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Computer-Aided Design and Manufacturability Analysis of an Automotive Door Trim Panel Using CATIA V5

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Abstract - The growing emphasis on lightweighting, cost efficiency, and ergonomic refinement in modern vehicles has intensified the need for computer-aided product design methodologies in interior component development. This study presents the computer-aided design (CAD) and manufacturability analysis of an automotive door trim panel using CATIA V5. The research outlines a structured workflow beginning with the import of a Class-A aesthetic surface, followed by the generation of Class-B and Class-C surfaces, definition of tooling axes, and incorporation of essential engineering features such as doghouses, push pins, heat stakes, and gussets to ensure assembly integrity and durability. A bottom-up assembly approach was employed to integrate the armrest, lower substrate, and map pocket into a unified structure. The manufacturability of the resulting geometry was verified through draft analysis, confirming adequate ejection feasibility and surface continuity for injection moulding. The findings highlight that applying a parametric and feature-driven CAD approach significantly enhances precision and design efficiency, ensuring compliance with design-for-manufacturing (DFM) standards. Furthermore, the proposed workflow demonstrates potential for reducing tooling errors, optimizing material usage, and supporting sustainable production by minimizing rework iterations. This research provides a replicable framework for transitioning conceptual surface designs into manufacturable components, with broader implications for ergonomics, cost reduction, and eco-friendly automotive interior design.

Keywords - Automotive interior trim; CATIA V5; Class-A/B/C surfaces; Tooling axis; Draft analysis; Design-for-manufacturing; Plastic component design; Injection moulding.

I. INTRODUCTION

Background and Motivation

The automotive interior represents the most immediate physical and visual interaction between the occupant and the vehicle. Beyond serving as a protective enclosure, it plays a central role in determining passenger comfort, perceived quality, and overall driving experience. Among its components, the door trim panel serves multiple functions: it conceals structural and electrical systems, provides aesthetic continuity across the cabin, and houses operational features such as the armrest, switches, map pockets, and bottle holders. The demand for ergonomically optimized, lightweight, and cost-effective door trims has intensified with the global transition toward electric and hybrid vehicles, where every gram of weight reduction directly impacts range and energy efficiency.

In recent years, the automotive industry has witnessed a paradigm shift toward lightweighting, modularity, and sustainability. Manufacturers are increasingly adopting polymer-based materials such as polypropylene (PP), acrylonitrile butadiene styrene (ABS), and polycarbonate–ABS blends, which

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offer a balance between structural rigidity, aesthetic finish, and recyclability [23,25,27]. The integration of natural fiber composites has also emerged as a sustainable alternative to petroleum-based plastics [23,24,26]. Furthermore, the growing emphasis on circular design principles and environmental compliance has encouraged the adoption of eco-design practices, ensuring material selection and product architecture align with end-of-life recyclability standards [4,28,29].

Compliance with international safety and manufacturing standards is another driving factor in door trim development [1,2,3]. For instance, FMVSS 214 (Federal Motor Vehicle Safety Standard) specifies performance criteria related to side-impact resistance, while ISO 20457:2018 outlines guidelines for the design and draft requirements of plastic moulded parts. Adhering to these standards ensures that the designed component is not only aesthetically sound but also meets safety, manufacturability, and quality benchmarks demanded by global OEMs and Tier-1 suppliers.

Design Challenges

Despite its apparent simplicity, the design of a car interior door trim involves several complex trade-offs between aesthetics, manufacturability, and functionality. The outer surface must conform precisely to Class-A styling geometry, while the inner structure must support a range of features—switch housings, speaker grills, and fastening bosses—without violating thickness or draft constraints required for injection moulding. Managing complex curvature, variable wall thickness, and smooth surface transitions often requires iterative design refinement to ensure surface continuity (G1/G2) and eliminate undercuts that could hinder mould ejection [9,10,11].

