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Automotive Portfolio

Body and White Structures (ACHA7004)

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ABSTRACT

The current report offers an extensive and critical engineering assessment of the changes made to convert a production SEAT Leon into a racing car known as the SEAT Leon TCR through observation at the University of Wales Trinity Saint David (UWTSD). This investigation analyses eight major engineering areas: structural rigidity, Noise, Vibration and Harshness (NVH), materials, manufacturing techniques, joining methods, safety features, passenger comfort, and restrictions imposed by regulations.

A systems approach is applied in analysing both the changes made and the engineering concepts behind those changes. The production model is viewed as a multiple objective system that aims for safety, comfort, durability, and economic efficiency (Heisler, 2002), while the TCR model is analysed as a performance-restricted system regulated by the FIA (FIA, 2023).

The study of photographic images related to internal structures shapes, welds, and external body design provides evidence for theoretical notions such as the alteration of load paths, enhanced stiffness, and hierarchical structures change. It can be observed that motor sport BIWs are designed in terms of stiffness, effective load paths, and accurate driver input without considering comfort, longevity, and compliance with the regulations.

Therefore, it is quite obvious that the construction of BIWs must be inherently contextual, and the conversion of a streetcar into a racing car is an outright change in its structure.

1. INTRODUCTION

The Body in White (BIW) forms the skeletal structure of the automotive system. It can even be described as the foundation upon which other systems and subsystems are designed and assembled. The design of the BIW influences the transfer and dissipation of mechanical loads through the automotive system. This makes the design of the BIW significant to vehicle performance, dynamics, and behavior, among others.

When applied to automobiles, the design of the BIW is subjected to various conflicting design parameters, such as crashworthiness, cost reduction, passenger comfort, and durability. This implies the need for multi-objective optimization to obtain better results. This is because any improvement made in one area will result in deterioration of performance in another. For instance, improvements in stiffness lead to dynamic performances at the expense of ride comfort, while improvements in energy dissipation capability influence structural efficiency.

This particular design case study represents one more example of achieving several goals at once. First of all, BIW is designed in order to provide effective performance under different road conditions (for instance, road surface, environment, driver behavior, and so on). Controlled deformation is caused by external loads, resulting in energy dissipation and improved safety measures.

The process of race car operation takes place only under predefined conditions, which means that performance improvement remains the only goal of vehicle engineering. In this regard, it should be noted that the SEAT Leon TCR model was developed for racing

purposes, where stiffness, weight optimization, and driver sensations become more important than durability and comfort.

In the framework of this project, special attention will be paid to the examination of the theory and practice associated with the SEAT Leon TCR model supplied by UWTSD. Namely, the changes in BIW design and their influence on the vehicle performance will be explored.

2. METHODOLOGY

The methodology used in the current research consists of theoretical and empirical investigations, which allows for obtaining the overall understanding of the important principles associated with the change in BIWs. Primary data used in this investigation includes a SEAT Leon TCR car in the UWTSD workshops. The analysis of this car included its visual inspection to find out any possible modifications applied to it, as well as different engineering aspects of BIWs design.

The car's pictures were analyzed according to the following characteristics: its interior structure, welding joints and exterior bodyshell. This has helped to evaluate the load paths, behaviour and design of the car. Thus, the use of car pictures as a part of investigation process allows establishing a link between theory and practice in this case.

At that, secondary data was also gathered from the different sources. Scientific literature was chosen as a secondary data source, including books published by well-known scientists in the field of engineering, such as Heisler (2002), Milliken and Milliken (1995) and Gillespie (1992). Methodology applied here includes these two approaches.

3. ORIGINAL VEHICLE DESIGN (ROAD BIW SYSTEM)

The manufacturing structure for the SEAT Leon BIW is designed such that all the forces within the vehicle are transmitted through a chain of interconnected sheet metal components, which include the floorpan, the roof assembly, side panels, and the pillar structures. All these form an integrated system which can handle various types of forces.

One feature of this design is the idea of progressive energy absorption. In case there is an accident, particular parts of the structure are designed in a manner that will enable them to absorb energy progressively. This is made possible due to the use of materials with different strengths and plasticities. Geometric properties also help to determine the type of deformation experienced.

