Turbo Technologies

HTi

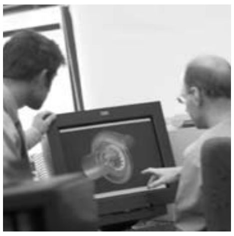
The Latest Turbocharger News

Quiet Please!

Inlet Noise Reduction

EDITION 9:

Comments from the Leadership Team



In this ninth edition of HTi, we discuss the latest tier of exhaust emission regulations for China and the USA. Cummins Turbo Technologies' global presence is enabling our customers to comply with all emission standards simultaneously. Investment in our Chinese plant and technical centre, outlined in this issue of HTi, is keeping us right on pace with the rapid changes in China, both technically and commercially.

Sophisticated air-handling is central to achieving Euro IV and EPA07 emissions levels and we have the right technologies and products whether the solution be exhaust gas recirculation (EGR) or selective catalytic reduction (SCR). Cummins Turbo Technologies' Holset VGT™ is a key tool in providing enabling technologies and is complemented by our latest fixed geometry and wastegate turbochargers and power turbines for turbocompounded engines.

Our mission encompasses not only supplying the best technical solutions but also the most cost effective solutions. Our new technique for making impellers achieves both objectives and on pages 7 and 8 we explain the benefits of semi-solid moulding (SSM), as a new premium impeller material.

Although SSM is a new method of manufacturing impellers, we introduce it with full confidence thanks to the work of our worldwide laboratory operations. Their extensive testing capability underpins the performance, reliability and durability assurances we give our customers. I am sure you will be impressed by this edition's summary of their work. We also explain in more detail how we measure and tackle turbocharger noise, a complex but increasingly relevant issue.

Mark Firth

The world's largest engine manufacturers are our primary customers but we also cater for many other diverse applications, from the Czech Republic based Frankie Truck Racing Team and the Earthrace attempt to break the circumnavigation record for a powerboat. We are also out and about at exhibitions and events all over the world to meet existing and future customers; we conclude this issue with next year's dates.

Mark Firth
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HTi is the Cummins Turbo Technologies' magazine focusing on the world of medium and heavy-duty turbocharging. It aims to bring you news on product and market developments.

HTi is produced using an environmentally approved printing process and is printed on fully recyclable and biodegradable paper.

Keeping Pace with China

Written by Li Mingzhe; Project Engineer

July 2007 was an important month for the Chinese vehicle industry. Arguably, it was even more important for the people of China in terms of their health and their environment.

It was on 1 July that the country started the move to the next tier of exhaust emissions limits, cutting levels of harmful gases and pollutants from vehicle tailpipes. Exhaust emission standards in China are governed by the State Environmental Protection Administration (SEPA). It was in 2005 that SEPA last tightened vehicle emission standards, moving from its Phase I to Phase II standard. In July this year, it introduced the national Phase III exhaust emission standard for light-duty vehicles, equivalent to the Euro III standard in Europe.

The drive to cut vehicle emissions such as oxides of nitrogen (NOx) and hydrocarbons in order to protect the environment and improve people's health and quality of life is recognised all over the world. It is particularly important in China, where the growth of the economy has led to rapid urbanisation. It is in these fast expanding urban areas where controls on vehicle related pollution are most critical to protect the living environment.

The 1 July date for the introduction of Phase III refers to the approval of new models. Sales and registrations of existing vehicle designs that comply with the Phase II limit can continue for another year until 30 June 2008. Only then, on 1 July 2008, will Phase III take full effect, covering every new light vehicle coming onto the road in China. Then in 2010, the Phase IV standard is due to be introduced for the approval of new models. One year later in 2011, this will apply to all new light vehicles coming onto the road. There is a similar timetable for implementing Phase III and Phase IV emission limits for heavy-duty diesel engines too.

Cummins Turbo Technologies has been developing and investing in its Chinese operation; Wuxi Cummins Turbo Technologies, to ensure that it is positioned to match the pace of change in China. The objective is to have not only the best technical solutions to suit the engineering and legislative requirements of the ever more stringent emissions limits but also the production capacity to fulfill the burgeoning market demand.

New expansion plans at the Wuxi Cummins Turbo Technologies site

Therefore, on 30 May 2007, Jim Lyons; President, Cummins Turbo Technologies, unveiled new expansion plans at the Wuxi Cummins Turbo Technologies site. It increases the total build area to 14,600m^2 and the site area goes up to 29,300m^2. The new development will include investment in an additional heavy-duty and a new light-duty production line.

We have been developing and investing in our Chinese operation; Wuxi Cummins Turbo Technologies, to ensure that it is positioned to match the pace of change in China.

Wuxi Cummins Turbo Technologies has also signed an agreement to enhance technical cooperation with the authority in its home city; the New District Administrative Committee of Wuxi. The aim is to develop our existing technical centre so that it is able to support all the local engineering needs and it will include roles such as design engineering, laboratory operations, plant engineering and technical project teams. It will also bring new capabilities such as applied mechanics and air-handling expertise to China. New roles will be added later, expanding the technical centre's range of skills still further and making a valuable contribution to Cummins Turbo Technologies' global technical resources.

Wuxi Cummins Turbo Technologies' sales in the first half of 2007 were the highest ever. In the face of strong competition, our share of the medium and heavy-duty turbocharger market in China rose to 46%, keeping the Holset brand in the number one position in the sector. The developments and expansion already underway mean the company is strategically placed to push our market share even higher. As the Chinese automotive industry accelerates to ever higher production levels and embraces ever more stringent exhaust emission limits, Cummins Turbo Technologies is poised to meet these demands.

Testing Times

Worldwide Laboratory Operations

Written by David Clay; Chief Engineer, Laboratory Operations

Computer-aided engineering (CAE) has progressed hugely during the last 20 years, reducing reliance on testing to iterate and optimise designs. However, conventional testing still remains a critical part of the product development cycle, validating designs and ensuring that performance, durability and reliability targets are met.

It also provides a valuable source of data for calibration and verification of computer models, used for development of future products. Cummins Turbo Technologies therefore maintains an extensive test capability, with facilities in both its technical centres in China and the UK. Their test work supports not only product development and validation but also supplier selection and research into advanced materials.

Test Rigs

Turbocharger testing may be conducted either on an engine on a test bed, or on a gas stand rig that simulates the engine exhaust conditions. Cummins Turbo Technologies has 19 gas stands, each using a burner system fed with a mixture of diesel and compressed air. By controlling the fuel and air pressure, and flow rate we generate a variety of turbine inlet conditions, driving the turbocharger through its complete operating range. Separate circuits within the test cell supply oil and cooling water.

