International Journal of Multimedia and Ubiquitous Engineering
Vol.11, No.4 (2016), pp. 243-252
http://dx.doi.org/10.14257/ijmue.2016.11.4.25

A Generalized Design Making for Safe Wave-Off Area of Carrier-Based Aircraft

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Abstract

To reduce the landing risk of carrier-based aircraft during wave-off maneuvering, this paper introduced a generalized design manner of safe wave-off area. Wave-off maneuvering procedure and force should be analyzed, and safe wave-off area near from touchdown and safe wave-off area far from touchdown would be defined. Compositing traditional wave-off criterion, a generalized design manner of safe wave-off area is presented. The model simulation results indicate the better performance of the design one and the influence of safe wave-off area with velocity and interference rate of descend had been researched.

Keywords*: Safe Wave-Off Area; Deck Clearance; Sea-Surface Clearance; Carrier-Based Aircraft*

1. Introduction

Because of the particularity of operation situation and complexity of landing process, wave-off maneuvering as one of normal operations also exists risk. To ensure landing safely during final approach, it is important to research the safe wave-off strategy which is based on safe wave-off area [1-5].

Traditional safe wave-off area is established with safe wave-off criterion which considering ramp clearance merely, and it is inadequate for the whole approach. Under the traditional safe wave-off area design manner, this paper will present a generalized design making for safe wave-off area of carrier-based aircraft.

The rest of this paper is structured as follows: next section we first analyze the wave-off maneuvering procedure. Section 3 illustrates the design manner of traditional safe wave-off area. Generalized safe wave-off area should be shown in Section 4. Finally, we conduct simulation analysis on safe wave-off area influencing factors.

2. Wave-Off Maneuvering Procedure Analysis

Generally speaking, "wave-off" maneuvering should be defined as "a give-up flight when confirming landing insecurity for carrier-based aircraft", and it is a most important manner to prevent landing risk happening [6-12].

The wave-off maneuvering procedure should be described as steps below:

Step 1: The wave-off command is received by pilots of carrier-based aircraft from Landing Signal Officer (LSO) on the deck of carrier.

Step 2: Pilot stops landing, and carries out wave-off maneuvering.

Step 3: Throttle should be operated, to military thrust position.

Step 4: Stick also would be handled, to keep suitable angle-of-attack.

The force analysis of wave-off maneuvering answering on carrier-based aircraft as shown in Figure 1.

ISSN: 1975-0080 IJMUE

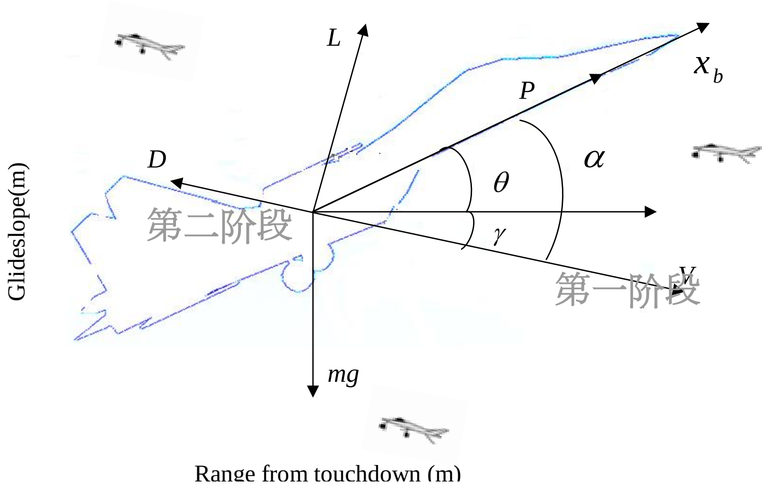

Figure 1. Force Analysis of Wave-Off Maneuvering Answering

As shown in Figure 1, the force relationship of vertical loop during wave-off maneuvering is:

$$\begin{cases} dV_{xg}/dt = (P\cos\theta + L\sin\gamma - D\cos\gamma)/m \\ dV_{zg}/dt = (G - P\sin\theta - L\cos\gamma - D\sin\gamma)/m \\ dx_g/dt = V\cos\gamma \\ dh/dt = V\sin\gamma \end{cases} \tag{1}$$

Where aerodynamic lift $L = C_L \rho V^2 S/2$, and $C_L = C_{L0} + C_{L\alpha}\alpha + C_{L\delta_e}\delta_e$; aerodynamic drag $D = C_D \rho V^2 S/2$, and $C_D = C_{D0} + A_\alpha \alpha^2 + A_{\delta_e}\delta_e^2$.

