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Ramp-Strike Risk Evaluation Making of Carrier-Based Aircraft

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Abstract

To make "Ramp-Strike Risk" evaluation making accurately, this paper introduces a new wave-off risk assessment method based on neural network of carrier-based aircraft. On account of defining "Wave-Off Retain Clearance", the wave-off operation system with military power and vertical elevator is established as evaluation medium. The "Wave-Off Risk State Area" established by limited wave-off envelope can reduce network training burden, and the quantitative "Ramp-Strike Risk" function with flight state is presented through BP neural network finally. Simulation results show that the risk with flight states can be predicted by using new estimation method, moreover auxiliary rectification and early-warning for landing is provided.

Keywords: *Ramp-Strike Risk; Evaluation Making; Wave-Off Retain Clearance; Neural Network; Wave-Off Risk State Area*

1. Introduction

On account of the significance of "Ramp-Strike Risk" problem and the gravity of evaluation circumstances, "Ramp-Strike Risk" evaluation making technology of carrier-based aircraft has the identical status with landing technique from a safety point of view. It is meaningful for analyzing risk emerging reason and making reasonable evaluation [1-2]. At present, the research of "Ramp-Strike Risk" evaluation making is based on initial flight state of aircraft and estimated qualitatively. This method is rough for analyzing approaching risk tendency by Landing Signal Officers (LSO) [3].

To make up the limitation of qualitative "Ramp-Strike Risk" evaluation technology, this paper presents a new risk evaluation making method based on neural network on account of the synthesize wave-off motion model. It computes landing risk under current flight status in real time. Simulation results show the predictive accuracy of the new way.

2. Problem Formulation

"Ramp-Strike Risk" where hook strikes ramp is the much important risk for carrier pilots universally acknowledged, and traditional wave-off risk research aims at this one. Because of fast velocity of aircraft and uncertainty of approaching status, it is difficult to evaluate the risk. Figure 1 shows the description of carrier-based aircraft "Ramp-Strike Risk".

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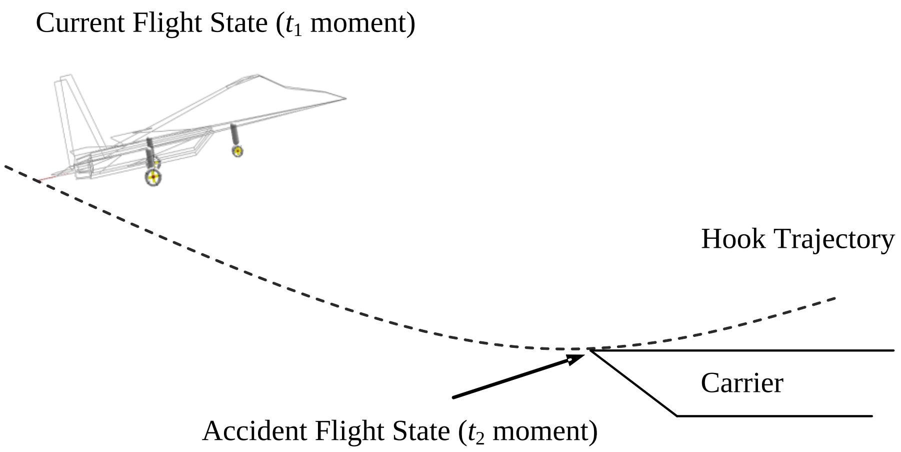

Figure 1 "Ramp-Strike Risk" of Carrier-Based Aircraft

Take into account of all of influencing factors, we will establish high-dimensional space probability function for the whole landing approach. "Ramp-Strike Risk" at t_1 moment is the actual accident occur probability at t_2 moment.

$$R(p_1^{t_1}, p_2^{t_1}, \dots, p_n^{t_1}) = f(p_1^{t_2}, p_2^{t_2}, \dots, p_n^{t_2}) \, . \tag{1}$$

Where $p_i^{t_k}$ (i=1, 2,…,n; k=1, 2) are flight states and environment states at t_k moment.