Gas stands have two clear advantages over engine based testing. First, the elimination of the engine means tests can be controlled more precisely and more reliably. Second, they allow the compressor and turbine stages to be decoupled from one another so that we can explore the complete performance envelope. However, Cummins Turbo Technologies also has seven engine test beds, used when it is vital to understand the interaction between engine and turbocharger, such as determining the effect of exhaust pressure pulsing on turbine nozzle dynamic loads.

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Performance Testing

Precise measurements of turbine and compressor aerodynamic performance are among the key product tests conducted on our dedicated performance gas stands, quantifying pressure, flow and stage efficiency across the full operating range. When measuring compressor performance, we drive the turbocharger open loop and throttle the compressor outlet in order to map all flows from choke to surge. Inlet air is controlled very carefully and both compressor inlet and outlet pressures and temperatures are measured to ensure that we obtain accurate data for operating efficiency.

The compressor stage is replaced with a hydraulic dynamometer when testing turbine performance. This allows us to obtain mass flow and efficiency characteristics over a wide range of turbine pressure ratios and shaft speeds, unrestrained by the compressor and with great accuracy. The test is run on a steady state gas stand incorporating a dynamometer that absorbs the gross power ie. including the bearing reaction, produced by the turbine.

Test work supports not only product development and validation but also supplier selection and research into advanced materials.

Burst Testing

One of the safety related tests we conduct on both the turbine and compressor stages is a containment or burst test. This is a vital part of product validation, ensuring that in the event of catastrophic failure the rotating components of the turbocharger are completely contained and that housings and fasteners remain intact. Performed on a gas stand, the test involves driving the rotor system beyond its maximum speed until a point when either the turbine or the compressor wheel fails, or 'bursts'.

Proving Durability

Burst testing is designed to ensure Cummins Turbo Technologies' products are safe. Durability is another key requirement, particularly in the heavy-duty engine market. Impeller and turbine wheels are subjected to intense stresses at high speed. As speed and load vary through the engine's duty cycle these stresses also change and this can cause fatigue damage, commonly referred to as low-cycle fatigue.

In order to ensure our products are capable of meeting the most demanding duty cycles, we carry out low-cycle fatigue durability tests on all our designs. They are conducted on a gas stand, with the output from the burner rig split to feed two turbochargers. Control valves mounted upstream of each turbocharger are opened and closed repeatedly, so that each turbocharger is cycled from minimum to maximum speed. Each cycle takes about five seconds; over 15,000 cycles are completed each day. The test continues for days, or even weeks, until the wheel fails. Several wheels of the same design are tested to establish both durability and reliability. This data is then used to calibrate computer fatigue models, allowing us to make accurate life predictions for real world duty cycles.

High-cycle fatigue due to resonant vibration is also a potential threat to the durability of turbine or impeller blades. Gas loading of the blades can be highly dynamic, so Cummins Turbo Technologies uses sophisticated CAE tools to develop designs that minimise these loads. We validate the designs by applying strain gauges to the blade surface to measure the level of blade vibration under realistic loading conditions. The gauge positions are selected by finite element modelling of the blade geometry and with gauge lengths in the order of just one millimetre, even gauge application is a highly skilled process.

Specialised high temperature strain gauges fixed with ceramic cement are needed to cope with the extreme temperatures when measuring turbine blade vibration. This is one of the tests we run on an engine test bed in order to understand the interaction between engine and dynamic blade loading.

Less Noise

Customers have become more discerning about noise levels in recent years. As we describe on page 9 in this edition, there are several potential sources of turbocharger noise that have to be separated in order to measure them.

Cummins Turbo Technologies has developed a unique noise test cell capable of doing this and measuring each simultaneously. The turbine stage is driven by a gas stand rig with its burner system housed in an adjacent room to isolate the noise it generates. Body radiated noise from the turbocharger housing is measured in a hemi-anechoic chamber using a hemispherical array of microphones. Compressor intake noise is ported to another hemi-anechoic chamber for simultaneous measurement. Special high temperature probes are used to take in-duct turbine exhaust noise readings. Data from each measurement point is analysed after major components such as blade-pass noise have been extracted, with results plotted against flow and pressure characteristics to generate noise maps.

Cummins Turbo Technologies' test rigs are computer controlled for optimum productivity and repeatability. There are routines with automatic control that allow standard tests to run unmanned. Data from tests are uploaded to a results database held within the Cummins Turbo Technologies global product data management system so that results can be shared with company engineers all over the world. Requests for test work are also handled via this channel, making it a truly global test management system.

This is a summary of only a small part of our worldwide test capability. Whether it is bearing durability, accelerated thermal cycle or vibration testing, the Cummins Turbo Technologies test department is dedicated to providing accurate and timely input into the product.

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USA Market
EPA 2007 Comes into Force

Written by David Wilcox; Deputy Editor of Transport Engineer Magazine

David Wilcox takes a look into the USA market and how the recent introduction of the next round of emissions legislation is affecting the marketplace.

Heavy-duty truck sales in the USA have collapsed. The number of Class 8 trucks, those with gross weights over 33,000 lbs (14.97 tonnes), sold during the first nine months of 2007 was down by 45% on the same period last year. Some analysts expect year-end sales to be almost 50% down. However, this sharp decline is not unexpected. The reason for such a downturn is the arrival of the USA Environmental Protection Agency's new heavy-duty diesel engine exhaust emissions regulations, EPA 2007, which came into force in January this year.

In comparison, 2006 was a record year for USA Class 8 trucks, with sales reaching 284,000 units. Truck factories were at full stretch to satisfy demand from operators pulling forward their 2007 purchasing programmes so that they could buy the last trucks complying with the outgoing EPA 2004 emission rules before the 2007 limits came into effect.

Examining the emissions limits for 2007 explains the dip in the demand. The scale of the reduction in both particulate matter (PM) and oxides of nitrogen (NOx) is immense. The PM limit is cut by 90% and NOx is halved. The EPA 2007 limits are tougher than the Euro V emission rules that do not apply in Europe until October 2009. Achieving the NOx reduction needed for EPA 2007 requires modifying the exhaust gas recirculation (EGR) technique already widely adopted by USA engine manufacturers for EPA 2004 limits. The modified EGR technique recirculates more of the exhaust gases, lowering the combustion flame temperature and thus reducing NOx production. The adoption of turbocharger technology such as Cummins Turbo Technologies' Holset VGT,™ is a key tool for managing the recirculation of such a high proportion of exhaust gases.

