SELECTION OF A FIGHTER AIRCRAFT TO IMPROVE THE EFFECTIVENESS OF AIR COMBAT IN THE WAR ON TERROR: PAKISTAN AIR FORCE - A CASE IN POINT

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ABSTRACT

The selection of military aircraft, by nature, is a process consisting of conflicting goals and objectives at the conceptual, preliminary, and detailed level. In order to ease the process of making decisions wisely from a varied group of options available, Multiple Criteria Decision Making (MCDM) methods are applied effectively. A scenario is put forth pertaining to defense acquisition, when a contemporary air force needs to select and add new and better fighter aircrafts to their pre-existing fleets. This paper studies the Pakistan Air Force (PAF) and its goal to improve its aerial defense and precise ground strike capabilities. Moreover, this paper aims to help raise the bar of general aerial defense and counter terrorism operations. This research paper also sets an appropriate methodological approach for defense procurement and the fleet up-gradation planning process via the use of the Analytic Hierarchy Process (AHP), an MCDM technique. Furthermore, this study specifically focuses on a set of ten technical and economic criteria, applied over six alternative aircraft while, keeping in mind, the counter-insurgency and aerial defense requirements of PAF. Lastly, a Cost Benefit Analysis (CBA) has been applied to ensure that the selected alternative is in line with the economic constraints faced by the limited fiscal budget of Pakistan.

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1. Introduction

The definition of a "good" overall design for a military weapon system almost always depends on one's point of view. From a performance standpoint, necessary important phases are required for an advanced multirole strike aircraft. For example, significant ground attack capability exists in the form of delivering a maximum payload to a target at an appropriate range including some air-to-air capability at certain Mach-altitude combinations. The resulting size and geometry of such an aircraft, however, may result in a poor level of survivability due to increases in their radar and infrared signature. Further, passive improvements in these signatures may dramatically drive up the aircraft cost.

It is predicted that there will be 5% growth per year in commercial aviation over the next 20-25 years (Palut & Canziani, 2007). Usually, most aircraft are expected to have a service time of 30 years or longer, however, there are various uncertainties that can affect the aircraft's feasibility and viability during its service period. For example, fuel prices are always fluctuating and this influences the viability of the aircraft. With advancing technology and political difficulties in the world, tensions between nations are also on the rise. Not only this, but the contours of war have changed over time too. Hence, instead of decisive battles, wars are becoming asymmetric and are being fought under unpredictable circumstances. The enemy is no longer well-defined and the frontlines are not marked. Therefore, armies in great numbers are not sufficient to win wars; instead, it is technology, strategy and diplomacy that can lead to winning wars in this 21st century. Because of the existence of weapons capable of mass destruction, nations cannot afford to go for an all-out war. Thus, to counter these changes and difficulties, surgical strikes are a rapid option that is available with precise measures and policies. At the center of modern warfare lies a country's air force. The air force of a nation serves both as its sword and its shield; thereby, giving a nation the capability to strike its enemy a decisive blow, while protecting it from both retaliation and aggression.

Pakistan is a vulnerable country, easily targeted and prone to attacks. This is evidenced by the fact that just beyond Pakistan's eastern front, lays its neighbor and traditional rival India, with which it has fought four wars in history. Moreover, within its borders Pakistan is faced by the threat of growing radical extremism. Being a nuclear armed nation of 182.1 million[1], it needs to maintain a strong military force to tackle these continuous security challenges. The most crucial asset for Pakistan, in the current era, has been its air force. Over the span of time, Pakistan has faced global sanctions, which has made it unable to upgrade its fleet of aircraft.

At present, the Pakistan Air Force is facing a widespread challenge in the form of radical extremism. This is known to mostly originate from the remote and rugged terrain of the North West Frontier that is inaccessible with rapid-response forces at the ground level. To counter this issue, the PAF needs efficient state-of-the-art aircraft, equipped and fully competent with the latest precision strike technology for

[1] The World Bank 2015 Global Census Data (http://data.worldbank.org/indicator/SP.POP.TOTL)

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targeting its enemies with pin-point accuracy and minimum collateral damage. These aircraft will also be useful in the fleets responsible for countering international security threats.

In general, selection of a combat aircraft is a very complicated matter that is governed by economic, technical and geopolitical constraints. In addition to this, it is necessary for an air force to adhere to its operational and ever-changing defense requirements. Therefore, strategic planning is critical in making an efficient and particular choice.

In the literature review, the aircraft selection process has been performed in various ways, but specifically focuses on civilian applications in which the issue in question is relatively well-explained. However, a novel approach is required when considering military applications.

The implicit purpose of this research paper is to solve the issue regarding selection of aircraft in the Pakistan Air Force. This involves replacing its increasingly aging fleet and matching its requirements to counter terrorist operations while keeping in mind the diplomatic and economic constraints. It is essential not to forget that the problem is the inherent multi-criteria decision making. The Analytic Hierarchy Process (AHP) is used for this purpose to select an appropriate aircraft. AHP has been successfully applied in resource allocation and forecasting. Since aircraft selection is a process which is closely connected to these areas, the use of AHP is reasonable in this case.

The advantage of this decision support tool is that the final ranking is obtained on the basis of pair-wise assessment between the criteria and the alternatives, both of which are selected as part of this study. Additionally, the AHP approach is engaged because its algorithm is rational and easily comprehensible. Further, to ensure that the economic constraints are well accounted for a Cost Benefit Analysis was implemented to the periodic operational and maintenance costs involved in addition to the initial investment. This paper is organized in the following order: literature review, methodology, conclusion, discussion of results and future considerations.

2. Literature review

The Analytical Hierarchy Process was introduced by Thomas Saaty (Saaty, 1990). This method has been applied specifically in various situations, ranging from comprehensive economic studies to very critical defense acquisitions. It has been repeatedly applied on cases pertaining to airline aircraft acquisitions with studies focused on civilian travelling requirements (Bhadra, 2003; Harasani, 2006; Harasani, 2013). It has been used successfully as a measure of decision-making in procurement of defense assets and has been asserted to be a suitable decision making tool for defense acquisitions (Tsagdis, 2008). Henceforth, the aforementioned reference emphasizes the fact that the complexity of the decisions involved in defense asset procurement are due to social disapproval of budget allocation for the defense sector. This further reflected in the solution to this problem by considering the cause, which is the variety of criteria ranging from technical to socio-economic factors.

