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Enhanced Zonal Analysis Rating and Inspection Intervals Determination of Civil Aircraft

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Abstract: One of the most important things in formulating aircraft maintenance program is to determine the zonal inspection intervals. The process of Zonal Analysis is composed of standard zonal analysis and enhanced zonal analysis process. Since the latter always touches upon stuffs like wire, combustible materials and EWIS components, it's more complicate to conduct concrete and logical analysis. This article analyzes the impact of enhanced zonal rating factors, establishes a hierarchical index evaluation system and then utilizes the improved Fuzzy Analytic Hierarchy Process (FAHP) to determine the indexes' weight. Moreover, the zonal inspection intervals can be established according to the correspondence between rates and intervals. Finally, simplify the operation of the model by applying Mathematica Programming and take a typical zone of an aircraft as an example to verify the method.

Key words: MSG-3, enhanced zonal analysis process (EZAP), rating, intervals, FAHP

INTRODUCTION

The process of MSG-3 analysis is regarded as the approach to establishing the maintenance program, which provides aircrafts with sustainable air worthiness. With almost half-century development of this method, it is able to satisfy the requirements of security as well as its economic concerning about airlines operation. An essential characteristic of the process is to use the zonal analysis logics and construct relative zonal inspection tasks. By integrating General Visual Inspection (GVI) tasks deriving from systems and power plant analysis, structures analysis and lightning/HIRF protection system analysis into zonal inspection tasks without bringing down security level, it will reduce the work loads of maintenance and achieve the goal of saving operational costs (Gregory and John, 2008). However, as for different aircrafts and dissimilar zones, there are assorted factors that will influence the rating of

various elements during the actual zonal analysis process (MSG-3, 2011). In order to resolve this problem, this article is going to concretely combine enhanced zonal analysis process and specific numerical analysis method, establish the model of zonal rating index system and propose a method to determine zonal inspection intervals.

AN OVERVIEW OF ENHANCED ZOAL ANALYSIS PROCESS

The zonal inspection procedures can be formulated along with the zonal analysis program, which require each part of aircraft zones being evaluated comprehensively after the logical analysis of structures, systems and power plant. Zonal analysis is composed of standard zonal analysis and enhanced zonal analysis and both of them have diverse considerations. For example, standard zonal analysis is mainly considering the normality and security of installed accessories in certain zones by conducting GVI tasks. The zonal analysis program also takes the layout of electronic wirings into account. Therefore, apart from determining the tasks of zonal inspection, the logical map provides appropriate and effective approaches to limiting contaminations as well as eliminating installed deviation of undetectably essential wirings.

Analysis of enhanced zonal rating factors: As for zones that maybe contain combustible materials, it's necessary to conduct Enhanced Zonal Analysis Process (EZAP), which forms singular inspection task and that will reduce the aggregation of combustible materials. Enhanced zonal analysis utilizes rating table to confirm inspection levels, which is supposed to consider a couple of elements as

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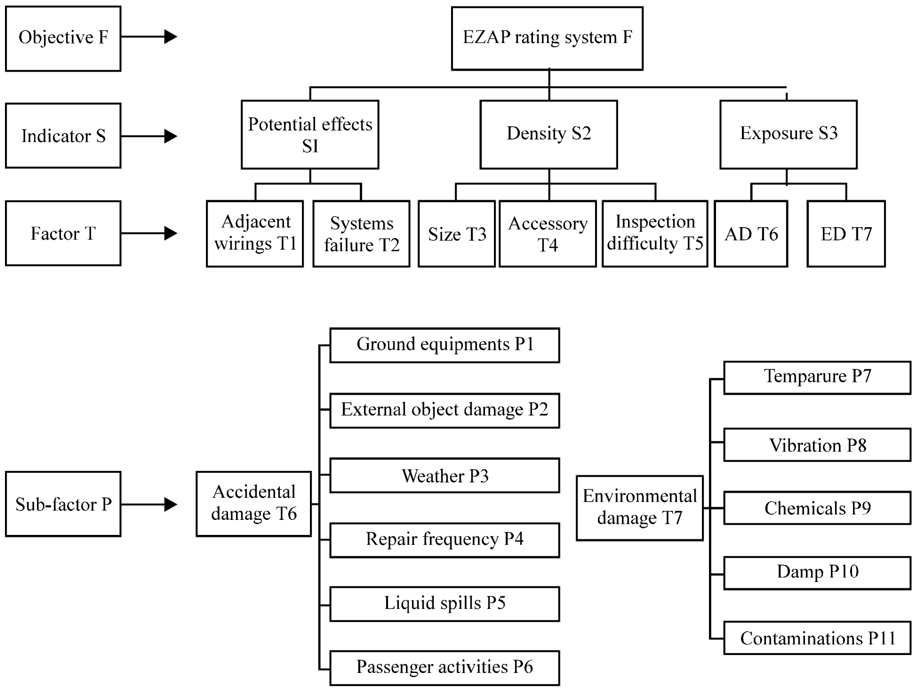

