Application of WAVE in Motorcycle Prototyping

Robert Wirtz
Davide Mazzoni
DUCATI Motor S.p.A., Bologna, Italy

Abstract

Under its new ownership DUCATI MOTOR S.p.A. has begun a new era of technical design and development.

The increasing demand for rapid prototyping in the motorcycle industry implies the application of simulation tools in early stages of technical development. Using WAVE as a one-dimensional fluid-dynamic engine-cycle simulation tool, prediction and optimization of engine performance and noise emission caused by gas exchange pressure waves is possible.

The following paper describes the application of WAVE in the early stage of prototyping the new DUCATI 900SS evolution.

The main objective was to optimize engine performance and noise emission of the intake/exhaust system with low-cost modifications and application. In only three months the evolution of the old 900SS carburetted engine to a more powerful fuel-injected engine has been completed.

Introduction

Nowadays engine-cycle simulation has become an essential and common tool for predicting and optimizing engine performance. Beginning a new era of technical development DUCATI MOTOR S.p.A. applies simulation tools to improve engine performance and shorten time of prototyping. Due to the increasing importance of noise prediction in engine development, particular attention must be paid to the acoustical analysis of pressure wave noise generation.

The following paper gives a brief impression of the application of WAVE in predicting engine performance focusing on noise emission of the intake and exhaust system of the new Ducati 900SS evolution.

State-of-the-Art

The DUCATI 900 SuperSport is a sporting motorcycle powered by a 2 Cylinder 90°V-2 Valve carburetted engine with a displacement of 904 cc, Figure 1.

Figure 1, Ducati 900 SS

900 SS technical specification:

Displacement:	904 cc
Bore:	92 mm
Stroke:	68 mm
Max. power:	75 hp at 7000 rpm
Max. torque:	80 Nm at 5000 rpm
Max. velocity:	220 km/h
Pass-By noise:	82 dB(A)
Homologation:	1992

Main Targets of Development

Today's motorcycle market requests more powerful engines, however, legislative noise and pollution limits are becoming more severe.

In order to reduce development cost only small modifications were allowed. Entirely new designs of technical components (i.e. cylinder head) had to be avoided.

In additon, the complete development had to be finished in a relatively short time of about three months.

The most important targets of development were:

- better engine performance:
  - more max. power: → **+5 hp**
  - more torque at low rpm
- lower noise emission:
  -2 dB(A) → **80 dB(A)** (89/235/CEE)
- change from carburettor to fuel injection system

Engine performance calculation with WAVE

A complete model of the new engine concept (fuel injection) with actual intake- and exhaust geometry allowed us to set up a reference engine-cycle-simulation model for further optimization.

The most important parameter-variation during the cycle-studies to improve volumetric efficiency were:

- intake duct length
- valve timing
- constant or even lower exhaust backpressure

Figure 2 shows the improvement in calculated engine performance due to different intake-duct length and modified valve timing.

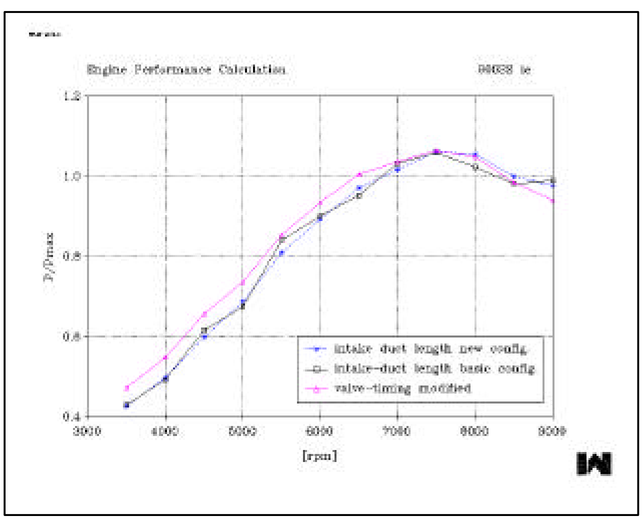

Figure 2

Figure 3 gives an example of accuracy of the calculation results compared with measured data of engine performance with new intake-duct length.

