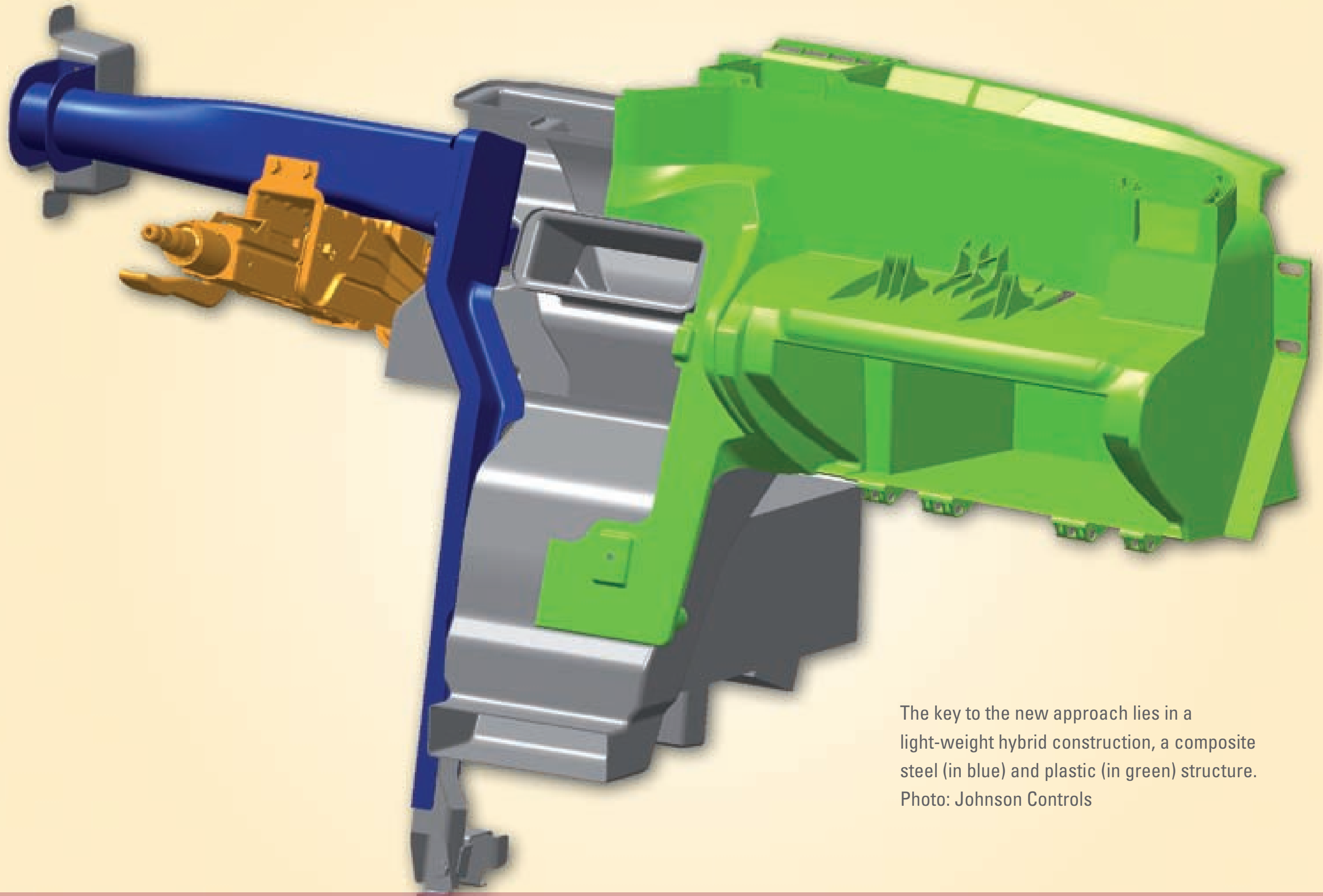

The key to the new approach lies in a light-weight hybrid construction, a composite steel (in blue) and plastic (in green) structure. Photo: Johnson Controls

Cross-interface Development
The Key to a New Cockpit Design

Traditionally cockpits are developed in parallel: suppliers produce the relevant components according to product specifications and deliver these to the automaker, where individual parts are assembled to make a cockpit. With each order, the parts supplier gains experience, resulting in continuous product enhancement and increasing sophistication until components become technical masterpieces. But what happens when, despite outstanding components, the overall quality of the entire system can no longer be improved? In this case new approaches are required, presented here by Johnson Controls and ThyssenKrupp.