However, no amount of combustion technology can slash particulates by 90%, so exhaust after-treatment such as a diesel particulate filter is essential. The filter needs periodic regeneration to burn the sooty particulates that it has trapped. If active regeneration is used, fuel is injected in the exhaust to raise the temperature sufficiently to burn the soot, thus using even more fuel. Furthermore, the filter gradually accumulates ash from burnt engine oil and needs to be cleaned every 300,000 miles/480,000 kilometres.

It has been forecast that the combination of active regeneration and the slight rise in exhaust back pressure as the ash accumulates, will cause fuel consumption to deteriorate by 2-3%. Add the extra capital cost, durability concerns about recirculating more sooty exhaust gases into the engine and the on-cost of maintaining particulate filters, it is not surprising that so many truck companies chose to buy the last 2004 specification engines.

Time will tell if operators' caution about the EPA 2007 engines was justified. Engine and truck manufacturers insist operators will not detect any real change in fuel consumption. They also claim to have met the durability challenges. One thing however is certain; by 2009, USA truck operators will be rushing to buy 2007 specification engines. EPA 2010 emissions limits are the toughest in the world and will require further advances in technologies to meet the requirements. USA engine and truck manufacturers are already planning to increase production to meet a 2009 truck sales spike that could be higher than ever.

USA engine and truck manufacturers are already planning to increase production to meet a 2009 truck sales spike that could be higher than ever.

USA Environmental Protection Agency Exhaust Emission Standards				
	USA Units		Metric Units	
EPA tier	NOx (g/bhp-hr)	PM (g/bhp-hr)	NOx (g/kW-hr)	PM (g/kW-hr)
2004*	2.5**	0.1	3.35	0.134
2007	1.2	0.01	1.61	0.013
2010	0.2	0.01	0.27	0.013

* The 2004 limits applied from 1 October 2002 for the seven engine manufacturers who signed a consent decree after a so-called 'cycle-busting' episode.

** This NOx level includes non-methane hydrocarbons (NMHC).

Semi-Solid Moulding: A New Way of Making Impellers

Written by Qiang Zhu; Principal Engineer, Materials Engineering

The fundamental principle of the turbocharger is to increase the density of an engine's ambient inlet air by harnessing the energy of the waste exhaust gas. The turbine wheel captures the energy of the exhaust gas and transmits it along a shaft to the compressor wheel or impeller. It is the impeller that has the task of stepping up the pressure to increase the density of the inlet air.

Maximising the increase in density calls for a turbocharger with a high compression ratio; the air pressure at the compressor's outlet compared with the inlet pressure. Due to developments in turbocharger technology and materials, compression ratios of up to 5:1 are now possible for some modern diesel engines.

High compression ratios provide huge gains in an engine's power density and emissions performance but also bring a number of challenges, not least for the impeller itself. The impeller needs very complex blade geometry to achieve such high ratios. Compressing the air also increases its temperature, so the impeller not only has to withstand rotational speeds of up to 150,000rpm but must do so whilst coping with high temperatures and a significant temperature gradient: the impeller becomes progressively hotter towards its outlet.

This combination of sophisticated geometry and tough operating conditions means that the modern impeller demands the very best material technology.

Casting or Machining

Impellers for many years have been cast from aluminium alloys containing silicon and copper. These alloys offer relatively high strength-to-weight ratios at reasonable cost and can easily be cast into complex shapes.

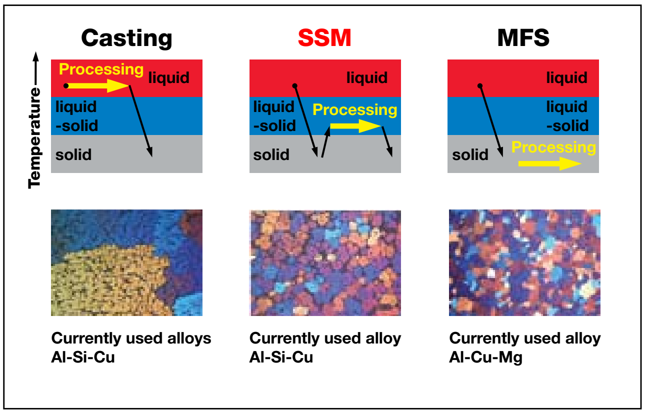


Fig 1 - Schematic showing casting, SSM and MFS processes and grain structure produced with these processes

However, it is necessary to restrict their release speed during operation to achieve the specified durability targets. Aluminium foundry technology has improved in recent years to address this issue and Cummins Turbo Technologies has also pioneered the use of high resolution eddy current defect detection techniques to increase our knowledge of casting defects and how to counter them.

Since 2002, Cummins Turbo Technologies has also produced impellers using the machined from solid (MFS) process. Impellers are formed from solid blocks of alloys containing aluminium, copper and magnesium using five-axis machining. They are significantly more durable because of their higher so-called alloying content and finer grain structure meaning they are stronger than cast impellers. MFS impellers are also virtually defect-free owing to the large size of the cast ingot from which the blanks for machining the impellers are made, by plastic working such as extrusion and forging.

Machining MFS

The improvement in durability also means MFS impellers can run reliably at the higher speeds now demanded by some of the latest diesel engines that use above average turbocharger compression ratios. The downside is that MFS is more expensive than casting.

In search of yet higher compression ratios to suit certain specific applications, we turn to titanium alloys because they can outperform aluminium alloys when it comes to coping with high temperatures and speed. Titanium impellers may be manufactured either by investment casting or MFS.

Fig 2 - Semi-solid alloy behaves like a solid under compression but like a liquid under shear

Semi-Solid Moulding

The very latest technique for impeller manufacture is called semi-solid moulding (SSM). Cummins Turbo Technologies developed SSM impellers in 2005/6 as a way of achieving cost and durability performance somewhere between that of cast and MFS aluminium alloy impellers. Cummins Turbo Technologies has a patent application for applying SSM to impeller manufacture.

As its name suggests, the SSM process occurs while the alloy is in both its liquid and solid phases (figure 1). It produces a grain structure that is finer than casting and similar to that of MFS, giving SSM impellers mechanical and fatigue properties comparable to those made by MFS.

The SSM process takes advantage of the characteristics of alloys that solidify over a temperature range. While they are between the liquidus and solidus states, alloys are in a semi-solid zone where they behave like a solid under compression but a liquid under shear, as shown in figure 2. The semi-solid billet can be processed into an oxide defect free net shape with virtually no shrinkage porosity (the tiny holes that open up in a casting as it solidifies). Figure 3 shows an SSM impeller made of an alloy of aluminium, silicon, copper and magnesium after very little machining to achieve the final profile. Ultrasonic and fluorescent penetrant inspections show the impeller has very good surface quality and no detectable shrinkage porosity or oxide defects.

