

# Applications – Car body – Crash Management Systems

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## 4 Crash management systems

In the design of an automobile, a most important task is to minimize the occurrence and consequences of automobile accidents. Automotive safety can be improved by "active" as well as "passive" measures. Active safety refers to technology which assists in the prevention of a crash. Passive safety includes all components of the vehicle that help to reduce the aggressiveness of the crash event. Crash protection priorities vary with the speed of the car when crash occurs:

- at speeds up to 15 km/h, the main goal is to minimize repair costs;
- at speeds between 15 and 40 km/h, the first aim is to protect pedestrians;
- at speeds over 40 km/h, the most important concern is to guarantee occupant protection.

The term "Crash Management System" is generally used to describe the structural module consisting of the bumper and the related attachments which connect to the longitudinal beams of the car. Front bumpers are normally connected to the front longitudinal beam by a separate deformation element ("crash box"). Rear bumpers are, however, mounted directly to the rear longitudinal beam. But the bumper system can't be considered as an isolated structural module. Its design must be optimized taking into account the crashworthiness of the overall body structure, in particular the deformation characteristics of the safety cell and the crumple zones.

The purpose of the front/rear bumper system is:

- To absorb energy at the start of a crash and to guide the remaining crash forces into the rest of the body structure.
- At low and medium speed: to minimize the damage of the vehicle in order to reduce insurance cost.
- At higher speed: to guide the crash forces into the body structure in such a way that the probability for a disintegration of the body structure is low and the survival of the occupants is ensured.
- To meet the legal (as well as any higher, OEM-specified) requirements regarding the energy absorbing ability.

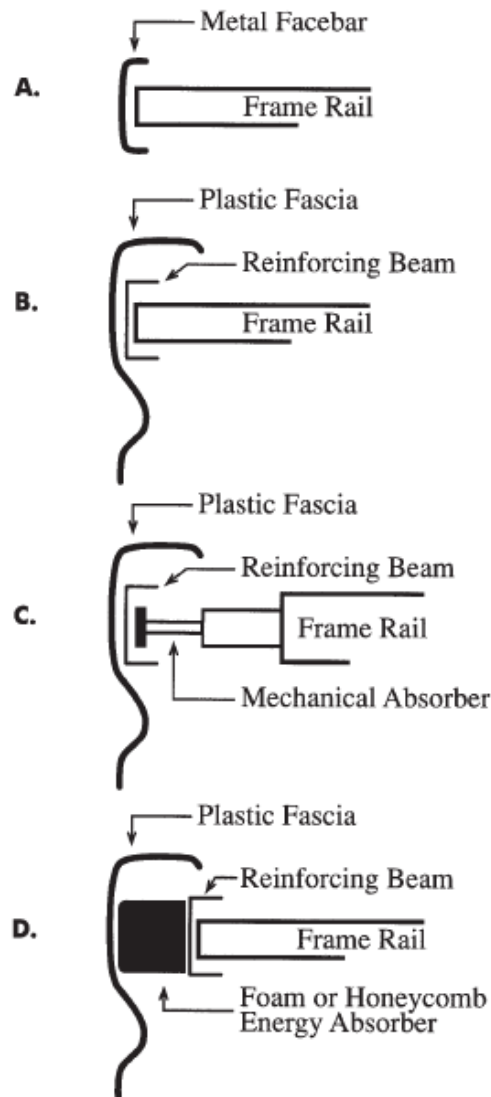
Another important (and often quite challenging) function of the front/rear bumper system is the towing function. This function requires both stiffness and strength.

Bumper design concepts have changed drastically over the last 20 to 30 years. In the past, cars were equipped with bulky, protruding bumpers to comply with the bumper standards of the 1970s and early 1980s. More demanding safety regulations and different styling concepts have resulted in new designs. Styling fashion has drastically changed the visual appearance of the bumpers. Whereas in the past, bumpers also served as a bright shiny decorative design element, they are now predominately concealed by a painted thermoplastic fascia. Since the late 1980s, most bumpers fascia systems are colour coordinated with the body.

The four basic bumper design principles (where specific features can also be combined) are:

- The traditional design with a visible metallic transverse beam that decorates the front or rear end of the vehicle and acts as the primary energy absorber in a collision. This concept has been popular in the past, but is seldom used today.
- The plastic fascia and reinforcing beam system that is fastened directly to the front/rear longitudinal beams. The reinforcing beam also serves as the first structural cross-member. While this arrangement leads to a small sacrifice in bumper performance, it increases the overall vehicle crashworthiness
- The system consisting of a plastic fascia, a reinforcing beam and mechanical energy absorbers. The energy absorbers are either of a reversible type ("shock absorbers") or deformation elements ("crash boxes") which are replaced after a crash.
- A system which includes a plastic fascia, a reinforcing beam and a propylene foam or a honeycomb energy absorber which is placed between the plastic fascia and reinforcing

beam. This approach offers in particular also an improved pedestrian protection (leg impact).



**Basic bumper design principles**

**(Source: autosteel)**

In principle, aluminium can also be used for both foam and honeycomb energy absorber. Aluminium foams as well as aluminium honeycomb structures offer excellent energy absorption characteristics and have been successfully used in prototype and niche applications. But up to now, there are no known applications in larger series. As an example, Faurecia is working on modules that combine an aluminium honeycomb structure with foam or plastic energy absorbers. The weight saved is 25% to 30% compared to all-metal solutions. Another benefit is the extra space gained by reducing the vehicle's front overhang.

## 4.1 Aluminium extrusions for crash management systems

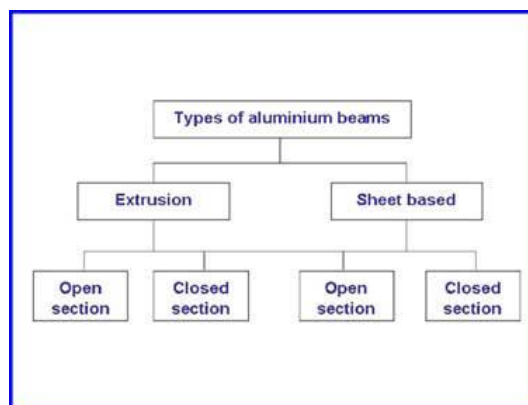
Crashworthy aluminium structures are the result of a total systems approach taking into account the benefits achieved by specifically developed alloy qualities, design concepts and appropriate fabrication methods. Vehicle safety considerations have led to a conceptual approach where the front and rear crash management systems are part of the structural load path. Thus compliance with the supporting longitudinal beams and other vehicle components must be recognized. The impact energy is typically distributed between the following standard elements of the crash management system:

- The beam where the impact energy results in elastic flexure and plastic deformation.
- The crash boxes which absorb energy by plastic deformation.
- Possible hydraulic spring-damper energy absorbing units that may fully or partially recover.
- The attachment brackets which may or may not plastically deform, depending on the design and the specific requirements.
- Possible foam inclusions which absorbs energy when compressed.

Furthermore a total system approach needs to take into account also the energy dissipation in vehicle rebound and tire scrub. Depending on the nature of the impact and the vehicle involved, different criteria are used to determine the crashworthiness of the structure. Today, crashworthiness is normally assessed using computer models and confirmed by experiments.

There are several factors that must be considered in the design of a crash management system. The most important factor is the ability of the system to absorb sufficient crash energy to meet the OEM's internal standard. Another important factor is the requirement to stay intact even at high-speed impacts. Weight, manufacturability and cost are also issues that must be considered during the design phase. Both initial cost and repair cost are important. The design of aluminium crash management systems is not covered in this section. For a detailed description of the design process, see the case study "Crash Management System" in the Design section of this manual.

The specific characteristics of aluminium alloys offer the possibility to design cost-effective lightweight structures with high stiffness and excellent crash energy absorption potential. In principle, bumper beams can be manufactured from rolled aluminium sheet as well as aluminium extrusions.



Today, 100% of the aluminium beams for crash management systems are extrusions, and more than 95% possess closed cross sections. Sheet designs exist only in niche markets. Sheet-based bumper designs were more prominent in the past when visible bumper beams were in fashion. Lightweight, polished and brightly anodized aluminium sheet and extruded bumpers could compete favourably with chrome-plated steel bumpers.



**BMW 325e sedan (produced for the North American market in 1984–1987) with elongated front and rear aluminium bumpers**

The main reason for the preference of the aluminium extrusion technology is the design freedom (i.e. the possibility to realize multi-chamber profiles with varying wall thicknesses) and the cost-efficiency. Aluminium profiles can be reliably joined by various methods and combined with other aluminium product forms as well as with steel or other materials to form complete structural modules. Because of the low cost of the extrusion tools and the small lead times for tool manufacturing, aluminium crash management solutions are highly flexible and enable fast and simple modifications to adjust for specific crash conditions reducing both development times and costs.

