SEPTEMBER 200

GARRETT

booster

MAGAZINE

Focus on Gasoline Boosting

Sharing knowledge and experience

Audi's winning ways

Interview with Ulrich Baretzky, Audi Sport´s head of engine design

Boosting SAE´s global impact

Face to face with Dr. Shahed

Garrett®

Engine Boosting Systems

On Track

Of the 19.4 million light vehicles produced in Europe every year, 59% are powered by gasoline and 41% by diesel.

Diesel penetration continues to grow every year, from 17% in 1992 to 41% in 2002. Almost 100% of these vehicles now benefit from turbocharging.

Gasoline boosting is expected to grow significantly in Europe over the next few years, from the current 6% of gasoline powered light vehicles to more than 30% by 2010.

Garrett has invested 100 million euros in increased capacity over the last 2 years to support the growth in boosting demand.

Garrett has hired 50 engineers in the last 2 years to support diesel and gasoline opportunities – a substantial increase in engineering headcount.

Garrett's output in Europe increased 37% year on year from 1995 (1.7 million units) to 2001 (5.5 million units)

By the end of 2002 all the European Garrett sites will be ISO / TS 16949 certified, the most recent and demanding Quality standard, and ISO 14001 certified, an international standard for environmental management.

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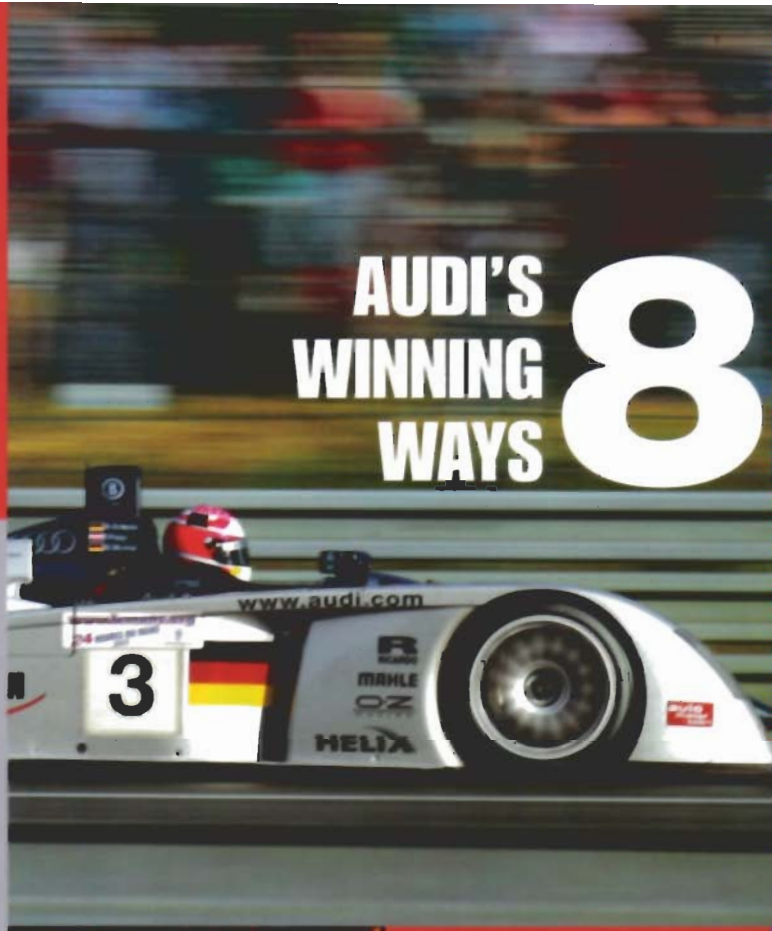
LISTENING AND LEARNING



Dear Readers,

It is with no little pride that I present our new "Booster Magazine" to you.

You may wonder 'why another magazine'? The main reason is that we want to enhance our communication with all the people who are important to our business: our customers, our suppliers and our end users. We cannot communicate enough, a fact demonstrated time and time again during the many discussions we hold regularly with so many of you.

We live in a rapidly changing environment where product requirements are becoming ever more challenging, where environmental considerations are getting tougher – albeit for good reason – and where engine system complexity makes close cooperation between customers, suppliers and our development teams mandatory.

Trying to accumulate as much knowledge as possible as soon as possible about the different parameters influencing system performance, sharing best practices and running timely system tests are the only way to ensure the ultimate satisfaction of the end customer. The speed at which innovations need to happen, the time constraints we operate under to meet deadlines and the ongoing pressure to bring down costs determine the processes as well as the structure we have to put in place.

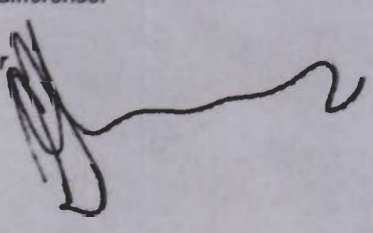
We need to involve all the key players at the right time and with the right targets and objectives in mind: the open exchange of information, a sense of urgency and an in depth understanding of the challenges ahead – these are the things that determine the difference between success and failure.

The common factor in addressing all these issues is communication, listening to our partners and acting on feedback from our end customers. Out of such knowledge comes a deep understanding of the real requirements of all our stakeholders, expressed as innovative, creative and cost effective solutions to better serve their respective needs.

In short, we want to take this opportunity to introduce ourselves to those of you who do not know us yet; and we want to reconfirm our commitment to those of you who already know us. We want to know where you think you can help us become an even better company. Communication is not only about information sharing and listening to each other. More crucially, from my point of view, communication proves very often to be the beginning of a dialogue which leads to an improvement in the way we work.

If we are successful in achieving this objective, we will all benefit from it. Together we can make the difference.

Bert Snijders
Vice President and General Manager
Europe and Global Accounts



BOOSTING SAE'S

Dr. Syed M. Shahed, Vice President, Advanced Technology, Garrett Engine Boosting Systems, is the 2002 President of the internationally renowned Society of Automotive Engineers, an 80,000-member organization.

Dr. Syed M. Shahed

Dr. Shahed earned his Master of Science degree and Doctorate from the University of Wisconsin after gaining his Bachelor of Engineering degree from Osmania University in Hyderabad, India. He has written many technical papers in the field of combustion, chemical kinetics of pollutant formation, diesel and gasoline engine emissions control technology and the turbocharging and supercharging of engines. Several of Dr. Shahed's papers have been recognized internationally for their technical excellence. He has been active in SAE since 1971. Dr. Shahed brings unusual depth of expertise to his SAE mission, including a resolutely international perspective cultivated both in his native India and the USA.

Dr. Shahed recognizes the key role that the engineering community can play in meeting the challenges of transportation in the future – particularly in addressing the issues of harmful emissions, fuel economy and environmental concerns.

Booster magazine caught up with Dr. Shahed midway through his term of office and found him eager to promote a culture of shared vision and collaborative working.

GLOBAL IMPACT

How has SAE developed as an organization over the last few years?

"SAE has a strong 100-year history in all fields of mobility – aerospace, automobile, truck and off-road. It started with a US member base, but it has always had an international focus. I always tell people SAE doesn't stand for Society of 'American' Engineers, it is SAE International because there is no doubt that SAE is expanding its worldwide role. SAE's ethos is founded on being inclusive in the way it works with members and partner organizations."

What have been SAE's key achievements in recent times?

"One of the most important developments recently has been the recognition that mobility products include an ever increasing range of technologies – not just those associated with mechanical, aerospace and chemical engineering. Today, we are playing an active role in the development of materials, in bio-mechanics, electronics and software. This increased scope of activity is reflected in many ways, but notably in the conferences we arrange – jointly with other societies, where appropriate: Digital Human Modeling Conference (with VDI-Germany), Digital Car Conference (with Consumer Electronics Association-USA), Advanced Transportation Technology and International Body Engineering (with SIA France).

We are also investing considerable resources in bringing mobility practitioners closer together through electronic communication – making it easier for technical information to be shared worldwide and enabling as many people as possible to participate in a global discussion forum and decision making processes.
Such a network presents huge opportunities for technology transfer for a company like Honeywell which, like SAE, is global and touches so many areas – automotive, aerospace and commercial vehicles/equipment."

What are your priorities for your year as President of the SAE – and which are the most important?

"SAE's strength is its technical knowledge base, so my focus is fixed on how we augment our leadership position in this area.

Our culture is one of continually improving the quality of this knowledge base, increasing the presence and visibility of SAE at the cutting edge of mobility technology and being an unbiased and credible resource in policy setting.

What do you believe SAE's primary role to be?

" At SAE we share a vision to advance mobility technology and the community of mobility technologists and, in doing so, to serve the larger interests of the world community. I want there to be greater recognition of the direct correlation between mobility and Gross National Product (GNP).

Society in general needs to recognize that contributions to mobility technology by mobility practitioners are actually a direct contribution to human well being. At a functional level, our key activities involve technical meetings, conferences, publications, education, continuing professional training, technical standards – in short SAE is an unbiased, neutral, forum where issues are discussed and resolved."

I also want SAE to widen its perspective globally and to strengthen its involvement in key issues by increasing dialogue with other international organizations. We need also to engage the interests of young people and women."

One of the major mobility issues at the moment is the harmonization of standards worldwide. What role can SAE play in making this happen?

"The most significant role that SAE can play is by starting the standard setting process proactively. SAE has a strong history and working tradition of adopting standards by consultation and consensus. Electronic communication and organizational procedures now make it possible to speed up this process. The diverse nature of SAE membership, coupled with its reputation for technical excellence and independence, enables regulatory bodies to adopt SAE consensual standards by simple reference. I invite you to visit the SAE web page at www.sae.org to experience first hand the power of this electronic network of mobility practitioners worldwide."

Who does the SAE need to influence to achieve its objectives?

"SAE has four clear customer groups – members, industry, governments and academia. We need to take every opportunity we can to demonstrate to industry our leadership position, so that they encourage their employees to participate fully in SAE. Involvement in writing and reviewing papers, organizing and attending technical meetings, taking professional courses, mentoring young SAE members and students, writing and reviewing SAE standards. All these processes will pay high dividends to participating organizations and individuals, creating a win-win situation involving SAE, the individual and the organization. I am very appreciative of the support Honeywell has given me to make full use of these opportunities. Likewise, I am sure that Honeywell's continuing support of SAE will be beneficial to all concerned: SAE, Honeywell and the mobility community.

So, who does SAE need to influence? I actually believe that the question should be 'Who needs to influence SAE?' Above all we must make it easy for our members to fully participate in our processes and influence SAE policies."

Are there any specific issues in Europe that you aim to address?

"The issues of mobility most vividly illustrate how small the world is and how much smaller it is getting. There are plenty of common issues around the world ... emissions, safety, fuel economy, cost, quality. And while there are still regional differences – diesel technology in Europe, fuel cell ▶

technology in the US, hybrid technology in Japan – I don't see issues that are specific and local to Europe. What is clear is that the customer will have many more choices in the future. There is more of an emphasis in some parts of the world on urban pollution vs. global warming, but this just illustrates how important it is for the technical community, wherever it is located, to become more of a forthcoming resource in the policy discussion process. So while we recognize and respect the strong traditions of European technical societies and work with them towards common goals, we must remind ourselves that it is not just Europe, the UK, Russia, Romania, Italy and active members in ALL the countries of Europe – this is the real strength of SAE."

How do you intend making the technical achievements of SAE members more visible – and more visible to whom?

"SAE has a strong tradition of recognizing individual member achievements, both in technical fields and in service to the Society. SAE Fellow grade involves a very rigorous selection process of technical contributors over the world – today we have Fellow members from

Automobile Crash Avoidance System

we also have strong agreements with JSAE, SAE China; we have SAE Sections in Taiwan, Hong Kong and Malaysia; we have held SAE meetings in Thailand and Malaysia; we have SAE India Affiliate, SAE Brazil Affiliate; we have a relationship with SAE Australia."

Who are the key partners in Europe for the SAE?

"I am delighted that my message of international cooperation is finding a strong response all over the world. The way we intend to strengthen ties with our key partners is to recognize each others' traditions, work cooperatively and share information freely.

At a functional level, SAE has agreements with IMechE, VDI and SIA and, of course, SAE has sections in Europe, Japan, China and India.

We also present internationally recognized awards in all fields of technology at the Honors Convocation of the SAE World Congress (and a few other major SAE functions). We recognize and award members for their technical work and organizational contribution to the Society.

