

TRACING MATERIAL PROPERTIES TO SYSTEM-LEVEL PERFORMANCE: A NORMALISED SENSITIVITY ANALYSIS FOR A BOEING 737-CLASS AIRCRAFT

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Abstract

This paper presents a framework for linking material properties to top-level system performance in aircraft design. By formulating a Normalised Sensitivity Matrix (NSM) and an Aggregated Design Impact Matrix (ADIM), the analysis quantifies how fractional variations in material strength, stiffness, density and temperature capability influence payload, range and climb rate. The Boeing 737–800 configuration is used as a representative baseline single-aisle transport, with fixed maximum take-off weight (MTOW), fuel volume and geometry. Airframe materials primarily influence payload through structural mass: a 1% reduction in structural density yields a 1.14% gain in payload. Hot-section engine materials govern range and climb rate through weight, efficiency and thrust capability. Turbine temperature capability carries the highest single sensitivity in the matrix (S = +1.20 for climb rate). The ADIM confirms a clear disciplinary separation, with airframe materials dominating payload (aggregate impact 2.12) and engine materials dominating climb rate (2.64) and range (0.75). The results demonstrate a direct traceability between material-level parameters and system-level performance metrics, providing materials engineers with a quantitative understanding of the impact of property improvements at the operational level. The framework is computationally inexpensive, applicable at the conceptual design stage and can be directly used to evaluate emerging materials.

Keywords: normalised sensitivity matrix; material properties; aircraft performance; multidisciplinary design; aggregated design impact matrix

1. Introduction

Aircraft performance is the integrated outcome of aerodynamics, structural mechanics and propulsion. At each level of this hierarchy, material properties play a defining role. In the airframe, strength-to-weight and stiffness-to-weight ratios govern structural mass and, through it, the payload and range capability of the aircraft. In the propulsion system, high-temperature strength, creep resistance and thermal stability of hot-section materials determine the maximum turbine inlet temperature and, through it, the thermodynamic efficiency and specific thrust of the engine. Despite this coupling, materials research and aircraft system performance analysis have traditionally been conducted in separate disciplinary communities, with material improvements evaluated at the coupon or component level rather than in terms of their effect on top-level operational metrics.

The present paper addresses this gap by developing a normalised sensitivity framework that maps material properties directly to aircraft-level performance metrics, Figure 1. The method extends the Normalised Sensitivity Matrix (NSM) formulation introduced by [1] and given its normalised form by [2] to include material parameters as the primary design variables. The Aggregated Design Impact

Matrix (ADIM) concept [3] is then applied to group sensitivities by material domain, airframe and engine, producing a compact, hierarchical view of material relevance across disciplines.

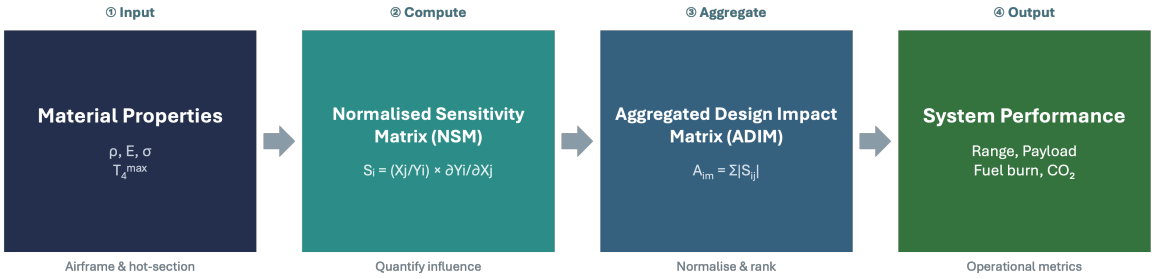


Figure 1 – NSM–ADIM workflow: from material properties to system-level performance metrics

