



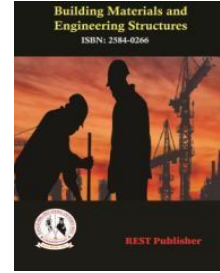
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Electrical Evolution in Modern Aircraft: Advancements and Challenges

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Abstract: This article introduces the concept of More Electric Aircraft (MEA) and explores its potential advantages for manned aircraft. It outlines typical electrical power systems, loads, and future challenges in the aerospace industry. The importance of power electronics in enabling this shift in aircraft design is highlighted, along with examples of system designs. The MEA and the transition to electric vehicles have been extensively studied, aiming to reduce emissions and fuel consumption, aligning with similar objectives in automobiles. Conventional aircraft systems rely on various types of power—electrical, hydraulic, mechanical, and pneumatic—each with its drawbacks, impacting overall efficiency. The shift towards new electrical systems in future aircraft aims to enhance engine start, efficiency, emissions, reliability, and cost-effectiveness by replacing primary non-electric systems. The essay deeply examines evolving aviation systems, discussing potential innovations like gas-electric propulsion and electric taxis. It also delves into the application of the Weighted Aggregated Sum Product Assessment (WASPAS) method in Multi-Criteria Decision Making (MCDM) for addressing manufacturing decision challenges across diverse areas like cutting fluids, industrial robots, and material machinability. The study emphasizes the WASPAS method's effectiveness in precisely ranking alternatives across these scenarios and explores the impact of the parameter λ on its performance. Test results using the WASPAS method offer insights into classifying the best and worst aircraft alternatives.

Key words: electrical system, ram air turbine, Aircraft power system, MCDM

1. INTRODUCTION

Over recent decades, considerable strides have been taken in advancing more electric aircraft, replacing components once reliant on hydraulic, mechanical, or pneumatic power with electrical systems. In modern commercial transport aircraft, the integrated drive generator (IDG) has been replaced, a key evolutionary development. Previously, the IDG mechanically regulated jet engines' variable speed to a constant pace, providing consistent voltage and frequency to the aircraft's electric bus. However, recent aircraft like the Boeing 787 and Airbus A380 have replaced this with main engine generators directly linked to the jet engine via a gearbox, synchronizing engine speed with electrical frequency. These aircraft can now vary electrical frequency from 350 Hz to 800 Hz while a generator control unit maintains the output AC voltage at fixed levels like 115 or 230 Vac. This shift has standardized constant voltage and variable frequency power buses, detailed in MIL-STD-704 and DO-160, in modern aircraft. Consequently, traditional aircraft, relying on a constant 400 Hz, require additional conversions—AC-DC or DC-AC—to manage these changes. This evolution underscores the growing significance of power electronics and electric machinery in aviation, influencing aspects like weight, size, reliability, and efficiency of power electronic converters and electric engines. Furthermore, the shift away from using bleed air in environmental control systems is another example of the expanding reliance on electrical systems within aircraft.

Cabin environmental control systems manage cabin temperature and pressure to ensure passenger comfort during flights. Traditionally, aircraft obtained bleed air for these systems from one of the main engine compressor stages. However, in the Boeing 787, electrically powered compressors have replaced the use of bleed air, eliminating the pneumatic system and engine air ducts. This shift necessitated a significant increase in internal power generation for the main engine generators to meet the substantial electricity demands of regulating cabin conditions. Additionally, the aircraft's engines now utilize electricity, rather than compressed air from auxiliary power units or ground carts, for engine start-up, further contributing to the electrification trend. The electric start-up of the main engine also eliminates pneumatic systems within the airplane. These transitions exemplify the shift from hybrid to all-electric systems in modern aircraft.

Aircraft power system: Aircraft rely heavily on batteries, integral to their electrical systems, serving various crucial functions. They enable engine and auxiliary power unit (APU) startups, act as backup power for essential avionics and lighting during emergencies, ensure continuous power supply to navigation units and fly-by-wire computers, facilitate ground power for maintenance checks, and conduct preflight inspections. The reliability of aircraft batteries is paramount due to their critical role in safe aircraft operation. Essential characteristics encompass power and energy density, environmental stability, operating temperature range, maintenance simplicity, rapid recharge capability, shelf life, cycle life, and resilience to abuse. Traditionally, two primary types of aircraft batteries dominate: lead-acid and nickel-cadmium, with limited use of silver-zinc and the more recent adoption of lithium-ion batteries. This discussion focuses solely on the currently prevalent types: lead-acid, nickel-cadmium, and lithium-ion aircraft batteries. Aircraft utilize generators or transformers to generate electrical power, typically driven by engines but alternatively by an APU, hydraulic motor, or a ram air turbine (RAT). These generators commonly produce output at 115-120V/400HZ AC or 28V DC / 14V DC. The aircraft's electrical system comprises three main elements: a battery, a generator or alternator, and an electrical bus for power distribution. In certified piston aircraft engines, spark plugs are powered by engine-driven magnetos, eliminating the need for extra electricity to operate the engine.