Fig. 1: Hierarchical structure of EZAP rating index system

follows: The potential effects of fire, density grade and exposure level (including environmental damage level and accidental damage level). In details, the potential effects of fire are the measurements of danger to certain zones, which refers to the consequence of fire caused by a wiring/EWIS failure on adjacent wiring and systems (e.g., the risk to aircraft controllability). The density grade is related to the size of zone, the number of accessories and the degree of difficulty of inspection. Similar to standard zonal analysis, interval determination may be accomplished using rating tables that consider accidental damage and environment. The accidental damage level is related to factors such as ground support equipments, external object damage, weather, repair frequency, liquid spills, passenger activities, etc. The environmental damage level is related to temperature, vibration, chemicals, damp and contaminations. Then, according to the property relations between each indicator, establish the multi-level hierarchical structure of zonal rating factors, which constitutes the enhanced zonal rating index system (Fig. 1).

Enhanced zonal analysis procedure: If some zones have electronic wirings and combustible materials, enhanced zonal inspections should be conducted; namely, implement independent inspections and tasks to minimize the contaminations caused by combustible materials. It's necessary to give appropriate attention to deterioration of installed system (EWIS), in particular for wiring in close proximity to both primary and back-up hydraulic, mechanical, or electrical flight controls. General visual inspections may be found effective for the complete zone. Detailed inspections may be found applicable and effective for specific item in a zone. The potential effects of fire caused by a wiring/EWIS failure on adjacent wiring and systems, the size of the zone and the density of installed equipment may be used to determine the inspection level.

For example, bigger zones and higher density of equipment will lead inspections to be less effective; therefore, it's essential to carry out stand-alone or high level inspections. In general, detailed inspections (DET) and tasks to minimize contamination should be included in the Systems and Power plant tasks. General Visual Inspections arising from the enhanced zonal analysis may be compared with the Zonal Inspections determined from the standard zonal analysis (Fig. 2 and 3). The former may be considered fully covered by the zonal inspection if the access requirement is the same and the proposed interval is at least as frequent. Otherwise, a stand-alone GVI should be included with the tasks identified in the System and Power plant maintenance program.