The coupling between materials, structures and propulsion has long been recognized as central to aircraft performance. At the airframe level, the progressive transition from aluminium-alloy primary structures to carbon-fibre-reinforced polymers (CFRP) has demonstrated structural weight reductions of 15–30%, with corresponding improvements in fuel efficiency of 20–25% in recent wide-body programmes [4, 5]. In the propulsion system, advances from conventionally cast to directionally solidified and single-crystal nickel-based superalloys have progressively raised the maximum turbine inlet temperature from below 1100 K in early jet engines to beyond 1900 K in the most advanced current engines, enabling corresponding improvements in thermal efficiency and thrust-to-weight ratio [6, 7]. More recently, silicon carbide ceramic matrix composites (SiC/SiC CMCs) have entered commercial service in the CFM LEAP engine, offering simultaneous reductions in component density and further increases in temperature capability [8].

Despite these well-documented material-level gains, their quantitative translation to top-level aircraft performance metrics such as payload, range and climb rate, is rarely formalised in a unified traceable framework. The multidisciplinary design optimisation (MDO) community has addressed system-level coupling through decomposition architectures and disciplinary sensitivity analysis [9, 10]. However, MDO frameworks typically treat materials as implicit boundary conditions rather than explicit design variables. To bridge the gap, the present work develops a normalised sensitivity model that maps material properties to top-level performance metrics.

The Breguet range equation [11] provides the analytical backbone for the propulsion-related sensitivities: its linearisation under fixed fuel load and geometry directly yields the range sensitivity to specific fuel consumption used in the NSM. For structural mass, the material index framework of Ashby [12] provides the physical basis for interpreting the density and strength sensitivity terms. The present framework can be seen as a system-level counterpart to the component-level material selection methodology, bridging the gap between the two scales.

The paper is organised as follows. Section 2 presents the reference aircraft and baseline data. Section 3 defines the constraint conditions and fixed quantities. Section 4 develops the normalised sensitivity formulation. Section 5 focuses on material parameters and their sensitivity mechanisms. Section 6 presents the results on NSM and ADIM while Section 7 discusses the results and their implications for materials research prioritisation. Section 8 draws conclusions.

2. Reference Aircraft and Baseline Parameters

The Boeing 737–800 is selected as the reference platform. It is representative of the single-aisle, medium-range transport category that accounts for the majority of global commercial aircraft operations and fuel consumption. The aircraft uses a conventional aluminium-alloy primary airframe structure with limited secondary composites, and is powered by CFM56-7B turbofan engines with moderate turbine inlet temperature limits, making it a well-characterised baseline against which the effects of emerging materials can be assessed.

2.1 Reference Data Sources

The reference data for the 737-800 were taken primarily from official Boeing documentation and validated secondary sources:

- **Boeing Commercial Airplanes (2017):** *Airplane Characteristics for Airport Planning, 737 Next Generation (Rev B)* [13]. This document provides certified weight limits, fuel capacities, and geometric characteristics for all 737NG variants.
- **Skybrary Aviation Safety (2021):** *Boeing 737-800 (B738) Technical Data* [14], providing typical operational and performance parameters.
- **Aircraft Commerce (2003):** *737NG Family and CFM56-7B Specifications* [15], giving detailed propulsion system data and variant comparisons.

2.2 Baseline Mass and Performance Data

Based on the reference data sources, the representative values adopted for the baseline configuration were calculated and are presented in Table 1.

Table 1 – Design Parameters

Parameter	Symbol	Value
Maximum take-off weight, MTOW	W_0	79,000 kg
Operating empty weight, OEW	W_e	41,400 kg
Design fuel mass	W_f	21,300 kg
Design payload	W_{pl}	16,300 kg
Design range	R	5,400 km
Max turbine inlet temperature	$T_{4,\max}$	$\sim 1,650$ K
Bypass ratio	BPR	5.1

The corresponding mass ratio between the operating empty weight and the design payload is:

$$\lambda_e = \frac{W_e}{W_{\text{pl}}} = \frac{41\,400}{16\,300} = 2.54. \tag{1}$$

This value is representative of modern medium-range single-aisle transport aircraft and provides a realistic baseline mass balance for the subsequent aircraft performance and propulsion analyses.