### 4.1.1 Bumper beams

Bumper systems were originally installed to protect the engine and radiator at the front of the vehicle. A modern front crash management system, however, has to fulfil a range of different additional requirements. The primary function of the bumper system is the protection of the vehicle in a low speed crash (no damage of functionally relevant parts and only minimal or no plastic deformation of any other vehicle component). In addition, the bumper system plays an important role within the total passive safety concept of the vehicle and has to satisfy all pedestrian protection requirements in particular in relation with lower leg impact (for SUV's also upper leg impact).

There are different legislative regulations in North America (IIHS test, Part 581, CMVSS 215) and Europe (ECE R-42) where the crash energy absorption capability and the kind of acceptable damage (functionality and appearance of the vehicle) is defined for low speed impact ( $\leq 8$  km/h) on a rigid wall and / or a pole. The elastic energy absorption capacity and the resistance to localised plasticity of the bumper beam are the major controlling factors in this case. Also important is the stiffness and energy absorption capacity of any additional foam (or other low speed energy absorption unit) placed between the plastic fascia and the beam.

A very important test requested by the insurance companies since 2010 is the new RCAR test. It incorporates a rigid bumper-shaped barrier fitted with an energy-absorbing material and cover. The barrier is 100 mm tall, mounted to an immovable surface and impacted at 10 km/h by the test vehicles. The given height of the barrier encourages automobile designers to use uniform vehicle bumper heights from the ground. The deformable energy-absorbing element favours designs that remain stable when impacting deformable material like another vehicle's bumper system. It also features a solid rear backstop that can replicate real world damage severities where under ride occurs. Lastly, it encourages designs that absorb crash energy while limiting intrusion into the vehicle.



**RCAR bumper test**  
**(Source: RCAR, 2010)**

In addition, there are various requirements for the verification of the incurred repair costs which are defined in Europe (AZT, Thatcham) for an impact speed of 16 km/h, whereas the IIHS test asks for crash tests at 8 km/h against the rigid wall as well as a pole. In these tests, the performance of the bumper system is rated on how much of the impact energy is absorbed in the front crash management system and how much is transferred to the surrounding vehicle structure resulting in structural damage.

Furthermore, there are specific regulations with regard to high-speed impact (up to 64 km/h) on a deformable barrier as well as pedestrian safety (e.g. Euro NCAP and related EC directives). Furthermore it may be necessary to consider additional demands defined by the respective car producers (e.g. no damage of the hood up to a certain impact speed).

This variety of requirements on the bumper system will generally lead to the selection of different design solutions when the technically feasible alternatives are evaluated under the overall condition of cost effectiveness.



**Front bumper of the Mercedes A Class model**  
**(Photo: Constellium)**

The primary advantage of aluminum bumper systems is their weight reduction potential of 30 - 50% compared to traditional steel solutions. As a result, a life cycle assessment shows significantly lower greenhouse gas emissions for the aluminum version over the lifetime of the car. The reduced weight at the end of the car – farthest from the centre of gravity – is also

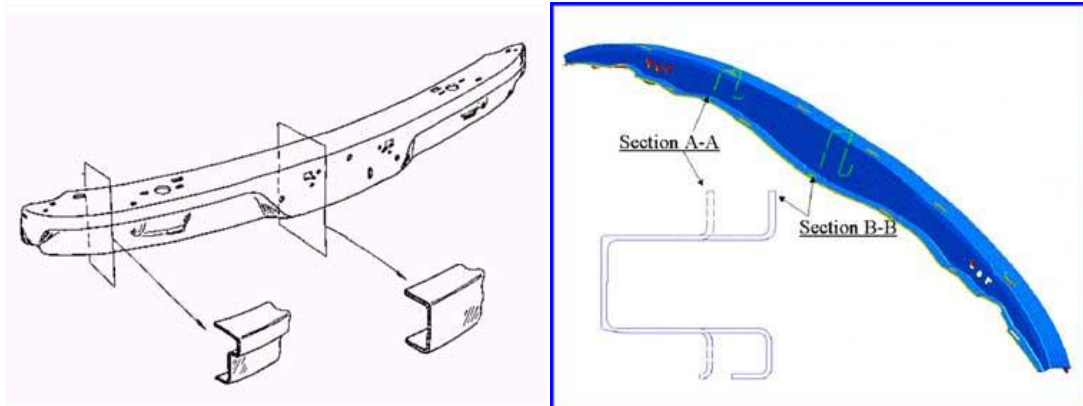


most interesting due to its direct impact on the axle load. A reduced load on the front axle generally transforms to a better driving performance due to the improved axle load distribution. In addition, front end body weight reduction counterbalances the trend towards heavier (more powerful) engines and the introduction of additional equipment for improved performance and comfort. In some countries (e.g. Germany), a decisive incentive for the introduction of an improved crash management system is also the possibility to achieve a better insurance rating, i.e. a reduction of the insurance cost for the final customer.



**Extruded aluminium bumper beams**  
(Photo: Constellium)

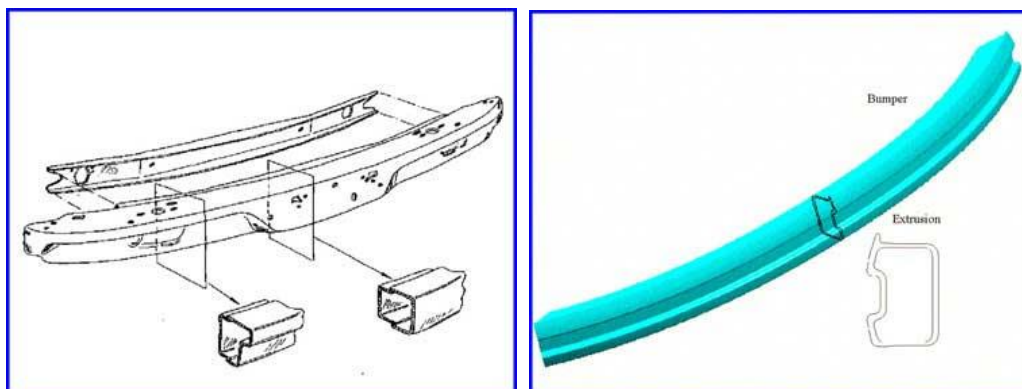
In general, aluminum bumper concepts involve a bent, extruded hollow beam which absorbs the total low speed crash energy (up to 8 km/h) through deformation and thus prevents any damage to the rest of the vehicle. Depending on the region where the vehicle is marketed, the different national and international standards may lead to the selection of different bumper design concepts.



**Aluminium bumper beams of the “open section” concept for the BMW 7xx (E38) model (left) and the Audi A4 (B4) (right)**

Designed to fulfill the European regulation ECE-R42, bumper beams of the “open section” design concept absorb the impact energy through elastic deflection. The cross section can be

varied along the beam to tailor the beam stiffness and moment to optimize the local energy absorption. The bumper beams shown above were produced using the alloy EN AW-7108; the extruded sections were stretch-bent and calibrated. Finally the holes were punched.

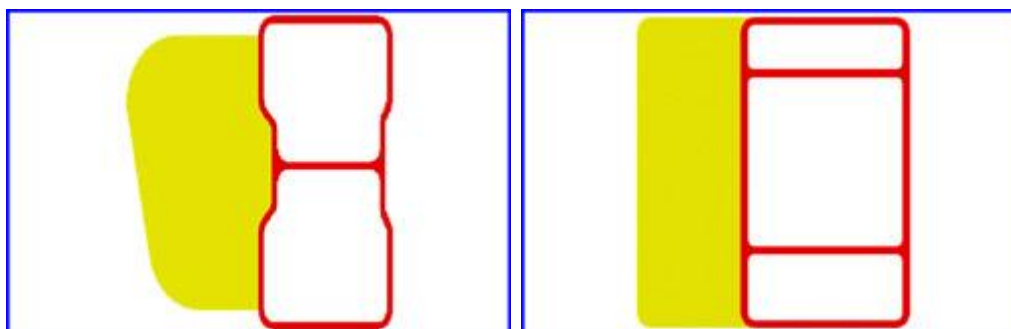


**Aluminium bumper beams of the “closed section” concept for the US versions of the BMW 7xx (E38) model (left) and the VW Passat (B5) (right)**

In order to fulfill the requirements for the US market (US FMVSS 581), the bumper beam design had to be improved. In case of the bumper beam for the BMW 7xx model, this was simply done by closing the open section with a properly formed sheet part. The closing sheet metal increases the cross-section and the beam can absorb much more elastic energy. The two parts are joined by welding.

