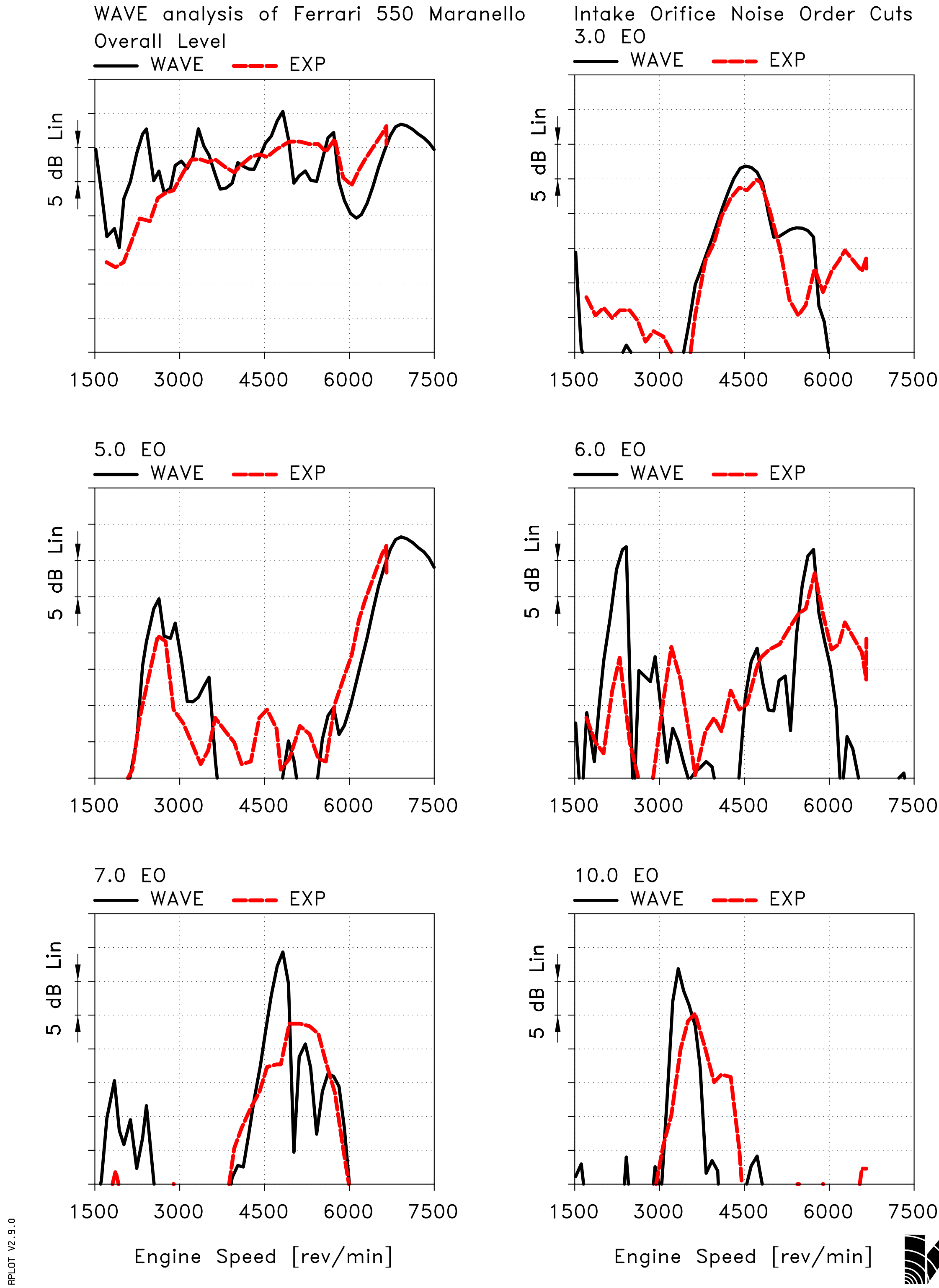

Figure 11

Quarter-wave pipe resonator

The quarter-wave pipe resonators were tuned at 250 Hz in order to reduce the firing frequency (6th engine order) contribution at 2500 rev/min in order to comply with noise legislation. The location of the resonators was chosen using the Fast Fourier Transformation option in the Animation Post Processor WAPP to transform in the frequency domain the dynamic pressure traces calculated by WAVE. As shown in Figure 12, the ideal location for the resonators is at the elbow before the throttle bodies (that is where the maximum pressure amplitude at 250 Hz is). In fact, due to packaging constraints, the second best location was selected.

