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Design and Development of an Automotive Lower Door Trim and Map Pocket

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ABSTRACT-

Designing automotive interior trim components is, in many ways, a thankless engineering problem. Nobody really notices a door trim panel unless something goes wrong with it — a rattle, a crack, a pocket that sags under the weight of a water bottle. Yet producing one that meets structural, aesthetic, manufacturing, and cost requirements simultaneously is genuinely difficult, and the development process behind even a seemingly mundane part like a lower door trim with an integrated map pocket involves a surprising amount of engineering depth. This paper works through that problem systematically. The authors built a development framework around a polypropylene-based door trim, which is a fairly standard material choice for this application, though the specific optimization decisions are where things get interesting. The methodology connects Class-A surface extraction, tooling axis definition, and DFMA-informed feature development with finite element analysis across multiple loading scenarios and moldflow simulation for process validation. Prototypes were then produced using rapid prototyping and aluminium soft tooling before committing to production tooling — a sensible sequencing that avoids the expensive mistake of discovering dimensional or warpage problems too late. The results are worth paying attention to. Topology optimization brought the part weight down by roughly 8% without compromising structural performance under static, impact, door-slam, or thermal loading.That last condition is easy to underestimate; a door trim in a car parked in direct summer sun sees temperatures that would surprise most people outside the industry. Cooling time in the injection molding process was cut by 22%, which translates directly into cycle time and, at the volumes automotive production demands, meaningful cost savings. The per-part manufacturing cost landed at around ₹235, something like 6% below the original cost target, which confirms the commercial viability of the approach rather than just its technical elegance. That said, there are limits worth acknowledging. Soft aluminium tooling performs well for prototype validation, but it doesn't always replicate the thermal behavior of hardened production steel tools with full cooling channel networks. The gap between prototype performance and series production behavior can occasionally surprise you. Similarly, the study's loading conditions, however comprehensive they appear, are necessarily a subset of what a component experiences across a full vehicle lifecycle in varied climates and usage patterns. These aren't damning criticisms, more just honest boundaries to keep in mind when reading the results. What the study does accomplish, and this is genuinely useful, is demonstrating a coherent, scalable workflow that bridges digital engineering and physical production. That bridge is harder to build than it sounds, and frameworks that make it replicable are the kind of contribution the industry actually needs.

1. INTRODUCTION

The automotive industry has been quietly undergoing a materials revolution. Over the past decade or so, there has been a genuine shift away from conventional synthetic plastics toward polymer composites and natural fiber reinforced materials, driven by a combination of regulatory pressure, cost logic, and something that feels increasingly like genuine environmental conscience. The appeal is not hard to understand lighter components, lower production costs, and a smaller carbon footprint are difficult arguments to ignore, particularly when some estimates suggest cost reductions in the range of 35% are achievable through smarter material choices. Whether that figure holds consistently across different applications is, admittedly, still debated.

What this paper is actually trying to work out is something fairly specific. How do you design a lower door trim and map pocket, components that most people never think twice about, in a way that satisfies real functional and aesthetic requirements without defaulting to materials that end up in landfill? That sounds straightforward, but it is not. Mold-in-color plastics and natural fiber composites have both matured considerably, yet there remains a frustrating gap between what is technically possible and what gets implemented in practice.

Part of the problem is a genuine tension between durability and biodegradability. A door trim needs to survive door slams, UV exposure, and the occasional coffee spill for the better part of a decade. Bio-based composites can struggle to convincingly promise all of that, and the cost of switching from proven conventional plastics is not trivial.