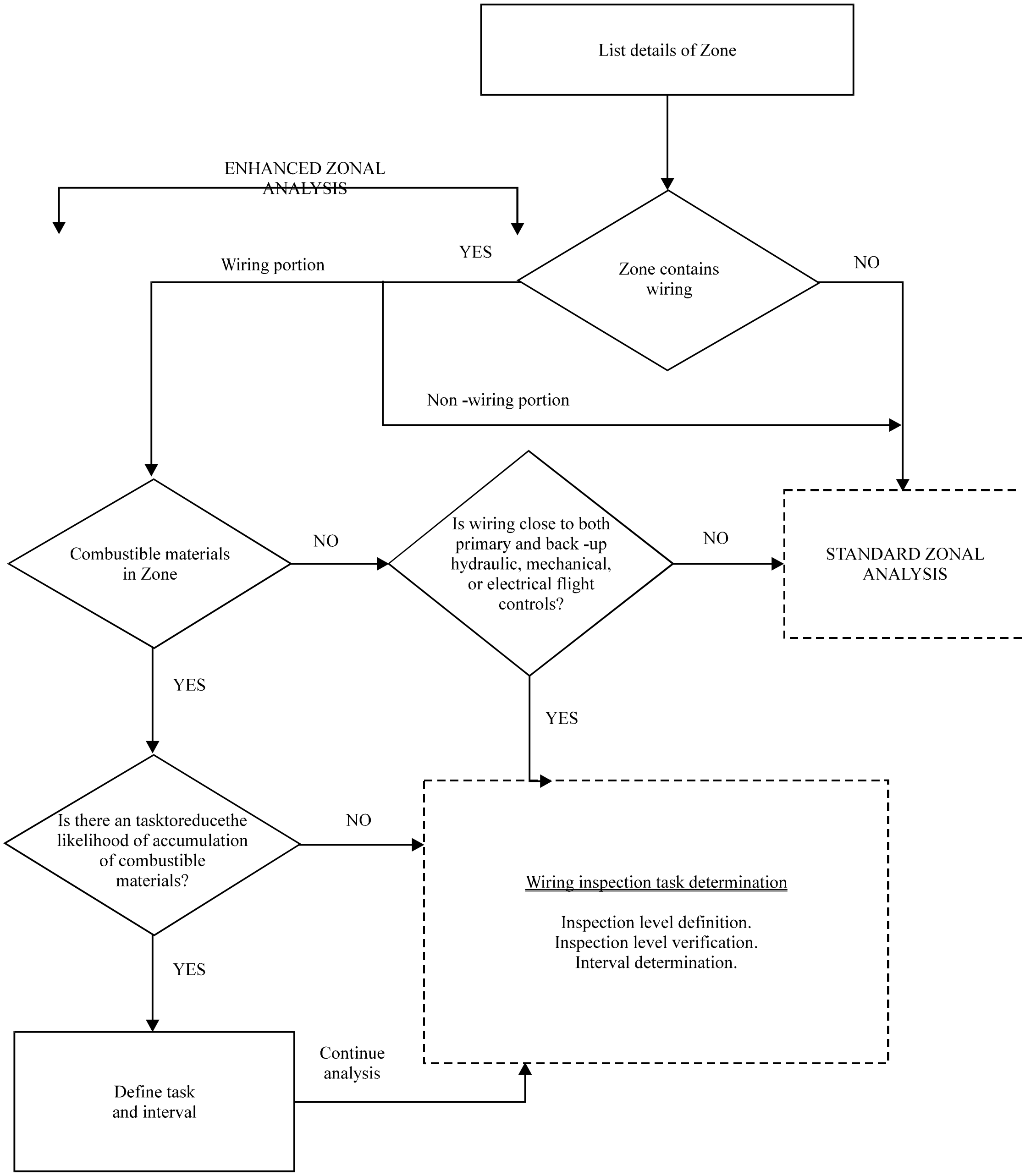

Fig. 2: Enhanced Zonal analysis procedure

ESTABLISHMENT OF ENHANCED ZONAL RATING INDEX SYSTEM

Application of Improved Fuzzy Analytic Hierarchy Process (FAHP) to Determine the Index Weight: Fuzzy Analytic Hierarchy Process (FAHP) (Du, 2012) based on traditional analytic hierarchy process takes into account people's judgment fuzziness when evaluating complex matters (Duru *et al*., 2012). It's a decision making approach which brings in fuzzy consistent matrix. This method not only addresses the problem that conventional comprehensive index calculation methods have not considered the integrated impact of each factor (Vaidya and Kumar, 2006) but also resolves the defect that Analytic Hierarchy Process (AHP) is largely subject to personal judgments. This article utilizes the improved FAHP method to determine the respective index weights. By refining the hierarchical index system and changing