Standard commercial airliners commonly operate with an electrical system featuring 115V AC voltage and a 400 Hz frequency. The generator, linked mechanically to the main engine, maintains a constant engine speed, thereby ensuring a steady electrical frequency across the aircraft's electric bus. As numerous critical aircraft functions like engine start, environmental control systems, de-icing, and hydraulics are not electrically powered; the per-engine electrical output remains lower compared to recent electric aircraft designs. In this setup, electricity primarily drives fans for air circulation within the aircraft, as well as avionics, hotel loads (such as entertainment systems), lighting, and galley equipment (like refrigerators and coffee makers). Most fans operate directly at 400 Hz without requiring a power electronic converter, potentially resulting in high current spikes during the induction motor start-up within this power system. The electrical system typically includes a 28Vdc bus, obtained by converting 115Vac, 400 Hz using transformer rectifier units (TRUs). Further voltage reduction occurs at each line replaceable unit (LRU), enabling lower voltage outputs like 5V or 3.3V to power integrated circuits, microprocessors, and signal-level electronics.

Selecting workforce assignments is a multifaceted challenge influenced by specific company goals, resource availability, and individual decision makers' preferences. Addressing this complexity, Multi-Criteria Decision Making (MCDM) methods offer valuable resolutions by simultaneously considering multiple criteria, incorporating diverse weights and thresholds, effectively capturing decision makers' nuanced preferences (Afshari & Mojahed, 2010). MCDM delineates a structured process facilitating consensus among decision makers, reducing conflicts and streamlining arguments in resolving intricate problems (Lazim & Rabiatal, 2014). Decision making involves identifying and opting for alternatives aligned with the decision maker's values and inclinations. The objective is not merely to recognize numerous alternatives but to select the one most likely to succeed or align best with specific objectives, preferences, and values (Karami, 2011).

Reliance on past experiences, judgment, and intuition alone for decision making has become challenging. Human cognitive limits hinder the simultaneous consideration of numerous parameters, shifting decision making from an artistic mental model approach toward a more scientific method. Scientific decision making utilizes mathematical models to address organizational problems (Habiba & Asghar, 2009). In contemporary management, prompt and effective decisions are vital. Quantitative techniques, particularly in industries, have gained significance, aiding decision makers grappling with extensive data, numerous alternatives, and diverse decision contexts (De Felice, Deldoost, Faizollahi, & Petrillo, 2015). With industries evolving into multi-objective entities, decision makers face

growing complexity, prompting the development of various MCDM approaches tailored to diverse decision problems.

Thorough analysis is crucial as it could significantly influence air traffic. Hence, a shift toward objective evaluations of aviation vehicles is vital, replacing existing subjective methodologies. This study focuses on implementing the Weighted Sum Model (WSM) within Multi-Criteria Decision Making (MCDM) techniques. Its aim is to assess aviation vehicle capacities objectively and optimize the selection of aviation vehicles for specific operations. Additionally, the paper provides an outline of the latest power conversion technology employed in large commercial transport aircraft.

2. MATERIAL AND METHOD

In modern aircraft like the Boeing 787 and Airbus A380/A350, the traditional constant voltage and frequency setup has been replaced by a constant voltage with variable frequency configuration. This adjustment regulates voltage at 115 or 230 Vac while allowing the bus frequency to vary between 350 and 800 Hz, corresponding to engine speed. This shift necessitates power conversion for various loads, including motor drives, leading to the requirement for power electronic converters to manage AC-to-DC and DC-to-AC power conversions. For instance, [12] explores the control of multilevel active filters within the context of the More Electric Aircraft (MEA) grid architecture, focusing on applications. Additionally, DC-to-DC power conversion becomes essential for numerous systems, such as battery chargers [13].

The Airbus A350 and A380 use a pneumatic air start turbine system, while the Boeing 787 has recently eliminated its pneumatic system, including air ducts and ATS (air turbine starters). Instead, it employs main engine generators as motors for engine start-up, referred to as main engine starter generators. Power lines deliver the necessary power for initiating the main engines [10]. This updated system necessitates DC power conversion from the APU generators and a subsequent conversion back from DC to AC to enable variable voltage and frequency control for the main engine starter/generators. Consequently, rectifiers and inverters are essential components. Incorporating electrical, magnetic, and thermal assessments of the starter/generators is integral to the new system analysis. Maintaining the maximum torque for engine start within limits to avoid additional weight or volume penalties is a key consideration. Exploring control strategies for this novel electric start system remains an active area of research, addressing concerns regarding its implementation [31].