2.SUMMARY OF THE PREVIOUS STUDIES

Table 1 sketches out the broader research landscape around plastic product design for lower door trims and map pockets, and the range of what's been studied is genuinely wider than you might expect. Materials alone span everything from conventional plastics to bio-based composites and natural fiber reinforced polymers, which already signals that researchers aren't converging on a single solution. Methodologies are similarly spread out. Some studies go the experimental route, fabricating samples and running mechanical tests. Others take a more analytical approach through life cycle assessments or computer simulations. The disciplinary spread across this body of literature is fairly telling. Contributions come from automotive These unresolved trade-offs have real consequences. Sustainable materials remain underused in automotive manufacturing, not necessarily because engineers are indifferent, but because the guidance for navigating these decisions remains incomplete. The framework developed here draws on mold-in-color technology, natural fiber reinforced polymer composites, and life cycle assessment to evaluate design alternatives in a structured, if necessarily imperfect, way. The goal is to connect material properties, processing constraints, and environmental outcomes into something coherent enough to actually inform decisions rather than merely describe them engineering, materials science, and sustainability research, sometimes overlapping within a single paper, and that reflects something real about the design problem itself. A lower door trim panel isn't a purely technical object. It has to perform structurally, look and feel acceptable to someone sitting in a showroom, and increasingly, satisfy environmental criteria that regulators and manufacturers are taking more seriously than they did a decade ago. No single discipline owns all of that, which is probably why the literature doesn't either.

Table 1 Literature Review

Study	Material Performance	Aesthetic Quality	Environmental Impact	Manufacturing Efficiency	Functional Integration
[8]	Sustainable injection molding decreases waste and emissions	Focus on material choice to boost aesthetics	Promote the use of bio polymers and biodegradable polymers	Hybrid molds and process optimization	Boost circularity of the product and its functionality
[12]	NFRCs exhibit competitive mechanical and thermal properties	Natural fibers provide acceptable interior aesthetics	Life-cycle assessments show reduced ecological footprint	Manufacturing challenges and additive treatments discussed	Functional performance enhanced by fiber-matrix compatibility
[16]	Bamboo fiber and talc composites improve mechanical properties	Enhanced surface compatibility and texture	Higher environmental impact due to fiber processing	Injection molding process studied for efficiency	Good friction and wear properties for interiors

Study	Material Performance	Aesthetic Quality	Environmental Impact	Manufacturing Efficiency	Functional Integration
[17]	Surface treatments enhance polystyrene composite strength	Improved gloss and color stability with treatments	Supports circular economy and sustainability	Manufacturing methods impact composite quality	Functional for automotive interior applications
[4]	Comprehensive design strategies for strength and stiffness	Discusses surface finish options, design for aesthetics	Addresses life cycle and recycling concerns	Reviews multiple manufacturing processes	Emphasizes design for assembly and function
[18]	Biobased composites with natural fibers show good mechanical properties	Natural fiber texture influences aesthetics positively	Biodegradable, renewable, eco-friendly materials	Various advanced manufacturing techniques reviewed	Design parameters optimize composite properties
[19]	Natural fiber-epoxy composites show high tensile and erosion resistance	Surface treatments improve mechanical and visual quality	Sustainable and recyclable composites	Mechanical and erosion testing performed	Functional for automotive applications
[7]	Bio-based plastics face design and recycling challenges	Limited aesthetic adoption in durable products	Barriers include cost and recycling infrastructure	Design strategies for bio-based plastics	Functional design must consider lifecycle
[20]	Plant fiber composites improve strength and reduce weight	Surface treatments improve visual appeal	Sustainable, biodegradable, and renewable composites	Hybridization and nano-fillers improve processability	Addresses automotive body part functional needs
[21]	Lignocellulosic composites show promise but need durability improvements	Aesthetic potential with natural fiber composites	Cost-effective and environmentally friendly	Processing techniques impact performance	Focus on overcoming fiber-matrix compatibility issues
[1]	Plastics contribute to weight reduction and safety	Advances in plastic aesthetics and smart materials	Highlights recycling and circular economy	Emerging sustainable plastic technologies	Functional design supports automotive safety and comfort
[22]	Natural fibers reduce weight and cost in composites	Natural fiber composites offer unique textures	Environmental burden reduced by fiber substitution	Established composite manufacturing processes	Used in door panels and interior components

[15]	Graphene-enhanced PP composites improve strength and reduce weight	Maintains surface quality suitable for interiors	95% CO2 reduction via waste PP upcycling	Efficient injection molding with improved flow	Meets automotive interior part mechanical demands

