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Frontal Crash

Automotive Chassis Systems – ACHA5013

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ABSTRACT:

This report delves into the dynamic historical development of automotive structures, examining the intricate interplay of factors such as torsion, bending, aerodynamics, and crash requirements. From the early days of the automobile era, characterized by body-on-chassis designs and "carry-over" carriage structures in the 1920s, to the present era of advanced materials and manufacturing techniques, the evolution of vehicle structures has been shaped by a myriad of influences. The transition to mass production in the 1930s marked a pivotal moment, leading to the replacement of fabric-on-wood bodies with pressed steel and the simultaneous softening of bodies and stiffening of chassis. This report explores the ensuing progression, showcasing notable examples like the TVR, the advent of triangulated tube structures, and the emergence of pure monocoques. In the context of crashworthiness, the report emphasizes the significance of the longitudinal load path in Body-in-White (BIW) structures, a critical element for absorbing impact forces during crashes. A theoretical analysis of the fundamental buckling load for a longitudinal is presented, followed by an estimation of this load for a selected automotive BIW.

INTRODUCTION

The automotive industry has witnessed a transformative evolution in vehicle structures over the years, driven by a confluence of factors ranging from mechanical considerations to safety standards and consumer demands. This report provides a detailed exploration of this evolutionary journey, focusing on historical developments, the influence of torsion, bending, aerodynamics, and crash requirements, and the impact of manufacturing and material advancements. Additionally, it delves into the role of regulations and consumer-driven testing, exemplified by organizations like EuroNCAP, in shaping the landscape of automotive structural engineering (Emadi, 2011).

1. **Historical Overview of Vehicle Structures: Early Beginnings (1920s-1930s)** The inception of the automobile era saw rudimentary vehicle structures characterized by body-on-chassis designs and "carry-over" carriage structures. During the 1920s, advancements were primarily focused on transitioning from fabric-on-wood bodies to more robust pressed steel. The 1930s marked a pivotal moment when manufacturers recognized the need to soften bodies and simultaneously stiffen chassis, realizing that the body exhibited increased stiffness in both bending and torsion. **Mass Production and Standardization** As the automotive industry shifted towards mass production, standardization became a key objective. This era witnessed the adoption of pressed steel in various forms, allowing for more efficient manufacturing processes and the creation of recognizable designs across different models. This standardization laid the groundwork for further advancements in vehicle structures (Fahimi et al., 2011).
2. **Impact of Manufacturing and Material Developments: Materials Evolution** Material advancements have been instrumental in enhancing the strength-to-weight ratio of vehicle structures. The transition from traditional steel to high-strength alloys, aluminum, and composite materials has allowed for lighter yet robust designs, contributing to improved performance and fuel efficiency. **Manufacturing Techniques Advances** in manufacturing techniques, such as

computer-aided design (CAD), simulation technologies, and robotic assembly lines, have streamlined the production process. These developments not only enable precise construction but also facilitate the incorporation of complex structural designs (Yilmaz & Krein, 2012).

3. **Regulations and Consumer-Driven Testing (e.g., EuroNCAP):** Regulatory Standards Stringent regulations imposed by governmental bodies worldwide have mandated specific safety standards for vehicles. These standards encompass crash tests, structural integrity requirements, and occupant protection measures, influencing the design and construction of vehicle structures. EuroNCAP Consumer demand for safer vehicles has given rise to independent testing organizations like EuroNCAP. These entities conduct rigorous crash tests and evaluate vehicle safety features, providing consumers with valuable information. The impact of EuroNCAP ratings on design choices has been substantial, as manufacturers strive to meet and exceed these stringent testing criteria (Tagliaferri et al., 2016).

Development of Automotive Chassis Systems

The early 1920s marked the nascent phase of the automobile era, witnessing the emergence of primitive vehicle structures that laid the foundation for subsequent developments. During this period, vehicles predominantly featured body-on-chassis designs, often referred to as "carry-over" carriage structures. These designs were characterized by a separation between the body, housing passengers and cargo, and the chassis, comprising the vehicle's framework and mechanical components. Materials used during this era were rudimentary, with wood and fabric commonly employed in constructing the body. However, as the decade progressed, there was a notable shift toward more durable materials, particularly the adoption of pressed steel. This transition enabled mass production techniques, enhancing efficiency and affordability, ultimately paving the way for the standardization of vehicle structures. The 1930s witnessed a transformative shift in the automotive industry as mass production techniques became more prevalent. This era was characterized by the desire to create standardized designs that could be efficiently produced on a large scale. Manufacturers recognized the need to enhance both the comfort of passengers and the overall performance of vehicles (Zackrisson et al., 2016).