Definition 1. "Wave-Off Retain Clearance (WRC)" is defined as the nearest clearance between hook of aircraft and ramp of carrier during wave-off process. "Ramp-Strike Risk" evaluates with WRC $S_{\min}^{t_k}$ defined as [4-8]:

$$R(p_1^{t_k}, p_2^{t_k}, \dots, p_n^{t_k}) = g(S_{\min}^{t_k}) \, . \tag{2}$$

To consider the generalization of system, this paper introduces BP neural network to impend over WRC $S_{\min}^{t_k}$, and finishes the conversion from flight state to $S_{\min}^{t_k}$.

3. Wave-off Maneuvering Analysis

3.1. Wave-off operation

Wave-off operation is the flight maneuvering when carrier-based aircraft makes sure land unsafely, it guarantees reasonable climbing rate and land safely. The force analysis of aircraft responding wave-off operation is shown as Figure 2.

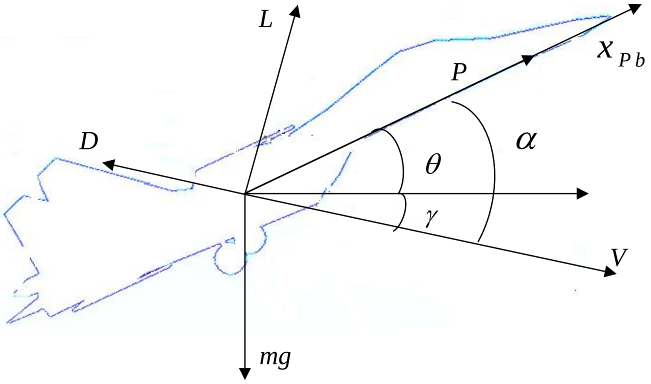

Figure 2 Force Analysis of Wave-off Operation

Through wave-off maneuvering process, the vertical motion relationship for carrier-based aircraft is:

$$\begin{cases} dV_{xg} / dt = (P\cos\theta + L\sin\gamma - D\cos\gamma)/m \\ dV_{zg} / dt = (G - P\sin\theta - L\cos\gamma - D\sin\gamma)/m \\ dx_g / dt = V\cos\gamma \\ dh/dt = V\sin\gamma \end{cases}. \tag{3}$$

Where lift force is:

$$L = C_L \rho V^2 S / 2 . \tag{4}$$

$$C_L = C_{L0} + C_{L\alpha}\alpha + C_{L\delta_e}\delta_e . \tag{5}$$

Drag force is:

$$D = C_D \rho V^2 S / 2 . \tag{6}$$

$$C_D = C_{D0} + A_{L\alpha}\alpha^2 + A_{\delta_e}\delta_e^2 . \tag{7}$$

3.2. Wave-off system

To choose military power and fuzzy elevator as wave-off maneuvering controller which can guarantee an appropriate angle of attack kept for reducing altitude loss [9], there are three limiting factors as follow.

Definition 2[10]. Airplane wave-off boundary criteria:

(1)Hook-to-ramp clearance shall be 10 feet.

(2)Pilot response shall be 0.7s.

(3)Wave-off technique is including military power with longitudinal control.

Through the rules above, the wave-off motion model which controlled by military thrust and elevator integrated control is established as Figure 3. We can describe the wave-off trajectory of carrier-based aircraft with function (8) as follow.

