Palestine Journal of Mathematics

Vol 14(Special Issue I)(2025) , 34–56

INTEGRATING HYBRID MULTI-OBJECTIVE OPTIMIZATION METHOD BY RATIO ANALYSIS FOR THE SELECTION OF WIDE-BODY AIRCRAFT

A. Dhara, J.V.M. Lal Jeyan and A.K. Thakur

MSC 2010 Classifications: Primary 90B06; Secondary 90B50.

Keywords and phrases: MCDM, CRITIC, MOORA, aircraft selection, wide-body aircraft.

The authors would like to thank the reviewers and editor for their constructive comments and valuable suggestions that improved the quality of our paper.

Abstract The pursuit of Middle-of-the-Market (MOM) aircraft, commonly referred to as the "sweet spot," aims to stimulate global market demand while ensuring customer satisfaction in the foreseeable future. The aim of future aircraft designs is to effectively balance profitability and consumer satisfaction, with a focus on wide-body aircraft that offer superior performance, lower fuel consumption, and reduced emissions. This emphasizes the importance of utilizing Multi-Criteria Decision-Making (MCDM) techniques to carefully evaluate and select aircraft based on specific criteria. The primary aim of this research is to identify the most suitable and unsuitable wide-body aircraft across thirteen key criteria under four critical areas such as aerodynamic considerations, structural considerations, performance factors, and operational missions. These technical and operational criteria include fineness ratio (FR), aspect ratio (AR), Maximum Take-off Weight (MTOW), empty weight fraction (W_E/W_{T0}), fuel weight fraction (W_F/W_{T0}), payload (n_{PL}), thrust-to-weight ratio (T/W), range (R), take-off cycle (S_{T0}), cruise speed (Vc), rate of climb (RoC), and specific fuel consumption (SFC). In this research work, an integrated CRITIC-MOORA MCDM technique is employed as the decision-making methodology to determine the optimal aircraft. The research examines twenty-two alternatives using real case studies of wide-body aircraft to validate the proposed concept. Additionally, a comparative analysis was conducted using other approaches such as MOORA, WASPAS, and TOPSIS methods to check the robustness of the model. The findings demonstrate that the Airbus A310-200 (A2) and Boeing B747-100 (A10) are identified as the best and worst wide-body aircraft, respectively. The findings provide evidence for the effectiveness of the CRITIC-MOORA method, as it is consistent with airline market statistics and establishes its superiority over alternative MCDM techniques.

1 Introduction

The aerospace industry places a high priority on sustainable air transportation by employing innovative design methodologies that focus on aerodynamics, propulsion systems, and retrofit technologies. The modern approach to aircraft design emphasizes the implementation of novel methodologies and revolutionary concepts to optimize performance and minimize carbon emissions. Design engineering, which encompasses aerodynamics, propulsion systems, and retrofit technologies, plays a vital role in achieving these objectives. Within the industry, there is a strong emphasis on reliability, passenger comfort, and safety, with the ultimate aim of increasing profitability by reducing overall costs, including fuel prices, maintenance expenses, and indirect expenditures. The process of aircraft development begins with the identification of operational requirements, and this paper primarily focuses on passenger-based commercial air transportation within the middle market. Passenger-based aircraft are categorized into regional, narrow-body, and wide-body types, with particular attention given to the latter for its potential to reduce fuel consumption and emissions, as illustrated in Figure 1. Designers in the industry are actively adapting to the challenges of climate change, as demonstrated by the Airbus A321 Neo, which

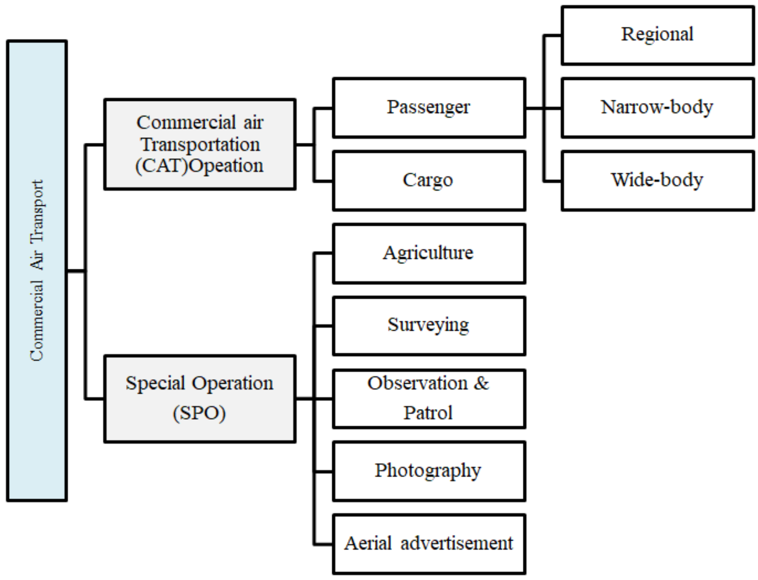

Figure 1. Classification of air transportation

offers a spacious interior to enhance customer comfort. Despite achieving a 15 percent increase in profits through re-engineering efforts and a modest 3 percent from retrofitting cabin interiors, the constraints of design prompt the exploration of new conceptual ideas to enhance airline profitability, reduce emissions, and improve fuel efficiency [1] [2]. Boeing's introduction of the Middle-of-the-Market (MoM) aircraft aims to meet the demands of airlines without compromising customer satisfaction, positioning it as a potentially lucrative opportunity for global market expansion [3] [4]. The MoM aircraft can accommodate 180 to 350 passengers, bridging the gap between single-aisle and twin-aisle configurations, and has a range of 5,000 to 12,000 kilometers [5]. Progressive technologies, such as green aviation technology, which has been endorsed by the International Air Transport Association [6], are expected to significantly enhance fuel efficiency per passenger by up to 70 percent, driven by advancements in airframe technology, aerodynamics, and engine performance. The design of aircraft meticulously considers various parameters, including speed, range, altitude, take-off distance, wing loading, and thrust loading, while also evaluating factors such as reliability, profitability, safety features, accident rates, costs, revenue generation, and fuel efficiency. Although the selection of the optimal MoM aircraft can be a challenging task, the utilization of multiple criteria decision-making (MCDM) can provide valuable assistance to design professionals in the process of choosing an aircraft that is best suited to meet specific operational requirements.

The design and development of new aircraft involve multiple stages, each requiring adherence to standards and informed decisions. Strategic planning in these phases often encompasses various criteria, making it crucial to employ multiple criteria decision-making (MCDM) methods for design professionals to make suitable selections. Popular MCDM approaches include Analytic Network Process (ANP) [7] Analytic Hierarchy Process (AHP) [7] [8] [9] [10], COmplex PRoportional ASsessment (COPRAS) [11], Entropy weight method (EWM) [12], Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [13] [14] [15] [16] [17], VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [16], Simple Additive Weighting (SAW) [18], Evan Swaps Method (ESM) [9], Multi-Objective Optimization Method by Ratio Analysis (MOORA) [16] [19] , Multiple Objective Optimization on the basis of Ratio Analysis Plus Full Multiplicative Form (MULTIMOORA) [20], Novel Approach to Imprecise Assessment and Decision Environments (NAIADE) [21], ELimination Et Choice Translating Reality (ELECTRE), Reference Analysis for Reference Ideal Solution (PARIS), Fuzzy Reference Ideal Method (FRIM) [21] [22], Weighted Aggregates Sum Product Assessment (WASPAS) [12] [23], and others.

Table 1 presents an overview of the contributions of MOORA MCDM methods utilized in the

Table 1. Application of MOORA MCDM method in the aerospace industry

Authors	Implementation	Key findings
[23]	Materials selection	Computing the material selection under technical aspects utilizing MOORA
[24]	Commercial aircraft selection	Evaluate the best selection and compared with other MCDM methods to find the robustness of the method.
[29]	Ground handling services	Method utilized as neutrosophic MULTIMOORA method on different airline services.
[20]	Airport runway selection	Hybrid methodology utilized based on the stakeholder's decision and to select the best one.
[30]	Civil aircraft safety status	Selection of aircraft utilizing index fuzzy segmentation and MULTIMOORA
[27]	Training aircraft for flight training	Prediction of optimal aircraft under hybrid techniques such as neutrosophic AHP and MULTIMOORA method
[31]	Drone selection	Utilization for sustainable traffic management using MCDM techniques.
[32]	Armored Military Vehicles	Global Fuzzy MULTIMOORA Method
[33]	Friction Stir Welding (CFSW)	Method outperforms the conventional method in terms of strength and hardness.
[11]	Aerospace cabin interior	Evaluating cabin safety and ranking the best cabin interior using different MCDM methodologies.
[25]	Fighter aircraft selection	Determination of rank based on technical aspects and economic aspects and compared with other MCDM methods.
[34]	Autoclave method (OoA) technology	Prepregs materials are accepted for qualitative and low-cost aerospace components
[35].	Additive manufacturing	Evaluate the best additive manufacturing techniques using MCDM techniques and find the robustness under different technical aspects.

aerospace industry, specifically in the selection and evaluation of transport [24], fighter [25], military, Unmanned Aerial Vehicles (UAV) [26], regional aircraft [27] or even product design [28]. The table 1 also emphasizes the extensive opportunities and challenges in implementing MCDM for selecting or evaluating aircraft based on objective functions, demonstrating its relevance across diverse technical aspects and sub-parameters [29] [30]. These methods are instrumental in addressing decision-making challenges throughout different design stages, incorporating technical, financial, and safety considerations for both commercial and defense applications [31] [32] [33] [34] [35]. MCDM methods play a significant role in tackling decision-making challenges related to the quality of services and passenger comfort in airlines. They aid in the evaluation of technical parameters and the resolution of conflicting aspects among alternatives. The versatility of MCDM approaches lies in their capacity to predict both objective and subjective factors using various techniques, making them valuable for engineering selection processes, technical aspects, and operational research. The MOORA MCDM method can enhance aircraft design by assisting in the selection of the most suitable alternative based on multiple criteria. This method takes into account the diverse expertise and preferences of decision-makers, encompassing various aspects of a multiple-criteria decision-making problem. It combines multi-objective optimization based on ratio analysis and Pythagorean fuzzy sets, enabling the selection of the optimal alternative. By utilizing multi-objective optimization based on ratio analysis, the MOORA method aids in the identification of optimal solutions for aircraft design issues. This approach is particularly effective in dealing with intangible information and has the potential to advance research in the field of multiple-criteria decision-making.

