EXPERIMENTAL STUDY OF NO TAIL ROTOR (NOTAR) HELICOPTER

Luo Xiaoping
First Aeronautical college of the Air Force
Zhang Chenlin, Wang Huaming
Nanjing University of Aeronautics and Astrinautics

Abstract

In order to study the new anti-torque system on helicopter circulation control tail boom, two helicopter models with circulation control tailboom was designed and tested to measure the pressure distribution on tail boom surface with the model in tunnel and under rotor respectively. The main purpose of the test was to study the effect of the momentum coefficient, the slot's geometry variables and the flying velocity on the aerodynamic forces of the circulation control tailboom. The aerodynamic forces on the tailboom have been calculated and their changes with the circulation control variables were drawn in curves. By discussing the test results, circulation control and its application was studied. Reasonable explanations have been given about the test results and some new conclusions have been obtained.

Introduction

On the single main rotor type helicopter, the tail rotor equilibrates the required antitorque produced by the main rotor and maneuvering forces in all flight regimes. However, the tail rotor rotating with high speed has many drawbacks in safety, vabration and acoustics. Many studies have been directed toward eliminating the exposed tail rotor. These studies include the 'fan-in-fin', 'fan -in-tail cone', auxiliary thrusters and No Tail Rotor(NOTAR) antitorque new systems.

The NOTAR system was first conceived by McDonnell Douglas Helicopter Company. It combines circulation control along the tailboom with a derect jet thruster at the back of the boom to provide the main rotor antitorque and maneuvering forces instead of the tail rotor. The heart of NOTAR system is the circulation control tailboom which achieves the antitorque forces by a thin stream of air exiting from the slot in the tail boom deflecting the maim rotor wake much like the wing of a fixed wing aircraft.

In order to study the new concept and principle of NOTAR , two helicopter model with circulation control tailboom were designed and tested in tunnel and under rotor respectivelly. The effect of the variables on the circulation control efficiency was studied by measuring the pressure distribution and showing the flow on the tailboom.

The NOTAR Model

Two organic glass cylinder with circulation control were used to model the circulation

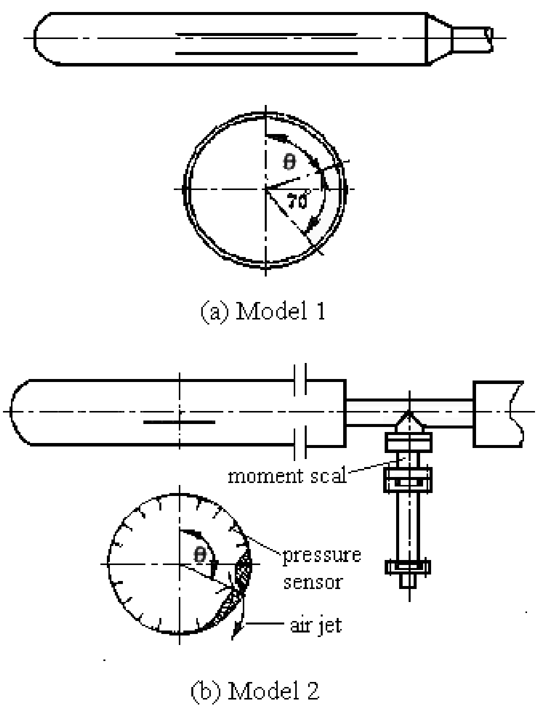


Fig.1 Models of circulation control

control tailboom (Figer 1). Two parallel slots with 300mm long located 70°wide were made on the surface of model 1. At first, the two slots' width were 0.9mm and 0.5mm, the second slot was enlarged to 1.4mm in later experiment. At the middle of the slots, there is a section around which arranged holes perpenticular to the surface every 10 degree. The model attached a trestle by a steel tube so the tailboom could rotate about the axis to change the position of the slots. One slot with 200mm long, 2mm wide on model 2 . In the middle of the model 2 micro-pressure-sensor(ENDEVC08510-B1) were located around the section. Model 2 was connected with a trestle by a linker. Another cylinder same as the model was fixed to the linker. Between the linker and the trestle is a scale limited to 300N.m. Model 2 is also can rotate about its axis. The jet exiting from the slots of the two models was supplied by two shunt-wound air compressor with total 1.1m3/min value of flow.