Another solution is to replace the open section by an extruded closed single-chamber beam. Also in this case, the alloy EN AW-7108 was chosen. Both bumper versions for the US market were attached to reversible dampers, i.e. the impact energy is absorbed by the dampers as well as by elastic deformation of beam.

But also relatively simple multi-chamber extrusions combined with foam fulfil the North American bumper requirements (CMVSS 215 for Canada and FMVSS 581 for the US).

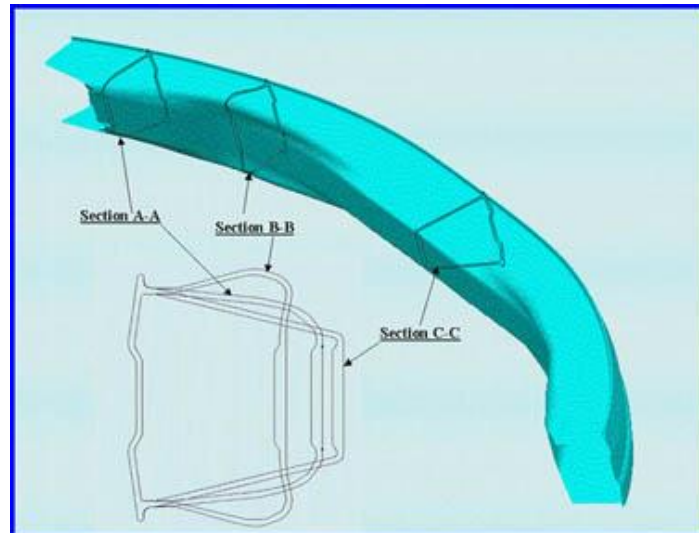


**Aluminium bumper cross sections which were used for the Oldsmobile Aurora / Buick Riviera (left) and the Toyota Avalon (right)**

The applied aluminium alloys were EN AW-6061 (for the GM models) and EN AW-7003 (Toyota).

The 15 km/h crash repair test (AZT test) which is used in Europe for insurance rating, however, asks for a more sophisticated design of the crash management system. An appropriate approach based on a closed flexible beam concept was used in the first generation of the Audi TT. The bumper beam was an extruded EN AW-7108 profile which was stretch-bent and subsequently formed. The varying cross section along the beam ensures an optimized absorption of the impact energy through a properly adapted stiffness and bending moment of the beam.

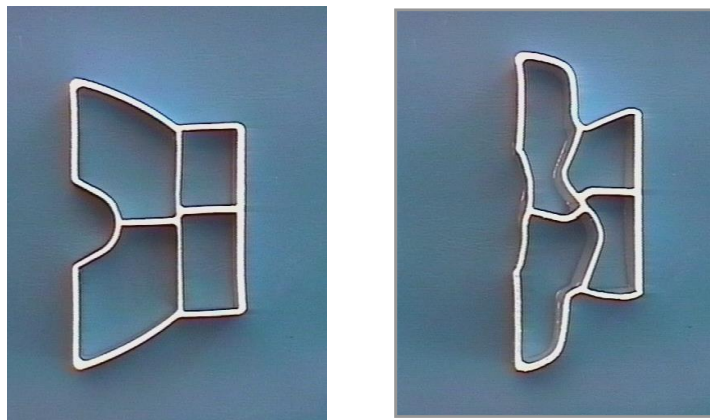




**Aluminium front bumper of the Audi TT, a closed flexible beam**

Another possibility is the use of a closed multi-chamber beam. In this case, the inner webs prevent early buckling and thus maintain the potential for further impact energy absorption during a crash by plastic deformation of the beam. With the multi-chamber cross section design, it is possible to fully exploit the unique potential of extruded aluminum sections. The freedom in the design of the cross section of extruded aluminum sections offers the possibility to develop tailor-made solutions based on the detailed specifications given by the OEM with minimum packaging requirements:

- The energy absorption characteristics can be closely controlled by an adequate cross section design (based on computer aided design and engineering methods).
- Multi-wall profiles offer high redundancy if a wall fails in a crash (most important to ensure the envisaged crash behaviour also in non-standard crash situations).



**Cross section design of multi-chamber aluminium profiles for controlled crash absorption characteristics**

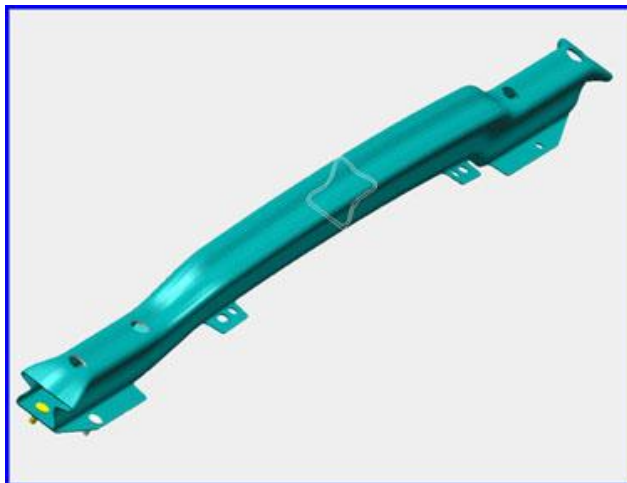
But the change from a single chamber to a multi-chamber profile requires the application of an aluminium alloy which is easier to extrude. Consequently, alloys from the 6xxx system are generally used for multi-chamber profiles. Popular alloys for bumper beams are today EN AW-6008 and En AW-6082. The extruded sections are subsequently stretch-bent and, if necessary, subjected to additional forming and machining operations.



**Front bumper of the Opel Corsa C (alloy: EN AW-6060)**  
**(Photo: Constellium)**

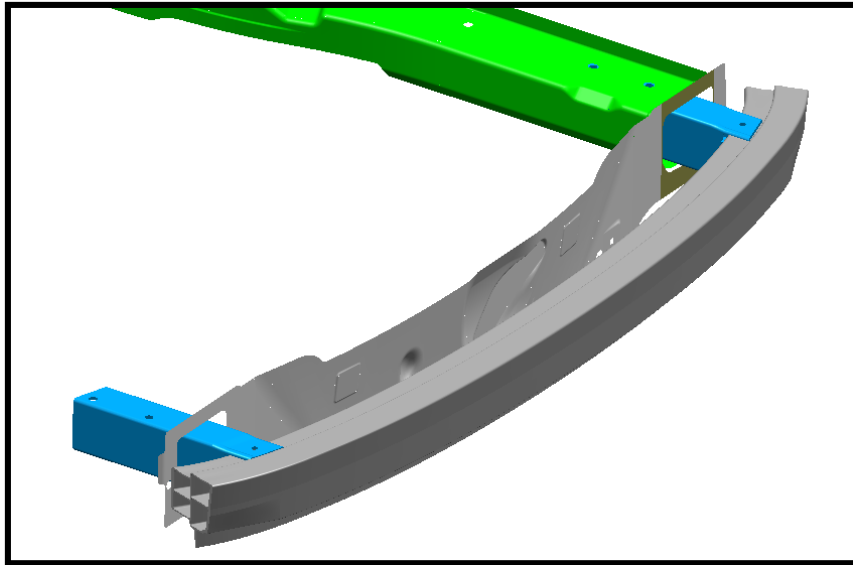
In general, front bumpers designed to meet the 15 km/h crash reparability test are not directly fixed to the front longitudinal member. Mostly, a deformation element is used to connect the bumper beam and the longitudinal beam. The deformation element (crash box) prevents any damage of the longitudinal beam and is easy to replace, thus the repair cost are drastically reduced.

On the other hand, rear bumpers can be attached directly rear longitudinal members and still fulfil the AZT insurance test. An extruded mono-block beam with a specially designed cross section absorbs enough energy to provide the envisaged insurance rating and integrates at the same time the brackets used for the connection to the rear longitudinal beam. The applied extrusion alloy was EN AW-7108; the extruded section was stretch-bent and formed. In a additional operation, the necessary holes were punched and the redundant webs were cut and removed.

