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Letter

Wind tunnel tests of stratospheric airship counter rotating propellers

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ABSTRACT

Aerodynamic performance of the high-altitude propeller, especially the counter rotation effects, is experimentally studied. Influences of different configurations on a stratospheric airship, included 2-blade counter-rotating propeller (CRP), dual 2-blade single rotation propellers (SRPs) and 4-blade SRP, are also indicated. This research indicates that the effect of counter rotation can greatly improve the efficiency. It shows that the CRP configuration results in a higher efficiency than the dual 2-blade SRPs configuration or 4-blade SRP configuration under the same advance ratio, and the CRP configuration also gains the highest efficiency whether under the situation of providing the same trust or absorbing the same power. It concludes that, for a stratospheric airship, the CRP configuration is better than the multiple SRPs configuration or a multi-blade SRP one.

The development of the stratospheric airship is considered to be a super puzzle in the 21st Century. Its ultra-long endurance requires a propulsion plant with high efficiency. In low-altitude flight, using propeller as a propulsion device can gain high efficiency. However, the stratospheric airship is working at very high attitude (about 20 km). There is a significance difference between the properties of air at 20 km attitude and that at the sea level. Compared with the air at the sea level, the density of the air at 20 km altitude is just 1/14 and the pressure is 1/19. On the contrary, the viscosity of the air (at 20 km altitude) is 11 times larger. Meanwhile, the stratospheric airship moves at a slow speed (10–30 m/s). The unique flight condition leads to the low Reynolds number around the flow field of the stratospheric airship propellers. Thereby the propeller designed in traditional way suffers a great loss in efficiency.

Using counter-rotating propellers (CRPs) on stratospheric airship has been proposed to improve the efficiency. Many experiment researches have shown the superiority of the CRP. In 1941, D. Biermann et al. [1] did a series of wind tunnel tests on CRPs. The research indicated that the peak efficiency of an eight-blade dual-rotating propeller was found to be from 1% to 8% higher than that for a corresponding single-rotating propeller. In the next year, another research did by D. Biermann et al. [2,3] found that dual-rotating propellers were more efficient for the takeoff and climbing conditions of flight than the single-rotating propellers, particularly for operation at high power coefficients. But all these conclusions were drawn with the propellers working at relative low altitude and general cruise speed. High-altitude propellers, especially counter-rotating propellers, have not been researched currently. This paper will discuss the effects of counter-rotation and numbers of propellers in a stratospheric environment and eventually find the optimum propeller layout form on stratospheric airships. Several configurations were taken into contrast to achieve this goal, included 2-blade CRP, dual 2-blade single rotation propellers (SRPs) and 4-blade SRP.

This experiment is conducted in the D5 wind tunnel in Institute of Fluid Mechanics of Beihang University. The sectional dimension of the D5 wind tunnel test section is 1 m × 1 m and the turbulence intensity is 0.08%. Figure 1 is some photographs about the test setup. The low Reynolds number circumstance can be hardly achieved in underground wind tunnel. To simulate the real flight conditions, a scale-model, which the scale is 1:8, is used in the experiment. By using the scale model, the Reynolds number and Strouhal number are similar to the high attitude environment. According to the similarity principle, the diameter of propeller model is 0.75 m whereas the diameter of hub is 0.2D (D is the diameter of the propeller model). The distance between front and rear propeller disks is 0.15 m. The 2-blade SRP and 4-blade SRP are just the same except their blade number.

To concern the effects of different Reynolds number, it is taken

$$Re = \frac{nD^2}{\upsilon}. \tag{1}$$

The rotational speed is set to 500, 750, 1000, 1250, 1500 rpm and the wind speed refers from 0 to 30 m/s. The wind tunnel tests

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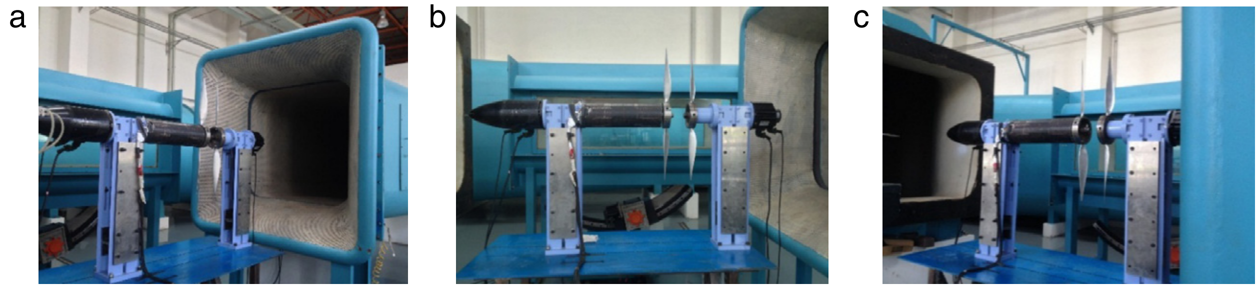

Fig. 1. Test set-up. D5 wind tunnel. Two-blade counter-rotating propeller.