Apart from absorbing energy, the BIW is designed with noise vibration and harshness considerations in mind. The use of insulating and damping materials and the compliant mounts makes it comfortable for the passengers. However, the use of these materials means that the stiffness of the structure is reduced.

In terms of manufacturing, BIW is constructed via highly automated methods like robotic spot welding and accurate stamping. Such manufacturing methods guarantee outstanding consistency, repeatability, and efficiency in cost, all of which are important in mass production settings.

But even though the design method is efficient in on-road use, it has inherent limitations when considering engineering performance. Due to the utilization of load paths and plastic deformation, the design tends to operate outside the elastic range during heavy loading. While this is beneficial for crashworthiness, it is not ideal for motorsport designs that require rigidity and elasticity.

4. VEHICLE MODIFICATIONS OVERVIEW

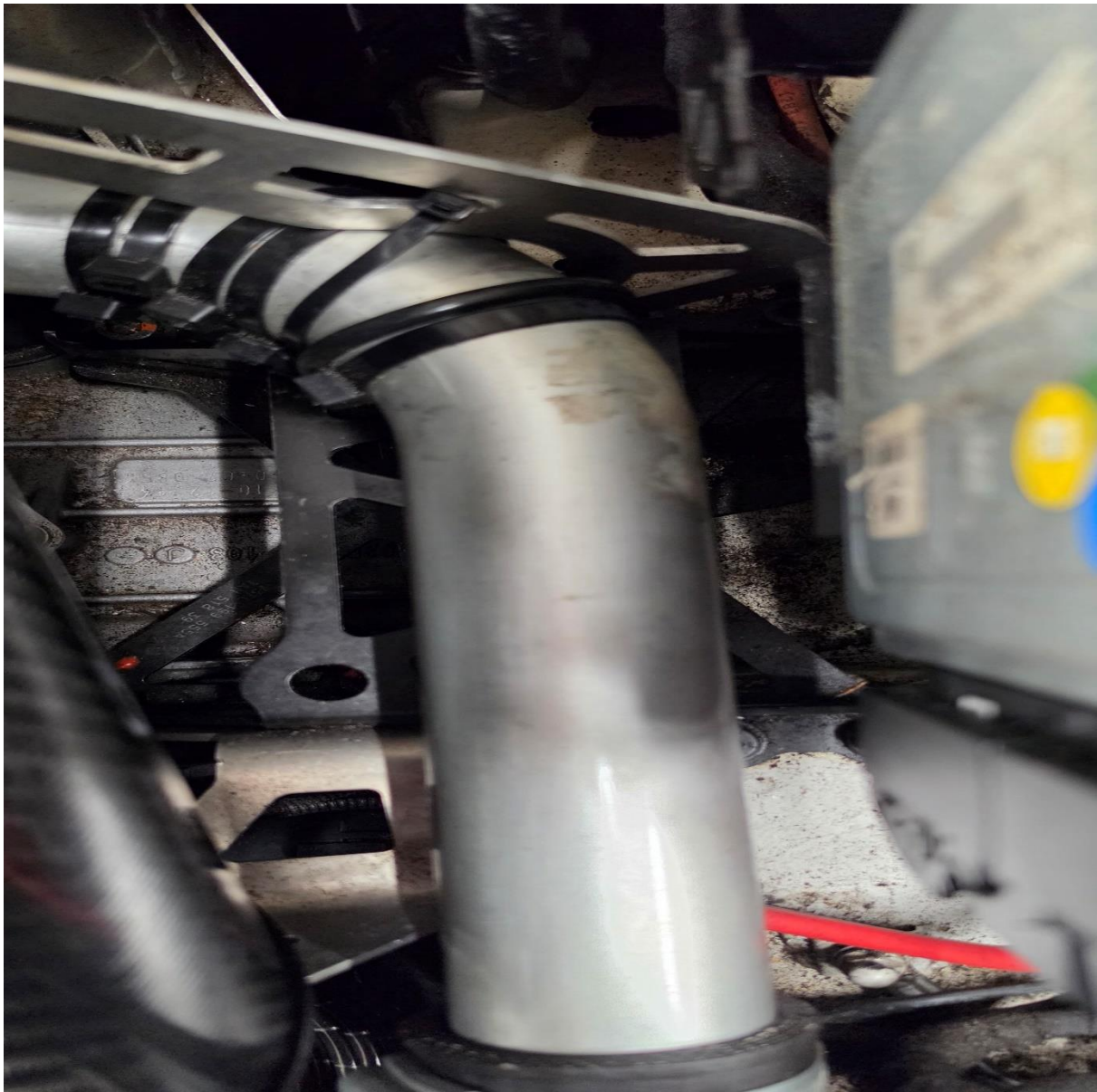
The conversion of the SEAT Leon to its TCR version requires major changes in the initial BIW structure. In particular, one of the largest changes made includes fitting a completely legal FIA roll cage that is then welded to the vehicle chassis and becomes its new load-bearing element.