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1 Introduction

The companies ThyssenKrupp and Johnson Controls have combined their areas of expertise within a single cooperation project: ThyssenKrupp Steel as a specialist for steel, components, assemblies and bodywork, ThyssenKrupp Presta with experience in the area of steering columns, and Johnson Controls as an expert in the development and production of instrument panels and cockpits. According to the motto "Three areas of expertise. Two companies. One solution.", they initiated a cross-interface system approach with the project name: EcoSpace Cockpit. A patent is pending for this concept.

Their goal was to develop an integral cockpit structure concept, in which the components and processes, in comparison with conventional structures, are coordinated with each other and complex functions are improved. Whilst taking commercial aspects into consideration, this new support structure should be characterized by low weight, high integration potential and optimum structural properties – such as superior strength, high natural frequency (dynamic stiffness) and good crash performance.

2 Development Goals Exceeded

The two companies thus developed a complete cockpit structure, integrating instrument panel and steering column with the support structure. This new concept not only simplifies the assembly process for the automaker. In fact, compared with conventional structures, this cost-effective structure is distinguished by high dynamic stiffness and lightweight construction, producing a 20 % weight saving. Moreover, it is much stiffer than a conventional system – 46 Hz instead of around 39 Hz.

In crash situations the concept even stands up to the worst case scenario: the benchmark for a frontal crash is a combination of the highest requirements of the Euro NCAP and the American FMVSS208. For example, the companies chose the higher speed of 64 km/h from the European standard, instead of 48 km/h for America. From the American regulations they selected the condition that occupants are not wearing seatbelts. This results in higher reaction forces – for example, 10.2 kN for knee impact. All simulations produced positive results. They also demonstrated that the properties of the new structure are so homogenous that it makes no difference on which side the collision takes place: crash performance is identical on the driver and passenger sides.

3 Material Analysis for Optimum Material Selection

But how was this improvement achieved? The solution is a combination of many success factors. One essential element of the new structure is selection of the right material. Conventional structures are either made of steel, magnesium/aluminum or, in isolated cases, also entirely out of plastic. Generally, plastic has a lower weight compared with steel and magnesium cross-car beams, while steel cross-car beams are superior to both materials in structural terms. Magnesium and plastic possess an impressive integration potential (connection to other components). In short, these approaches each have their advantages and disadvantages. The challenge was to develop a customized hybrid structure, which combines the advantages of all materials.

4 The Solution is a Hybrid of Plastic and Steel

Even today, many initially associate lightweight construction with the materials aluminum and magnesium. It is often ignored that successful lightweight construction depends on many factors, in addition to the density of the materials in question. If the available space is small, for example, then aluminum and magnesium perform worse in terms of stiffness requirements. The two materials can not offset their lower stiffness compared with steel due to a lower modulus of elasticity (stiffness) by means of cross section enlargement. They can only achieve this through greater sheet thicknesses. Component weight increases as a consequence.

Since the modulus of elasticity indicates whether a material will meet stiffness requirements (E value), the ratio of E value to density determines the comparative advantage of a material. Figures show that steel, aluminum and magnesium possess roughly the same lightweight potential for stiffness requirements, **Table 1**. Aluminum and magnesium are expensive materials, so a hybrid of plastic and steel came into consideration for the new structure.

5 Selection of the Suitable Plastic

The two materials are used where their specific advantages have greatest effect. Plastic has its strengths in the integration of functions. Long glass fiber-reinforced polypropylene demonstrated its advantages over other potential materials, such as SMA and PC/ABS, with physical properties like high energy absorption. Good aging properties also speak in favor of this material. Some characteristic values may be found in **Table 2**. The air ducts (defrost and comfort), the connection to the airbag, and the glove box are integrated directly in the plastic construction and also take on a reinforcing functions.

6 Innovation with Optimized Use of Steel

The steel material is positioned where good structural properties are required. In order to reduce the proportion of metal and there-fore the overall weight of the component, steel is used only on the driver side – in the form of a T³ (Thyssen Tailored Tube) profile. This means half of the cross -car beam may be spared. The new construction is a closed profile tube with load-dependent geometry, to which the steering column may be directly attached. Integrated in the structural cockpit assembly, it can absorb forces in all directions (X, Y and Z). The steering column connection is integrated ideally in the structure.

