

DaimlerChrysler

Introduction

As with any world-class product, design specifications are exceedingly high and increasingly difficult to achieve. DaimlerChrysler's new eight-cylinder diesel engine for its S-Class product line was no exception.

Approximately one month before a major project milestone, final testing on test rigs and in-vehicle were underway when the cooling engineers experienced an unexpected challenge with a specific area of the cooling system: the exhaust-reconducting radiator.

The functionality of this part of the cooling system is to extract calculated amounts of heat from the exhaust gas ensuring that the most efficient use of energy is utilised.

DaimlerChrysler AG (DaC) contacted Flowmaster GmbH, the German sales and support company and member of the Flowmaster Group, for modelling and methodologies advice that would help to evaluate the technical options available.

From their extensive experience in applying 1-D modelling methodologies for complex applications, Flowmaster GmbH, were able to provide advice and practical suggestions to overcome DaC's cooling system difficulties.

*DaimlerChrysler
AG meet stringent
performance
specifications of their
new eight-cylinder
diesel engine
cooling system using
Flowmaster.*



Modelling Approach

In as little as 20 working days, the Flowmaster GmbH team working closely with the DaC cooling team recommended a practical result through simulating a series of parametric studies.

Measured test data was already available and so a different modelling strategy was adopted than would be used if no measured test data were available. From past experience the Flowmaster GmbH team advised DaC to follow a steady state modelling approach for an identified set of operating points across a range of operating conditions.



This steady state based simulation applied in this specific situation has several benefits over a transient simulation:

- Measured data already available for set operating points (engine speed and coolant temperature)
- Steady State simulation requires less data to be input

Validity of measured data and transfer into the model

Due to the chosen modelling approach and the presence of measured test data many of the components in the model such as the exhaust reconducting radiator (see Figure 1) were modelled as discrete losses i.e. their performance characteristics were represented as curves describing pressure drop vs flow rate. This data was measured across components whilst in the cooling system rather than using component manufacturers data, which is generally, reported on for ideal flow conditions.

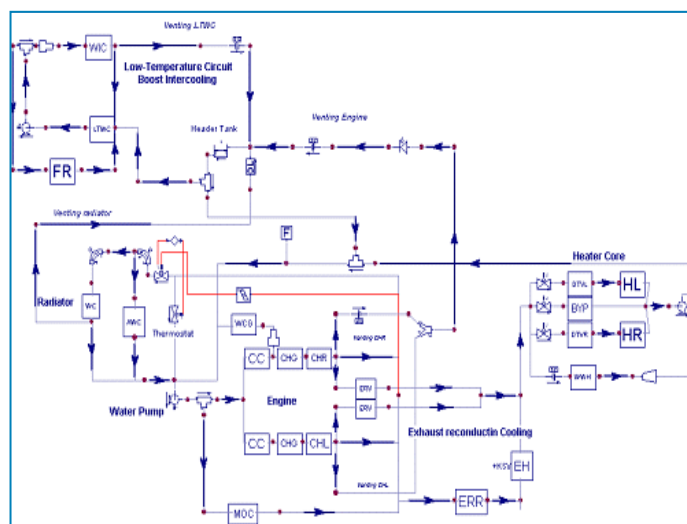


Figure 1: Flowmaster - Simulation model for the cooling system of the Eight - cylinder Diesel Engine of DaimlerChrysler AG

Practical Hint 1

Using manufacturers component data in simulations can sometimes lead to underestimated pressure loss in the system as a whole, due to the ideal flow conditions at which the measurements were taken.

Practical Hint 2

Always ensure when measuring pressure drops across components or single flow paths that the measuring instrument will influence the flow conditions and a certain error will be present in the measurement.

Practical Hint 3

Always check measured data for compatibility i.e. the continuity equation is fulfilled for a subsystem. This will give increased data quality assurance and will save time in the long run.

The measured data was added into the discrete loss component as a curve that was either a pressure loss or a loss coefficient over a range of volumetric flow rates that represent the max and min operating conditions of the system.

