SURVIVABILITY EVALUATION AND SUSTAINABLE DEVELOPABILITY INTEGRATED TRADEOFF METHODS FOR MILITARY AIRCRAFT

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Keywords: *military aircraft; survivability; sustainable developability; cost*

Abstract

The effect factors of aircraft survivability are analyzed, and according to the importance degrees of the effect of the factors on survivability, a weight coefficient method and an integrated evaluation method are proposed to evaluate aircraft survivability. To scientifically integrate the effectiveness and life cycle cost of military aircraft, a new concept "the sustainable developability of military aircraft" is proposed. The sustainable developability of military aircraft expresses the capability to form the sustainable battle effectiveness through making valid use of national resources, opens out the essence of military aircraft development, and can be applied to compromise aircraft survivability synthetically.

1 Introduction

With the continual promotion of the design requirements for military aircrafts and the rapid development of the modern airfight, aircraft survivability becomes more and more important [1]. Being a high efficient weapon system, the design of a new military aircraft is required from four aspects: affordability, lethality, supportability and survivability [2]. As a new design requirement of military aircraft, the appearance of survivability makes it is very necessary to study survivability evaluation and design methods for military aircraft; affordability, lethality, supportability and survivability have to be compromised synthetically in military aircraft design to obtain the optimal design scheme [3-5]. In this paper, firstly, the effect factors of aircraft survivability are analyzed, and aircraft survivability evaluation methods are studied; secondly, a new concept "the sustainable developability of military aircraft" is proposed. The sustainable developability of military aircraft is a highly integration of the system effectiveness and life cycle cost of military aircraft, and can be applied to compromise aircraft affordability, lethality, supportability and survivability synthetically.

2 Effect Factors of Aircraft Survivability

Aircraft survivability is defined as the capability of an aircraft to avoid or withstand a man-made hostile environment without sustaining an impairment of its ability to accomplish its designated mission. Videlicet, on the battlefield, an aircraft should have the capability of not being detected by hostile under hostile threats environment (low detection susceptibility), the capability of resisting lethal damages while hit by hostile threats (low vulnerability), and the capability of restoring aircraft functions to perform the next task by rapid repair (high combat resilience). Therefore aircraft susceptibility, vulnerability and combat resilience are three basic effect factors of aircraft survivability [6]. Susceptibility is about the capability of an aircraft to avoid being detected and hit, vulnerability is about the capability of withstanding hits, and combat resilience is the capability of a battle-scarred aircraft to restore its mission capability by rapid repair. When being detected and hit, an aircraft with low vulnerability is not easy to be killed and can land despite battle damages; after rapid repair, the battle-scarred aircraft can restore its battle effectiveness, and thus the survivability is enhanced.

Combat resilience is defined as the capability of an aircraft to restore its mission capability or self-saving capability by rapid repair in the stated time at war. According to the definition, combat resilience has relation to aircraft reliability, maintainability and supportability [6]. If the reliability is higher, the capability of an aircraft to resist battle damage at war is better, and the repair workload is less. Combat resilience is the performance of a battle-scarred aircraft to be repaired effectively and rapidly, and is the representation of maintainability and supportability at war. Therefore, combat resilience can be measured with reliability, maintainability and supportability (RM&S).

Aircraft susceptibility, vulnerability and combat resilience are three basic effect factors of aircraft survivability, and combat resilience can be measured with RM&S. So susceptibility, vulnerability, reliability, maintainability, supportability can be considered as the effect factors of aircraft survivability (see Fig. 1).