The longitudinal wave-off flight voyage of carrier-based aircraft is shown as Figure 2.

There are two maneuvering steps answering wave-off.

1st step: Flight velocity is increasing, Rate of Descend (ROD) is decreasing, and longitudinal position will be drop until ROD reaches zero.

2nd step: Vertical velocity will be reverse, and longitudinal position will be rise.

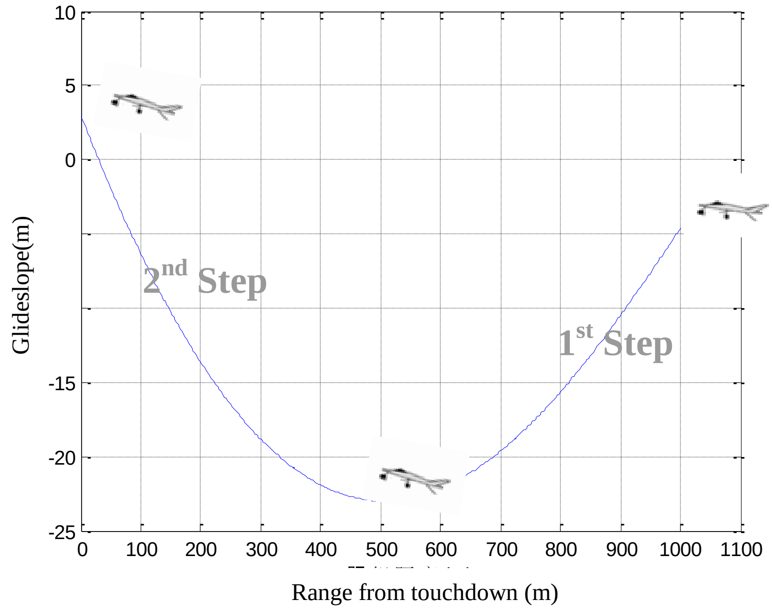

Figure 2. Longitudinal Wave-Off Flight Voyage of Carrier-Based Aircraft

3. Traditional Safe Wave-Off Area

Safe altitude when aircraft reaches ramp (we call it ramp clearance), response lag of pilots to wave-off command and essential wave-off maneuvering operational approach should be considered in traditional safe wave-off criterion [6,13-19].

(1) Ramp clearance will be 3m to keep probable pitch, roll of aircraft and pitch, heave of carrier.

(2) Response time of pilot to wave-off command is not greater than 0.7s.

(3) Essential wave-off maneuvering operational approach is military thrust control merely without stick operation.

In line with traditional safe criterion, the wave-off system structure of carrier-based aircraft is shown in Figure 3.

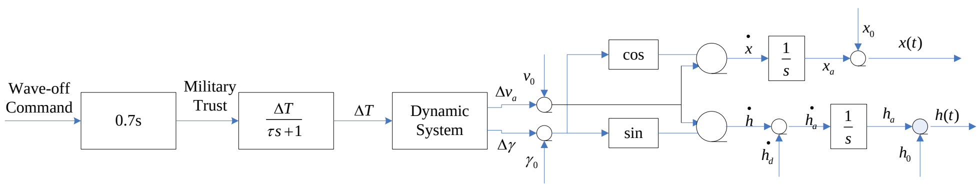

Figure 3. Wave-Off System Structure of Carrier-Based Aircraft

The wave-off trajectory should be drawn with x and h during different moments as shown in Figure 4.

$$\begin{cases} x(t) = x_0 + \int (v_0 + \Delta v_0) \times \cos(\gamma_0 + \Delta\gamma) \\ h(t) = h_0 + \int (v_0 + \Delta v_0) \times \sin(\gamma_0 + \Delta\gamma) + \dot{h}_d \end{cases} \tag{2}$$