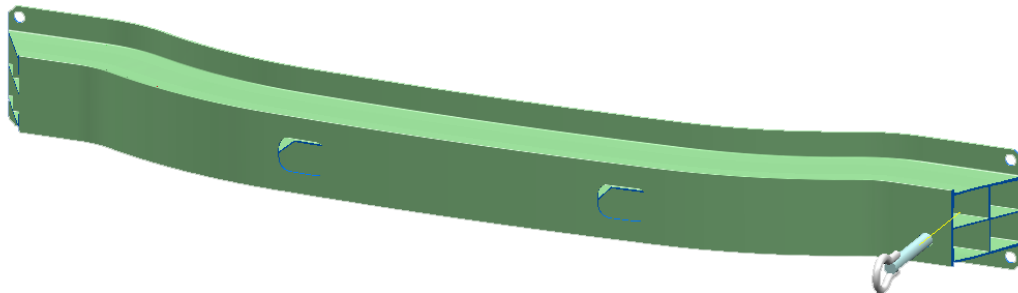


**Rear bumper of the Opel Corsa C**

Other solutions for rear bumper beams – based on the multi-chamber extrusion concepts – are also possible.



**Multi-chamber aluminium rear bumper beam for the Audi A6 (C6)**  
(Source: Constellium)



**Rear bumper beam for the Citroen C4 Picasso, alloy EN AW-6082-T6**  
(Source: Constellium)

### 4.1.2 Front crash management system

#### a) Design aspects and alloy selection

The front crash management system is a structural module where the individual elements fulfil carefully balanced functions. It consists of the bumper beam, the energy absorbing elements, the brackets and often a foam layer which is placed between the plastic fascia and the bumper beam. As soon as the impact energy exceeds the load which can be absorbed by elastic deflection of the beam (and the foam present in front of the beam), the crash energy is consumed by the bumper beam which is straightened and then plastically deformed. At higher crash loads, the energy absorbing elements take over (e.g. the crash boxes are plastically deformed) and only if the energy absorption capacity of the crash box is exhausted, deformation of the front longitudinal occurs.

In specific cases, the bumper beam can also be connected to the longitudinal members by brackets which do not need to have any energy absorption capability, but can be designed for

maximum functionality (unless plastic deformation is specifically desired). As an example, the bracket can be integrated into the reinforcing bumper beam (a one single multi-chamber section designed for high stiffness) and minimum weight (adaptation of wall thickness to local load).



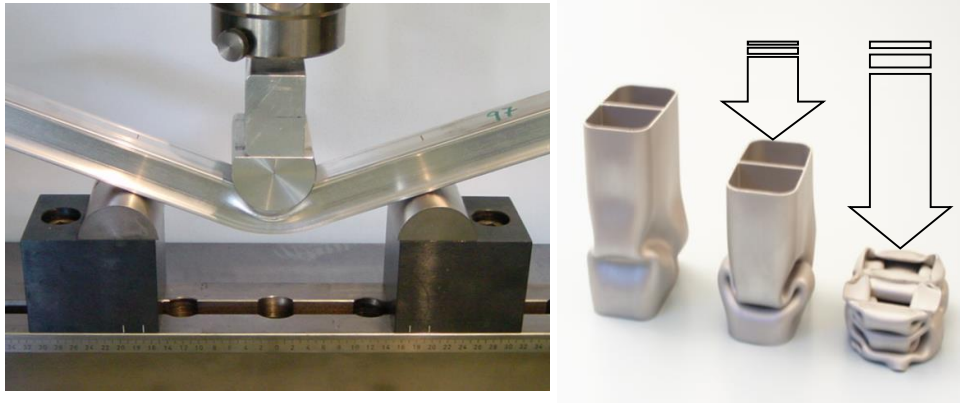
**Citroen C4 Picasso CMS front**

**(Photo: Constellium)**

The freedom in the design of the cross section of extruded aluminum sections allows the realization of different concepts for the front crash management system, depending on the detailed specifications given by the OEM. Intimate knowledge of the material characteristics including its crash behaviour and extensive design experience enable rapid product development based on computer aided design and engineering methods. Based on an assumption of the envisaged energy absorption characteristics, it is possible to calculate an initial geometry for each component (to be validated subsequently by laboratory tests). Taking into account the low costs of aluminum extrusion tools and the short lead times for tool manufacturing, new design concepts can be developed and tested in series production quality within a few months. Thus, aluminum crash management solutions are highly flexible and enable fast and simple modifications to adjust for specific crash performance.

Apart from the design, the performance of the crash management system is determined by the properties of the applied material. In principle, there are two basic two different loading situations: bending and axial crash. Depending on the loading condition, the material has to meet different requirements, i.e. different material characteristics must be optimized for excellent crashworthiness. Excellent bending characteristics ask for a high formability together with a high uniform elongation. On the other hand, for axial crush, the ductility of the material is most important together with a high amount of plastic deformation (folding without premature cracking).

Depending on the detailed specifications, various 6xxx alloys in different tempers are used. For bumper beams, the fully age hardened T6 temper is generally preferred, both for higher strength alloys (e.g. EN AW-6082) showing a fibrous microstructure (used for relatively simple cross sections) and for the lower strength alloy variants (e.g. EN AW-6060) which offer a finely recrystallized grain structure. For crash boxes, an overaged T7 temper is usually chosen; typical alloys for these applications are the medium strength alloys of the type EN AW-6008.



**Loading conditions for an aluminium extrusion in crash management systems: 3-point bending (left) and axial crash (right)**

**(Source: Constellium)**

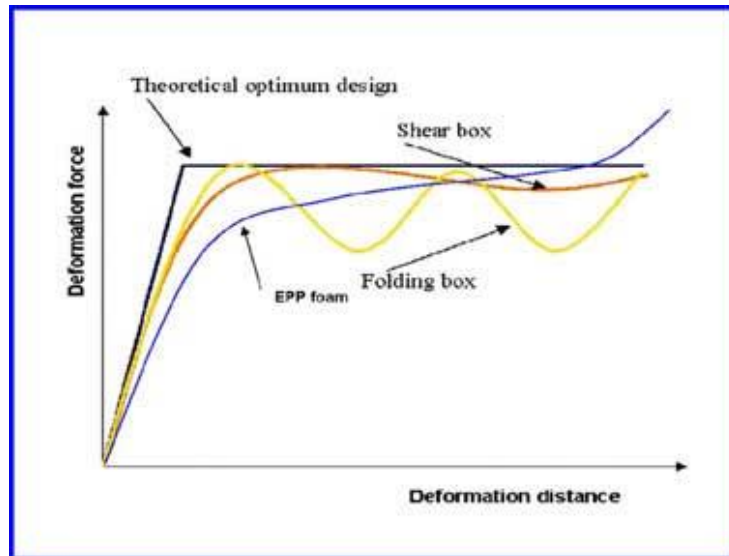
The failure mechanism of a crash management system, however, is often determined by very detailed local failure mechanism. Beside the crash loading conditions and the material properties, microstructural irregularities and local defects determine the actual mode of failure. This is important for example in welded structures where possible welding defects need to be taken into account. Also it must be kept in mind that welds in heat treatable (i.e. 6xxx) aluminium alloys exhibit a heat affected zone with reduced strength. For joints made with fasteners, the bearing strength of the aluminium often controls the joint strength and the failure mode rather than the strength of the fastener. Special attention, and sometimes additional reinforcement, must be used when designing the joints in an aluminium bumper system, i.e. one should try to protect the joints and shift the potential plastic deformation into regions away from the joints.

### **b) Deformation elements, in particular aluminium crash boxes**

The purpose of the integration of deformation elements into the crash management system is to control the level of force at the interfaces between the bumper system and the car body. They must prevent damage to the bumper system itself (low speed) and reduce damages to the rest of the vehicle structure (medium speed). Two types of energy absorbers are used:

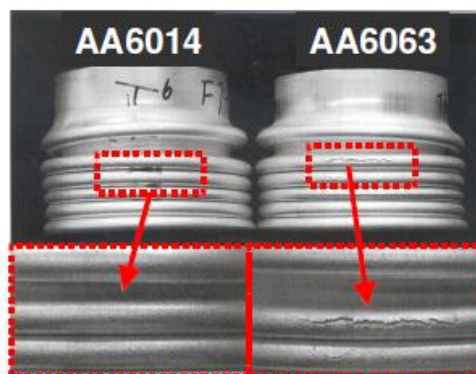
- Regenerative energy absorbers which can be used several times (e.g. dampers filled with viscous material or compressible materials (for example expanded polypropylene (EPP))
- Non-regenerative energy absorbers which can be used only once (e.g. folding crash boxes, shear crash boxes, tube in tube systems, metallic foams, etc.).

Depending on the type of energy absorber, different energy absorption characteristics can be observed.



## Typical performance of some energy absorbers

Aluminium is well suited for the design of lightweight deformation elements (i.e. crash boxes). An important prerequisite is, however, the selection of the proper alloy and temper. The aluminium crash boxes must be able to absorb the impact energy without premature failure, i.e. no fracture or formation of slivers, crack nucleation must be hindered as long as possible.