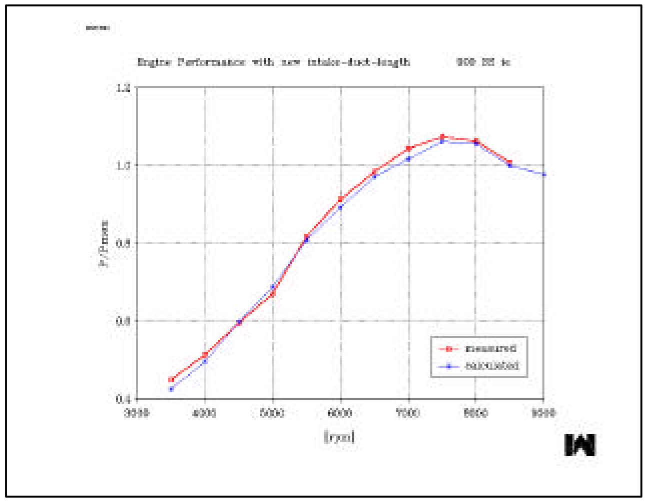

Figure 3

Figure 4 illustrates the final engine performance with modified valve-timing, intake-duct length and new exhaust silencer. A comparison of measured performance data between the original and the redesigned engine gives shows the improvements in terms of maximum power and torque at low rpm.

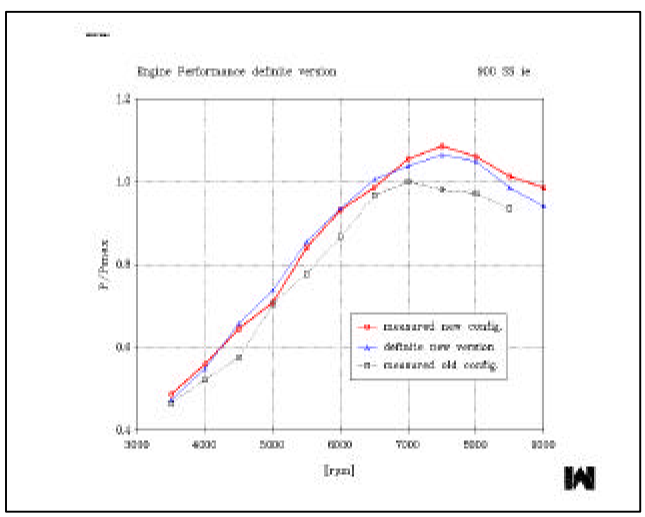

Figure 4

Noise prediction with WAVE

Taking into account the actual noise legislation limits a reduction of the pass-by noise of 2 dB(A) had to be reached to pass homologation.

The most important noise sources are the intake- and exhaust pressure waves, which contain nearly 80% of the whole acoustic energy emitted during a pass-by measurement of a motorcycle.

Analysing intake noise

Figure 5 shows a far-field “pseudo” pass-by simulation at 4500 rpm of intake noise calculated with WNOISE at real microphone distance. The major frequency peak at 265 Hz evident in the spectra describes the resonating air column of the characteristic intake duct length.

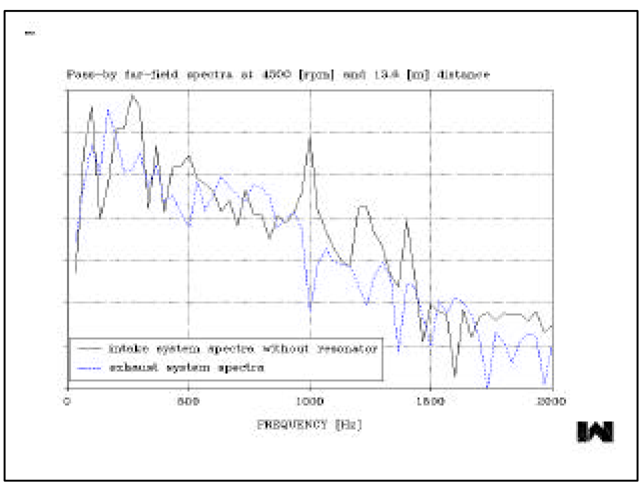

Figure 5

Applying a Helmholtz resonator working at this frequency an attenuation of sound pressure can be achieved.