These awards are highly visible within the technical community. But they should provide recognition of service and technical achievement beyond SAE. These achievements should become visible to industry leadership and to some extent to the general society.

We must increase the profile of achievement first in industry management and academic circles and then in the eyes of the general public. It is unfortunate that in a recent poll in the US, the word associated most frequently with "engineer" was "train operator", NOT "engineer-inventor". We must change that."

What is the purpose of the SAE student design competitions in Europe?

"SAE Student Design Competitions are very popular and provide young people with fantastic opportunities for teamwork and learning. There are many competitions ... Formula SAE, Mini-Baja, Aero-Design, Super-Mileage, Clean Snow-Mobile ... to name just a few. I, personally, have had the good fortune to interact with many student teams and they tell me that they learn more from participating in a Student Design Competition than in two or three courses.

Above all, they learn the value of teamwork (and many employers use the competitions as talent spotting opportunities and are therefore keen to sponsor such events).

Of course, education is a key objective of SAE. My vision, ultimately, is for a worldwide SAE Student Design Olympics.

We will soon be celebrating the centenary of the very first controlled flight. Orville Wright was a very active member and supporter of SAE and I hope that this programme will come

SAE Student Design Competition:

Unmanned, semi-autonomous tractor

Aircraft Crash Avoidance Display

together with young people at the center."

Does SAE have a role to play in reconciling the commercial success of auto manufacturers with environmental concerns?

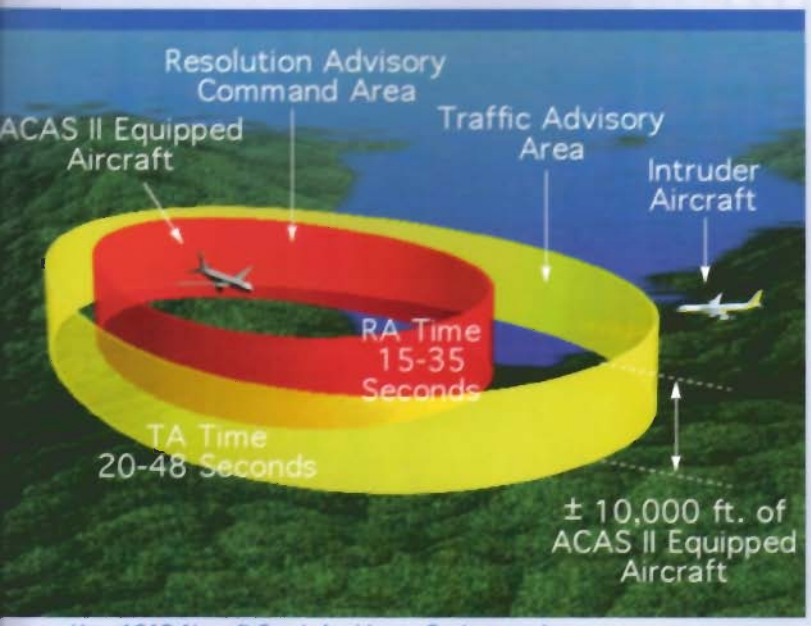
"Actually, I don't think that there is a need for "reconciliation" between commercial success and environmental concerns. There is complete compatibility between what we call environmental sustainability and commercial success. SAE organizes a conference dedicated to environmental sustainability and there are many more meetings organized around the technologies of emissions reduction, fuel economy and safety.

So we are extremely active in this area – but from all the research that we have undertaken it is clear that commercial success and environmental concerns are entirely compatible."

How important is the transfer of technology from one area of mobility to another?

" SAE members work in all sectors of the mobility industry – automotive, aerospace, commercial, agricultural ... but they all share a passion for technology and its application. SAE is the 'glue' that binds this intellectual capital together, that facilitates the sharing of ideas and concepts. For example, technology developed for aerospace, such as anti-collision systems, could quite possibly become a feature of future passenger cars.

When we ask people to think about autonomous or semi-autonomous vehicles, what comes to mind? The usual answer is 'UAV' – unmanned vehicles for reconnaissance and the like – or autopilot functionality, yet agricultural and construction equipment is fast becoming semi-autonomous. Such vehicles also have "learning capabilities" which in turn will make them safer and more productive. This "crossfertilization" of ideas is a natural fit for a company such as Honeywell, which has technologies in the aerospace segment that it might quickly apply to automobiles. At the same time, the cost sensitivity of the automobile industry might likewise benefit the aerospace industry."



How ACAS Aircraft Crash Avoidance System works

How will you judge the success of your term?

"There are several levels to this question. At a personal level I will measure the success of my term with the learning and growth opportunities it is giving me. I have had the chance to represent SAE with industry and government leaders all over the world and they have been very gracious in sharing the state of knowledge around issues of interest and discussing how SAE might help. This has provided me tremendous learning opportunities and a very broad perspective. A second level involves the global reach of the Society – an area where we are already making a lot of progress. International cooperation is very important. I think it is also very important for SAE (and other technical societies) to reach young people.

The average age of SAE membership has been steadily increasing. I have a particular soft spot for young people and for education and I will judge the success of my term by our ability to reach young people.

The concept of "my term" is also very important. Obviously one year is a very short time to make a substantial difference. Fortunately, it is a one year term as president, NOT a one-year term as a member of SAE. When my term as president ends, my term as member will continue and I expect to continue to be active in SAE through the remainder of my professional life and into my retirement. I am also proud that my term continues a tradition of support for SAE by Honeywell – another Vice President of Technology of Honeywell (AlliedSignal Aerospace Division), John Mason served as President of SAE in 1990 and has continued to actively serve SAE well after his "retirement"."

SAE

Over 83,000 engineers, business executives, educators, and students from more than 97 countries form the SAE membership network, sharing information and exchanging ideas for advancing the engineering of mobility systems.

More than 16,000 volunteer leaders serve on the board of directors and the many other boards, councils and committees. SAE technical committees write more new aerospace and automotive engineering standards than any other standards-writing organization in the world.

Thousands of technical papers and books are published each year, as well as leading-edge periodicals and internet and CD ROM projects. SAE's Cooperative Research Programme helps facilitate projects that benefit the mobility industry as a whole. Numerous meetings provide worldwide opportunities to network and share information and SAE also provides a full complement of professional development activities such as seminars, technical symposia, and e-learning products.

Every day, SAE demonstrates its commitment to society through local, national, and international public awareness programs that promote vehicle safety and maintenance and energy resource conservation. Through the SAE Foundation, the organization is also deeply involved in the engineering-related education of children, teachers and college students. Industry and faculty awards provide recognition to outstanding contributors in the profession. Since its founding in 1905, SAE's dedicated people, strong technical base, and vision have helped serve the professional needs of engineers and the transportation needs of humanity.

INTERVIEW WITH ULRICH BARETZK

AUDI'S WIN

Quality culture defines partnership approach

Race track success built on dialogue

ULRICH BARETZKY

AUDI SPORT'S HEAD OF ENGINE DESIGN

NING WAYS

When it comes to the world's most famous motor endurance event, there's simply no one to touch Audi Sport Team Joest. This year, Audi once again claimed 1st, 2nd and 3rd places in the Le Mans 24-hour race and earned the right to keep the trophy outright by winning the event for the third successive year.

Audi engines have taken all the podium positions in the last three years – and the team has not had an engine or turbo failure in the last four Le Mans events. Garrett Booster magazine endeavoured to discover the secret of Audi's success ... and spoke to Ulrich Baretzky, Audi Sport's head of engine design, about the power behind the podium....

■ The Le Mans race puts tremendous pressure on technology and on people – which is more important to the success of the team?

"The philosophy of the 24h Le Mans has always been to test technical and human capability. The drivers, of course, rely upon the technology to give them the opportunity to win – at the same time the technology can only be as good as the people behind the wheel. Engineers can avoid technical failures in certain circumstances by a very sophisticated monitoring system during the race, our mechanics can fix components – but clearly this is a true enterprise built on a partnership of technological advantage and human skill and determination. Both sides have to do their duty."

■ What is the principal reason for Audi's racing advantage over the last few years?

"The main reason for our success is an extremely thorough and detailed approach to the preparation of the cars and engines. While this preparation for sure cannot guarantee the success that Audi has enjoyed, without it you would just be competing on the basis of luck. Luck cannot be the only driving force for a Le Mans race.

At Audi, the level of preparation is part of a culture that applies equally to the development of the production car. Hand in hand with this approach goes the quality of the suppliers who cooperate in the development – this partnership approach is the key to the development of successful and reliable cars."

■ How important is the partnership with Garrett in the team's success?

"Garrett's commitment to quality was one of the main reasons that Audi embarked on the partnership with Garrett at the beginning of the Le Mans project. And the success we have achieved together over the last 4 years confirms our faith in Garrett's technology and the company's commitment to the project. As I said to the Garrett Motorpsorts Manager after the race at Le Mans, I cannot remember having had any trouble whatsoever with Garrett turbochargers. In fact, this is an area of the engine that we have almost forgotten about because it is working without any trouble. You really can't say more about such a highly stressed component."

■ What level of support do you receive from Garrett in terms of engine development?

"With Garrett we quickly developed a very open partnership founded on the exchange of information and ideas – about their strengths and weaker points in relation to the project. This doesn't mean anything negative – on the contrary, an enduring partnership can only be good and reliable for a long time if it is based on a very open dialogue. Garrett were clear at the outset about the technological parameters but were committed to helping us address the improvements we were seeking. The results speak for themselves."

■ What in particular did you expect Garrett to deliver to the project?

"Our expectations with regard to Garrett and this project were – and remain – few and simple: to keep the quality level we agreed at all times – honesty in all difficulties, to give us the chance to sort things out in time – reliability in all aspects of a professional and commercial partnership – openness in all problems and a willingness to commit to a partner-based approach to finding solutions."

The E

■ Can you indicate how you work with key partners to maximize technological advantage?

"We integrate our key partners in our development process. We show them their importance and their responsibilities – and we work together to find solutions to our common problems. We treat them as "partners" in the best sense of the word. And we encourage them to go with us into new technological territory – even when there is a risk of failure. This creates an atmosphere where our partners feel encouraged to go beyond existing boundaries, to make suggestions and to take risks. We don't let them down, they know about the strength of our working relationships because we are looking for very long-term partnerships."

■ What advantages did the use of DI with turbocharging give the Audi team and was the technology refined this year?

"The advantage of our FSI named direct injection system on the TC engine is best illustrated by the following figures:
+ 8 % more torque throughout the whole speed range of the engine
- 8 % better fuel consumption, or in other words 1 lap (13,6 km) more in the race with the same amount of fuel.
This combination gave much better driveability even under the most difficult track conditions (wet, dirt ...) and delivered an increase in efficiency which brought this technology close to the economy of diesel engines. Our drivers said that they could not believe that this was a turbocharged engine – they said that it felt more like a big normally aspirated engine. The best use of FSI is with supercharged or turbocharged engines because you get a bigger gain in compression ratios."

■ Will any of this technology filter through to more mainstream Audi passenger cars?

"The FSI technology as it has been developed for Le Mans will go into many new engines in the Audi group. In the near future more and more engines will be equipped with the FSI technology. All AUDI advertising activities in 2002 are based on the Le Mans victory and our slogan is: "More power from every single drop." Audi's new engine programme started with the A2 1.6 l FSI in April, now the A4 2.0 l FSI has been launched and many other engines are on the way. So, we can see that our achievements on the race track have a direct benefit for the people who we value the most – the customers who drive our cars. In this way, they share in our success."

ngine

The turbocharged Audi V8 engine delivers 610hp @ 6500 rpm, is the first purpose built race engine produced by Audi since the 1930s and the first to use direct injection technology in modern times. Audi Sport developed this FSI engine, which was not based on any existing hardware because the quantities of fuel that need to be delivered into the combustion chamber on every stroke are greater than any production system can provide. The system comprises little more than an injection nozzle per combustion chamber, with on either side of the engine a high-pressure three piston fuel pump driven by the inlet camshaft. A common pressure valve in the middle of the engine regulates the whole system. The best use of DI is with supercharged or turbocharged engines because this results in bigger gains in compression ratios. Garrett supplied specially designed and manufactured twin TR30R turbochargers, featuring a lightweight aircooled ball bearing system, two integral magnetic speed sensors, a thin wall HK30 turbine housing and a magnesium compressor housing. The unit weighed 9.6lb / 4.3kg (compared to 23.4lb for a standard unit) and provided 1.67 bar boost (the maximum permitted).