The Airbus A350 and A380 use a pneumatic air start turbine system, while the Boeing 787 has recently eliminated its pneumatic system, including air ducts and ATS (air turbine starters). Instead, it employs main engine generators as motors for engine start-up, referred to as main engine starter generators. Power lines deliver the necessary power for initiating the main engines [10]. This updated system necessitates DC power conversion from the APU generators and a subsequent conversion back from DC to AC to enable variable voltage and frequency control for the main engine starter/generators. Consequently, rectifiers and inverters are essential components. Incorporating electrical, magnetic, and thermal assessments of the starter/generators is integral to the new system analysis. Maintaining the maximum torque for engine start within limits to avoid additional weight or volume penalties is a key consideration. Exploring control strategies for this novel electric start system remains an active area of research, addressing concerns regarding its implementation [31].

Advancements in electrical systems have stemmed from the elimination of bleed air usage in Environmental Control Systems (ECS), crucial for maintaining passenger comfort by managing cabin temperature and air pressure. Traditionally, bleed air was sourced from the main engine's compressor stages [37]. The ECS in Airbus A350 and A380 relies on a leaky air architecture, while the Boeing 787 employs electrically powered compressors instead of tapping exhaust air from the engine, removing the need for pneumatic systems and air ducts within the engine. However, transitioning to an electric ECS poses challenges in system sizing and calculating the requisite electrical power across aircraft phases. The electric system demands larger motors and power electronic converters for compressors. Ensuring reliability and redundancy are key in ECS design, shaping the overall electrical power system architecture. The significant electricity demand for regulating cabin conditions necessitates substantial power output from main engine generators [38]. Consequently, recent research, like Reference [39], explores non-electrical ECS systems, including simulating and experimentally testing alternative control configurations to reduce reliance on ram air.

WASPAS method: The WASPAS method is a unique amalgamation of two established Multiple Criteria Decision Making (MCDM) techniques: the weighted sum model (WSM) and the weighted product model (WPM). Its operational framework encompasses several key stages. Initially, it involves obtaining linearly normalized performance values to enable fair comparisons across different criteria. Following this, the method computes both WSM and WPM measures for each alternative, leveraging the strengths of both models. Subsequently, through a calculated aggregation process, the approach derives a specific overarching measure, unique to the WASPAS approach, for each alternative, synthesizing evaluations from multiple perspectives. Finally, the alternatives are ranked based on their respective WASPAS Coefficients, offering a comprehensive and ordered view of their suitability or preference within the decision context. This fusion of methodologies provides decision-makers with a robust framework for evaluating multiple criteria scenarios comprehensively and with nuance.

TABLE 1. Evaluation parameters

C1	number engines
C2	number generator per engine
C3	generator rating per engine (KVA)
C4	generator output voltage (V)
C5	number generator per APU
C6	generator rating per APU (KVA)

Table 1 outlines several evaluation parameters related to generators and engines used in a system. The parameters include C1, which signifies the number of engines present. C2 represents the count of generators per engine, while C3 indicates the rating of each generator per engine in KVA (kilovolt-amperes). Moving on, C4 denotes the output voltage of the generators. Additionally, the table covers aspects related to auxiliary power units (APUs) with C5 specifying the number of generators per APU, and C6 indicating the generator rating per APU in KVA. These parameters collectively provide essential insights into the configuration and capacities of engines and generators within the system, contributing significantly to its operational understanding and performance assessment.

3. RESULT AND DISCUSSION

TABLE 2. Comparison of the key electrical systems of recent large commercial transport aircraft

Aircraft	C1	C2	C3	C4	C5	C6
Boeing 787	2	2	250	235	2	225
Airbus 380	4	1	150	115	1	120
Airbus 350	2	2	100	230	1	150

Table 2 presents a comparative analysis of the primary electrical systems among recent large commercial transport aircraft. The table outlines specific details for each aircraft, including the number of engines (C1), generators per engine (C2), generator rating per engine in KVA (C3), generator output voltage (C4), as well as the number of generators per Auxiliary Power Unit (APU) (C5) and their respective ratings in KVA (C6). The Boeing 787 features two engines, each equipped with two generators rated at 250 KVA and an output voltage of 235V. In contrast, the Airbus 380 boasts four engines with one generator per engine, rated at 150 KVA and outputting at 115V. Meanwhile, the Airbus 350 showcases two engines with two generators per engine, rated at 100 KVA, and an output voltage of 230V.