Study	Material Performance	Aesthetic Quality	Environmental Impact	Manufacturing Efficiency	Functional Integration
[23]	Bamboo fiber-PP composites optimized for strength	Natural fiber aesthetics with improved surface quality	Life cycle assessment identifies carbon hotspots	Compression molding parameters optimized	Functional for automotive structural parts
[24]	PP-paper composites show good flexural and impact strength	Paper fibers provide distinct natural aesthetics	Low carbon footprint and water uptake	Hybrid wet-lay/compression molding optimized	Suitable for automotive interior applications
[25]	Nanoscale modifications improve NFC mechanical properties	Enhanced thermal stability and aesthetics	Biodegradable and renewable materials	Molecular dynamics simulations guide design	Functional applications in automotive sectors
[26]	Natural fiber composites exhibit recyclability and adaptability	Mechanical properties comparable to traditional composites	Environmentally safe and sustainable	Chemical treatments improve processing	Broad engineering applications including automotive
[14]	Composite design reduces carbon footprint in automotive parts	Design for sustainability includes aesthetics	Life cycle assessments guide material selection	Emerging technologies improve manufacturing	Balances lightweighting and environmental goals
[9]	Fully bio-based composites show promising mechanical properties	Bioprepregs offer improved aesthetics	Biodegradable and renewable materials	Various bio-based processing techniques reviewed	Functional for automotive interior applications
[27]	NFCs provide competitive mechanical and physical properties	Natural fibers offer cost-effective aesthetics	Biodegradable and lightweight composites	Overview of fabrication methods	Applications in automotive and packaging
[2]	Biofiber composites reduce weight and improve efficiency	Natural fibers provide desirable aesthetics	Environmentally friendly alternatives	Used in dashboards, door panels, pockets	Functional for automotive interior components
[13]	Lightweight PP blends with talc, good mechanical properties	Standard automotive finish, no special aesthetic focus	Supports lightweight design, indirect environmental benefits	Cost-effective low-density material, easy processing	Suitable for door panel structural requirements

[11]	NFPCs exhibit superior mechanical and tribological properties	Surface treatments enhance aesthetics	Biodegradable and flame retardant composites	Advanced fabrication methods reviewed	Functional for high-temperature applications

tudy	Material Performance	Aesthetic Quality	Environmental Impact	Manufacturing Efficiency	Functional Integration
[28]	Optimized oat-hull PP composites balance properties	Cost-effective natural fiber composites	Eco-friendly with minimized cost	Statistical mixture design applied	Suitable for automotive applications
[29]	Sisal fiber composites improve impact resistance	Alkali treatment enhances surface properties	Lightweight and biodegradable composites	Compression molding with factorial design	Functional for light automotive parts
[6]	Bio composites High performance and degradability	Bio-based matrices for aesthetics	Environmental and economic benefits	Commercial scale challenged,	Functionality Interiors and exterior parts

3. RESEARCH GAP

High volume plastic components like map pockets and lower door trims demonstrate recent advancements in automotive interior design, which emphasize the convergence of light waiting, functional integration, manufacturability, and sustainability. Previous research has mostly focused on material-level innovations, such as the creation of new bio-based polymers, natural fiber-reinforced composites, and mold-in-color technologies, or it has only examined specific aspects of environmental performance and aesthetics, frequently failing to validate their applicability through full-scale component design, structural verification, and production feasibility. The current study, on the other hand, fills this gap by combining well-established polymer materials (PP-based systems) with an extensive, industry-focused design and validation workflow that includes mold flow-driven manufacturing refinement, detailed engineering feature design, Class-A surface development, finite element-based structural optimization, and prototype-level testing. Although research shows that sustainable composites and sophisticated processing methods can lower component weight and environmental impact, issues with durability, cost, recyclability, and process reliability usually prevent their widespread use. The project report directly addresses these limitations by demonstrating that measurable improvements in weight reduction, cost effectiveness, structural performance, and production cycle time can be made by employing a conventionally viable material system, applying DFM principles rigorously, optimizing FEA-based results, and controlling the injection molding process. Furthermore, the design choices are verified by the mechanical, environmental, ergonomic, and manufacturing performance criteria, which offer a useful and expandable framework for the development of automotive interior trim, unlike many earlier works that are still in the conceptual stage or at the material testing level. As an application-driven extension of current research in the field, where theoretical content and design knowledge can be translated into a production-ready automotive component solution, this alignment supports the contribution of the research presented in this article.