Multi-criteria decision making (MCDM) is a process that allows one to make decisions in the presence of multiple, potentially conflicting criteria (Hwang & Yoon, 1981; Sen and Yang, 1998). Furthermore, a study that applies the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) to allow for the selection of an optimal training aircraft in an uncertain environment has been further probed in Wang and Chang (2007). AHP has also been used in ill-defined environments with a comparison of the results, attained via TOPSIS, to propose a solution to the air combat effectiveness assessment problem; thus framing it as a multi-criteria decision making (MCDM) case (Wang et al., 2008a,b). A study based on a certain Cost Benefit Analysis application was considered where the said method had been used to allow for the addition of a new fighter aircraft in the Hellenic Air Force (Kyriazis & Salavrakos, 2006). The study, closest to the one presented by the authors of this paper, is the evaluation of military training aircrafts through the combination of multi-criteria decision making with ambiguous logic looking at the Spanish Air Force (Sánchez-Lozano et al., 2015). Hence, this research paper aims to associate the weights to the criteria using AHP and further evaluate it using the TOPSIS method.

It is essential to know that the data set being addressed has not been studied to date. Perhaps, these criteria have been used for the purposes of Pakistan Air Force; however, they have not yet been applied and inspected as a measure of asset procurement by academia. With no more than nine, totally independent alternatives, the usage of AHP may allow for excellent results (Salomon & Montevechi, 2001). This assertion is strongly supported by another study which lays down a comparison between AHP and ANP as options of applicative methods. The study also determines how the complex inter-relation between criterion and alternatives leads to the application of ANP in a certain scenario (Büyükyazıcı &Sucu, 2003). However, the application of ANP, though an exception that it is applicable in our present case, may cause complications in data collection through surveying in addition to the error due to incorrect perception of the questionnaire by the respondent.

Saaty (1980), in his research claimed that if we decide on the available options intuitively we may acquire misleading results since the larger the quantity of options the better the AHP performs. AHP is most useful where teams of people are working on complex problems, especially those with high stakes, involving human perceptions and judgments, whose resolutions have long-term repercussions. It has unique advantages when important elements of the decision are difficult to quantify or compare, or where communication among team members is impeded by their different specializations, terminologies, or perspectives (Stewart & Belton, 2002).

At its simplest, MCDM is a shelter that has all major formal methodologies that require many criteria when making a decision by individuals or even by groups. It originates from operational research and supports a single decision maker making an appropriate decision (Martins & Mendoza, 2006). Hence, the AHP proves to be an important technique in this scenario. While making a decision we need to focus on the purpose of the decision, all the sub criteria for the decision making process and the groups affected by them. AHP is used extensively by leading organizations across the globe (Bhushan & Rai, 2007).

The Department of Defense in the United States uses AHP frequently and extensively to make major decisions including how to distribute their resources across diversified activity areas (Forman & Gass, 2001). Similarly, the General Service Department (GSA) in the U.S used the AHP to decide what kind of new technology initiatives they needed in order to meet the increasing demands while at the Information Technology Conference (Udo, 2000). Apart from governmental organizations, there are many successful examples of AHP use in leading multinationals operating across the globe (Saaty, 2008). In 1998, British Airways employed this method with their

Board of Directors to determine which entertainment system vendor would be the optimum one for their entire fleet of planes (Saaty, 2004). Xerox Corporation used AHP to allocate their billion dollars of funds in research and development projects (Dey, 2002). In 1999, Ford Motor Company used AHP to design a scale for the satisfaction of customers based on the priorities (Saaty, 2008). All of these examples support the reliability of the use of this technique in fighter aircraft selection to improve the effectiveness of air combat in the war on terror.

Thus, AHP provides a convenient solution to be applied on the data set. Moreover, it may be asserted that though publications pertaining to defense assets have been previously published in large numbers, among the ones focusing on aerial defense in the context of Cost-Benefit Analysis assessment, AHP is not highly represented. It may be further noticed that works pertaining to the effectiveness of the air force in the war against terrorism remain alarmingly low and thus, it was difficult to review the literature in this particular context.

3. Methodology

3.1 Analytical Hierarchy Process

The Analytical Hierarchy Process is a powerful and flexible Multi-criteria Decision making tool (MCDM), introduced and developed by Saaty (1990). It involves pair-wise comparisons between a set of alternatives for each criterion. Comparisons are made using a scale of absolute judgments (1, 3, 5, 7, 9), as well as intermediate values between the two judgments that represents the relative measure of one alternative over another with respect to a given criteria (Dožić & Kalić, 2015). By reducing complex decisions to a series of simple comparisons and rankings and then synthesizing the results, the AHP not only helps the analysts arrive at the best decision, but also provides a clear rationale for the choices made (Wang et al., 2008a). Its main steps include:

1. Statement of the goal, decision criteria and alternatives.
2. Development of a pair wise comparison matrix.
3. Development of a standardized/normalized matrix.
4. Development of a priority vector.
5. Computation of the consistency ratio which should be less than 0.1.
6. Development of a priority matrix.

After steps 2 through 5 have been performed for each criterion, the results of step 4 are summarized in a priority matrix by listing the decision alternatives vertically and the criteria horizontally. The column entries are the priority vectors for each criterion.

7. Development of a criteria pair wise development matrix.
8. Development of an overall priority vector.

Multiplying the criteria priority vector (from step 7) by the priority matrix (from step 6) may then be used to determine the overall ranking of alternatives (step 8).

9. Choosing the alternative with the highest rank.

In this study, the goal was to select the best combat aircraft for PAF that has optimal precision striking capability within a limited budget. Wang and Chang (2007) proposed a systematic evaluation model to help the Air Force Academy with selection of an optimal training aircraft, mainly from the perspective of pilot drillmasters and trainees (Dožić & Kalić, 2014). Figure 1 explains the flow of the research.

