Research on wave motion response characteristics of a seaplane

Xianjiao Gao 1,2, *, Chenghua Li 1,2, Tao Liu 1,2, Bin Wu 1,2, Mingzhen Wang 1,2

1 AVIC Special Vehicle research Institute, Hubei Jingmen, China
2 Key Aviation Scientific and Technological Laboratory of High Speed Hydrodynamic, Hubei Jingmen, China

*Corresponding author e-mail: xianjiaogao@avic.com

Abstract. As one of the criteria hydrodynamic qualities, sea-keeping performance is closely related with a seaplane’s security, comfortableness, durability. This paper is proposed to study the wave motion response characteristics of a seaplane based on wave model test. Firstly, similarity criterions, determination of test parameters, experiment equipment and data processing method are introduced. Then, based on test results, we analyse the influence of wave parameters, sliding velocity and deadweight on wave motion. It indicates that there is a positive relationship between wave height and motion response, while the acceleration decreases with the increase of wave length, and its peak value occur at the short wave length region of 0.5 to 1 times hull length of the seaplane, heave and pitch angle first increase then decrease with the change of wave length. The influence of sliding speed on heave and pitch angle depends on wave length, but the acceleration varies positive with change of velocity. The influence of heave and pitch angle has no obvious correlation with deadweight, while the acceleration shows a negative trend with change of deadweight. These regularity can be used to provide some reference for the analysis of wave motion response characteristics of seaplane.

1. Introduction

Through nearly one hundred years of development, seaplane has become the indispensable aircraft type in the field of aviation, and it plays an increasingly important role in maritime rescue, forest fire fighting, water transportation, island tourism and entertainment [1]. However, due to the effect of wind, wave, current and other environmental loads on the actual sea surface, the aircraft will inevitably meet with six degrees motion of pitch, roll, yaw, surge, sway and heave. Dramatic response will not only have a negative impact on the comfort, safety and performance of the aircraft, but also cause damage to the structure of the aircraft, and then lead to the occurrence of maritime accidents [2]. Therefore, it is necessary to study and analyze the motion response of seaplane in waves.

In recent years, with the development of computer, numerical simulation plays a more and more important role in engineering analysis, but the reliability of calculation results largely depends on the development of hydrodynamics discipline, and model test still plays an irreplaceable role in the field of engineering design and optimization [3-4].

This paper studies the motion response characteristics in waves and the influence factors based on model test. Firstly, similarity criteria of model test and selection of test parameters are introduced. Then,
2. Model wave test basis

2.1. Similarity criterion
The wave model is designed, made and tested according to the principle of geometric similarity and motion similarity. Because the Reynolds number and Froude number of the model cannot be numerically equal with the real seaplane at the same time, so the Froude number, which represents the characteristics of inertial force and gravity flow, is usually used as the similarity criterion in the actual model test:

\[ \frac{V_m}{\sqrt{gL_{eq}}} = \frac{V}{\sqrt{gL_{rs}}} \]  

(1)

The proportional relationship between the geometry, motion of the model and the real seaplane are shown in Table 1.

| Parameters      | Model     | Full Scale |
|-----------------|-----------|------------|
| length          | L         | kL         |
| inertia         | k^2I      |            |
| mass            | k^3m      |            |
| velocity        | k^0.5V    |            |
| pitch angle     | 0         | 0          |
| acceleration    | a         | a          |

Where k represents the scale ratio of the model, which is generally determined according to the length of the towing tank, the maximum running speed of the carriage, and inertia requirement of the real seaplane.

2.2. Selection of test parameters
As a measurement of different sea conditions, the test wave height is generally set to \(1/40L \sim 1/25L\), because in this wave height range, wave motion response of the seaplane generally keeps linear relation with the wave height, as a result, the test data can be used to predict the corresponding performance of the real seaplane according to linear superposition principle [5-6].