Back-to-back aerodynamic performance tests at Cummins Turbo Technologies' Technical Centre show that SSM impellers are the equal of cast and MFS impellers and have excellent repeatability because of good consistency of blade thickness and form. Other back-to-back testing includes a comparison of durability, using accelerated speed cycle tests. The SSM impellers emerge as being significantly more durable than cast equivalents and approaching that of MFS impellers.

Our conclusion is that SSM impellers can be used in applications where tough duty cycles would preclude the use of cast aluminium impellers. Equally, where the cost of MFS impellers may be prohibitive, SSM impellers are a viable alternative.

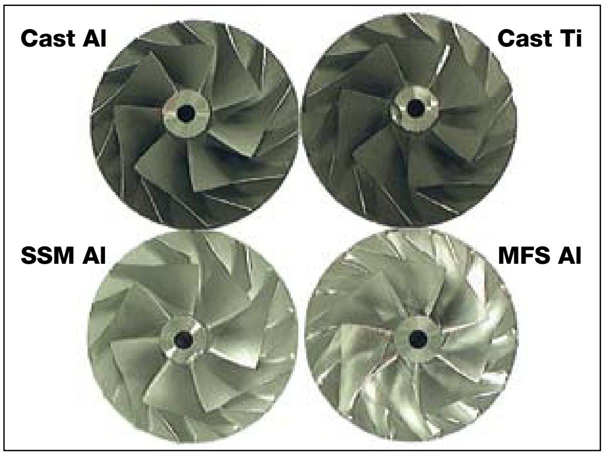


Fig 3 - A SSM impeller, together with cast aluminium, MFS aluminium and cast titanium impellers, which are currently used in Holset turbochargers

Quiet Please!
Inlet Noise Reduction

Written by Xiaozhen Sheng; Senior Engineer, Applied Mechanics

Xiaozhen Sheng outlines how we make turbochargers quieter, focusing on reduction of compressor intake blade-pass noise.

Compared with the engine to which it is attached, the turbocharger may not strike the layman as a source of noise, but it is. After all, it is a high-speed rotational machine that generates fluctuations in air pressure. If those pressure fluctuations occur within the frequency range that is audible to humans; about 20 to 20,000Hz, then we can regard them as sound. Unwanted sound is noise and one of the many objectives when designing a turbocharger is to reduce that noise to a minimum.

Turbocharger noise emanates primarily from three sources (figure 1). First, there is the body-radiated noise coming from vibration of the turbocharger's body surface. Second, there is turbine exhaust noise, generated by the interaction between turbine blades and the gas flow. Finally, there is compressor intake noise, caused by the interaction of the compressor blades and the airflow.

Compressor Intake Blade-Pass Noise

This third source, compressor intake noise, contains a wide range of frequency components of which the most dominant is normally at the blade-pass frequency. This frequency is equal to rotor speed multiplied by the number of main blades on the impeller. So, for an impeller with seven main blades and rotating at 60,000 to 120,000rpm the blade-pass frequency is in a range from 7,000 to 14,000Hz. The human ear is sensitive to tonal sound at these frequencies, so blade-pass noise is an issue that must be addressed.

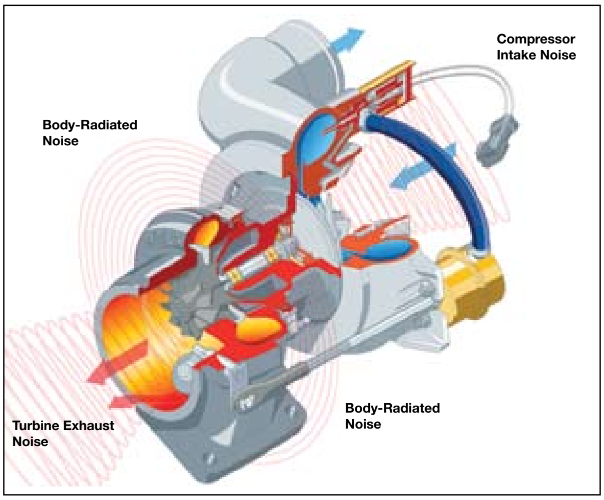


Fig 1 - Noise from a turbocharger

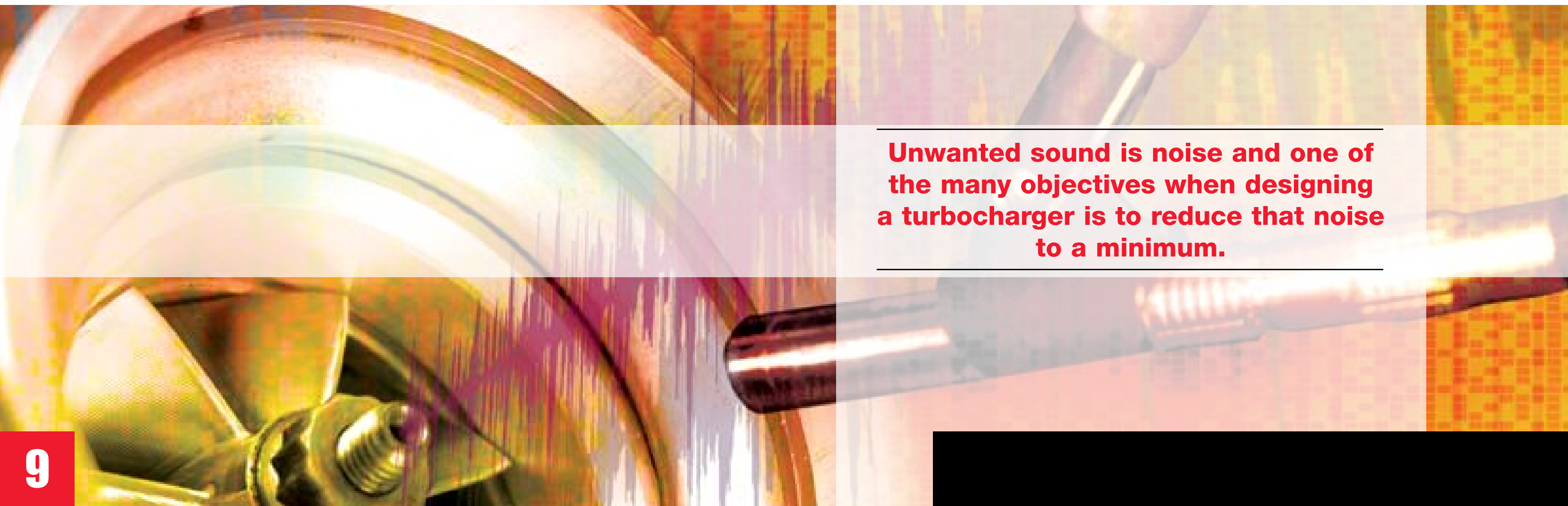
As already mentioned, the source of compressor intake noise is the interaction between the impeller blades and the airflow. Even the academic community does not claim to have a full understanding of the complex aerodynamics involved. As the impeller rotates, it forces a periodic displacement into the airflow and this is one of the mechanisms generating noise. At the same time, each blade applies a force onto the airflow. The force is time-varying in magnitude and rotating with the blade. These rotating and varying forces are another mechanism of noise generation with the immense speed of the blade tips contributing to the noise level. The noise generated is particularly high when the blade tip speed is supersonic ie. higher than the speed of sound, which is 343m/s in air at a temperature of 20°C.

