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Numerical Simulation Study on Propeller Slipstream Interference of High Altitude Long Endurance Unmanned Air Vehicle

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Abstract

In this paper ,the control equation of Multiple Reference Frame(MRF) as the propeller calculation model was present and analyzed, the propeller slipstream interference on HALE UAV was studied with three-dimensional numerical simulation. It is shown that the flow field of the MRF model is good consistent with true propeller flow, and MRF can accurately simulate aerodynamic interference on the aircraft. The stream traces on the V-tail surface were deflected and shrank, pressure distribution ,C_{mx} and C_{mz} on V-tail surface was changed apparently too.But slipstream had little effect on wing. The influence of propeller slipstream on the aerodynamic performance of the UAV at the status of taking off is biggest, become weaker at status of climbing and smallest at the status of cruising. The influence of propeller slipstream is enhanced with increment of propeller thrust and basically familiar in the same thrust between the two blade attack angle. The pressure drag on aft of UAV fuselage increased rapidly by the interference of propeller slipstream, leading aerodynamic performance of UAV become badly.

1. Introduction

Turboprop engine has low fuel consumption, high efficiency and low-speed flight characteristics, thus, many medium tactical transport aircraft and small unmanned aerial vehicles still widely used turboprop propulsion systems. Such as the European Airbus A400 transport aircraft and the U.S. C-130 "Hercules" transport aircraft and Predator

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series of UAV (shown as fig.1)[1-2],as well as domestic MA60, YUN7, YUN8, YUN12 transport aircraft and so on[3], are all using turboprop propulsion systems. In the development process of propeller aircraft aerodynamic design must take into consideration on the aerodynamic performance of the propeller slipstream interference on the configuration .This interference is more prominent than the slipstream affect of turbojet, even can determine the success of the entire aircraft design .So it is very important to carry out research of the aircraft propeller slipstream aerodynamic interference .Propeller slipstream aircraft interference assessment has been one of the difficulties of propeller aircraft aerodynamic design[4-9]. This paper uses MRF model to simulate propeller rotation, both the axial and rotational effect, to study the effects of slip effect push type propeller of high altitude long endurance UAV using numerical simulation method ,as shown in Fig2.

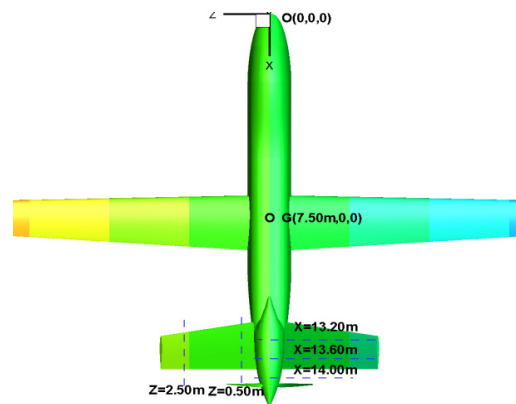Fig.1 Propeller thrusting layout of Predator UAV

Fig.2 Propeller thrusting layout of HALE UAV, calculation coordinate and V-tail section defined

2. MRF model

MRF model is a common and simple effective steady method for rotational fluid motion calculation, widely used in fields of rotary fluid machinery and propeller design. The basic idea of MRF model is the computational grid area, which was divided into fixed region and rotation region. The flow field in rotating propeller is located within the region, which was simplified as instantaneous flow blades in a position and made the unsteady problem with constant method. Rotation region of grid remained stationary in the calculation, the effect of Coriolis and centripetal force were steady computed in rotating coordinates; and the fixed region of aircraft in the inertial coordinates was in accordance with the steady calculation .Exchange fluid parameters of inertial coordinates at the junction of the two sub regions, to ensure the continuity of interface, achieved using steady calculations to study the unsteady problem.

3. Calculation and analysis of the influence of slip effect

The slip effect on the aerodynamic characteristics with and without propeller rotation were calculated by MRF model in the condition of taking off, climbing and cruising. Aerodynamic coefficients are calculated reference to the vertex at the origin (0, 0, 0), the torque reference points for UAV position of the center of gravity (7.50m, 0,0), pitching moment coefficient was negative as viewed to bow to it. Aerodynamic coefficient calculated by the wing area as the reference area was Sref=32m2, reference average air wing chord was Cref=1.76m.