1.1 Research Gap

Current MCDM methodologies have remains unexplored on wide-body aircraft, and its effectiveness for other aircraft types. Previous studies focuses on technical and operational criteria may overlook market dynamics and customer preferences, limiting the critical factors such as performance impact, which is essential in modern aviation decision-making [2]. Based on the literature survey, many authors implemented variant hybrid techniques like WASPAS and TOPSIS but lacks in-depth examination of how these methods compare under varying market conditions and a sensitivity analysis using established methods. The potential use of 'CRITIC method' for deriving objective weights from real-time statistical data has not been fully explored in any existing literature. No studies have utilized the integrated CRITIC-MOORA MCDM technique specifically for determining optimal aircraft. This gap limits the understanding of how this hybrid approach can enhance decision-making in the air transportation sector. Addressing these gaps could significantly contribute to the field of aerospace decision support systems, ultimately leading to more informed and sustainable aircraft acquisition strategies.

1.2 Contribution

The present work aims to investigate and address the subsequent issues:
(1) What are the design factors that impact the selection of wide-body aircraft?
(2) What are the signification considerations of each design criterion?
(3) Which among the considered alternative aircraft is the most favorable wide-body category?
To address inquiries that arise from the novelty of the proposed Multiple Criteria Decision-Making (MCDM) technique, we will employ a range of objective criteria, including technical aspects, economic considerations, and safety aspects. Upon a thorough examination of Table 1, it is evident that the utilization of MCDM in the aerospace sector presents both opportunities and challenges for future exploration. It is necessary to implement various other techniques to effectively select or evaluate aircraft. The purpose of this paper is to contribute to the field by focusing on the CRITIC-MOORA MCDM approach, which aims to determine the best and worst wide-body aircraft. It is worth noting that CRITIC approaches have not previously been utilized in the aerospace sector to obtain the objective weights of the considered criteria. The MOORA Method, renowned for its high level of accuracy, serves as an appropriate foundation for this hybrid MCDM approach.
The research is centered around the selection of wide-body aircraft based on twelve distinct criteria (C1 to C13) across twenty-three alternative aircraft variants (A1 to A22) as illustrated in Figure 2. The considered alternatives are limited to wide-body aircraft, encompassing both narrow-body and wide-body options, with a flight range between 5000 km and 12000 km. Furthermore, the paper expands its investigation to include a sensitivity analysis utilizing other well-known MCDM methods such as WASPAS, and TOPSIS to validate the results. The implementation of the Symmetric Mean Absolute Percentage Error (sMAPE) is employed to estimate the error in ranking obtained from various MCDM techniques, thereby providing a comparative analysis.
Section 2 explores the literature review concerning the design parameters of Middle-of-the-Market (MOM) and the utilization of the Multi-Criteria Decision Making (MCDM) approach. Section 3 delineates the hybrid MCDM methodology, whereas Section 4 scrutinizes the findings and performs an exhaustive examination of the sensitivity. Ultimately, Section 5 draws conclusions and highlights the potential future consequences of this research endeavor.

2 Case Study with Literature Review

The design of an aircraft is a complex process that involves optimizing various parameters to meet specific objectives and address concerns related to operating and maintenance costs, as well as environmental factors such as noise and emissions. These objectives are tailored to the mission for which the aircraft is designed, known as the "design mission." This research paper aims to focus on three main objective-based studies on the technical, economic, and safety aspects of wide-body aircraft. Therefore, a collection of thirteen different wide-body aircraft is to evaluate

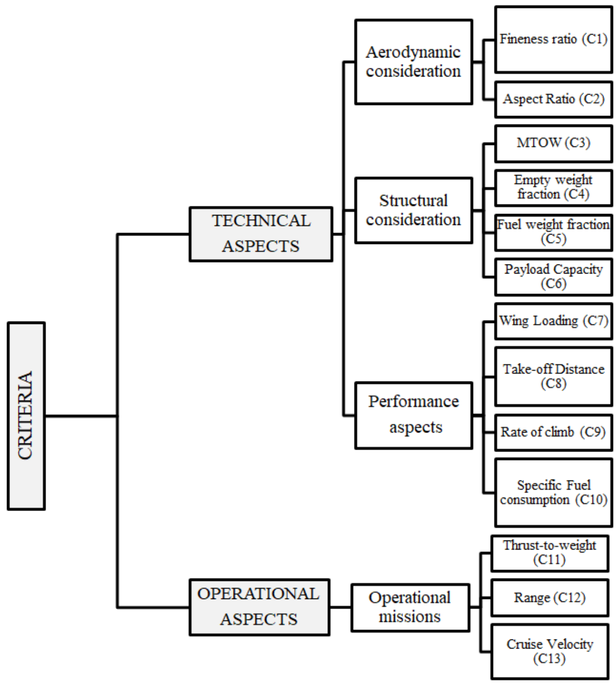

Figure 2. Selected criteria selection for the proposed findings

statistical data and characteristics of the aircraft are as A300-600R (A1), A310-200 (A2), A330-900N (A3), A330-300 (A4), A340-300 (A5), A340-600 (A6), A380-800 (A7), A350-900 (A8), A350-1000 (A9), B747-100 (A10), B747-200 (A11), B747-400 (A12), B777-200IGW (A13), B777-300 (A14), B787-10 (A15), B777-9X (A16), DC10-30 (A17), MD-11(A18), L1011-100 (A19), Il-86 (A20), Il-96-300 (A21), and Il-96M (A22) aircraft. These four main criteria are broken down into aerodynamic consideration, structural consideration, performance factor, and operational factors are discussed below.

2.1 Aerodynamic consideration:

The study of airflow over any shape or size defines aerodynamics. Most aircraft are designed with smooth and efficient patterns to reduce drag resulting in reduced wake creation [36]. Mathematically, drag is the function of Flight speed, altitude, wing area, and drag coefficient. Looking deep into the drag coefficient (C_D) is a sum of the parasite drag coefficient ($C_{D,0}$) and induced drag coefficient ($C_{D,i}$) [36] [37]. These two coefficients contribute in terms of fineness ratio (FR) and aspect ratio (AR) as indicated in Equations (2.1) and (2.3). Equation (2.1) represents the parasite drag coefficient as a product of skin friction drag coefficient (CD,SF), form factor (F.F), interference factor (I.F), and wetted surface area fraction (Swetted/Sref). The assessment of all $C_{D,0}$ factors were derived from the flight speed and Reynolds number (Re) that depends on the value of FR is the ratio of the length of the fuselage (L_f) to the diameter of the fuselage (D_f) [37] [38] [39]. Raymer [38] investigated that the fuselage body contributes about half a percent of the total drag obtained in the aircraft's other components. Roskam [39] analyzed and stated that the FR value is eight proved to be supreme. However, the optimized value of FR is between 5 and 9 for the least drag contributor to the aircraft. The essential value of FR depends on the seating capacity, cabin dimension, cargo compartment, and other comfort requirements. Figure 3 illustrates a detailed cabin dimension for a single-aisle first class and economy class passenger varies from four to six abreast for Airbus A320. In accordance with seat width, aisle width, no. of abreast, no. of galley and lavatory, seat capacity, and seat pitch deploy the required FR for an aircraft [39]. The dimensions of cabin width, fuselage width, fuselage height, and length of wide-body aircraft are represented in Table 2.

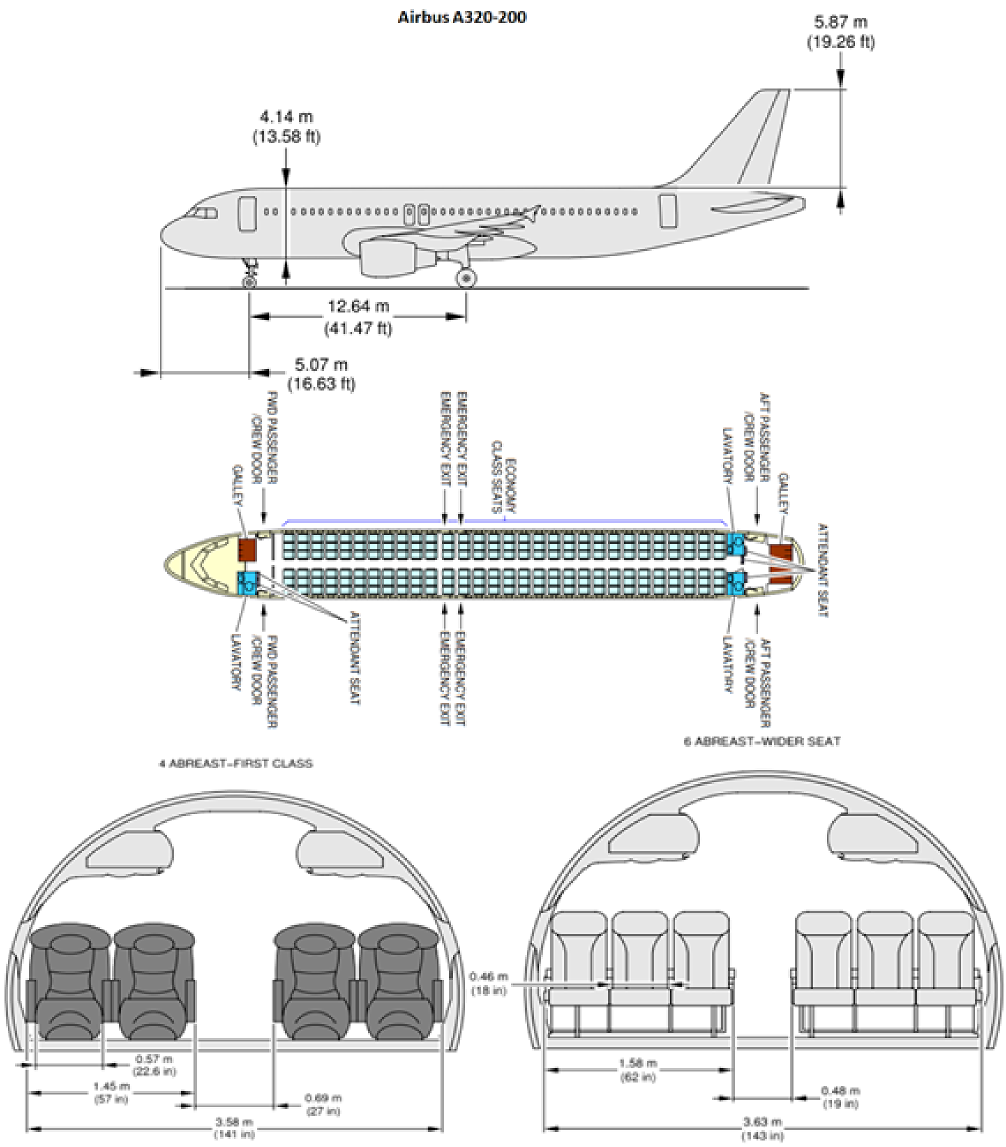

Figure 3. Cabin dimension for Airbus A320-200

$$C_{DO_{component}} = C_{D0_{wing}} + C_{D0_{Fuselage}} + C_{D0_{HT}} + C_{D0_{VT}} + C_{D0_{nacelle}} \tag{2.1}$$