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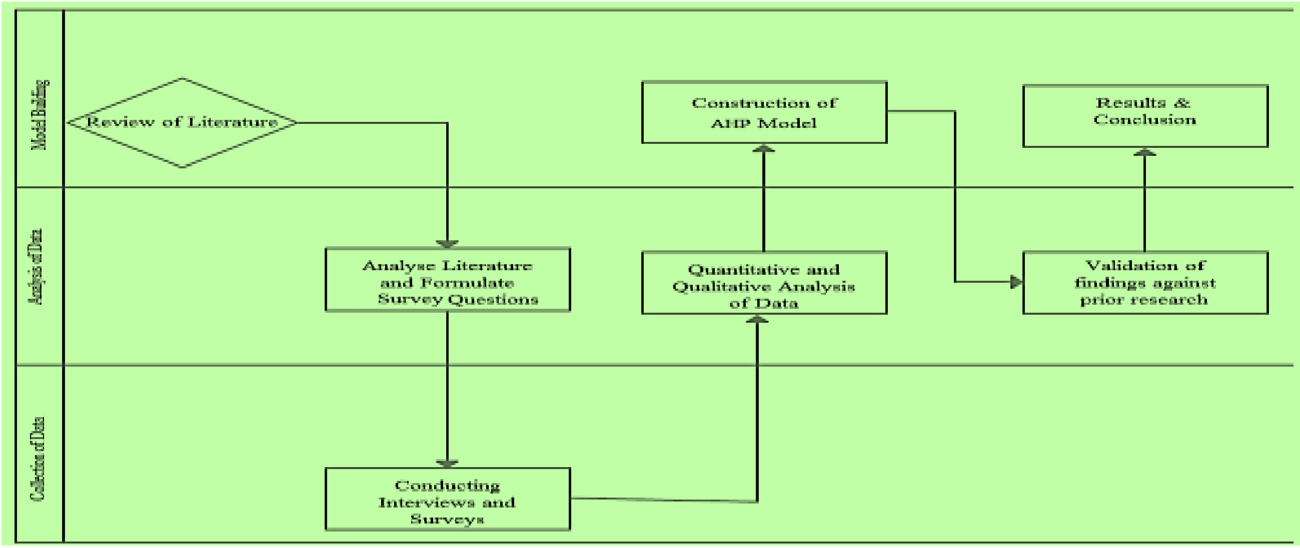

Figure 1. Flow chart of the research

There are three levels of hierarchy and at level one the main goal or objective is to select a fighter aircraft to meet the counterinsurgency and air superiority requirements of the Pakistan Air Force. As such, a similar model, based on the literature review and expert opinions (as shown in Appendix A) was implemented, which made use of a set of the ten most critical and relevant multiple criteria, namely: Service Ceiling, Maximum Take-off Weight (MTOW), Precision Target Capability, Cruising Speed, Maneuverability, Acquisition Cost, Operation Cost, Maintainability and Availability. These are at level 2 of the hierarchy. Of all the current modern combat aircraft, six were shortlisted as decision alternatives, keeping the critical technological requirements of precision target capability and political and financial constraints in view. These are at level three of the hierarchy. The importance of placing political constraints became apparent after a recent occurrence when the U.S. Congress rejected partially financing the sale of eight F-16 aircraft through the Foreign Military Financing program (Syed, 2016). The alternatives chosen were: Dassault Rafale, Saab JAS 39 Gripen, Mikoyan Mig-35, Sukhoi Su-35, Chengdu J-10 and PAC JF-17 Thunder. The hierarchy structure model of the problem is shown in Figure 2.

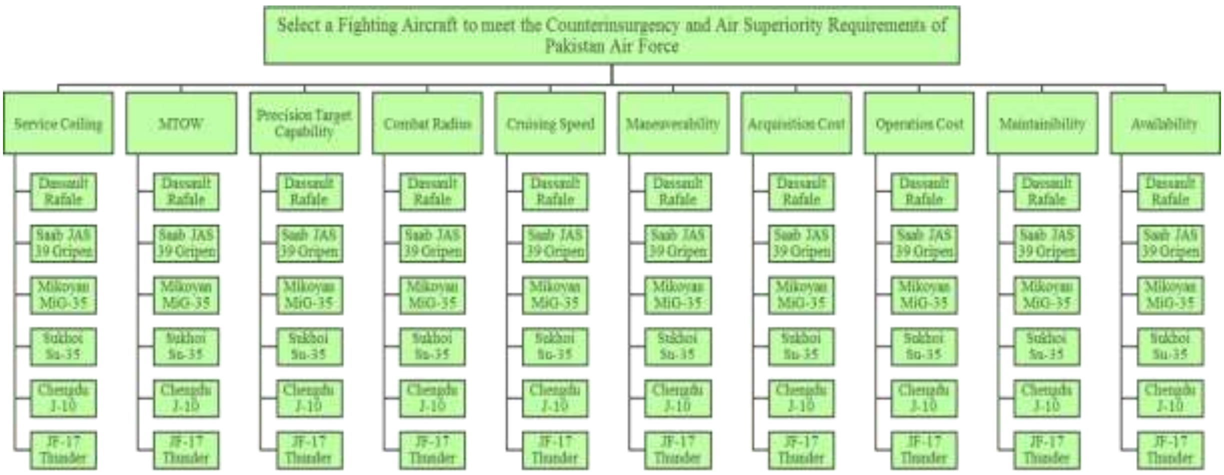

Figure 2. Hierarchy structural model

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In order to develop a pair wise comparison matrix for each criteria (Table 1), a rigorous literature review using manufacturer's web sites and research articles was done in order to collect the relevant technical specifications of each alternative. Those specifications were used to assign values, on the scale of 1 to 9, in pair wise comparison matrix for each criterion.

A Microsoft Excel template for carrying out computations was used (Pyzdek, 2014). Through this template, a normalized matrix (Table 2), priority vector (Table 3) and consistency ratio for each criterion was calculated.