Facing up to the CO_2 challenge

Over the last 10 years, CO_2 emissions from road vehicles in Europe have climbed by more than 10%, with passenger cars responsible for the majority of that growth. Yet by 2008, the goal in Europe is to cut average CO_2 emissions in cars by about one third. These more and more stringent emission regulations have obliged car manufacturers for the last five years to work on possible solutions to reducing CO_2 emissions, focusing on industry agreed standards that begin with a target of 140 grams of CO_2 per kilometer by the year 2008 and look set to reduce to 120 grams by 2012. At Garrett, the trend is clear. The company is now engaged in a number of partnership projects that will transfer the knowledge gained in diesel boosting into the gasoline engine sector – heralding smaller engines with better fuel economy and lower emissions... but with the performance to deliver the joy of driving.

Focus on Gas
Sharing Knowl

A single-cylinder engine with full optical access

Leading Garrett's pioneering work in this area is Dominique Petitjean, a senior engineer with specific responsibility for new product development. The work of Dominique and his team embraces collaborative research and development with key technical suppliers, customer R&D units and scientific research institutes – often supported by government funding. For example, Dominique and his team are currently actively involved in an EC-sponsored project called GET (Gasoline Engine Turbocharging) which is focusing on boosting a 1 liter engine to deliver the performance of a 1.8 liter naturally aspirated counterpart.

Currently, a lot of work is underway on marrying GDI (Gasoline Direct Injection) technology with supercharging. One of the key players in this area is IFP, the Institut Français du Pétrole, which Garrett invited to participate in an ongoing research program looking at how best to couple gasoline engines with boosting technologies. Part of this program involves looking at how the Garrett Variable Geometry Turbocharger (VGT) – originally developed for the diesel segment – can be applied to gasoline engines. Much of the IFP focus is on engine downsizing, which is viewed as a central feature of improving the fuel consumption levels of spark ignited engines while maintaining the advantage of the low emissions capability of the three way catalytic system.

The IFP activity is based on engine knock management technologies that allow the use of a high fixed compression ratio and an excellent low-end torque capability for good fuel economy. Moreover, IFP was the first to demonstrate the high potential of gasoline direct injection system coupled with adapted turbochargers and engine camphaser. This approach creates the opportunity to enhance engine knock resistance, especially at high loads and low engine speed where existing MPFI turbocharged engines are still limited. The work that Garrett has conducted with IFP has generated a huge amount of data relevant to turbocharging design and engine matching process. This work has shown how, depending on the volumetric efficiency and the load acceptance of both the MPFI and the DI combustion chambers, the turbocharger turbine design can bring about considerable torque and power improvements. It has demonstrated the real synergy between gasoline combustion and turbocharging.
For instance, the flow division of a twin scroll turbine housing design enables the engine to

oline Boosting
dge and Experience

work at 1250 Engine Revolution Per Minute (erpm) full load with almost no interaction from cylinder to cylinder. It brings a better volumetric efficiency as well as a lower internal Exhaust Gas Recirculation. This makes the engine much less sensitive to knock and ensures increased air mass flow. The turbine can then be enlarged to the requirements of the customer to help reduce Brake Specific Fuel Consumption (BSFC) at rated speed. On a MPFI engine a 3% volumetric efficiency improvement @ 1250 erpm enables 10% more air mass flow with no significant impact on ignition timing. Torque is increased by 10% as well.

On a DI engine with proper valve timing (made possible thanks to fresh air only being used to scavenge the combustion chamber) the flow division provides more than 11% volumetric efficiency improvement @ 1250 erpm. Thanks to turbocharging, the air mass flow increase provides a 20% torque increase. The optimized engine/turbocharger combination provides at the same time as much as a 10% BSFC improvement at rated speed for the same power output.

A recent IFP prototype 1.8 liter turbocharged 4-cylinder direct injection gasoline engine equipped with the proper turbocharger delivers the same acceleration performance as of a 3.0 liter naturally aspirated engine but with 15% better fuel consumption.

At full load, the specific fuel consumption is less than 300 g/kWh over the whole engine speed range with a BMEP of 20 bar below 1500 rpm and a power density of 82.5 kW/l with a fix compression ratio over 10.

These very impressive performances are achieved with a significantly improved combustion stability that guarantees an optimized control for low emissions. Needless to say the stoechiometric (λ=1) combustion brings a major advantage over the stratified injection approach in terms of engine control. Part load strategy is made easier and development time is reduced. Furthermore it negates the needs for expensive NOx after-treatments. Importantly, this also gives engine manufacturers the opportunity to access – with only one engine technology – the car markets in the world where very low sulphur fuels are not available yet. The results of this study will be unveiled in a joint-paper being presented at a conference in Dresden in October 2002.

They demonstrate that Garrett's commitment to technological development is delivering significant progress in integrating the turbocharger in modern gasoline engines. At each stage, the results are used to optimize turbine housing design options and to refine future development.

In the same time, IFP has clearly benefited from this partnership approach by making the most of the opportunity to test innovative designs in turbocharger hardware – so expanding significantly the knowledge base relating to new engine/turbocharger combinations for gasoline engines in the short and medium term.

IFP customers as well as Garrett's – they are often the same – will no doubt benefit from this very exciting joint work.

IFP Partnership

IFP is Europe's leading independent industrial R&D, training and documentation center serving the petroleum and automotive industries. It was established in 1944 and is today active across the world with a total staff of 2,000. IFP Powertrain Engineering has more than 50 years' experience in designing engines and fuels for automobiles, commercial vehicles and trucks. Its main areas of expertise include combustion, modelling, new engine and fuel technologies and exhaust emissions reduction. IFP Powertrain Engineering is heavily involved in the development of the new generation of clean, fuel efficient, engines for passenger cars, working closely with several manufacturers on collaborative projects. The organization is at the forefront of the development of engines based on new combustion processes, such as the NADI™ concept (Narrow Angle Direct Injection), based on diesel homogeneous combustion. IFP research programs are founded on advanced fundamental and exploratory research conducted often in partnership with scientific technical and industrial communities globally. For gasoline direct injection, one of the main IFP Powertrain Engineering development strategies is founded on a high level of turbocharging and a stoechiometric mixture as an alternative to stratified charge combustion. IFP Powertrain Engineering's work in the field of exhaust after-treatment is also internationally renowned, particularly in the areas of NOx traps and diesel fuel particulate filters.

Twin scroll geometry

Focus on Gasoline Boosting

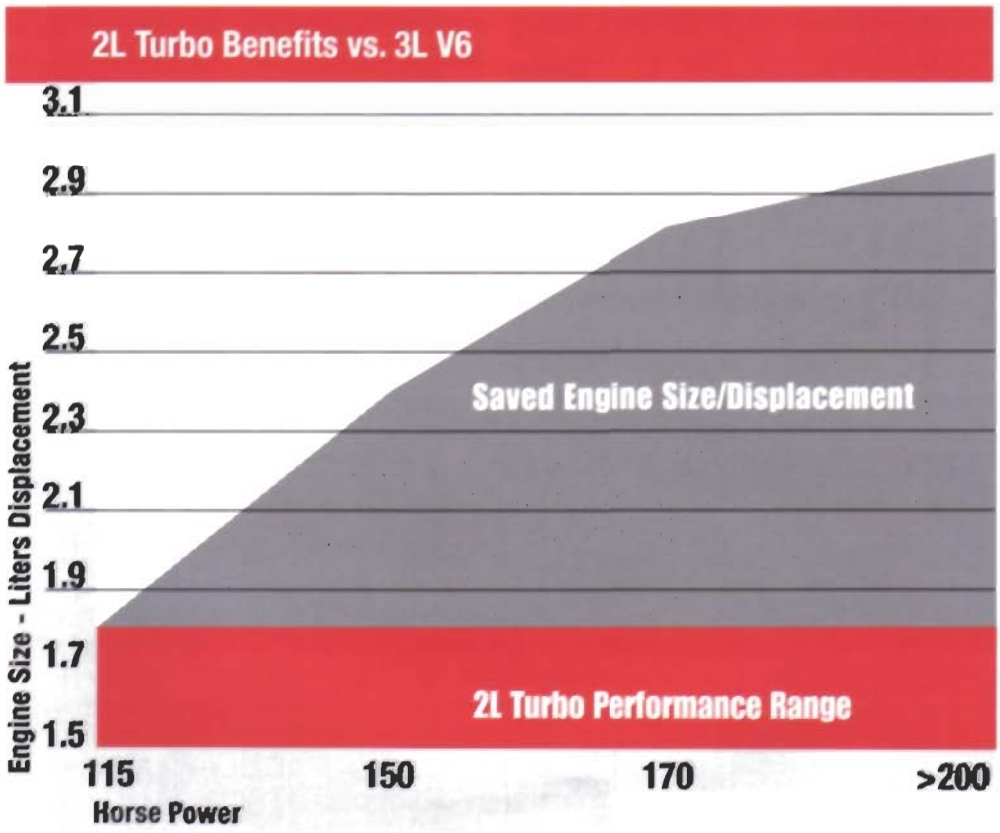
Face to face with

Alexandre Ismail, Vice President, Sales and Customer Management for Garrett, explains why the company is now focusing on boosting technology for gasoline powered vehicles. OEMs are showing increasing interest in gasoline boosting as they strive for smaller engine solutions that deliver lower emissions and better fuel economy without compromising the joy of driving.

Gasoline Turbocharging Offers Compelling Benefits

Customer Value

- Lower engine costs
- 15% CO_2 reduction
- 15% Better fuel economy
- 50 lb. mass savings
- 9% Better Performance
- Safety improvements
- Fun-to-drive!



Alexandre Ismail

What potential does Garrett see in gasoline boosting compared to diesel boosting?

"The potential is clear. Of the 19.4 million light vehicles produced in Europe every year, 59% are powered by gasoline and 41% by diesel. Yet, less than 6% of the gasoline engine population is turbocharged whereas almost 100% of diesel engines have a turbocharger. By comparison, in the US 97% of light vehicles are powered by gasoline engines and, of these, less than 1% are turbocharged.

As environmental legislation becomes more stringent, turbocharging presents an exciting opportunity around the world to deliver to end users better performance, better fuel economy and improved emission control through smaller gasoline engines."

The statistics are interesting but in themselves do not provide a rationale for greater demand for boosting technology in gasoline powered vehicles. What will drive car manufacturers to embrace gasoline turbocharging?

"Stringent new environmental legislation demands lower engine emissions and better fuel economy but, over and above this, businesses also recognize their obligations to do what they can to embrace greener technologies. In the case of car manufacturers this translates, fundamentally, into the need for engine downsizing. But there is a dilemma – a commercial reality that must also be acknowledged.

Downsizing will only be successful if it can be achieved without detriment to performance on the road and the pleasure of driving. After all that's what sells cars. People will still want the levels of performance that make driving a fun experience – and Garrett technology will help manufacturers to satisfy all these requirements."

Garrett is known for its innovative diesel boosting technologies – how easy is it to apply this knowledge to gasoline boosting?

"This is an exciting area of work for Garrett – but one with its own distinct challenges. Adapting, for example, our Variable Geometry Turbocharger (VGT) from diesel to a gasoline application is not simply a matter of "plug and play." Gasoline engines differ markedly from their diesel counterparts. Stresses are greater, engine RPM is higher, catalyst light-off issues are challenging and operating engine temperatures are hotter (>1000°C compared to 700-800°C in diesel).

However, our technological strength through VGT is a good foundation to build upon for our customers. Our partnership projects are already well advanced and focus on delivering clear and proven benefits to manufacturers and end users."

Can you give any illustrations of some of these tangible benefits?

"Better fuel economy and improved performance are clear benefits. Our work so far has delivered some impressive results. For example, by using wastegate turbocharging technology, a 2L 'in-line' 4 cylinder gasoline engine is able to deliver the same horsepower as a naturally aspirated 3L V6 engine, but with improved performance and better fuel economy.

Furthermore, simulated VGT technology shows an even greater ability to boost horsepower and improve performance while delivering incremental improvements in fuel economy and performance when measured against wastegate technology. The same 2L i-4 turbocharged engine also delivers a CO_2 reduction of up to 15% and improved overall fuel economy of 15% vs. the normally aspirated 3L V6 engine at iso power rating. These are not insignificant numbers. Moreover, manufacturers will also see genuine cost reductions as a result of engine downsizing – but, critically, will still be able to provide their customers with a fun experience of driving."