2.3 Airframe Materials

The 737–800 airframe is constructed predominantly from aerospace-grade aluminium alloys (2xxx and 7xxx series) in primary structure, with some titanium alloy components in highly loaded fittings and fasteners, and limited CFRP in secondary structures. This composition is typical of aircraft designed before the widespread adoption of composite primary structures that characterises more recent designs such as the Boeing 787 and Airbus A350. The key material parameters that influence structural mass, and hence payload through the MTOW constraint, are the specific strength (σ/ρ) and specific stiffness (E/ρ) of the primary structural materials. Improvements in either ratio, at fixed geometric design, reduce the structural mass required to carry a given load, and this reduction transfers directly to payload under the fixed-MTOW assumption used throughout this analysis.

2.4 Engine Materials

The CFM56-7B uses nickel-based superalloys in the high-pressure turbine (HPT) blades, vanes and discs, with thermal barrier coatings (TBCs) on the first-stage HPT airfoils. The maximum turbine inlet temperature is constrained by the temperature capability of the HPT blade alloy, which currently limits T_4^{max} to approximately 1,650 K. The high-pressure compressor casing and fan components use titanium alloys. Engine weight is a direct contributor to operating empty weight and any reduction in hot-section component density, achievable, for example, by substituting metallic components with CMCs, reduces OEW and thereby increases payload at fixed MTOW.

3. Constraint Conditions and Modelling Assumptions

The physical relevance of a normalised sensitivity analysis depends critically on which system variables are held fixed. In a coupled system such as a transport aircraft, many quantities are implicitly related through aerodynamic, structural, and propulsion constraints. If these relationships are not controlled, computed sensitivities may reflect mixed or double-counted effects rather than the intended material-driven influences. The following constraints define the analytical closure used throughout this work.

3.1 Fixed Quantities

The following quantities are held constant throughout the analysis:

- Maximum take-off weight W_0 and fuel mass W_f. This maintains a consistent mission class and ensures that changes in operating empty weight are absorbed entirely by the payload, providing a direct link between structural/engine mass changes and payload performance.
- Airframe and engine geometry. Structural layout, aerodynamic shape, and engine hardware dimensions are unchanged. Variations in mass, efficiency, and thrust arise solely from material properties rather than geometric redesign.
- Aerodynamic and operational conditions. Flight Mach number, altitude, and climb conditions are fixed. Changes in range or climb rate therefore reflect material-induced propulsion changes, not aerodynamic schedule effects.
- Cooling fraction ϕ_{cool}. Thermal improvements are expressed through temperature capability T_4^{max}, not through changes in cooling-air scheduling, avoiding secondary flow management coupling. Engine geometry, bypass ratio and compressor pressure ratio are held fixed.

3.2 Permitted Variations

The following quantities are allowed to vary in response to material property changes:

- Operating empty weight W_e. Engine mass and airframe structural mass may change with material density, strength and stiffness, causing W_e to vary and payload to respond accordingly.
- Specific fuel consumption c. Changes in hot-section temperature capability alter cycle efficiency and thereby c, affecting range.
- Thrust T. Changes in temperature capability and high-temperature strength in the hot section alter delivered thrust, which affects climb rate through excess power.

These constraints together make sure that the system characteristics change only because of material-induced variations in structural mass, propulsion efficiency or thrust capability, providing a clean causally traceable mapping from material properties to system performance.