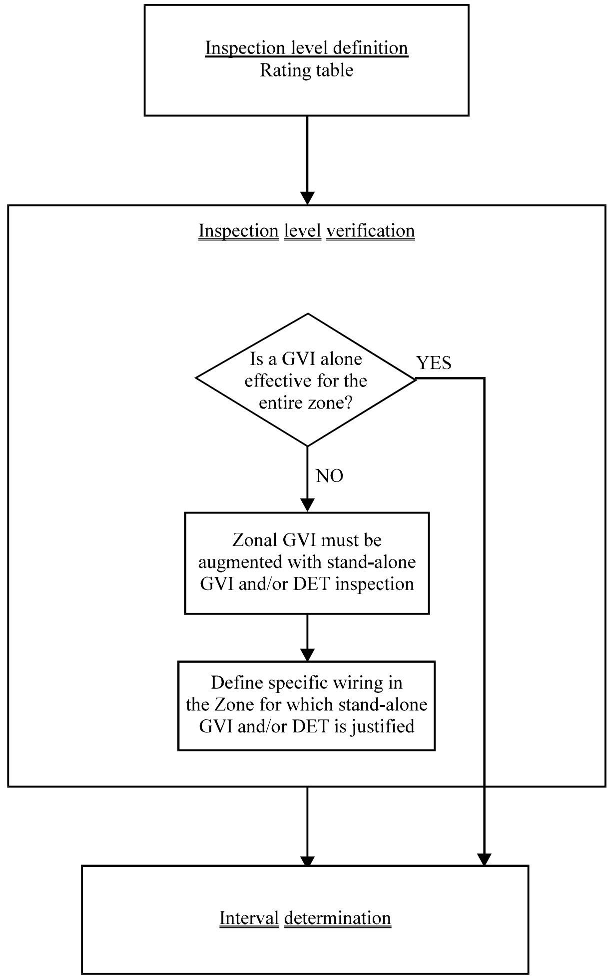

Fig. 3: Enhanced zonal analysis procedure

the algorithm formula commonly used in the calculation of factor weights, it will improve the resolution of zonal rating index weights and augment the credibility of zonal rating index system (Kabir and Hasin, 2011).

Fuzzy Consistent Matrix:

Definition 1: Let the matrix $R = (_{ij})_{n\times n}$, if it satisfies: $0 \le r_{ij} \le 1$, ($i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, n$), then R is called a fuzzy matrix.

Definition 2: If the fuzzy matrix $R = (_{ij})_{nHn}$, meets: $r_{ij}+r_{ij} = 1$, ($i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, n$), then fuzzy matrix R is called a fuzzy complementary matrix

Definition 3: If the fuzzy matrix $R = (_{ij})_{nHn}$, meets: $\forall i, j, k$, $r_{ij} = r_{ik}-r_{jk}+0.5$, then fuzzy matrix R is called a fuzzy consistent matrix

Theorem 1: Convert fuzzy complementary matrix R into a fuzzy consistent matrix: Let the fuzzy complementary matrix $R = (_{ij})_{nHn}$, sum it up by row and denote as:

$$r_i = \sum_{k=1}^{n} r_{ik}, i = 1, 2, \cdots, n$$

Perform the following mathematical transformation $r_{ij} = (r_i-r_j)/2n+0.5$, then the transformed new matrix is a fuzzy consistent matrix

Algorithm analysis: The fuzzy consistent matrix is in accordance with the thinking of human strategic decision. Therefore, the FAHP method based on fuzzy consistent matrix has been used a lot in plan optimization when there are many indicators or the evaluation has great ambiguity (Torfi *et al*., 2010). The general algorithmic steps of FAHP are as follows:

Establish the priority relationship matrix: Create matrices according to the relative importance of each layer factors corresponding to its upper layer. This matrix is a fuzzy complementary matrix. The values in the matrix are scaled from 0.1-0.9. (2) Convert the priority relationship matrix into fuzzy consistent matrix. According to Theorem 1, the priority relationship matrix is able to be transformed into a fuzzy consistent matrix. (3) Level of a single layer. Calculate the sequence of importance of each factor in lower layer relative to the upper objective layer based on fuzzy consistent matrix. The sequence method derived from the relationship between elements of fuzzy consistent matrix and weights has a higher resolution, which is able to render decision-making more scientifically. Thus, this method is to be utilized to calculate the weight of each factor. The weight s^k_i of factor A_i relative to the target O_k is:

$$s_i^k = \frac{1}{n} - \frac{1}{2\alpha} + \frac{\sum_{j=1}^{n} r_{ij}}{n\alpha}, i = 1, 2, \cdots, n \quad (1)$$

Parameter α meets $\alpha \geq (n-1)/2$. Array s^k_i ($i = 1, 2, \ldots, n$) in the downward order and it will demonstrate the importance level of each factor A_i relative to the target O_k.