This compressor intake noise propagates as sound waves through the compressor inlet and the upstream intake duct. Once the noise leaves the intake system it may find its way to any of a number of locations, including the vehicle's cab where it may be detected by the occupants. Fortunately, not all the noise reaches their ears. Some of the sound energy is lost because it is dissipated or reflected back to the compressor, the degree of which is influenced by the design of the intake duct. The duct will not allow propagation when the frequency of the blade-pass noise is below a certain value, so there is potential to minimise noise by achieving the optimum match between the compressor and the intake duct.

Measuring Turbocharger Noise

In order to quantify the relative contributions from the three primary sources of noise, it is necessary to segregate them so that each may be measured separately. Cummins Turbo Technologies has developed a dedicated noise test cell to do this (figures 2 and 3). Compressor intake noise, for example, is guided through a straight pipe into a hemi-anechoic noise chamber where it is measured using the hemispherical method. The measuring procedure entails a number of speed ramp-downs, from the maximum rotor speed to a set lower speed, using a range of compressor flows and pressure ratios. Noise data and turbocharger operating points such as flow parameter, rotor speed and pressure ratio are logged during each ramp-down. When the series of ramp-downs is completed, a noise map is constructed. This shows the flow parameter and pressure ratio on the x and y-axes, with the noise level at each point on the map plotted in a range of colours. It provides a graphical representation of noise generated throughout a range of turbocharger operating conditions.

The noise maps of two different turbocharger designs can be compared directly by producing what is called a difference noise map. Instead of depicting absolute noise values, this shows the



Unwanted sound is noise and one of the many objectives when designing a turbocharger is to reduce that noise to a minimum.

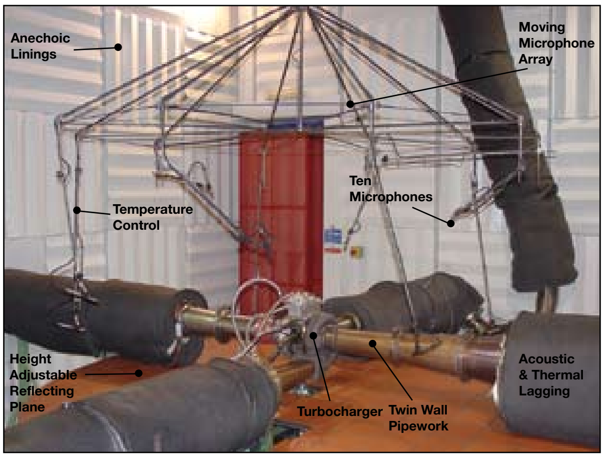


Fig 2 - The main chamber of the Cummins Turbo Technologies noise cell

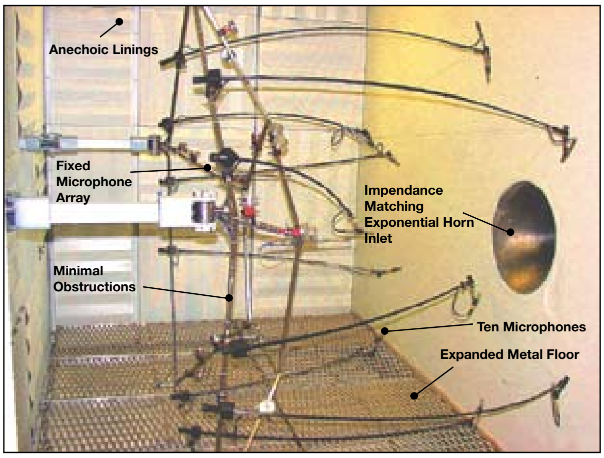


Fig 3 - The intake chamber of the Cummins Turbo Technologies noise cell

difference in the noise levels between the two designs (figure 4). The difference noise map reproduced here shows one design is about nine to ten decibels lower than the other at most of the operating points. That is a significant difference; if one noise level is nine decibels lower than another then it is perceived by the human ear to be only half as loud.

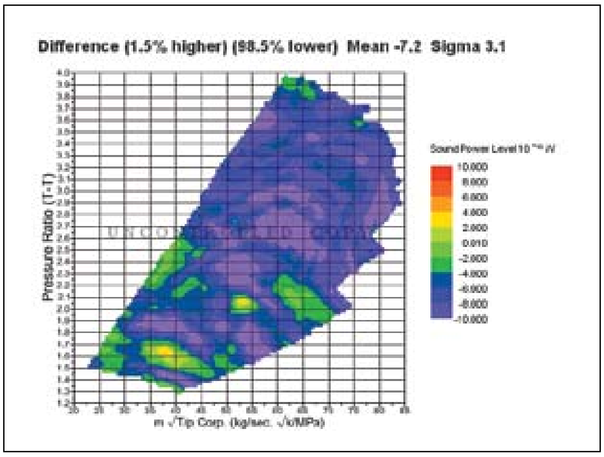


Fig 4 - A difference noise map

Reducing Compressor Blade-Pass Noise

Noise can be reduced by minimising its generation at the source or by attenuating it afterwards; both techniques may be used in combination. Engineers at Cummins Turbo Technologies have a number of projects to expand our understanding of how noise is generated and propagated so that we can develop better ways of controlling it.

It is acknowledged that a compressor inlet with the Map Width Enhancement (MWE) feature is far noisier than one without. The additional annular passage created by the MWE feature allows noise to propagate more easily and the struts in the passage cause vortex shredding; an extra mechanism for generating noise. The number of struts affects noise generation and propagation; there is an established rule for specifying the number of struts in the passage, based on the number of blades on the impeller. Silencing techniques can be applied to this area of the inlet passage, including the use of expansion cavities as illustrated in figure 5. This reduces propagation of noise through the passage into the upstream duct. The Noise and Vibration Group at Cummins Turbo Technologies is now developing advanced models that will help optimise these geometries.