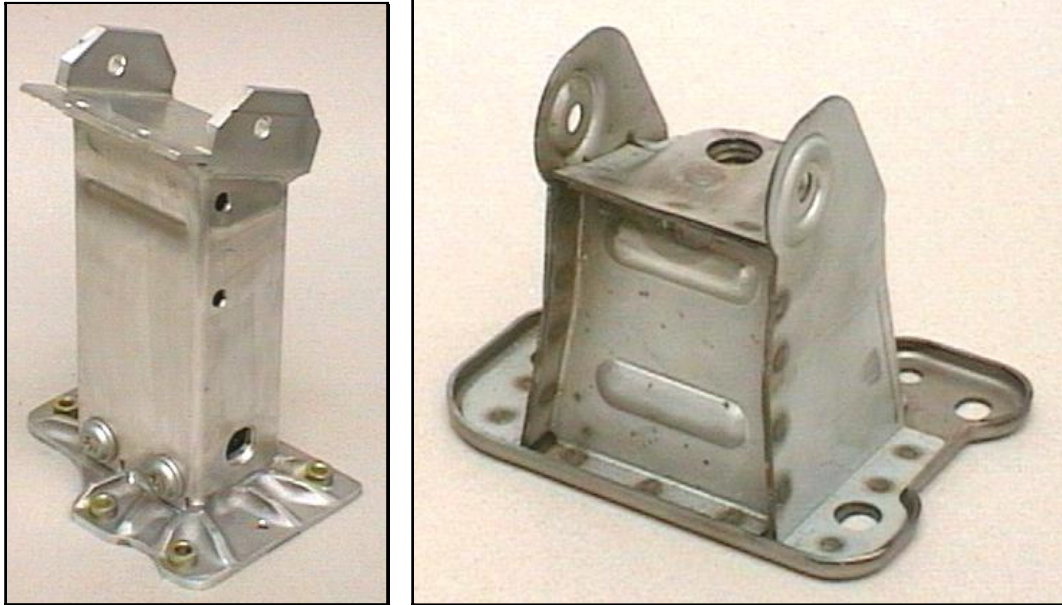
**Folding performance of the alloy EN AW-6014 which is optimized for crash performance compared to that of the alloy EN AW-6063**

(Photo: Constellium)

Suitable aluminium alloys have been developed, e.g. EN AW-6014. Perfect folding of a crash box without any cracks is obtained in particular in the T7 temper. Therefore this temper is generally preferred when crash worthiness is the top priority.

Crash boxes can be produced both from rolled and extruded products. Aluminium bumper beams are mostly combined with crash boxes made from extruded aluminium profiles. However, also combinations of extruded aluminium bumper beams with steel crash boxes are in use. Up to now, there are no aluminium sheet-based crash boxes on the market although such variants would be also possible.





**Aluminium crash box produced from extruded profiles with a high pressure die cast aluminium baseplate (left) and a crash box made from steel sheets (right)**

The design freedom of extruded aluminium profiles offers additional possibilities for the design of crash boxes. The primary goal is the improvement of the crash performance within the given package restrictions and weight limitations, i.e. to increase the weight-specific energy absorption capacity.



**Crash boxes made from extruded aluminium profiles designed for transverse (left) and axial folding (right)**

One possibility is the exploitation of the controlled crash performance of transversally loaded multi-chamber profile. The application of a multi-chamber profile with a suitably designed cross section (which also fulfils the functionality of a bracket) is possible for vehicles of low to medium weight. However, if higher crash performance is envisaged, axial folding crash boxes are preferred.

The crash worthiness of axially folding aluminium extrusions (single and multi-chamber profiles) with different cross sections has been examined extensively, using both numerical simulation and experimental methods. It has been shown that an optimized cross section design offers some advantages. As an example, an octagonal cross section shows higher energy absorption and mean load than a rectangular or hexagonal cross sections when a numerical simulation of the single part model is carried out. Numerical simulations using a simplified model based of the full indicates that the rectangular cross section shows the best

performance as a crash box. The hexagonal and octagonal cross sections undergo torsion and buckling as the width of cross section decreases while the rectangular cross section does not. Similar experiences have been made when multi-cell cross sections were examined.

An interesting option is the integration of a foam material into a hollow section crash box. Suitable foam materials are for example expanded polypropylene foams, but also aluminium foams can be used. It has been shown that foam-filled sections absorb slightly more impact energy than empty sections of similar mass. However, properly designed multi-cell cross sections are more efficient energy absorbers! A more important advantage of foam-filled crash boxes is therefore the improved impact energy absorption in off-axis collisions.



**Extruded profiles filled with aluminium foam for crash boxes**

(Photo: Cymat)

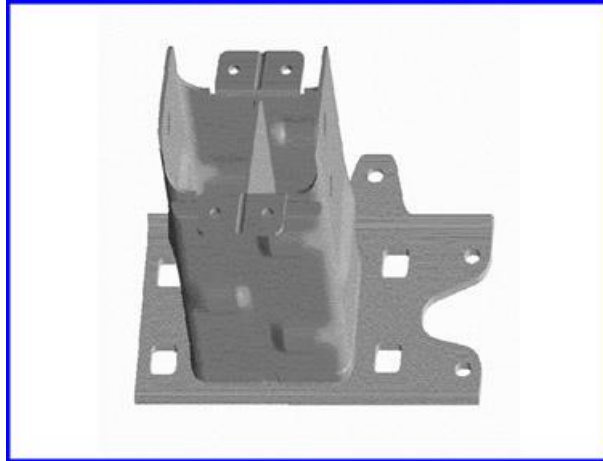
In practice, the benefits resulting from special cross section designs proved to be not cost efficient. Thus axial folding aluminium crash boxes show usually of a single or two-cell design with a rectangular cross section. But also in this case, the possibility for tailored wall thickness variations in aluminium extrusions offers some optimization potential. The addition of material where required enables a significant performance improvement.



**Reinforced corners increase the specific energy absorption capacity (SEA) of aluminium extrusions**

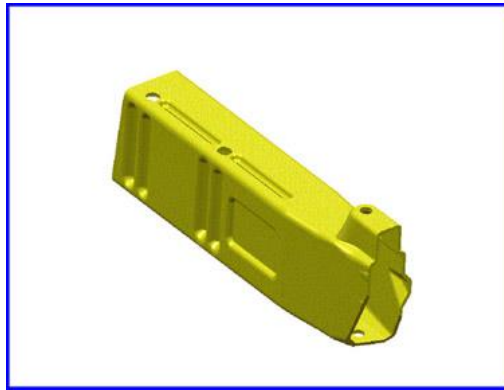
(Photo: Constellium)

A specific requirement on a crash box may be that the impact energy is absorbed at a constant force level. An example of such a crash box is outlined below. The impact energy is absorbed as the two-chamber tube starts to fold. It consists of an aluminium extrusion; the fixing plate is an aluminium sheet. Both parts are reshaped; the necessary holes are punched and the components are finally assembled to the crash box by welding. In the forming process, suitably positioned “folding initiators” are introduced. Consequently, the folding force is smoothed as the chambers partly fold in anti-phase.



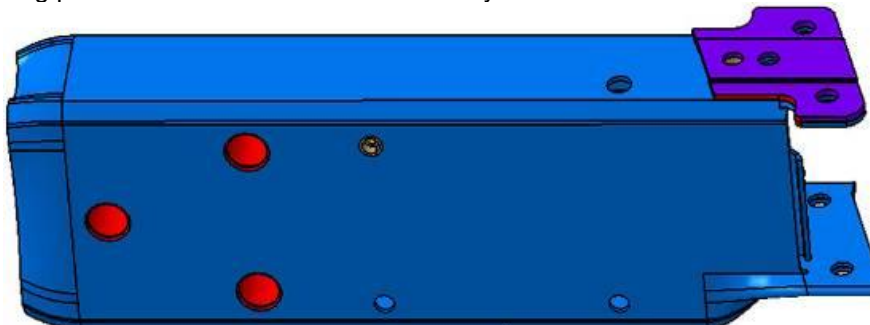
**Folding aluminium crash used for the BMW 7xx (E38) models (alloy EN AW-7003)**

Another possibility to absorb the impact energy at a constant force level is to cut the upper and lower walls of the extruded and reshaped aluminium section by attachment bolts.



**Aluminium crash box formed using the extrusion alloy EN AW-6063**

The most advanced design concept is today the “inserted crash box”, a crash box which is inserted into the front end of the longitudinal beam. This type of crash box is systematically used by major car producers like BMW, Daimler and GM, it offers most significant additional lightweighting potential and excellent cost efficiency.