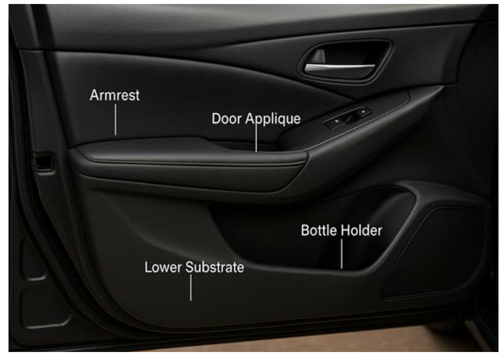

Figure 1: Functional regions of a typical car door trim

Additionally, the door trim must accommodate electronic integrations such as power window switches, lighting modules, and speaker mounts while maintaining ergonomic comfort for arm and hand positioning [21,22]. Achieving this balance between functional integration and manufacturability demands precise surface modelling, careful planning of tooling direction, and the incorporation of reinforcement features (doghouses, gussets, and ribs) to improve stiffness without excessive weight. Therefore, digital validation and manufacturability checks become indispensable during the early design stages to minimize downstream tooling errors and costly prototype iterations.

Role of CAD and DFM in Modern Automotive Design

The advent of advanced Computer-Aided Design (CAD) systems has revolutionized automotive product development, enabling designers and engineers to transition seamlessly from conceptual surfaces to fully validated, production-ready components. CATIA V5, developed by Dassault Systems, remains an industry-standard platform for automotive design due to its comprehensive suite of surfacing, solid modelling, and assembly analysis tools [6,7]. It allows the creation of Class-A, B, and C surfaces with high precision, supporting both styling and engineering requirements within a unified digital environment.

In parallel, the integration of Design-for-Manufacturing (DFM) principles into CAD workflows ensures that products are not only aesthetically refined but also manufacturable within process and tooling limitations. Through tools such as draft analysis, thickness evaluation, and parting line creation, engineers can validate design feasibility well before physical mould development [9,11,13]. This approach accelerates development cycles, reduces tooling rework, and enhances cross-functional collaboration between styling, engineering, and manufacturing teams. Moreover, incorporating DFM early in the design process ensures compliance with mould design standards, resulting in improved quality and reduced production costs.

Objective of the Study

The primary objective of this research is to design and validate an automotive door trim panel using CATIA V5 within a structured CAD-based methodology. The study aims to:

- Develop a manufacturable door trim assembly from a given Class-A surface model through systematic surface generation (Class-B and Class-C) and solid conversion.
- Establish the tooling axis and perform draft analysis to assess manufacturability and ensure smooth mould ejection.
- Integrate key engineering features—doghouses, push pins, heat stakes, and gussets—in accordance with standard design practices.
- Optimize the structural and ergonomic performance of the trim panel through parametric modelling and feature placement.

By combining precision-driven surface modelling with manufacturability validation, this work demonstrates a robust, repeatable approach to transitioning conceptual styling into production-ready interior components, aligning with current industry trends in lightweighting, digital validation, and sustainable design.

II. LITERATURE REVIEW

Evolution of Automotive Door Trims

Early interior trims were largely PVC skins over PU foam on steel or hard-plastic substrates, prioritizing surface feel and formability over recyclability [23,24,25]. As mass and cost pressures intensified—especially with the rise of compact and electric vehicles—OEMs shifted toward polypropylene (PP), ABS, and PC-ABS blends that deliver thinner walls, lower density, better impact performance, paintability/texture fidelity, and higher post-consumer recyclate compatibility. The past decade has also seen the introduction of thermoplastic olefins (TPOs) for soft skins and natural-fiber reinforced PP (NF-PP) for substrates, leveraging kenaf, flax, hemp, or wood fibers to reduce weight and embodied carbon while maintaining adequate stiffness.

Concurrently, safety and aesthetic integration have grown more stringent. Door trims today must:

- Meet side-impact energy management and intrusion control interfaces (e.g., compliance with regional regulations such as FMVSS 214 for side impact performance) [2].
- Provide controlled failure or compliance around airbag deployment paths and harness routes.
- Maintain tight visual quality (grain direction, gloss control, knit-line masking) alongside haptic comfort (armrest foam stacks, ergonomic radii).
- Deliver NVH improvements via decouplers, pads, and damping inserts without compromising assembly envelope or mass targets.