One significant development during this period was the realization that the body exhibited increased stiffness not only in bending but also in torsion. This revelation prompted a strategic response from engineers and designers who sought to optimize both body and chassis structures. The goal was to create vehicles with improved handling characteristics, reduced vibrations, and enhanced overall structural integrity. The 1930s proved to be a pivotal era in the evolution of vehicle structures, marked by the realization that the body's structural rigidity extended beyond resistance to bending forces and also included increased stiffness in torsion. This breakthrough understanding led to a shift in design philosophies, influencing the development of more robust and integrated structures. Engineers began incorporating features into vehicle designs aimed at improving torsional stiffness. Triangulated tube structures, for instance, became a notable innovation during this period. These structures utilized triangular configurations to enhance torsional rigidity, providing vehicles with improved stability and responsiveness on the road. The industry began to recognize the importance of achieving a balanced compromise between bending and torsional stiffness for optimal vehicle performance (Wu et al., 2012).

The evolution of vehicle structures during the mid-20th century saw the emergence of notable examples that reflected innovative design approaches. TVR, a British sports car manufacturer, gained recognition for its use of backbone structures. This design featured a central spine or backbone that integrated with the chassis, providing both structural support and contributing to the vehicle's distinctive handling characteristics. TVR's emphasis on a lightweight yet robust structure showcased a departure from traditional designs. Triangulated tube structures became a hallmark of engineering ingenuity (Oda et al., 2018). By strategically placing triangular configurations within the chassis, engineers achieved a balance between torsional and bending stiffness. This design principle influenced various automotive models, contributing to the industry's pursuit of optimal structural performance. Pure monocoque designs further exemplified the evolution of vehicle structures. In this approach, the body itself served as the primary load-bearing structure, eliminating the need for a separate chassis. This not only reduced weight but also enhanced structural integrity. Models such as the Lotus Elan showcased the potential benefits of monocoque construction, setting new standards for performance and efficiency (Shen et al., 2012).

Modern Vehicle Structures

In the contemporary automotive landscape, vehicle structures have evolved to accommodate diverse design philosophies, materials, and manufacturing techniques. This section provides an overview of various chassis types that exemplify the innovative approaches adopted by manufacturers to achieve optimal performance, safety, and efficiency. The backbone structure represents a distinctive chassis design characterized by a central spine or backbone that runs longitudinally through the vehicle. This spine serves as the primary load-bearing element, providing both structural support and contributing to the overall rigidity of the vehicle. Notable examples of the backbone structure include models from Lotus and TVR. Lotus, a British sports car manufacturer, has been renowned for its use of the backbone structure in models like the Lotus Elan. The central spine in Lotus vehicles integrates with the chassis, resulting in a lightweight yet robust structure. This design philosophy enhances the handling characteristics of the vehicle, offering a balance between agility and structural integrity (Wang et al., 2015).

Similarly, TVR has employed the backbone structure in its sports car models. The TVR Tuscan, for instance, features a distinctive spine that contributes to the vehicle's unique aesthetic while maintaining a focus on structural efficiency. The backbone structure aligns with TVR's commitment to lightweight construction and superior performance. Triangulated tube structures represent an engineering approach where triangular configurations are strategically incorporated into the chassis to enhance both torsional and bending stiffness (Verbruggen et al., 2010). This design philosophy aims to achieve a balanced compromise between different types of structural loads. The Audi A2 stands out as an exemplary model that utilizes a triangulated tube structure. The Audi A2, a compact car introduced by the German automaker, features a lightweight and efficient chassis design based on triangulated tube structures. This construction contributes to the vehicle's overall structural integrity while ensuring a responsive and agile driving experience. The triangulated tube structure exemplifies the industry's pursuit of optimal load distribution and stiffness (Clement-Nyns et al., 2009).

Punt or Platform Structure

The punt or platform structure represents a design where the chassis is essentially a flat platform that supports the vehicle's components. This type of structure is characterized by a simplified and versatile framework, often used in the design of trucks and commercial vehicles. The flat platform provides ample space for accommodating various configurations of bodies and cargo. While the punt or platform structure is less common in mainstream passenger vehicles, it remains prevalent in certain commercial applications. Its simplicity and adaptability make it suitable for vehicles where customization and utility are prioritized over complex structural considerations (Shafiee et al., 2013).