In this instance it was done manually, however automation of this task is possible enabling direct transfer into the Flowmaster Data Manager for use in the model.

Model verification against measured system characteristics

Once measured component data is validated, and transferred into the Flowmaster Data Manager the simpler components such as pipes, bends and T-junctions that provide the fluid connections and resistances are added to the model. It is at this stage that the simulation model can be verified against the measured system characteristics on a per operating condition.

At this stage the verified model was ready to be used for sensitivity studies. Taking a defined system condition over a range of engine speeds lead the team to establish that the maximum error between calculated results and measured results for measurement positions at the water pump, thermostat bypass, Heater core and engine around the system was less than 5% (see Figure 2. Normalised volumetric flow rate for verification points). However further investigation showed that in a specific area this error was slightly higher.

System specific challenge

A main challenge to the DaC cooling system engineers was meeting the required minimum flow rate through the exhaust reconducting radiator. From test measurements this flow rate was below the target normalised volumetric flow rate of $Q_{norm} = 401$ and at some operating conditions the coolant flow reversed. This adversely affected the cooling efficiency of the exhaust reconducting radiator which in turn reduces the coolant flow to the cabin heater circuit.

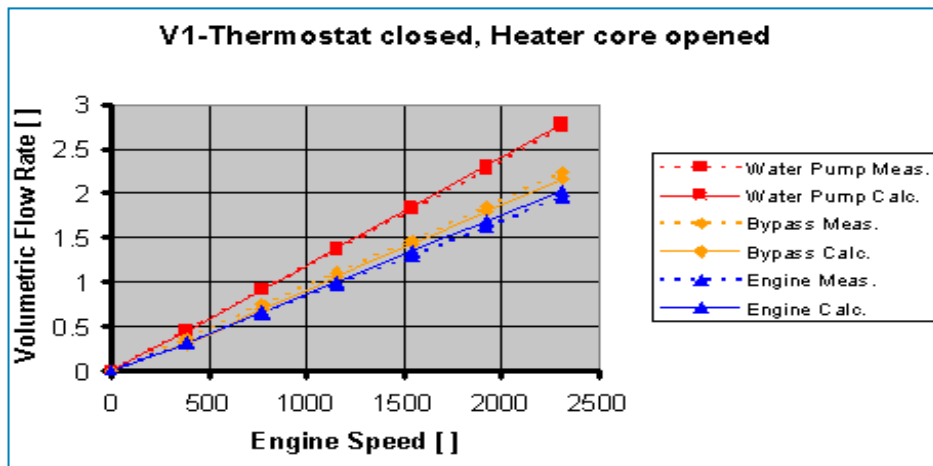


Figure 2: Normalised Volumetric Flow Rate for Verification points

Taking a closer look at this specific area of the model highlighted the fact that the predicted and measured data deviated as the engine speed increased. Figure 3 shows as the engine speed increases the predicted volumetric flow rate reverses earlier than the measured flow rate for the exhaust reconducting radiator. It also indicates that the predicted volumetric flow rate through the exhaust reconducting valves was slightly overestimated. This difference was explained as:

- The ERV and ERR are in a parallel branch and so compete against each other.
- The resistance of the ERV path was lower and so the volumetric flow rate was higher.