Turbocharger whistle was once considered a desirable noise that demonstrated the power of the engine but today it is considered undesirable; our customers stipulate that no turbocharger noise should be heard at all. Our analysis capability and testing facility allow us to develop innovative designs that will meet or exceed our customers' requirements.

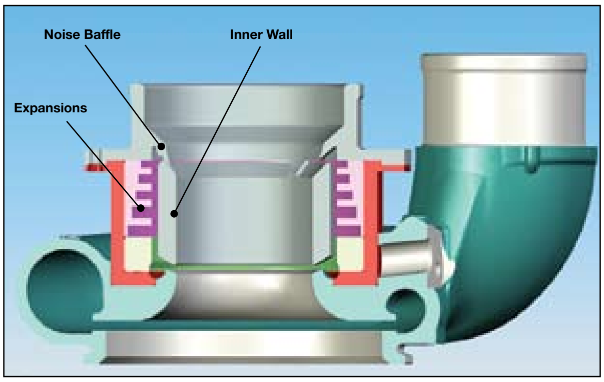


Fig 5 - A low-noise compressor inlet

Turbine Matching

Written by Owen Ryder; Senior Engineer, Air Handling

The beauty of turbocharging is that its benefits; more engine power, reduced tailpipe emissions and better fuel consumption, are all derived from the energy in the waste exhaust gas. Inserting a turbine into the exhaust gas flow to extract that energy is a simple concept to understand but controlling the process across a range of operating conditions is rather more complicated.

Although it is the turbine that drives the compressor, when it comes to selecting the turbine the reverse is true; it is the compressor that determines the choice of turbine. We start the matching process by referring to the compressor map, showing the compressor's output and efficiency at various operating points. The input power needed to drive the compressor is calculated using the following equation:

$$\text{Compressor Power} = \dot{m} \times C_p \times T_{in} \times \frac{PR^{\left[\frac{(\gamma-1)}{\gamma}\right]} - 1}{\eta_c}$$

where $\dot{m}$ = air mass flow
C_p = specific heat at constant pressure
T_{in} = inlet air temperature
PR = pressure ratio
γ = ratio of specific heats
η_t = compressor efficiency

The turbine needs to produce this power, plus a little extra to overcome bearing losses. Turbine power is calculated by the equation:

$$\text{Turbine Power} = \eta_t \times \dot{m} \times C_p \times T_{in} \times \left[1 - \left(\frac{1}{PR}\right)^{\left[\frac{(\gamma-1)}{\gamma}\right]}\right]$$

where η_t = turbine efficiency

The constants C_p and γ are looked-up values for exhaust gas, the air mass flow through the engine is known and the turbine inlet air temperature can be estimated. Turbine efficiency and turbine pressure ratio (the ratio of the turbine inlet pressure to its outlet pressure, also known as the expansion ratio) depend on the turbine's characteristics, revealed by referring to its performance map.

Turbine Maps

Turbine maps define the relationship between mass flow, pressure ratio, speed and efficiency. This relationship is different for each type of turbine and can be presented in two formats:

1) A swallowing capacity curve (figure 1) shows the points at which the turbine is likely to run, which are the peak efficiencies for each pressure ratio. The x-axis is the mass flow; the y-axis is the turbine pressure ratio (expansion ratio). The graph shows the relationship between these two parameters and illustrates the turbine's efficiency. The line on the graph climbs vertically at the maximum flow value, usually referred to as the choke flow. This is the maximum flow the turbine can handle, defining the size of the turbine.

2) A full turbine map (figure 2) contains more data about speed and operating points away from peak efficiency. These measurements have to be made on a turbine dynamometer; Cummins Turbo Technologies is one of the very few test facilities with this capability (see article on turbine performance mapping in HTi edition 7).

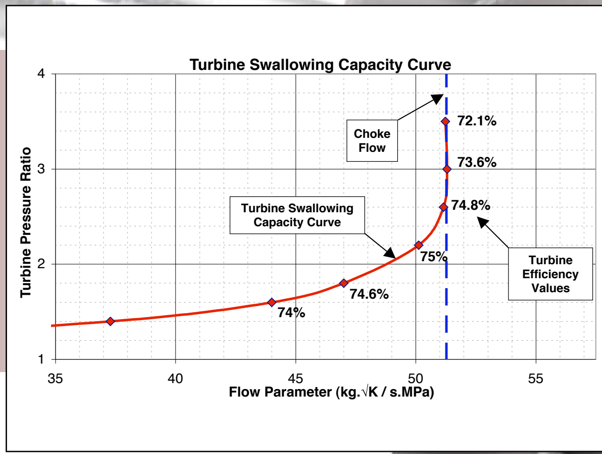


Fig 1 - Swallowing capacity curve

The beauty of turbocharging is that its benefits; more engine power, reduced tailpipe emissions and better fuel consumption, are all derived from the energy in the waste exhaust gas.

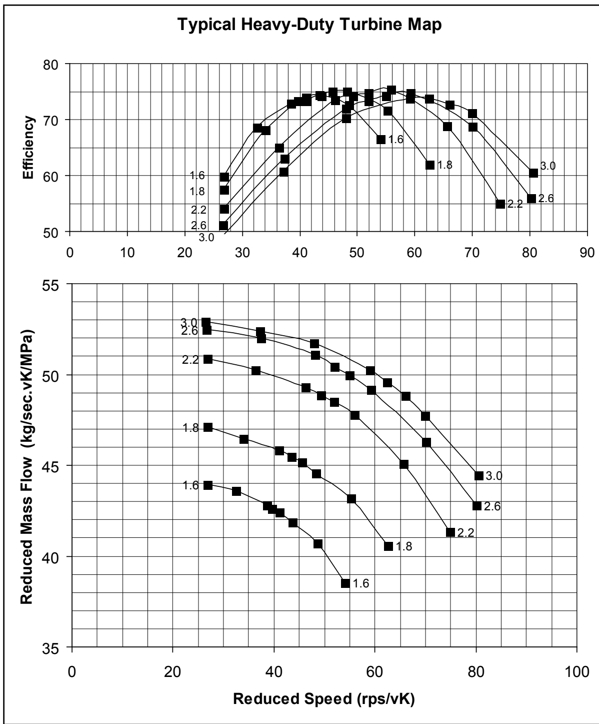


Fig 2 - Typical heavy-duty turbine map

Specifying the Turbocharger

There are four steps in matching the turbocharger to the engine:

1) Establish the engine's air requirements.
2) Select a compressor map that fulfils those requirements.
3) Calculate the power needed to drive the compressor at its key operating points.
4) Select a turbine that will provide that power, by reference to turbine maps. A turbine with a lower choke flow value will generate more power for a given air flow than a turbine with a higher choke flow value.