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Table 1
Pair wise comparison matrix for service ceiling

CR Value = 0.004 < 0.1						
Pair wise comparisons						
Item Number	1	2	3	4	5	6
Item Description	Dassault Rafale	Saab JAS 39 Gripen	Mikoyan Mig-35	Sukhoi Su-35	Chengdu J-10	PAC JF-17 Thunder
Dassault Rafale	1.00	1.00000	0.20000	0.20000	0.16667	0.33333
Saab JAS 39 Gripen	1.00	1.00	0.20000	0.20000	0.16667	0.33333
Mikoyan Mig-35	5.00	5.00	1.00	1.00000	0.33333	3.00000
Sukhoi Su-35	5.00	5.00	1.00	1.00	0.33333	5.00000
Chengdu J-10	6.00	6.00	3.00	3.00	1.00	7.00000
PAC JF-17 Thunder	3.00	3.00	0.33	0.20	0.14	1.00
Sum	21.00	21.00	5.73	5.60	2.14	16.67

Table 2
Standardized matrix for service ceiling

Standardized Matrix						
	Dassault Rafale	Saab JAS 39 Gripen	Mikoyan Mig-35	Sukhoi Su-35	Chengdu J-10	PAC JF-17 Thunder
Dassault Rafale	0.05	0.05	0.03	0.04	0.08	0.02
Saab JAS 39 Gripen	0.05	0.05	0.03	0.04	0.08	0.02
Mikoyan Mig-35	0.24	0.24	0.17	0.18	0.16	0.18
Sukhoi Su-35	0.24	0.24	0.17	0.18	0.16	0.30
Chengdu J-10	0.29	0.29	0.52	0.54	0.47	0.42
PAC JF-17 Thunder	0.14	0.14	0.06	0.04	0.07	0.06

Table 3
Priority vector for service ceiling

Alternatives	**Priority Vector**
Dassault Rafale	**0.043935647**
Saab JAS 39 Gripen	**0.043935647**

Mikoyan Mig-35	**0.194122677**
Sukhoi Su-35	**0.214122677**
Chengdu J-10	**0.41951089**
PAC JF-17 Thunder	**0.084372462**

Similar computations were carried out for each of the ten aforementioned criteria and the priority vectors for each criterion were obtained and combined in the form of a priority matrix as shown in Table 4. Conspicuously, the table shows the essential factors while carrying out these calculations for the six mentioned alternatives. This way it is easier to figure out which aircraft would be the most suitable amongst all or which particular feature stands out among other characteristics. For example, from the table we can perceive that the Sukhoi Su-35 has the highest precision target capability rate as compared to the other alternative aircraft, which is estimated to be 0.444 respectively. The data has been compiled in this table which will then shape into a priority matrix.

Table 4
Priority matrix

	Acquisition Cost	Operation Cost	Cruising Speed	Precision Target Capability	Combat Radius	MTOW	Service Ceiling	Maneuverability	Availability	Maintainability
Dassault Rafale	0.024853892	0.042068137	0.043859165	0.257950168	0.040440475	0.165533541	0.043935647	0.106139709	0.055040292	0.117350003
Saab JAS 39 Gripen	0.059670772	0.155277281	0.137430675	0.025935677	0.244689405	0.042697225	0.043935647	0.030107595	0.033615004	0.162488892
Mikoyan Mig-35	0.152929786	0.080478493	0.48754419	0.082711433	0.038079892	0.253810553	0.194122677	0.353267989	0.345335425	0.064605294
Sukhoi Su-35	0.072226552	0.025121824	0.146802014	0.444426704	0.405517136	0.434505123	0.214122677	0.358476322	0.345335425	0.051055158
Chengdu J-10	0.2555856	0.27353918	0.146802014	0.141423021	0.051715962	0.077086391	0.41951089	0.121764709	0.110336926	0.209821978
PAC JF-17 Thunder	0.434733398	0.423515086	0.037561942	0.047552996	0.21955713	0.026367167	0.084372462	0.030243676	0.110336926	0.394678676

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Table 5
Criteria pair wise development matrix

	Service Ceiling	MTOW	PTC	Combat Radius	Cruising Speed	Maneuverability	Acquisition Cost	Operation Cost	Maintainability	Availability
Service Ceiling	1	3	3	3	5	2	2	1	3	2
MTOW	(1/3)	1	2	4	4	2	2	3	2	1
PTC	(1/3)	(1/2)	1	6	7	6	5	4	4	5
Combat Radius	(1/3)	(1/4)	(1/6)	1	5	5	(1/5)	(1/3)	5	3
Cruising Speed	(1/5)	(1/4)	(1/7)	(1/5)	1	3	2	4	4	3
Maneuverability	(1/2)	(1/2)	(1/6)	(1/5)	(1/3)	1	5	4	5	4
Acquisition Cost	(1/2)	(1/2)	(1/5)	5	(1/2)	(1/5)	1	5	7	4
Operation Cost	1	(1/3)	(1/4)	3	(1/4)	(1/4)	(1/5)	1	6	4
Maintainability	(1/3)	(1/2)	(1/4)	(1/5)	(1/4)	(1/5)	(1/7)	(1/6)	1	5
Availability	(1/2)	1	(1/5)	(1/3)	(1/3)	(1//4)	(1/4)	(1/4)	(1/5)	1

In order to acquire data to develop a criteria pair wise development matrix, a questionnaire was carefully designed and dispatched to aviation experts comprised of on-duty, retired PAF officers and aeronautical engineers of varying ranks. Refer to Appendix B for the questionnaire. The challenge was to combine all the questionnaire responses into a single equivalent response so that its data could be used to assign the values, on the scale of 1 to 9, in pair wise comparison matrix between criteria. For each pair wise comparison between one criteria, e.g. between Service Ceiling and Precision Target Capability, the number of responses for each scale value was recorded and plotted on a histogram as shown in Figure 3.

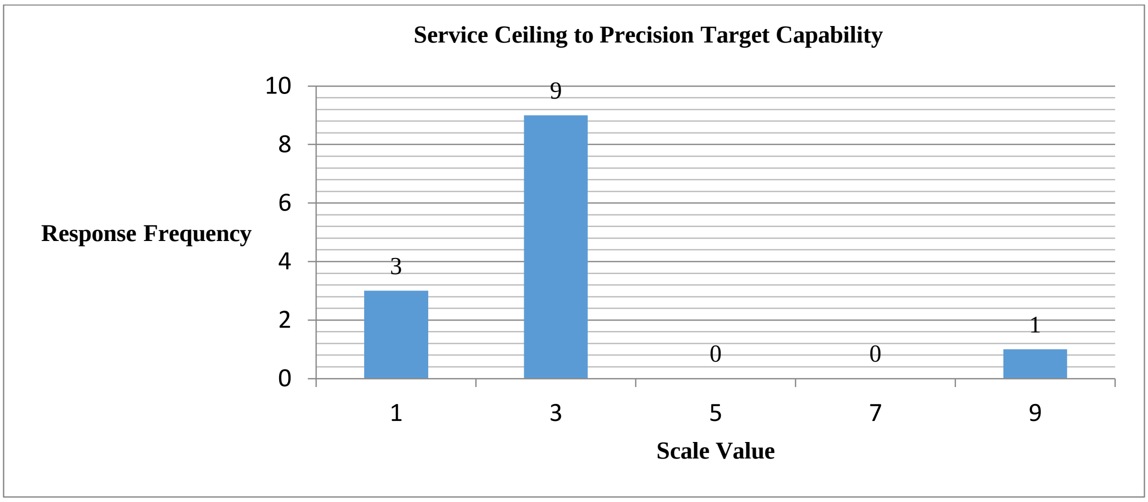

Figure 3. Histogram showing response frequency for service ceiling to precision target capability