4. METHODOLOGY

The process for creating an automotive lower door trim with an integrated map pocket is methodical and industry-focused, as shown in Figure 1. To guarantee both aesthetic appeal and manufacturability, the process starts with defining design objectives, then extracts Class-A surfaces and performs a thorough tooling axis style analysis. Then, using DFMA principles, engineering features are added to the Class-B and Class-C surfaces to create a complete solid model that improves assembly efficiency and structural integrity. Because of its mechanical qualities, affordability, and suitability for injection molding, PP-T20 is preferred when choosing materials. Finite element analysis is used to evaluate structural soundness under various load scenarios, and injection molding and mold flow simulations are used to evaluate manufacturing feasibility. Lastly, testing and prototype development verify that the design satisfies structural, functional, and production requirements.

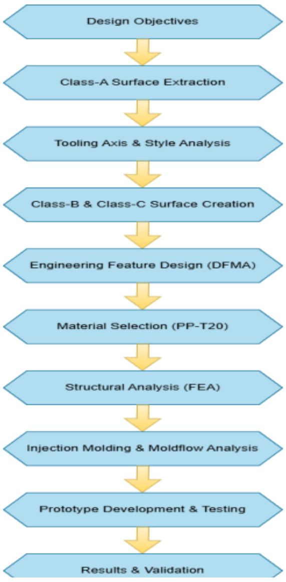


Fig 1 Methodology Flow Chart

5. DESIGN STEPS

Following the receipt of the style (3D CAD surfaces), the plastic component is designed according to these steps. The styler supplies the full door style. Breaking down the style into its component elements is essential. Which is why, in order to move on to the design phase, the style's surfaces need to be extracted. These details are shown in Figure 2.*Extracting the Class, A surfaces.*

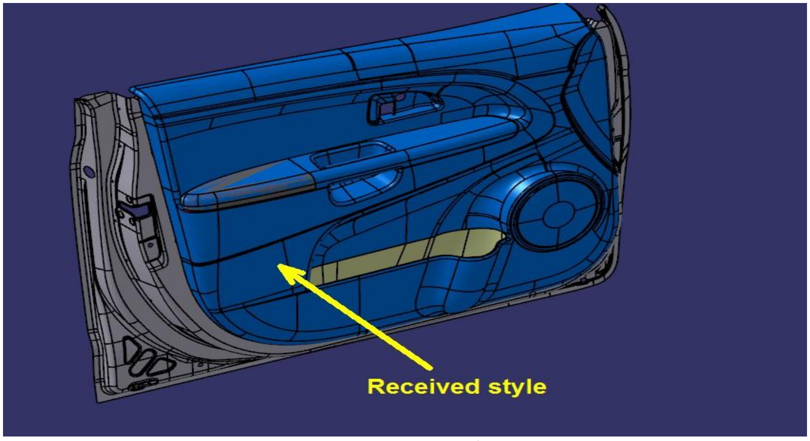


Fig 2 Class – A Surface

B. Creation of tooling Axis

This tooling direction is kept parametric, so that we can change it according the draft analysis. Details of tooling directions are shown in fig3

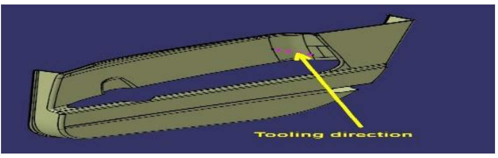
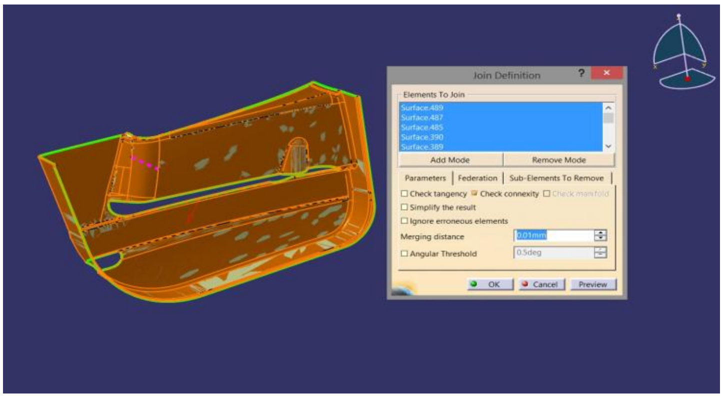


Fig 3 Tooling direction

C. Style analysis of Class A surface

In this analysis the merging distance between the all-engineering surfaces (style surfaces) are checked. Depending upon various OEM the merging distance can be varied. Style analysis shown in fig 4.