The flight state calculation conditions was shown in table 1. Comparison of Stream traces with and without propeller was shown in fig3.Comparison of pressure coefficient along sections Z=±0.50m ,±0.50m,2.50m with and without propeller slipstream interference at taking off status was shown in fig4~fig6.Comparison of computational results with and without slipstream interference of the UAV model was shown in table2.Comparison of Cmx and Cmz of the UAV V-tail with and without propeller was shown in fig7. Comparison of stream trace of the UAV wing with and without propeller was shown in fig8.

The lift-to-drag increment of UAV in different thrust of propeller status was shown in fig9. The lift-to-drag increment of UAV in different blade attack angle status was shown in fig10.

Table1 Computational condition at different status

Flight status	Attack angle $\alpha/^\circ$	Altitude H/km	Thrust T/N	Velocity $V_0/$ (ms^{-1})	Rotate speed n/rpm
Taking off	4	0	6020	45	2500
Climbing	4	3	3365	55	2400
Cruising	2	7	1150	75	2290

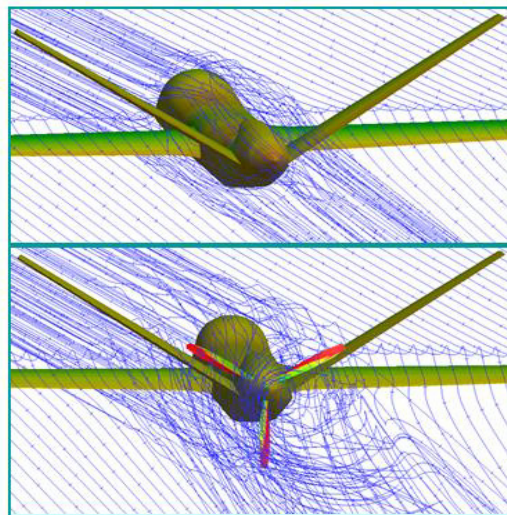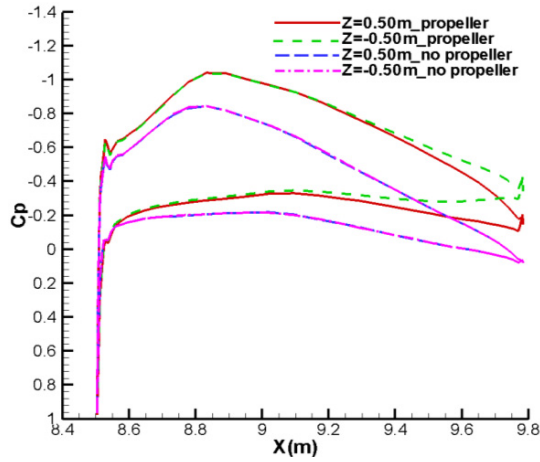

Fig.3 Comparison of Stream traces with and without propeller

Fig.4 Comparison of pressure coefficient along section Z=±0.50m with and without propeller slipstream interference at taking off status, α=4o
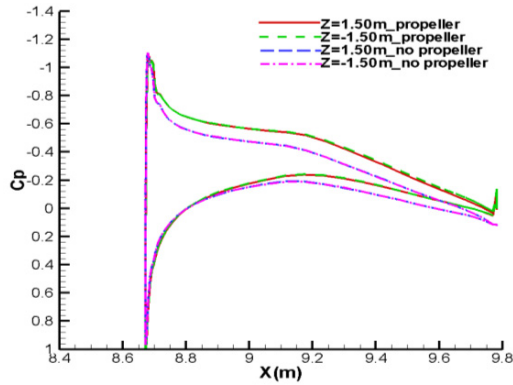

