Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 13 (22): 5524-5526, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.5524.5526

A Hybrid Model for Aero-engine Health Assessment Based on Condition Monitoring Information

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Abstract: This study models the aero-engine health assessment problem as a Multi-Criteria Decision Making (MCDM) problem and proposes a two-step evaluation model, combining the technique of fuzzy AHP (fuzzy analytic hierarchy process) and TOPSIS (technique for order performance by similarity to idea solution). This study applies the fuzzy AHP method to determine relative weights of multiple evaluation criteria and synthesize the ratings of candidate aero-engines. Aggregated the evaluator's attitude toward preference, then TOPSIS is employed to obtain a crisp overall performance value for each alternative to make a final decision. To illustrate how the approach is used for the aero-engine health assessment problem, an empirical study of a real case involving eleven evaluation criteria and ten initial commercial aero-engines of Air China is conducted. The case study demonstrates the effectiveness and feasibility of the proposed evaluation procedure.

Key words: Aero-engine health assessment, MCDM, fuzzy AHP, hybrid model

INTRODUCTION

Aero-engines could be disabled at any time because of their complicated structures and poor working conditions of high temperature and high speed. According to the recent statistics of the Aviation Safety Network, aero-engine failure is one of the most important mechanical factors that cause all kinds of air accidents (Azadeh *et al*., 2007). Also, aero-engines are highly complex engineering systems, which are extremely expensive to maintain and operate. According to the statistics, the maintenance costs of aero-engines account for more than 30% of the whole operation costs of airlines. Aero-engine health assessment plays an important role in solving flight safety problems and cost considerations (Yu *et al*., 2007). The main purpose of aero-engine health assessment is to determine the real health status of aero-engine with advanced condition monitoring methods, reliable evaluation methodologies and complete operating data. These, in turn, can contribute to the scientific fault diagnosis and recognition of early fault symptoms. Therefore, it is highly necessary for airlines to introduce aero-engine health assessment into the fleet maintenance management.

EVALUATION CRITERIA

Condition assessment is a systematic process and the assessment methods such as TOPSIS (Chamodrakas *et al*., 2009; Chen and Hwang, 1992; Ertugrul and Karakasoglu, 2009; Wang and Chang, 2007), AHP (Cakir and Canbolat, 2008; Dagdeviren *et al*., 2009; Duran and Aguilo, 2008; Gumus, 2009), wavelet analysis (Zhou *et al*., 2009) and group method of data handling (Csutora and Buckley, 2001; Li *et al*., 2006) are frequently used on numerous occasions.

Evaluating the aero-engine health condition according to qualitative attributes such as performance states, fault states, time states and initialized states is frequently quite difficult. To improve understanding, this study combined the qualitative analysis and provided decision-makers with performance data obtained from monitoring platform to assess the aero-engine health states.

We establish the hierarchical framework for aero-engine health assessment and it is shown in Fig. 1, which is evaluated in terms of four basic aspects: Performance states, fault states, time states and initialized states.

Aero-engine health assessment experts were requested to express their perceptions level of importance for the four basic criteria in linguistic variables according to the linguistic scales and corresponding triangular fuzzy numbers. After pairwise comparisons are finished at a level, a fuzzy reciprocal judgment matrix can be established as:

	Performance	fault	Time	Initial
Performance	1	[1 1 2]	[1 1 2]	[2 3 4]
Fault	[$\frac{1}{2}$ 1 1]	1	[1 1 2]	[2 3 4]
Time	[$\frac{1}{2}$ 1 1]	[$\frac{1}{2}$ 1 1]	1	[2 3 4]
Initial	[$\frac{1}{4}$ $\frac{1}{3}$ $\frac{1}{2}$]	[$\frac{1}{4}$ $\frac{1}{3}$ $\frac{1}{2}$]	[$\frac{1}{4}$ $\frac{1}{3}$ $\frac{1}{2}$]	1

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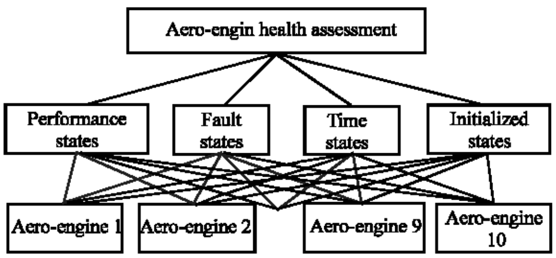

Fig. 1: Hierarchical model of assessing aero-engine health level

Table 1: Fuzzy important weight and rank of each criterion

Criteria	Fuzzy importance weight	Rank
Performance states	0.32	1
Fault states	0.32	1
Time states	0.26	3
Initialized weights	0.10	4