Figure 6 illustrates the frequency-response-function (FRF) of the modified airbox with and without the described Helmholtz resonator calculated with random-noise on the acoustic-piston.

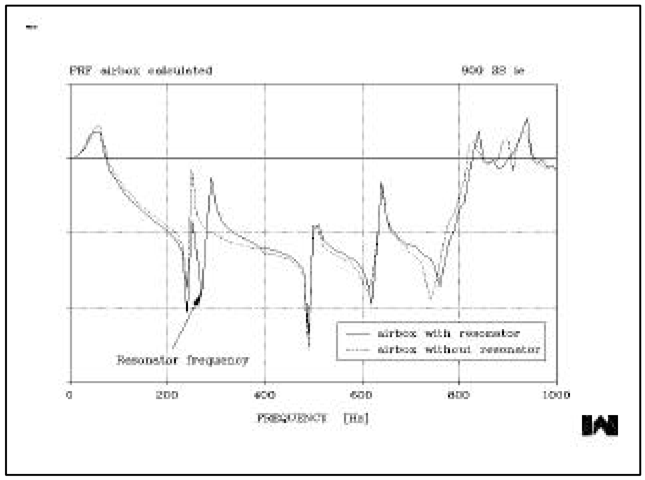

Figure 6

The working frequency of the resonator can be seen clearly in Figure 7 both in the calculated data and in the measured results. The differences between the calculated and measured data are caused by the quite simple modeling of the airbox (only 14 subvolumes) and type of measurement problems under real conditions (leakage, absorbing material effects, etc).

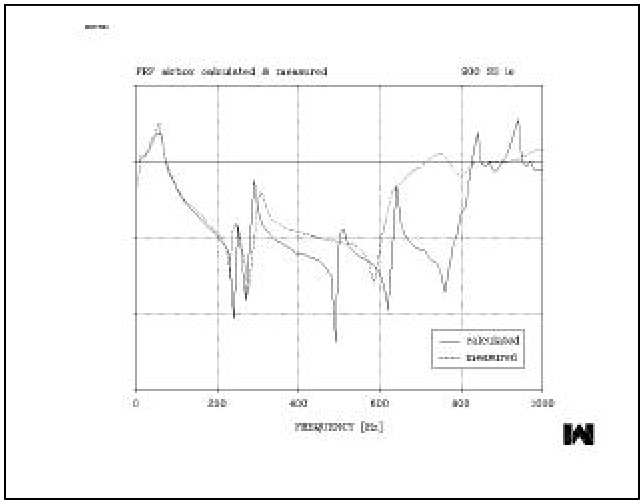

Figure 7

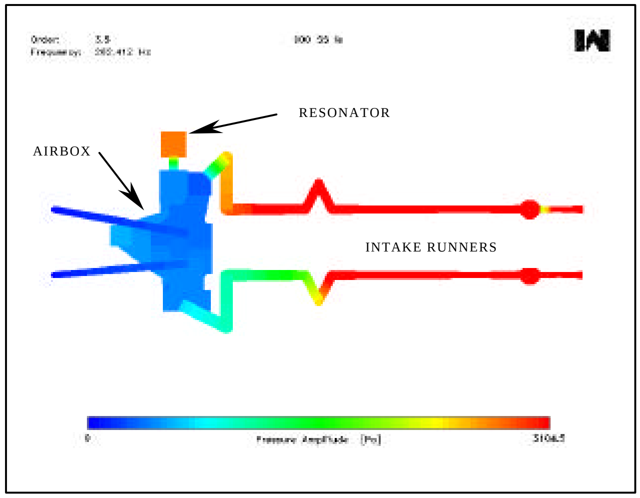

Figure 9

Figure 8 demonstrates the noise reduction of the resonator applied during a “pseudo” pass-by calculation at 4500 rpm.