TABLE 3. Performance value

	C1	C2	C3	C4	C5	C6
Boeing 787	0.50000	1.00000	1.00000	1.00000	1.00000	1.00000
Airbus 380	1.00000	0.50000	0.60000	0.48936	0.50000	0.53333
Airbus 350	0.50000	1.00000	0.40000	0.97872	0.50000	0.66667

Table 3 depicts the performance values assigned to different parameters for the Boeing 787, Airbus 380, and Airbus 350 aircraft. Each row corresponds to a specific aircraft model, while columns C1 through C6 represent distinct

performance metrics. For the Boeing 787, the values uniformly stand at 1.00000 for C2 through C6, indicating consistent and optimal performance across these parameters. In contrast, the Airbus 380 exhibits variations in performance metrics, with C1 at 1.00000, while C2 through C6 have values lower than 1.00000, suggesting comparatively lower performance in these specific areas. The Airbus 350 displays similar trends to the Boeing 787 in C1 and C2 but demonstrates lower performance in C3 and C5, as indicated by values less than 1.00000, denoting potential areas for improvement or differences in capability compared to the Boeing 787.

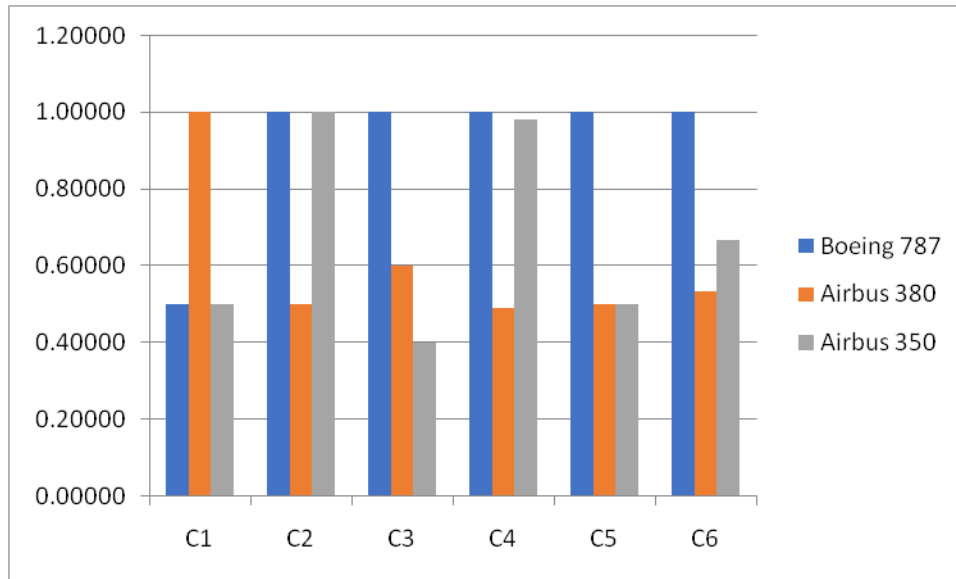


FIGURE 1. Performance value

Figure 1 outlines the performance values across various criteria for the Boeing 787, Airbus 380, and Airbus 350 aircraft models. Each row represents a specific aircraft, while columns C1 through C6 denote distinct performance metrics. For the Boeing 787, the performance values stand at 0.50000 for C1, while C2 through C6 demonstrate optimal performance, all rated at 1.00000, indicating consistent and high performance across these parameters. In contrast, the Airbus 380 exhibits variations in performance metrics, scoring 1.00000 in C1 but displaying lower values in C2 through C6, reflecting comparatively reduced performance in these specific areas. On the other hand, the Airbus 350 showcases excellence in C2 and C5 with scores of 1.00000, but it demonstrates lower performance in C1, C3, and C6, while scoring exceptionally high in C4, denoting its unique strengths and weaknesses across the evaluated criteria.

TABLE 4. Weight

	C1	C2	C3	C4	C5	C6
Boeing 787	0.16	0.16	0.16	0.16	0.16	0.16
Airbus 380	0.16	0.16	0.16	0.16	0.16	0.16
Airbus 350	0.16	0.16	0.16	0.16	0.16	0.16

Table 4 outlines the weight distribution for different components across the Boeing 787, Airbus 380, and Airbus 350 aircraft models. Each row represents a specific aircraft, while columns C1 through C6 signify different components or parameters related to weight. Notably, all aircraft models exhibit uniform weight distribution across these components, denoted by the consistent value of 0.16 for each parameter. This consistency suggests an equal allocation or proportion of weight across the various aspects or systems represented by C1 through C6 for all three aircraft, implying a balanced weight distribution strategy implemented in these respective aircraft designs.