Elements To Join
Surface.489
Surface.487
Surface.485
Surface.390
Surface.389

☐ Check tangency ☑ Check connexity ☐ Check manifold
☐ Simplify the result
☐ Ignore erroneous elements
Merging distance 0.01mm
☐ Angular Threshold 0.5deg

Fig 4 Merging of style.

Figure 5 illustrates the draft analysis, which is used to verify that all styles in the tooling direction have sufficient draft angles to prevent manufacturing issues. The draft analysis is conducted on the A side, with draft angles ranging from 3 degrees to 7 degrees, depending on the manufacturing method and surface graining.

Certain parts feature graining on the A surface, which necessitates specific draft angles to ensure proper coverage during production. To confirm whether the required draft is achieved, a comprehensive analysis is performed. This assessment is crucial for verifying the draft, especially since some manufacturing processes demand particular draft specifications on the A side.

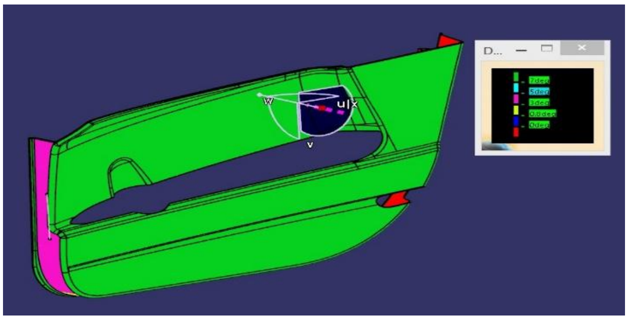
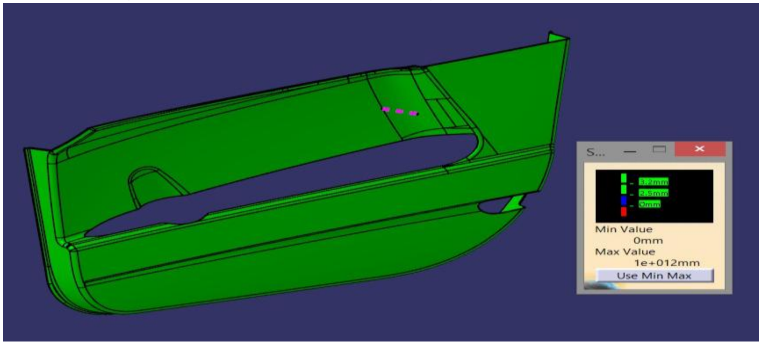


Fig 5 Draft analysis.

In design, manufacturing, and quality control, radius of curvature analysis of plastic parts is an essential procedure, especially in sectors like automotive and aerospace. It involves assessing the surface or edge curvatures of plastic components to ensure that they satisfy structural, functional, and aesthetic standards. Inorder to avoid stress concentrations or flow problems during molding, curvature analysis guarantees that mold cavities have the proper radii. Figure 6 provides the following details.



Min Value
0mm
Max Value
1e+012mm

Fig 6 Radius curvature analysis

D. Under Flush

A panel or component that is recessed or rests just behind the adjacent surface is defined as follows. Visual Description: Picture a car door that seems to be slightly affixed to the vehicle rather than sitting level with the body of the vehicle. Along the edge, this may produce a shadow effect. For instance, a door panel that is under flush might not meet the fender, leaving a gap that is less appealing to the eye. Refer to Figure 7.