Fig.5 Comparison of pressure coefficient along section Z=±1.50m with and without propeller slipstream interference at taking off status, α=4o
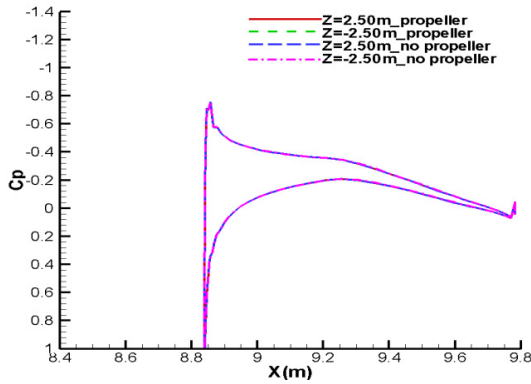

Fig.6 Comparison of pressure coefficient along section Z=±2.50m with and without propeller slipstream interference at taking off status, α=4o

Table2 Comparison of computational results with and without slipstream interference of the UAV model

	Flying status	$\alpha/^o$	C_l	C_d	C_z	C_{mx}	C_{my}	C_{mz}	C_l/C_d
UAV without propeller	Taking off	4	1.0012	0.0390	0.0001	0.0002	-0.0004	0.0007	25.70
	Climbing	4	1.0024	0.0393	0.0002	0.0002	-0.0005	0.0005	25.51
	Cruising	2	0.8045	0.0312	0.0001	0.0002	-0.0004	-0.0283	25.76
UAV with propeller	Taking off	4	1.0135	0.0495	-0.0020	-0.0018	0.0053	0.0379	20.48
	Climbing	4	1.0084	0.0445	-0.0012	-0.0001	0.0035	0.0209	22.67
	Cruising	2	0.8039	0.0323	-0.0006	0.0001	0.0016	-0.0308	24.88

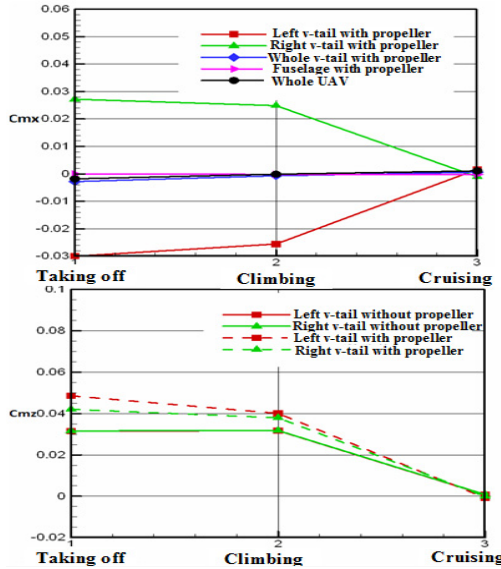

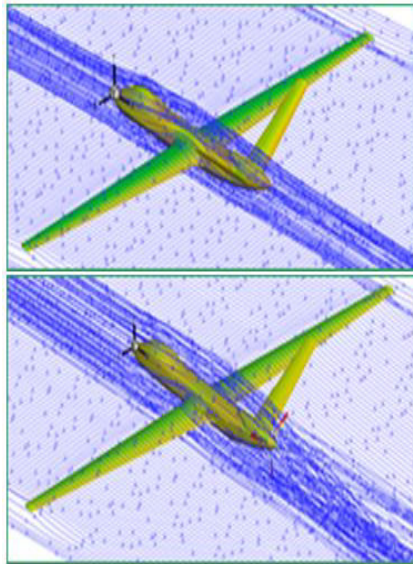Fig.7 Comparison of Cmx and Cmz of the UAV V-tail with and without propeller