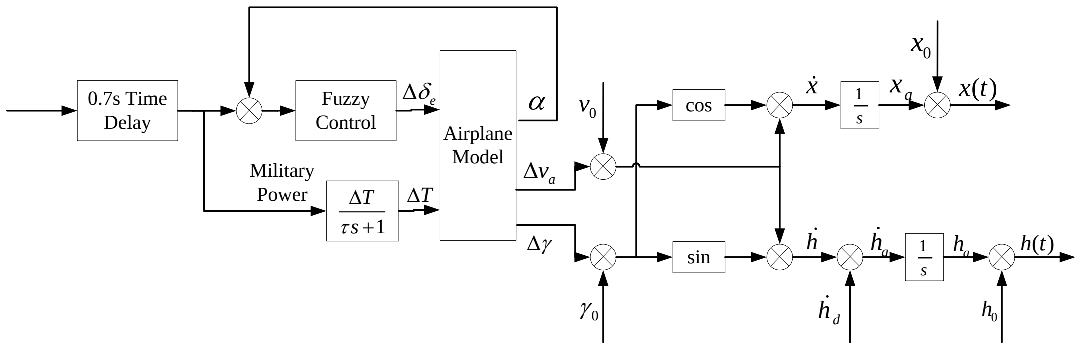

Figure 3 Military Thrust and Elevator Integrated Control Wave-off System

$$\begin{cases} x(t) = x_0 + \int (v_0 + \Delta v_a) \times \cos(\gamma_0 + \Delta\gamma) \\ h(t) = h_0 + \int [(v_0 + \Delta v_a) \times \sin(\gamma_0 + \Delta\gamma) + \dot{h}_d] \end{cases} . \tag{8}$$

Where x_0, h_0, v_0, γ_0 are the initial distance from ramp, height, closing speed and gliding angle of aircraft, and $\dot{h}_d$ is the interference sink rate.

To reduce mating difficulty of pilot conduct and optimal state, we choose the fuzzy control of manipulating elevator. Figure 4-6 present the attack angles, height deviations and wave-off boundaries with an interference sink rate $\dot{h}_d = 0.5$ m/s and approach speed v=69.96m/s for different control systems [10-12].

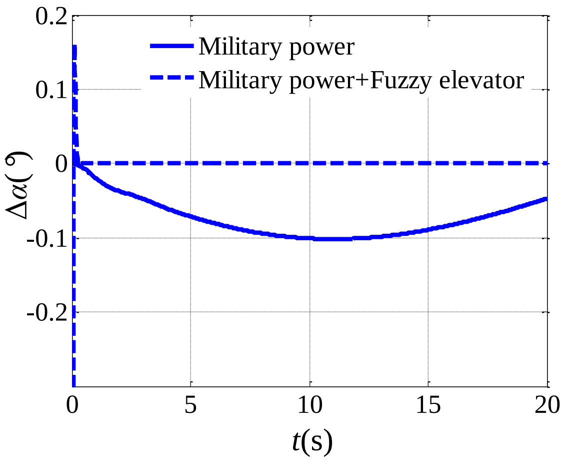

Figure 4 Response of Attack Angles

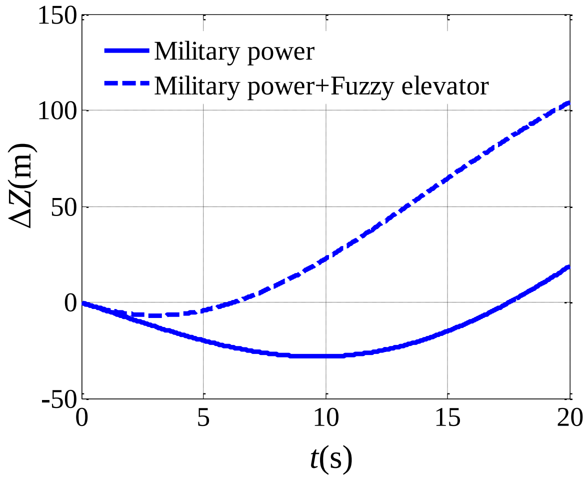

Figure 5 Response of Height Deviations

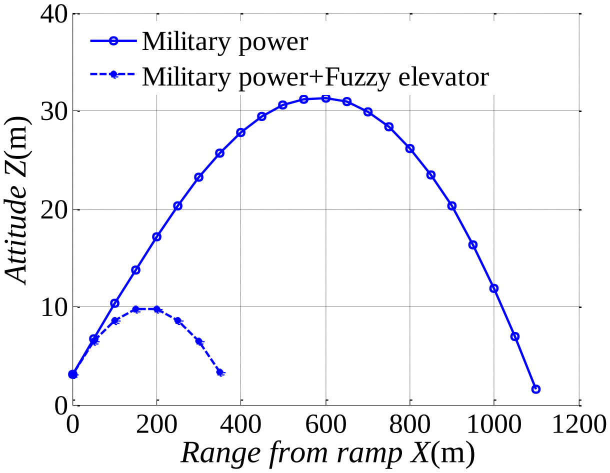

Figure 6 Wave-off Boundaries

Compared with only military power control technology, the integrated fuzzy control can decrease altitude loss (from 28.32m to 6.86m), and has better control effect.