Cummins Turbo Technologies has developed in-house computer software to perform this matching process, eliminating time consuming iterations of manual calculations. In addition to these sizing calculations, turbine choice must also take account of issues such as speed and temperature limits, ensuring durability in service.

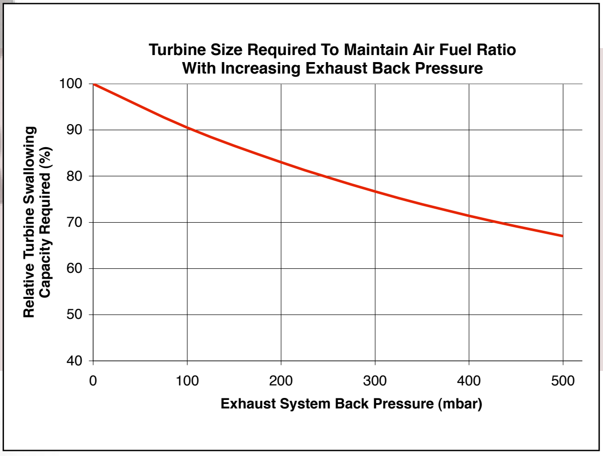


Fig 3 - Turbine size required to maintain air fuel ratio with increasing exhaust back pressure

Back Pressure and Turbine Efficiency

It is apparent from the formula for turbine power that pressure ratio is a critical factor, so anything that affects the turbine's outlet pressure will also affect its power. This brings exhaust back pressure into focus. This is a particularly topical issue because of the increasing prevalence of exhaust aftertreatment systems such as diesel particulate filters. If the aftertreatment increases exhaust back pressure, this in turns raises the turbine's outlet pressure, lowering its pressure ratio and cutting its power output. A smaller turbine housing is needed to restore its performance. Figure 3 illustrates the sensitivity of the relationship between back pressure and turbine size.

The variable geometry turbine's peak efficiency in the middle of the flow range is useful for lowering fuel consumption across the middle of the engine's speed range.

Back pressure from aftertreatment systems is seldom constant. It increases as soot and ash accumulate in the particulate filter; periodic regeneration of the filter (burning the soot) and removal of ash will reduce back pressure. A variable geometry turbine helps achieve consistent turbocharger performance despite such pressure variations.

Variable geometry turbines such as Holset VGT™ and wastegated turbines are often specified to enhance performance, improve torque output and quicken transient response (reduce turbocharger lag). They are also in demand to help engines meet emissions legislation. For example, engines with exhaust gas recirculation (EGR) frequently have variable geometry turbines because the lower efficiency it provides at low engine speeds helps create a pressure difference across the engine, making it easier to feed exhaust gases back into the inlet manifold. The variable geometry turbine's peak efficiency in the middle of the flow range is useful for lowering fuel consumption across the middle of the engine's speed range.

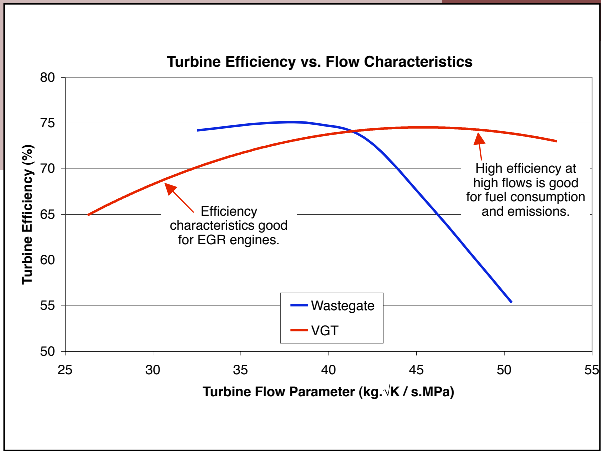


Fig 4 - Turbine efficiency versus flow characteristics

In contrast, a wastegated turbine can vary the flow across a wide range of engine speeds but loses efficiency when the by-pass valve opens. This means a wastegated turbine is efficient at low flows but less so at high flows. Figure 4 shows the contrasting efficiency characteristics of a variable geometry turbine and a wastegated turbine.

It is not easy to measure turbine efficiency. The rapid pressure pulses in the exhaust system make it difficult to measure overall pressure. In the case of twin-entry turbines, flow is momentarily greater in one volute than the other, so turbine performance when on the engine is not the same as when testing on a turbine dynamometer gas stand test cell. This difference in gas flow is most noticeable with twin-entry turbines at low engine speeds, when the pulses are most distinct. As figure 5 shows, the engine data can make the turbine appear more than 100% efficient at low engine speeds.

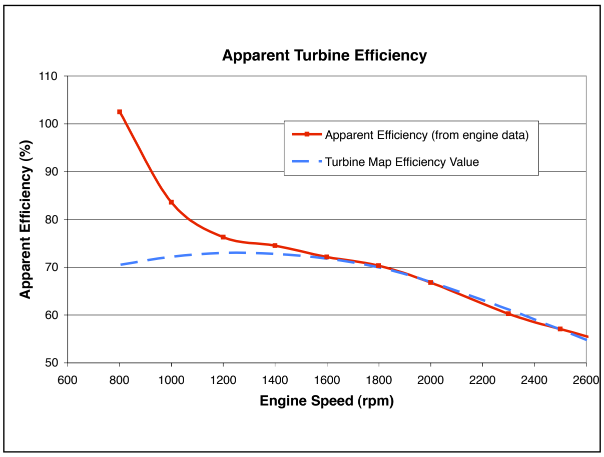


Fig 5 - Apparent turbine efficiency

Cummins Turbo Technologies provides customers with turbine maps in a variety of formats, including a spreadsheet version of the full map or in Society of Automotive Engineers (SAE) format for use in simulation programs. Our application engineers are also available to provide information about our turbines to customers, helping them select the optimum product for their engines.

Holset Turbochargers Around the World

Written by Sara Walls; Senior Communications Co-ordinator

Cummins Turbo Technologies design and manufacture Holset turbochargers for a diverse range of applications.

Racing Trucks

Cummins Turbo Technologies has designed and manufactured Holset turbochargers for the Frankie Truck Racing Team's Renault vehicles, which are competing in the Fédération Internationale de l'Automobile (FIA) European Truck Racing Championships 2007.

After analysing the engine data from Renault Trucks to establish the correct specification of turbocharger, engineers from Cummins Turbo Technologies recommended the Holset HE551 turbocharger. The engineering team also optimised the gauging dimensions for the turbocharger's compressor cover, whilst the Aerodynamic department at Cummins Turbo Technologies has worked closely with Renault engineers in the design of the air inlet on the truck. This year, the Frankie Truck Racing Team celebrated their best results in the FIA European Truck Racing Championship.