A weighted arithmetic mean was calculated to define a scale value for that particular pair wise comparison. Because a weighted arithmetic mean is based on all the observations, determined for almost every kind of data, it is least affected by fluctuations of sampling and is finite and not indefinite. Only the scale values with responses greater than one were considered in the computation of the mean. The mean was chosen as a measure of central tendency to eliminate the error due to incorrect questionnaire perception by the respondent. The expression to evaluate the mean is stated as follows:

$$\text{Weighted Arithmetic Mean} = \left(\frac{\sum(\text{Scale Value} \times \text{Response Frequency})}{\text{Sum of Acceptible Response Frequencies}}\right)$$

For the histogram of pair wise comparison between Service Ceiling and Precision Target Capability, shown in Figure 1, the sample calculation is as follows:

$$\text{Weighted Arithmetic Mean} = \left(\frac{(1 \times 3) + (3 \times 9)}{3 + 9}\right) = 3 \text{ (to the nearest unit)}$$

This procedure was adopted and applied exhaustively for each pair wise comparison as a result of which a criteria pair wise development matrix was developed as shown in Tables 5 and 6.

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Moreover, Table 5 depicts that the factual data has been computed and blended in a pair mode to form a development matrix of the above mentioned criteria, giving us a clear view of the facts. Table 6 also contains a section of sum total of all the descriptive values significantly. The highest value of the sum total is seen to be under the maintainability column which shows a value of 37.20. The table also highlights those figures which are above the range of the staircase of 1.00 figures. Additionally, the lowest value of the sum of 5.03 is seen under the service ceiling column.

Table 6
Criteria pair wise development matrix in MS Excel template

CR Value = 0.048 < 0.1										
Pair wise comparisons										
Item Number	1	2	3	4	5	6	7	8	9	10
Item Description	**Service Ceiling**	**MTOW**	**PTC**	**Combat Radius**	**Cruising speed**	**Maneuverability**	**Acquisition Cost**	**Operation Cost**	**Maintainability**	**Availability**
Service Ceiling	1.00	3.000	3.000	3.000	5.000	2.000	2.000	1.000	3.000	2.000
MTOW	0.33	1.00	2.000	4.000	4.000	2.000	2.000	3.000	2.000	1.000
PTC	0.33	0.50	1.00	6.000	7.000	6.000	5.000	4.000	4.000	5.000
Combat Radius	0.33	0.25	0.17	1.00	5.000	5.000	0.200	0.333	5.000	3.000
Cruising Speed	0.20	0.25	0.14	0.20	1.00	3.000	2.000	4.000	4.000	3.000
Maneuverability	0.50	0.50	0.17	0.20	0.33	1.00	5.000	4.000	5.000	4.000
Acquisition Cost	0.50	0.50	0.20	5.00	0.50	0.20	1.00	5.000	7.000	4.000
Operation Cost	1.00	0.33	0.25	3.00	0.25	0.25	0.20	1.00	6.000	4.000
Maintainability	0.33	0.50	0.25	0.20	0.25	0.20	0.14	0.17	1.00	5.000
Availability	0.50	1.00	0.20	0.33	0.33	0.25	0.25	0.25	0.20	1.00
Sum	5.03	7.83	7.38	22.93	23.67	19.90	17.79	22.75	37.20	32.00

A Microsoft Excel template for carrying out computations was used (Pyzdek, 2014). Through this template, a normalized matrix (Table 7), priority vector (Table 8) and consistency ratio was calculated. The consistency ratio determined was less than one; hence, the degree of consistency was acceptable. The following table clearly displays how the template was designed to add the figures and information. The table shows that the service ceiling value under the PTC column was up to 0.41, thus making it the highest value in the table, while 0.01 is the most frequent and lowest value shown in the matrix. The table has a number of uniform values which pointedly shows the consistency.

Table 7
Standardized matrix for criteria

	Service Ceiling	MTOW	PTC	Combat Radius	Cruising Speed	Maneuverability	Acquisition Cost	Operation Cost	Maintainability	Availability
Service Ceiling	0.20	0.38	0.41	0.13	0.21	0.10	0.11	0.04	0.08	0.06
MTOW	0.07	0.13	0.27	0.17	0.17	0.10	0.11	0.13	0.05	0.03
PTC	0.07	0.06	0.14	0.26	0.30	0.30	0.28	0.18	0.11	0.16
Combat Radius	0.07	0.03	0.02	0.04	0.21	0.25	0.01	0.01	0.13	0.09
Cruising Speed	0.04	0.03	0.02	0.01	0.04	0.15	0.11	0.18	0.11	0.09
Maneuverability	0.10	0.06	0.02	0.01	0.01	0.05	0.28	0.18	0.13	0.13
Acquisition Cost	0.10	0.06	0.03	0.22	0.02	0.01	0.06	0.22	0.19	0.13
Operation Cost	0.20	0.04	0.03	0.13	0.01	0.01	0.01	0.04	0.16	0.13
Maintainability	0.07	0.06	0.03	0.01	0.01	0.01	0.01	0.01	0.03	0.16
Availability	0.10	0.13	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.03

As the table shows the finalized calculated figures of priority vectors, we can see that the availability and maintainability values are the lowest total values in comparison to other factors. Moreover, the Precision Target Capability priority vector values are estimated to be the highest amongst all as shown in the table.

Table 8
Priority vector for criteria

Criteria	Priority Vector
Service Ceiling	**0.173045816**
MTOW	**0.123824884**
PTC	**0.184514908**
Combat Radius	**0.08809149**
Cruising Speed	**0.078225126**
Maneuverability	**0.097506387**
Acquisition Cost	**0.102863666**
Operation Cost	**0.07705485**
Maintainability	**0.039176898**
Availability	**0.035695973**

In the end, the overall priority matrix was developed accordingly as shown in Table 9. This matrix was necessary in order to deduce a final conclusion pertaining to aircraft alternatives and their rankings.