ThyssenKrupp Presta is responsible for the steering column. There was a challenge in the direct steering column connection to the cross-car beam: up to seven components are required in the tradi-tional construction. The new concept saves on six components. Connection of the steel and plastic support structure is achieved by plastic covered steel inserts, which are secured to the T³ profile by laser welding. This connection is high-strength and rigid, providing an optimum, stable fixing.

7 The Joining Process Plays an Important Role

In order to achieve a weight reduction of more than 20 %, other factors such as join type, type of production and component design, structure concept and restrictions are decisive, as well as the choice of the suitable material .

Cockpit cross-car beams of shell construction require the joining process step to connect both shells. Normally, conventional welding procedures are available here, with a differentiation made between point-shaped and line-shaped welds. The resistance point welding procedure is used in high-volume production. Possible procedures for line-shaped joins with addition of heat include MIG, MAG, plasma and laser welding. These are also used in body and chassis construction. Depending on the type of join selected, a certain amount of energy (heat) is transferred to the component. Possible structural changes in the heat-affected zone or component distortion on account of the heat input are negligible as their influence may be kept within tolerable limits by the choice of joining process and the sequence of joining operations.

With regard to dimensioning of the cross-car beam, the influence of a continuous line-shaped connection on the dynamic stiffness in comparison with point-shaped connections, **Figure 1**, is decisive. The result of the natural frequency determination is clear: in order to achieve the same first natural frequency, the cross-car beam needs a 14 % greater sheet thickness with a point-shaped connection than with a line-shaped one. This means that any first natural frequency desired by the customer can be achieved with less material usage when a line-shaped join connection is used.

8 Closed Profile as an Influencing Factor in Lightweight Construction

Another factor in lightweight construction was the question of whether a closed profile cross-car beam should be preferred to a classic shell solution, **Figure 2**. So as to realistically compare the two different concepts, the companies developed both cockpit cross-car beams under identical construction space restrictions.

For the half-shell solution they chose mini flanges each with a width of 5 mm. Line-shaped joins were used throughout on both sides of the half-shell components. On account of the identical construction space, the cross section depth (x direction) of the half-shell over the entire longitudinal axis (y direction) is less than that of the closed profile by 2 x 5 mm flange width. This means that the cross-car beam has to be welded with the mem-brane surface of the vertical strut, causing membrane vibration (on vibrational excitation).

In order to achieve the same performance of the closed profile with 1.4 mm, a sheet thickness of 1.8 mm is required for the cross-car beam with shell construction due to the reduced cross section and membrane vibration. Regarding weight advantages, the companies prefer the closed profile for the new cockpit structure.

Nowadays in modern bodies we find a whole range from profile reinforcements in the A-pillar and in the roof frame, to the largely complete profile design. The question of when a closed profile can be used advantageously depends on the particular case. Since the connection of two closed profiles is still associated with challenges in terms of joining, conventional processes are employed in the cockpit structure concept. The connection of a tube, for example, with a half-shell of the A-pillar is already state of the art. This basic principle is therefore also used with the new cockpit structure.

Table 1: Material properties of steel, aluminium, magnesium to evaluate the material-specific light weight potential (source: Johnson Controls)

	A_{80} [%]	E-Modulus *10³ [N/mm²]	Density [kg/dm³]	E/Density
Steel	17-45	210	7.85	26.75
Al	7-12	70	2.7	25.93
Mg	2-5	45	1.7	26.47

Table 2: Material properties of some plastics (source: Johnson Controls)

Material Properties	Evaluation regarding	SMA GF15	PC+ABS-GF10	PP-LGF30
Density [g/cm³]	EN 323	1.12	1.19	1.1
E-Modulus [N/mm²]	EN 63	3000	2200	4100
Tensile Strength [N/mm²]	EN 61	40	40	52
Impact Strength [kJ/m²]	DIN 53453	10	25	48
Energie Absorption [J]	ISO 6603	2	4	9

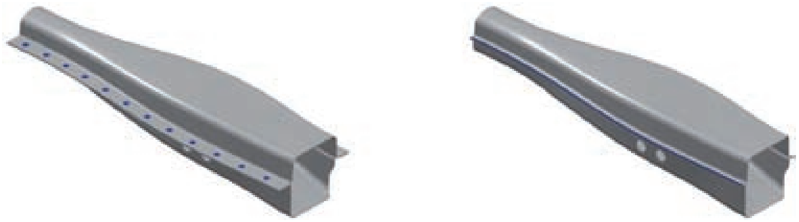

Figure 1: Cockpit cross member in shell construction with different joining technologies to evaluate the influence on the light weight potential – spot welding (left) versus laser welding (right). Photo1 - 6: ThyssenKrupp Steel