TABLE 5. WSM Weighted normalized decision matrix

	C1	C2	C3	C4	C5	C6
Boeing 787	0.08000	0.16000	0.16000	0.16000	0.16000	0.16000

Airbus 380	0.16000	0.08000	0.09600	0.07830	0.08000	0.08533
Airbus 350	0.08000	0.16000	0.06400	0.15660	0.08000	0.10667

Table 5 presents a weighted normalized decision matrix, reflecting the prioritization and comparative evaluation across multiple criteria for the Boeing 787, Airbus 380, and Airbus 350 aircraft models. Each row represents a specific aircraft, while columns C1 through C6 signify different criteria. The values within the matrix demonstrate the weighted priorities assigned to each criterion for every aircraft model. In this matrix, the Boeing 787 maintains consistent weightings across all criteria, with each criterion valued at 0.16 except for C1, which stands at 0.08. Conversely, the Airbus 380 and Airbus 350 display variations in their prioritization, emphasizing different criteria with varying weights. These variations indicate distinct emphasis or importance placed on certain criteria for each aircraft model, illustrating differing strategic priorities or performance emphases among them.

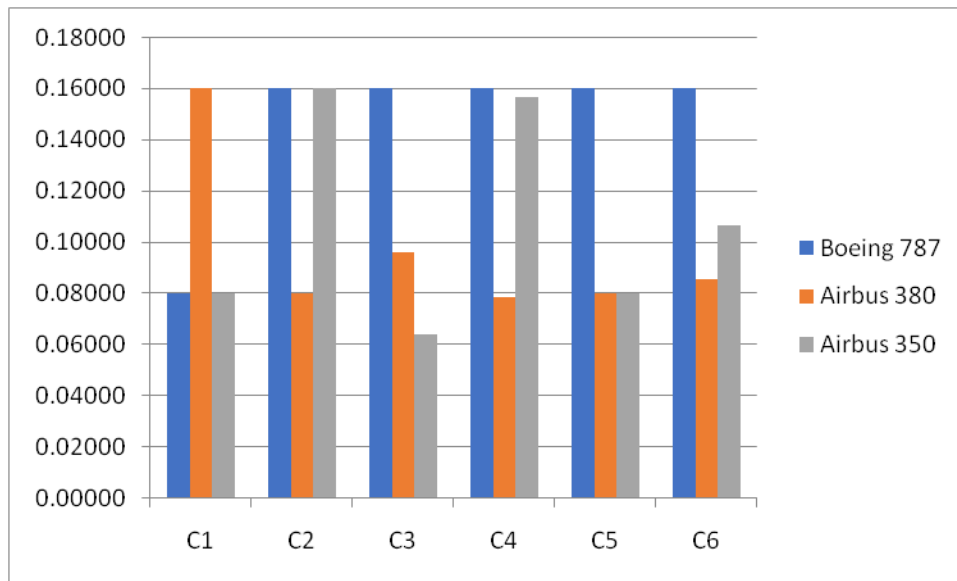


FIGURE 2. WSM Weighted normalized decision matrix

In figure 2, the Weighted Normalized Decision Matrix (WSM) illustrates the weighted priorities assigned to distinct criteria for the Boeing 787, Airbus 380, and Airbus 350 aircraft models. Each row represents an aircraft model, while columns C1 through C6 depict different criteria. The values within the matrix highlight the weightings assigned to each criterion for every specific aircraft. For the Boeing 787, the emphasis is evenly distributed across the criteria, with a consistent value of 0.16000 for C2 through C6 and a slightly lower weight of 0.08000 for C1. In contrast, the Airbus 380 and Airbus 350 display varying prioritizations, placing differing importance on specific criteria. The Airbus 380 assigns higher weights to C1 and C3 compared to other criteria, while the Airbus 350 emphasizes C4 and C6, indicating unique prioritization strategies across these aircraft models. These values provide insights into the weighted significance of individual criteria within the evaluation framework for each aircraft.

TABLE 6. WPM Weighted normalized decision matrix

	C1	C2	C3	C4	C5	C6
Boeing 787	0.89503	1.00000	1.00000	1.00000	1.00000	1.00000
Airbus 380	1.00000	0.89503	0.92152	0.89195	0.89503	0.90432
Airbus 350	0.89503	1.00000	0.86363	0.99656	0.89503	0.93719

Table 6 showcases a Weighted Normalized Decision Matrix (WPM), indicating the prioritization and comparative evaluation across various criteria for the Boeing 787, Airbus 380, and Airbus 350 aircraft models. Each row corresponds to a specific aircraft, while columns C1 through C6 represent different criteria. The values within this matrix denote the weighted priorities assigned to each criterion for every aircraft model. In this context, the Boeing

787 demonstrates consistent and high prioritization across all criteria, with nearly full weights for C2 through C6 and a slightly lower weight for C1. On the other hand, the Airbus 380 and Airbus 350 reveal variations in their prioritization strategies, emphasizing certain criteria more than others, reflecting differing strategic focuses or performance emphases among these aircraft models. These weightings provide insights into the specific areas of emphasis or importance within the evaluation framework for each aircraft.