In another form, the equation 2.1 can also be written as

$$C_{DO_{Component}} = \sum_{K=1}^{Components} (C_{f,e}).FF.Q.(S_{wet}/S_{ref}) \tag{2.2}$$

Where C_f is the Skin friction drag coefficient depending on Reynolds number, skin roughness, fuselage length, and speed. F.F Form factor depends on the fineness ratio; Q is the Interference factor depends on location.

$$C_{f,e} = \frac{0.455}{(lgRe)^{2.58}(1+0.144M^2)^{0.65}} \tag{2.3}$$

$$FF_{W,Ht,VT} = \left[1 + \frac{0.6}{(x/c)_m}\left(\frac{t}{c}\right) + 100\left(\frac{t}{c}\right)\right]\left[1.34M^{0.18}\left(\cos\Lambda_{c/4}\right)^{0.28}\right] \tag{2.4}$$

$$FF_f = \left[1 + \frac{60}{(FR)^3} + \frac{FR}{400}\right] \tag{2.5}$$

$$S_{wet,w} = 4 * \left(\frac{b}{2}\right)_e \left(\frac{C_R, e + C_T}{2}\right)\left(1 + 0.25\frac{t}{c}\right) \tag{2.6}$$

$$S_{wet,f} = \pi.L_f.D_f.\left(1 - \frac{2}{FR}\right)^{2/3}\left(1 + \frac{1}{FR^2}\right) \tag{2.7}$$

$$S_{wet,HT,VT} = 4 * \left(\frac{b}{2}\right)_e \left(\frac{C_{R,HT,e} + C_{T,HT}}{2}\right)\left(1 + 0.25\frac{t}{c}\right) \tag{2.8}$$

The second most effective parameter is the Aspect ratio (AR). The value of AR determines the wing's effectiveness, either in the form of better lift or better maneuverability. A high value of AR surge to reduce the induced drag coefficient (CD,i). Furthermore, a concept of winglet installation is to minimize trailing vortices by increasing the AR expressed in equation (2.9). Equation (2.9) concludes that the higher value of AR provides drag-reduction aids to fuel economy [40] [41]. NASA's Technology Transfer Program announced the significant fact that a winglet is likely to save fuel costs and reduce carbon footprint, and emissions to the atmosphere. In addition, the appropriate installation of aerodynamic peripherals such as slats, wing fences, and other variants would increase flight performance [36]. Examine other aerodynamic features, most wide-body transport aircraft are configured with low-wing monoplane, a swept wing of angle about 25 degrees to 32 degrees, and a thickness-to-chord ratio limited to 12 percent to 9 percent (Nicolai, & Carichner, 2010). The above-mentioned features are discussed based on the case study made on the analysis of wide-body aircraft.

$$C_{D,i} = \frac{(C_L)^2}{\pi AR} \tag{2.9}$$

Where, CL is the lift coefficient AR is Aspect Ratio is the ratio between the square of wing span (b) and wing area (S) can be represented as For monoplane, $AR = b^2/S$

2.2 Structural Consideration:

The objective of aircraft structural design is to endure various forms of air and mechanical stresses throughout diverse flight conditions. Based on the study, multi-spar structures impart to overcome adverse flight conditions for transport aircraft. Data shows that the structural design consideration is subjected to the gross weight (MTOW) depending on payload weight (W_{PL}), empty weight fraction (WE/WTO), and fuel weight fraction (Wfuel/WTO) as expressed in equation 2.12. MTOW drastically affects the performance in terms of rate of climb (ROC), climb angle (θ_{CL}), landing take-off operation (LTO) Cycle, and lift-to-drag (L/D) ratio [37] [38]. Additional buildup MTOW results in huge demand on power requirement steer to decrease climb performance radically. Besides, MTOW also influences the parameter called climb angle (θ_{CL}) indicated in equation (4). Boosting the value of MTOW gives drop-off ROC. However, gain in MTOW directly or indirectly affects the take-off or landing distance. Likewise, equation (4) expresses the parameters that intrude the MTOW such as aircraft stalling velocity, aerodynamic efficiency, and other essential parameters. Thus, MTOW can be controlled by the appropriate selection of materials, type of structures, and range (R) of the flight. Primarily design criteria that contribute to the payload weight as the number of passengers for transport aircraft. Secondly, the empty weight fraction (W_E/W_{TO}) structures the avionics systems and material used on the aircraft. As per design rule, WE are about 40 percent to 60 percent of the MTOW. A lower value of WE/WTO aids lighter-weight airframes employing composite or advanced structures, to enhance the strength-to-weight ratio and other factors. Aircraft designers must iterate to reduce aircraft weight and avoid structural collapse [40]. The influence of airframe structure on airplane performance is significant (Bellucci). A third prime factor is fuel weight fraction depends on the aircraft's mission profile, range, speed, engine selection, fuel consumption, and aerodynamic efficiency [40]. The Breguet equation holds the dependency factor of Wfuel/WTO affects the performance of the aircraft.

Table 2. Selection criteria of parameters for the proposed model

Selecting Parameters	Notations	Significance & Implementations	Reference(s)
Fineness Ratio (no unit)	FR	drag estimation using a wetted area results in drag-reduction.	[41] [38]
Aspect Ratio (no units)	AR	To determine the induced drag coefficient of the aircraft wing. Larger the AR triggers to decrease the vortices and hence to decrease drag.	[14] [39] [40] [41] [39]
Maximum Take-off Weight MTOW (kg)	W_{TO}	Signifies the decrease in fuel fraction by innovative technology can enhance long-range flight, better aerodynamic efficiency, and reduces TSFC in an aircraft. It strongly associated with payload, structures, speed, range, and fuel burn.	[14] [12] [13]
Empty weight Fraction (no units)	W_E/W_{T0}	It depends on the material selected and used in the structural airframes. Light weight can reduce emission and improve fuel efficiency.	(Proposed criteria)
Fuel Weight Fraction	W_F/W_{TO}	The amount of fuel required to cover a certain range of distance in a one load of fuel. The value can be determined by the mission profile	[12] [13] [38]
Payload	n_{PL}	The amount can be obtained by the number of passengers, crew, and cargo associated with competitiveness.	[12] [13] [9] [10]
Wing Loading (kg/m2)	W/S	Low W/S offer better sustained performance to create greater lift for the same amount of engine power. As a result, increasing W/S lengthens STO distances and reduces manoeuvrability.	[14] [12] [13] [39]
Thrust to Weight ratio (no units)	T/W	An aeroplane with a high T/W ratio will have a high thrust flying capabilities.	[37]
Range (km)	R	The challenge of efficient range operating of an aircraft cover better distance out of a given fuel load. number of passengers, crew, and cargo associated with profits.	[14] [12] [13]
Take-off Landing Cycle (km)	STO	The main aim is to decrease the STO distance to improve the performance and fuel efficiency. By better design configuration can achieve improve STO.	[12] [13]
Cruise Speed (km/hr)	VC	Parameter is most economical to fly, somewhat quicker than the speed that allows for maximum range but slower than the aircraft's highest speed.	[14] [12] [13] [21]
Rate of Climb (m/s)	ROC	Signifies the parameter of performance of the flight. A better ROC can be generated by greater the propulsion force, the lesser the resistive force, and the lowering the MTOW.	[37]
Fuel Consumption (kg/hr/N)	SFC	In order to the proper selection of engine and aerodynamic configure the reduction of fuel consumption. Also by lowering the fuel use can lead lower the CO2 emissions.	[40]

$$W_{TO} = W_{PL} + W_{CARGO} + W_{Fuel} + W_E \tag{2.10}$$

$$W_{TO} = \frac{W_{PL} + W_{CARGO} + W_E}{\left(1 - \frac{W_{Fuel}}{W_{TO}}\right)} \tag{2.11}$$

In addition to it, a small amount of fuel is kept as trapped by the systems and reserved for emergency purposes about 6 to 8 percent of the total fuel [38] [37] is expended throughout these mission stages is quantitatively represented by a specific equation 2.12. This equation (2.12) is assumed as the fuel reserved and trapped about 6 percent of fuel.

$$\frac{W_{Fuel}}{W_{TO}} = 1.06\left(1 - \frac{W_8}{W_{TO}}\right) \tag{2.12}$$

2.3 Performance factors:

Improving flight dynamics and control mechanisms is one of the most common tasks for every aircraft. Flight performance may be improved achieved by reducing MTOW at a reasonable rate and distance of operation [42]. However, during the landing and take-off phases, the aircraft layout seems to have a bigger impact on flight effectiveness of airspeed, resistance, maneuverability, reliability, and several other factors. However, each aircraft can handle a variety of load factors, which may be analyzed using the flying envelope. Air travel outside an aircraft's operational or permitted flying envelope can cause structural damage. Matching charts are required in every aircraft design situation for combining aerodynamic integrated propulsion systems with manufacturers to achieve optimal performance. Likewise, changes in altitude can have an impact on flight performance and control systems. A rise in altitudes indicates a decline in air density in the environment, which signals a significant fall in engine power, and engine thrust as a result impacts fuel efficiency [42].