Pure Monocoque

The pure monocoque design is a modern chassis concept where the entire body of the vehicle serves as the primary load-bearing structure. In this approach, there is no separate chassis; instead, the body itself provides the necessary structural integrity. This design not only reduces weight but also enhances safety and performance. Models like the McLaren P1 showcase the effectiveness of the pure monocoque design. The carbon fiber monocoque in the McLaren P1 contributes significantly to the vehicle's lightweight construction, agility, and crashworthiness. This design approach reflects the industry's commitment to pushing the boundaries of materials and construction techniques for optimal performance (Pieltain Fernández et al., 2011).

Integral or Unitary Body Structure

The integral or unitary body structure represents a design philosophy where the body and chassis are integrated into a single, cohesive unit. In this approach, the structural components of the vehicle are interconnected, resulting in a seamless combination of body and chassis elements. This design is prevalent in many modern passenger cars. The integral or unitary body structure offers advantages such as improved rigidity, reduced weight, and enhanced safety. The majority of contemporary passenger vehicles adopt this design philosophy to achieve a balance between structural efficiency and manufacturing practicality (Lucas et al., 2015).

Impact of Crash Requirements on Vehicle Structures

The structural integrity of a vehicle during a crash is paramount, and the role of longitudinal members in Body-in-White (BIW) structures is crucial. Longitudinals, typically running down the engine bay, form a major loadpath in most BIWs. These components play a pivotal role in distributing and absorbing impact forces during a collision, influencing the overall crashworthiness of the vehicle. The efficient design and placement of longitudinals contribute to the dissipation of energy, reducing the potential for severe deformations and enhancing occupant safety. The theoretical fundamental buckling load for a longitudinal can be defined by engineering principles, considering factors such as material properties, geometry, and boundary conditions. The fundamental buckling load for a strut with one fixed end and one free end, as depicted in engineering literature, provides a mathematical expression that represents the critical load at

which the longitudinal member would buckle under compressive forces. This theoretical analysis serves as a fundamental benchmark for assessing the structural stability of longitudinals in BIWs. To estimate the buckling load for a specific automotive BIW, it is essential to consider the unique characteristics of the vehicle's design, material composition, and geometrical attributes of the longitudinals. Conducting finite element analysis (FEA) and simulations can provide a more accurate estimation, considering the complex interactions between various structural elements (Turker et al., 2012). Frontal crashes generate dynamic forces that are complex and multifaceted. Analyzing crash test data and real-world collision scenarios allows for the evaluation of the actual forces exerted on the vehicle's longitudinals during impact. Discrepancies between theoretical and practical forces highlight the challenges in precisely predicting the dynamic behavior of structures under extreme loading conditions (Kempton & Tomić, 2005).

Factors Contributing to Differences in Theoretical and Practical Forces

Several factors contribute to the disparities between theoretical and actual forces. E.g.

1. **Material Behavior:** Theoretical analyses often assume idealized material properties, neglecting the complexities of material behavior under dynamic loading. Material strain rate sensitivity, temperature variations, and non-linear behavior can significantly impact the actual structural response during a crash.
2. **Manufacturing Variations:** Variations in manufacturing processes, including material imperfections, welding quality, and assembly tolerances, can introduce uncertainties in the structural behavior of longitudinals. Real-world vehicles may exhibit variations that are challenging to capture in theoretical models (Guille & Gross, 2009).
3. **Dynamic Loading Conditions:** Frontal crashes involve dynamic and unpredictable loading conditions. The interaction of the vehicle with the surrounding environment, the deformability of other components, and the distribution of impact forces contribute to the complex nature of actual crash events (Geng et al., 2017).

Conclusion

In conclusion, the evolution of automotive structures is a dynamic journey influenced by a multitude of factors, including historical developments, mechanical considerations, safety standards, and consumer demands. From the rudimentary body-on-chassis designs of the 1920s to the cutting-edge chassis types of the modern era, the automotive industry has continually adapted to meet evolving demands for safety, performance, and efficiency. The growing emphasis on crashworthiness has led to the adoption of longitudinal loadpaths in Body-in-White (BIW) structures, playing a crucial role in absorbing impact forces during collisions. Material and manufacturing developments have played a significant role in enhancing the strength-to-weight ratio of vehicle structures. The transition from traditional steel to high-strength alloys, aluminum, and composite materials has allowed for lighter yet robust designs. Advances in manufacturing techniques, such as computer-aided design and robotic assembly lines, have streamlined production processes, enabling the incorporation of complex structural designs. Regulations and consumer-driven testing, exemplified by organizations like EuroNCAP, have contributed to the

establishment of stringent safety standards. These standards encompass crash tests, structural integrity requirements, and occupant protection measures, influencing the design and construction of vehicle structures. In the context of crash requirements, the report highlighted the importance of longitudinal members in BIWs.