Table 9
Overall priority vector and ranking of results

Alternatives	**Overall Priority**	**Ranking**
Dassault Rafale	0.078673059	6
Saab JAS 39 Gripen	0.09445625	5
Mikoyan MiG-35	0.224425901	1
Sukhoi Su-35	0.220934651	2
Chengdu J-10	0.193553652	3
PAC JF-17 Thunder	0.187956487	4

The results, as shown in Table 9, are that the top three choices should be MiG-35, Su-35 and J-10. Furthermore, a Cost Benefit Analysis was applied to counter examine these results. The table depicts the ranking under the grading scale ranging from 1-10 with 1 being the highest value and top rank in the scale to 10 being the lowest and least ranked amongst the choices available. Thus, the top ranked alternatives are MiG-35, Su-35 and J-10 which received the rankings of 1, 2, and 3 respectively. While on the other hand, Dassault Rafale received the lowest rank with a value of 6, which is least likely to be selected as a suitable alternative. Therefore, this table gives a precisely perfect idea of the final results In order to determine the final results, a Cost Benefit Analysis methodology was carefully administrated.

3.2 Cost Benefit Analysis

Cost Benefit Analysis (CBA) deals with an inspection of a certain process to be performed in order to verify if carrying out such an activity is economically viable.
The process generally involves an inspection of various indirect and direct costs incurred on the data. Following the determination of costs, any values of tangible and intangible benefits are gathered and assigned numeric values. These values are then gathered and compared with each other to yield a comparison and determine whether the benefits attained at a certain expense yield a project that is economically viable or not. Further study on the CBA may involve looking at a payback period. This would evaluate the benefits of the cost and see if during that period whether the investment on a project would equal the benefits that are being strived for and would from then onwards, convert the net cash flow on the project to benefits for the investor. That being said, a similar analysis has been performed earlier as a study (Kyriazis & Salavrakos, 2006).

The CBA presented in this paper was comparable to the study done for Hellenic Air Force. However, due to the similar nature of the problem being dealt with in this scenario, the strategy of inspection was kept similar to the one proposed in the earlier study. Since the study required the execution of an exact Cost Benefit Analysis, it could become intricately complex owing to the indefinite nature of Military, Strategic, Economic and Social Benefits. Therefore, the study was redefined to adopt a factor of Efficiency-Cost Indicator (ECI) which was calculated for every fighting aircraft as conducted in the aforementioned study. Once again, the purpose of the study is to conduct a verification of the results being obtained by the AHP and as such, a detailed study of the CBA, though it may be recommended for future considerations, would not allow for an efficient final result in this study.

$$\text{Efficiency Cost Indicator} = \left(\frac{\text{Efficiency Score)}}{\text{Cost}}\right)$$

The value of the Efficiency Score was determined on the basis of a selected set of technical characteristics and relative weights associated to each characteristic. The weights were given numeric values based on the responses from the surveys that were distributed to various aeronautics and air defense officials, while the ratings were determined on the basis of a comparative study conducted on the basis of a detailed literature review of the technical specifications and comparative data of each aircraft.

The Total Weighted Score or the Efficiency Score for each aircraft was determined as the sum of weighted scores. These scores were obtained as a product of the weight attributed to each technical criteria and the rating each aircraft attained in the said criteria. Efficiency Scores for each alternative are shown in Table 10. The table illustrates the measure of efficiency of each alternative in a percentage rating. It is evident from the table and figures that the total efficiency score with regards to weight is 25. Moreover, the combat radius is only 50% with regards to weighted rating which is the lowest among other factors.

The Cost was determined as a sum of Acquisition Cost and Operation Cost. The Operation Cost of each aircraft was evaluated on a steady run of the aircraft at standard conditions for a single hour of operation. This data was obtained from the technical manuals of the aircraft manufacturing firms. The evaluation of costs is shown in Table 11. This table shows the tallied costs in USD of the alternative aircrafts respectively. As shown in the table, the highest total cost is of the Dassault Rafale aircraft which is measured as 130.028 million USD. The table also shows that the lowest total price is of the JF-17 Thunder, which is astonishing.

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Table 10
Efficiency scores for each alternative

Criteria	Weight	Dassault Rafale		Saab JAS 39 Gripen		Mikoyan Mig-35		Sukhoi Su-35		Chengdu J-10		PAC JF-17 Thunder	
		Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Service Ceiling	2	70%	1.4	70%	1.4	90%	1.8	90%	1.8	100 %	2	60%	1.2
MTOW	3	70%	2.1	40%	1.2	80%	2.4	100%	3	50%	1.5	30%	0.9
PTC	5	80%	4	40%	2	70%	3.5	100%	5	50%	2.5	20%	1
Combat Radius	4	50%	2	90%	3.6	70%	2.8	100%	4	50%	2	90%	3.6
Cruising Speed	3	70%	2.1	90%	2.7	100%	3	90%	2.7	90%	2.7	70%	2.1
Maneuverability	1	80%	0.8	60%	0.6	100%	1	100%	1	80%	0.8	50%	0.5
Maintainability	4	80%	3.2	80%	3.2	70%	2.8	70%	2.8	100 %	4	100%	4
Availability	3	60%	1.8	50%	1.5	100%	3	100%	3	80%	2.4	80%	2.4
Efficiency Scores	25		17.4		16.2		20.3		23.3		17.9		15.7

Table 11
Evaluation of costs

Alternatives	Acquisition Cost (USD)	Operation Cost (USD/hour)	Total Cost (USD)	Total Cost (Million USD)
Dassault Rafale	130,000,000	28,000	130,028,000	130.028
Saab JAS 39 Gripen	45,000,000	28,001	45,028,001	45.008
Mikoyan Mig-35	55,000,000	28,002	55,028,002	55.016
Sukhoi Su-35	75,000,000	28,003	75,028,003	75.036
Chengdu J-10	35,000,000	28,004	35,028,004	35.005
PAC JF-17 Thunder	25,000,000	28,005	25,028,005	25.004

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Table 12
ECI of alternatives

Alternatives	ECI	Ranking
Dassault Rafale	0.133817332	6
Saab JAS 39 Gripen	0.359936011	4
Mikoyan Mig-35	0.368983568	3
Sukhoi Su-35	0.310517618	5
Chengdu J-10	0.511355521	2
PAC JF-17 Thunder	0.627899536	1

As shown in Table 12, the results show the PAC JF-17 Thunder as an optimal air combat aircraft. This assessment is based on the technical characteristics and economic constraints, and is followed in rank by the Chengdu J-10 and Mikoyan MiG-35. Surprisingly, we see that the JF-Thunder has the highest ranking among other aircrafts, while the Dassault Rafale aircraft has the lowest ranking after all the calculations. Thus, a long procedure with various calculations using these methodologies is needed in order to determine the conclusions effectively. This table presents a clear view of one that is the most suitable option for the purposes of this study.