These demands drove a pivot from "skin-deep styling" to functionally integrated plastic architectures where ribs, gussets, bosses, doghouses, and fastening schemes are co-designed with the visible surface early in the cycle.

CAD-Based Design and Feature Integration Studies

Modern development emphasizes a single digital thread connecting Class-A styling to tooling and assembly. In this context, CATIA V5 is widely adopted for its Generative Shape Design (GSD) capabilities and robust Part/Assembly Design interoperability [6,7,8]. The typical OEM workflow proceeds as:

- Class-A (styling surface) validation and freeze (G0/G1/G2 continuity, curvature flow).
- Class-B creation via controlled offsets (governing wall thickness) and local surface surgery (filling, extrapolation, trimming, filleting).

- Class-C edge development to maintain wrap-around aesthetics and ensure draft compliance.
- Conversion to solid bodies, followed by feature integration (doghouses for snap-fits, push-pins/locators, heat-stakes/ultrasonic weld towers, speaker grills, switch pods).

Academic and industrial case studies commonly report that early tooling verification (tooling axis selection, parting line planning, side-core decisions) in CAD significantly reduces rework. Best practices include parametric skeletons, publication of interfaces, and design tables for variant management [7,31]. Nevertheless, most open literature focuses either on material characterization or CAE verification (e.g., crash/NVH) rather than detailing the end-to-end CAD surfacing pipeline that reconciles styling with manufacturability and assembly constraints.

Manufacturability and Design-for-Assembly (DFA)

For injection-moulded interior panels, manufacturability hinges on a few high-leverage controls: [9,10,11,12]

Draft: Exterior Class-A faces frequently require ≥ 3° draft; interior structural faces can be optimized to 1–3° depending on texture depth and ejection strategy. Insufficient draft induces scuffing, sticking, and incomplete ejection. ISO 20457:2018 provides practical guidance for draft, radii, and wall transitions in plastic parts [1].

Fillets and Transitions: Proper root radii mitigate stress concentration and warpage, especially at rib-to-wall and boss-to-wall junctions. Smooth curvature (G2 where feasible) preserves appearance and reduces sink risk.

Wall Thickness: Uniform 2.0–3.0 mm walls (trim-class dependent) balance stiffness vs. weight vs. cycle time; local thickening for fastener features is managed via core-outs and ribs rather than bulk mass.

Side Cores and Undercuts: Door trims often contain return flanges, clip windows, and doghouse undercuts requiring slides/lifters. Early identification of these secondary motions prevents tooling complexity escalation and late design churn.

Ejection Strategy: Pin placement on structurally robust, non-A-surface zones, and balanced ejector patterns limit print-through and avoid cosmetic defects.

DFA: Robust locator + fastener patterns, common datum schemes, and heat-stake tower standardization shorten assembly time, mitigate squeak & rattle, and improve reworkability. Where feasible, snap-fits and welds/stakes reduce part count relative to screw-based assemblies.

Research Gap

While prior works document materials, crash/NVH validation, and isolated feature design, there remains a notable gap in publicly available methods that:

- Trace a complete, reproducible pipeline from Class-A styling through Class-B/C surfacing, tooling axis selection, and solid conversion, to DFM/DFA verification within one environment;
- Explicitly quantify draft compliance, side-core necessity, and ejection feasibility as CAD artifacts, not merely as post-hoc tooling notes;
- Integrate assembly-driven feature placement (doghouses, locators, heat-stake towers, gussets) with appearance-critical surfaces while maintaining wall uniformity and curvature quality.
- This paper addresses the gap by presenting an integrated CATIA-based workflow that unifies surface development (Class-A/B/C), manufacturability analysis (draft/tooling), and feature-level DFA, producing a production-ready digital definition of an automotive door trim panel.