Powerboat Record Attempt

Earthrace is a bid to break the world record for circumnavigating the globe in a powerboat. It will also be the first time in history that an official Union International Motonautique (UIM) Powerboat record will be attempted using only renewable fuel.

During an 18 month tour, set to begin in March 2008, the boat will visit 60 of the world's major cities to raise awareness about the sustainable use of resources and promote greener fuels such as biodiesel.

Earthrace is the highest profile powerboat in the world and is powered by two Cummins Mercruiser Diesel engines with two Holset HX55W turbochargers made at Cummins Turbo Technologies in Charleston, USA. Running on biodiesel, it is a showcase of environmentally friendly technologies such as low-emission engines, with a non-toxic anti-foul and efficient hull design.

Circumnavigating the globe is the pinnacle of powerboat challenges and at 24,000 nautical miles, is also the world's longest race. The current record of 75 days was set by British boat 'Cable & Wireless' in 1998. Earthrace aims to smash this record by completing the voyage in less than 65 days.

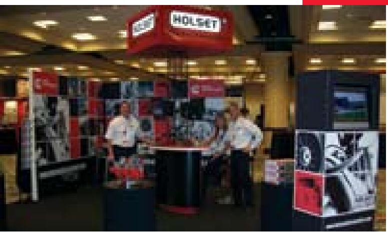
Image courtesy of Jim Burkett

Olympic Buses

The public transport system for the 2008 Beijing Olympic Games will feature buses powered by Holset HX35W turbochargers manufactured by Cummins Turbo Technologies in Huddersfield.

Beijing Public Transport Holdings has ordered 250 Cummins Westport B Gas Plus engines for the Beijing Jinghua Coach Company buses from Cummins Westport Inc, a leading provider of high performance alternative fuel engines for the global market.

Rated at 230bhp and running on clean-burning compressed natural gas (CNG), these buses will be in addition to the current fleet of CNG powered buses providing environmentally friendly transport for the 2008 Beijing Olympic Games.



ADS


ADS

Engine Expo


Festival of Speed

Out and About with Cummins Turbo Technologies

Written by Tim Eady; Marketing Co-ordinator

Tim Eady reviews the exhibitions and events attended by Cummins Turbo Technologies during 2007.

ADS International Convention - USA

The Association of Diesel Specialists (ADS) held its annual international convention and tradeshow this year in San Diego, California in July. The ADS is for those manufacturing, selling and servicing diesel engines and although its membership is predominately North American, its big annual convention attracts visitors and exhibitors from as far afield as Mexico and Europe too.

The forward looking theme for this year's five day event was 'Charting the Future'. Tom Folmar; ADS President and David Fehling; Executive Director, opened proceedings with a 'state of the nation' review of the ADS before turning the platform over to a series of speakers with presentations and seminars covering the latest developments in the industry.

Turbochargers and fuel injection systems are core subjects for the ADS and all major manufacturers of this equipment were at the event. Cummins Turbo Technologies played a leading part, with Matthew Wilman; Aftermarket Engineering Leader, presenting a paper covering new products and developments including turbocompounding and the latest turbocharger with electric actuation.

Also attending the convention from Cummins Turbo Technologies were Kenny Taylor; North America OES Account Manager, Martyn Howorth; General Manager Worldwide Aftermarket and Yelena Domashova; Account Manager, Cummins Parts and Service.

Meanwhile, various sectioned turbochargers and the interactive CD-ROM demonstration brought visitors to the Cummins Turbo Technologies stand. To conclude the event, Cummins Turbo Technologies was also presented with a plaque in recognition of its five year membership of the ADS.

Festival of Speed - UK

With almost 150,000 spectators, this year's event once again lived up to the Festival of Speed's claim to be the world's largest celebration of motor sport. Held over three days in June at Goodwood, near Chichester in West Sussex, the centrepiece of the event is a hill climb competition that attracts stars from all sectors of the motor sport world, ranging from Sir Stirling Moss to Lewis Hamilton.

Cummins Turbo Technologies seized the opportunity to display a range of products, including no fewer than four Holset HE851 turbochargers, all fitted to a single engine. This is the mighty Cummins 60-litre, 2,700hp, V16 QSK60, used in the mining and quarrying industry. Alongside it was the iconic USA pick-up truck, the Dodge Ram 2500, fitted with a Cummins ISB engine, complete with Holset HE351Ve turbocharger. Also on the stand and attracting just as much attention was the Cummins sponsored Bowler Wildcat off-road racer from the Paris-Dakar Rally.

Engine Expo - Germany

Engine Expo, held in Stuttgart, Germany during May claims to be the largest trade fair in the world for the powertrain industry. This year's event attracted over 11,000 visitors making it the biggest in Engine Expo's nine year history. Cummins Turbo Technologies exhibited for the first time at Engine Expo alongside Cummins Engines and Cummins Emission Solutions. Among the turbochargers on display were the Holset HE531Ve and the Holset HE351Ve for the Dodge Ram. Also on show were the Holset HY55V, as used on Iveco's Cursor 10 and 13 engines and the Holset HX25, showing the versatility of Holset turbochargers.

Stuart Westley; Business Development Manager, Mike Dolton; Applications Manager, Europe and Gerben van de Biezen; Aftermarket Area Sales Manager, Central Europe, were all available during the three day show to answer numerous technical enquiries from visitors to the Cummins Turbo Technologies stand.

Under the theme 'The Right Technology Matters' all three business units used Engine Expo to promote and communicate Cummins' global ability to provide reliable and durable products to the automotive industry.

Exhibitions 2008

Cummins Turbo Technologies is scheduled to participate in the following shows during 2008.

March	April	July	September	October
Con Expo, Las Vegas, USA, 11-15 March Mid America Truck Show, Louisville, USA, 27-29 March	SAE Detroit, Detroit, USA, 14-17 April	Goodwood Festival of Speed, East Sussex, England 11-13 July	IAA Hannover, Hannover, Germany, 25 Sep – 2 Oct	China International Combustion Engine Show

Turbo Technologies

Our Goals

Cummins Turbo Technologies places the utmost importance on achieving high levels of product and service quality.

Our people are the single most valuable asset we have to ensure we meet your requirements. Through structured training development programmes we encourage our employees to spend approximately 5% of their working time in training and personal development.

Our operations worldwide are certified to TS16949 quality standard and we welcome suggestions as to how we can further improve our performance to meet your needs.

We take our environmental obligations seriously and all our worldwide sites have achieved ISO14001. Our products have an important part to play in helping to improve engine emissions.

Our goal is to provide the lowest total cost solution for your turbocharging needs.

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