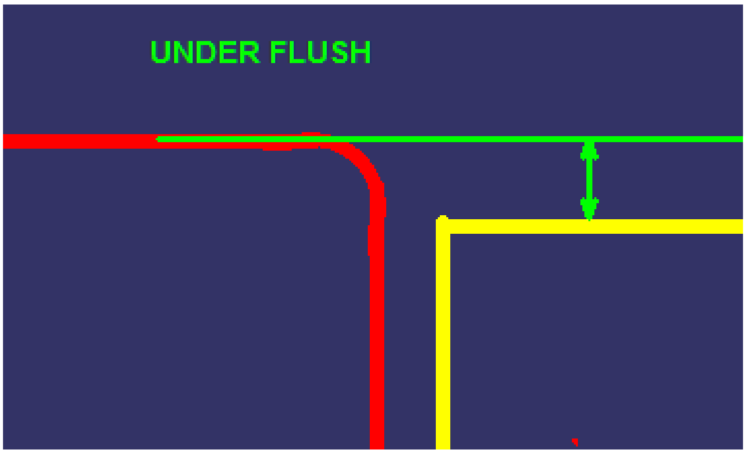


Fig 7 Under Flush

B.Over Flush

Definition: A panel or part that extends beyond the surface next to it. Visual Description: Imagine a hood that rises above the level of the fenders, causing a visible bump or raised area along the edges. This can result in misalignment, impacting both the appearance and operation. Example: A trunk lid that sits too far out may stick out past the rear fenders, interrupting the vehicle's sleek contours. Figures 8 and 9 provide additional details.

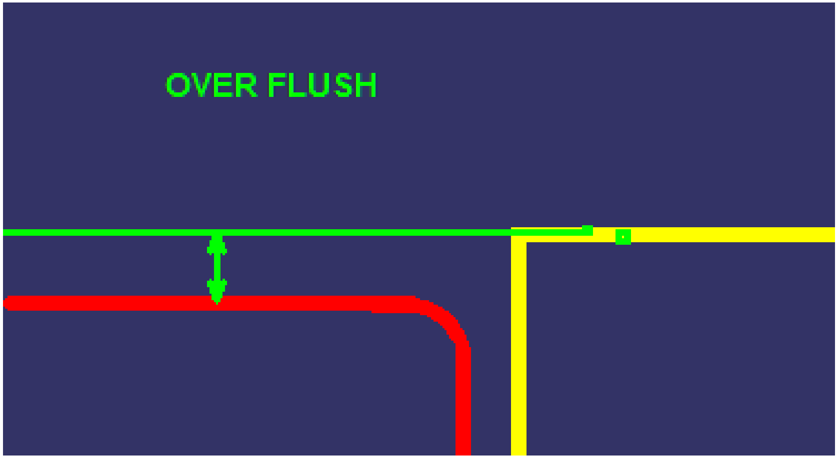
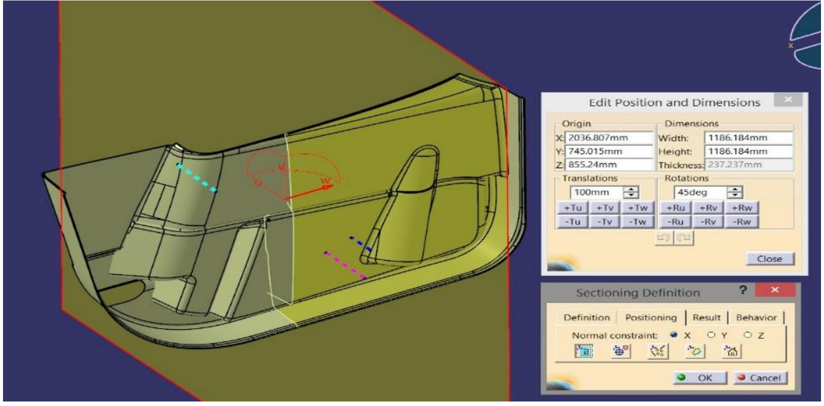


Fig 8 Over Flush



Edit Position and Dimensions

Origin
X: 2036.807mm
Y: 745.015mm
Z: 855.24mm

Dimensions
Width: 1186.184mm
Height: 1186.184mm
Thickness: 237.237mm

Translations: 100mm
Rotations: 45deg

Sectioning Definition

Normal constraint: ● X ○ Y ○ Z

Fig 9 Details of flush

C. Creation of Class-B surface

Fig 10 illustrates the creation of the B surface by offsetting the Class A surface according to the component's thickness and incorporating engineering elements such as ribs, bosses, and locators. These features are designed to remain invisible and are usually developed initially before being smoothly integrated into the base surface.

The procedure generally includes extracting surfaces from the Class A model, generating features like ribs, applying extrusion or offset operations, and then merging all elements to form the complete B surface.

Specifically, the B surface is formed by offsetting the A surfaces by 2.5mm, based on the part's thickness.