$$S_{TO} = S_G + S_R + S_{TR} + S_{CL} \tag{2.13}$$

where, Ground distance, $S_G = \frac{V_{TO}^2}{a}$ and ground rolling acceleration,
$a = \frac{g}{w}\left[T - D - \mu\left(W - L\right)\right]$
Rotation distance, $S_R = t_R V_{TO}$; for commercial flights, t_R ranges from 3 to 6 sec.
Transition distance, $S_{TR} = R sin\theta_{CL}$
where, transition height, $h_{TR} = R\left(1 - cos\theta_{CL}\right)$ and
climb angle = $\theta_{CL} = sin^{-1}\left(\frac{T}{W} - \frac{1}{\frac{L}{D}}\right)$

2.4 Operational Factors:

According to Wright [43], engineering design has a direct impact on cost. As illustrated in the figure 4, costs in the aviation sector may be divided into two categories: direct operating costs and indirect operating costs. The cost of the aircraft depends on the mission in terms of fuel consumption. Short-haul missions have greater consumption of fuel than medium or long-haul missions [44]. The study says that short-haul aircraft accessibility and levels of production are reduced compared with medium and long-range flights. It is also observed that a short-distance operation requires greater maintenance expenses, which results in lower profitability. Thus, maintenance cost or operating cost affects the design characteristics in five different ways are as follows: aircraft efficiency, engine number, size, speed, and aircraft age. According to Wesseler [45], the cost is determined by the aerodynamic profile. Improving fuel economy can be accomplished by optimizing overall power and minimizing the resistance of airflow accessories. The power plant and its force during the flight are the primary sources of fuel efficiency [43]. Fuel is a significant expense in aviation which is subject to major industrial attempts to seek efficiencies [46]. Fuel efficiency has a direct influence on the aerodynamic profile and the payload in terms of seat capacity, depending on the cost involved per passenger [47]. According to Hassan et al., [48] stated that fuel consumed (Wfuel) is a function of empty weight, MTOW, range (R), and LTO cycle as expressed in equation (2.14).

$$ASK = n_{PL} * R \tag{2.14}$$

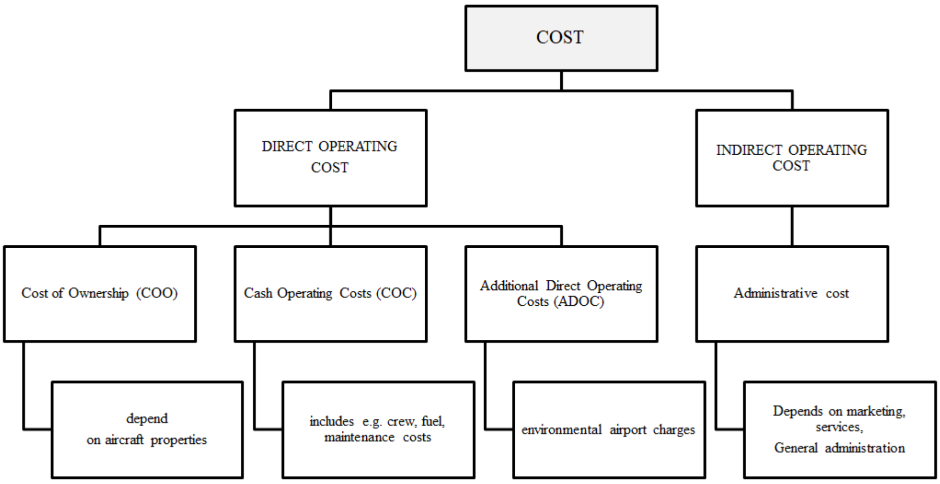

Figure 4. Aviation sector cost categories

In the year 2015, statistics say each one percent weight reduction corresponded to an increase in 0.75 percent fuel economy leading to increased coverage [40]. In practice, high-speed leads to improved profitability for certain seat capacities. If the planes are new then their life cycle and fuel efficiency will be improved [44]. According to Lee & Mo reported [47], the Airbus A380 appears to be more fuel-efficient than the Boeing B747-400. The gross weight of the airplane may grow as the number of passengers increases. The weight of an aircraft has a modest relationship with fuel economy. As a result, as a developer, MTOW is one of the essential characteristics that should be lowered by modifying the light structure and materials. However, it can increase effectiveness by extending the aircraft's distance and lowering its ecological footprint.

3 Methodology

The complexity of solving intricate problems in Multiple Criteria Decision-Making (MCDM) necessitates significant innovation and the advancement of revolutionary techniques. Over the past decade, various new approaches have emerged to address the practical challenges associated with MCDM. This paper aims to integrate the CRITIC and MOORA approaches within a decision-making system to ascertain the weights of individual criteria and ultimately assess the priority ranking of aircraft, as illustrated in Figure 5.

The proposed methodology initiates real-time data collection for wide-body aircraft, which is detailed in Tables 2, 3, and 4, and is categorized into three subgroups. The first step involves selecting criteria and formulating a decision matrix based on the identified criteria. Subsequently, the CRITIC method is applied to determine the objective weights and the significance of each criterion. Finally, the best alternative is computed based on the considered criteria using the MOORA method.

3.1 Criteria Selection

The design process of an aircraft involves careful consideration of various key parameters that play a crucial role in shaping the aircraft's performance, efficiency, and overall capabilities. The aircraft design spiral offers comprehensive insights into the pivotal factors significantly impacting various parameters. These four core design factors can be further sub-sectioned into the decision Criteria Selection into thirteen fragments as shown in Table 2. The list of selected criteria shows the significance of parameters for aircraft design and the selection of suitable wide-body aircraft. Based on the thirteen criteria, the real-time wide-body aircraft data is collected and tabulated in Table 3. According to the civil aviation aircraft datasheet, twenty-two sets of data

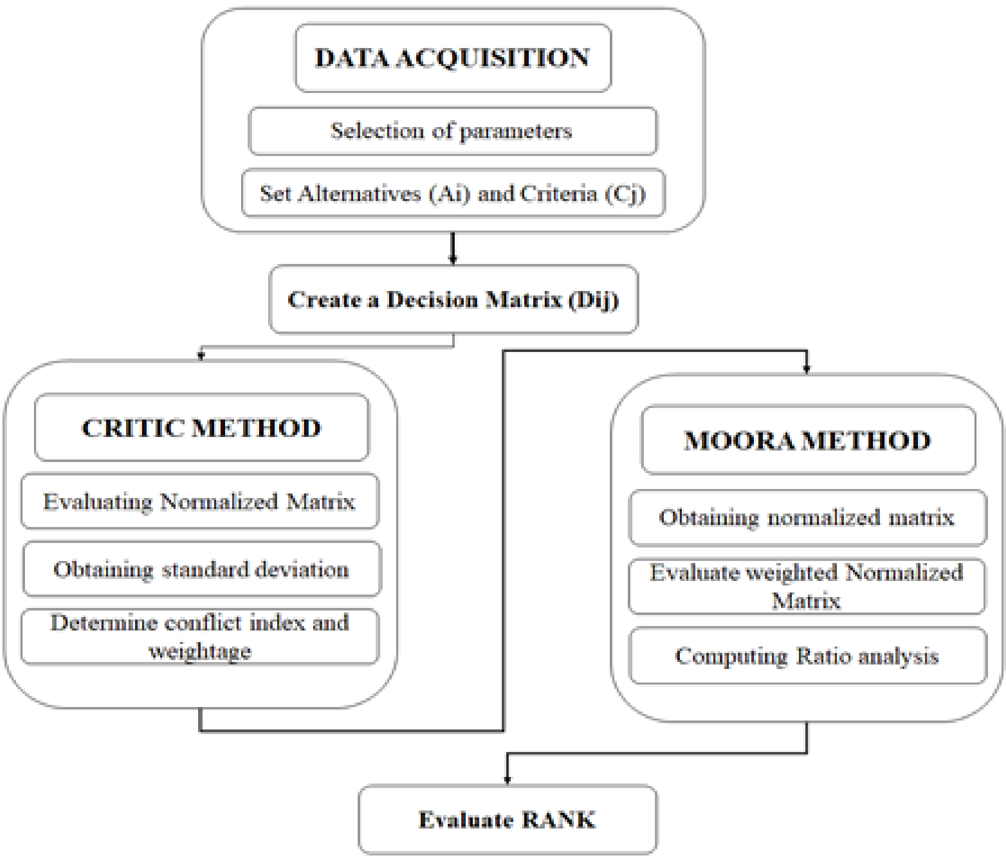

Figure 5. A hybrid method to select the aircraft

is fetched including the models are A300-600R (A1), A310-200 (A2), A330-900N (A3), A330-300 (A4), A340-300 (A5), A340-600 (A6), A380-800 (A7), A350-900 (A8), A350-1000 (A9), B747-100 (A10), B747-200 (A11), B747-400 (A12), B777-200IGW (A13), B777-300 (A14), B787-10 (A15), B777-9X (A16), DC10-30 (A17), MD-11(A18), L1011-100 (A19), Il-86 (A20), Il-96-300 (A21), and Il-96M (A22) aircraft, respectively.

3.2 Criteria Importance Through Inter-criteria Correlation (CRITIC) Approach

The primary goal of the CRITIC approach is to determine the objective weights assigned to the considered criteria. This method operates on the fundamental principle of measuring conflicts through statistical data, as established by Diakoulaki in 1995 [49]. The CRITIC approach offers weight priorities based on conflict measures, particularly utilizing the standard deviation for each criterion. The formulation of objective weights involves four key steps:

Step 1: Create a Decision criteria matrix. The process commences with the creation of a decision criteria matrix. This matrix, tailored for wide-body aircraft, is a fusion of alternatives and criteria integral to aircraft design. In this problem statement, there are m = 1, 2, 3, . . . , 22 different alternatives with n = 1, 2, 3, ..., 13 different criteria. A generic equation (3.1) of criteria-decision matrix 'D' is expressed as

$$.D_{m\times n} = \begin{bmatrix} D_{11} & D_{12} & \dots & D_{1n} \\ D_{21} & D_{22} & \dots & D_{2n} \\ \dots & \dots & \dots & \dots \\ D_{m1} & D_{m2} & \dots & D_{mn} \end{bmatrix} \tag{3.1}$$

Where, 'm' number of alternatives, and 'n' number of criteria.