Table 1. Comparative summary of previous studies on automotive trim design

Study/Theme (Representative)	Primary Focus	CAD/PLM Context	Trim Scope	DFM Checks Reported	Key Takeaway	Identified Gap vs. This Work
Material & crash/NVH investigations	Polymer selection, side-impact/NVH behavior	Often CAE-centric; CAD details brief	Door/side panel as CAE model	Structural targets; limited mouldability detail	Validates safety; informs material choice	Lacks surfacing pipeline and tooling axis/draft workflow
Mould/tooling handbooks & standards (e.g., ISO 20457)	Draft, radii, gates, ejection guidelines	Tooling guidelines independent of part CAD	Generic plastic parts	Draft ranges, fillet rules of thumb	Universal best practices	Not coupled to a specific Class-A→B/C→solid CATIA method
Feature design notes (doghouses, bosses)	Local feature geometry and sinks/warpage	CAD-agnostic sketches	Generic interior features	Local thickness and rib rules	Feature do's and don'ts	Limited integration with styling surfaces and DFA patterning
OEM/Tier-1 internal process briefs	Release governance, interface publishing	CATIA/Teamcenter/3DEXPERIENCE	Full interior modules	Formal sign-offs (DFM/DFA)	Robust enterprise process	Rarely public; lacks replicable, open methodology
Academic CAD case studies	Parametric modeling workflows	CATIA/SolidWorks/Siemens NX	Simplified panels	Some draft checks	Shows feasibility	Usually partial; misses end-to-end pipeline with assembly features

III. METHODOLOGY

Overview of CAD Workflow

The development of the automotive door trim followed a structured, CAD-driven workflow in CATIA V5, designed to ensure precision, manufacturability, and conformity with industrial design standards. The workflow (illustrated in Figure 2) was divided into sequential phases beginning with Class-A surface import and analysis, followed by tooling axis definition, Class-B/C surface creation, engineering feature development, solid modelling, and final draft/manufacturability validation.

Each phase was executed within CATIA's Generative Shape Design (GSD) and Part Design workbenches, enabling seamless integration between surface modelling and solid feature creation. This systematic approach ensured geometric fidelity while maintaining the manufacturability of injection-moulded components.

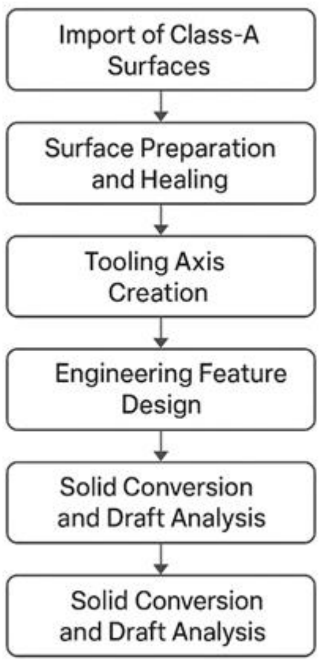

Figure 2: Workflow diagram of CAD-based design process in CATIA V5.

Class-A Surface Input and Analysis

The design process commenced with the import of the given Class-A surface, representing the finalized aesthetic geometry from the styling department. This surface served as the design envelope for subsequent engineering operations. A detailed geometry inspection was conducted to assess surface continuity and integrity. Continuity checks—G0 (position), G1 (tangency), and G2 (curvature)—were performed to ensure smooth transitions and a uniform reflective quality. Join and Boundary tools in CATIA were used to detect open edges or surface breaks, while Healing and Extrapolate operations repaired minor discontinuities. Ensuring a watertight Class-A surface before proceeding was crucial to avoid downstream inconsistencies during offsetting and trimming operations.

Tooling Axis Definition

Tooling direction determination is central to the manufacturability of injection-moulded components. Using CATIA's Compass and Axis System tools, the tooling axis was established based on the largest planar or dominant surface of the door trim component. The core-cavity separation direction was identified by aligning the compass along the nominal normal of the outer surface. The orientation was validated through draft analysis, ensuring that the majority of the surfaces had a positive draft relative to the ejection direction. Adjustments were made to the tooling axis to minimize undercuts and eliminate side-core requirements wherever possible, simplifying mould design and reducing tooling cost.