4. "Ramp-Strike Risk" Evaluation Making Based on Neural Network

4.1. Wave-Off Risk State Area (WORSA)

There are some affecting factors for the final hook-to-ramp clearance, such as: aircraft position (x, z), closing speed v, interference sink rate $\dot{h}_d$ and ramp motion h_s. Figure 7 shows the dynamic curves of wave-off envelop with influencing factors above.

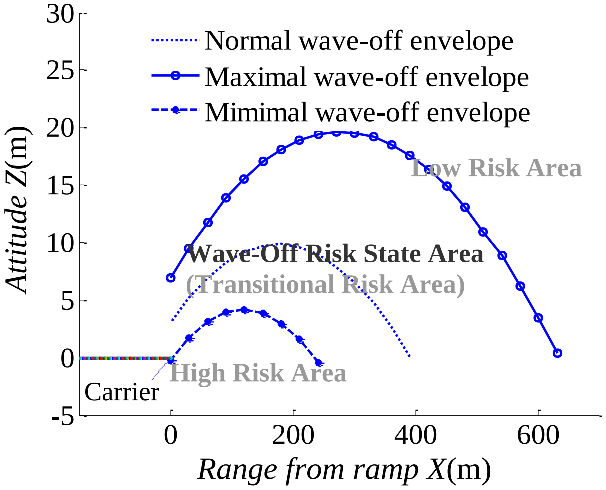

Figure 7 Wave-Off Risk State Area

"Maximal envelope" and "Minimal envelope" decollate the landing space into three parts: "Low Risk Area $\Gamma_{LowRisk}$", "High Risk Area $\Gamma_{HighRisk}$" and "Transitional Risk Area $\Gamma_{TransRisk}$". It attaches the constants for $\Gamma_{LowRisk}$ and $\Gamma_{HighRisk}$ on account of less relationship related landing risk. But in $\Gamma_{TransRisk}$, there is a close relation between "Ramp-Strike Risk" and flight states of aircraft. As we know, $\Gamma_{TransRisk}$ is the "Wave-Off Risk State Area" in this paper. Function (9) can describe "Ramp-Strike Risk" under different areas.

$$R(p_1^{t_k}, p_2^{t_k}, \ldots, p_n^{t_k}) = \begin{cases} 0.1 & (x,z) \in \Gamma_{LowRisk} \\ g(S_{\min}^{t_k}) & (x,z) \in \Gamma_{TransRisk} \\ 0.9 & (x,z) \in \Gamma_{HighRisk} \end{cases}. \tag{9}$$

4.2. BP neural network risk evaluation making

4.2.1. Model training and testing: Figure 8 shows the BP network model with a 4-7-1 structure. After 600 model training, the network error shall be 0.00014. 102 groups of normalized test data is input to test for verifying generalization ability, as shown in Table 1.