How quickly can Garrett accelerate the technology?

"We are already well advanced in our collaborative projects with our customers and we have the resources in place to ensure that we can meet the expected demands of the gasoline segment for at least the next five years. We believe that the take-up of boosting technology in gasoline engines will grow significantly in Europe over the next few years – from its current 6% to 30% or more by 2010.
This is a time of great opportunity – and considerable challenge – for car manufacturers and for Garrett. Garrett's experience and expertise will play an important role in the partnerships with customers that will ultimately deliver robust solutions for gasoline engines."

Differentiated Technology Delivers Customer Value

Engine	Horsepower	Performance 0-60 MPH	Fuel Economy City/Highway
3L V6	200HP	10.0 sec	18/24 mpg
With Naturally Aspirated Engine			
2L I4	200HP	9.8 sec	22/27 mpg
With Wastegate Turbocharger			
2L I4 Turbo	200HP	8-9 sec	24/30 mpg
With Variable Geometry Turbocharger			

Boosting – Regional Drivers

	Europe	Americas	Asia	Total
Light Vehicle Prod.	19.4M/1.9L	17.5M/3.4L	17.1M/2.0L	54.0M
Gasoline Vehicles	59%	97%	88%	80%
Diesel Vehicles	41%	3%	12%	20%
Turbo Penetration	43%	4%	11%	20%
of which Diesel	37%	3%	8%	17%
of which Gasoline	6%	1%	3%	3%

Electronic

Accelerating tow

The authors:

Craig Balis

Pierre Barthelet

Calogero Morreale

Driving pleasure is decisively influenced by the torque characteristics of the engine. For this reason, turbochargers are used to improve the air flow to both gasoline and diesel engines. The latest developments from Garrett are focused on the technology of smart boosting systems in order to achieve the maximum benefit for the turbocharging process by means of innovative product design and effective use of electrics and electronics. Electronically assisted turbocharger systems, such as electrically assisted turbochargers and electronically driven compressors, significantly improve the boosting effect. This allows the torque to be increased while at the same time permitting further engine downsizing.

Boosting ards the future

Introduction

Developed torque and the resulting driving experience are derived from the air flow made available to the engine. In both gasoline and diesel engines, turbochargers are used to improve airflow and ultimately torque. For gasoline and diesel vehicles, Garrett has in the past successfully developed turbochargers of the small GT series with a wastegate and – more recently – introduced VNT+REA (Variable Nozzle Turbine + Rotary Electric Actuator) technology to better cope with the latest generation of high-pressure diesel direct injection systems. Now, in close cooperation with engine manufacturers, development has been oriented towards "smart boosting systems" in order to exploit the ultimate functionality of turbocharging via innovative product design and intelligent use of electrics and electronics. Electronic Boosting Systems (EBS) such as the electrically-assisted turbocharger (e-Turbo™) or the electrically-driven compressor (e-Charger™) significantly improve the boosting effect, increase air flow ("torque on demand") and allow aggressive engine downsizing. Developments in internal combustion engine technology continue to be driven by the need to reduce emissions, improve fuel economy and reduce global warming gases. The electronic control of fuel has traditionally been recognized as a significant contributor towards achieving these goals. By comparison, the control of the air flow has received less attention, even though it requires roughly 20,000 liters of air per liter of diesel fuel and 9,000 liters of air per liter of gasoline for a typical internal combustion engine. The purpose of this paper is to show that effective air delivery in both diesel and gasoline engines has the potential to enable further advantages. The well-known benefits of turbocharged diesel engines have been progressively increased by improvements in turbocharger efficiency and inertia reduction as well as wastegate and variable geometry technologies. The modern DI diesel engine provides higher torque at lower speeds than comparable gasoline engines. The mechanisms and benefits of turbocharged gasoline engines are less well understood and less well accepted. It is known that the primary driver of torque is not engine displacement but the amount of air supplied to the engine. However, it is clear for both engine types that further improvement is made possible by the use of electrically assisted turbocharger technology. When the advantages of electrical assist are deployed in conjunction with advanced electronic control, we use the term Electronic Boosting Systems (EBS).

Gasoline Engine Turbocharging

The fundamental benefits of downsizing gasoline engines are derived from reductions in displacement, weight and, when possible, number of cylinders (1). Conventional boosting generally compensates for the reduction in displacement, but further benefits in terms of transient response and low speed torque are achieved by using EBS technology.

Fundamentals of Turbocharging

The typical engine develops far more brake mean effective pressure (BMEP) than the vehicle's road load curve requires for steady-state operation. The excess BMEP or torque margin is used for acceleration. The higher the torque margin, the better the driveability. Unfortunately, it also means that the optimum island of the brake specific fuel consumption (BSFC) moves away from the cruise condition, contributing to reduced fuel economy. A downsized, turbocharged gasoline engine, under cruise conditions, gives an optimum BSFC island closer to the road load curve. When high torque at low speeds is required, EBS technology can "fill the gap."

Effects of Turbocharging on Fuel Consumption and Displacement

Vehicle manufacturer data from published sources (2) were taken and analyzed by Garrett to compare the fuel consumption and the displacement of turbocharged engines with naturally aspirated engines. Data of the model years 2000 and 2001 were grouped by engine power range. The results are shown in Figure 1. The advantage of turbocharging in fuel consumption is approximately 10%, Figure 1 left. It was mentioned above that torque and power developed by an engine are a function of the amount of air it is able to breathe. Hence, turbocharging enables the effective downsizing of engines. The same data set as above was analyzed for the effect of turbocharging on engine displacement. It is also shown in Figure 1 right that, in the power range analyzed, turbocharged engines have a displacement of 2 liters while non-turbocharged engines need about 3 liters to develop the same power.

Low Speed Torque Deficit

Figure 2 shows data of a state-of-the-art 3.0-liter, non-turbocharged engine. Steady-state full-load torque is shown against engine speed. Superimposed on the same graph are data from a 2.0-liter turbocharged engine. As expected, over most of the speed range, the downsized turbocharged engine delivers torque equivalent to the larger non-turbocharged engine.

It is only at very low speeds that there is a small torque deficit. Under these conditions, the exhaust flow rate and therefore energy to the turbine is not high enough to provide sufficient boost. Furthermore, this low-end steady-state torque gap is amplified during transient operation, due to turbocharger inertia and the thermal inertia of engine, exhaust manifold and turbine housing. Electronic boosting aims to address this low-end torque deficit, in particular during transient driving.

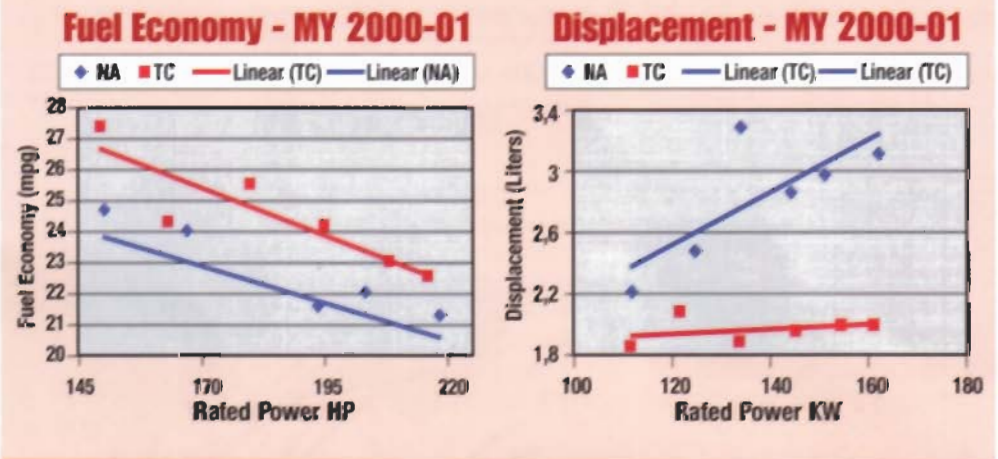


Figure 1: Fuel consumption (left) and downsizing (right) of several turbocharging (TC) and naturally aspirated engines (NA)

Electrically Assisted Turbocharger Technology

Early assessment of electrically assisted turbocharging was performed with evaluation prototypes. Using these prototypes, Figure 3, in a broad combination of Garrett and customer testing, functional and technology requirements have been established.

The focus is now on a production-feasible design. New engine and controller technologies, compatible with both 14V and 42V vehicle electrical networks, are under evaluation.

The resulting products, the e-Turbo™ and the e-Charger™, will provide significant improvements in cost, temperature, efficiency and packaging. Garrett recently reported on this technology at the Vienna Motor Symposium in 2002 (3). We have further evaluated Electronic Boosting Systems in order to better define the related benefits. The three primary benefits which solve the downsizing low engine RPM challenge can be expressed as follows:

- Torque = Boost gradient (bar/s) which influences driving pleasure
- Acceleration = Time to full boost (s) which can be linked to acceleration performance (e.g. time to accelerate from 30 to 60 km/h)
- Power = Overboost above the steady-state boost to allow aggressive downsizing.

Additional benefits of electrically assisted boosting, which complement the turbocharged engine features, include:

- Fuel economy due to better matching, reduced turbine backpressure
- Emission reduction due to better control of air at cold start and transient operation
- Power generation to supplement Vehicle Electrical Network (VEN)

Analytical Studies of Electronic Boosting Systems

In order to obtain consistent data, a complete suite of models has been developed at Garrett to understand the benefits of EBS and optimize it using a structured system specification methodology, Figure 4.

EBS technology involves two different types of boosting configurations: e-Turbo™ and e-Charger™. The e-Turbo™ is an electrically assisted turbocharger with electric motor/generator mounted on the same shaft as the turbocharger wheels. The e-Charger™ is an electrically driven compressor in series with a conventional wastegate or VNT turbocharger. The two alternatives are shown in Figure 5. Extensive validation of the system models was performed. For example, Figure 6 compares test data and analytical models during a boost transient for an e-Turbo™ system, showing good agreement. It is important to consider the two possible levels of usage of EBS, remembering that the primary purpose is to improve the transient torque response of the engine or vehicle. As depicted in Figure 7, the low electrical duty mode corresponds on the one hand to using EBS to reach the baseline boost pressure set value faster during a transient. This will enable the system to develop torque as close as possible to the value measured in steady state. On the other hand, the high electric duty mode corresponds to an overboost strategy. This level of overboost can be seen as a percentage of steady-state torque increase. In that case, the transient torque will exceed the steady-state torque obtained without electric assistance. Clearly, the power requirement of these two alternatives is quite different, with the light duty fitting better within the capabilities of a 12V battery while the high duty would probably require a 42V system.

Effect of Electronic Boosting Systems on the Torque Deficit under Steady-State Conditions

Figure 8 shows experimental results of using electrically assisted turbocharging on a number of gasoline engines. At low speeds in gasoline engines there is an undesirable torque deficit. Torque data are averaged over three engines and normalized by using the peak torque value at baseline conditions. It can be seen that a torque increase between 18 and 40% is obtained in the speed range of 1000 and 1500 rpm. This more than overcomes the torque deficit shown in Figure 2. These results can be expanded analytically. For example, Figure 9 indicates engine steady-state torque increase as a function of engine displacement and mechanical power applied to the Electronic Boosting System.

The computer models have also been used to compare systems based on e-Turbo™ and e-Charger™ systems. Figure 10 compares e-Turbo™ and e-Charger™ response with 1.8kW electric power available and a 70% motor efficiency, showing similar performance between the two systems. However, it is important to note that the e-Turbo™ performance is dependent on initial compressor matching and on the margin available before running into compressor surge. Subsequently, the turbocharger matching has to be carefully conducted.