Together with adding a roll cage to the body of the car, it is also essential to remove a large number of non-structural items, such as interior trimmings, soundproofing materials, airbags, etc. This allows not only reducing the weight of the vehicle but also getting rid of NVH dampers.

These targeted structural stiffeners can therefore be added to certain critical locations, especially in the regions of attachment of the suspension as well as high loading conditions. These types of stiffeners could be added to the structure of the BIW by welding them on the structure, which would stiffen these localized portions of the structure but at the same time cause stress concentrations.

It is very important to note here that such changes cannot be viewed independently; they need to be looked at from an integrated systems view point. This includes not only the addition of the roll bars, but also the removal of any compliant components and structural stiffening. All these changes help modify how the loads are transferred across the vehicle system. This means that all three characteristics, structural stiffness, NVH, and fatigue behaviour, are interconnected through the entire system.





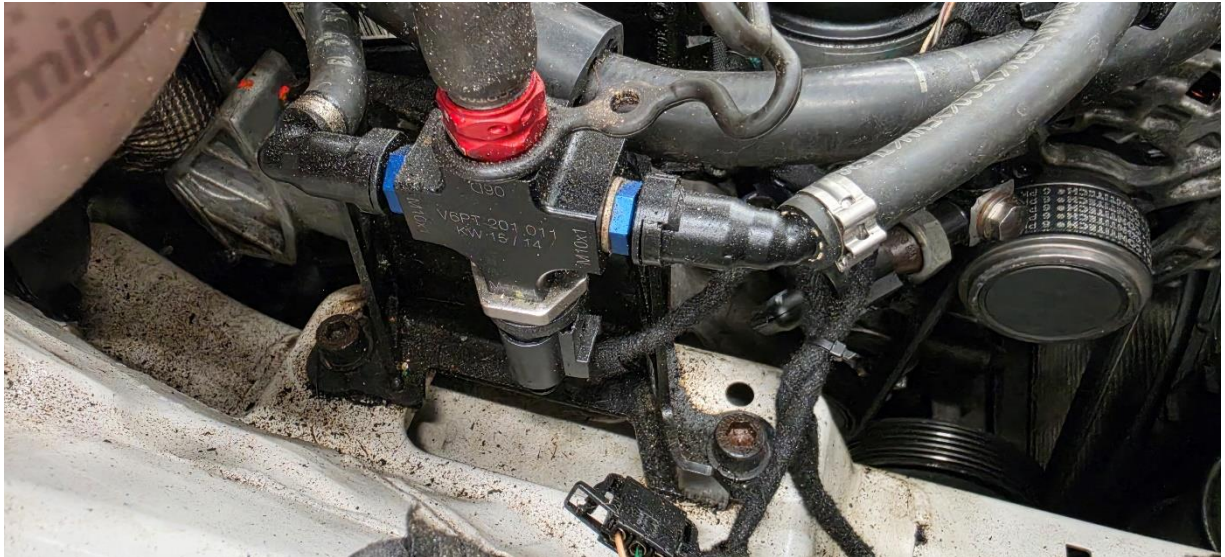






FIGURE 1: INTERIOR VIEW SHOWING INTEGRATED ROLL CAGE AND STRIPPED BIW STRUCTURE (UWTSD WORKSHOP)

As seen in Figure 1, the interior is completely stripped, revealing the BIW structure as well as the roll cage. The design of the cage in triangles allows for the creation of direct load paths to critical structural nodes.