Level of the overall ranking: Based on the ranking of a single layer and the level synthesis, it is available to work out the overall weight ω_i of each factor relative to the whole objective:

$$\omega_i = \sum_{k=1}^{n} \omega_k s_i^k (i = 1, 2, \cdots, n) \quad (2)$$

Overall rating and the determination of inspection intervals: After working out the overall weight of each factor in zonal rating, the integrated rating of aircraft zones is able to be determined and its mathematical formula is as follows: $R = R_n \cdot \omega_n$, where R_n is the score of each index in the factor layer and ù is the overall weights of the factor layer relative to the objective. R_n is the score matrix of every factors decided by a group of experts according to the criteria of index level. Each factor has four levels (High: 1, Intermediate: 2, Low: 3). The algorithmic expression of R_n is: $R_n = (R_{T1}\ R_{T2}\ R_{T3}\ R_{T4}\ R_{T5}\ R_{T6}\ R_{T7})$. The level of accidental damage and environmental damage is the minimum value of the factors rating; namely, $R_{T5} = \min (R_{P1}\ R_{P2}\ R_{P3}\ R_{P4}\ R_{P5}\ R_{P6})$, $R_{T6} = \min (R_{P7}\ R_{P8}\ R_{P9}\ R_{P10}\ R_{P11})$

Currently, it is common to utilize the overall rating and inspection intervals conversion table to determine the maintenance intervals. However, this method does not take into consideration the respective weight of each factor to the overall rating. By considering the relationship between overall ratings and inspection intervals, a fitted regression equation is to be established. According to the statistical data of engineering practice and the direction of the development of determining repair intervals in maintenance program, continuous numerical inspection intervals are given. Finally, by incorporating related data from companies like BOEING and AIRBUS, a fitted regression equation has been established to help determine the zonal inspection intervals of certain aircrafts:

$$T = \begin{cases} \text{Redesign} & R < 1 \\ 24.1R - 22.7 & 1 \leq R < 2 \\ 94.5R - 163.5 & 2 \leq R < 3 \\ 120 \text{ or more} & R > 3 \end{cases}$$

EZAP PROGRAMMING DESIGN AND VERIFICATION

By using the scientific computational software Mathematica to compile codes (Tranquillo, 2011), it's able to effectively trim down the workloads of matrices transformation and solving weight values, which will definitely enhance the efficiency of analysis (Keller, 2010). Choose typical zones of certain aircrafts to perform enhanced zonal analysis and compare the computational results obtained from the model with empirical statistics from actual production activities. Then, it's able to estimate and assert the accuracy of the model and its analytical precision.

Choose the zone to be verified: Pylon is one of the most important targets of zonal inspection tasks. The structure of large aircraft's pylon and its connection with the wing are vital parts of aircraft structural design. Excellent pylons not only can transmit engine load to the wings effectively but also can lessen the weight of structures to benefit assembly and maintenance in the future, which will create great economic benefits. In order to verify the above method, take the upper forward pylon (ZONE 413) of certain aircrafts as an example for validation.

