# WIND TUNNEL TEST OF THE PERFORMANCE OF COAXIAL RIGID ROTOR

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**Abstract**
Tests of 2m-diameter rigid coaxial rotor model were conducted in theΦ3.2m wind tunnel of CARDC to investigate the hovering and forward flight aerodynamic characteristics of rigid coaxial rotor. The aerodynamic data such as rotor lift, drag and power were acquired in the test, and the aerodynamic force of upper and lower rotor were measured individually. The hover test results show that the FM of the upper and lower rotors is lower than that of the isolated single rotor, and the FM of the lower rotor is lower than that of the upper rotor. Increasing lift offset will result in a decrease in the required power of the rotor and an increase in drag. When the effect of reducing power is greater than the effect of increasing drag, the lift-to-drag ratio of the rotor increases as the lift offset. In the forward flight state, the lift-to-drag ratios of the upper and lower rotors are smaller than the isolated single rotor. And the lift-drag ratio of the upper rotor is lower than that of the lower rotor, which is significantly different from the hover state.

## 1. INTRODUCTION

Coaxial rigid rotors utilize the concept of advancing blade concept (ABC) rotor, this rotor system featured a pair of coaxial, counter rotating rotors. During high-speed forward flight, the lift is mainly borne by the advancing side of the rotor disk, and the coaxial rotors balance the rolling moment and counter torque, the stall on retreating blade would then be greatly less important. This would result in an enhanced high-speed forward flight capability. Coaxial rigid rotors have aerodynamic characteristics that are different from conventional edgewise rotors, such as lift offset and coaxial rotor aerodynamic interference [1][2]. Carrying out coaxial rigid rotor wind tunnel test to study rotor lift offset and mutual interference of coaxial rotor is great value for the theoretical research and engineering design of coaxial rigid rotor.

In the 1970s, Sikorsky conducted a serious full-scale trail of coaxial rigid rotors in the 40-by 80- foot wind tunnel [3], and subsequently conducted a XH-59A vehicle wind tunnel test in the 1980s [4]. The full-scale rotor wind tunnel test studied the performance and load characteristics of the coaxial rigid rotor. However, these two tests did not give the aerodynamic performance of the upper and lower rotors separately.

In recent years, with the development of X2, S97, and SB1 high-speed helicopters, many researchers have carried out wind tunnel test investigation on coaxial rigid rotors. Furthermore, the coaxial rotor test rigs recently developed have independent balances measured for the upper and lower rotors. A coaxial test rig was developed by Maryland university, a custom modified six component cell is mounted on the rotating frame directly below the rotor hub to measure the force of rotors independent. Cameron carried out lift offset test research of single rotor and coaxial rotor, and obtained the aerodynamic performance and load of the rotor in hovering and forward state [5] [6] [7]. In forward flight, the rotor lift-to-drag ratio was found to increase with increasing advance ratio and lift offset, with a maximum increase of 40%compared to the zero lift offset case. Vibratory loads increased with





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advance ratio, with the largest loads in the two- and four-per-revolution harmonics. The lower coaxial rotor was found to operate at higher lift-to-drag ratio than the upper rotor, in contrast to the behaviour in hover. A 0.303 S-97 scale powered model and a 0.2 S-97 scale powered model were testing in the NFAC 40-by 80- foot section using Sikorsky Aircraft Coaxial Rotor Test Rig (CARTR), these two tests were examined rotor performance and rotor/fuselage interference [8] [9].

A better understanding of lift offset and coaxial rotor interference, and rotor aerodynamic performance as a function of tilt angle presents opportunities for improving the design of aircraft flight control systems, which should lead to improved efficiency and expanded operational envelope.

Recently, a coaxial rotor wind tunnel test rig was developed by CARDC to investigate coaxial rigid rotor aerodynamic characteristics. The measurement of a coaxial rigid rotor system was carried out at different rotation speeds, lift offsets, and tilt angles, and the performance of a single rotor at the same pitch angle was compared. The performance of coaxial rotor and isolate single rotor at hover and forward flight status, and the experimental equipment and process are described here.