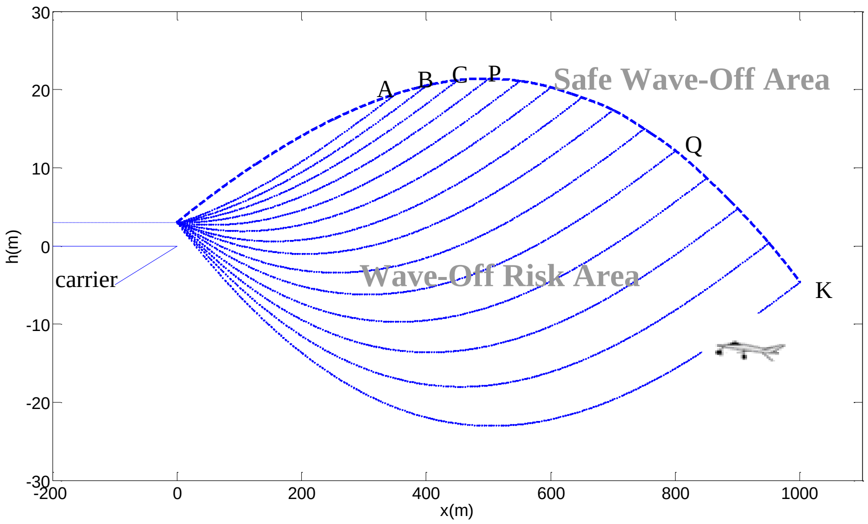

Figure 4. Traditional Safe Wave-Off Area

4. Generalized Safe Wave-Off Area

As a matter of fact, it is complicated to glideslope, 3m ramp clearance is a most important factor for affecting wave-off safety. However, this criterion is only a safe index of one point during final approach, and not sufficient to formulate safe wave-off area. It is essential to extend area for ensuring wave-off safety.

4.1. Safe Wave-Off Area Near from Touchdown

Definition 1: Deck Clearance: During wave-off maneuvering of carrier-based aircraft, the vertical altitude between tail-hook and deck when the horizontal position of carrier-based aircraft locates over the deck and ROD is zero.

In the near touchdown period, it is one of criterions to keep deck clearance during wave-off process. Follow traditional ramp clearance, let minimal safe surplus of deck clearance is 3m, and the near part of safe wave-off area is changing, as shown in Figure 5.

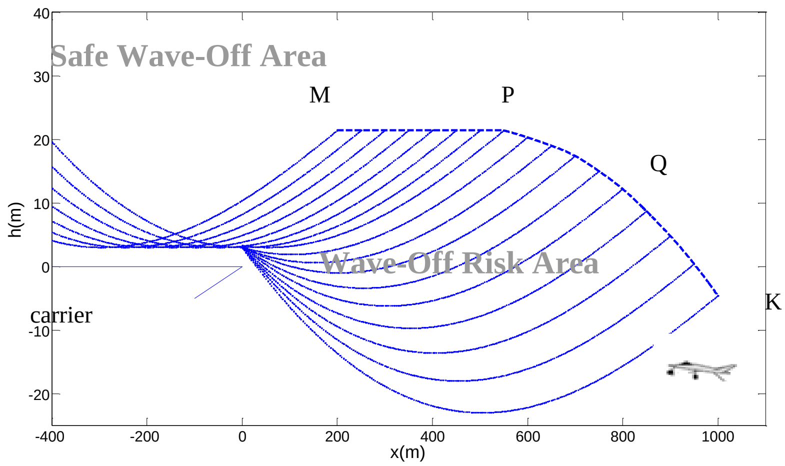

Figure 5. Safe Wave-Off Area Near from Touchdown

4.2. Safe Wave-Off Area Far from Touchdown

Definition 2: Sea-Surface Clearance: During wave-off maneuvering of carrier-based aircraft, the vertical altitude between tail-hook and sea level when the ROD is zero.