Effects of Electrically Assisted Turbochargers on Transient Response

The torque deficit noted above can be responsible for a slight hesitation at vehicle launch until the engine speed has increased enough to provide enough energy to the turbocharger. As already shown beforehand, electrically assisted turbochargers can readily overcome the steady-state torque deficit. However, there is one other source of vehicle hesitation: the turbocharger rotating inertia. With improvements in materials, bearing speeds and resulting increase in

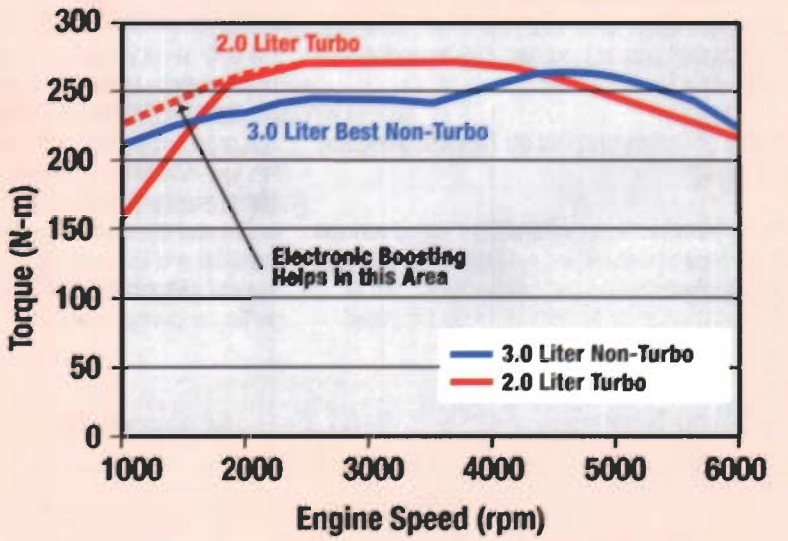


Figure 2: Electronic boosting system compensates the torque deficit at low speed of a downsized gasoline engine

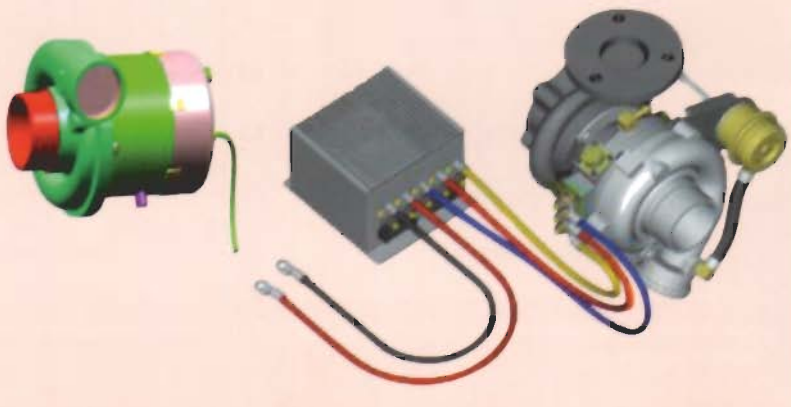


Figure 3: Electrically assisted turbocharger e-Turbo™ and electrically driven compressor e-Charger™

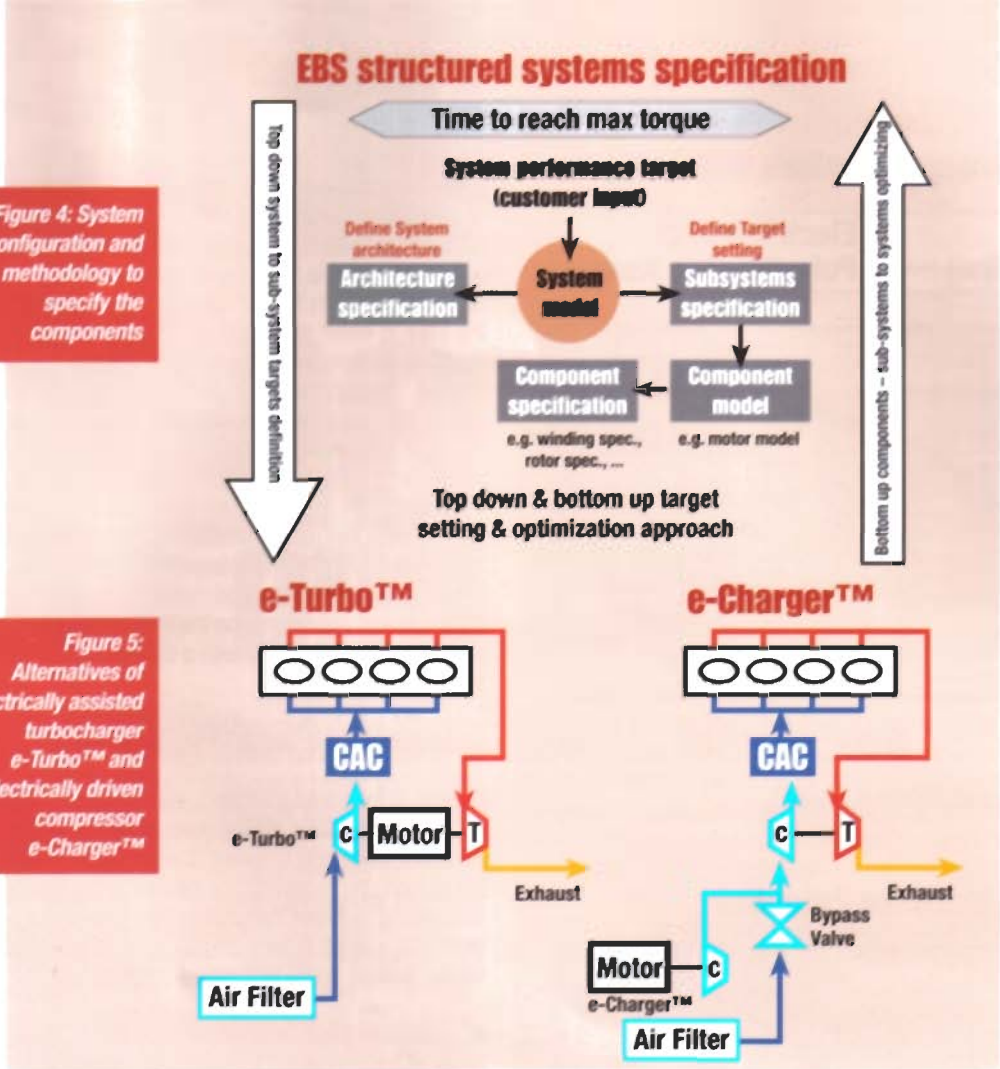


Figure 4: System configuration and methodology to specify the components

Figure 5: Alternatives of electrically assisted turbocharger e-Turbo™ and electrically driven compressor e-Charger™

turbocharger speed capability, the rotating inertia of turbochargers has been reduced by more than 80% over the last 25 years. EBS technology provides the opportunity to completely eliminate the effects of so-called turbocharger lag. Figure 11, provided by courtesy of FEV, shows the simulation results of transient behavior for acceleration in second gear with a 2.0-liter non-turbocharged engine and a downsized 1.4-liter turbocharged engine. Torque vs. time is shown. It can be seen that the downsized 1.4-liter engine catches up with the torque of the larger engine within 3 seconds. However, this 3-second hesitation will not be acceptable for a smooth driving experience. The figure also shows that electrically assisted turbocharging in a 1.4-liter engine is capable of delivering the same torque as the baseline, 2.0-liter non-turbocharged engine, completely overcoming the effects of torque deficit. The benefit of electrically assisted turbocharging is achieved by supplying 2 kW of electrical power to the turbocharger. Of course, the 2 kW power increase only supplies the additional air, and this develops the increased torque in combination with additional fuel. It is interesting to compare simulation results with an integrated motor/generator flywheel system (pink line in Figure 11): in this case, 10 kW of power has to be supplied to the integrated motor/generator in order to get an equivalent torque response.

Effect of Electrically Assisted Turbochargers on Diesel Engine Performance

Before discussing the impact of EBS technology on diesel engine performance, it is illustrative to look at the basic diesel engine first, remembering that nearly all diesel engines today are turbo-charged. It should also be noted that all current turbo-diesel engines are real examples of downsizing, since naturally aspirated engines of comparable power would have to be much bigger in displacement and size. The fuel economy of a turbo-diesel vehicle is about 50% better than that of a comparable gasoline engine powered vehicle (4). In spite of the higher torque at lower speeds and much improved power density at high speeds, there are still questions about the response of the turbo-diesel engine. The use of variable geometry turbocharging has greatly mitigated issues of transient response. The discussed EBS technology provides the promise of even further improvements, and is being evaluated on many engines and vehicles. EBS enables additional fuel to be burnt and if the control system is set to maintain the same air/fuel ratio as the baseline engine, an increase in low speed torque by as much as 50% is possible. Figure 12 shows the effect on steady-state full load torque versus engine displacement at different engine RPM for a fixed EBS input power of 2 kW. Under this limited input power, the EBS

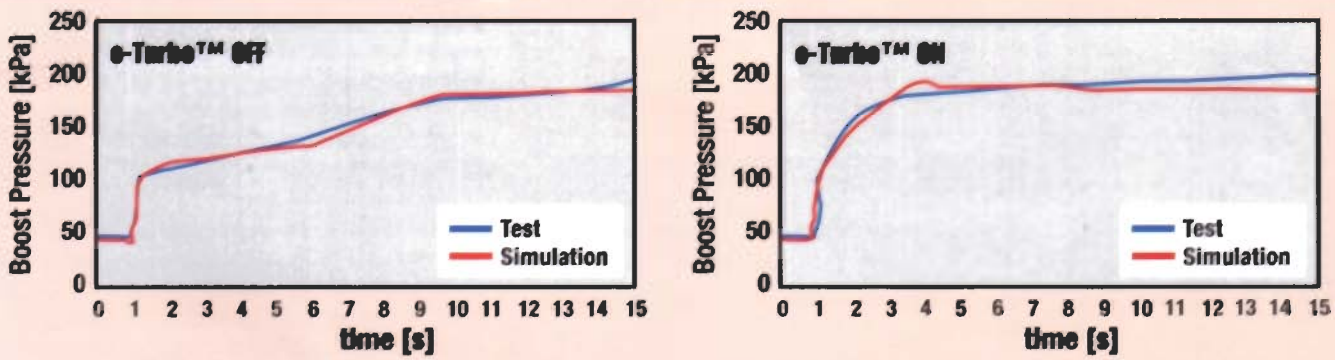


Figure 6: Agreement of simulation and testing data concerning the boost transient (gasoline engine with e-Turbo™, 2 l displacement, 1600 kg car weight, full load acceleration from 1000 rpm)

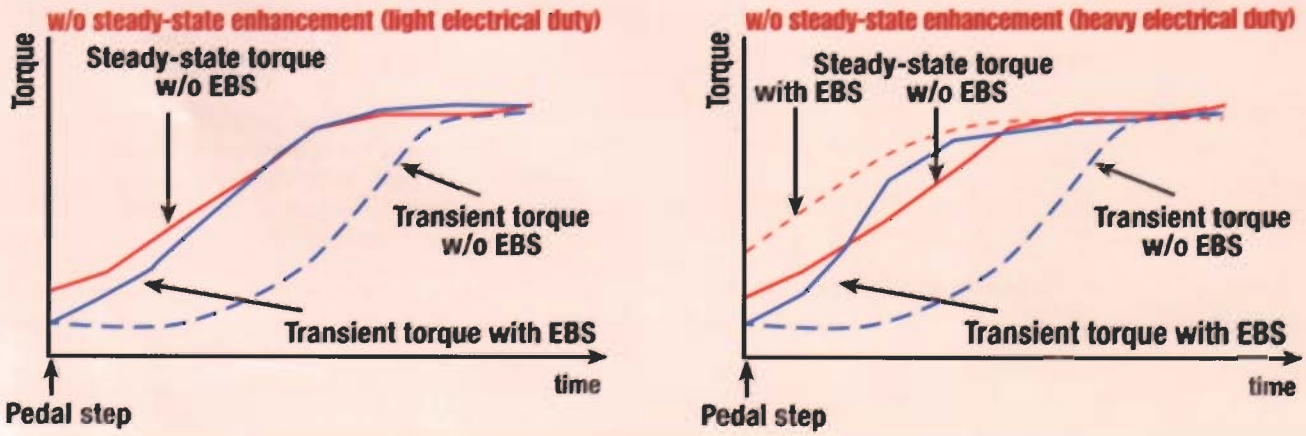


Figure 7: Improvement and shaping of torque following low and high electrical duty modes

Figure 8: Torque increase with EBS: Measurements on three gasoline engines (mean data averaged and normalized)