This clearly shows that the loads in the structure are not transmitted through flexible sheet metal anymore but are now transmitted through the stiff tube structure.

5. STIFFNESS

Thus, when assessing stiffness, attention needs to be paid not only to the global torsional stiffness of the body, but also to local stiffness distribution and properties. In relation to the production SEAT Leon, there is uneven stiffness distribution, which allows certain deformations of body elements depending on loading. This feature allows dissipating energy, but at the same time, deformation becomes absolutely unpredictable.

As opposed to the previous example, the TCR version demonstrates greater stiffness due to the presence of the roll cage. Geometric stiffness of the roll cage allows achieving rigidity through the use of material, but without increasing metal thickness. This feature is important because torsional deformation can be reduced by the presence of a stable triangle shape.

In the dynamic environment, higher stiffness leads to increased vibration frequency of body elements. Thus, there are lower chances that there will be resonance between the vibration frequencies of the body and the suspension frequencies, which ensures greater stability of car operation during fast driving. However, greater stiffness makes the transfer of loads onto other elements of the car more difficult.

However, along with the shift of load distribution, there will be some differences in the manner of load transmission, especially under the effect of lateral loads. Specifically, regarding the TCR vehicle, load transmission can occur due to the suspension geometry rather than the flexibility of the chassis, hence becoming predictable but less adaptable to surface imperfections.

Perhaps, what matters the most, is that because there are regions of concentrated stiffness at the roll cage connection points with the BIW, there is a discontinuous character of load transmission right in these particular points, where the occurrence of stress concentrations will make the welds susceptible to fatigue breakage. Hence, although there is an improvement in stiffness, there is a worsening of the characteristics of local stress.

Certainly, the increase in torsional stiffness contributes significantly to the improvements in both handling and operation consistency, since it brings better stability to the suspension system; however, it leads to an interesting challenge for an engineer, as it increases load concentration along the stiffness paths.

6. NVH (NOISE, VIBRATION, HARSHNESS)

NVH technology in automobiles could either be done through passive or active ways. Some of the passive methods include vibration dampening and vibration isolation, while some of the active methods are noise cancellation technology and active suspensions.

By stripping away everything that is NVH technology from the TCR vehicle, there has been a change in how the flow of energy happens in the car. The vibrations do not dissipate but instead, transfer themselves through the frame of the car, straight into the driver. This leads to the vibrations intensifying, as well as the vibrations happening on a larger frequency range.

This problem could also be described from a signal processing point of view, where there would be an increase in the Signal-to-Noise Ratio. The useful signals, like tyre grip and

surface data, would then be clearer to understand. But the high frequency signals would also increase, which could harm the driver's concentration and endurance.

Moreover, the lack of dampers means that the energy absorption capacity of the system is compromised. This is due to the fact that energy remains trapped in the system oscillating and causing resonance in the structure and, hence, increased fatigue loads in the structure as well as the machinery.

Simply put, as much as there are gains in the form of increased sensitivity through the decrease in NVH, there are other challenges that come with it regarding human factors engineering and durability.

Clearly, there is a big trade-off brought about by the decrease in NVH dampers, whereby sensitivity is improved on one hand, while energy absorption is decreased on the other hand.

7. MATERIALS

After the situation analysis, one is able to deduce that apart from being durable, there are other aspects of chromoly steel that distinguish it from the mild steel.

In regard to use in road vehicles, mild steel is very flexible; hence, it is capable of absorbing high pressure without breaking. The reason why this metal can withstand high pressure is that it does not break until it changes shape. Mild steel can be used effectively where the material takes up high energy during collisions.

In terms of the chromoly steel that has been used in roll cages, it is stronger than mild steel. This is because this steel can resist high levels of pressure without changing its shape, unlike mild steel, which is very brittle.