Table 2: Weighted normalized decision matrix of ten candidate aero-engines

Engine No.	Fault states	Performance states	Time states	Initialized weights
1	0.048	0.0352	0.1872	0.026
2	0.1248	0.1696	0.2236	0.031
3	0.0672	0.176	0.1976	0.031
4	0.1312	0.2336	0.2132	0.037
5	0.1312	0.144	0.1898	0.03
6	0.0704	0.0608	0.234	0.03
7	0.1216	0.1312	0.208	0.028
8	0.0768	0.1632	0.1924	0.051
9	0.0736	0.1056	0.1742	0.026
10	0.0672	0.128	0.1742	0.029

RELATIVE WEIGHTS OF CRITERIA

We can calculate the weights according to the Fuzzy AHP methodology (Mikhailov, 2000; Mikhailov and Tsvetinov, 2004). The weight values presented in Table 1 reveal that the two most important performance criteria for assessing aero-engine health level were performance states (0.32) and fault states (0.32), whereas the other two performance criteria were time states (0.26) and initialized weights (0.10).

DECISION MATRIX

Since the importance weights of criteria are different, the weighted normalized decision matrix can be obtained and it is shown in Table 2.

REFERENCE POINTS

The closeness coefficient can be obtained and the health index can be calculated. The index values and ranking results are shown in Table 3.

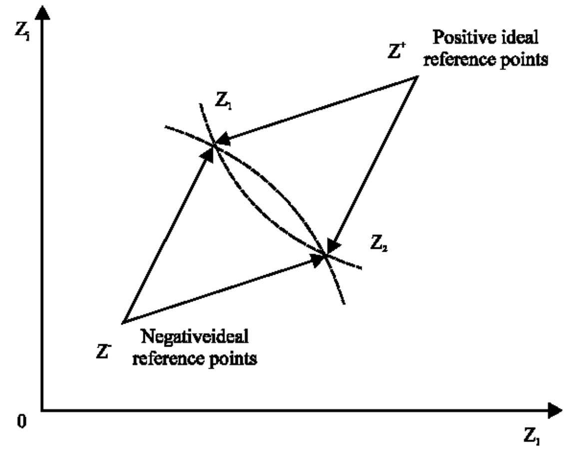

Fig. 2: TOPSIS method is described with the vector graph

Table 3: Health index and ranking results of ten candidate aero-engines

Engine No.	d_i^+	d_i^-	C_i	Ranking
1	0.221585	0.013	0.055417	10
2	0.068155	0.162564	0.704597	2
3	0.095597	0.144104	0.601182	3
4	0.025073	0.218922	0.897241	1
5	0.102092	0.13791	0.574619	5
6	0.184384	0.068914	0.272067	9
7	0.108549	0.125616	0.536442	6
8	0.098214	0.134795	0.578496	4
9	0.154605	0.07491	0.326384	8
10	0.138951	0.094813	0.405592	7

RANK THE PREFERENCE ORDER

TOPSIS method assumed that if each criterion is monotonously increasing or decreasing, then it is easy to define an ideal solution. Such a solution comprises all the best achievable values of the criteria, while the worst solution is composed of all the worst criteria values achievable. The algorithms of this method can be described with a vector graph as shown in Fig. 2.

HEALTH INDEX

A candidate aero-engine with a closeness coefficient close to 1 has the shortest distance from the positive ideal reference point and the largest distance from the negative ideal reference point. In other words, a larger health index of an aero-engine indicates a better aero-engine health level. The evaluation results can be simulated in Fig. 3.

According to the requirements of decision-makers, the three aero-engines (No. 2, 3 and 4) whose health indexes are less than 0.4 shown in Fig. 3 are considered to be repaired immediately in order to reach the 70% on-wing rate of aero-engines and the aero-engine 5, 7 and 8 should be monitored constantly. The other four aero-engines

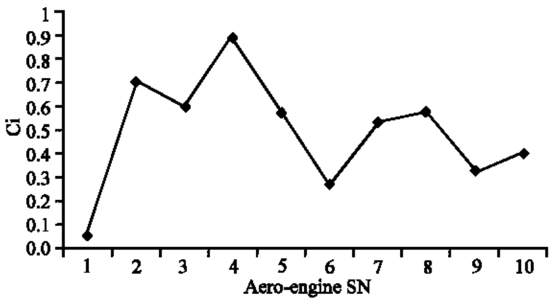

Fig. 3: Health index assessment results of ten candidate aero-engines

need to keep on-wing this time. So, we can prove that this method for aero-engine health assessment is an important and effective technical measure for ensuring an engine's safe working, meeting the on-wing rate of aero-engine and prolonging its operating life.

CONCLUSION

This study models the aero-engine health assessment problem as a multi-criteria decision making problem and proposes a two-step evaluation model, combining the technique of fuzzy AHP and TOPSIS. As the results shown in the application example, we find that the proposed method is practical for ranking aero-engine health level in terms of their overall performance with respect to multiple interdependence criteria. While using linguistic variables makes the evaluation process more realistic. Because evaluation is not an exact process and has fuzziness in its body. Here, the usage of fuzzy AHP weights in TOPSIS makes the application more realistic and reliable.

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