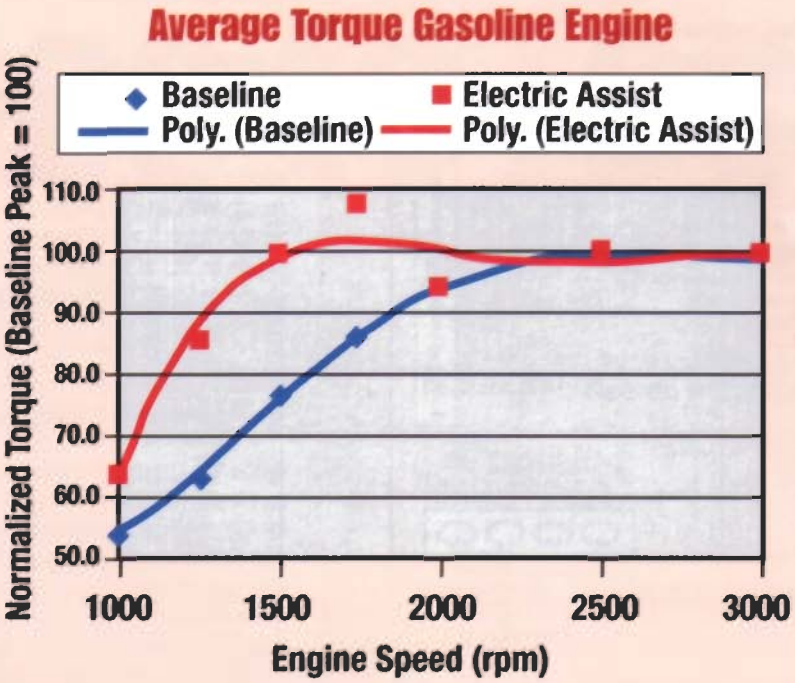


Figure 9: Torque increase in % (steady-state at 1500 rpm)

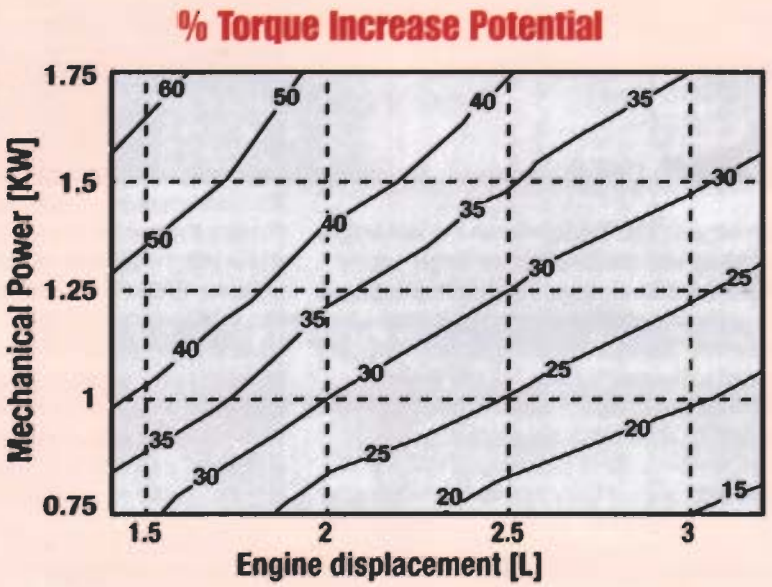
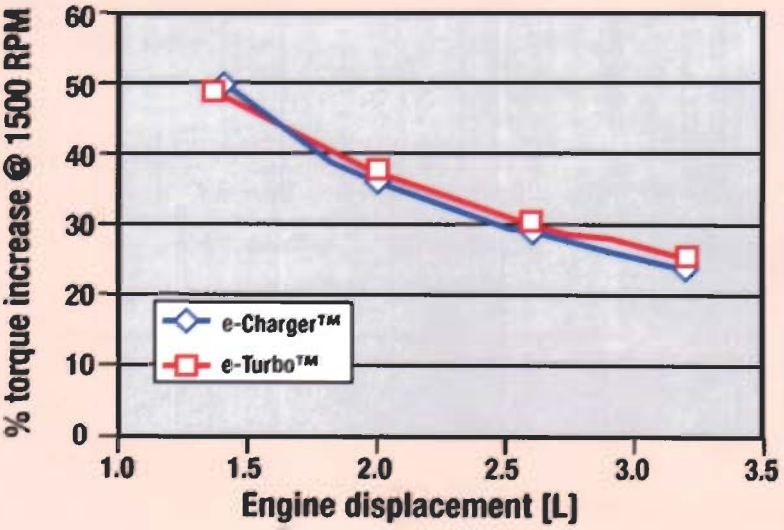


Figure 10: Comparison of torque increase for e-Turbo™ and e-Charger™ at 1.8 kW electrical power and 70% motor efficiency



benefit increases with decreasing engine size and lower engine speed. EBS benefits could be further increased, particularly for larger engine sizes or higher engine speeds, if additional electrical input power is available from the vehicle electrical network (VEN). In term of transient improvement, the time to boost predicted at different engine speed is depicted in Figure 13 for a 2.0-liter diesel engine. The improvement under 1500 rpm with EPS is particularly significant. The earlier torque increase was also predicted during acceleration of a vehicle (1600 kg).

Back to back test measurements during acceleration indicated 5 to 10% improvement (reduced delay in reaching the target speed, based upon gear and RPM starting conditions) on the EBS powered vehicle vs. same vehicle with a conventional VNT turbocharger.

Comparison of e-Turbo™ with e-Charger™

As seen in the previous sections, both e-Turbo™ and e-Charger™ offer a similar level of performance. However, trade-offs in terms of extra package and installation cost requirements have to be considered in selecting between the options: the space to accommodate a larger e-Turbo™ turbocharger vs. extra valves, ducting, hoses for the add-on e-Charger™.

In addition to these considerations, further functionality of turbo braking and electricity generation may lead to the conclusion that the e-Turbo™ is a better, integrated solution. But to achieve this better solution, it must be recognized that the e-Turbo™ requires more technical know-how, particularly related to the high-speed electric motor and thermal management.

Integration of EBS into the Vehicle's Electrical Network

Finally, for either EBS solution, whether it be e-Turbo™ or e-Charger™, the vehicle electrical network integration will be a key to success. EBS may require high peak currents to be supplied by the VEN; and this in turn will be likely to create unacceptable system voltage drops. To assess these integration challenges, analytical models of EBS/VEN integration have also been developed. Figure 14 shows the analytical results for two EBS input power scenarios: 100% power provided by the alternator, and 100% power provided by the battery. It can be seen that the alternator supply is an unacceptable solution because, due to alternator braking, an engine torque lag effect is created. Conversely, although the battery supply scenario provides better performance, it has significant implications for battery size, life, and VEN architecture.

It is clearly expected that short-term changes to current 14V network will be needed for EBS to succeed. In the long term however, there is an important opportunity to integrate EBS with 42V architectures to fully optimize system performance and benefits.

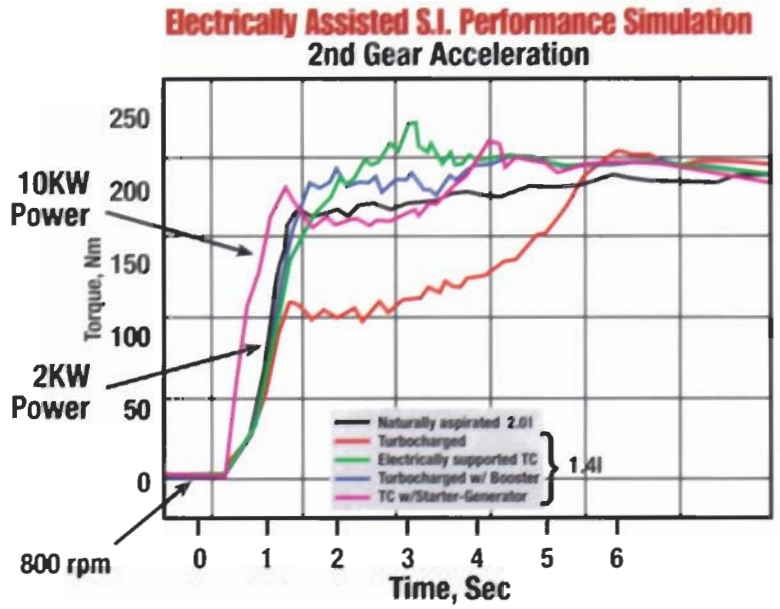


Figure 11: Simulation with e-Turbo on a gasoline engine

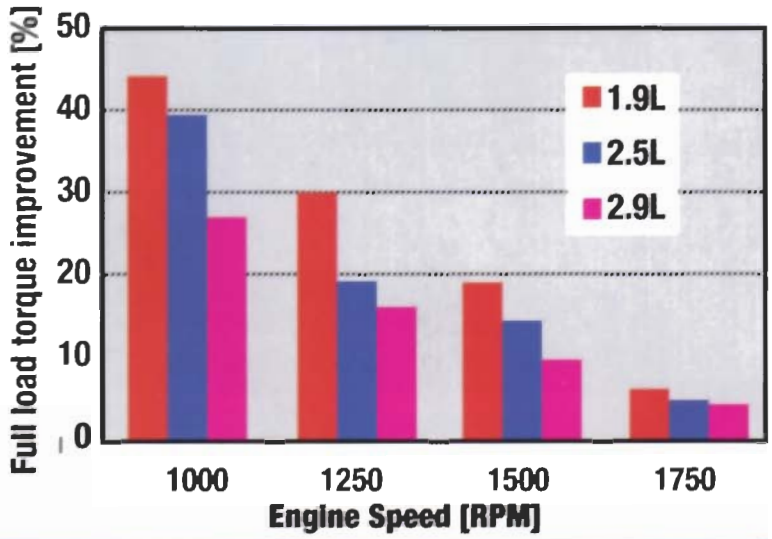


Figure 12: Torque increase with e-Turbo on diesel engines with three different displacements

Conclusions

The torque developed by an engine is directly related t the amount of air supplied because it takes 9,000 to 20,000 liters of air per 1 liter of fuel for gasoline and diesel engines. Therefore, boosting has an important beneficial effect on both types of engines. In gasoline engines, boosting enables engine downsizing and consequently an important improvement in fuel economy Data comparing turbocharged vs. non-turbocharged engines show a 10% improvement in fuel economy for turbocharged engines (effect of downsizing). In diese engines, boosting reduces emissions and improves torqu and power density, making possible the installation in small vehicles such as passenger cars and light vans. In both types of engines, low speed torque and turbo inertia still present issues of vehicle response, particularl during acceleration. Clever management of the wastegat and variable geometry turbocharging as well as lower inertia wheels address this problem, but complete mitigation can only be achieved with Electronic Boosting Systems. These systems make it possible to supply "ai on demand," allowing the shaping of the transient torqu curve to ideal levels. This enables the full realization o engine downsizing benefits with simultaneous improvement in the driving experience. However, in order to fully achieve these benefits, integration with the vehicle electrical network must be addressed. The electronic boosting systems e-Turbo™ and e-Charger™ provide similar performance. In either case, torque increases of up to 40% are achievable below 2000 rpm But, although it requires more technical know-how, the e-Turbo™ has the potential to provide a better integrated solution with enhanced functionality.