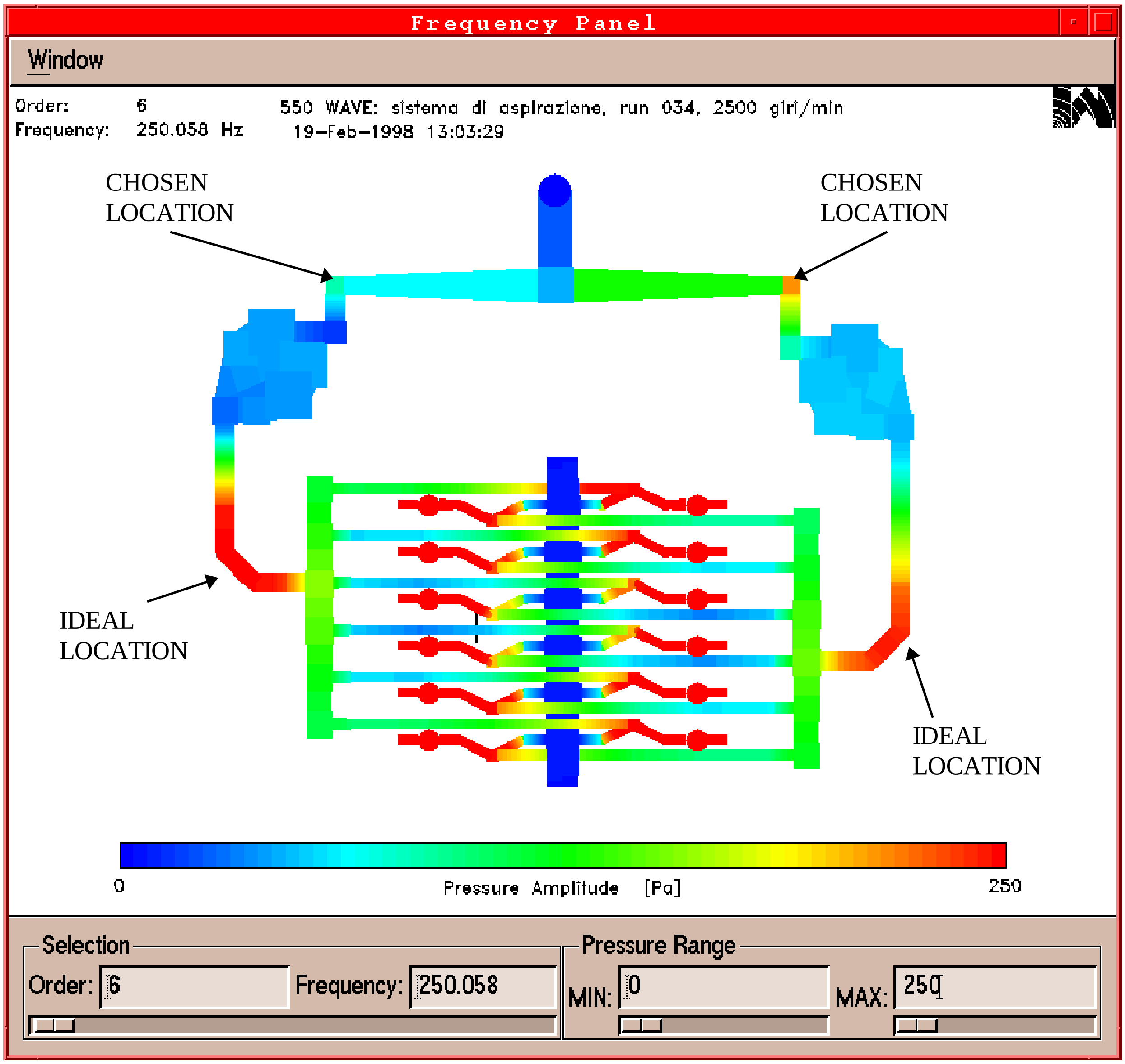

Figure 12 - WAPP Frequency Transformation

The effects of the quarter-wave pipe can be seen in Figure 13.