4. Normalised Sensitivity Formulation

4.1 Normalised Sensitivity Matrix

The general form of the normalised sensitivity is defined as

$$S_{ij} = \frac{X_j}{Y_i} \frac{\partial Y_i}{\partial X_j}, \tag{2}$$

where X_j denotes a material design parameter (e.g., strength, stiffness, density or temperature capability), and Y_i represents a system characteristic (e.g., payload, range or climb rate). Each element S_{ij} quantifies the fractional change in Y_i produced by a fractional change in X_j. A value of +1.0 indicates that a 1% increase in the parameter produces a 1% improvement in the characteristic; a value of -1.0 indicates a 1% deterioration. The sign convention carries physical meaning: positive values indicate that increasing the parameter improves the characteristic, while negative values indicate a detrimental effect. The magnitude indicates the strength of the coupling. This makes the NSM directly interpretable by engineers without further transformation.

4.2 Payload Sensitivity

For fixed W_0 and W_f, the allowed payload is

$$W_{\text{pl}} = W_0 - W_e - W_f. \tag{3}$$

Differentiation gives

$$\frac{\Delta W_{\text{pl}}}{W_{\text{pl}}} = -\frac{W_{\text{air}}}{W_{\text{pl}}}\frac{\Delta W_{\text{air}}}{W_{\text{air}}} - \frac{W_{\text{eng}}}{W_{\text{pl}}}\frac{\Delta W_{\text{eng}}}{W_{\text{eng}}}. \tag{4}$$

Here the first term corresponds to airframe material effects, and the second to engine mass contributions. The coefficients W_air/W_pl and W_eng/W_pl act as leverage factors: because W_pl is much smaller than W_air, small fractional changes in airframe mass produce large fractional changes in payload.

4.3 Range Sensitivity

For range, at fixed W_0 and W_f, the first-order sensitivity is dominated by the change in specific fuel consumption (c) and lift-to-drag ratio (L/D):

$$\frac{\Delta R}{R} \approx -\frac{\Delta c}{c} \tag{5}$$

since aerodynamic geometry and fuel volume are held constant.

4.4 Climb Rate Sensitivity

For climb rate, the relationship follows from the excess-power formulation

$$\dot{h} = \frac{(T-D)V}{W} \tag{6}$$

and, under the present closure (fixed W_0, fixed geometry):

$$\frac{\Delta \dot{h}}{\dot{h}} = S_{\dot{h},T}\frac{\Delta T}{T}, \qquad \text{where} \qquad S_{\dot{h},T} = \frac{TV}{W\dot{h}} \approx 4.8. \tag{7}$$

Thrust changes are driven by hot-section material strength, stiffness, density, and temperature capability.
The climb-rate sensitivity coefficient is based on a representative excess-thrust margin for a transport-aircraft climb condition and should be regarded as an approximate first-order value.

4.5 Aggregated Design Impact Matrix

The aggregated sensitivities for each material domain are obtained by summing the absolute values of sensitivities associated with all material properties within that domain:

$$A_{im} = \sum_{j \in \mathscr{M}_m} |S_{ij}|, \tag{8}$$

where $\mathscr{M}_m$ is the set of design parameters associated with material m.

This provides a measure of the total influence of a material group on each system characteristic. It is important to note that the sign of S_{ij} carries physical meaning: a positive value indicates that an increase in the design parameter X_j improves the system characteristic Y_i, while a negative value indicates a detrimental effect. For airframe density ρ, for instance, $S_{\text{Wpl},\rho} < 0$ because higher density increases structural mass and thereby reduces the payload allowance at fixed MTOW. The absolute-value summation in Eq. (4) therefore provides a measure of total influence magnitude, irrespective of whether that influence is beneficial or detrimental, and is consistent with the ADIM formulation of [3].

5. Material Parameters and Sensitivity Mechanisms

The material parameters used in the NSM are selected to represent the dominant pathways by which material properties affect aircraft-level performance. Under the fixed-MTOW, fixed-fuel and fixed-geometry assumptions, material changes influence the system through three mechanisms: changes in structural mass, changes in engine mass, and changes in propulsion efficiency or thrust capability.