Experiment Equipment

Wind Tunnel

The experiments were done in two wind tunnel at Nanjing University of Aeronautics and Astronautics(NUAA). One is a recycling low-speed wind tunnel in which Model 1 was put at the opening part and made the tailboom axisal perpenticular to the coming wind with maxium speed of 30m/s. The other is a bigger direct wind tunnel in which Model 2 was also put at the opening part with the tailboom axisal perpenticular(vertical flight) and parallel(foward flight) to the coming wind respectivelly.

Rotor Model

The rotor system was used to produce the main rotor wake like a helicopter. There were two rotor models. One is 1.1m in diameter with four NACA0012 blades fixed at 12.5 degree and working at 1400rpm. The other is 3.0m in diameter with four NPL9627 blades . Model 2 was tested under the second rotor in hover and forward flight states .

Measuring Instrument

The pressure on the tailboom surface of model 1 was obtained by multi-tube manometer. The data was taken by camera for later reading in order to shorten the instrument working time. The power of the pressure sensors on model 2 was supplied by a special adapter. The adapter maganified and translated the output single to a computer for data acquiring and saving.

Results and Discussion

The upperward force on the circulation control tailboom is assosiated with the coming wind speed V_0, the slots' width h and position D, the synthetical jet parameter-momentum coefficient C_μ .The momentum coefficient is the comparison of jet momentum from the slots and the coming wind momentum.

$$C_\mu = 2\frac{\rho_j h}{\rho_0 D}\left(\frac{V_j}{V_0}\right)^2$$

where:

ρ_j — jet density;

ρ_0 — tunnel wind density;

h— hight of the slot, for two slots $h = h_1 + h_2$;

D — diameter of the boom;

V_j — jet speed;

V_0 — wind speed.

The pressure and the side force are expressed as pressure coefficient C_P and side force coefficient C_z :

$$C_P = \frac{p_i - p_0}{\frac{1}{2}\rho_0 V_0^2} \qquad C_z = \frac{F_z}{\frac{1}{2}\rho_0 V_0^2 S}$$

where:

p_i — pressure of a certain measuring point;

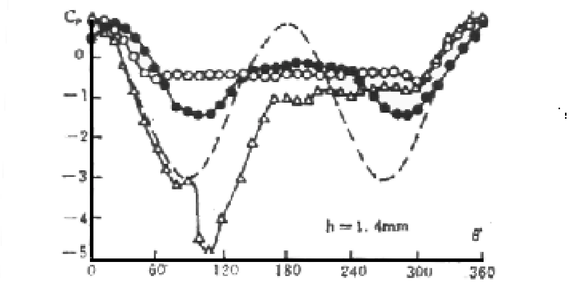
p_0 — static pressure of the coming wind,;

F_z — side force on one model;

S— refered squire (the diameter of the model mutiplies the slot length).

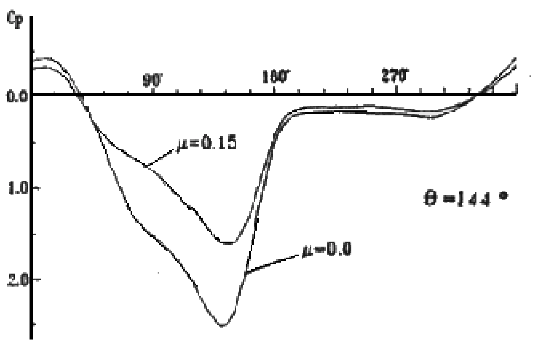
Pressure Distribution on Tailboom

The pressure distribution on model 1 from the test was shown in Fig.2(a) while model 2 in Fig.2(b). In Fig.2(a) the curve when Cu=0 is the same with the one in literature [1] and the side force messured by the scale on model 2 is almost the same as the one caculated from the pressure distribution by the pressure sensors. All these confirms the accuracy of the test.



——— potential theory, $C_\mu=0$; ○ in tunnel, $C_\mu=0$
● under rotor, $C_\mu=0$; △ in tunnel, $C_\mu=0.4$.