4. Discussion of results

Combat Aircraft Fleet Planning is a process of strategic importance for an air force engaged on multiple fronts with warfare ranging from conventional air superiority to precision driven, counter-insurgency operations. Procurement or development of such aircraft requires huge defense budget expenditures, thereby rendering selection of an appropriate aircraft, a key determinant of effectiveness of a modern air force. Hence, when selecting an aircraft, the operational requirements of an air force must be carefully evaluated, keeping in view the economic and geopolitical challenges related to defense procurements. The air force is interested in acquiring the best possible aircraft in adequate numbers. The opposition between the requirements and constraints need to be dealt with, ensuring a perfect tradeoff to approach the optimal selection. The combat aircraft selection problem for the Pakistan Air Force was considered in this paper. Keeping in view the fiscal defense budget of Pakistan, the requirement of precision target capability and geopolitical constraints, six alternatives were shortlisted. By further considering technical and financial characteristics as criteria (Service ceiling, MTOW, Precision Target Capability, Combat Radius, Cruising Speed, Maneuverability, Acquisition Cost, Operation Cost, Maintainability and Availability), various aspects of an aircraft purchase were evaluated.

The results show that by using the AHP, the MiG-35 turns out to be the best possible solution, closely followed by Su-35. Even though the MiG-35 outweighs the technologically superior Su-35, in both acquisition and operational cost, the Su-35 outweighs the MiG-35 in precision targeting capability. The other aspects of both aircraft are somewhat similar. CBA was applied to ensure that the constraint of cost was not exceeded, and ensuring that financial constraints were taken into consideration. Application of CBA to our six alternatives proved that the locally

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manufactured JF-17 is the most economical choice, closely followed by the J-10. The JF-17 is a technologically inferior aircraft in comparison to the J-10; however, the ECI for both aircrafts closely matches. Therefore, the J-10 could be considered a better option over the JF-17, fulfilling both the technological and financial constraints. Basing a conclusion on the results of the three independent analyses performed, the Mikoyan MiG-35 offers the best solution to the stated problem since it possesses an optimal trade-off between the technological requirement and the budget limitations.

5. Conclusion

Multi-Criteria Decision making is a well-known branch of decision making. The AHP is one of the most commonly used methods for decision making in the literature. In our study, we focused on the problem of aircraft selection for the Pakistan Air Force in order to improve the effectiveness of air combat in the war on terror. This however is not only a problem of the Pakistan Air Force, for today's growing and competitive military air forces, aircraft selection is so important.

The results of the three methods of assessment showed different aircraft leading by a small margin. However, it may be noted that the order of preference of the alternatives hints at the reoccurrence of some alternatives. The MiG-35 turns out to be the best possible solution, closely followed by Su-35 as seen in the AHP application, while the Su-35 turns out to be the best option followed by J-10 and MiG-35. However, CBA concludes that the JF-17 is the most economical choice, closely followed by the J-10 Chengdu and the MiG-35. Owing to its reoccurrence in the preferred order of selection on the basis of the analyses conducted, it was concluded that the MiG-35 is the optimal choice in the case of a fleet up gradation scenario for PAF.

For the future research, the problem can be solved by other MCDM techniques and the solutions can be compared. Also, AHP and ANP with fuzzy numbers could be used for the aircraft selection processes for military air forces, and intelligent software which calculate solutions automatically can be developed.

6. Future considerations

A general observation of the results recommends that the Pakistan Air Force should consider the J-10, Su-35 and Mig-35 as its top choices. The final choice amongst these three aircrafts can only be realized when the economic and geopolitical constraints have been well specified. The Su-35 provides the best solution if Pakistan can manage to negotiate the price and ensure a guaranteed supply of spares and expert backing. Nevertheless, if the Pakistan Air Force could manage to upgrade the J-10 to the tier of its contenders as it did for the Mirage 3 while keeping its cost within the desired range, the J-10 could be the best option for Pakistan Air Force. Alternately, the Mig-35 could serve as the desired option in the case where Russia agrees to furnish a continuous supply of spares and technical backing, but disagrees to negotiate the price.

As such, it may be affirmed that even though a resolution has been achieved after a well-constructed and much thought out strategy as presented in the determinations of this composition, further written reports relating to a more detailed economic situation (which includes the time based fluctuation of the economy, an assessment of the Internal Rate of Return and Net Present Value) and a thorough political analysis of the case is recommended which may offer a more accurate answer to the scenario.

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APPENDIX A

a. List of experts and their PAF experience

RANK OFFICERS	REPRESENTATION	YEARS OF EXPERTISE	NUMBER OF RESPONSES
AIR COMMODORE	Air Cdre	Minimum 10-13 Years	12
GROUP CAPTAIN	Gp Capt	Minimum 8-10 Years	16
WING COMMANDER	Wg Cdr	Minimum 5-10 Years	22
SQUADRON LEADER	Sqn Ldr	Minimum 5-10 Years	11
FLIGHT LIEUTENANT	Flt Lt	Minimum 5 Years	28
FLYING OFFICER	Flg Off	Minimum 3 Years	36
PILOT OFFICER	Plt Off	Minimum 3 Years	18
CIVILIAN GAZETTED OFFICERS	GO	Minimum 5 Years	25
MINISTERIAL STAFF	ML	Minimum 5 Years	10
TECHNICAL STAFF	TL	Minimum 5 Years	20
GROUND COMBATIERS	GC	Minimum 8 Years	22

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b. Questionnaire

Questionnaire Purpose:
Pakistan's role in the War on Terror is a widely discussed topic among policy-makers of various countries and political analysts around the world. **Recent crashes, retirement of old fighter jets and ongoing war on terror has increased the need to purchase <u>new modern</u> aircraft.** Hence, there is a need for procurement of such modern aircrafts so as to increase our efficiency in war on terror in Pakistan.
Questionnaire Methodology:
We will use Multi-criteria Decision Making, Analytical Hierarchy Process (AHP) in particular, for our objective.
AHP uses a hierarchical structure and pair-wise comparisons. This technique requires data to develop a decision matrix showing pair-wise comparisons between the decision criteria.
Questionnaire:
Please mark a cross (X) in the boxes given in the following tables for pair-wise comparisons of the following criteria:

1. Service ceiling
2. Maximal Take-off Weight (MTOW)
3. Precision Target Capability
4. Combat Radius
5. Maximum Cruising Speed
6. Maneuverability
7. Acquisition Cost
8. Operation Cost
9. Maintainability
10. Availability

The definition of each criterion is given in the glossary at the end of this questionnaire.