5.1 Airframe Material Parameters

The airframe material parameters affect system performance primarily through structural mass. Increased tensile strength, σ, allows load-carrying structures to satisfy stress constraints with less material, thereby reducing structural weight. Increased stiffness, E, reduces deformation and improves resistance to stiffness- or buckling-driven sizing constraints, again contributing to lower structural mass, although through a less direct pathway than strength. Density, ρ, acts directly on structural mass. For a fixed airframe geometry, lower density reduces the mass of the load-carrying structure and therefore reduces the operating empty weight. Under the fixed-MTOW and fixed-fuel constraint, this mass reduction is transferred into increased allowable payload according to the payload balance in Eq. (3).

5.2 Hot-Section Engine Material Parameters

Hot-section engine material parameters affect performance through engine mass, thrust capability and thermal efficiency. Increased high-temperature strength improves the ability of rotating turbine components to sustain mechanical loading at elevated temperature, supporting higher thrust capability or reduced stress margins. Increased high-temperature stiffness limits deformation of hot-section components, helping to maintain blade clearances and efficiency. Density influences both mass and rotating-component loading. Lower hot-section density reduces engine weight and centrifugal loading, which can contribute to payload through operating empty weight and to propulsion performance through improved stress margins. The maximum temperature capability affects the thermodynamic cycle directly: a higher allowable turbine entry temperature increases thermal efficiency and specific core power, thereby improving range through lower specific fuel consumption and climb rate through increased excess power.

6. Results

6.1 Normalised Sensitivity Matrix

For fixed V, L/D and cruise weight ratio, the Bréguet equation [11] gives $R \propto c^{-1}$. Hence

$$S(R, T_4^{\max}) = \frac{\partial \ln R}{\partial \ln T_4^{\max}} = -\frac{\partial \ln c}{\partial \ln T_4^{\max}}. \tag{9}$$

The propulsion model is varied locally at the baseline cruise condition while engine geometry, bypass ratio, compressor pressure ratio, cooling fraction and required net thrust are held fixed. The resulting coefficient $\partial \ln c / \partial \ln T_4^{\max} = -0.29$ gives $S(R, T_4^{\max}) = +0.29$ as shown in Table 2. Thus, a 1% increase in the allowable turbine entry temperature reduces the TSFC by approximately 0.29% and increases the cruise range by approximately 0.29%. This sensitivity is local to the selected engine and operating point. The sign convention is defined such that positive sensitivity corresponds to an improvement in the characteristic with increasing parameter value, while negative sensitivity indicates a detrimental effect.

Table 2 – Normalised Sensitivity Matrix (NSM) for fixed geometry, fixed W_0, and fixed W_f.

System Characteristic	σ	E	ρ	σ^*	E^*	ρ^*	$T_4^{\max}$
Allowed Payload W_{pl}	$+0.67$	$+0.31$	-1.14	$+0.12$	$+0.02$	-0.10	0.00
Range R (fixed W_0, W_f)	0.00	0.00	0.00	$+0.31$	$+0.12$	-0.03	$+0.29$
Climb rate $\dot{h}$	0.00	0.00	0.00	$+0.86$	$+0.10$	-0.48	$+1.20$

Key observations:

Table 3 – Aggregated Design Impact Matrix (ADIM): total absolute sensitivities grouped by material class.

System Characteristic	Airframe material	Hot-section material
Allowed Payload W_{pl}	2.12	0.00
Range R (fixed W_0, W_f)	0.00	0.75
Climb rate $\dot{h}$	0.00	2.64

- Payload is driven exclusively by airframe parameters, with density (S = -1.14) and strength (S = +0.67) as the dominant contributors. Engine material improvements have negligible direct effect on payload under the present closure.
- Range is governed entirely by hot-section parameters. High-temperature strength (S = +0.31) and temperature capability (S = +0.29) are the primary levers, reflecting their role in reducing TSFC through improved cycle efficiency.
- Climb rate shows the largest individual sensitivity in the matrix: T_4^{max} at S = +1.20, followed by hot-section strength at S = +0.86 and hot-section density at S = -0.48. The negative sign on density reflects that reduced hot-section density reduces centrifugal stress and enables higher thrust at the same material stress limit.
- The zero entries in the airframe columns for range and climb rate, and in the engine columns for payload, confirm the clean disciplinary separation enforced by the fixed-geometry, fixed-MTOW closure.