Programming design and results analysis: According to the logic of enhanced zonal analysis and the procedure of rating-intervals determination, utilize Mathematica matrices and module function to carry out programming (Gerdt and Prokopenya, 2010). First, based on the hierarchical structure of zonal rating index system, establish the priority relationship matrix according to the experts' data. The matrix for the layers of objective and

Table 1: F-S priority relationship matrix

F	S1	S2	S3
S1	0.500	0.900	0.700
S2	0.100	0.500	0.400
S3	0.300	0.600	0.500

Table 2: S1-T p-r matrix

S1	T1	T2
T1	0.500	0.600
T2	0.400	0.500

Table 3: S2-T p-r matrix

F	S1	S2	S3
S1	0.500	0.600	0.400
S2	0.400	0.500	0.400
S3	0.600	0.600	0.500

Table 4: S3-T p-r matrix

S1	T1	T2
T1	0.500	0.700
T2	0.300	0.500

indicators is F-S; the matrices for the layers of indicators (Table 1) and factors are S1-T (Table 2) S2-T (Table 3) and S3-T (Table 4). These matrices can be obtained by the relative importance of evaluation factors.

Second, apply the values in the priority matrices above to eight variables in the program and run it. It's able to get the transformed fuzzy consistent matrices, the weight of each factor in corresponding layers and the overall weight of each factor relative to the whole objective, etc.

The weight of each factor in layer S relative to layer F is:

$$\omega_1 = (s_1^1 \;\; s_2^1 \;\; s_3^1)^T = (0.4333 \;\; 0.25 \;\; 0.3167)^T$$

The corresponding weight of each factor in layer T relative to layer S is:

$$\omega_{21} = (s_{11}^2 \;\; s_{12}^2)^T = (0.5500 \;\; 0.4500)^T$$

$$\omega_{22} = (s_{21}^2 \;\; s_{22}^2 \;\; s_{23}^2)^T = (0.3333 \;\; 0.3 \;\; 0.3667)^T$$

$$\omega_{23} = (s_{31}^2 \;\; s_{32}^2)^T = (0.6000 \;\; 0.4000)^T$$

$$\begin{aligned}\omega_n &= (s_1^1 \cdot s_{11}^2 \;\; s_1^1 \cdot s_{12}^2 \;\; s_2^1 \cdot s_{21}^2 \;\; s_2^1 \cdot s_{22}^2 \;\; s_2^1 \cdot s_{23}^2 \;\; s_3^1 \cdot s_{31}^2 \;\; s_3^1 \cdot s_{32}^2)^T \\ &= (0.2383 \;\; 0.195 \;\; 0.0833 \;\; 0.075 \;\; 0.0916 \;\; 0.19 \;\; 0.1267)\end{aligned}$$

According to the indication from the group of experts, the index score of each factor is:

$$\begin{aligned}R_n &= (R_{T1}\, R_{T2}\, R_{T3}\, R_{T4}\, R_{T5}\, R_{T6}\, R_{T7}) \\ &= (1.50, 1.45, 2.90, 2.80, 1.95, 1.85)\end{aligned}$$

Zonal overall rating is:

$$R = Rn.\omega n = 1.9572$$

Finally, in accordance with the rating-intervals regression equation, the corresponding inspection interval of the pylon is: T = 24.4677 MO.

In order to verify the accuracy and precision of this method, it is necessary to compare the above result with the data of mainstream aircrafts regarding certain zonal inspection interval: the data in MRBR (Maintenance Review Board Report) is 24 MO, 5500FC; the data in MPD (Maintenance Planning Document) is 2C. It can be analyzed from the result that the error of zonal inspection interval based on improved FAHP is 1.95% compared with the actual inspection interval, which is eligible.

CONCLUSION

From what has been discussed and analyzed above, here comes the conclusion that:

- Enhanced zonal analysis procedure needs to consider adjacent wirings, combustible materials and EWIS components. General visual inspections may be found effective for the complete zone. Detailed inspections may be found applicable and effective for specific item in a zone
- It's reasonable and effective to utilize the improved FAHP method to determine the weight of each factor. By refining the hierarchical index system and changing the algorithm formula commonly used in the calculation of factor weights, it will improve the resolution of zonal rating index weights and augment the credibility of zonal rating index system
- The specific inspection interval values can be determined in accordance with the rating-intervals regression equation. According to the statistical data of engineering practice and the direction of the development of determining repair intervals in maintenance program, continuous numerical inspection intervals are rendered, which can facilitate airlines to make reasonable arrangements for inspections according to the real situation, improve maintenance efficiency and reduce costs

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