(a) Model 1



(b) Model 2

Fig.2. Pressure distribution on the models

The separate point can be find from the pressure destribution with the law that the pressure in separate region is the same. In Fig. 2 the separate point in tunnel test is about 75° from the top center line of the tailboom when there was no circulation control while under rotor it is much farther after 75°. The reason is the separate point is not only related to Reynolds number but also determined by the turbulence of the coming flow and the crudeness of the cylinder surface. Although the Reynolds number is small, the downwash of the main rotor was swirl and unsteady making the boundary layer into turbulent flow from laminar flow, so the separate point moves back and the negative pressure became high. In forward flight, the downwash of the main rotor flows backward providing a flow component along the boom axis disturbing the control jet from the slot and reducing the efficiency of the circulation control.

We can also see from Fig. 2 that there is no side force without circulation control because the pressure at both side of the tailboom is symmetry. While with circulation control, air exited the slots tangentially to the boom and attached itself to the surface to apply energy to the coming flow and circulated the flow around the boom. The separate point was put back to 175°. The negative pressure at 90°side surface of the boom increases greatly but pressure at the other side almost not changed, so the side force was preduced. This shows that circulation can be applied on the helicopter's tailboom efficiently.

Influence of Momentum Coefficient

The momentum coefficient plays a important part to the circulation control aerodynamic efficiency, the effect of coming flow speed is involved in it.

In Fig.3, the side force coefficient C_z increases with C_μ. Obviously, as C_μ rised, more energy was added , the ability of the airflow to restrain the resistance of friction and pressure became strong to make the separate point retreat. So the side force increased.

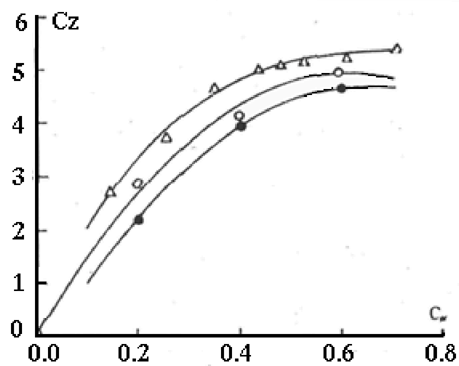


Fig. 3. Influence of momentum coefficient;
○ h=1.4mm, θ=140°; ● h=1.4mm, θ=100°;
△ h_1=0.9mm, h_2=0.5mm, θ_1=70°, θ_2=140°.

The momentum coefficient also varied while only the wind speed of tunnel was changed at certain jet speed. The curve of C_z with V_j/V_0 is almost the same as that of $C_z - C_\mu$. But at low V_j/V_0 volume, low C_z does not imply little force.

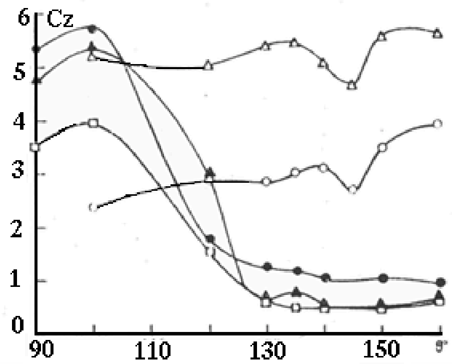
Generally, high momentum coefficient leads to high aerodynamic efficiency. But it does not mean high C_μ is a good thing because high C_μ needs more power. If less power result in high efficiency, the related C_μ undoubtedly is goood. In Fig.3, when C_μ <0.45, the slope of the curve is steep, as C_μ >0.45, C_z changes little while C_μ increases. So C_μ lower than 0.45 is a better choice.

Infuence of Slots' Geometry Variables

The slots' geometry variables include the number, size and position of the slots. Fig.4(a) shows the side forces on the model 1 with one and two slot(s) as the function of the slots' position at certain C_μ and total size. Fig.4(b) shows the side force on model 2 changing with the slot's location. The cures show that C_z of two slots is much higher than that of single one. It changes little with slots' angle. This is useful in practice for the complexity of the helicopter flying condition lead to constant changes of the direction of the downwash or the slots' position. These changes must not cause great difference of aerodynamic forces on circulation control tailboom in all flight regimes.