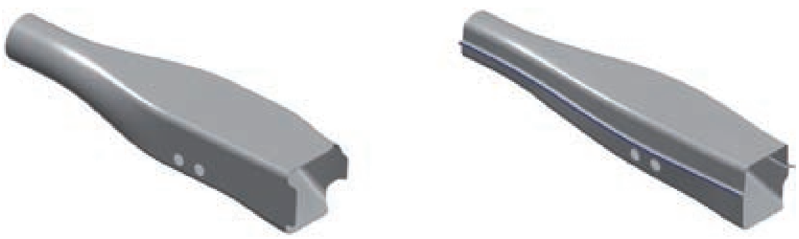

Figure 2: Cockpit cross member as closed profile in comparison to a shell construction solution to evaluate the influence on the light weight potential

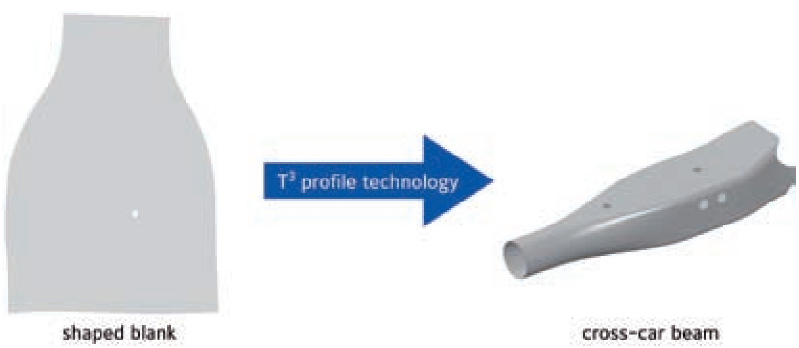

Figure 3: Manufacturing of a cockpit cross member from a shape blank by the utilisation of T³ technology

9 Another Success Factor – the Shape

After a closed profile showed itself to be advantageous for the requirements of a cockpit cross-car beam, the companies faced a decision about the shape: is a rounder or a more rectangular cross section advantageous for meeting stiffness requirements? The suitability of a cross section for torsional stressing may be evaluated with the assistance of the torsional moment of inertia, W_t. The construction space available for a cross-car beam in the cockpit of a vehicle is described by the contours of adjacent units (components). So that the basic comparative advantage of a cross sectional profile may be evaluated in model form, the following assumptions are made: a constant cross-car beam cross section and a construction space with constant cross section. Then a differentiation is made between two cases – on the one hand a quadratic, and on the other a cylindrical construction space.

Assuming a quadratic construction space, this is identical with the largest possible square cross-car beam cross section. The largest possible circular cross section touches the construction space tangentially from within. If sheet thicknesses for both cross sections are chosen for identical torsional moment of inertia, then a circular profile would be around 2 % heavier than a quadratic hollow body. With a cylindrical construction space, the largest possible circular cross beam cross section is, as in the first case, congruent with the package space, while the square touches the package space at four points from within. In this model, the circular cross section leads to a weight advantage of 26 %. In conclusion, depending on construction space boundary conditions, a circular profile may be slightly disadvantageous or significantly better than a square cross section. Here, the weight was correlated for an identical W_t.

However, this does not answer the question of what percentage greater stiffness is offered by one of the two cross sections, given the same mass. Help is provided by Bredt's 2nd formula, which shows that, assuming constant cross sections and identical sheet thickness, the torsional moment of inertia of a circle is 62 % greater than a square, given identical mass, **Figure 3**.

Since this result was derived analytically, this correlation applies for all cross section sizes. Applied to a real component, this means that a cockpit cross-car beam should, as far as possible, employ circular cross sections. The companies also implemented this finding with the new cockpit structure. It adapts ideally to construction space restrictions: everywhere where a circular profile is best, it is also used. The new T³ technology makes this possible.