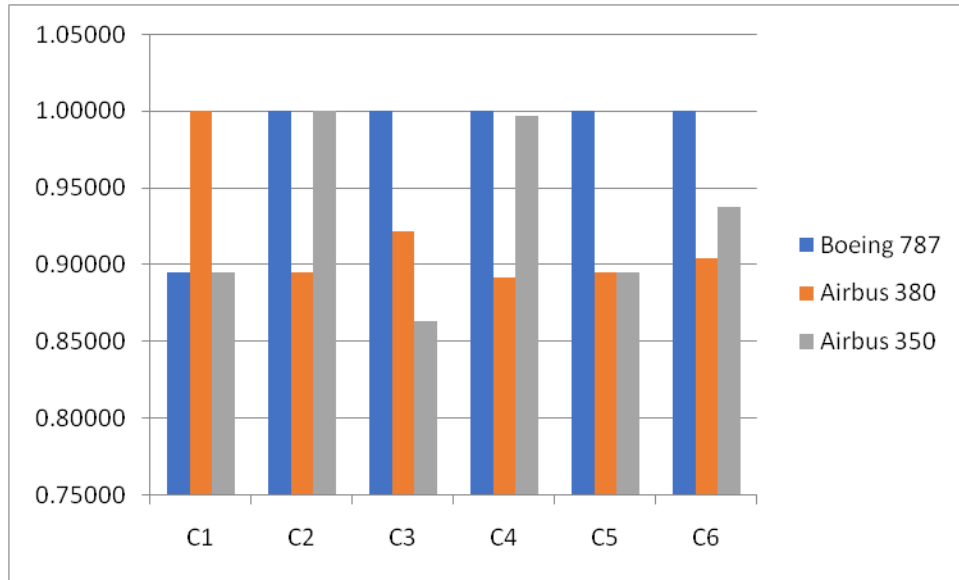


FIGURE 3. WPM Weighted normalized decision matrix

In figure 3, the Weighted Normalized Decision Matrix (WPM) provides a detailed view of the prioritization and comparative assessment of distinct criteria for the Boeing 787, Airbus 380, and Airbus 350 aircraft models. Each row represents an aircraft model, while columns C1 through C6 denote different criteria. The values in this matrix indicate the weighted priorities assigned to each criterion for every specific aircraft. The Boeing 787 exhibits consistently high prioritization across all criteria, with nearly full weights for C2 through C6 and a slightly lower weight for C1. Conversely, the Airbus 380 and Airbus 350 showcase variations in their prioritization strategies, assigning differing weights to specific criteria. The Airbus 380 emphasizes C3 more than other criteria, whereas the Airbus 350 places substantial importance on C4 and slightly higher emphasis on C6 compared to other criteria. These values offer insights into the weighted significance and relative importance of individual criteria within the assessment framework for each aircraft model.

TABLE 7. WSM and WPM Preference Score

	WSM Preference Score	WPM Preference Score
Boeing 787	0.88	0.89503
Airbus 380	0.579631	0.595436
Airbus 350	0.647262	0.646146

Table 7 outlines the Preference Scores derived from the Weighted Normalized Decision Matrix (WSM) and Weighted Normalized Decision Matrix (WPM) for the Boeing 787, Airbus 380, and Airbus 350 aircraft models. These scores represent the overall preference or ranking of each aircraft based on the respective evaluation methodologies. In this comparison, the Boeing 787 exhibits a higher Preference Score in both the WSM and WPM methodologies, indicating a stronger overall performance or desirability according to the criteria considered in both matrices. The Airbus 380 and Airbus 350, while showing differences in their scores between the WSM and WPM, generally display lower preference scores compared to the Boeing 787. These Preference Scores offer a condensed and comparative assessment of the aircraft models' desirability or performance based on the different evaluation approaches, providing insights into their relative strengths or advantages within the evaluated criteria.