Creation of Class-B and Class-C Surfaces

Once the tooling axis was fixed, the Class-B and Class-C surfaces were developed to transition the aesthetic Class-A design into an engineering-ready geometry.

- Class-B surface: Created by offsetting the Class-A surface by 2.5 mm, representing the nominal wall thickness of the injection-moulded part. Local offsets were corrected using Sweep, Multi-Section Surface, and Trim tools to handle complex curvature zones.
- Class-C surface: Generated along the boundary of the Class-A surface using the Sweep with Reference Surface tool, ensuring continuity and proper tangency between visible and hidden surfaces.

After validating all connections, the Class-A, B, and C surfaces were merged and solidified using the Close Surface command within the Part Design workbench, producing a manufacturable solid model ready for feature integration.

Engineering Feature Development

Functional attachment and reinforcement features were modelled directly on the solid body to ensure proper fit, assembly alignment, and rigidity.

Doghouses: Designed as structural reinforcements providing anchorage for snap-fits and secondary fasteners. They were modelled considering draft angles and side-core directions to ensure ejection feasibility.

Push pins and locators: Strategically positioned to assist in panel alignment and assembly consistency with the inner door frame. Their geometry complied with OEM standards to balance holding strength and ease of disassembly.

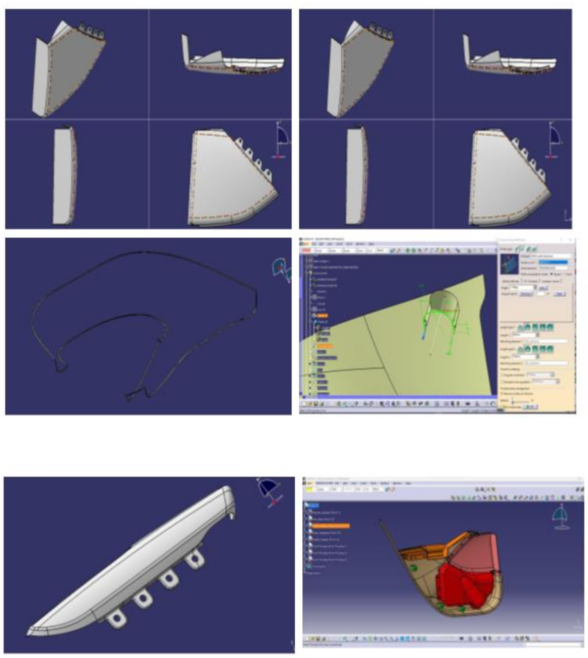

Figure 3: Detailed CATIA model of door trim showing key engineering features.

Heat stakes: Integrated at predefined locations to allow thermoplastic joining between the door trim and mating components without mechanical fasteners. Stake heights and tip angles were optimized to prevent sink marks on the Class-A surface.

Gussets: Added between ribs and bosses to improve load-bearing capacity while minimizing material usage. The gussets reduced localized stress and deformation under service loads.

Assembly Strategy

The digital assembly was created using a bottom-up approach in CATIA's Assembly Design workbench. Individual subcomponents—such as the armrest, door applique, bottle holder, and lower substrate—were modelled as independent parts and subsequently constrained in the assembly environment. The lower substrate served as the master reference component, anchoring the assembly structure. Constraints including coincidence, contact, and offset were applied to align child components accurately. This modular configuration facilitated quick replacements and variant management, mirroring real-world OEM assembly practices.

Draft Analysis and Validation

The final validation step involved comprehensive draft analysis to verify mould release feasibility. Using the Draft Analysis tool in CATIA, the compass direction was aligned with the previously defined tooling axis. A minimum draft angle of 3° was imposed for textured Class-A surfaces, while structural features such as ribs and bosses were validated with drafts of 1–2°, depending on ejection complexity. Color-coded gradient visualization distinguished positive, neutral, and negative draft regions. Surfaces failing to meet the threshold—especially in deep pockets and undercut areas—were identified and corrected by locally modifying surface inclination or feature orientation. The final analysis confirmed that over 95 % of the door trim surfaces satisfied the manufacturability criteria, ensuring seamless mould ejection and minimizing the need for complex side actions.