## 2. EXPERIMENTAL SETUP

### 2.1. Rotor Test Rig

The coaxial test rig was developed by CARDC is shown as installed in wind tunnel in Fig. 1. The rotor system is mounted on a specially designed rectangular frame articulated with fixed platform, with provision for the shaft tilt angle of the upper rotor and lower rotor changed synchronous. The coaxial rotor is driven by a 150kw motor, the coaxial transmission is compromised by 5 bevel gear boxes mounted on the rectangular frame caused the upper and lower rotors counter rotating. The upper rotor and the lower rotor each have a swash plate and a six-component balance, and a torque meter individually. Rotating electrical signals from each rotor were transmitted through sliprings located bellowed the bottom of the rotor gear box. For a more detailed description of this test rig, see the ref[10]- ref[12].

### 2.2. Test Procedure

The test employed a pair of 4 blade rigid rotor diameter of 2 meters. The forward flight test was conducted in the Φ3.2 m closed throat wind tunnel of CARDC, this wind tunnel has a nominal maximum speed capability of 105m/s. The rated rotating speed of rotor is 1860 rpm. In the wind tunnel test, in order to obtain a higher advance ratio, a test of 1100 rpm was also carried out, and the advance ratio reached a maximum of 0.7.

The operation procedures of the wind tunnel test were to set the desired rotor rotation speed, tilt angle and wind speed, then coupled collective pitch and coupled cyclic pitch were adjusted to provide the lift coefficient of the coaxial rotor to 0.012, and adjust the hub moments to approximately zero. Lift lateral displacement control changed the lift offset to the specified value, and lift longitudinal displacement maintained approximately zero during the test. In the hover test state, the change in the differential collective pitch adjusted the rotor torque difference to approximately zero.

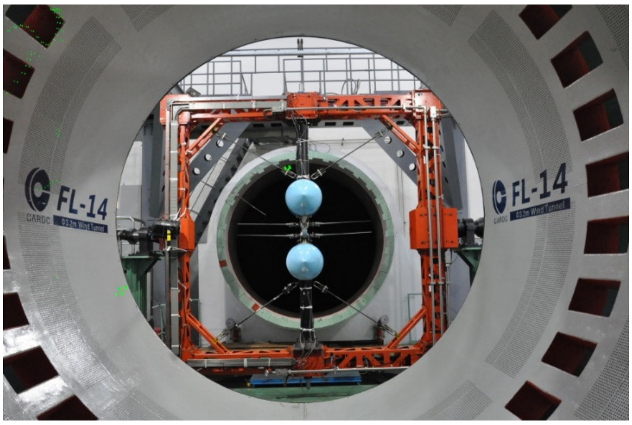


Fig.1. Φ2m coaxial rigid rotor model and test rig in CARDC Φ3.2m Wind Tunnel

## 3. RESULTS AND DISCUSSION

Fig. 2 shows the figure of merit obtained by the hovering tests under the 1860rpm rotation speed. The torque difference of the coaxial rotor was trimmed by the differential collective pitch to give torque balance. to approximately zero. Fig.2 also contains the isolate single hovering test result. Due to the aerodynamic interference of the rotor, the hovering efficiency of the upper and lower rotors of the coaxial rotor is lower than that of the isolated single rotor, and the hovering efficiency of the lower rotor is considerably lower than that of the upper rotor, while increase in axial inflow cause an decrease in figure of merit.

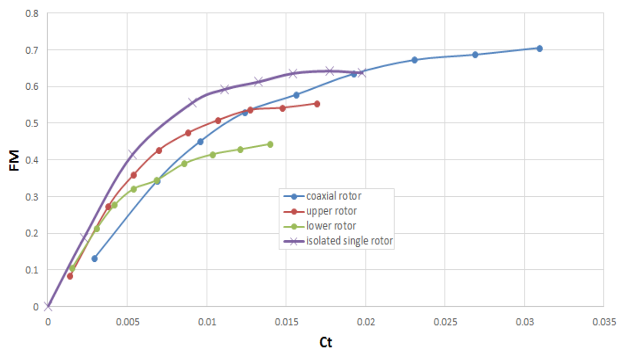


Fig. 2. Comparison of Figure of merit between coaxial rotor and single rotor



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Fig. 3 and Fig. 4 show the power coefficient and L/D (lift-to-drag ratio) of coaxial rotor at advance ratio range of 0.2 to 0.4, rotational speed of 1860 rpm, the shaft tilt angles of -4, -2, 0, 2, 4, and LOS = 0. Fig. 5 and Fig. 6 show the power coefficient and L/D (lift-to-drag ratio) of coaxial rotor under the rotational speed at 1100 rpm, the advance ratio range of 0.2 to 0.65, the tilt angle of -4, -2, 0, 2, 4, and LOS = 0. All the above test was performed with the lift coefficient of the coaxial rotor trimmed to 0.012.