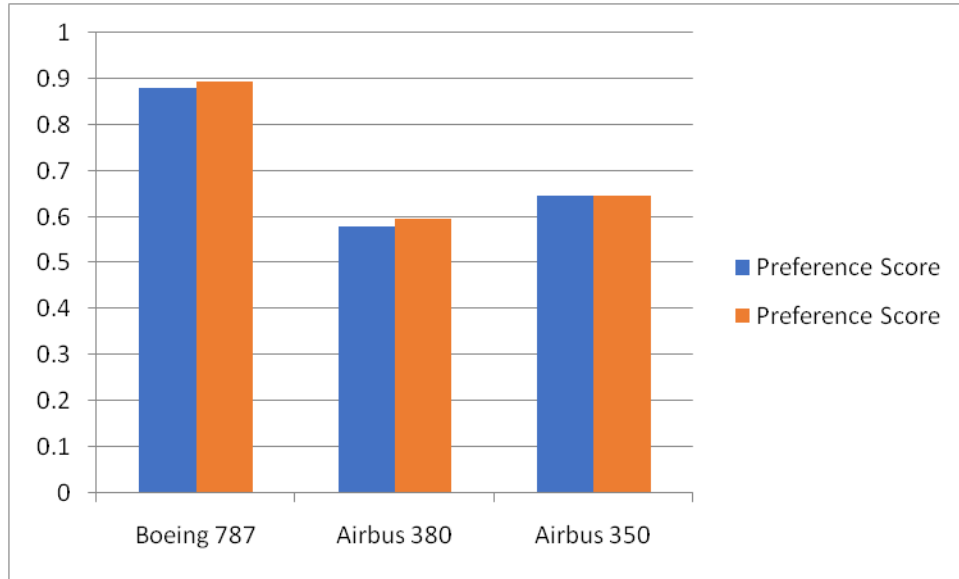


FIGURE 4. WSM and WPM Preference Score

In figure 4, the Preference Scores derived from the Weighted Normalized Decision Matrix (WSM) and Weighted Normalized Decision Matrix (WPM) for the Boeing 787, Airbus 380, and Airbus 350 aircraft models are displayed. These scores represent the overall preference or ranking of each aircraft based on the respective evaluation methodologies. For the Boeing 787, both WSM and WPM methodologies accord high Preference Scores, indicating a strong overall performance or desirability according to the considered criteria in both matrices. However, the Preference Scores for the Airbus 380 and Airbus 350, while differing slightly between WSM and WPM, generally present lower scores compared to the Boeing 787. These Preference Scores offer a compact assessment of the aircraft models' desirability or performance based on the different evaluation approaches, highlighting their relative strengths or advantages within the evaluated criteria.

In mathematics, lambda (λ) represents a parameter used in various contexts, including statistics, calculus, linear algebra, and computer science. When the value of lambda is set to 0.5, it denotes a specific numerical assignment within an equation or model. In statistics or machine learning, a lambda value of 0.5 might be associated with regularization techniques such as Lasso regression or Ridge regression, where lambda controls the strength of regularization applied to the model. In calculus or mathematical equations, lambda often signifies a scaling factor or a rate of change within a function. Its value of 0.5 can impact the behavior of the function, influencing outcomes or relationships between variables. In general, the specific impact of lambda at 0.5 depends on the context in which it's used, but it commonly denotes a moderate or balanced influence or adjustment within a mathematical or statistical framework.

TABLE 8. WASPAS Coefficient

	WASPAS Coefficient
Boeing 787	0.88751
Airbus 380	0.58753
Airbus 350	0.64670

Table 8 showcases the WASPAS (Weighted Aggregated Sum Product Assessment) Coefficients assigned to the Boeing 787, Airbus 380, and Airbus 350 aircraft models. These coefficients represent a weighted assessment derived from the WASPAS method, offering a comprehensive evaluation of the performance or desirability of each aircraft model based on the considered criteria. In this comparison, the Boeing 787 attains the highest WASPAS Coefficient among the three aircraft, indicating a relatively stronger overall performance or desirability according to the criteria integrated into the WASPAS assessment. The Airbus 380 and Airbus 350, while exhibiting varying coefficients, generally secure lower WASPAS Coefficients compared to the Boeing 787, suggesting comparatively

lesser performance or desirability according to the integrated criteria within the WASPAS methodology. These coefficients encapsulate a synthesized evaluation, providing insights into the relative strengths or advantages of each aircraft model based on the aggregated assessment carried out through the WASPAS approach.