10 Innovative Production – the T³ Technology

The production method of a closed profile is another factor in lightweight construction. One means of manufacturing the Eco-Space cockpit cross-car beam is by high-pressure tube hydroforming (HF). If a conical semi-finished product is used here to manufacture a cross-car beam, a maximum plastic circumferential strain of 38 % is necessary. Even soft steel with very good forming properties would fail when faced with such requirements. The solution would be an intermediary annealing process, but this gives rise to additional costs. On account of high strain requirements, the HF process needs a semi-finished product sheet thickness around 38 % greater than with the T³ process in order to produce a comparable natural frequency. The sheet thickness distribution of an HF component is also non-uniform due to the process. This leads to a higher component weight than with the T³ process.

A much more economical method of producing profiles is offered by the 3rd generation Thyssen Tailored Tube profile technology (T³) developed by ThyssenKrupp Steel. Depending on loading conditions, cross section changes from circular to square may be integrated along the length of a single profile in different dimensions without intermediate annealing processes. A cockpit cross-car beam produced with this technology has maximum plastic strain of 12 %.

Welding profiles to one other is still a challenge for mass production. The use of closed profiles, however, is also often hindered by high production costs. ThyssenKrupp Steel has pressed ahead with the development of a new procedure for the production of profiles. An additional requirement was encountered at an early stage on the way to greater component complexity: the need for lower production costs through short process chains and integrated processes. As long as two years ago, this led to the creation of the procedural one-step-solution (T³) for highly structured hollow profile components.

11 Six Becomes One

The usual production process for a complex hollow profile consists of the steps: profile molding, longitudinal seam welding, pre-forming, bending, high-pressure tube hydroforming, in addition to end- and hole-cutting. Each of these steps requires a production operation with corresponding systems engineering, transfer units, operating staff and relevant cost rates. In total, this amounts to six steps.

With the T³ profile technology, the finished component is created from a shaped blank by a compact unit incorporating all shaping steps and laser welding, **Figure 4**, therefore combining, at best, all six steps into one. This profile technology was used for the first time to manufacture a near production-ready cockpit cross-car beam for the EcoSpace cockpit and was presented at the IAA 2007. The advantages of the T³ cockpit cross-car beam are obvious: compared with the traditional shell construction, less components are used and weight is reduced thanks to a flangeless profile and load-oriented profile design.

Furthermore, impressive stiffness is demonstrated on account of a closed profile. Thanks to the high degree of process integration offered by T³ profile technology, hollow profiles may be produced economically.

12 EcoSpace May Be Integrated Into All Automobiles

Together, all the previously mentioned points lead to the desired weight advantage. Ultimately, however, the question must also be asked: in which models can this concept be integrated? The air conditioning system is a central unit which takes up a relatively large amount of package space in the cockpit, **Figure 5**. To

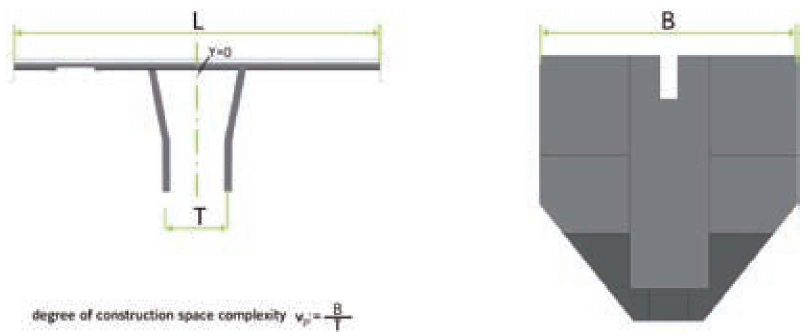

Figure 4: Definition of a package complexity level for cockpits of passenger cars

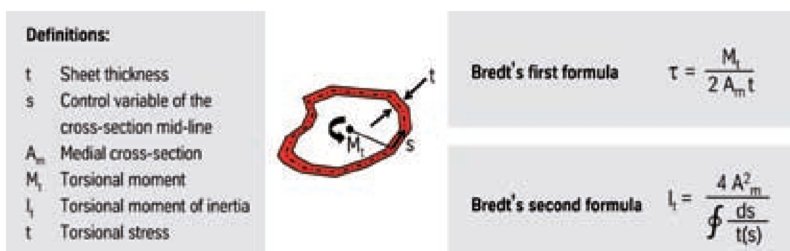

Figure 5: Utilization of Bredt´s first and second formulae to evaluate types of cross-sections for torsional stress. Photo: ThyssenKrupp Steel