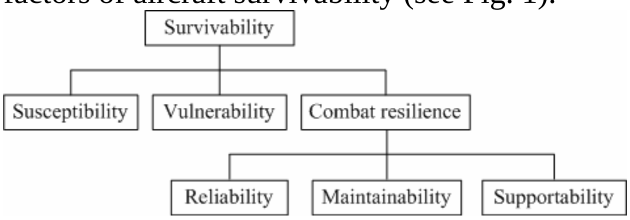

Fig. 1 The Effect Factors of Aircraft Survivability

3 Aircraft Survivability Evaluation Methods

Modern aircraft survivability has relation to aircraft susceptibility, vulnerability, reliability, maintainability and supportability. If aircraft susceptibility and vulnerability are lower, aircraft survivability is higher; if aircraft RM&S are higher, aircraft survivability is also higher. According to aircraft susceptibility, vulnerability, reliability, maintainability and supportability, aircraft survivability evaluation methods can be given.

3.1 A Weight Coefficient Method

The effect degrees of the factors on aircraft survivability are different, aircraft survivability evaluation should consider the effect degree of every factor. According to importance degrees of the effects of the factors on survivability, the weight coefficient method endues every factor with a weight coefficient, and then obtains the survivability evaluation value from every effect factor value and its weight coefficient. Aircraft survivability evaluation based on the weight coefficient method can be described as [6]

$$z = \sum_{i=1}^{2} \xi_i \frac{1}{F_i} + \sum_{i=3}^{5} \xi_i F_i \,, \tag{1}$$

where F_i (i=1,2) are aircraft susceptibility and vulnerability, F_i (i=3,4,5) are aircraft reliability, maintainability and supportability; ξ_i ($i = 1,2,\cdots,5$) are the weight coefficients of the corresponding factors, their summation is 1.

3.1.1 Susceptibility

Susceptibility is the probability of a military aircraft to be hit while on its mission, and can be measured with P_H which is the probability of being hit of the military aircraft. P_H can be described as

$$P_H = P_A \cdot P_{DIT} \cdot P_{LGD} \,, \tag{2}$$

where P_A is the probability of single threat or multi-threats to be active and prepare to attack the aircraft; P_{DIT} is the probability of the aircraft to be detected, identified and tracked by threats; P_{LGD} is the probability of the aircraft to be hit by threats.

3.1.2 Vulnerability

Aircraft vulnerability is the degree that an aircraft can't resist the hit by damage mechanism. Aircraft vulnerability can be described with $P_{K/H}$ that is the probability of an aircraft to be damaged by single hit or multi-hits,

$P_{K/H}$ is a conditional probability. Actually, vulnerability is considered as the ratio of the number of lost aircrafts to the number of hit aircrafts; vulnerability can also be measured by vulnerability area A_V, A_V can be described as

$$A_V = A_P \cdot P_{K/H}\,, \tag{3}$$

where A_P is the exposed area.

3.1.3 Reliability

Aircraft reliability is defined as the capability of an aircraft to accomplish it stated function under the stated condition in the stated time. Reliability can be measured commonly with T_{MTBF} that is the mean time between failures.

3.1.4 Maintainability

Maintainability is the probability of keeping or restoring the prescriptive state by the stated procedure for the period of time intended under the operating conditions encountered. It can be measured with T_{MTTR} that is the mean time to repair:

$$T_{\mathrm{MTTR}} = \sum_{i=1}^{n} (\lambda_k M_{ctk}) \Big/ \sum_{i=1}^{n} (\lambda_k)\,, \tag{4}$$

where M_{ctk} and λ_k are the mean time to repair and failure rate of number k component of an aircraft; n is the number of an aircraft components.

3.1.5 Supportability

Supportability is the capability of system design characteristics and planned logistic resources to satisfy operational requirements during combat readiness time and wartime. It can be measured with military aircraft readiness or operational availability (A_{O})

$$A_{\mathrm{O}} = \frac{T_{MTBM}}{T_{MTBM} + T_{MDT}}\,, \tag{5}$$

where T_{MTBM} is the mean time between maintains; T_{MDT} is mean down time.