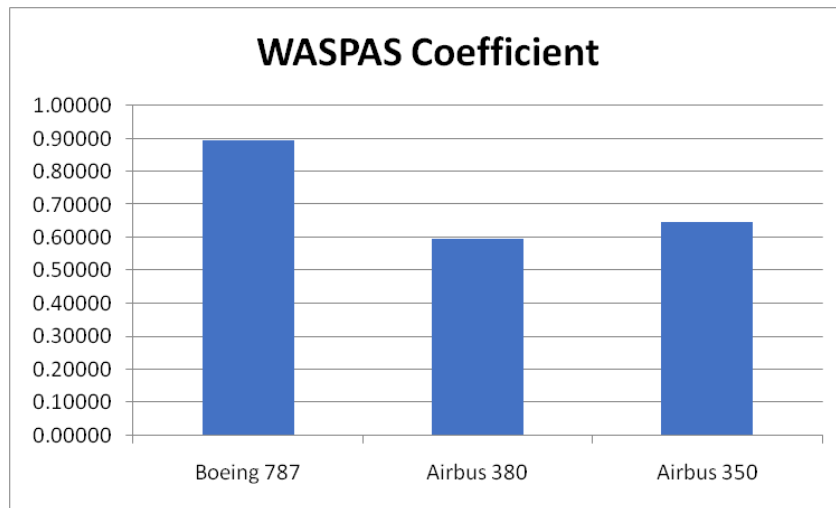


FIGURE 5. WASPAS Coefficient

In Figure 5, the WASPAS Coefficients are presented for the Boeing 787, Airbus 380, and Airbus 350 aircraft models. These coefficients encapsulate a synthesized evaluation derived from the WASPAS method, offering an aggregate assessment of the performance or desirability of each aircraft model based on the considered criteria. The Boeing 787 secures the highest WASPAS Coefficient among the three aircraft, with a value of 0.88751, indicating a relatively stronger overall performance or desirability according to the integrated criteria within the WASPAS assessment. On the other hand, the Airbus 380 and Airbus 350 exhibit lower WASPAS Coefficients, with values of 0.58753 and 0.64670, respectively, suggesting comparatively lesser performance or desirability according to the aggregated criteria within the WASPAS methodology. These coefficients serve as a comprehensive evaluation, offering insights into the relative strengths or advantages of each aircraft model based on the synthesized assessment carried out through the WASPAS approach.

TABLE 9. Rank

	Rank
Boeing 787	1
Airbus 380	3
Airbus 350	2

In Table 9, the provided rankings offer a straightforward comparative assessment among the Boeing 787, Airbus 380, and Airbus 350 aircraft models based on the evaluated criteria or methodologies. The rankings depict the relative positions of these aircraft concerning their overall performance, desirability, or compliance with the assessed criteria. In this ranking, the Boeing 787 secures the top position with a rank of 1, signifying its superior performance or desirability compared to the other aircraft models considered. The Airbus 350 follows closely behind, securing the second rank, while the Airbus 380 occupies the third position in this evaluation. These rankings provide a simplified yet impactful depiction of the comparative performance or desirability of these aircraft models based on the integrated assessment criteria, clearly delineating their relative positions within the evaluated set.

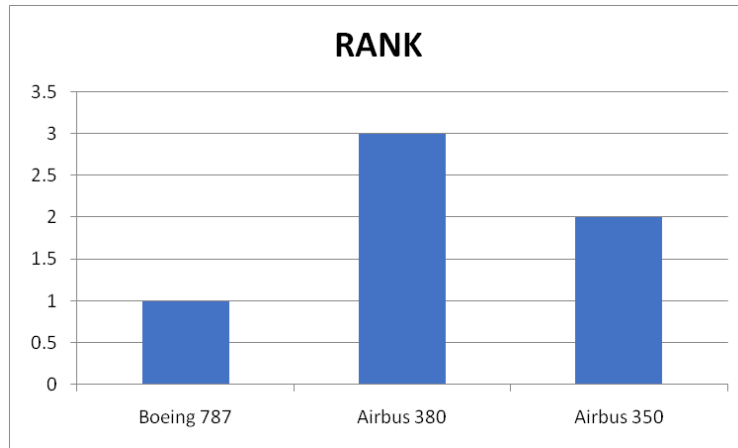


FIGURE 6. Rank

In figure 6, the provided rankings offer a clear comparison among the Boeing 787, Airbus 380, and Airbus 350 aircraft models based on the evaluated criteria or methodologies. The rankings illustrate the relative positions of these aircraft concerning their overall performance, desirability, or compliance with the assessed criteria. The Boeing 787 secures the top position with a rank of 1, signifying its superior performance or desirability compared to the other aircraft models considered. Following this, the Airbus 350 takes the second rank, while the Airbus 380 holds the third position in this evaluation. These rankings provide a simplified yet effective representation of the comparative performance or desirability of these aircraft models based on the integrated assessment criteria, delineating their relative positions within the evaluated set.

4. CONCLUSION

In the realm of aircraft advancements, recent innovations in aircraft technology, exemplified by models like the Boeing 787 and Airbus A350/A380, showcase a significant shift toward electrical systems, marking a departure from traditional pneumatic and constant voltage and frequency setups. These modern aircraft employ constant voltage with variable frequency configurations, necessitating power conversion for various systems like engine start, environmental control, and more. The elimination of bleed air systems in favor of electrical alternatives in environmental control systems exemplifies this transition. However, this shift poses challenges such as increased power demand, necessitating higher output from main engine generators. The adoption of electric systems requires careful sizing, power calculation, and consideration of reliability and redundancy in the overall electrical power system architecture. The evolution toward electric systems in aircraft represents a paradigm shift, demanding research into control strategies, system analysis, and exploring alternative configurations. The ongoing advancements and investigations in power conversion technologies, engine start mechanisms, and environmental control systems signify an industry-wide effort to optimize efficiency, reduce weight, and enhance overall performance in modern aviation.

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