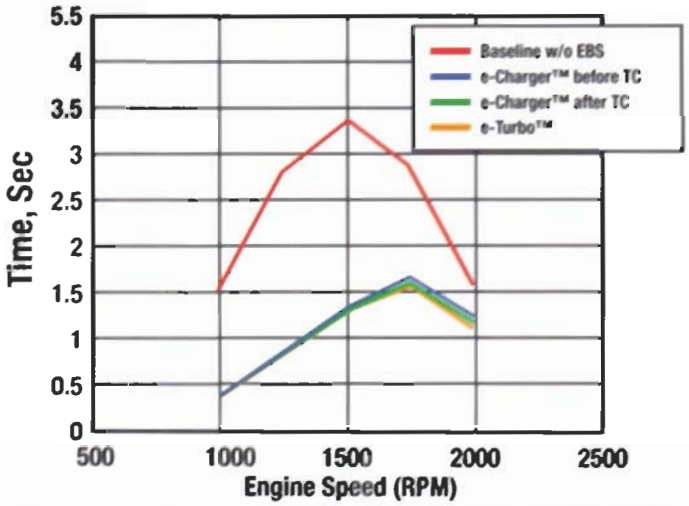


Figure 13: Time to full boost with different electric boosting systems

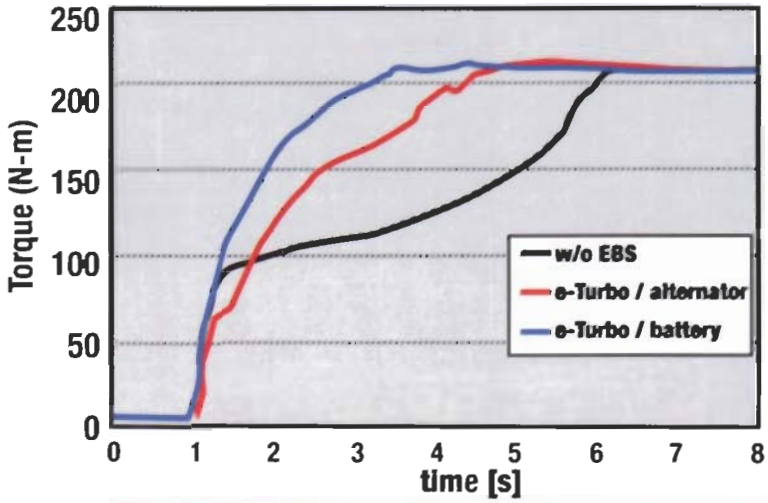


Figure 14: Effect of different EBS energy supplies on engine torque

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Article from MTZ 63 (2002), Nr. 9, S. 716–725

Garrett Supplier Profile

Wescast

Wescast Industries Inc. is the world's largest supplier of exhaust manifolds for passenger cars and light trucks. The company designs, develops, casts and machines high-quality iron exhaust manifolds for automotive OEMs. Wescast has sales and design centers in Canada, the United States, Germany and the United Kingdom, as well as sales representation in France and Japan.

The Company operates seven production facilities in North America, including a 49% interest in United Machining Inc., an accredited Minority supplier in Michigan, and a 50% joint venture interest with Linamar Corporation in Weslin Autoipari Rt. "Weslin", a Hungarian based supplier of cast iron exhaust manifolds and turbocharger housings for the European light vehicle market.

Recently, Wescast entered the turbocharger components and the integrated turbo-manifold market by combining Wescast's exhaust manifold expertise with best-in-class turbo-boosting systems manufacturers. In additon, Wescast has recently moved forward with their diversification plans by entering the brake and suspension component business.

BUILDING WINNING RELATIONSHIPS

Multi-million dollar investment pays dividends

Partnership built on shared values of quality and innovation

Competitive advantage comes from many sources within Garrett, but equally important is the role played by partnerships built throughout the supply chain.

Innovation, flexibility and quality are the key factors increasingly demonstrated by Garrett's manufacturing partners – and all of these attributes are reflected in an emerging relationship with Wescast Industries, the world's largest manufacturer of exhaust manifolds for passenger cars and light trucks.

Wescast's presence in Europe has been augmented through its joint venture investment in a multimillion dollar production facility in Hungary as part of a worldwide growth and diversification strategy. Its strength in its core market has led the company to look to new, but related, product areas, notably turbocharger housings and catalytic converter containers.

" Dialogue with Garrett initially originated in 1999 at the suggestion of some of our customers because they recognized the potential synergy in our businesses and the benefits of them working together," comments Rick Williams, Wescast Director of Product Design and Development.

"It quickly became clear that as companies we share many common goals – both companies want to develop rapidly; both invest heavily in appropriate technology; and both are demanding of suppliers. We also share a commitment to partnership with customers and the development of manufacturing processes underpinned by culture a quality."

The embodiment of Wescast's business philosophy can be found in Oroszlány in Western Hungary, twenty kilometers from the Budapest-Vienna motorway, where a 20,000 m² state-of-the-art integrated casting and machining facility employs 223 people. The site embraces the same business culture evident in Wescast across the globe.

"People are the biggest source of our competitive advantage," says Rick Williams. "Our people are better informed and consulted than any other company in our area of activity – they know our business, know our customers and as a result, show long-term commitment to the company."

This participative management system is embraced in the concept of HEART (Helping Everyone Achieve Rewards Together), which seeks to treat all stakeholders fairly based on four principles – equity, participation, identity and competence.

These principles support Wescast's growth strategies, which revolve around capitalizing on core competences, achieving operational excellence, increasing global sales and developing customer solutions through focused research and development.

" We have made a significant investment in our future in Europe with our joint venture facility in Hungary. In the case of Garrett, we have also invested in new design software and new people – in this way we aim to deliver on our own plans for the future by helping create success for our customers."

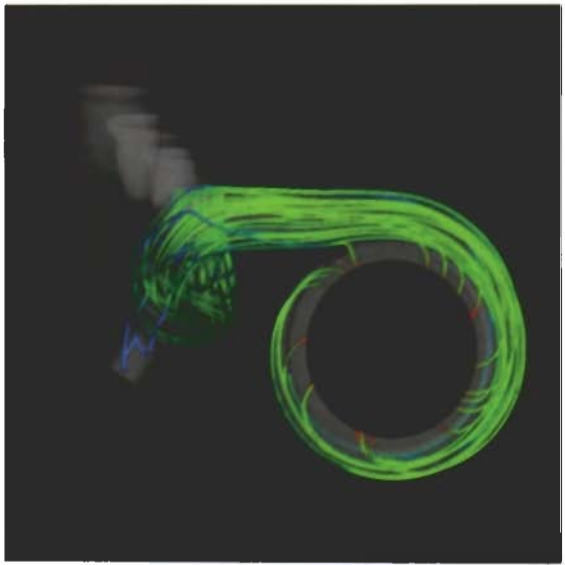
The Wescast Approach

Manifold with Integrated Turbocharger Volute

A solid model of the turbo-manifold is created followed by a suite of analysis software tools and testing procedures used to evaluate and optimize the integrated system.

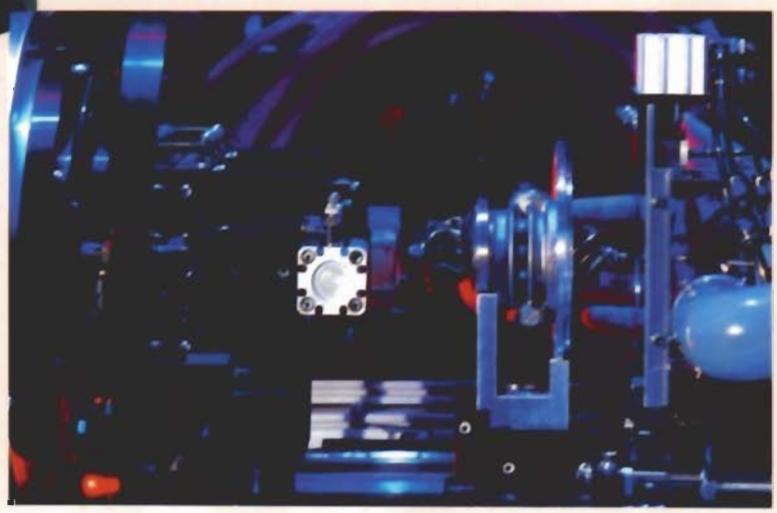
The first step is to use Computational Fluid Dynamics (CFD) software to investigate the effects of varying key geometric parameters on the distribution of static pressure, velocity, and flow quality in the turbine volute. This allows the designer to assess the effects of several design and manufacturing variations on the behaviour of the manifold and the turbine-volute system without having to make multiple prototypes. The weight, durability, and thermal behaviour of the components can then be evaluated and optimized using Finite Element Analysis (FEA) on the virtual models.

At the final stage of the design cycle (validation), physical models are made and tested. Key tests would include efficiency mapping and durability assessments. The result is an integrated exhaust manifold and turbocharger offering compact packaging in the vehicle with superior performance and durability.



ROBOTIC R

Investment in Automation



EVOLUTION

• Integrating the human hand with robotics

• Investment focuses on quality and better use of skills

Garrett's drive for quality in manufacturing is being underpinned by a massive investment in automation across its plants in Europe.

Leading the way is Atessa, an 11,000 m² facility that outputs about two million turbochargers every year for passenger cars.

At the heart of Atessa's introduction of robots into the manufacturing process is a determination to improve competitiveness by bearing down on cost, improving overall quality and reducing waste.

The investment is focused on two key processes in the production cycle – the Vibration Sorting Rig (VSR), which balances the central housing rotary assembly, and the Shaft Wheel Assembly (SWA).

Both are critical to overall product quality and Garrett decided that investment in automation in these areas would deliver maximum business benefit while also improving the daily routines of the workforce at Atessa.

Enter the 6-axis anthropomorph robot which can replicate exactly the movement of the human hand. The machine provided an almost seamless integration into the plant's existing processes while, at the same time, doing away with the repetitive manual tasks that were monotonous for operators and of quality concern.

Now the operators concentrate on more skilled activities – setting the robot parameters and managing output while the machinery performs the product handling, assembly and quality checks.

Atessa's experience shows that with automation comes better quality, less waste and improved cycle times – which in turn has translated into shorter lead times for customers.

Atessa will eventually benefit from 19 robots, but across Europe an investment program is underway that will see 44 robots in place in four plants. For Garrett, greater automation is entirely in keeping with its Six Sigma Plus ethos – for customers the promise is for even higher levels of service.

" Performance is the key core value in our business. We believe in a culture of high expectation and ambitious goal setting – empowering employees in a way that adds value to their working lives and which, ultimately, contributes to the success of our customers."

Natasha Prehu, Garrett Human Resources Director Europe

PEO

"Empowerment is not a goal or tool, but a leadership philosophy."

This statement sums up the Garrett ethos in supporting its 3,400 people across five countries in Europe as they strive to meet the needs of customers.

Wherever the location, whatever the activity undertaken, the common factor that glues the whole Garrett operation together is customer focus and a determination to deliver year on year improvements.

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Six Sigma Plus principles set the quality context for employee performance, providing a structure and reporting process for every activity that leads from product design through to manufacture and delivery. Such a commitment to quality is also enshrined in Garrett's brand values – technical leadership, innovation and customer service. The profile that this engenders makes Garrett a top target for potential employees, which is good news at a time when the company is actively recruiting for engineers to support its gasoline and e-boosting activities.

The Garrett culture results from a commitment to teamwork at every level – with co-workers, between departments, with suppliers and, of course, with customers. The result is a productivity improvement year on year.

"The company commits to at least one week of training every year for every single employee," says Ms Prehu. " Learning is a critical tool to drive change and knowledge is considered our most powerful asset. In Garrett learning takes many forms but all focus on finding ways of performing better through training and education and partnering with our customers and suppliers."

" Our move to a teambased structure means that all our employees associate much more closely with the needs of our customers and ensure that, as a business, we are able to respond in a much more flexible way to their requirements," says Ms Prehu.

Every site in the Garrett network shapes its own culture according to local influences but all share Garrett's overriding aims and objectives. These targets are defined in terms of team performance at a local level and relate directly to outputs for each customer; visual management helps people focus on these goals; and a measurement matrix keeps track of progress.

" We are progressively moving towards one common approach, which absolutely is the involvement and empowerment of people for the benefit of customers."

EMPOWERMENT

Teamwork creates better customer focus

Commitment to learning supports high performance ethos

Teamwork – Customer Focus

Garrett's focus on the needs of its customers is founded on its team-based approach to customer service and continuous improvement. There are 10 cross-functional teams – one for each of Garrett's major customer accounts – led by a team leader who, in effect, is the eyes, ears and voice of the customer within the company. This focus enables Garrett to align its activities with the processes, procedures and expectations of car manufacturers, tailoring them to mesh as closely as possible with the aims of its customers. Such commitment enables the company to fine-tune the management of its downstream planning, engineering and production programs.