Selecting a basal aircraft or a basal aircraft survivability design scheme, aircraft survivability evaluation based on the weight coefficient method can be standardized as

$$z = \xi_1 \left(\frac{(P_H)_{\mathrm{b}}}{P_H} \right) + \xi_2 \left(\frac{(P_{K/H})_{\mathrm{b}}}{P_{K/H}} \right) + \xi_3 \left(\frac{T_{MTBF}}{(T_{MTBF})_{\mathrm{b}}} \right) + \xi_4 \left(\frac{(T_{MTTR})_{\mathrm{b}}}{T_{MTTR}} \right) + \xi_5 \left(\frac{A_{\mathrm{O}}}{(A_{\mathrm{O}})_{\mathrm{b}}} \right) \tag{6}$$

where the subscript '*b*' represents a basal aircraft or a basal aircraft survivability design scheme.

3.2 A Synthetic Tradeoff Method

Aircraft susceptibility and vulnerability are lower, RM&S are higher, and then aircraft survivability is high. In aircraft survivability design, the optimal scheme is to obtain an aircraft with low susceptibility and vulnerability and high RM&S. So aircraft survivability can be evaluated with a synthetic tradeoff method. Aircraft survivability evaluation based on the synthetic tradeoff method can be described as

$$z = \frac{T_{MTBF} \cdot A_{\mathrm{O}}}{P_H \cdot P_{K/H} \cdot T_{MTTR}}\,. \tag{7}$$

Similarly, the standardized synthetic tradeoff model is

$$z = \frac{(P_H)_{\mathrm{b}}}{P_H} \cdot \frac{(P_{K/H})_{\mathrm{b}}}{P_{K/H}} \cdot \frac{T_{MTBF}}{(T_{MTBF})_{\mathrm{b}}} \cdot \frac{(T_{MTTR})_{\mathrm{b}}}{T_{MTTR}} \cdot \frac{A_{\mathrm{O}}}{(A_{\mathrm{O}})_{\mathrm{b}}}\,. \tag{8}$$

The aircraft survivability evaluation methods can not only evaluate aircraft survivability, but also apply to compare aircraft survivability design schemes.

4 The Sustainable Developability of Military Aircraft

Availability, dependability and capability are key factors to determine aircraft system effectiveness and cost. Availability and capability are fixed when aircraft design is finalized [5]. During peacetime, the decisive factor in the aircraft dependability is mission reliability that does not take into account hostile threats; but during wartime, the decisive factor is aircraft survivability. Therefore, in time of war, aircraft survivability is equivalent to dependability where being hostile threats, and is equivalent to effectiveness [7]. In modern military aircraft design, survivability design affects directly the effectiveness and cost of the aircraft [8, 9].

To scientifically integrate the effectiveness and life cycle cost of military aircraft, a new concept "the sustainable developability of military aircraft" is proposed. The sustainable developability of military aircraft is defined as the capability of a military aircraft to make valid use of national defense resources to form sustainable battle effectiveness during the total life cycle. It is a new characteristic that integrates the system effectiveness and life cycle cost of military aircraft into a whole, and can reflect the integrative strength of military aircraft [4]. The sustainable developability of military aircraft can be described with *DV*

$$DV = CE/LCC, \qquad (9)$$

where *CE* is sustainable battle effectiveness and *LCC* is life cycle cost.

The physical meaning of *DV* in expression (9) is the battle effectiveness obtained with unit life cycle cost; *DV* expresses the probability to make valid use of national defense resources [4].

Generally, the sustainable developability of an aircraft is relative to another aircraft. Before determining the sustainable developability of an aircraft, a basal aircraft has to be selected. So the sustainable developability of military aircraft can also be described with

$$M(DV) = \frac{M(CE)}{M(LCC)} = \frac{CE/(CE)_b}{LCC/(LCC)_b} = \frac{CE/LCC}{(CE/LCC)_b} = \frac{DV}{(DV)_b}, \qquad (10)$$

where $M(DV)$ is the regularized *DV*; $M(CE)$ is the regularized *CE* and $M(LCC)$ is the regularized *LCC*. The subscript '*b*' denotes the basal aircraft.