The numerical values of the NSM coefficients should be interpreted as representative first-order sensitivities rather than exact performance derivatives. The coefficients are estimated from simplified analytical relationships and representative operating conditions for a Boeing 737-class aircraft.

6.2 Aggregated Design Impact Matrix

In the present context, the ADIM is applied to aggregate the effects of material properties into higher-level material domains. Grouping all $S_i^{(m)}$ values for each material m and characteristic Y_i yields the ADIM (Eq. 8. Each element A_{im} represents the total system-level impact magnitude of material m on characteristic Y_i. The ADIM thus provides a hierarchical extension of the NSM, suitable for post-analysis and strategic prioritisation of material development.
The ADIM values quantify the overall system leverage of each material domain:

- For payload, airframe materials carry an aggregate impact of 2.12, which is approximately nine times greater than the engine material contribution of 0.24. Payload improvement is primarily an airframe materials problem.
- For range, hot-section engine materials carry all of the leverage (0.75), with zero contribution from airframe materials. Range improvement is entirely an engine materials problem under the present formulation.
- For climb rate, the hot-section dominance is even stronger (2.64 vs 0.00). Temperature capability and high-temperature strength together drive the majority of this aggregate, making turbine material advancement the critical lever for climb performance.

These results are consistent with the physical intuition that structural mass governs mass-limited performance while thermodynamic cycle temperature governs power-limited performance. The ADIM makes this intuition numerically explicit and directly usable for research prioritization.

7. Discussion

The NSM–ADIM framework reveals a clear disciplinary separation between material domains: airframe materials dominate mass-limited characteristics (payload), while hot-section engine materials govern power-limited characteristics (climb rate and range). This separation is not merely qualitative — the ADIM quantifies it with sufficient precision to support quantitative research investment prioritisation. The strong negative sensitivity of payload to airframe density (S = -1.14) is consistent with well-established structural weight leverage in transport aircraft. Under the fixed-MTOW constraint, every kilogram saved in airframe structure transfers directly to payload capacity. This is the system-level manifestation of the Ashby material index familiar from component-level minimum-weight design [12]. The present framework extends that concept to the aircraft level.

The dominance of T_4^{max} for climb rate (S = +1.20) reflects the thermodynamic leverage of turbine inlet temperature on specific core power. This result is amplified by the excess-power factor S{ḣ,T} $\approx$ 4.8. Because a commercial airliner, such as the 737-800, operates with limited excess thrust at the design climb condition, even modest changes in thrust capability produce proportionally large changes in climb rate. This sensitivity is physically important as it means that advances in hot-section temperature capability, i.e. through improved alloys, coatings, or CMC adoption, have disproportionately large effects on climb performance relative to their material-level magnitude.

The framework is directly applicable to evaluating ongoing and prospective material transitions in both airframe and engine. For airframe structures, the transition from aluminium-alloy to CFRP primary structure, already achieved in the Boeing 787 (approximately 50% composite by weight), acts primarily through the density sensitivity term. The ADIM identifies this as the highest-leverage pathway for payload improvement, consistent with reported structural weight savings of 15–30% and fuel efficiency improvements of 20–25% compared to aluminium-intensive designs.

For hot-section materials, the introduction of SiC/SiC CMC components in the CFM LEAP engine represents the first commercial deployment of ceramic matrix composites in primary load-bearing hot-section roles [8]. CMCs act on both density (approximately one-third of metallic equivalents) and T_4^{max} (higher allowable gas temperatures due to improved temperature capability) simultaneously, making them particularly high-leverage according to the ADIM for both range and climb performance. The framework provides a quantitative basis for predicting the system-level performance benefit of such transitions prior to flight test.