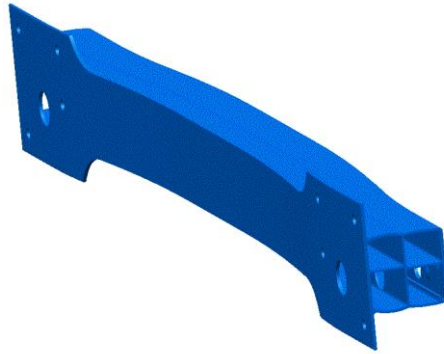


**Inserted crash box for the front crash management system of the BMW 3-serie (L7) models**

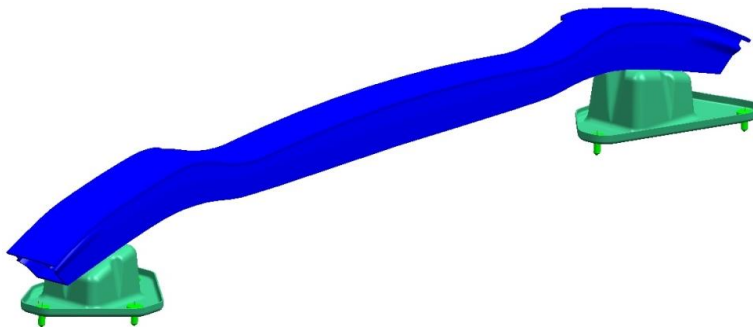
**(Source: Constellium)**

### c) Examples for aluminium front crash management systems

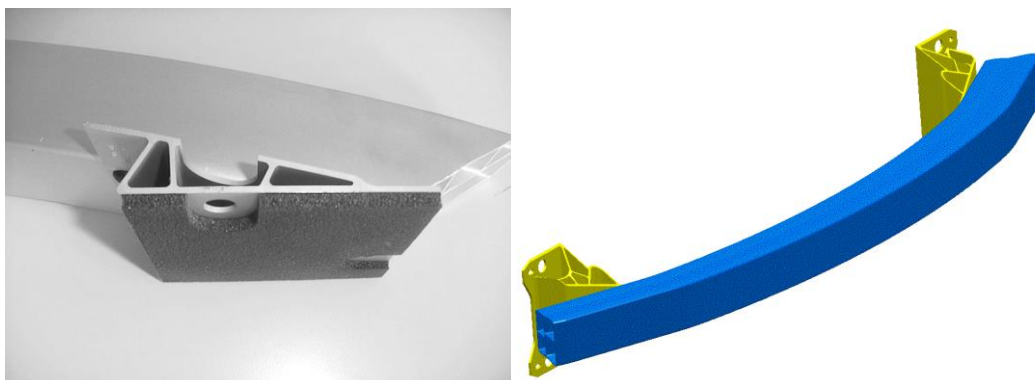
In the following, different examples for aluminium front crash management systems based on multi-chamber extrusions using alloys of the EN AW-6xxx series are shown. Depending on the type of car, the applicable design concept varies from a simple bumper beam (with suitable non-deformable brackets) to sophisticated front crash management systems with aluminium or steel crash boxes.



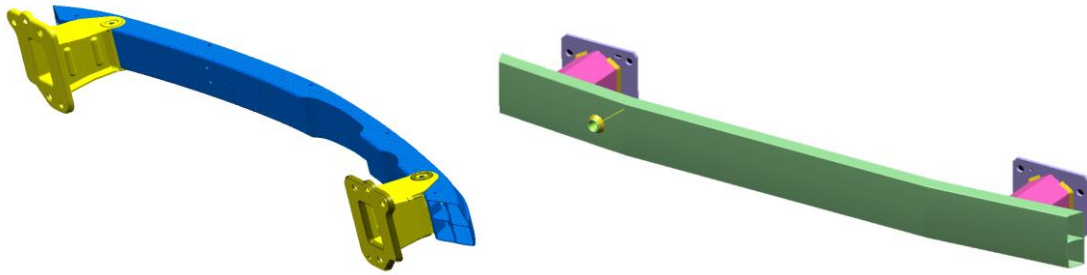
**Extruded aluminium bumper beam with integrated brackets for micro cars (<750 kg)**  
(Source: Constellium)



**Aluminium bumper beam (single cell extrusion) with non-deformable steel brackets**  
(Source: Constellium)

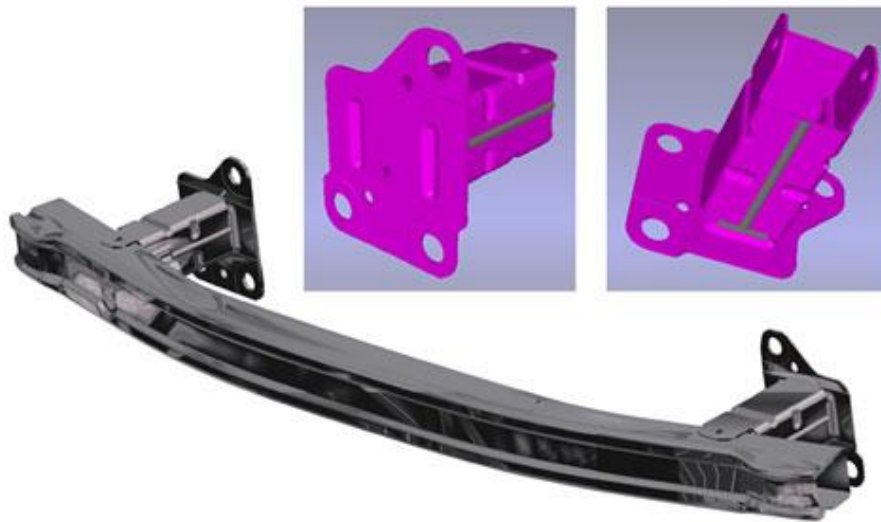


**Aluminium front bumper beams combined with extruded aluminium multi-cell deformation elements suitable for low to medium weight cars**  
(Source: Constellium)



**Energy absorption by the combined deformation of the aluminium multi-cell beam and folding type crash boxes made from steel (left) and an EN AW-6082-T6 aluminium extrusion (right)**

**(Source: Constellium)**



**Complete aluminium bumper system with reinforcing beam and crash boxes made from single-cell alloy EN AW-7003 extrusions for the Renault Megane**

The interface between the extruded aluminium crash box and the body structure is often a bolt-on connecting plate which can be also an aluminium part. The example shown below is a high pressure die casting of the alloy Silafont®-36 (AlSi9MgMn) in the T7 temper.

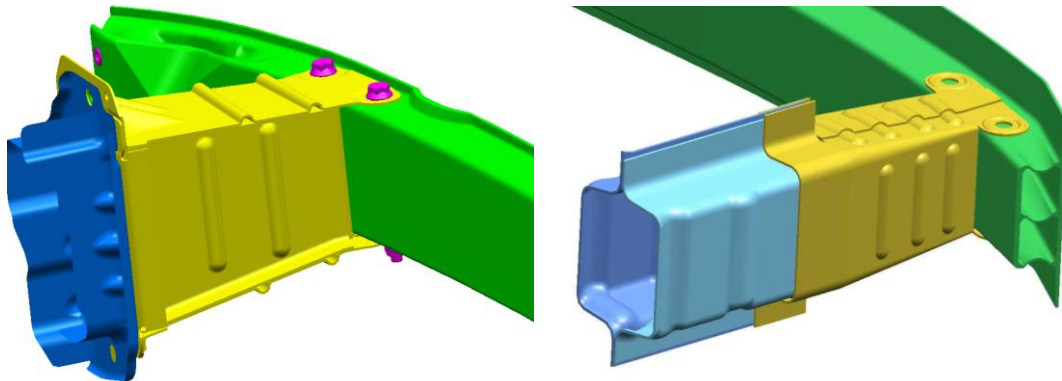


**Connecting plate (front crash management system of the Audi A2)**

**(Photo: Aluminium Rheinfelden)**



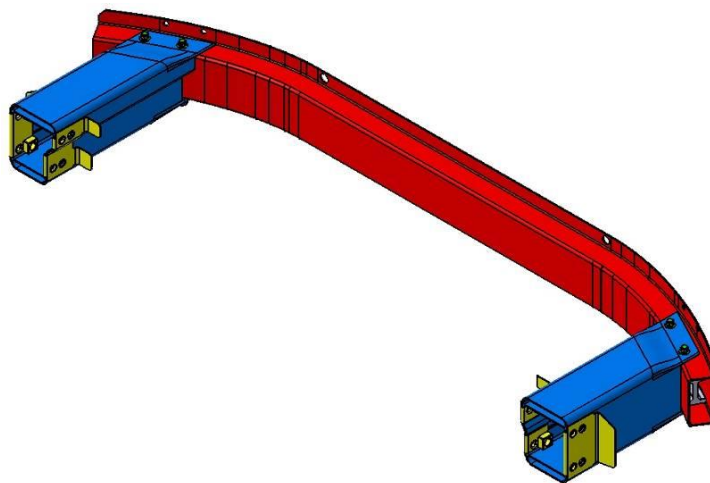
Newer developments focus in particular on the interface between the longitudinal beam and the crash box. The idea is to eliminate the traditional fixing plate, i.e. to attach the crash box directly onto the longitudinal beam.