The physical meaning of $M(DV)$ in expression (10) expresses the probability of the aircraft to make valid use of national defense resources compared with the basal aircraft [3].

When evaluating the sustainable developability of an aircraft, the variable changes compared with the basal aircraft are the most concerned. So expression (11) should be modified as

$$M(DV) = \frac{1+\Delta M(CE)}{1+\Delta M(LCC)}, \qquad (11)$$

where $\Delta M(CE)$ is regularized *CE* change that can be described as

$$\Delta M(CE) = \frac{CE-(CE)_b}{(CE)_b}. \qquad (12)$$

$\Delta M(LCC)$ is regularized *LCC* change that can be described as

$$\Delta M(LCC) = \frac{LCC-(LCC)_b}{(LCC)_b}. \qquad (13)$$

According to expression (11) and considering correlative restrictions, the feasible region and optimal scheme line of modern military aircraft design are obtained as fig.2.

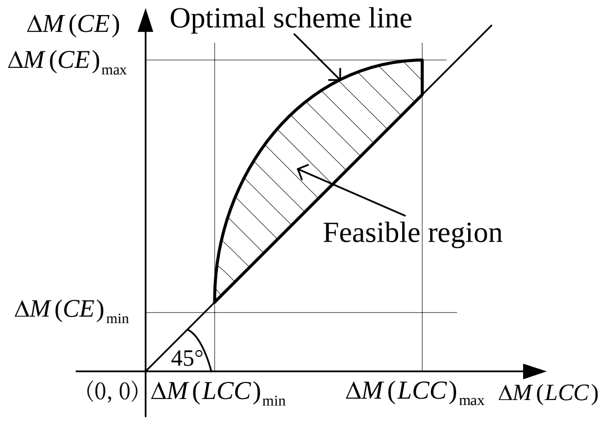

Fig. 2 Compromise Analysis of Sustainable Developability

5 Application of Sustainable Developability in Survivability Design

Survivability design affects directly the effectiveness and cost of an aircraft, the sustainable developability can measure the benefit of survivability design. Application of sustainable developability in aircraft survivability design can be expressed as

$$M_S(DV) = \frac{1+\Delta M_S(CE)}{1+\Delta M_S(LCC)}, \qquad (14)$$

where $\Delta M_S(CE)$ is the effect of survivability design on system effectiveness that can be described as

$$\Delta M_S(CE) = \frac{(CE)_S - (CE)_b}{(CE)_b}. \qquad (15)$$

$\Delta M_S(LCC)$ is the effect of survivability design on life cycle cost that can be described as

$$\Delta M_S(LCC) = \frac{(LCC)_S - (LCC)_b}{(LCC)_b}, \qquad (16)$$

Where $(CE)_S$ is the system effectiveness of the aircraft that is designed with survivability; $(LCC)_S$ is the life cycle cost of the aircraft that is designed with survivability.

An aircraft can be designed with survivability under the constraints of aircraft performance and cost. If $M_S(DV) > 1$ and the survivability design is in the feasible region of military aircraft design, the aircraft survivability design has well benefit and is feasible; else, the aircraft survivability design is not feasible.

6 Conclusions

Aircraft survivability evaluation methods reflect the main effect factors of aircraft survivability completely. Survivability not only involves aircraft susceptibility and vulnerability, but also has relation to aircraft combat resilience and the battle damage assessment and repair ability of the military (i.e. maintainability and supportability). Aircraft survivability evaluation integrates the survivability of military aircraft itself and the battle damage assessment and repair ability of the military into a man-machine compositive evaluation system.

The sustainable developability of military aircraft is a top characteristic to express the integrative strength of military aircraft. It integrates aircraft affordability, lethality, supportability and survivability into a whole, opens out the essence of military aircraft development, and can realize the evaluation and optimal design of military aircraft. The proposal of the sustainable developability has great significance to military, and is the inevitability of the military aircraft scientific development.

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