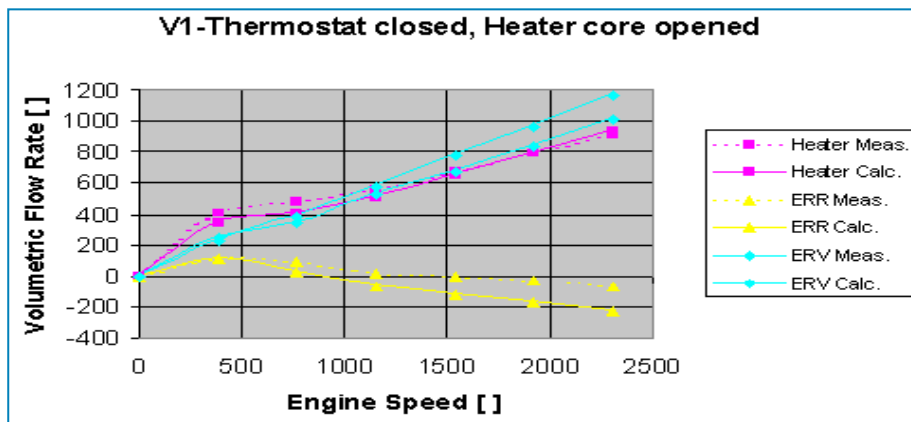


Figure 3: Normalised Volumetric Flow Rate for the heater circuit for verification point

Results and Practical Recommendations

The results from the cooling system simulation in the most part agreed well with the measured results for the cooling system behaviour. Practical recommendations that would alleviate the ERR poor and reverse flow conditions included:

- Increase the resistance in the flow path of the ERV by reducing the pipe diameter.
- Move the ERV and ERR into series and eliminate their competition.

Both of these recommendations were simulated using the validated cooling system model. In the first case the pipe diameters were restricted from 7.5 mm to 4 mm immediately after the ERV's. This increased the hydraulic resistance in these flow paths and therefore increased the volumetric flow rate through the ERR. Figure 4 highlights the difference in volumetric flow rate between the “with” and “without” throttles cases. As you can see with the throttles in place the volumetric flow rate remains positive over the entire engine rpm range.

The second recommendation was to move the ERV's in series with the output. This reduced the flow rate through the ERV's and increased the flow rate through the ERR.

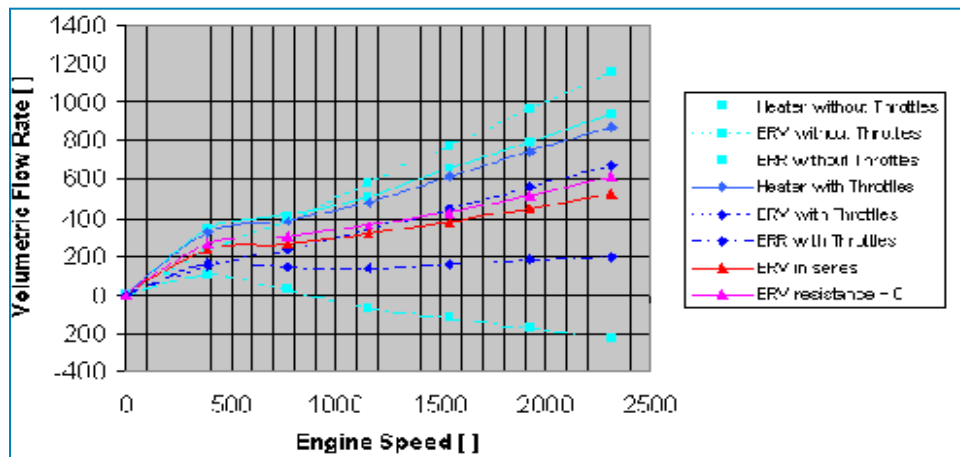


Figure 4: Highlights the difference in volumetric flow rate between the “with” and “without” throttles cases

From these simulations it was found that both of these recommendations fell short of the design target for the normalised volumetric flow rate of $Q_{norm} = 401$. However the DaC cooling team agreed that the better of the two solutions was to implement the throttling after the ERV's since it was the most practical solution to follow.

Project Wrap Up

The total replacement of physical testing may or may not ever be totally replaced by simulation techniques; this project clarifies how simulation can give practical direction to challenges that occur in the testing stages of the development process.

In total 14 day were used collecting, preparing and transferring test data into the Flowmaster internal Data Manager, model correlation with test took 2 days and all parameter studies took 2 days. A total time of 20 man days from initial identification in test to proposed practical solution supported by quantitative simulation results.

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