Step 2: Obtain the Normalized Decision Matrix. The subsequent stage involves acquiring the Normalized Decision Matrix. This is achieved by computing the linear normalized decision matrix, wherein the maximum value corresponds to the benefit, and the minimum value corresponds to the non-benefit. This screening process is applied to the decision matrix Dij through equations (3.2a) and (3.2b) expressed as

$$\overline{N_{ij}} = \frac{D_{ij} - D_{ij,worst}}{D_{ij,best} - D_{ij,worst}} \tag{3.2a}$$

$$\overline{N_{ij}} = \frac{D_{ij,best} - D_{ij}}{D_{ij,best} - D_{ij,worst}} \tag{3.2b}$$

Where i = 1, 2,. . . ., m and j = 1, 2,.., n, by setting the Best and worst parameters.

Table 4 illustrates the normalized decision matrix Nij along with the standard deviation values for each criterion from C1 to C13. The mathematical computation of the standard deviation (σ) is accomplished using MS Excel's STDEVPA function for each criterion.

Table 3. The real-time data acquisition of wide-body aircraft

	C1 FR	C2 AR	C3 MTOW (kg)	C4 $\frac{W_E}{W_{TO}}$	C5 $\frac{W_{PL}}{W_{TO}}$	C6 nPL	C7 W/S (kg/m²)	C8 T/W	C9 R (km)	C10 LTO (km)	C11 Vc (km/hr)	C12 RoC (m/s)	C13 SFC (hr^{-1})
A1	9.45	7.73	170500	0.52	0.316	375	655.769	0.307	7500	2280	897	16.26	0.0125
A2	8.27	8.8	144000	0.551	0.333	275	655.77	0.307	6500	2280	850	15.24	0.0122
A3	12.1	8.5	227703	0.551	0.701	460	657.53	0.307	1333	2280	1005	15.24	0.0186
A4	11.07	9.26	217000	0.544	0.357	440	597.632	0.28	11760	2770	870	10.16	0.0096
A5	11.07	9.26	271000	0.479	0.413	440	746.351	0.22	13700	3000	913	28.96	0.0123
A6	12.34	8.56	365000	0.485	0.423	475	834.667	0.278	14600	3140	915	28.96	0.0097
A7	10.18	7.53	575000	0.482	0.442	853	680.47	0.24	15400	3000	1,099	7.62	0.013
A8	11.91	9.49	280000.3	0.413	0.394	440	633.48	0.273	15000	2600	945	7.62	0.0093
A9	12.11	9.03	286670	0.491	0.385	480	633.48	0.273	16100	2,600	945	15.24	0.0075
A10	10.56	6.96	340195	0.497	0.461	516	665.744	0.250	9800	3246	939	5.08	0.018
A11	10.56	6.96	377840	0.465	0.427	516	739.413	0.255	12700	3200	969	5.08	0.013
A12	10.56	7.39	396830	0.457	0.407	660	755.867	0.259	13450	3310	933	7.62	0.0111
A13	10.13	8.67	286897	0.481	0.466	440	670.634	0.265	14000	2438	950	15.24	0.0121
A14	11.75	8.67	299370	0.521	0.452	550	699.789	0.288	11165	3230	950	15.24	0.0136
A15	11.83	9.59	254011	0.533	0.399	440	673.7	0.273	11750	2800	954	15.24	0.0121
A16	12.38	9.96	352441.27	0.511	0.451	426	682.1	0.270	20372	3000	1034.81	15.24	0.0086
A17	8.63	6.91	263636	0.461	0.414	380	716.99	0.273	9630	3000	981.56	10.16	0.0157
A18	9.74	7.91	283720	0.473	0.424	405	837.18	0.295	13408	3139	961	10.16	0.0105
A19	8.94	6.97	211374	0.529	0.374	400	657.46	0.271	6667	2350	957	14.224	0.0202
A20	9.23	7.22	208000	0.4	0.4324	350	650	0.245	10000	2700	869	15	0.0153
A21	8.41	7.89	216000	0.542	0.551	300	650	0.245	11500	2400	850	15	0.014
A22	9.95	7.89	270000	0.49	0.44	375	650	0.25	10000	2600	870	15	0.0157

Table 4. Normalized the decision matrix on benefit and non-benefit criteria

Alternative	Criteria												
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
A1	0.713	0.731	0.606	0.205	1.000	0.827	0.757	0.000	0.676	1.000	0.811	0.532	0.939
A2	1.000	0.380	0.630	0.000	0.956	1.000	0.757	0.000	0.729	1.000	1.000	0.575	1.000
A3	0.068	0.479	0.126	0.000	0.000	0.680	0.750	0.000	1.000	1.000	0.378	0.575	0.806
A4	0.319	0.230	0.835	0.046	0.894	0.715	1.000	0.318	0.452	0.524	0.920	0.787	0.831
A5	0.319	0.230	0.622	0.477	0.748	0.715	0.379	1.000	0.350	0.301	0.747	0.000	0.705
A6	0.010	0.459	0.827	0.437	0.722	0.654	0.010	0.362	0.303	0.165	0.739	0.000	0.487
A7	0.535	0.797	0.567	0.457	0.673	0.000	0.654	0.757	0.261	0.301	0.000	0.894	0.000
A8	0.114	0.154	0.858	0.914	0.797	0.715	0.850	0.432	0.282	0.689	0.618	0.894	0.684
A9	0.066	0.305	1.000	0.397	0.821	0.645	0.850	0.432	0.224	0.689	0.618	0.575	0.669
A10	0.443	0.984	0.173	0.358	0.623	0.583	0.716	0.712	0.555	0.062	0.643	1.000	0.545
A11	0.443	0.984	0.567	0.570	0.712	0.583	0.408	0.657	0.403	0.107	0.522	1.000	0.457
A12	0.443	0.843	0.717	0.623	0.764	0.334	0.339	0.599	0.364	0.000	0.667	0.894	0.413
A13	0.547	0.423	0.638	0.464	0.610	0.715	0.695	0.521	0.335	0.847	0.598	0.575	0.668
A14	0.153	0.423	0.520	0.199	0.647	0.524	0.574	0.240	0.484	0.078	0.598	0.575	0.640
A15	0.134	0.121	0.638	0.119	0.784	0.715	0.682	0.431	0.453	0.495	0.582	0.575	0.745
A16	0.000	0.000	0.913	0.265	0.649	0.739	0.647	0.464	0.000	0.301	0.258	0.575	0.516
A17	0.912	1.000	0.354	0.596	0.745	0.818	0.502	0.419	0.564	0.301	0.472	0.787	0.722
A18	0.642	0.672	0.764	0.517	0.719	0.775	0.000	0.149	0.366	0.166	0.554	0.787	0.676
A19	0.837	0.980	0.000	0.146	0.849	0.784	0.750	0.459	0.720	0.932	0.570	0.617	0.844
A20	0.766	0.898	0.386	1.000	0.698	0.870	0.781	0.716	0.545	0.592	0.924	0.585	0.852
A21	0.966	0.679	0.488	0.060	0.390	0.957	0.781	0.716	0.466	0.883	1.000	0.585	0.833
A22	0.591	0.679	0.354	0.404	0.678	0.827	0.781	0.716	0.545	0.689	0.920	0.585	0.708
σ	0.316	0.308	0.253	0.266	0.198	0.206	0.250	0.262	0.205	0.336	0.237	0.251	0.209

Step 3: Evaluate the correlation relation Matrix. Assessing the correlation coefficient relation matrix rij of each criterion is conducted using the MS Excel operator CORREL.

Step 4: Measures of conflict index (Ij) and weights (Wj). In this step, the determination of the conflict index Ij and objective weights Wj is undertaken to establish the weightage assigned to each criterion. This calculation is carried out using equations (3.3) and (3.4) presented in Table 5. Notably, the analysis reveals that aerodynamic considerations contribute 17.78 percent, structural considerations contribute 27.37 percent, performance has an impact of approximately 33.11 percent, and operational factors contribute 21.73 percent.

$$I_j = \sigma \sum_{j=1}^{n} (1 - r_{ij}) \tag{3.3}$$

$$W_j = \frac{I_j}{\sum_{j=1}^{n} I_j} \tag{3.4}$$

3.3 Multi-Object Optimization on the basis of Ratio Analysis (MOORA) Approach

Multi-Objective Optimization on the basis of Ratio Analysis [19], is a decision-making technique within the realm of multi-criteria decision analysis (MCDA). Its purpose is to assess and order alternative solutions or options by considering a set of diverse and conflicting criteria or objectives. MOORA finds application in various domains, including engineering, management, economics, and other fields where decision-making demands the consideration of multiple factors. MOORA offers to enable decision-makers to concurrently assess multiple criteria and adopt a systematic approach to evaluate and rank alternatives. Nevertheless, it is crucial to emphasize that the method heavily depends on accurately determining weights, and its sensitivity to changes in these weights should be noted. Moreover, MOORA assumes criteria independence, which may not always align with the interdependencies observed in real-world scenarios. This approach portrays a benefit in rank accuracy, rationality, and practicality preceded by basic four steps are as follows:

Step 1: Identification of Criteria: The first step involves identifying the criteria or objectives that are relevant to the decision-making process. These criteria should be measurable and represent different aspects of the problem are described in Table 4.