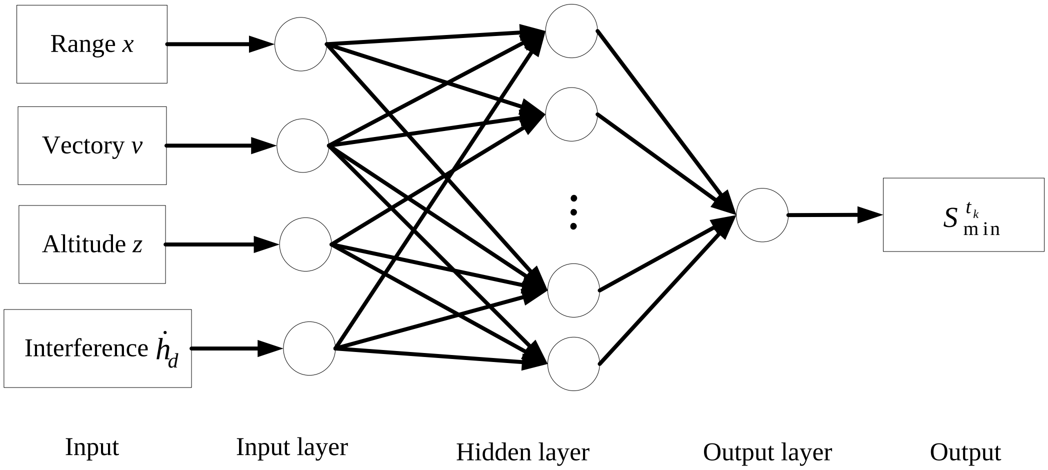

Figure 8 BP Network Model

Table 1 BP Neural Network Testing

Index	Input	Excepted output	Actual output	Index	Input	Excepted output	Actual output
1	(0.1 0.1 0.1 0.1)	0.1	0.1096	15	(0. 5 0.1 0.58 0.3)	0.1306	0.1620
2	(0.1 0.1 0.74 0.1)	0.1	0.1101	16	(0.5 0.3 0.1 0.9)	0.324 9	0.326 5
3	(0.1 0.3 0.26 0.26)	0.1878	0.1893	17	(0.5 0.3 0.9 0.26)	0.121 2	0.147 4
4	(0.1 0.3 0.9 0.26)	0.1878	0.1903	18	(0.5 0.5 0.74 0.3)	0.214 4	0.236
5	(0.3 0.1 0.42 0.3)	0.221 8	0.1890	19	(0.5 0.7 0.26 0.42)	0.433 3	0.444 4
6	(0.3 0.1 0.9 0.42)	0.241 9	0.1867	20	(0.5 0.7 0.9 0.74)	0.274 1	0.285 8
7	(0.3 0.1 0.74 0.42)	0.2231	0.1843	…	… …	… …	… …
8	(0.3 0.3 0.74 0.26)	0.2099	0.2124	96	(0.9 0.1 0.1 0.26)	0.6356	0.6605
9	(0.3 0.3 0.9 0.74)	0.1874	0.1882	97	(0.9 0.1 0.58 0.5)	0.4078	0.3501
10	(0.3 0.3 0.58 0.74)	0.1412	0.1370	98	(0.9 0.3 0.1 0.9)	0.6315	0.6571
11	(0.3 0.5 0.1 0.26)	0.1794	0.1585	99	(0.9 0.3 0.42 0.42)	0.8846	0.8909
12	(0.3 0.5 0.74 0.3)	0.1411	0.1417	100	(0.9 0.3 0.9 0.74)	0.8372	0.8046
13	(0.3 0.7 0.58 0.26)	0.2354	0.2355	101	(0.9 0.74 0.9 0.74)	0.8745	0.8224
14	(0.5 0.1 0.1 0.7)	0.2375	0.2560	102	(0.9 0.9 0.9 0.26)	0.8812	0.9087

4.2.2. Nonlinear transformation: After training network and inverse normalization (10), it is necessary to use nonlinear function (11) realizing the transformation from $s^{t_k}_{\min}$ in $\Gamma_{TransRisk}$ to "Ramp-Strike Risk" $R(x_k, z_k, v_k, \dot{h}_{dk})$.

$$S^{t_k}_{\min} = \frac{(vS^{t_k}_{\min} - 0.1)\times((S^{t_k}_{\min})_{\max} - (S^{t_k}_{\min})_{\min})}{0.8} + (S^{t_k}_{\min})_{\min} = 12.5\times vS^{t_k}_{\min} - 1.25 \,. \qquad (10)$$

$$R(x_k, z_k, v_k, \dot{h}_{dk}) = \begin{cases} 0.1 & (x,z)\in\Gamma_{LowRisk} \\ g(S^{t_k}_{\min}) = \dfrac{4}{5+5\exp(1.2\times S^{t_k}_{\min} - 5)} + 0.1 & (x,z)\in\Gamma_{TransRisk} \\ 0.9 & (x,z)\in\Gamma_{HighRisk} \end{cases} . \qquad (11)$$

5. Simulation

The 3-D surfaces of Wave-Off Retain Clearance $s^{t_k}_{\min}$ and "Ramp-Strike Risk" $R(x_k, z_k, v_k, \dot{h}_{dk})$ with *v*=55 m/s，67 m/s and 85 m/s are drawn as Figure 9 and Figure 10.