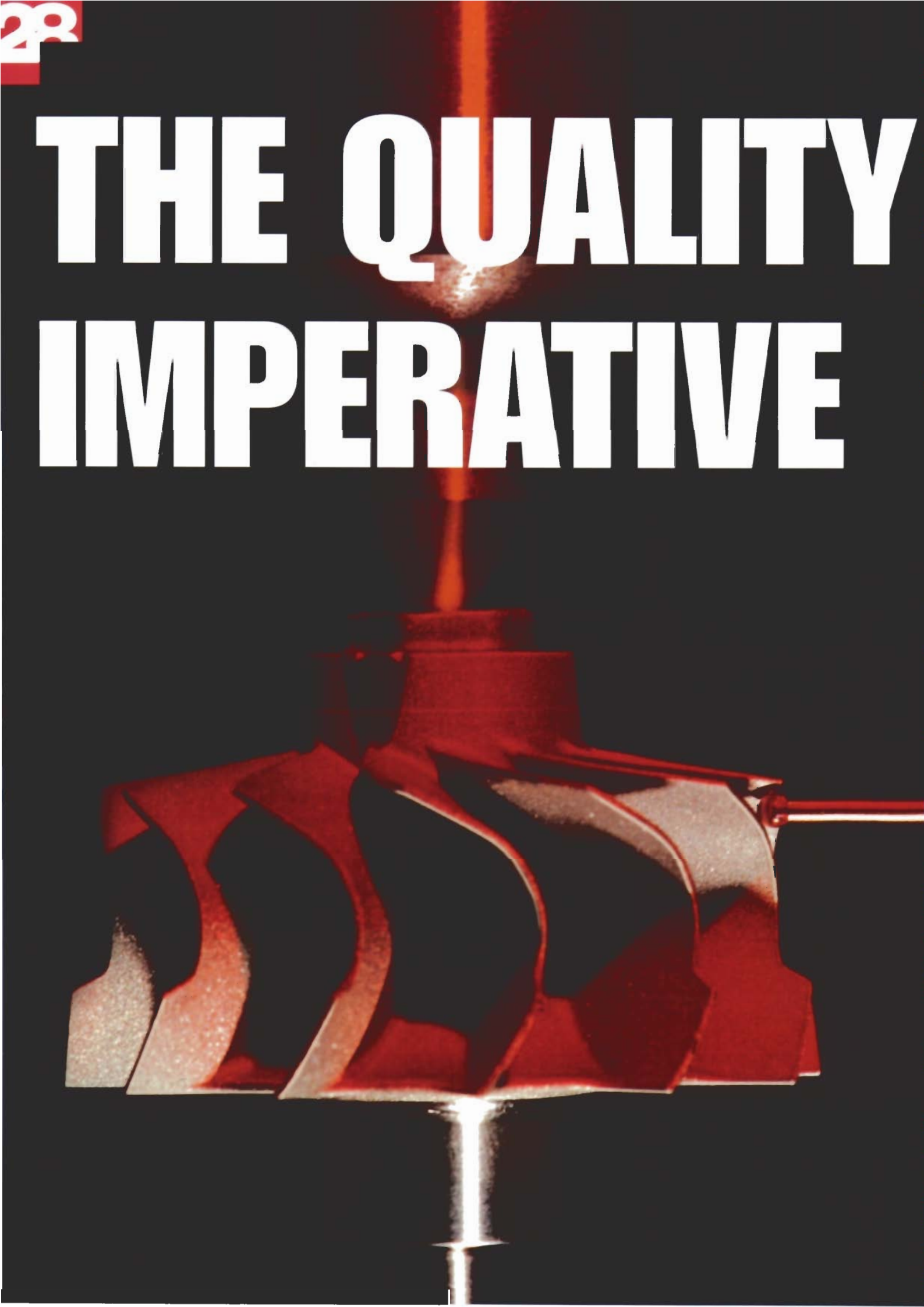
The teams operate across locations (across continents if necessary) and across functions – supply chain, engineering, quality, manufacturing, sales, finance... Each team is a small enterprise in its own right, expected to perform to targets established by Garrett in line with its Six Sigma Plus ethos and to the ultimate satisfaction of the customer. Such a structure provides maximum flexibility in responding to internal production issues, developing new opportunities and adapting to changes in market conditions whilst maintaining a continuous focus on the most important element of the business – the customer.

Teamwork

Teamwork – Manufacturing Excellence

Manufacturing facilities traditionally focus on process – on the methods that deliver product in the most efficient manner. At Atessa, Garrett has created a culture that places people – customers and the workforce – at the heart of its manufacturing activity. While process is clearly of paramount importance, improvements at Atessa come about as a result of the eyes of the workforce being fixed unerringly on the customer. This ethos manifests itself on the shopfloor in High Performance Work Teams (HPWT) – the heartbeat of a plant that outputs almost two million turbocharger units every year. The concept of HPWT came out of a Garrett Total Quality Leadership initiative in the mid-90s when Atessa was preparing for a period of sustained growth. The plant decided to move to a shopfloor structure that would empower individuals by clearly linking their activities to the product delivered to the customer. Eighteen distinct teams now operate across three shifts at Atessa. Each team is focused on meeting the requirements of a specific customer and channels all its energies into delivering on targets relating to output, quality, safety, cost and service. The team meets formally every month to discuss customer issues, to analyze results and to suggest solutions to any problems. A supervisor monitors progress against objectives and works closely with a process facilitator in focusing team activities and removing any obstacles to performance improvement. For Atessa, HPWT is delivering true customer benefit. Since 1998, rejects have reduced by almost one third and output per person per shift has more than doubled.

THE QUALITY IMPERATIVE



Closer customer collaboration

How can a company really understand the needs of its customers? At one level, Garrett applies the principles of Six Sigma to ensure that the quality of its mass manufacturing operation meets the requirements of its customers. This approach seeks to minimize all the variables in the production process and eliminate waste to enhance customer satisfaction, but how can Six Sigma add greater value to relationships with customers. For Garrett, the answer lies in Design For Six Sigma.

Design For Six Sigma catapults the whole quality ethos to the very beginning of the product development stage, to establish at the outset the customer priorities. The aim is to factor in as soon as possible the customers' key requirements, to measure Garrett's capacity for delivering the project and to plan accordingly.

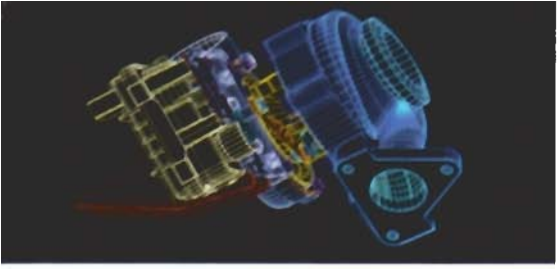
The Design For Six Sigma program is currently being rolled out among all of Garrett's New Product Development engineers in 40-hour training modules that focus on real projects in a cross-functional team environment.

The starting point for such projects is understanding fully the needs and priorities of the customer. This includes the relative importance of particular product features, the critical nature – or otherwise – of the materials to be used, the engineering tolerances – factors that can influence Garrett's approach to product development and manufacture. Such an open dialogue enables Garrett to manage its manufacturing capabilities to meet the specific needs of the product – so ensuring that any modifications happen at the design stage rather than in the machine room.

Garrett engineers utilize a number of tools to help shape how the company can best deliver competitive advantage on behalf of its customers.

Some of the tools include a QFD (Quality Function Deployment) which is used to capture the importance of the customer requirements and to understand what features of the product are important to meet these requirements. A thought Process Map is used to identify which of their actions actually add value to the customer – and which do not.

Garrett sees its investment in Design For Six Sigma as a natural extension of its main Six Sigma program – engaging the customer at the earliest possible opportunity and further enhancing the benefits of partnership.



TURBO TALK

What technological advantage does Garrett gain from being part of Honeywell?

One of Garrett's key strengths is its aerospace heritage – a connection that is just as strong today as it was when the company was formed more than 70 years ago.
This aerospace connection delivers significant benefits to customers through advances in aerodynamics, high temperature materials, thermal analysis, balancing technologies and oilless bearing systems. Turbochargers are the close cousins of modern jet power plants, minus combustors, and in certain respects actually exceed the design parameters set for large turbofans.

With Honeywell comes years of experience in technologies that impact on the design and configuration of boosting systems. Beyond this, Garrett's access to Honeywell laboratories is unlocking maximum potential in electric and electronic controls, particularly in relation to e-boosting technology.

How does Garrett approach the development of new technology and products?

A technology needs to serve a specific purpose in a given context. This purpose is customer benefit. It is vital, therefore, that at Garrett we share the aspirations of our customers and clearly understand what they need to serve their end users.

This demands a very close working relationship to define the best product development strategy. Our task is to develop the key technologies which will help our customers to stay one step ahead. We must provide them with a variety of customized technologies that suit their specific needs. Such an approach is not only built on technological development but on dialogue, consultation and trust – on shared values.

What will be the key environmental drivers for Garrett and its customers over the next decade?

World vehicle ownership is projected to increase from 122 vehicles per thousand people in 1999 to 144 vehicles per thousand in 2020. In the future there will be much more legislation directed at reducing emissions, while promoting alternative fuels and new vehicle technologies.

Garrett is already working closely with many partners (see IFP story) as passenger car manufacturers focus on meeting the stringent standards of engine exhaust gas emissions already adopted in Europe by downsizing their engines to improve fuel economy and CO_2 emissions.

How is Garrett working with its supplier network to improve the service to customers?

Quality is the prime concern of Garrett both in the relationships with customers and the development of the supplier network.

The company is committed to forging meaningful partnerships with the 208 suppliers in Europe to ensure that there is a continuous focus on common quality standards because, ultimately, this is how we deliver on our promises to customers.

There are a number of initiatives underway to support this process, including a digitization program that maximizes opportunities for the electronic exchange of data, while a culture of continuous improvement is promoted through shared benchmarking and performance analysis – all designed to enhance service to customers.

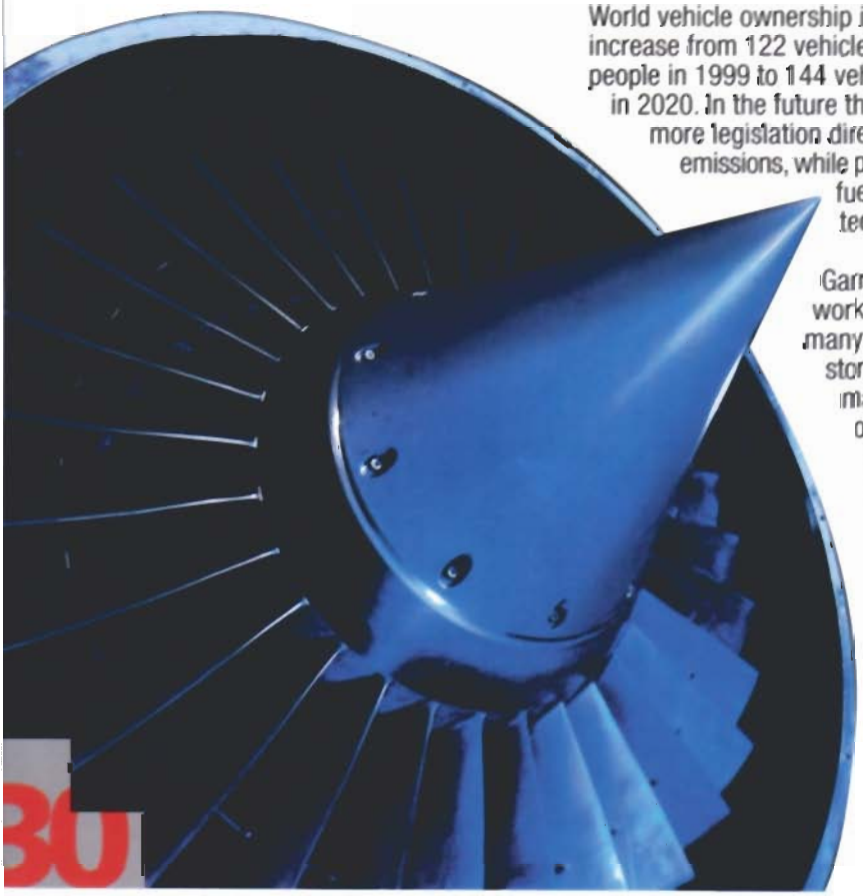
How does Garrett see the future for commercial diesel boosting in Europe?

Engine boosting has long been an integral part of commercial diesel applications. The future direction of boosting systems will be primarily driven by engine exhaust gas emissions legislation.

Garrett technology will help customers to balance the need for NOx and Particulate emissions control with excellent engine performance and fuel economy.

Looking ahead boosting systems will increasingly utilize variable nozzle turbines (VNT), exhaust gas recirculation (EGR) and various configurations of exhaust aftertreatment.

In this way, Garrett will ensure that turbocharger design features satisfy the needs of end users for higher boost pressure and long term durability while at the same time meeting the requirements of environmental legislation.



The Garrett way: Another dimension in the fun of driving

Garrett turbochargers allow engines to be smaller, lighter and more efficient. Achieving more performance, less fuel consumption, reduced emissions and increased safety. Providing the boost your engine needs.

Garrett®