References

1. Emadi, A. (2011). Transportation 2.0. *IEEE Power Energy Mag.*, 9(1), 54–64.
2. Fahimi, B., Kwasinski, A., Davoudi, A., Balog, R. S., & Kiani, M. (2011). Charge It! *IEEE Power Energy Mag.*, 9(1), 54–64.
3. Yilmaz, M., & Krein, P. T. (2012). Review of charging power levels and infrastructure for plug-in electric and hybrid vehicles. *IEEE Trans. Power Electron.*, 28(5), 2151–2169.
4. Tagliaferri, C., Evangelisti, S., Acconcia, F., Domenech, T., Ekins, P., Barletta, D., & Lettieri, P. (2016). Life cycle assessment of future electric and hybrid vehicles: A cradle-to-grave systems engineering approach. *Chem. Eng. Res. Des.*, 112, 298–309.
5. Zackrisson, M., Fransson, K., Hildenbrand, J., Lampic, G., & O'Dwyer, C. (2016). Life cycle assessment of lithium-air battery cells. *J. Clean. Prod.*, 135, 299–311.
6. Wu, Y., Yang, Z., Lin, B., Liu, H., Wang, R., Zhou, B., & Hao, J. (2012). Energy consumption and CO₂ emission impacts of vehicle electrification in three developed regions of China. *Energy Policy*, 48, 537–550.
7. Shen, W., Han, W., Chock, D., Chai, Q., & Zhang, A. (2012). Well-to-wheels life-cycle analysis of alternative fuels and vehicle technologies in China. *Energy Policy*, 49, 296–307.
8. Wang, R., Wu, Y., Ke, W., Zhang, S., Zhou, B., & Hao, J. (2015). Can propulsion and fuel diversity for the bus fleet achieve the win-win strategy of energy conservation and environmental protection? *Appl. Energy*, 147, 92–103.
9. Clement-Nyns, K., Haesen, E., & Driesen, J. (2009). The impact of Charging plug-in hybrid electric vehicles on a residential distribution grid. *IEEE Trans. Power Syst.*, 25(1), 371–380.
10. Shafiee, S., Fotuhi-Firuzabad, M., & Rastegar, M. (2013). Investigating the impacts of plug-in hybrid electric vehicles on power distribution systems. *IEEE Trans. Smart Grid*, 4(3), 1351–1360.
11. Pieltain Fernández, L., Gómez San Román, T., Cossent, R., Mateo Domingo, C., & Frías, P. (2011). Assessment of the impact of plug-in electric vehicles on distribution networks. *IEEE Trans. Power Syst.*, 26(1), 206–213.
12. Lucas, A., Bonavitacola, F., Kotsakis, E., & Fulli, G. (2015). Grid harmonic impact of multiple electric vehicle fast charging. *Electr. Power Syst. Res.*, 127, 13–21.
13. Turker, H., Bacha, S., Chatroux, D., & Hably, A. (2012). Low-voltage transformer loss-of-life assessments for a high penetration of plug-in hybrid electric vehicles (PHEVs). *IEEE Trans. Power Deliv.*, 27(3), 1323–1331.
14. Kempton, W., & Tomić, J. (2005). Vehicle-to-grid power fundamentals: Calculating capacity and net revenue. *J. Power Sources*, 144(1), 268–279.

15. Guille, C., & Gross, G. (2009). A conceptual framework for the vehicle-to-grid (V2G) implementation. *Energy Policy*, 37(11), 4379–4390.
16. Geng, Z., Conejo, A. J., Chen, Q., Xia, Q., & Kang, C. (2017). Electricity production scheduling under uncertainty: Max social welfare vs. min emission vs. max renewable production. *Appl. Energy*, 193, 540–549.
17. Verbruggen, A., Fishedick, M., Moomaw, W., Weir, T., Nadaï, A., Nilsson, L. J., Nyboer, J., & Sathaye, J. (2010). Renewable energy costs, potentials, barriers: Conceptual issues. *Energy Policy*, 38(2), 850–861.
18. Oda, T., Aziz, M., Mitani, T., Watanabe, Y., & Kashiwagi, T. (2018). Mitigation of congestion related to quick charging of electric vehicles based on waiting time and cost–benefit analyses: A Japanese case study. *Sustain. Cities Soc.*, 36, 99–106.