Fig.8 Comparison of stream trace of the UAV wing with and without propeller
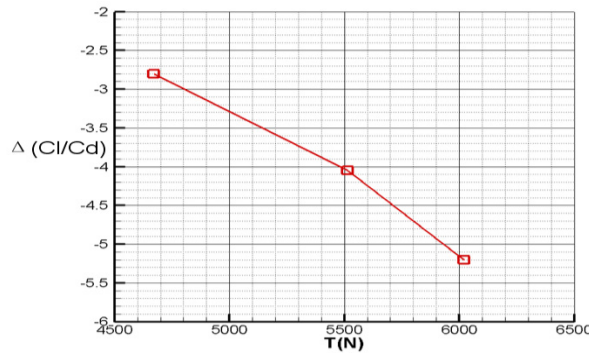
Fig.9 The lift-to-drag increment of UAV in different thrust of propeller status
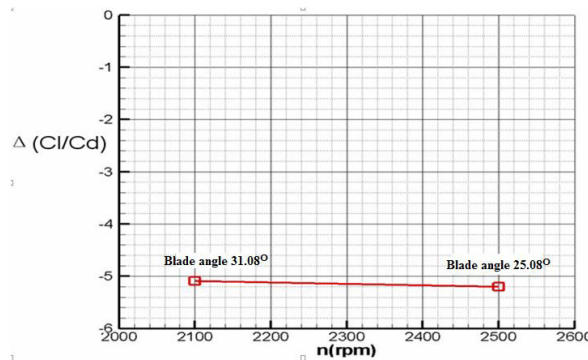

Fig.10 The lift-to-drag increment of UAV in different blade attack angle status

Propeller thrust reached maximum at taking off status, the power of air flow in front of propeller disk was achieved maximum. Flow pipe in front of disk was in sharp contraction ,acceleration and rotation. The flow of V tail where was affected by the strong acceleration and rotation effect, so that the V tail influence increment of the acceleration effect and rotation effect, and influence of aerodynamic coefficient reached the maximum. Propeller thrust was reduced at Climbing status, the influence of acceleration and rotational effect was weakening in front flow of propeller disc, and the influence range of slip effect on V tail decreased, the aerodynamic coefficient increment effects was also weakened. Minimum propeller thrust was at cruising status, The acceleration and rotation effect was the weakest in front flow of propeller disc, so that influence of the slipstream on V tail sphere was the smallest, and the aerodynamic coefficient was not affected at this status.

Overall, impact strength of propeller slipstream effect increased with the increment of thrust, and decreases with the increment of flow velocity, gradually weakened by the UAV longitudinal symmetrical externally oriented. UAV lift to drag ratio was sharply decreasing with the thrust increased , the same thrust between different pitch of slipstream effect were basically the same. Slipstream effect can only affect the UAV aft section of the fuselage and V-tail part , basically not affected the wing. Accelerating effect makes the aerodynamic coefficients of the whole UAV increase, resulting in pitching moment increasing. Rotation effect makes the V tail surface pressure asymmetry, and make increase roll moment and yaw moment of UAV. The longitudinal, lateral and yaw moment of UAV need to trim ,because of the slipstream effect.

4. Conclusion

Development of high altitude long endurance UAV propeller slipstream effect on numerical simulation method based on MRF model. Calculation of the influence of the propeller slipstream effect on V tail and the whole machine of aerodynamic coefficients, analysis the influence of propeller slipstream effect on taking-off, climbing and cruising UAV aerodynamic characteristics. The whole UAV slipstream effect study reached the following conclusions:

- The MRF model of simulation method could better simulate the propeller slipstream acceleration effect and rotation effect on aerodynamic characteristics. This method has important engineering application value, could provide technical support for propeller aircraft aerodynamic design.
- Propeller slipstream effect on the aerodynamic characteristics of UAV was strongest at taking off status, and aerodynamic coefficient was the largest increment . The influence of propeller slipstream effect was weaken at climbing status and minimum at cruising status. Aerodynamic coefficient was basically unchanged at cruising status. The aft fuselage pressure drag increases sharply by the slipstream effect at taking off status, led to decline in aircraft aerodynamic performance.
- The propeller slipstream effect intensity gradually increased with the increment of thrust, and decreased with the increment of flow velocity, weakened from the UAV symmetrical plane to externally oriented , affected by the same slipstream effect in the condition of the same thrust. Slipstream effect can only affect the aerodynamic characteristics of the rear section and V tail part ,and the wing basically was not affected For the tail section design needs to consider the influence of slipstream optimization design. Propeller engine matching needed to take into account between dynamic design and aerodynamic performance of slipstream effect.
- Acceleration effect made the whole UAV aerodynamic coefficients increase, resulting in pitching moment increment. Rotation effect made the V tail surface pressure asymmetry,resulting in the whole UAV roll moment and yaw moment increment.

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