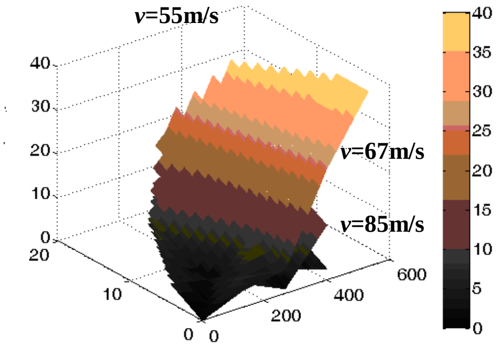

Figure 9 3D Surfaces of WRC

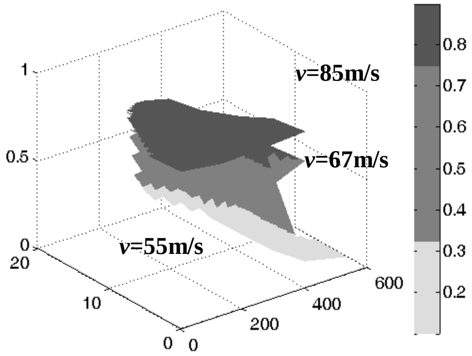

Figure 10 3D Surfaces of "Ramp-Strike Risk"

"Ramp-Strike Risk" increases with reduction of range and altitude. The law that the risk is gradually increasing with the increase of *v* can be obtained by the comparison of risk surface with different velocities.

The 3-D surfaces of Wave-Off Retain Clearance $s^{t_k}_{\min}$ and "Ramp-Strike Risk" $R(x_k, z_k, v_k, \dot{h}_{dk})$ with $\dot{h}_d = -2$ m/s， $\dot{h}_d = 0$ m/s and $\dot{h}_d = 2$ m/s are shown as Figure 11-12.

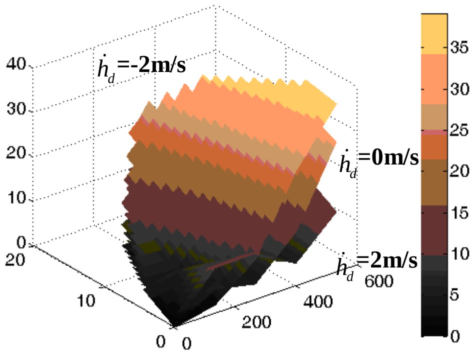

Figure 11 3D Surfaces of WRC

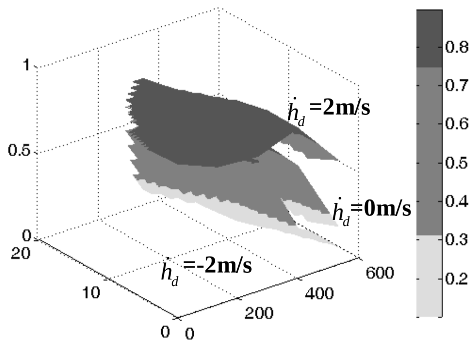

Figure 12 3D Surfaces of “Ramp-Strike Risk”

The risk is still increasing with range decreasing and attitude is proved again, and risk increases with the increase of $\dot{h}_d$ can be obtained.

6. Conclusion

This paper represents a new assessment way for “Ramp-Strike Risk” where Wave-Off Retain Clearance as evaluation index. With the description of Wave-Off Risk State Area, a new evaluation method through neural network can be introduced. Through simulation, quantitative risk expression can implement under any flight states.

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