In the far touchdown period, it is one of criterions to keep sea-surface clearance during wave-off process. Follow traditional ramp clearance, let minimal safe surplus of sea-surface clearance is 3m, and the far part of safe wave-off area is changing, as shown in Figure 6.

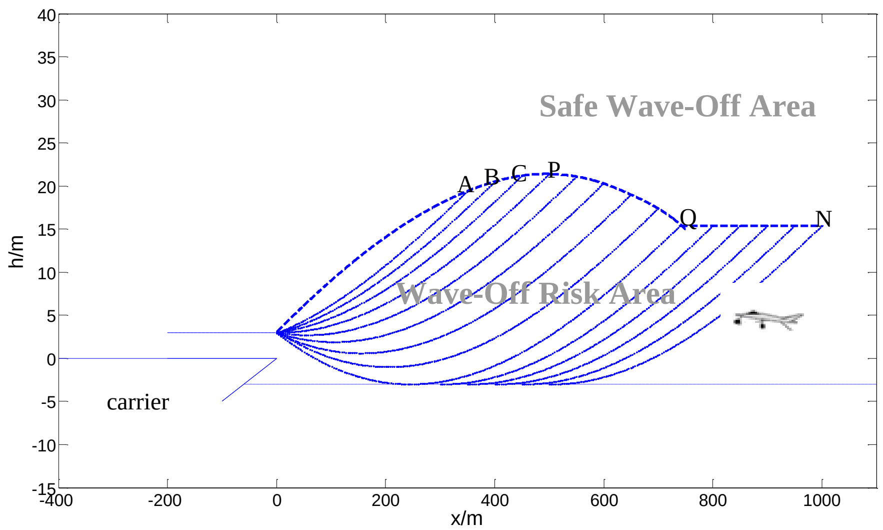

Figure 6. Safe Wave-Off Area Far from Touchdown

4.3. Generalized Safe Wave-Off Area

Traditional wave-off area, safe wave-off area near from touchdown and safe wave-off area far from touchdown should be synthesized together, in purpose of wave-off safety, we define generalized safe wave-off criterion.
Definition 3: Generalized Safe Wave-Off Criterion:

(1) Ramp clearance will be 3m to keep probable pitch, roll of aircraft and pitch, heave of carrier.
(2) Response time of pilot to wave-off command is not greater than 0.7s.
(3) Essential wave-off maneuvering operational approach is military thrust control merely without stick operation.
(4) Deck clearance will be 3m to avoid deck strike.
(5) Sea-surface clearance will be 3m to avoid sea follow.

According to generalized safe wave-off criterion, generalized safe wave-off area will be drawn as Figure 7.

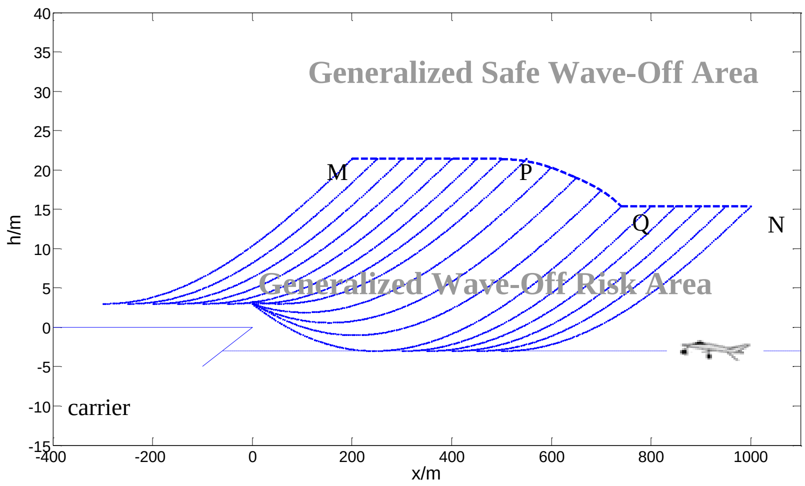

Figure 7. Generalized Safe Wave-Off Area

5. Simulation Analysis on Safe Wave-Off Area Influencing Factors

5.1. Flight Velocity

Simulation original condition:
(1) Range from touchdown x=1000m;
(2) Interference ROD $\dot{h}_d$ =0m/s;
(3) Velocity V=70m/s, 75m/s, 80m/s, 85m/s respectively.
The wave-off voyages with different velocities are shown as Figure 8.