The increase of the lift-drag ratio of the coaxial rigid rotor with the advance ratio is not monotonous. The increase of the rotor power in the range of the advance ratio of 0.5 to 0.6 leads to the decrease of the lift-drag ratio of the rotor. When the rotor shaft tilt angle is 0, the change of the rotor's lift-drag ratio with the advance ratio is more moderate. The L/D of coaxial rigid rotor at each tilt angle experienced a significant increase with the increment of advance ratio below 0.4. The coaxial rigid rotor reacts to shaft angle in much the same manner as conventional edgewise rotors, in that tilting the shaft into the wind(-ɑ) increase power, cause an decrease in L/D.

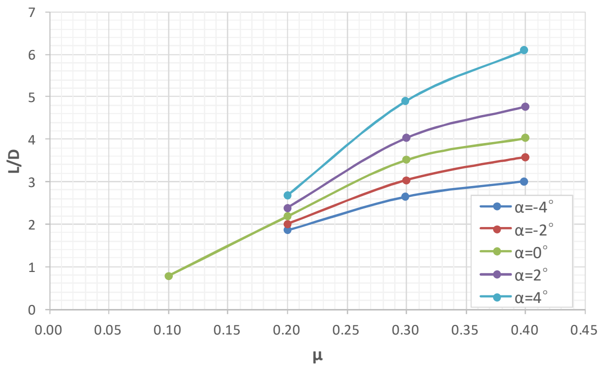


Fig. 3. Lift-to-drag ratio as a function of advance ratio, N=1860rpm

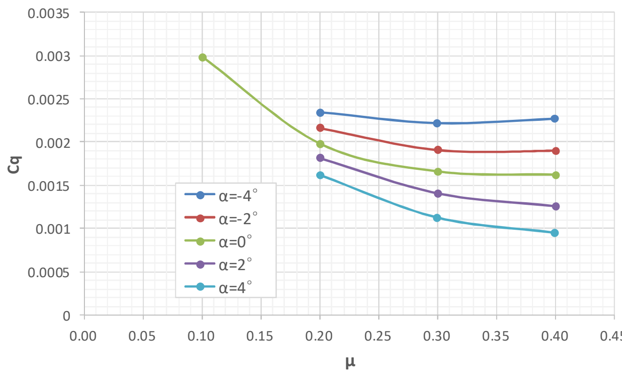


Fig. 4. Power coefficient as a function of advance ratio, N=1860rpm

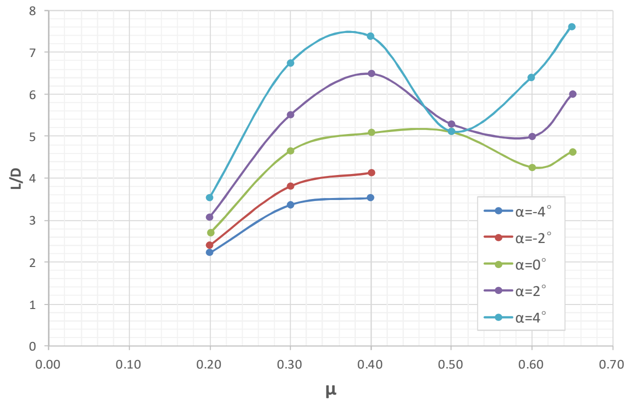


Fig. 5. Lift-to-drag ratio as a function of advance ratio, N=1100rpm

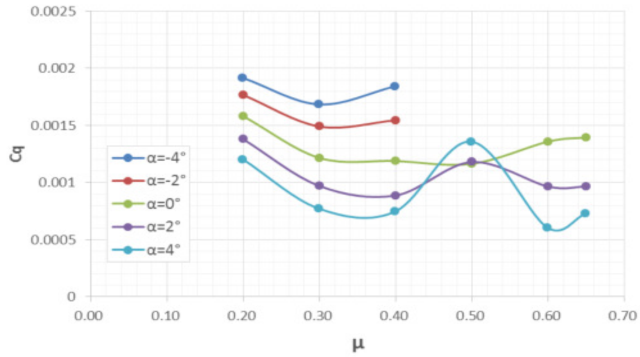


Fig. 6. Power coefficient as a function of advance ratio, N=1100rpm

Fig. 7 to Fig. 10 show the changes in aerodynamic performance of the coaxial rigid rotor with different lift offset at 1860 rpm and 2° shaft angle. As the lift offset increases, the magnitude of rolling moment is proportional to the LOS as anticipated. The angle of attack of blade element increase in the high dynamic pressure area of advancing side with LOS increase, horizontal force coefficient along wind directing increase are caused by the drag force enhancement of the advancing blades, and the needed collective pitch decrease cause the power of the rotor decreases. When the effect of decrease in rotor power is greater than the effect of increase in rotor drag, the rotor's lift-drag ratio increases with lift offset. At the advance ratio of 0.2, after the lift offset is greater than 0.2, the increase effect in the drag coefficient of the rotor exceeds the decrease effect in rotor power, and the rotor drag-to-drag ratio decreases.