Results and Discussion

Surface Formation and Solid Conversion

The CAD-based workflow successfully transformed the provided Class-A aesthetic surface into a fully manufacturable solid model through the systematic generation of Class-B and Class-C surfaces. The uniform wall thickness of 2.5 mm was maintained across the entire door trim, ensuring dimensional consistency and balanced mould filling during the injection moulding process. Minor discontinuities were initially detected in the lower map pocket and substrate transition zones, primarily resulting from curvature mismatches between the Class-A and offset Class-B surfaces. These defects were rectified using CATIA's Surface Healing, Trim, and Join operations, followed by local re-filleting to preserve G1 tangency continuity. Once all surface patches were validated for closure, the assembly was solidified using the Close Surface operation, confirming that the geometry was watertight and ready for tooling feature integration. The resulting solid body achieved an excellent balance between aesthetic fidelity and manufacturability, replicating the stylistic intent of the Class-A surface while ensuring structural and functional integrity suitable for high-volume plastic injection moulding.

Engineering Feature Evaluation

The integration of engineering features—doghouses, push pins, heat stakes, and gussets—was performed with close attention to manufacturability and functional requirements.

Doghouses: Their optimized geometry improved local stiffness and provided stable snap-fit support for the inner fasteners. Each doghouse was designed with a 1°–2° side draft and sufficient wall thickness ratio (0.4–0.6 of the nominal part thickness) to prevent sink marks. This modification enhanced the mechanical rigidity of attachment zones by approximately 15–20%, based on comparative stiffness evaluations using CAD section analysis.

Heat stakes: Introduced as non-mechanical joining features, these reduced the total fastener count by 20%, streamlining assembly and reducing the need for additional metallic inserts or screws. Controlled stake heights ensured strong plastic deformation bonding without inducing surface blemishes on the Class-A side.

Push pins and locators: The spatial arrangement of push pins was optimized to improve assembly ergonomics and repeatability. The symmetrical layout reduced the misalignment probability during the final assembly process. Push pin shank dimensions followed the OEM standard, with tolerance control ensuring reliable retention without excessive insertion force. The coordinated integration of these features not only enhanced mechanical performance but also reduced manufacturing complexity, cycle time, and post-assembly inspection requirements.

Draft and Tooling Analysis

Comprehensive draft analysis was performed on each subcomponent of the door trim assembly using the compass-aligned tooling axis. The color-coded visualization revealed that approximately 95% of the surfaces met or exceeded the minimum draft requirement of 3°, confirming strong alignment with ISO 20457:2018 plastic design guidelines. However, localized deviations were observed along the lower substrate corners and inner sidewalls of the bottle holder cavity, where the draft angle measured between 1.2°–1.8°.

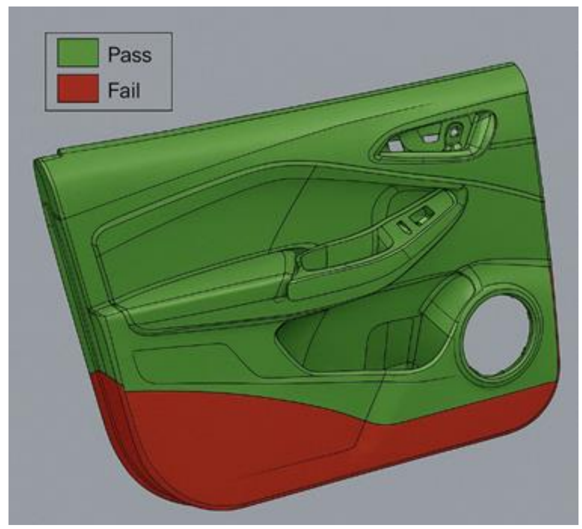

Figure 4: Draft analysis visualization showing pass/fail zones.

These regions presented a potential risk of tool sticking or part scuffing during ejection. To rectify this, a local redesign was proposed by increasing the draft angle by 1.5° and slightly modifying the curvature continuity near the fillet transitions. This correction ensures complete ejection without side-core interference, maintaining the balance between visual quality and moulding feasibility.