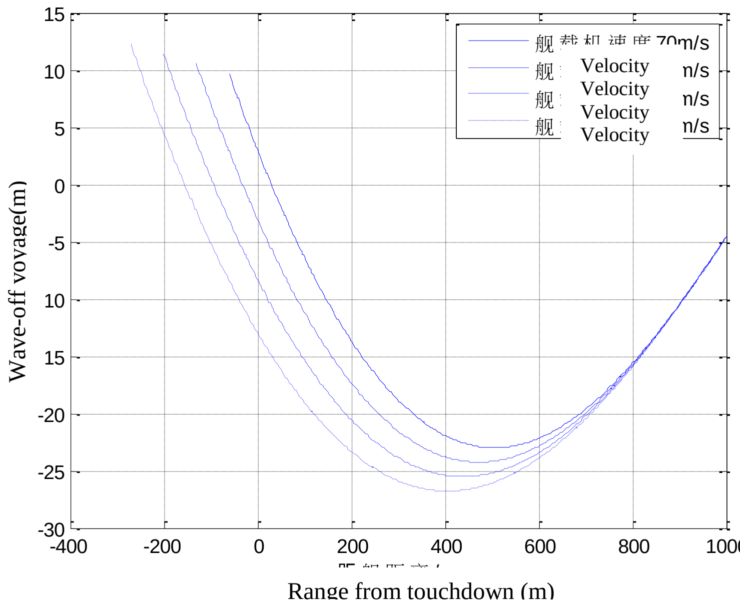

Figure 8. Wave-Off Voyages with Different Velocities

Comparing different curves in Figure 8, in the same wave-off maneuvering operation time, it is more horizontal displacement with more velocity, and because of the different initial ROD, it is more altitude loss with more velocity.

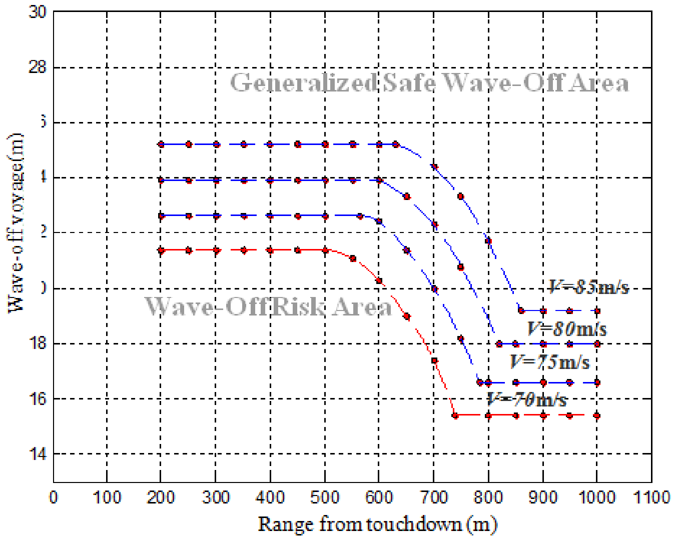

Figure 9. Wave-Off Voyages with Different Velocities

As a result of different wave-off maneuvering voyages with various velocities, there are different generalized safe wave-off boundaries as shown in Figure 9.

In Figure 9, we could know owing to more altitude loss with more velocity, safe wave-off area is less, meaning less area with more velocity.

5.2. Interference ROD

Simulation original condition:

(1) Range from touchdown x=1000m;

(2) Velocity V=69.96m/s;

(3) Interference ROD $\dot{h}_d$ =0m/s , 1m/s, 1.5m/s, 2m/s respectively.

The wave-off voyages with different interference ROD are shown as Figure 10.