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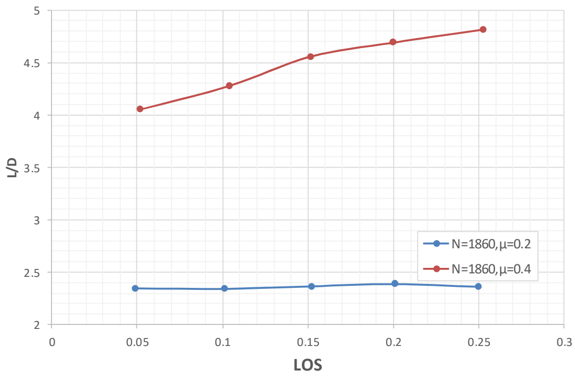


Fig. 7. Lift-to-drag ratio as a function of lift offset, N=1860rpm

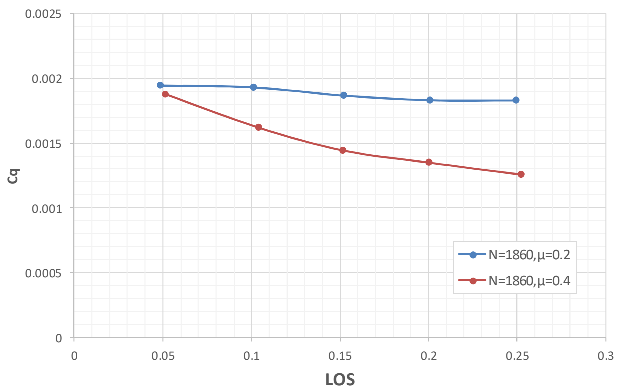


Fig. 8. Power coefficient as a function of lift offset, N=1860rpm

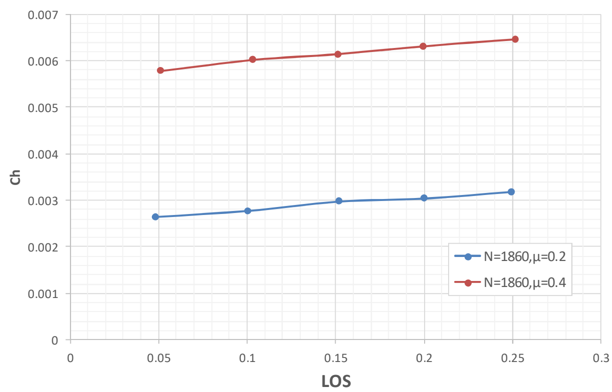


Fig. 9. Horizontal force coefficient as a function of lift offset, N=1860rpm

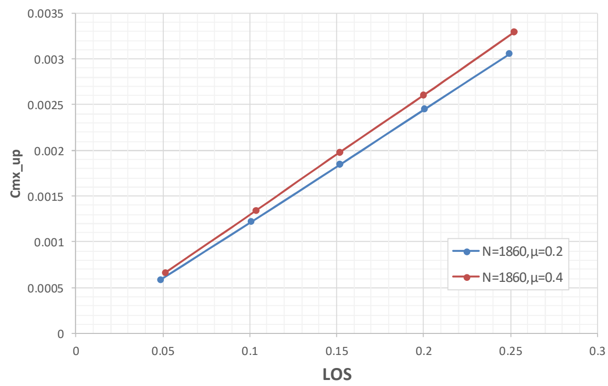


Fig. 10. Rolling moment coefficient of upper rotor as a function of lift offset, N=1860rpm

Fig. 11 shows the comparison of the L/D between single rotor and coaxial rotor, with the single rotor blade pitch was set equal to the lower rotor of coaxial rotor configuration at advance ratio of 0.1 and tilt angle of -4 ° to 4 ° at 1860 rpm. The lift-to-drag ratios of the upper and lower rotors in coaxial rotor configuration are lower than the isolated single rotor, and the lift-drag ratio of the upper rotor is lower than that of the lower rotor, which is significantly different from the hover state. Comparison of the thrust and power coefficient are showed in Fig.12 and Fig.13, respectively. Notice that the thrust produced by isolated single rotor are substantial greater than the upper and lower rotor in coaxial configuration, while there is very similarity in the thrust of upper rotor and lower rotor. For the coaxial configuration, the power of upper rotor is much larger than the lower rotor.