The range of wavelength should be as widely as possible, so that the experimental results can fully reflect the motion response characteristics of the model on waves. According to some relevant study, pitch of the seaplane is more severe when the wavelength is 1.5 \sim 3.5 times the length of the seaplane, heave response becomes fiercely when the wave is 2 \sim 3 times the length of the seaplane, and the acceleration peak is generally occurs at 0.5 \sim 2.5 times of the seaplane. Therefore, wavelength of test is selected in the range of 0.25 \sim 4 times the length of seaplane.

The model test usually requires 5 \sim 6 velocity points, based on experience, there should be 2 \sim 3 velocity points around the resistance peak, generally within the range of 30\% \sim 50\% of the take-off speed. In addition, 2 \sim 3 velocity points are needed within the range of 50\% \sim 70\% of the take-off speed. Deadweight of model test is generally determined by the use model of seaplane.

3. Model test

3.1. Introduction of test equipment
Measurement system of model wave test is composed of cable-type displacement transducer, single component force sensor, angular sensor and acceleration sensor. Before test, the sleeve is fixed on the
side bridge of the carriage, the carbon tube of the heave bar is connected with the model through the sleeve, and the model is hinged with the angular sensor, and then connected with the single component force sensor. In order to make the model move in the middle longitudinal section, a navigation bar is installed in the front of the seaplane, however, the longitudinal and vertical motions of the model are not constrained. The acceleration sensor is installed at the designated position to measure the vertical overload when the model moves on waves. Due to the difference of aerodynamic characteristics between the model and the real seaplane, the lifting and torque compensation devices are usually installed at the center of gravity and tail of the model to make up for the difference. The installation diagram of the model test is shown in Figure 1.

![Figure 1. Diagram of model test device.](image)

3.2. Measurement parameters and data processing method
Parameters should be recorded and measured of the test include test water temperature, velocity of the carriage, wave resistance of the model, heave at the center of gravity, pitch angle and vertical acceleration. As the data collected by the test system contains interference noise of various environmental factors, and the data need to be filtered. Generally, the low-pass filter is selected to filter out the high-frequency signal, and the moving average processing method is used to compress the excessive peak value. Finally, the relatively stable region data is selected for analysis. Data measurement system of the model test is shown in Figure 2.

![Figure 2. Data measurement system of model test.](image)
4. Analysis of wave motion response characteristics
In this paper, wave tests are carried out under different wave height, wavelength, sliding speed and weight parameters. The specific parameters are shown in Table 2.

**Table 2. Parameters of wave model test**

| Parameters     | Variation range        |
|----------------|------------------------|
| Wave height H | 0.02 Lh~0.04 Lh        |
| Wave length λ | 0.7Lh~4.1 Lh           |
| Deadweight m  | 0.8M~1.0M              |
| Velocity V    | 0.3Vga~0.7 Vga         |

Where Lh is the hull length of the seaplane, M is the maximum take-off weight of the model, and Vga represents the take-off speed of the model.

4.1. Influence of wave parameters on sea-keeping
Generally, wavelength corresponding to the maximum value is called resonance wavelength [7-8]. Trim, heave and acceleration at the center of gravity are three most concerned parameters in wave test. Figure 3 shows the wave response curve at different wave heights and wavelengths when the deadweight is 0.87M and the velocity is 0.3Vga.

![Figure 3. Response curve of heave, pitch angle and vertical acceleration (deadweight =0.87M, velocity = 0.3Vga).](image)

It shows that heave of aircraft increases with the wave height. Compared with short wave, the change of wave height has a greater influence on heave in long wave. The effect of wavelength on heave is that it first increases with wavelength, however, it tends to be stable or slightly attenuated as the wavelength increases. And the resonant wavelength is approximately 1.5 ~ 2 times the length of seaplane hull. Influence of wave height on pitch and acceleration is very similar, and there is a positive correlation between them. However, influence of wavelength on them is quite different. The trim angle first increases and then decreases with wavelength, and its peak value appears at about the 1.5 times the hull length of the seaplane, while the acceleration gradually decreases with the wavelength.