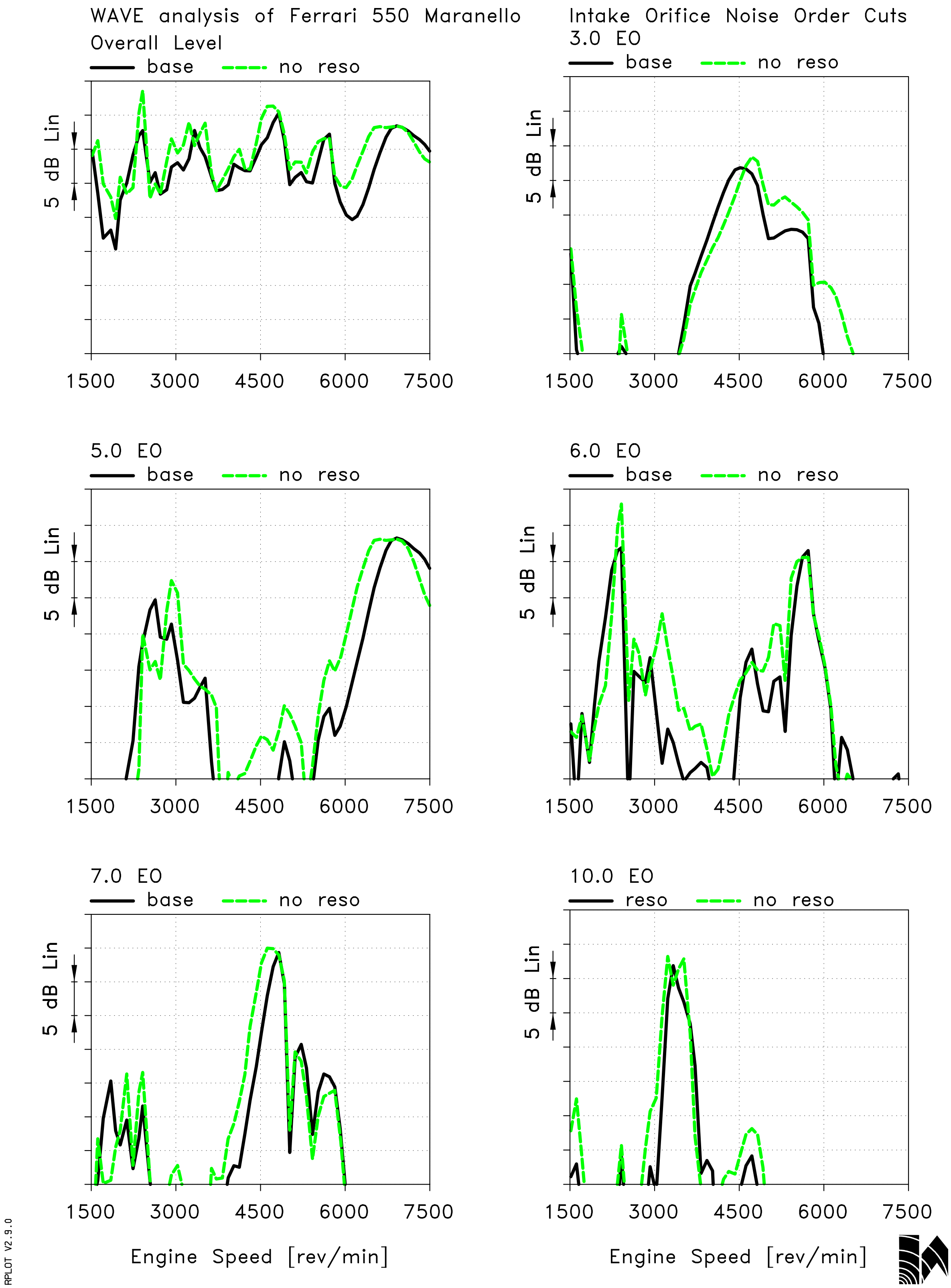

Figure 13

Modified firing order

Since this is a relatively inexpensive modification to the current engine, assessing the effect of modifying the firing order has been carried out. Even though the engine performance and the intake orifice noise order balance are practically unchanged compared to the standard firing order, the character of the sound produced by the intake system is notably different.