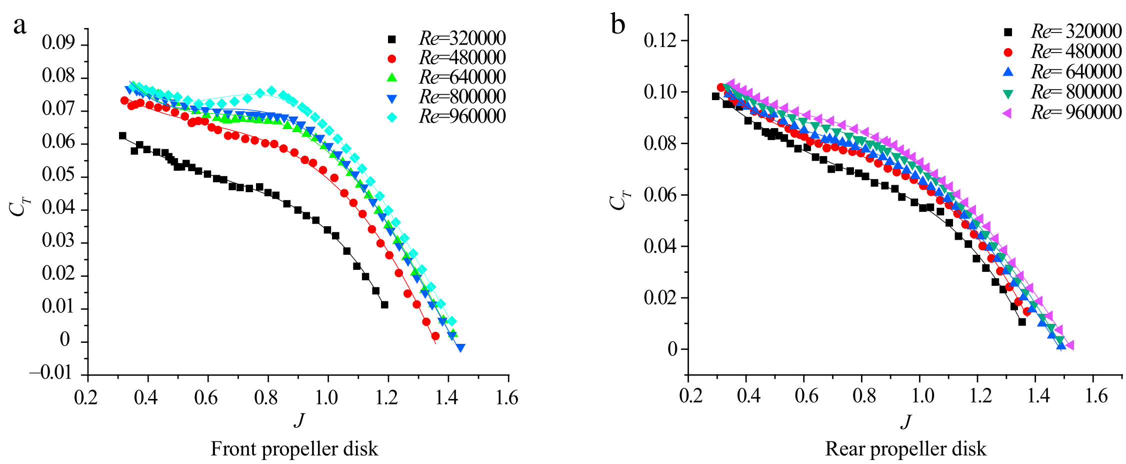

Fig. 2. Thrust coefficient of front and rear propeller disk.

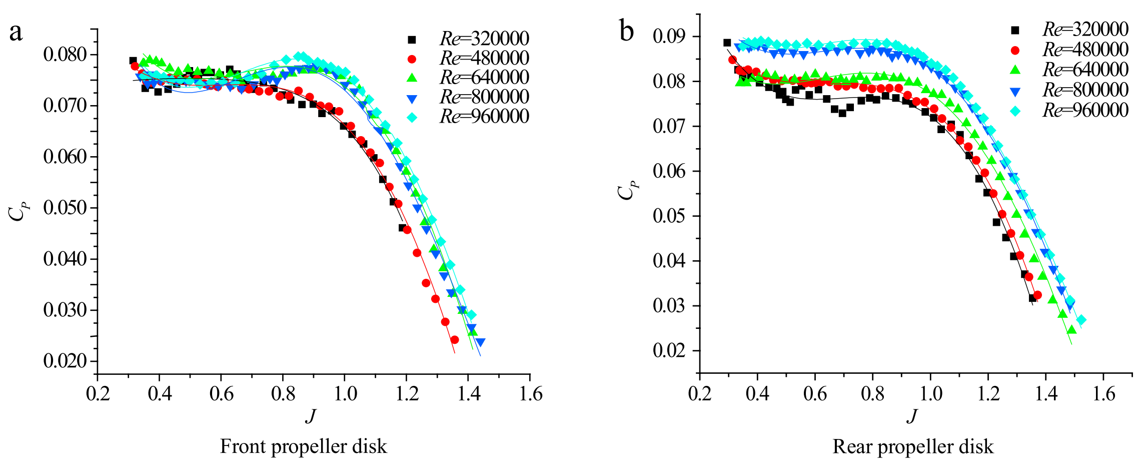

Fig. 3. Power coefficient of front and rear propeller disk.

include a 2-blade SRP, a 4-blade SRP and a 2 × 2 (2 blades in the forward rotor and 2 in the rear) CRP. This is done to consider three kinds of propeller arrangement: CRP, multiple SRPs, or multi-blade SRP. The measured value has been reduced to the usual coefficient of trust, power, and efficiency.

The measured value has been reduced to the usual coefficient of trust, power, and efficiency:
propeller thrust coefficient

$$C_T = \frac{T}{\rho n_s^2 D^4}. \quad (2)$$

propeller power coefficient

$$C_P = \frac{P}{\rho n_s^3 D^5}. \quad (3)$$

propeller efficiency

$$\eta = \frac{C_T}{C_P} J. \quad (4)$$

Here we have
power of propeller

$$P = 2\pi n_s Q, \quad (5)$$

advance ratio

$$J = \frac{V}{n_s D}. \quad (6)$$

According to the similarity principle, the thrust coefficient, power coefficient and efficiency of propeller are functions of advance ratio and Reynolds number. As we can see from Figs. 2–4