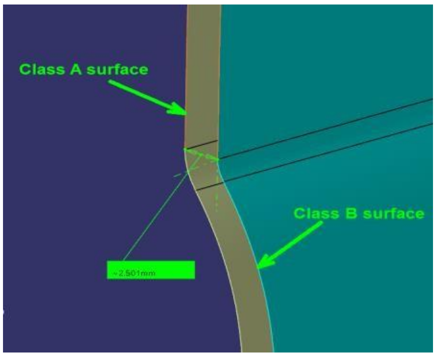


Fig 10 Class – B Surface

D. Creation of Class-c surface

To make a solid body we need to close the A and B surface. So closing surface i.e C surface is created. Details are as shown in fig 11.

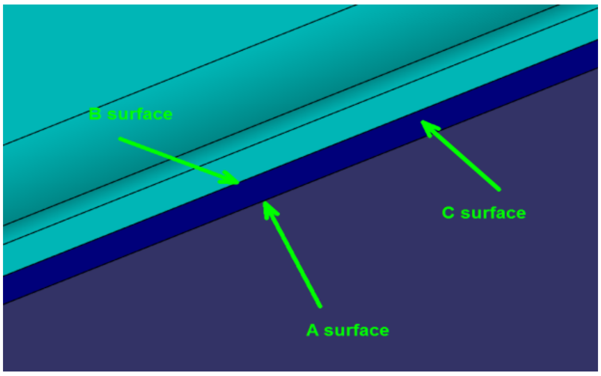


Fig 11 Class – C Surface

E. Addition of Features

Depending upon the environment and fixation strategy, the features are decided to be trim with plastic part. Hence with BIW doghouse and clip is used, with plastic part welding cylinder is used, and for reinforced part screw boss is used.See fig 12.

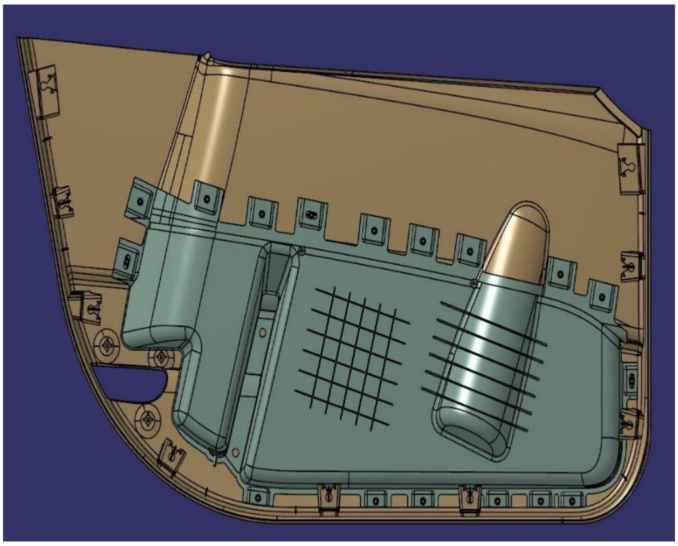


Fig 12 Addition of Features

F.Structural Analysis And FEA

The structural behavior of the lower door trim combined with the integrated map pocket was evaluated using Finite Element Analysis (FEA) to assess stress distribution, strain, and deformation under realistic operational conditions. The key objectives included verifying structural integrity under various load cases, identifying zones of high stress concentration, optimizing material usage, and predicting deformation prior to physical prototyping.

Several loading scenarios were simulated: static loading involving a 5 kg mass on the map pocket under gravity; impact loading simulating a 10 J energy drop across a 50 mm contact area; door slam loading represented by a 50 N distributed pressure; and thermal loading over a temperature range from -40°C to +85°C to account for environmental variations. The model was meshed using tetrahedral elements (SOLID187) with a global mesh size between 3 to 5 mm and refined locally to 1 mm at critical points. Mesh quality controls included maintaining an aspect ratio below 5 and orthogonal quality above 0.3, resulting in approximately 250,000 elements and 450,000 nodes to ensure accurate and dependable simulation outcomes.