Table 5. Compute the Index and weights for wide-body aircraft

Notations		Standard deviation (σ)	Conflict index (Ij)	Objective weights (Wj)	Objective Weight percent(%)
C1	FR	0.316	2.993	0.082	8.171
C2	AR	0.308	3.519	0.096	9.609
C3	MTOW (kg)	0.209	2.957	0.081	8.073
C4	WE/WTO	0.266	3.305	0.090	9.02
C5	WPL/WTO	0.198	2.212	0.060	6.039
C6	nPL	0.206	2.044	0.056	5.581
C7	W/S(kg/m^2)	0.250	2.659	0.073	7.262
C8	T/W	0.262	3.417	0.093	9.331
C9	R (km)	0.205	2.271	0.062	6.200
C10	STO (km)	0.336	3.478	0.095	9.496
C11	Vc (km/hr)	0.237	2.271	0.062	6.201
C12	RoC (m/s)	0.251	3.033	0.083	8.282
C13	SFC(km/hr/N)	0.253	2.465	0.067	6.730

Step 2: Weighted Normalization of Criteria: The criteria are often measured in different units and scales. To make them comparable, the first normalization is performed. This step ensures that all criteria are on a similar scale, typically between 0 and 1 using the normalized equation (3.5) as expressed as

$$Dij^* = \frac{D_{ij}}{\sqrt{\sum_{j=1}^{n} {D_{ij}}^2}} \tag{3.5}$$

Furthermore, weights (Wj) of each criterion are assigned to each criterion based on their importance. The decision-maker can provide these weights, or they can be determined through a more systematic approach, such as using the CRITIC approach. Aggregated scores are computed for each alternative by combining the normalized performance values and their corresponding weights. This is typically done using weighted sum or weighted product methods. In order to obtain the weighted normalized matrix, equation (3.6) is utilized and tabulated.

$$\overline{W_{ij}} = W_j \times {D_{ij}}^* \tag{3.6}$$

Step 3: Determine Ratio Analysis. In the Ratio System approach of the MOORA (Multi-Objective Optimization by Ratio Analysis) method, the importance assigned to objectives plays a crucial role in shaping the evaluation process. This method involves assigning weightage or significance to different objectives based on their importance in the decision-making process. The modification in this approach primarily involves adjusting the ratios assigned to each criterion, reflecting the relative importance of these criteria in achieving the overall objectives.

In other words, the significance of each criterion is considered, and the ratios are adjusted accordingly to reflect the priority or emphasis placed on specific objectives using the equation (3.7) as

$$Y_j = \sum_{i=1}^{g} \overline{W_{ij}} - \sum_{i=1}^{h} \overline{W_{ij}} \tag{3.7}$$

The optimization problem involves a set of objective criteria where some are to be maximized (g criteria) and others are to be minimized (h = n - g criteria). The final predilection value is calculated by considering the criteria to be maximized and minimizing the impact of the criteria to be

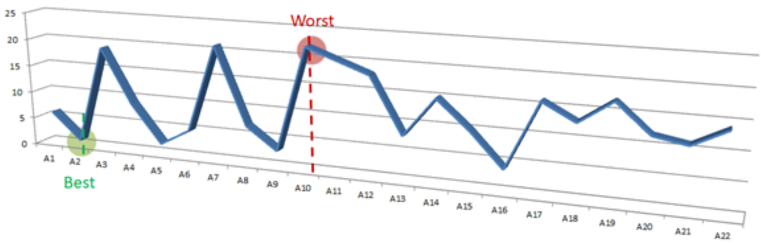

Figure 6. Performance score of the best and worst MoM aircraft

minimized. This formulation is common in Multi-Criteria Decision-Making (MCDM) problems where decision-makers need to balance competing objectives, some of which are desirable to maximize, while others are desirable to minimize. Finally, The alternative with the highest score is considered the most favorable one as shown in Figure 6.

A hybrid MOORA (Multi-Objective Optimization by Ratio Analysis) Multi-Criteria Decision-Making (MCDM) technique is utilized to assess and rank alternatives based on multiple criteria. In the context of selecting wide-body aircraft, the application of the MOORA method involves a systematic process to determine the relative performance of different aircraft options elaborate on the context: Airbus A310-200 > Airbus A340-300 > Airbus A350-1000 > Boeing B777-9x > Airbus A340-600 > Airbus A300-600R > Airbus A350-900 > Boeing B777-200IGW > Airbus A330-300 > Boeing B787-10 > Ilyushin Il-96-300 > Ilyushin Il-86 > Mc Douglus MD-11 > Ilyushin Il-96M > Boeing B777-300 > Douglus DC10-30 > Lockheed Martin L1011-100 > Boeing B747-400 > Airbus A330-900N > Boeing B747- 200 > Airbus A380-800 > Boeing B747-100.

i.e., A2 > A5 > A9 > ….. > A7 > A10.

Hence, the Airbus A310-200 is the best wide-body aircraft, and second best wide-body aircraft is considered as Airbus 340-300 model, and the worst wide-body considered as Boeing B747-100 model.

4 Results and Discussions

The section practicality shows the proposed CRITIC-MOORA MCDM approaches are utilized in assessing wide-body aircraft. The CRITIC method is employed to interpret design parameters and configurations, determining the weights of thirteen different objective criteria (C1 to C13). The focus is on elucidating the significance of each criterion in aircraft design. According to the CRITIC method, the Aspect Ratio (C2) is identified as the pivotal design consideration, followed by take-off distance (C10), thrust-to-weight ratio (C8), empty weight fraction (C4), and other parameters. This objective order is crucial in understanding the hierarchy of importance in achieving optimal aircraft performance. Table 8 represents the importance of objective criteria, emphasizing the critical role of design parameters as C2 > C10 > C8 > C4 > C12 > C1 > C3 > C7 > C13 > C11 > C5 > C6. The objective weights signify the relative importance of various aircraft performance parameters, providing insights into the intricacies of aircraft design.

The paper effectively distinguishes the variables that affect the design of aircraft, providing a comprehensive comprehension of the criteria that are considered. Looking ahead, the paper intends to ascertain the position of alternative wide-body aircraft by utilizing the hybrid MOORA method outlined in equation (12). This method uncovers that the Airbus A310-200 (A2) is the most desirable alternative while the Boeing B747-100 (A10) is the least desirable alternative based on the aforementioned objectives. The MOORA MCDM method corroborates these findings, demonstrating that the Airbus A310-200 (A2) attains the highest position among wide-body aircraft, thereby showcasing its superiority in fulfilling the established criteria. Conversely, the Boeing B747-100 (A10) is identified as the least favorable option, aligning with the assessment of the aforementioned objectives. Overall, this section successfully navigates through the

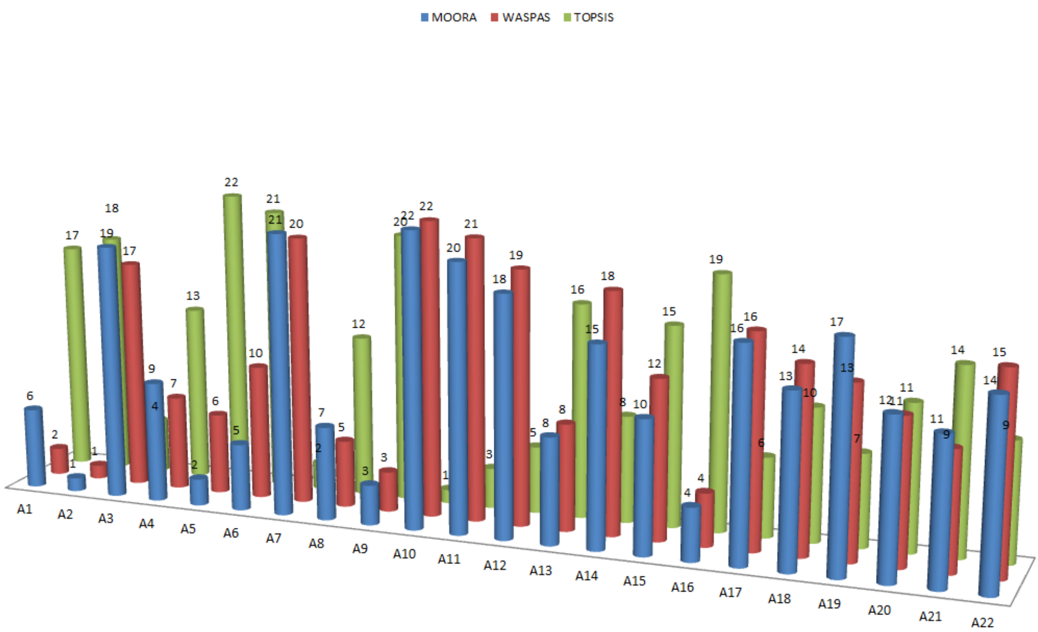

Figure 7. Rank analysis through various MCDM Approaches

CRITIC and MOORA methodologies, shedding light on the significance of design criteria in wide-body aircraft. The ranking of alternatives, with a particular emphasis on the superiority of the Airbus A310-200 and the inferiority of the Boeing B747-100, underscores the practical application and effectiveness of the proposed CRITIC-MOORA approach in the evaluation and optimization of wide-body aircraft designs.

The objective of the conducted investigation is to evaluate the level of accuracy in ranking achieved by the MOORA method in comparison to other MCDM techniques, specifically WASPAS and TOPSIS. The focus of this investigation is to compare the rank orders obtained from MOORA, WASPAS, and TOPSIS, without altering the weight distribution obtained from the CRITIC method. Figure 7 illustrates the rank orders of the aircraft alternatives using three distinct approaches - MOORA represented by blue bars, WASPAS by orange bars, and TOPSIS by grey bars. Notably, A2 (Airbus A310-200) consistently obtains the first rank order across the majority of the approaches, particularly in MOORA and WASPAS. Conversely, A10 (Boeing B747-100) tends to be consistently ranked as the least preferred aircraft among the alternatives. In order to further evaluate the accuracy of these rank orders, the research extends to computing error metrics among the methods. The evaluation of error is crucial in identifying the extent of variation between the predicted and actual ranks. The Symmetric Mean Absolute Percentage Error (sMAPE) is selected as the error metric and is represented by Equation (4.1).

$$sMAPE = \frac{1}{n}\sum_{a=1}^{b}\frac{|A_a - O_a|}{\left(\frac{A_a - O_a}{2}\right)} \tag{4.1}$$

Where Aa is the values related to the MOORA parameter, Oa is the other MCDM methods, and n is the number of alternatives considered. (n = 1, 2,. . . ,22).

The sMAPE is used as a metric to assess the accuracy of the MCDM techniques in predicting the rank orders of the aircraft alternatives, by measuring the percentage difference between the forecasted and actual ranks and considering the magnitude of the ranks. This error metric enables a comprehensive assessment of the accuracy of the MCDM techniques in predicting the rank orders of the aircraft alternatives.