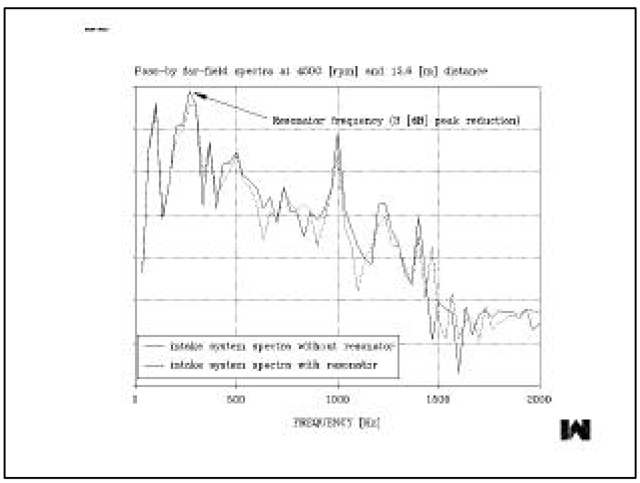

Figure 8

Figure 9 shows the pressure amplitude at the resonant frequency of the Helmholtz resonator (265 Hz) in the intake system using a colour scale. As it can be seen, the resonator’s pressure is in opposite phase relative to the runners.

Analysing tail-pipe exhaust noise

The performance of an exhaust silencer is characterized by the backpressure and by the noise attenuation at the tail-pipe in terms of transmission loss (TL). The new exhaust silencer offers better noise reduction and its FRF describes similar sound behaviour.

In order to predict silencer performance with satisfactory accuracy, a quite complex WAVE-model has been created of the original and new silencer. Small discretization lengths (x=10mm) were necessary to obtain the desired accuracy. Therefore, a huge amount of junctions and tubes have been created.

Figure 10 shows the difference between the calculated TL of the original and new silencer. The frequency domain up to 400

Hz is the most important range to improve attenuation, due to the main engine orders working in this interval.

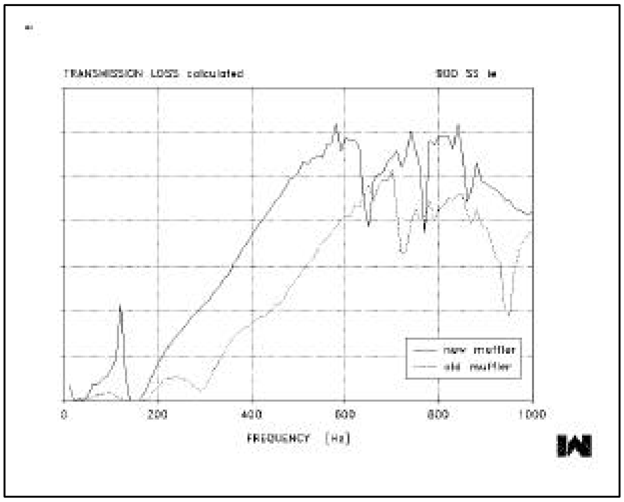

Figure 10

Figure 11 clearly shows the problems of correlation between the calculated and measured FRF of the silencer. The differences of the curves at higher frequency are caused by the fact that WAVE is not able to predict absorbing material and leakage.

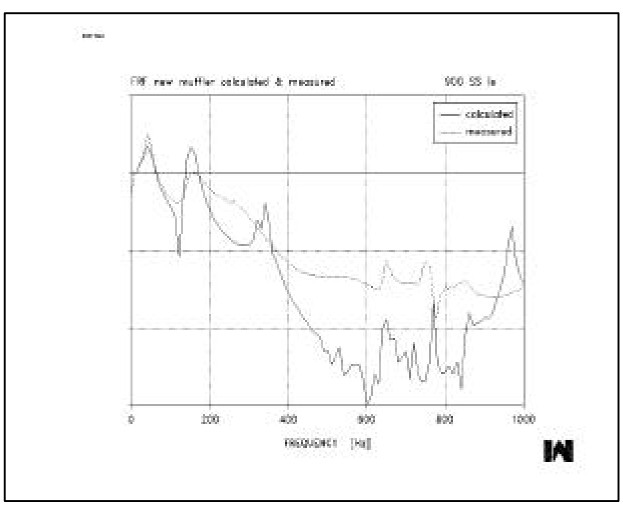

Figure 11

A far-field “pseudo” pass-by simulation at 4500 rpm confirmed the improved attenuation of the new exhaust silencer. Figure 12 shows a difference about 5 dB between the major spectral peaks.