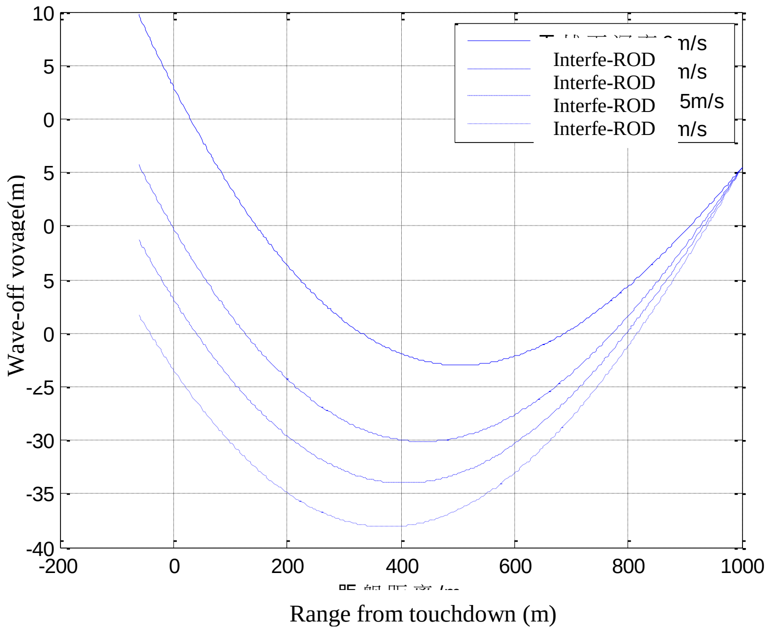

Figure 10. Wave-Off Voyages with Different Interference ROD

Comparing different curves in Figure 10, in the same wave-off maneuvering operation time, it is more altitude loss with more interference ROD, and the same horizontal displacement.

As a result of different wave-off maneuvering voyages with various interference RODs, there are different generalized safe wave-off boundaries as shown in Figure 11.

In Figure 11, we could know owing to more altitude loss with more interference ROD, safe wave-off area is less, meaning less area with more interference ROD.

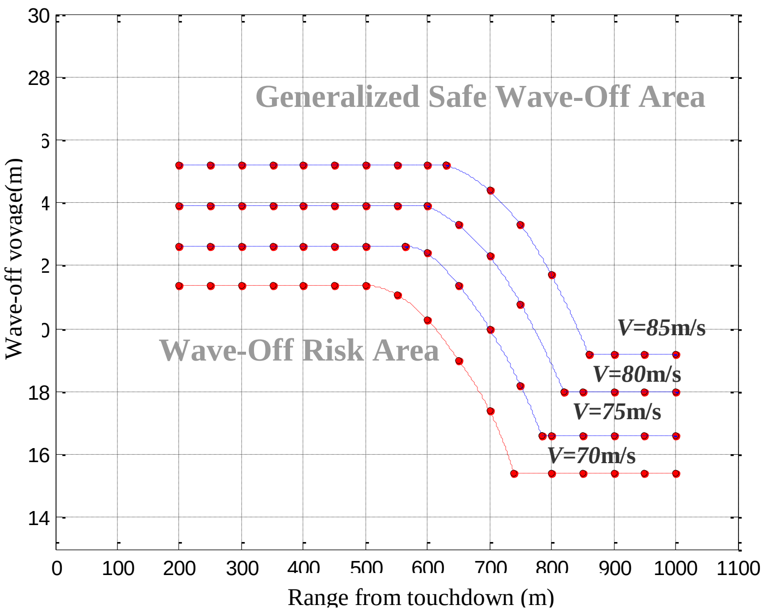

Figure 11. Wave-Off Voyages with Different Interference ROD

6. Conclusion

This paper has analyzed the wave-off maneuvering procedure and force, considering near and far risk from touchdown point, we defined deck clearance and sea-surface clearance, and introduced a generalized design manner of safe wave-off area. Finally, the influence of safe wave-off area with velocity and interference ROD had been researched. It is the base for researching wave-off strategy and formulating wave-off scheme.

Acknowledgement

The author would like to thank the anonymous referees for their valuable suggestions. This work was supported by the Natural Science Foundation of Heilongjiang Province of China (Grant Nos. F2015045).

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