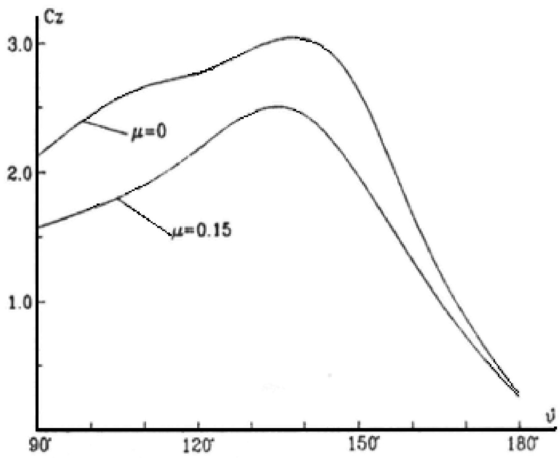
Fig.4 also shows that the circulation control coefficient is the highest when the single slot's is at 100°, 25°after the sepatate point 75°without circulation control. The jet circulated the air flow and bring the separate point to 170°(Fig.2).

Fig.4 indicates that small slot(s) results in high coefficiency of circulation control with given C_μ or flux. As the slot(s) narrowed, the jet sped and the energy of the jet air became greater, so the side force coefficient was higher. But if the slot was two small, the Mach number would be big and C_z would reduce quickly. This is identical to the conclusion in literature[4].



● h=0.5mm; ▲ h=0.9mm; □ h=1.4mm; △ h_1=0.9mm, h_2=0.5mm; ○ h_1=0.9mm, h_2=1.4mm.

(a) Model 1 in tunnel (Cu=0.4)



(b) Model 2 under rotor

Fig.4. Influence iof slots' position

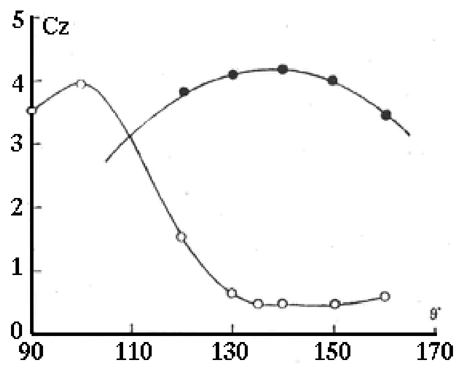


Fig. 5. Comparason of tests in tunnel and under rotor; C_μ=0.4, h=1.4mm, ○ test in tunnel; ● test under rotor.

Farther more, the power needed for the injection is in direct proportion to the momentum coefficient and the square of jet speed. Given C_μ, extreme narrow slot means much high jet speed and the power needed would increase rapidly.

The influence of different coming flow on circulation control is shown in Fig.5. The best slot's position in tunnel is not the same to that under the rotor because the separate points is different. The turbulence of the main rotor wake makes the separate point back to 140° or so with $C_\mu = 0$ while in tunnel it is at 70°.

Conclusions

Through the analyses about the experiment result, some valuable conclusions were obtained.

Circulation control can be applied on the helicopter's tailboom efficiently to provide the antitorque and maneuvering forces by making use of the main rotor wake;

The working condition and its structure of the circulation control tailboom, the variables such as Reynolds number, slots' geometry, momentum coefficient should be considered when circulation control is applied on tailboom, where Reynolds number, momentum coefficient and slots' geometry variables are especially important.

It is considered to be better that the momentum coefficient is 0.4 or so when the circulation control efficiency and the needed power for air jet are considered;

The aerodynamic forces of two slots on circulation control tailboom is obviously higher than that of single slot, and its change is gently which is more suitable for the complex downwash of main rotor at the helicopter various flying states;

The best slot's position is determined by the separate point which is influenced by Reynolds number, coming flow turbulance and the smoothness of the tailboom. The best location of single slot is about 20 degree after the separate point, for two slots, the first slot should be at this position;

Usually it is better for narrow slot on circulation control tailboom, but it is not absolute for that too narrow slot may be no use. The size of slot should be determined by the critera of high efficiency in actual use.

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