For nickel superalloys, the progression from polycrystalline to directionally solidified to single-crystal alloys has progressively raised temperature capability and creep resistance, with current single-crystal alloys sustaining metal temperatures of 1,050–1,150 °C under coating protection [6, 7]. The sensitivity results indicate that further advances in this direction, whether through alloy chemistry, coating systems, or manufacturing process control, carry the highest system-level return for climb and range metrics in the current aircraft configuration.

Several modelling assumptions bound the validity of the results. The linearisation underlying Eq. (1) is accurate for small fractional property changes, typically less then 10%, but may underestimate or overestimate sensitivities for larger material transitions, particularly for nonlinear quantities such as thrust at elevated turbine inlet temperature. Second, the fixed-geometry assumption prevents the framework from capturing structural resizing benefits that would follow from a sustained reduction in material density. A structural-index correction, in which reduced density permits thinner sections and further mass reduction beyond the first-order scaling, could be introduced as a second-order refinement.

Third, the cooling fraction is held constant, so improvements in temperature capability are expressed entirely through thermodynamic cycle gains. In practice, advanced materials that reduce the required cooling fraction would deliver additional efficiency gains. Reduced cooling air extraction means more air available for core work, which is not captured by the present first-order model. Fourth, the analysis excludes manufacturing constraints, certification timelines, and in-service durability, all of which influence the practical achievability of material property improvements in a programme context.

Several natural extensions of the framework merit further development. Incorporating probabilistic material property distributions would enable uncertainty bounds to be placed on the NSM elements, consistent with reliability-oriented MDO approaches [10]. This would be particularly valuable when

evaluating novel materials with greater property variability than established production alloys.
The approach could be extended to include environmental performance indicators such as CO_2 per revenue-tonne-kilometre, which are increasingly central to next-generation aircraft requirements. Under such an extension, the range sensitivity to TSFC would translate directly to an emissions sensitivity, providing a materials-level lever on the fleet-level carbon intensity targets set by ICAO and industry associations.
Finally, the methodology is not specific to the 737-class baseline. By substituting appropriate mass fractions, thermodynamic parameters, and performance sensitivities, the framework can be applied to regional jets, widebodies, turboprops, or novel configurations including hydrogen-fuelled or hybrid-electric aircraft, where the balance between structural and propulsion material leverage may differ significantly from the conventional case analysed here.

8. Conclusions

A normalized sensitivity framework has been developed and applied to trace material properties to top-level performance metrics for a Boeing 737-class transport aircraft. The following conclusions can be drawn:

- The Normalised Sensitivity Matrix (NSM) provides a quantitative, first-order mapping from fractional changes in material properties to fractional changes in payload, range, and climb rate, enabling direct comparison of material influences across disciplines.
- Airframe material density is the single most influential parameter for payload, with a normalized sensitivity of $S = -1.14$, meaning a 1% reduction in structural density yields approximately a 1.14% gain in allowable payload at fixed MTOW and fuel load.
- Hot-section material temperature capability is the dominant driver of climb rate ($S = +1.20$) and a primary contributor to range ($S = +0.29$), reflecting the direct link between maximum turbine inlet temperature and available thrust and thermal efficiency.
- The Aggregated Design Impact Matrix (ADIM) confirms a clear disciplinary separation: airframe materials govern mass-limited performance (payload ADIM = 2.12) while hot-section engine materials govern power-limited performance (climb rate ADIM = 2.64, range ADIM = 0.75).
- The framework is computationally inexpensive and applicable at the conceptual design stage, before detailed geometry or high-fidelity analysis is available, making it a practical tool for prioritising materials research investment by expected system-level return.
- The methodology is directly extensible to evaluate emerging material technologies, including CFRP airframe structures and ceramic matrix composites in the hot section, within the same unified traceable framework.

The approach offers a systematic route for integrating materials engineering into early aircraft design decisions.

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