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1. Combat Radius

	Extremely Preferred (9)	Very Strongly Preferred (7)	Strongly Preferred (5)	Moderately Preferred (3)	Equally Preferred (1)	
Combat Radius						Service Ceiling
Combat Radius						MTOW
Combat Radius						Precision Target Capability
Combat Radius						Cruising Speed
Combat Radius						Maneuverability
Combat Radius						Acquisition Cost
Combat Radius						Operation Cost
Combat Radius						Maintainability
Combat Radius						Availability

2. Service Ceiling

	Extremely Preferred (9)	Very Strongly Preferred (7)	Strongly Preferred (5)	Moderatel y Preferred (3)	Equally Preferred (1)	
Service Ceiling						MTOW
Service Ceiling						Precision Target Capability
Service Ceiling						Combat Radius
Service Ceiling						Cruising Speed
Service Ceiling						Maneuverability
Service Ceiling						Acquisition Cost
Service Ceiling						Operation Cost
Service Ceiling						Maintainability
Service Ceiling						Availability

3. Maximum Take-off Weight (MTOW)

	Extremely Preferred (9)	Very Strongly Preferred (7)	Strongly Preferred (5)	Moderately Preferred (3)	Equally Preferred (1)	
MTOW						Precision Target Capability
MTOW						Combat Radius
MTOW						Service Ceiling
MTOW						Cruising Speed
MTOW						Maneuverability
MTOW						Acquisition Cost
MTOW						Operation Cost
MTOW						Maintainability
MTOW						Availability

4. Precision Target Capability

	Extremely Preferred (9)	Very Strongly Preferred (7)	Strongly Preferred (5)	Moderately Preferred (3)	Equally Preferred (1)	
Precision Target Capability						Combat Radius
Precision Target Capability						Cruising Speed
Precision Target Capability						Maneuverability
Precision Target Capability						Acquisition Cost
Precision Target Capability						Operation Cost
Precision Target Capability						Maintainability
Precision Target Capability						Availability

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5. Availability

	Extremely Preferred (9)	Very Strongly Preferred (7)	Strongly Preferred (5)	Moderately Preferred (3)	Equally Preferred (1)	
Availability						Precision Target Capability
Availability						Combat Radius
Availability						Service Ceiling
Availability						Cruising Speed
Availability						Maneuvera bility
Availability						Acquisition Cost
Availability						Operation Cost
Availability						Maintainab ility

6. Cruising Speed

	Extremely Preferred (9)	Very Strongly Preferred (7)	Strongly Preferred (5)	Moderately Preferred (3)	Equally Preferred (1)	
Cruising Speed						Maneuverability
Cruising Speed						Acquisition Cost
Cruising Speed						Operation Cost
Cruising Speed						Maintainability
Cruising Speed						Availability

7. Maneuverability

	Extremely Preferred (9)	Very Strongly Preferred (7)	Strongly Preferred (5)	Moderately Preferred (3)	Equally Preferred (1)	
Maneuverability						Acquisition Cost
Maneuverability						Operation Cost
Maneuverability						Maintainability
Maneuverability						Availability

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8. Acquisition Cost

	Extremely Preferred (9)	Very Strongly Preferred (7)	Strongly Preferred (5)	Moderately Preferred (3)	Equally Preferred (1)	
Acquisition Cost						Operation Cost
Acquisition Cost						Maintainability
Acquisition Cost						Availability

9. Operation Cost

	Extremely Preferred (9)	Very Strongly Preferred (7)	Strongly Preferred (5)	Moderately Preferred (3)	Equally Preferred (1)	
Operation Cost						Maintainability
Operation Cost						Availability

10. Maintainability

	Extremely Preferred (9)	Very Strongly Preferred (7)	Strongly Preferred (5)	Moderately Preferred (3)	Equally Preferred (1)	
Maintainability						Availability

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Glossary

Term	**Definition**
Service Ceiling	The service ceiling is the altitude at which the maximum rate of climb is 100 ft/min. (0.5 m/s) for piston powered aircraft or 500 ft/min (2.5 m/s) for jet powered aircraft.
MTOW	The maximum takeoff weight (MTOW) of an aircraft is the maximum weight at which the pilot is allowed to attempt to take off, due to structural or other limits.
Precision Target Capability	Precision Targeting Capability refers to the attempted aerial execution of a target with some degree of accuracy, with the aim of limiting collateral damage.
Combat Radius	Combat radius is a related measure based on the maximum distance a warplane can travel from its base of operations, accomplish some objective, and return to its original airfield with minimal reserves.
Cruising Speed	Cruise is level flight after an aircraft climbs to a set altitude and before it begins to descend. Commercial, defense or passenger aircraft are usually designed for optimum performance at their cruise speed.
Maneuverability	Maneuverability is the quality in an aircraft which determines the rate at which its attitude and direction of flight can be changed.
Acquisition Cost	Acquisition Cost may include the negotiated and agreed cost of buying the aircraft and additional costs that can be capitalized and include payments for purchase rights or purchase options. These are distinct from manufacturer credits, and include amounts paid to secure the right to buy a certain aircraft at a certain time.
Operation Cost	Operation Cost includes direct and indirect, fixed and variable costs incurred to enable the aircraft to attain usefulness in operation. This may include Maintenance Cost and Cost incurred due to fuel expenditure whilst airborne.
Maintainability	Maintainability is defined as the probability of performing a successful repair action within a given time. In other words, maintainability measures the ease and speed with which a system can be restored to operational status after a failure occurs.
Availability	Availability is the degree to which a system, subsystem or equipment is in a specified operable and committable state at the start of a mission, when the mission is called for at an unknown, i.e. a random, time.

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