The third problem is in welding. According to Figure 2 below, there is a difference between the base material and the weld.

It is likely that these varying performances will cause the formation of fatigue cracks, especially at the junctions between the weld and base metals. It should be noted that since these cracks will have formed, they will be susceptible to further growth due to the minimal ductile quality of the metals used. In this respect, although the use of chromoly steel results in the production of stiff and hard metals, there are several challenges faced when using chromoly steel, including weld and fatigue issues.

This is because, although chromoly steel increases the stiffness of the materials, there are also negative aspects associated with the tolerance of the materials to fabrication defects and fatigue. In this respect, durability requirements should be replaced by inspection requirements.



FIGURE 2: CLOSE-UP OF WELDED JOINT SHOWING HEAT-AFFECTED ZONE (UWTSD WORKSHOP)

From Figure 2, it can be seen that the weld joint shows a well-defined heat affected zone.

This means that there are some changes in the properties of the material, which become potential initiation points for fatigue cracking under cyclic loads.

8. MANUFACTURING

As per manufacturing engineering analysis, the transition from automated manufacturing to hand-made constructions leads to significant changes in the efficiency of the latter.

Automated manufacturing in case of mass production involves robotic welding, which provides an identical level of heat, guarantees weld penetration, and preserves joints' geometry. Mechanical characteristics of such structures become stable, and driving behavior also becomes predictable.

Conversely, hand-made structures, as shown in Figure 2, greatly depend on the professionalism of a welder. Differences in welding speed, level of heat provided, and overall procedure used will inevitably lead to deviations in the shape of the bead, as well as impact penetration depth and heat-affected area size.

Additionally, hand-made constructions develop residual stresses because of dissimilar cooling speeds and stabilize them.

Nevertheless, it is necessary to mention that such limitations are considered reasonable in the motorsport manufacturing process due to the fact that the key thing here is performance adaptation and optimization.

This is one of the key distinctions:

- ❖ Making cars for road usage → reliability and uniformity
- ❖ Making cars for motorsports → adaptability and performance

Therefore, we can see that the key point in motorsport manufacturing process is not making any attempts to limit variations but controlling them using performance limitations.

It is crucial to mention that the key point in motorsport manufacturing process is adaptability and performance optimization.

9. JOINING TECHNIQUES

The move from spot welding to seam welding and full structure welding will have a definite impact on the characteristics of the welds.

In the case of spot welding, welds are made at particular spots with the freedom of relative motion between the plates being beneficial in terms of load and stress distribution.

However, seam welding results in continuous welds without any possibility of relative motion. The result is an increase in stiffness. At the same time, the ability of the weld to transmit loads is improved.

As far as fracture mechanics are concerned, welds are considered stress raisers because cracks are likely to occur in regions of high stress concentrations.

In the case of the TCR vehicle, the use of weld joints makes the integrity of the part largely dependent on the quality of the weld. For instance, porosity in the weld will decrease its fatigue strength.

Hence, even though these approaches will result in an increase in the stiffness of the part, they will become stress raisers and decrease fatigue strength.

10. SAFETY

But, a closer analysis of safety reveals that there are differences in terms of principles guiding the functioning of cars used on roads and those used in racing.

Safety in road cars uses probabilistic criteria in which case the vehicle has to be able to safeguard itself from the effects of accidents in unpredictable situations. This means that the vehicle needs to offer balance between rigidity and ability to absorb energy.

In racing cars, safety employs deterministic criteria in which the car resists certain loadings. The roll cage acts as the safety cell in this case.

On the other hand, the effectiveness of the above-mentioned idea assumes that the use of safety equipment such as harnesses, helmets, and HANS devices accompanies the BIW itself. Otherwise, the hard structure would transfer high forces to the body of the occupant.

In such a way, the safety issue in motorsports has to be viewed as an integral part of a complex system consisting of BIW, safety equipment, and driver.

Thus, one can notice that the motorsport safety cannot be viewed from the perspective of structural integrity only because it implies an integral process including BIW, safety equipment, and the driver.