G. *Manufacturing Process Design*

The manufacturing process was designed for injection molding using a machine capable of 650 tons clamping force, 1500 g shot capacity, and 1800 bar injection pressure to mold the lower door trim and integrated map pocket. A two-cavity family mold combining the map pocket and trim was employed to enhance production efficiency. This setup used a hot runner system with valve gates to balance material flow and minimize waste. Side actions accommodated undercuts, while a conformal cooling system circulated water at 25°C with a flow rate of 12 L/min, effectively dissipating heat. This cooling approach reduced the cooling time from 45 seconds to 35 seconds, contributing to an overall cycle time of 52 seconds. Optimized process parameters included a melt temperature of 220°C, mold temperature of 40°C, injection speed of 80 mm/s, packing pressure of 600 bar, and packing time of 8 seconds, ensuring consistent part dimensions, quality, and repeatability.

H. Prototype Development and Testing. Prototyping and testing were conducted to validate the design before mass production. Initial verification utilized rapid prototyping via stereolithography (SLA) with Accura 55 resin to confirm form, fit, and function. Subsequently, soft tooling using aluminum molds produced a pilot batch of 50 units to validate the process under near-production conditions. The prototypes underwent comprehensive testing protocols covering mechanical, environmental, and functional aspects. Mechanical tests showed satisfactory performance, with a maximum deflection of 3.1 mm under a static 5 kg load for 24 hours; impact and fatigue tests revealed no failures or cracks. Environmental exposure to temperature cycling, humidity, and UV aging demonstrated dimensional stability and surface durability. Functional evaluations confirmed assembly compatibility, appropriate snap-fit forces, and excellent ergonomics, validating the component's robustness and production readiness.

6. RESULT AND DISCUSSION

The results from the design, analysis, and validation phases demonstrate that the developed lower door trim with integrated map pocket meets targeted functional, structural, and manufacturing criteria. The final component weighs 782 g, achieving an 8% weight reduction from the initial design while maintaining structural strength. This reduction was primarily realized through FEA-driven rib and material layout optimization, underscoring the value of simulation-based design refinement. Structural analysis indicated a maximum deformation of 3.2 mm under the static 5 kg load, well below the allowable limit of 5 mm.

The peak von Mises stress was 18.5 MPa, providing a safety factor of approximately 1.6 under normal use. Impact and door slam simulations confirmed stresses remained below the material's yield strength, with no permanent deformation observed, validating the suitability of PP-T20 material. Moldflow analysis confirmed manufacturing feasibility, showing uniform cavity filling within 1.8 seconds, minimal weld lines placed in non-critical areas, and sink marks controlled below 0.2 mm. Warpage was limited to 0.45 mm, ensuring dimensional stability and surface quality suitable for visible interior parts. Cooling channel optimization improved cooling efficiency by 22%, directly enhancing production throughput. Prototype testing corroborated the simulation predictions, with all units passing mechanical, environmental, and functional tests without failure. Ergonomic assessments yielded high user satisfaction scores, confirming easy access and usability of the map pocket. Economically, the optimized design met the target cost of under Rupees 235 per part, confirming commercial viability. Overall, the findings validate the integrated design-analysis-manufacturing approach proposed here as an effective and scalable method for automotive interior trim development.

7. CONCLUSION

This study presents a structured, industry-aligned methodology for developing an automotive lower door trim with an integrated map pocket, focusing on harmonizing design quality, engineering robustness, and manufacturability. Instead of treating design, analysis, and production as isolated stages, this work promotes a comprehensive workflow that integrates Class-A surface aesthetics with engineering and manufacturing considerations, ensuring alignment between styling intent and functional performance. A key insight is the importance of incorporating Design for Manufacturing and Assembly (DFMA) principles early, supported by simulation-driven validation, to enhance design reliability and reduce iterative cycles in tooling and production. The systematic use of FEA and moldflow analysis facilitated informed decisions regarding material distribution, feature placement, and process parameters, avoiding the trial-and-error methods common in conventional trim development. Beyond this specific component, the approach has broader applications for automotive interior development, addressing the increasing demands for weight reduction, cost efficiency, and high perceived quality. The production-ready solutions demonstrated here show that established polymer materials, when combined with robust digital engineering tools and disciplined design practices, can meet these requirements effectively. The main contribution is a validated end-to-end development framework bridging the gap between conceptual design and series production, integrating styling, structural integrity, manufacturability, and user experience in a replicable manner. Future work could expand this framework by incorporating sustainable materials, digital quality inspection techniques, and lifecycle assessment tools to further enhance environmental performance. The methodology and insights offered provide a solid foundation for developing next-generation automotive interior components with industrial practicality and scalability.

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