**Traditional design concept (left) and improved design where the (steel) crash box is directly attached to the longitudinal beam (right)**

**(Source: Constellium)**

Such innovative concepts can be realized also with aluminium crash boxes. Even more possibilities offered the development of the inserted crash box. The crash box is directly inserted into the front longitudinal beam of the car.

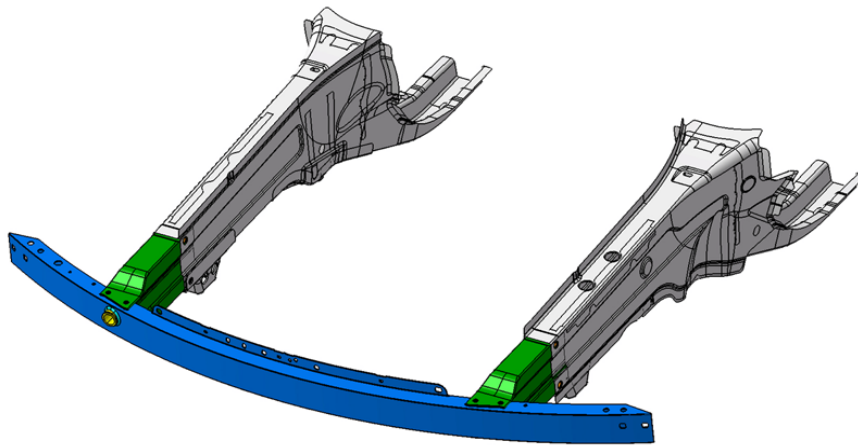


**Opel Insignia front crash management system with inserted crash boxes**

**(Source: Constellium)**

The new system developed by Constellium eliminates four fixing plates in the vehicle and the crash management system. As the crash management system is directly inserted into the vehicle's longitudinal members, a weight reduction of 2 – 3 kg is achieved in the strategically important area in front of the front wheels.





**All-aluminium crash management system of the Mercedes-Benz C class, the first car which uses an inserted crash box**

**(Source: Constellium)**

The patented crash box design allows even further lightweighting by simplifying the towing function. The system needs no separate towing nut as this function is integrated into one of the crash boxes. Additional benefits are a reduced welding length and lower number of parts.

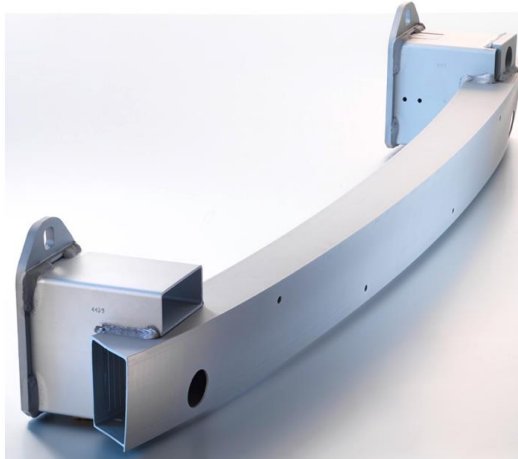


**Integration of the towing function into a crash box**

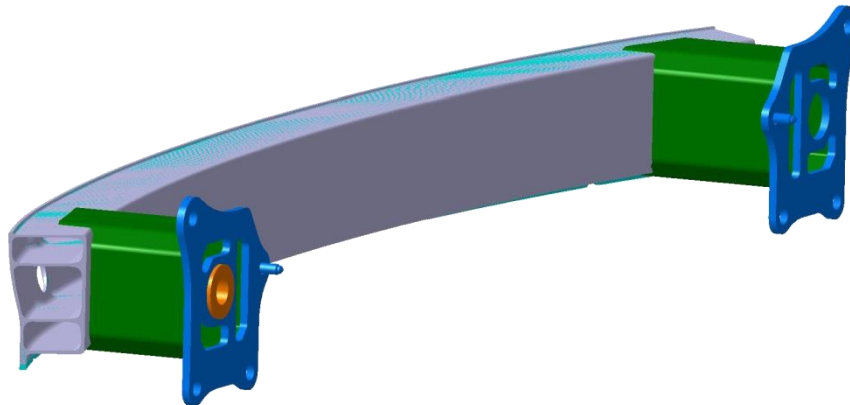
**(Photo: Constellium)**

### **4.1.3 Rear crash management systems**

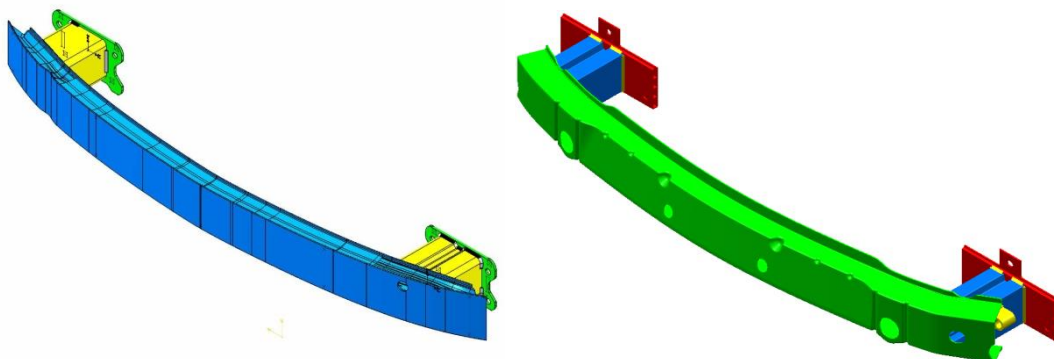
Similar design principles are used for rear crash management systems. The main difference is that even for modern car models, the aluminium rear crash management system is attached to the rear longitudinal beam with a fixing plate.



**Aluminium rear crash management system of the BMW 5 series GT**  
(Photo: Constellium)



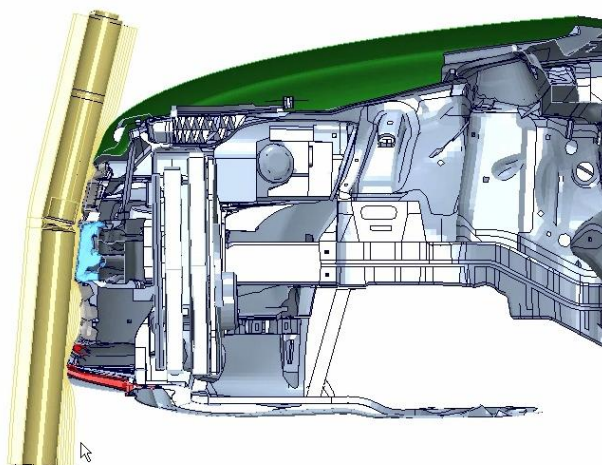
**Aluminium rear crash management system of the Audi A6**  
(Source: Constellium)



**Aluminium rear crash management system of the Opel Meriva (left) and the Opel Insignia (right)**  
(Source: Constellium)

#### 4.1.4 Pedestrian protection requirements

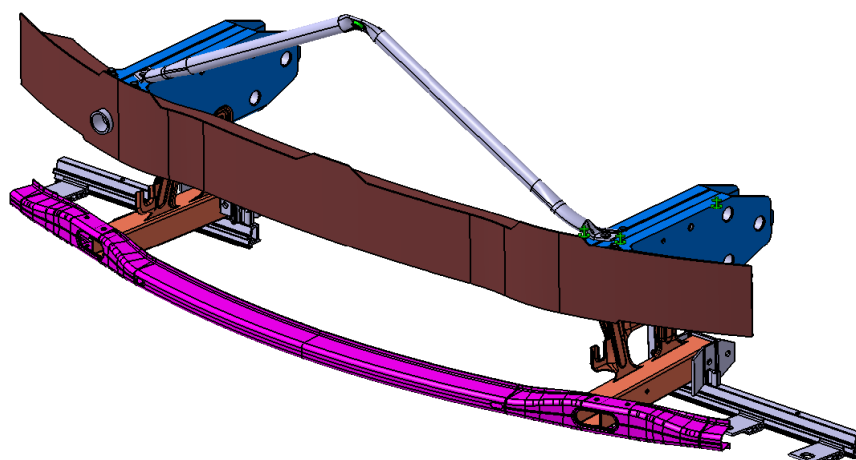
With respect to pedestrian protection, the primary objective for the crash management system must be to meet the requirements of pedestrian leg impact. This is a complex topic where the regulations are getting more and more severe. In principle, there are two possibilities to protect a pedestrian's lower limbs during an impact. The "kinetic" approach is to integrate impact sensors into the bumper cover panel and to deploy airbags or other deformable structural elements just prior to impact. The static approach aims to provide appropriate cushioning and support of the lower limb using the bumper energy absorber and an additional component, the lower bumper stiffener.