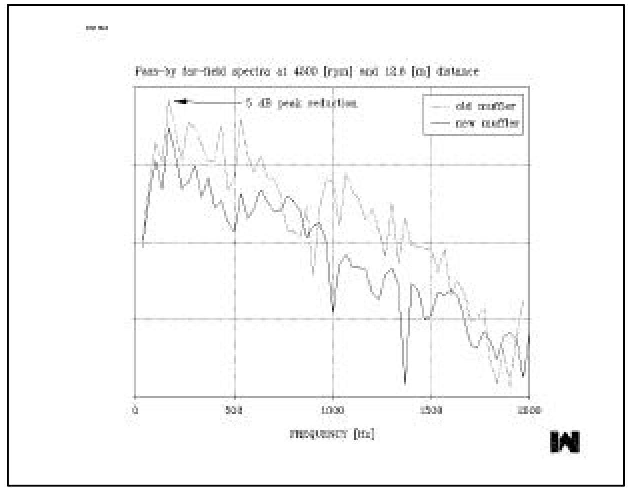

Figure 12

Analysing pass-by noise

Since it is not possible to add other noise sources (mechanical, combustion, tires, …) to the exhaust and intake orifice noise predicted by WAVE through WNOISE, it is not possible to accurately calculate the pass-by noise. Moreover WNOISE offers only the possibilty to combine acoustic calculation-channels with constant tail-pipe diameter (diameter at source boundary) in order to predict far-field noise. Due to this fact, WNOISE simulations of combined tail-pipe noises with different diameters are not reliable.

However, the predicted single channel noise calculations, as described before, of intake and exhaust noise give an idea of global noise reduction.

Finally, the measured pass-by noise with new exhaust silencer and airbox resonator confirmed the sufficient total noise reduction about 2 dB(A) for passing legislative noise limits.

Figure 13 shows a pass-by measurement with new exhaust silencers and airbox.

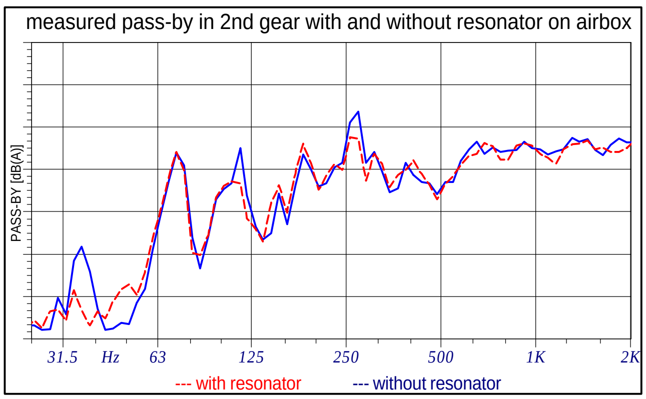

Figure 13

The important target to reduce noise emission by about 2 dB(A) in the pass-by test has been achieved as well.

WNOISE gave us an idea of far-field noise behaviour simulating a “pseudo” pass-by. Unfortunately it was not possibile to simulate a complete “pseudo” pass-by test, due to certain modeling restrictions of WNOISE.

Figure 14 shows the final result of the complete new evolved Ducati 900SS i.e..

Figure 14

Conclusion

Working with the one-dimensional fluid-dynamical engine-cycle simulation tool WAVE, we managed to optimize engine performance and noise emission. An improvement of engine performance about 5-7% of maximum power and better torque behaviour at lower rpm has been realized.

References

L. L. Beranek, Istvan L. Ver,
NOISE and VIBRATION CONTROL ENGINEERING

Lewis H. Bell, Douglas H. Bell,
INDUSTRIAL NOISE CONTROL

Ricardo Software,
WAVE manuals V.3.4.2