According to the study contributed by Lewis [50] and Flores [51], the approaches evaluate the accuracy of MCDM techniques, specifically focusing on the Symmetric Mean Absolute Percentage Error (sMAPE) and its interpretation based on percentile values. As per sMAPE of less than 10 percent is highly accurate, while a range of 10 to 20 percent indicates good accuracy, 20 to 50 percent suggests moderate accuracy, and beyond 50 percent suggests weak accuracy. The research encompasses two distinct comparative studies such as CRITIC-WASPAS (Case 1) and CRITIC-TOPSIS (Case 2) among MCDM techniques, as shown in Figure 8. In Case 1, the comparison between MOORA and WASPAS indicates agreement in the top best alternative rank, but disparity in the top worst alternative rank. However, the sMAPE error metric is less than 20 percent, indicating good accuracy. In Case 2, the contrast between MOORA and TOPSIS reveals differences in ranks for both the best and worst alternatives. The error metric in this scenario exceeds 20 percent, classifying it as having moderate accuracy. The results highlight the significance of not only comparing the rank orders but also considering the associated error metrics to provide a comprehensive evaluation of accuracy. The overall findings, based on the sMAPE, suggest that MOORA, and WASPAS methods demonstrate higher accuracy compared to the TOPSIS approach. This implies that the former set of methods is more reliable in predicting rank orders for the given set of alternatives. These results have significant implications for designers, engineers, decision-makers, and anyone involved in the managerial aspects of aircraft selection. The insights provided by the study can guide the implementation of new design technologies to enhance flight performance and fuel efficiency. Overall, this research contributes valuable information for decision-making in the aviation industry.

4.1 Contrast between the proposed model over CRITIC-WASPAS and CRITIC-TOPSIS

The section presents a comparison between the well-established Multiple Criteria Decision-Making (MCDM) method TOPSIS and the advanced MOORA method, with specific emphasis on the CRITIC variant. The formulation of the approach and the resulting ranks achieved by each alternative using these methods are meticulously scrutinized in Table 13. Notably, a common pattern emerges in the ranking order of the alternatives, which include A2, A10, A13, A16, and A17. The findings demonstrate that in both the CRITIC-MOORA and CRITIC-WASPAS methods, the Airbus A310-200 (A2) is consistently ranked as the top alternative, while the Boeing 747-100 (A10) consistently secures the lowest rank, as detailed in Table 9. Conversely, the CRITIC-TOPSIS method positions the Boeing 747-100 (A10) as the best alternative and the Airbus A350-900 (A5) as the worst.

An evaluation through the lens of market analysis reveals that the Airbus A350-900 (A5) demonstrates superior economic competitiveness due to its features such as raked wingtips, streamlined nacelle, and empennage, which contribute to enhanced aerodynamic efficiency and overall performance. It is worth noting that the report highlights the fuel efficiency of innovative technologies like raked winglets compared to sharklet-type winglets. Projections indicate that progressive advancements in aerodynamic accessories will substantially enhance fuel economy by 2030. Research data focusing on the Airbus A310-200 (A2) and Boeing 747-100 (A10) models indicates that the Boeing 747-100 (A10) is currently grounded, aligning with market dynamics. This underscores the accuracy of the CRITIC-MOORA method over the CRITIC-TOPSIS method. Recent news further supports this observation, as it reports the grounding of the Boeing B757-300 (A8) and plans for its replacement, significant disparities in results when implementing the TOPSIS method.

4.2 Managerial Insights

Based on the proposed research utilizing the CRITIC-MOORA approach, is considered more precise in reflecting market dynamics compared to the TOPSIS method. Looking forward in the aviation or air transportation sector, daily new aircraft design is coming-up into the market in order to improve airlines profitability and reducing environmental impacts [41]. These benefits can be contributed through aerodynamic contribution, structural contributions and results effective performance of an aircraft [37] [38] [39]. The Airbus A310-200 (A2) consistently emerges as the top choice among the considered wide-body aircraft alternatives. Interestingly, this research proven that by applying CRITIC-WASPAS method ranks the Boeing 747-100 (A10) as the worst alternative, while the CRITIC-TOPSIS method places the Airbus A350-900 (A5) in that position. The fact that the top three aircraft are all wide-body configurations suggests a common factor in-

Alternatives	Aircraft Models	CRITIC-MOORA	CRITIC-TOPSIS
A1	A300-600R	6	17
A2	A310-200	1	18
A3	A330-900N	19	4
A4	A330-300	9	13
A5	A340-300	2	22
A6	A340-600	5	21
A7	A380-800	21	2
A8	A350-900	7	12
A9	A350-1000	3	20
A10	B747-100	22	1
A11	B747-200	20	3
A12	B747-400	18	5
A13	B777-200IGW	8	16
A14	B777-300	15	8
A15	B787-10	10	15
A16	B777-9X	4	19
A17	DC10-30	16	6
A18	MD-11	13	10
A19	L1011-100	17	7
A20	Il-86	12	11
A21	Il-96-300	11	14
A22	Il-96M	14	9

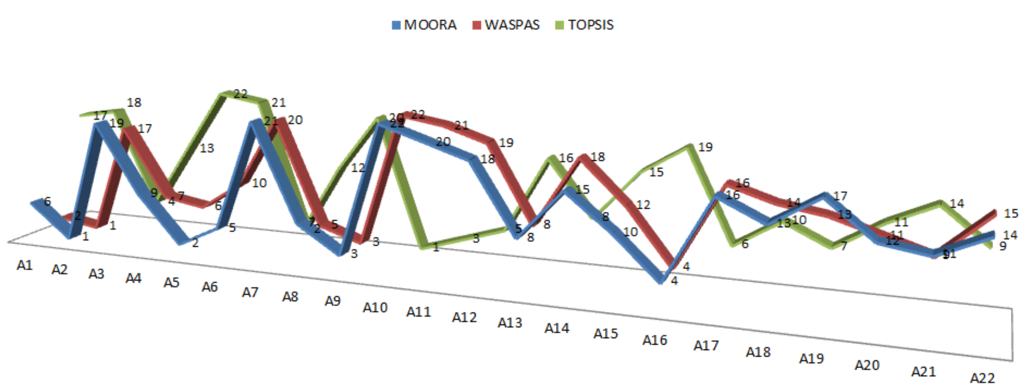

Figure 8. Sensitivity analysis using sMAPE

fluencing their rankings. This proposed method is very effective for aircraft owners [24] [25],and airport operations [23] before regulating into their countries. There are numerous studies have focused on aircraft evaluation for purchasing, and ground operations performance such as airlines, airports, air traffic management, and aircraft manufacturers [20] [31] [52],can benefited from the proposed methodology.

5 Conclusion remarks

The article presents an innovative Multi-Criteria Decision Making (MCDM) methodology for the choice of wide-body aircraft. It addresses the challenges found in existing literature concerning decision support in the aerospace industry. The study focuses on technical design and operational missions, with the goal of identifying the most suitable wide-body aircraft based on thirteen criteria. While the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method is commonly used for such selections, this research identifies limitations in its accuracy. As a solution, it proposes a hybrid decision-making approach that integrates CRITIC and MOORA techniques. A comparative analysis between the proposed hybrid method and the CRITIC-TOPSIS method demonstrates the superior accuracy of the proposed approach, particularly when compared to market statistics of wide-body aircraft. The objective weights, which are crucial in the decision-making process, are derived from the CRITIC approach. Among the four core factors considered, the operational mission is identified as the most significant criterion. The criteria related to aircraft operations exhibit a strong correlation with advancements in aerodynamic accessories and efficient engines. The investigation validates the proposed approach by comparing it with WASPAS and TOPSIS using Symmetric Mean Absolute Percentage Error (sMAPE) metrics. The combination of Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) with WASPAS demonstrates moderate accuracy compared to other methods. Importantly, the study identifies the Airbus A310-200 (A2) as the best alternative and the Boeing 747-100 (A10) as the worst alternative. This finding highlights the potential for design technology advancements to enhance fuel economy and economic competitiveness. The research acknowledges the limitations of the proposed framework and suggests considering more complex issues in aerospace and industrial engineering. It emphasizes the effectiveness of the proposed method in addressing real-time problems while recognizing the emergence of more sophisticated MCDM approaches, particularly those designed for uncertain environments such as fuzzy-TOPSIS and fuzzy-ELECTRE. In the future, the article suggests extending the proposed method by integrating fuzzy and neutrosophic set theory to handle uncertainties in criteria like speed, range, Maximum Takeoff Weight (MTOW), fuel consumption, and cost. This extension could contribute to a more robust decision-making process, especially when dealing with diverse types of aircraft, including transport, fighter, military, Unmanned Aerial Vehicle (UAV), and regional aircraft. The article highlights the potential benefits of combining Multiple Objective Optimization approaches with advanced methodologies, such as neutrosophic MCDM [53] or hybrid methods [52] [54] [55] [56] , for wide-body aircraft selection and evaluation.

References

[1] Dhara,A., Kishan,P.M., *Aircraft Design Guidebook for Freshman*,**1st Ed.**, Wings of AERO, (2019).

[2] Cai, Y., Rajaram, D., Mavris, D. N., *Simultaneous aircraft sizing and multi-objective optimization considering off-design mission performance during early design*, Aerospace Science and Technology, **126**, 107662,(2022).

[3] Ostrower, J. (2011). Boeing rules out 757-sized replacement for new narrowbody. Flight International, May 25.

[4] Arkell, D. (2003). Moving toward the middle. Frontiers Magazine. Boeing.

[5] Flottau, J. (2017). Emirates Considers Boeing's Midsize Aircraft 'A Winner. Aviation Daily. Aviation Week, March 9.

[6] IATA (2020a). Aircraft Technology Roadmap to 2050.

[7] Ozdemir, Y. & Basligil, H. (2016). Aircraft selection using fuzzy ANP and the generalized choquet integral method: The Turkish airlines case. Journal of Intelligent and Fuzzy Systems, 31(1), 589-600.

[8] Dozic, S., Lutovac, T., Kalić, M. (2018). Fuzzy AHP approach to passenger aircraft type selection. Journal of Air Transport Management, 68, 165–175. doi:10.1016/j.jairtraman.2017.08.003.

[9] Dozic, Kalić, (2015). Comparison of Two MCDM Methodologies in Aircraft Type Selection Problem. Transportation Research Procedia, 10, 910–919.