**Pedestrian protection: Leg impact**

(Source: Audi)

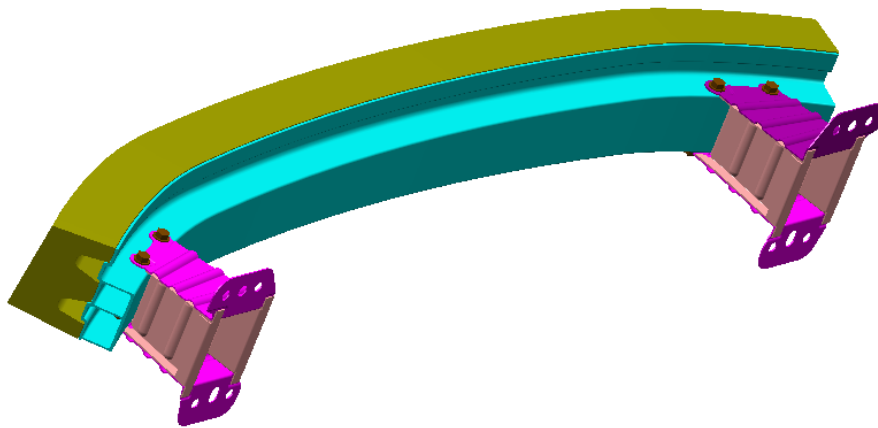
Most bumper designs for pedestrian impact include some type of lower stiffener. The idea behind the use of an upper and a lower load path is to reduce the intrusion by absorption of the impact energy using several types of energy absorbers and to manage, through the lower beam, the pedestrian leg impact. The key challenges in the design of the lower bumper stiffener are minimum weight, durability and vehicle styling. The location of the component generally results in visible changes to the vehicle's front end. The potential for lightweight design with aluminium facilitates the integration of the additional component.



**Front crash management system of the BMW 3 series models**

(Source: Constellium)

The pedestrian protection regulations also generate some constraints regarding the design of the crash management system. The problem is that the (structural) bumper beam is in general too stiff. There is a need for an additional energy absorber between the bumper beam and the pedestrian. The standard solution is to add low-density foam optimized for pedestrian protection in front of the stiff aluminium bumper to absorb the impact energy (with a depth of typically 70 mm). The consequence is that the available deformation path is reduced accordingly and a more compact crash management system is required. Furthermore, it must be ensured that bottoming out of the foam is avoided. The result of the necessary adaption of the bumper design is a narrower, but wider beam which shows a higher deformation force level.



**Aluminium front crash management system with steel crash boxes optimized for pedestrian protection**

**(Source: Constellium)**

There are also some proposals to modify the bumper beam to be an energy absorber or to add a suitable crash energy absorbing element behind the beam.

### 4.1.5 Bull bars

Traditionally, bull bars have been built to protect the vehicle. Recently, bull bars have become popular also as a cosmetic accessory, particularly on the larger four wheel drive vehicles and SUVs. They vary considerably in size and form, and are usually made of welded aluminium (or steel) tubes.

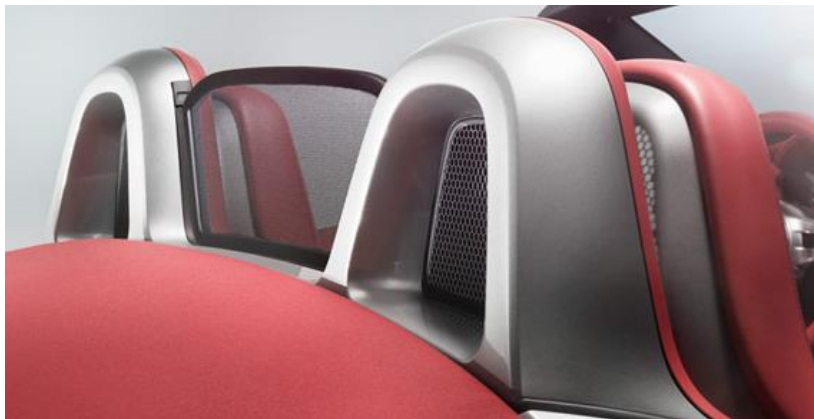
However, as a safety feature, the mounting of bull bars is considered to be less safe than allowing controlled deformation to absorb kinetic energy during a collision. Their role in increasing pedestrian deaths led to an agreement with the European carmakers not to install them on new vehicles starting from January 1, 2002.



## Lightweight aluminium bull bars

### 4.2 Roll-over protection

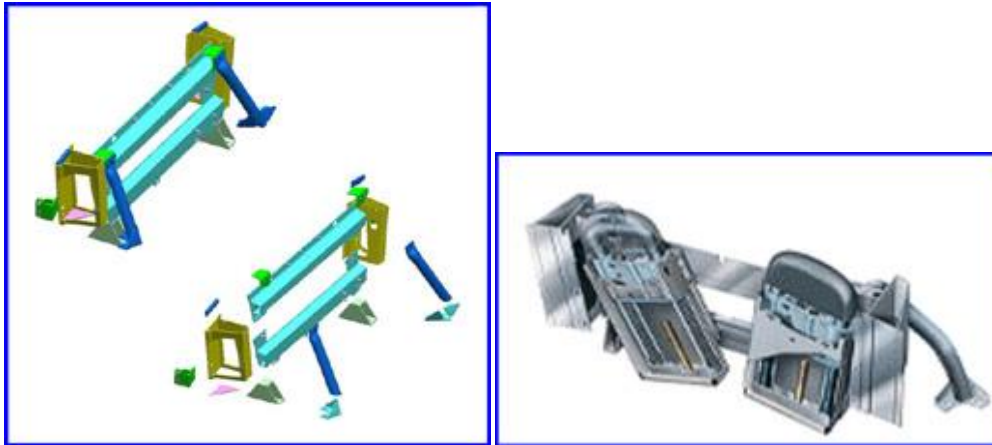
Roll-over protection systems refer to the structural elements which protect the occupants from injuries when a vehicle overturns. Normally the roof structure of a car fulfils this function, but in cabriolets and convertibles, a roll-over protection structure is necessary. It includes in the front of the car a reinforced A post and windshield design. In the rear, a specific roll-over bar was installed in the beginning. High strength aluminium alloy allow the integration of roll-over bars which provide the necessary protection, but also offer new styling opportunities.



**Roll-over bar for the Porsche Boxter models, a composite steel and aluminium design  
(Photo: Porsche)**

The first automatically deploying roll-over protection systems appeared at the end of the 1980s. A roll-over sensor continuously monitors the car's movements, contact with the road, as well as lateral and longitudinal forces. If the sensors determine that a roll-over is imminent, the roll-over protection system deploys instantly. The roll-over protection system usually consists of two hoops (arches) behind the rear seats, but it can be also a single bar. Depending on the styling requirement, the bars are hidden or serve as a characteristic styling element.

The Porsche 911 cabriolet (type 996) included an aluminium module located behind the rear seats for roll-over protection and seat belts fastening. The substructure included twelve straight and six bent extrusions. The alloy was EN AW-7108. The CNC-machined extrusions were joined by MIG and TIG welding; rivet nuts were used for mounting the assembly into the car.



**Structural aluminium module for roll-over protection and seat belts fastening in the Porsche 996**

Lightweight, strong aluminium designs are ideal for this application. In practice, different mechanisms are used to deploy the roll-over bars to a height above the heads of the rear passengers. There are pyrotechnically charged systems, spring-loaded bars as well as electromechanically operated systems. The system deploys regardless if the roof is retracted or not. If the roof is up, the hoops go straight through the rear window.



**Roll-over protection system of the Mini cabriolet, the one-piece aluminium bar  
(Photo: Mini)**



**Forged aluminium roll-over hoop (alloy. EN AW-6110A)  
(Photo: Otto Fuchs)**