11. COMFORT

Comfort plays an important role in the design of automobiles, but in the case of motorsports, comfort is totally stripped off from its design. Figure 1 below shows how uncomfortable a motorsport vehicle can be due to the lack of any comfort feature in it.

12. REGULATIONS





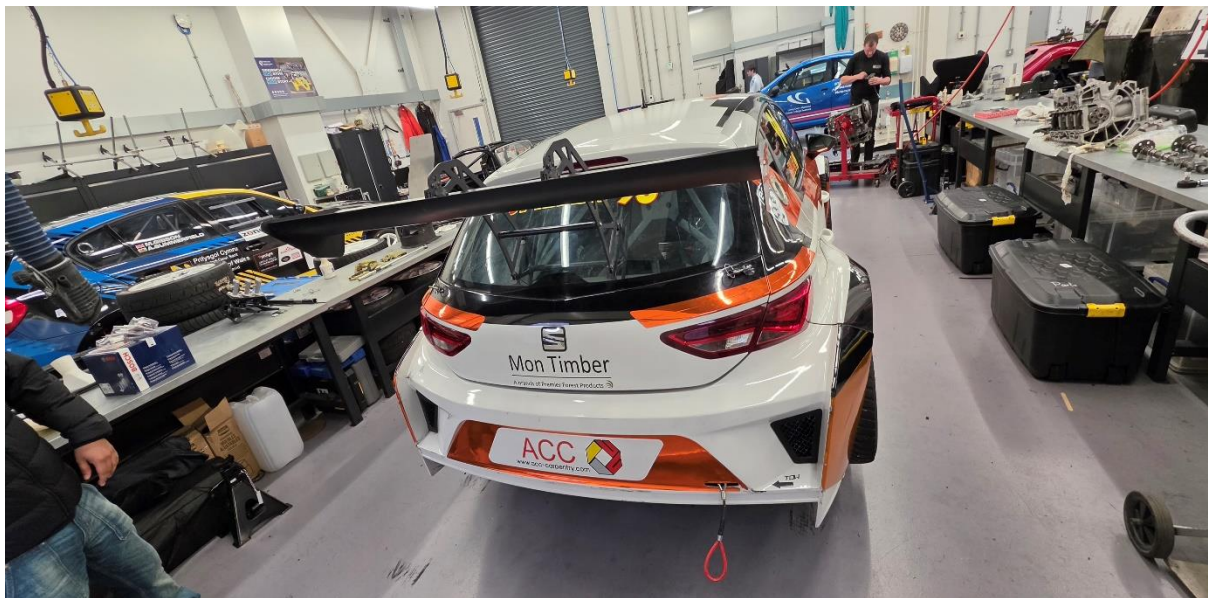
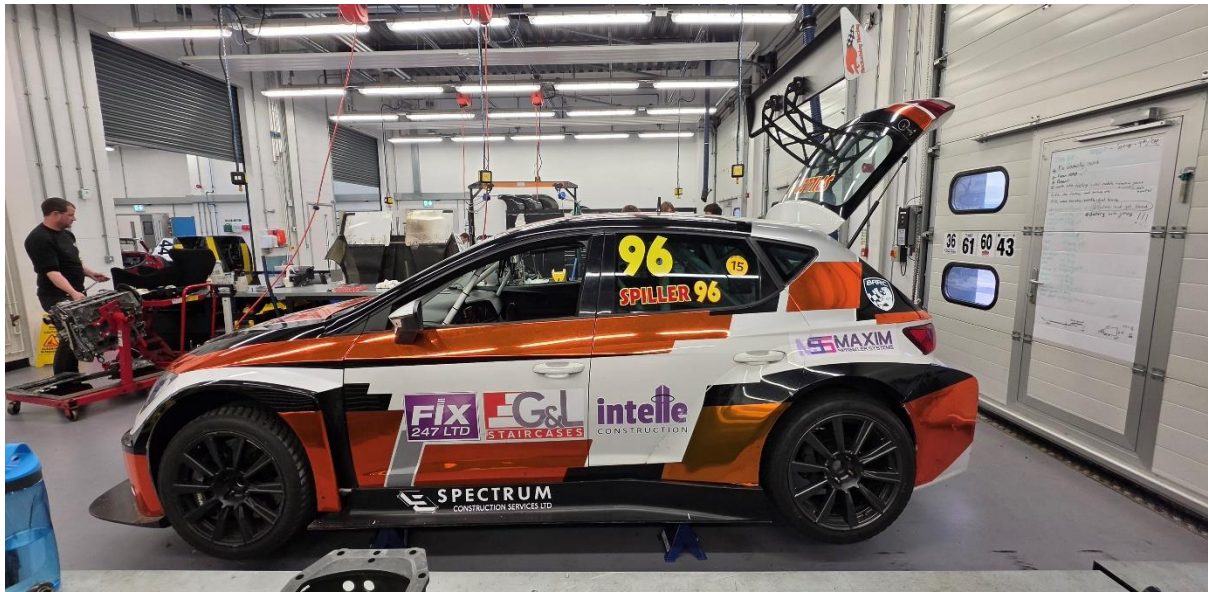