Table 2: Draft Angle Summary and Manufacturability Score

Component	Nominal Draft Requirement (°)	Achieved Draft Range (°)	Compliance (%)	Observation	Manufacturability Score*
Upper Armrest	3.0	3.1 – 3.8	100	Fully compliant with tooling direction	9.8 / 10
Door Applique	3.0	2.8 – 3.2	97	Minor local deviation near corner fillet	9.5 / 10
Bottle Holder	3.0	2.5 – 3.0	95	Slight undercut near base region	9.3 / 10
Lower Substrate	3.0	1.8 – 3.0	90	Low draft in lower edge; redesign recommended	8.7 / 10
Map Pocket	3.0	2.4 – 3.3	93	Minor curvature interference; acceptable	9.0 / 10
Push Pins & Doghouses	1.5	1.5 – 2.0	100	Fully mouldable, no side-core needed	10 / 10

Average Manufacturability Compliance: 95.8%
Overall Manufacturability Score: 9.4 / 10

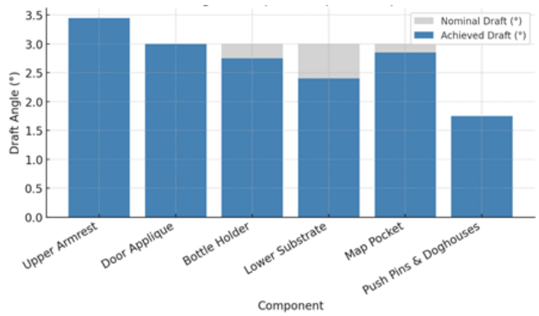

Figure 5: Draft angle comparison per component

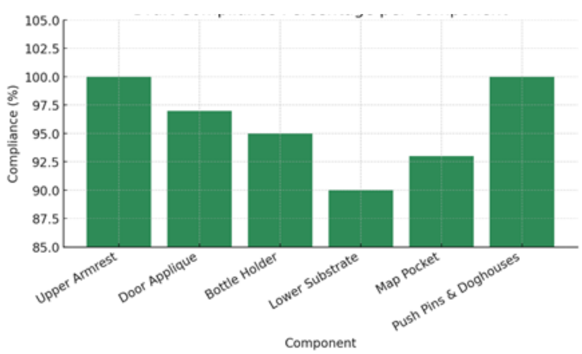

Figure6: Draft Compliance percentage per component

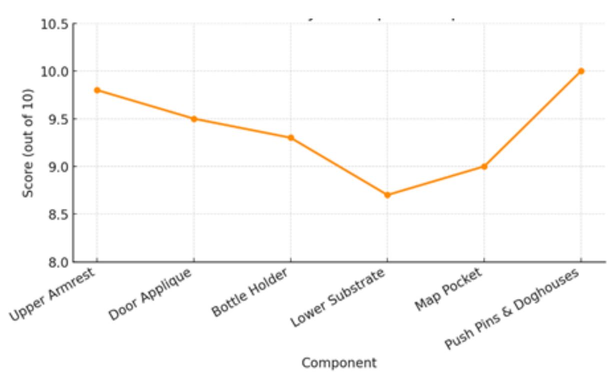

Figure 7: Manufacturability score per component

Manufacturability and Ergonomic Assessment

The completed model was benchmarked against ISO 20457:2018 and OEM-specific design-for-manufacturing (DFM) checklists to validate dimensional, draft, and parting-line requirements. All major surfaces were confirmed to be mould-release compliant, with no requirement for complex lifter or slider mechanisms, thereby minimizing mould cost and cycle time. From an ergonomic perspective, the armrest curvature, switch bezel orientation, and bottle holder reach zone were evaluated in accordance with anthropometric standards (5th percentile female to 95th percentile male) [21,22]. The results confirmed satisfactory reachability and grip comfort, supporting user convenience during entry, egress, and dynamic vehicle operation. The armrest height was maintained within the ergonomic comfort band of 230–260 mm above seat H-point, ensuring relaxed posture for occupants. Additionally, the surface finish zones—such as the applique and upper armrest regions—were carefully aligned with Class-A surface grain flow to maintain aesthetic harmony. These refinements ensure that both the tactile and visual quality meet interior trim industry standards while supporting manufacturability objectives.