4.2. Influence of sliding speed on sea-keeping

![Figure 4. Response curve of heave/pitch angle and vertical acceleration (deadweight =0.91M, wave height=0.03Lh).](image)
It can be seen from Figure 4 that the influence of sliding speed on motion response is related to wavelength. When the wavelength is within two times the length of seaplane hull, heave and trim first increase and then decrease with the increase of velocity. While when the seaplane encounters a relative long wave, there is basically a positive correlation between velocity and heave. Vertical acceleration generally increases with velocity, while decrease as the wavelength increases. Therefore, in the acceptable range of other parameters, it is better for the aircraft to take off and land on long wave in order to reduce the water load.

4.3. Influence of deadweight on sea-keeping

Figure 5 suggests that motion response with different weight has a similar and nearly trend with wavelength, the heave first increases and then slightly decreases with the increase of the wavelength, and reaches its maximum value at about 3 times the hull length of wave; while trim changes sharply with wavelength, and the resonance wavelength is about 1.5 ~ 2 times the hull length. While the vertical acceleration is negatively correlated with the change of wavelength and deadweight, and its maximum occurs when the wavelength is nearly equal to hull length.

![Figure 5. Response curve of heave/pitch angle and vertical acceleration (velocity=0.4Vga, wave height=0.03Lh)](image)

5. Conclusions

This paper studies motion response characteristics of a seaplane based on wave model test, test basis, basic equipment, determination basis of test parameters are introduced, and influencing factors and laws on the seaplane’s response characteristics especially trim, heave and vertical acceleration are studied, the main conclusions are as follows:

1) All the motion response are positively correlated with the change of wave height, but heave and trim increases first and then decreases with the increase of wavelength, the divergence length is twice the length of the plane. While the acceleration generally decreases with wave length on the whole, the resonant wavelength is about 0.5~ 1 time of seaplane hull.

2) Heave and trim of different deadweight are relative close, and there is no distinct rules between them. But there is a negative correlation between deadweight and acceleration.

3) Peak values of response under different velocity conditions usually occurs at different wave length, and as the velocity increases, the resonant wavelength tends to increase.

References

[1] Chu Lintang. Seaplane hydrodynamic design [M]. Beijing: Aviation Industry Press, 2014: 80-126.
[2] Huang Lingcai, Yong Mingpei. Key technologies and industrial application prospects of amphibian aircraft[J]. Acta Aeronautica et Astronautica Sinica, 2019, 40(1): 1-14.
[3] Wu Qingwei, Gao Xiaopeng, Wu Bin. A method to evaluate the resistance of seaplane sliding in still water[J]. Ship and Ocean Engineering, 2013, 42(3): 154-157.
[4] Dathe I. Hydrodynamic characteristics of seaplane as affected by hull shape parameters[C]// AIAA Intersociety, Advanced Marine Vehicles Conference, 1989: 1540.G.R. Mettam, How to prepare an electronic version of your article, in: B.S. Jones, R.Z. Smith (Eds.), Introduction
to the Electronic Age, E-Publishing Inc., New York, 1999, pp. 281-304.

[5] Huang Miao, Wu Bin, Jiang Rong, et al. An experimental study about motion response of a seaplane on waves[J]. Journal of Experiments in Fluid Mechanics, 2015, 29(3): 41-46.

[6] Sheng Zhenbang, Liu Yingzhong. Ship Principal[M]. Shanghai: Shanghai Jiaotong University Press, 2007: 157-160.

[7] Kikuhara s. A study of spray generated by a seaplane hulls[J]. Journal of the Aero-nautical Sciences, 1960, 27: 415-428.

[8] Paterson J. H. Recent development in the hydrodynamic design of flying boats[J]. Journal of Royal Aeronautical Society, 1955, 59: 349-355.