FIGURE 3: EXTERIOR VIEW SHOWING RETAINED PRODUCTION BODY SHELL (UWTSD WORKSHOP)

It can be noted from the image shown above that the body shell on the outside of the car remains unchanged.

Indeed, it proves that while modifications are being made in the interior of the car, the body of the car which is being produced is not modified at all, which highlights the shortcomings of the FIA homologation process.

Some legislative issues related to road cars are:

- ❖ Crash safety (Euro NCAP)
- ❖ Emissions
- ❖ Noise
- ❖ Pedestrian crash protection

All of these help in designing the BIW using the material and shape.

But as far as FIA TCR rules are concerned, the aspects taken into consideration are only safety and fair play. The constraints involved in this include:

- ❖ Production chassis
- ❖ Design of the roll cage
- ❖ Restriction on structure

In this regard, the method would bring about constrained optimisation where the engineers are only limited in the design of the entire vehicle but have to work on improving the existing BIW.

The important thing to remember is that the process of constrained optimisation cannot result in the creation of the ideal racing chassis, hence the design of a vehicle that incorporates both production and racing aspects. Although this will ensure that all cars race on an equal footing, it is far from being structurally ideal.

From the above constraint on optimisation, it can be noted that it becomes impossible to get the best structural design of the vehicle.

13. SYSTEM-LEVEL DISCUSSION

In particular, the SEAT Leon modification towards the TCR model demonstrates the transition from the distributed and flexible to the concentrated and rigid structure type.

The modification will affect several systems that work with each other, including:

- ❖ structural mechanics
- ❖ dynamics
- ❖ human-vehicle interaction
- ❖ fatigue

Other changes will take place, especially concerning the transformation of energy transfers among system elements. In the road car version, energy is wasted due to deformation and dissipation. Energy transfer becomes more efficient in the racing model and happens directly. Consequently, there is no possibility to dissipate any vibrations that may occur.

Therefore, the modified car turns out to be susceptible but resistant to outer impacts, which can be useful for a race but dangerous during everyday usage.

To summarize, this case study helps understand that optimal design does not equal ideal design and consists of the choice of correct parameters.

In particular, this modification cannot be considered solely an engineering task, but also energy and damping transformation.

14. CONCLUSION

In the presented example, the modifications performed by altering the SEAT Leon into the SEAT Leon TCR demonstrate that the Body-in-White technology is based on application-specific requirements rather than optimization in general terms. As in case with adding a roll cage to the body structure and eliminating of all elements related to compliance, there is an additional importance of stiffness and emergence of a completely new performance-oriented structural system.

Though such modifications undoubtedly improve the driving characteristics of the car in terms of higher level of stability, better precision, and effective energy transmission, they imply certain drawbacks in terms of comfort and reliability. Thus, engineering involves compromise, and all positive aspects have to pay for themselves through negative aspects in some other area.

What is more, it becomes clear that it would not be reasonable to refer to the racing car as a modification of the original road car. They can both be considered as separate systems because both of them are oriented towards fulfilling their purpose effectively.

The former is designed as multifunctional, reliable, and secure while the latter is focused on performance.

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