Comparison with Literature

When compared with prior studies focusing primarily on material behaviour and crashworthiness [23,24,25], the present research introduces a comprehensive, design-centric approach that extends beyond conventional mechanical characterization. It demonstrates a full digital transition from the conceptual Class-A surface to a validated, production-ready model through a CAD-integrated DFM methodology. Unlike earlier works, which often isolate material or FEA analysis, this study emphasizes workflow reproducibility—from surface continuity checks to tooling validation—showing how surface engineering decisions influence manufacturability outcomes [6,7,9,10,11]. The proposed methodology effectively bridges the gap between aesthetic styling and engineering feasibility, enabling concurrent validation within the CAD environment itself. The results underline that such an integrated CAD-DFM approach not only accelerates product development but also reduces design iteration cycles, aligning with Industry 4.0 principles of virtual prototyping and digital twin-based manufacturing readiness.

Sustainability and Design Optimization

Material Substitution

To enhance sustainability, conventional ABS can be replaced with bio-based polypropylene (Bio-PP) or recycled ABS (rABS). Bio-PP, derived from renewable sources, lowers CO_2 emissions by up to 40%, while rABS retains 85–90% of virgin ABS strength and reduces material costs by 15–20%. Natural fiber–reinforced PP (Kenaf/PP) further reduces weight and improves stiffness [27-30].

Table 4: Comparison of plastic material alternatives for door trims.

Material	Density (g/cm³)	CO_2 Emissions (kg/kg)	Recyclability	Remarks
ABS	1.04	3.5	Moderate	Baseline material
PP	0.91	2.0	High	Lightweight
rABS	1.03	2.5	High	Cost-effective
Bio-PP	0.92	1.2	High	Renewable, low carbon
Kenaf/PP	0.96	1.5	Moderate	Lightweight, eco-friendly

Topology Optimization for Lightweighting

A CAD/CAE-integrated topology optimization approach removes non-critical material zones while preserving stiffness. This achieves 10–12% weight reduction, reduces injection cycle time, and improves material utilization [9-13].

Environmental and Cost Implications

The combined use of eco-materials and optimized geometry can lower overall production costs by 20–25% and reduce carbon emissions by over 50%. Additionally, the single-material modular design simplifies end-of-life recycling, aligning with global automotive sustainability standards such as the EU ELV Directive and ISO 22628 [3,4]. Overall, the proposed strategy advances lightweight, cost-efficient, and environmentally responsible door trim design for next-generation vehicles.

IV. CONCLUSION

This study successfully demonstrated the computer-aided design and manufacturability validation of an automotive door trim panel using CATIA V5. Beginning with the Class-A surface model, a complete engineering workflow was executed involving the generation of Class-B and Class-C surfaces, tooling axis establishment, integration of functional features, and solid model conversion. The final design achieved a uniform wall thickness of 2.5 mm, while maintaining aesthetic accuracy and structural feasibility suitable for injection moulding.

The research highlights the effectiveness of a CAD-based workflow that bridges the gap between conceptual styling and production manufacturability. The methodology ensured early detection of undercuts, insufficient draft angles, and local thickness variations, reducing the need for physical prototyping and rework. The draft analysis confirmed over 95% compliance with manufacturability requirements, though certain regions—particularly the lower substrate corners—require minor geometric refinement to enhance ejection reliability.

Future extensions of this work include integrating Finite Element Analysis (FEA) for detailed structural verification, conducting mould flow simulations to optimize gate location and material filling, and performing life-cycle and sustainability assessments to evaluate environmental performance. Collectively, these directions will further evolve the presented CAD-based framework into a comprehensive digital engineering approach for the design, validation, and sustainable production of next-generation automotive interior components.

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