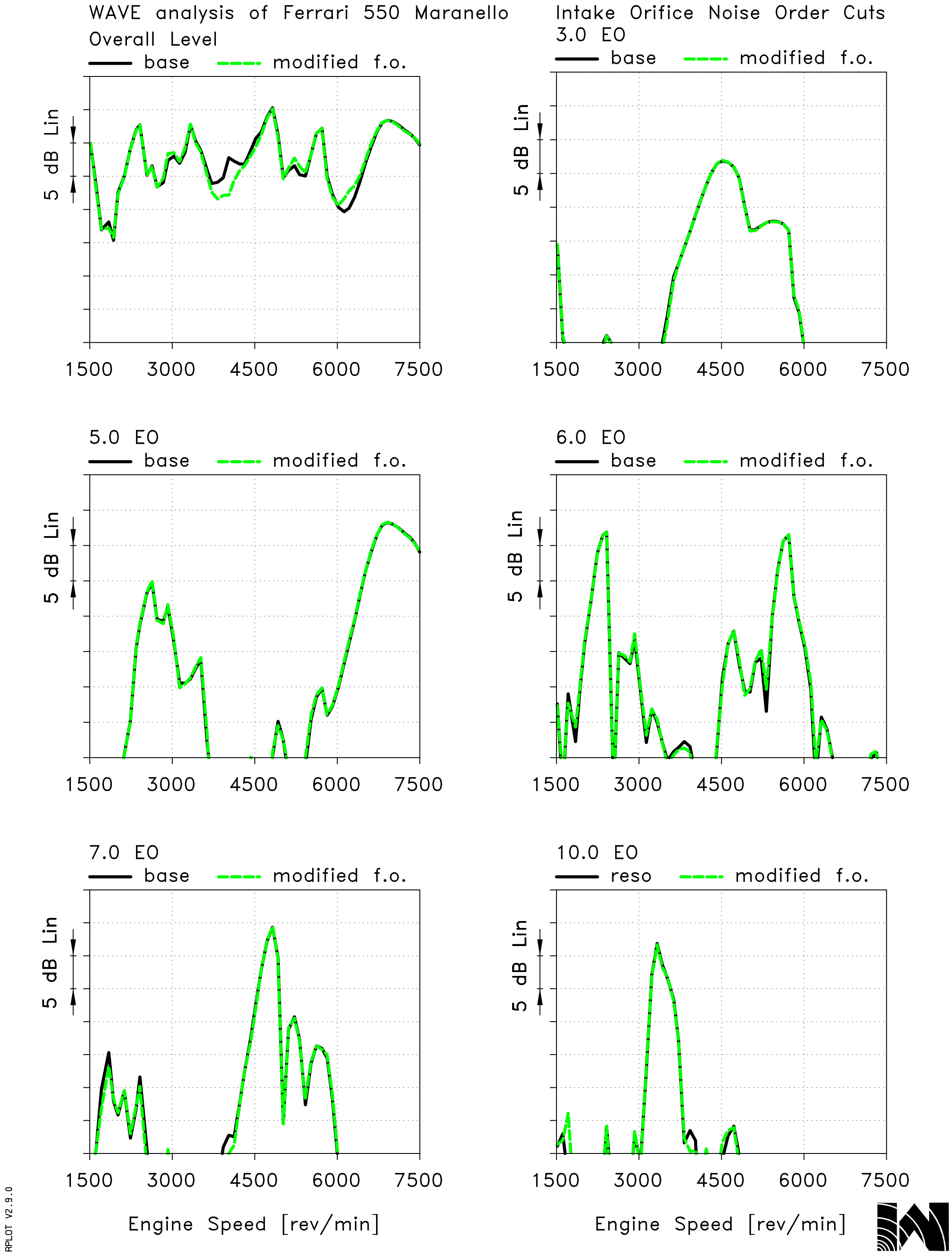

Figure 14

Conclusions

A WAVE model of the Ferrari 550 Maranello was built; great detail was placed in modeling the intake system. The model was successfully calibrated to measured engine performance and noise data, and thus constitutes a good starting point for further analysis. A first change (firing order) was carried out producing a different intake orifice noise sound with minimal change to overall sound pressure levels and engine performance.

Acknowledgment

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References

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