[10] Dozic, S., Kalić, M. (2014). An AHP Approach to Aircraft Selection Process. Transportation Research Procedia, 3, 165–174. doi:10.1016/j.trpro.2014.10.102

[11] Bhadra, D., & Dhar, N. R. (2022). Selection of the natural fiber for sustainable applications in aerospace cabin interior using fuzzy MCDM model. Materialia, 21, 101270.

[12] Deveci, M., Oner, S.C., Ciftci, M.C., Ozcan, E. & Pamucar, D. (2021). Interval type-2 hesitant fuzzy Entropy-based WASPAS approach for aircraft type selection. Applied Soft Computing, 114,108076.

[13] Kiraci, K., & Akan, E. (2020). Aircraft selection by applying AHP and TOPSIS in interval type-2 fuzzy sets. Journal of Air Transport Management, 89, 101924.

[14] Dhara, A, Kaur, G, Kishan, P.M., Majumder, A., & Yadav, R., (2021). An Efficient Decision Support System for Bizjet in CRITIC-TOPSIS Method. Aircraft Engineering and Aerospace Technology. doi:10.1108/AEAT-04-2021-0135.

[15] Yilmaz, A.K., Malagas, K.N., Jawad,M., Nikitakos, N. (2020). Aircraft selection process with Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and AHP Integration. International Journal of Sustainable Aviation, 6(3).

[16] Barak, S., & Dahooei, J.H., (2018). A novel hybrid fuzzy DEA-Fuzzy MADM method for airlines safety evaluation. Journal of Air Transport Management. 73, 134–149.

[17] Schwening, G.S., & Abdalla, A.M., ´ 2014. Selection of agricultural aircraft using AHP and TOPSIS methods in fuzzy environment. 29th Congress of the International Council of the Aeronautical Sciences, p. 0875.

[18] Sun, X., Gollnick, V., & Stumpf, E. (2011). Robustness Consideration in Multi-Criteria Decision Making to an Aircraft Selection Problem. Journal of Multi-Criteria Decision Analysis, 18(1-2), 55–64. doi:10.1002/mcda.471.

[19] Brauers, W. K., & Zavadskas, E. K. (2006). The MOORA method and its application to privatization in a transition economy. Control and cybernetics, 35(2), 445-469.

[20] Turskis, Z., Antuchevičienė, J., Keršulienė, V., & Gaidukas, G. (2019). Hybrid group MCDM model to select the most effective alternative of the second runway of the airport. Symmetry, 11(6), 792.

[21] Gomes, L. F. A. M., de Mattos Fernandes, J. E., & de Mello, J. C. C. B. S. (2012). A fuzzy stochastic approach to the multicriteria selection of an aircraft for regional chartering. Journal of Advanced Transportation, 48(3), 223–237. doi:10.1002/atr.206.

[22] Kaur, G., Yadav, R. & Majumder, A., (2020). An efficient intuitionistic fuzzy approach for location selection to install the most suitable energy power plant. Journal of Physics: Conference Series, 1531(1), 012057.

[23] Chakraborty, S., Zavadskas, E.K. and Antucheviciene, J. (2015). Applications of WASPAS method as a multi-criteria decision-making tool. Economic Computation and Economic Cybernetics Studies and Research, 49 (1).

[24] Kiraci, K., & Bakir, M. (2018). Application of commercial aircraft selection in aviation industry through multi-criteria decision making methods. Manisa Celal Bayar Üniversitesi Sosyal Bilimler Dergisi, 16(4), 307-332.

[25] Rajurkar, K. S., Khade, S. P., Sawant, O. M., Dobe, M. P., & Kamble, A. G. (2023). Selection of fighter aircraft by using multi attributes decision making methods. International Journal of Process Management and Benchmarking, 14(4), 460-477.

[26] Abdulvahitoğlu, A., Abdulvahitoğlu, A., & BAŞBOĞA, Ö. (2022). UAV Selection with MULTIMOORA Method: An International Comparison. 4th International Conference on Applied Engineering and Natural Sciences.

[27] Karamaşa, Ç., Karabasevic, D., Stanujkic, D., Kookhdan, A., Mishra, A., & Erturk, M. (2021). An extended single-valued neutrosophic AHP and MULTIMOORA method to evaluate the optimal training aircraft for flight training organizations. FACTA UNIVERSITATIS-SERIES MECHANICAL ENGINEERING, 19(3).

[28] Kumar, P., & Tiwari, A. (2021). MCDM-Based Decision Support System for Product Design and Development. Design for Tomorrow—Volume 2: Proceedings of ICoRD 2021, pp. 575-584. Springer Singapore.

[29] Aydin, S. and Yörükoğlu, M., 2018. Ground handling services firm evaluation based on neutrosophic MULTIMOORA method. In Data Science and Knowledge Engineering for Sensing Decision Support: Proceedings of the 13th International FLINS Conference (FLINS 2018) (pp. 1050-1057).

[30] Yang, X., Lin, X. and Jiang, L., 2020, October. Evaluation of civil aircraft safety status based on index fuzzy segmentation and MULTIMOORA. In 2020 IEEE 2nd International Conference on Civil Aviation Safety and Information Technology (ICCASIT (pp. 734-739). IEEE.

[31] Hamurcu, M., & Tamer, E. R. E. N. (2021). Selection and Ranking of the Most Suitable Drones for Sustainable Traffic Management Using Multi-Criteria Analysis Approach.

[32] Güler, M.A., 2022. Evaluation of the Performance of Armored Military Vehicles by the Global Fuzzy MULTIMOORA Method. Journal of Optimization and Decision Making, 1(1), pp.28-41.

[33] Boopathi, S., (2022). Experimental investigation and multi-objective optimization of cryogenic Friction-stir-welding of AA2014 and AZ31B alloys using MOORA technique. Materials Today Communications, 33, p.104937.

[34] Abbasi, S. and Peerzada, M., (2023). Rapid cure composites used in aerospace industry. Rapid Cure Composites. pp. 213-223. Woodhead Publishing.

[35] Paula, A., & Dasb, M. C. (2023). A decision support system for the selection of FDM process parameters using MOORA. Additive Manufacturing (AM).

[36] Anderson, J. D. (2017). Fundamentals of Aerodynamics (6th Ed.), McGraw Hill Education.

[37] Sadraey, M.H. (2017). Aircraft Performance: An Engineering Approach (1st Ed.), CRC Press.

[38] Raymer, D. (2018). Aircraft Design: A Conceptual Approach (6th Ed.), AIAA Education Series.

[39] Roskam, J. (1989). Airplane Design: Preliminary Sizing of Airplanes: Volume 1, Part 8, DARcorporation.

[40] Almussa, N. F., & Almaktoom, A. (2021). The Effects of Reducing Aircraft Weight on Profitability and Fuel Consumption – Palarch's Journal of Archaeology of Egypt/Egyptology, 18(15), 206-214.

[41] Dhara, A., & Lal, J.V.M. (2021). Sustainable Technology on Aircraft Design: A Review. IOP Conference Series: Earth and Environmental Science, 889(1).

[42] Rauscher, M. (1936). Some Secondary Factors Affecting Aircraft Performance. Journal of the Aeronautical Sciences, 3(10), 368–369.

[43] Wright, T. P. (1936). Factors Affecting the Cost of Airplanes. Journal of the Aeronautical Sciences, 3(4), 122–128. doi:10.2514/8.155.

[44] Camilleri, M. A. (2018). Aircraft Operating Costs and Profitability. Travel Marketing, Tourism Economics and the Airline Product (Chapter 12, pp. 191-204). Cham, Switzerland: Springer Nature.

[45] Wesseler, P. (2011). Determination of aircraft life-cycle cost during conceptual design phase, Diploma Thesis, Technische Universität München, Germany.

[46] IATA (2020b). Economic Performance of the Airline Industry.

[47] Lee, J., & Mo, J. (2011). Analysis of Technological Innovation and Environmental Performance Improvement in Aviation Sector. International Journal of Environmental Research and Public Health, 8(9), 3777–3795. doi:10.3390/ijerph8093777.

[48] Hassan, T.H., Sobaih, A.E.E., & Salem, A.E. (2021). Factors Affecting the Rate of Fuel Consumption in Aircrafts. Sustainability, 13, 8066. https://doi.org/10.3390/ su13148066.

[49] Diakoulaki, D., Mavrotas, G., & Papayannakis, L. (1995). Determining objective weights in multiple criteria problems: The CRITIC method. Computers & Operations Research, 22(7), 763–770.

[50] Lewis, C.D. (1982). International and Business Forecasting Methods. Butterworths, London.

[51] Flores, B. E. (1986). A pragmatic view of accuracy measurement in forecasting. Omega, 14(2), 93–98. doi:10.1016/0305-0483(86), 90013-7.

[52] Kulakli, A., & Şahin, Y., A Combined Multi-Criteria Decision Making Approach for Improvement of Airlines' Ground Operations Performance: A Case Study from Türkiye. Systems, 11(8), 421, (2023).

[53] Kaur, G., Dhara, A., Majumder, A., Sandhu, B. S., Puhan, A., & Adhikari, M. S., A CRITIC-TOPSIS MCDM Technique under the Neutrosophic Environment with Application on Aircraft Selection. Contemporary Mathematics, 1180-1203, (2023).

[54] Taghavi M. Aircrafts evaluation for purchasing decision-making using fuzzy MCDM (2024).

[55] Hasan, I., & Raza, A., A Knowledge discovery framework using fuzzy and wavelet methods for multi-criteria ranking. Palestine Journal of Mathematics, 12 (2023).

[56] Arora, H. D., & Naithani, A., An Analysis of Customer Preferences of Airlines by Means Of Dynamic Approach to Logarithmic Similarity Measures for Pythagorean Fuzzy Sets. Palestine Journal of Mathematics, 12(1), (2023).

Author information

A. Dhara, Department of Aerospace Engineering, GNA University, Phagwara, 144401; Department of Aerospace Engineering, Lovely Professional University, Phagwara, 144411, India.
E-mail: dharaaishwarya@gmail.com

J.V.M. Lal Jeyan, Department of Aerospace Engineering, Lovely Professional University, Phagwara, 144411, India.
E-mail: jvmlal@ymail.com

A.K. Thakur, Department of Aerospace Engineering, Lovely Professional University, Phagwara, 144411, India.
E-mail: amitthakur3177@gmail.com