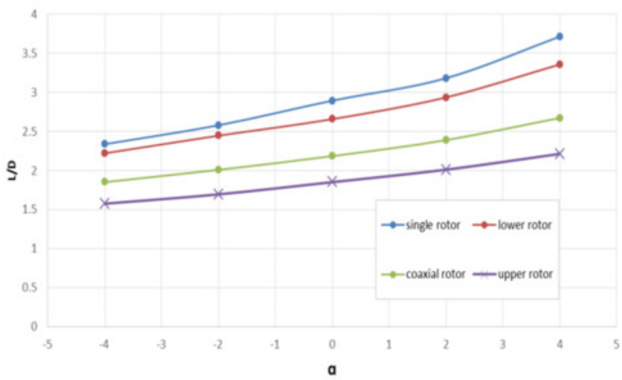


Fig. 11. Comparison of Lift-to-drag ratio between coaxial rotor and single rotor



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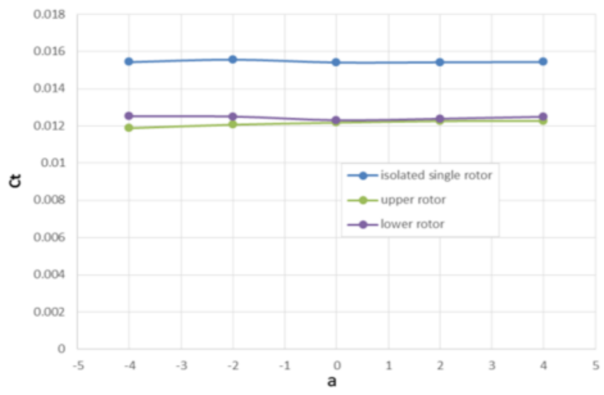


Fig. 12. Comparison of thrust coefficient between coaxial rotor and single rotor

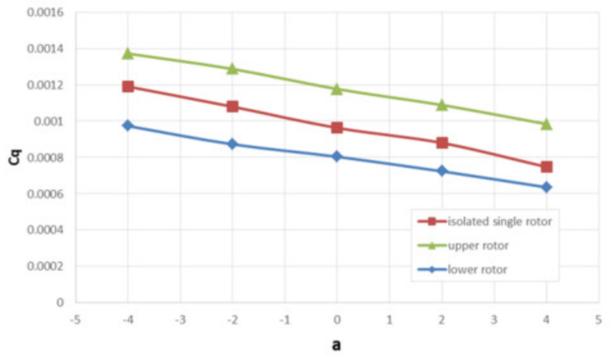


Fig. 13. Comparison of power coefficient between coaxial rotor and single rotor

## 4. CONCLUSIONS

Based on the results obtained in this test, the following conclusions are made:

1. The hover test results show that the FM of the upper and lower rotors is lower than that of the isolated single rotor, and the FM of the lower rotor is lower than that of the upper rotor.

2. The increase of the lift-drag ratio of the coaxial rigid rotor with the advance ratio is not monotonous. The increase of the rotor power in the range of the advance ratio of 0.5 to 0.6 leads to the decrease of the lift-drag ratio of the rotor. When the rotor shaft is tilted forward, the lift of the rotor is relatively high. When the rotor shaft tilt angle is 0, the change of the rotor's lift-drag ratio with the advance ratio is more moderate.

3. Increasing lift offset will result in a decrease in the required power of the rotor and an increase in drag. When the effect of reducing the rotor power is greater than the effect of increasing the rotor drag, the lift-to-drag ratio of the rotor increases as the lift offset. At the advance ratio of 0.2, after the lift offset is greater than 0.2, the effect of increasing the rotor's drag exceeds the effect of decreasing the rotor's power, lead the rotor's drag-to-drag ratio decreased.

4. In the forward flight state, the lift-to-drag ratios of the upper and lower rotors are smaller than the isolated single rotor. And the lift-drag ratio of the upper rotor is lower than that of the lower rotor, which is significantly different from the hover state.

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