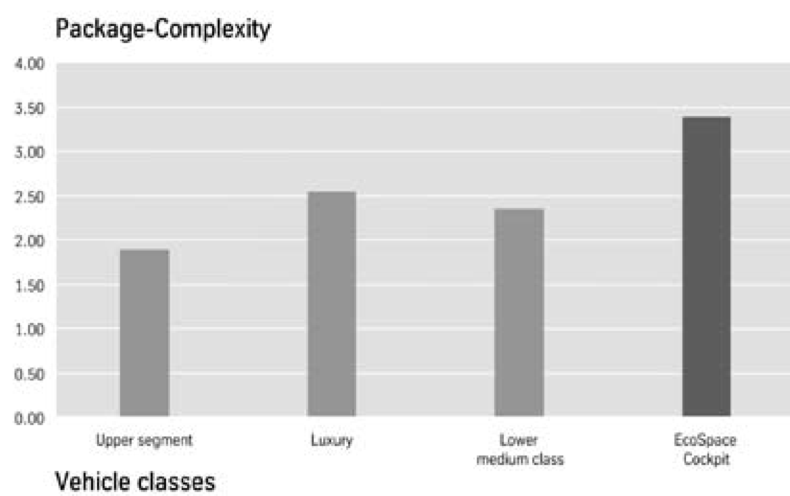

Figure 6: Level of complexity of different vehicle classes

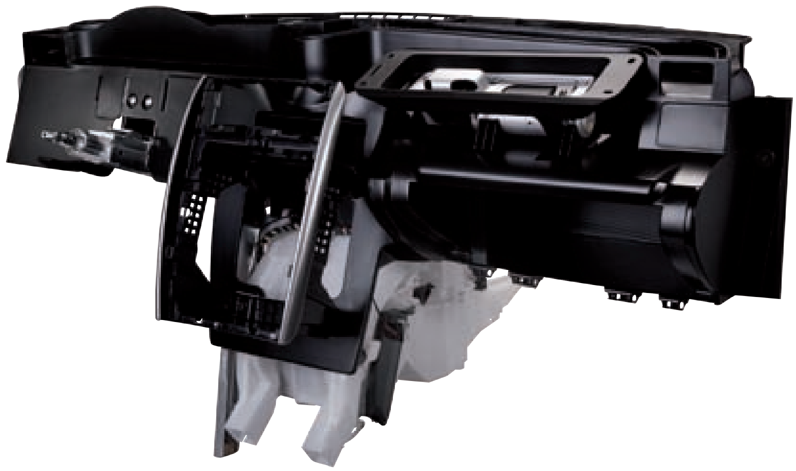

Figure 7: Concentrating the main structure on the driver side allows new options for different designs, particularly on the passenger side. Photo: Johnson Controls

a certain extent, smaller components may be positioned freely, whilst the air conditioning generally occupies a central position with respect to the tunnel (Y=0). The greater the air conditioning space requirement relative to cockpit width L (distance between the A-pillars), the more difficult it is for other units to find the necessary construction space. Smaller units are therefore expected to be able to adapt to a certain extent to the available space.

In contrast, any changes to the air conditioning system itself are avoided if possible for cost reasons. So as to evaluate the construction space problem covering different vehicle segments, the companies introduced a degree of construction space complexity relating the width of an air conditioning system B with the tunnel width T. If this value is 1, the air conditioning can be positioned between the diagonal struts of a conventional cockpit cross-car beam.

The higher the degree of complexity (greater than 1), the more construction space is taken up in the driver side, assuming symmetrical component alignment. The requirements also increase for developing a steel support structure conforming to the construction space, which ensures a high first natural frequency with low material use. **Figure 6** illustrates the degree of construction space complexity for vehicles of different segments. In the executive and luxury segment, air conditioning systems occupy a smaller proportion of the whole construction space, so additional units may be integrated. The degree of construction space complexity for the reference mid-range vehicle thus represents the worst case scenario for the development of EcoSpace, proving that the concept is generally suitable for, and adaptable to, extreme construction space conditions. Therefore, it may be concluded that the new cockpit structure is transferable to other construction space restrictions, such as sedans.

Whilst automakers benefit from assembly and system advantages, designers and consumers may also take pleasure in the new concept. As the main structure is located on the driver side, new design opportunities arise on the passenger side, **Figure 7**. This new structure could be used from the model year 2010. ■