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SUPPORT SYSTEM OPTIMIZATION AND SUPPORT INTERFERENCE COMPENSATION FOR HIGH SPEED WIND TUNNEL TESTING

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ABSTRACT

This paper mainly develops a numerical procedure to evaluate the interference of a support system and to optimize the shape of the support system to minimize the interference. The method is used to compute the support interference on a high-speed wind tunnel test article. The numerical compensated test result is also presented in this paper, and the result show that the correction method developed in this paper is reasonable and efficient.

INTRODUCTION

The test model is usually installed on the support system in test section of wind tunnel. Many kinds of support system, such as tail support system, abdomen support system, side wall support system and wing tip support system are used for wind tunnel testing. The difference between the flow around the test model and the flow around the real aircraft is caused by the support system and results in a difference between aerodynamic characteristics of the test article and the actual one which is referred to support interference. The support interference is one of the important topics of aerodynamic testing since it has important influence on the accuracy of the test data.

The support system and support interference becomes one of the main investigation areas of experiment aerodynamics. Researchers have began their study on the support system and support interference after the first wind tunnel was built. In China, most of this works focused on the support system used for the aircraft featuring low aspect ration wing(LA), such as fighters, bombers etc. We have little experience on the support system for aircraft featuring high aspect ration wings, the test requirements and the aerodynamic characteristics of such aircraft may different from that of aircrafts of low aspect ratio. The wing span of LA is very large while the wing chord is short, the body of it is also quite short, the normal force of the model is very large while the axial force is accordingly small and at same time the tested axial force need to be very accurate. The character of the test make the support system design very difficult because we have little experience in high speed wind tunnel testing for such aircraft. The details about the shape, size and support interference of the support system used for large aircraft wind tunnel testing have not been mastered yet, most of the support system for the wind tunnel tests of large aircraft is designed by applying available experience.

NOMENCLATURE

Ma	[-]	Mach number
α	deg	Angle of attack
β	deg	Angle of sideslip
C_L	[-]	Lift coefficient
C_D	[-]	Drag coefficient
mz(C_m)	[-]	Pitching moment coefficient
K	[-]	$=C_L/C_D$
dC_L	[-]	Support interference on lift coefficient
dC_D	[-]	Support interference on drag coefficient
dmz(C_m)	[-]	Support interference on pitching moment coefficient
dk	[-]	Support interference on k
Ω	[-]	Volume of cell element in Cartesian
Cp	[-]	Pressure coefficient
C_{PS}	[-]	Interfered Pressure coefficient
C_{PC}	[-]	Corrected Pressure coefficient
$\bar{Q}$	[-]	Conservative variable
$F(\bar{Q})$	[-]	Non-viscosity flux
Cp	[-]	Pressure coefficient
$G(\bar{Q})$	[-]	Viscosity flux
Dis	[mm]	The position of the support system

In this paper, we investigated several embodiments of the support system by CFD to find a support system that will not only meet the need of strength and stiffness to support the model but also have little support interference. We have also corrected the support interference of the test with the method developed in this paper.

MAIN RESEARCH CONTENTS AND METHOD

The LA model is used for the investigation. The position, sweepback angle and the size of the abdomen support system and the character of the support interference of the tail support system is studied in the paper; the results are used to design a novel support system. The support interference of LA test article is corrected with numerical and experimental method. CFD tools are used in the present investigation mainly to save money and convenience to find out the flow details that cause the support interference.

The support interference is computed by subtracting the aerodynamic forces of the test model without support system and from the one with support system. Both them have been computed through CFD. The support interfere is also used as the criterion to evaluate the support system.

The traditional support interference correction method requires specialized support interference experiments to obtain the interference [1], not only is the turn-around time long and the expensive, but also hard to reduce secondary interference effects.

Along with the fast developing of hardware technique and software technique, the ability and speed of computer and CFD software improving quickly, thus make it possible and efficient to study the support interference with CFD technique. The CFD method is used to study the support interference by solving an Euler or NS equation [2], which is a main way used in this paper.

At first, we compute the flows around the model with and without support system; then we get the difference of the two flow fields. We can also get the difference between the aerodynamic characteristic of the test model of two states. The difference is just support interference and used as the criterion to evaluate the support system and to correct the test data. This method is so called as support interference numerical simulation.

For example:

The interference of pressure coefficient is:

$$\Delta C_P = C_{PS} - C_P \qquad (1)$$

We can get the corrected aerodynamic characteristics by subtract the support interference from the test result:

$$C_{PC} = C_{PS} - \Delta CP \qquad (2)$$

The numerical simulation parameters are absolutely the same. The meshes used for calculate are almost same(through special method to be introduced later) in simulations with and without support system, thus the numerical error can be elliminated and the precision of support interference improved.

In this research, the abdomen support system will be placed 30 mm behind the leading edge, moving backward for 6 times by 10 mm or 30 mm every time. The last one is been apart from the leading edge 120 mm. The sweepback of the support system varies from -20 degrees to 60 degrees in 7 times. The support interference of each configuration would be calculated and the curves of how the support interference changes with the position and the sweepback of the abdomen support system will be drawn.

NUMERICAL METHOD AND GRID GENERATION

The governing flow equation used in this paper is three dimensional compressible RANS equation with SA turbulence model [refer to the original paper of spallant with modificaiton to [3]].

The NS equation of the integral form is:

$$\frac{\partial}{\partial t}\iiint_{\Omega} \vec{Q}\, dV + \iint_{\partial\Omega} F(\vec{Q})\cdot\vec{n}\, dS = \iint_{\partial\Omega} G(\vec{Q})\cdot\vec{n}\, dS \qquad (3)$$

After discretization of the governing equation by the finite volume method, we get a simi discrete equation:

$$\Omega_k \frac{d}{dt}\vec{Q}_k + RHS_k = 0 \qquad (4)$$

The Runge-Kutta multiple advancing scheme is used for time intergration. Mixed second and forth order self adapted dissipation is also used in procedure.

We use structured grid mainly while unstructured grid used in some special conditions in the paper. The Delaccnay advancing method and ellipsoid background grid are used in the building of unstructured grid. Some refinements have been done to the both structured and unstructured grid to improve the quality of the grid.

The surface grid must precisely reflect the shape of the model and the pressure distribution on the model surface, so we should refine the grid near tip and border of the model, and must also refine the grid near the wall to reflect the viscous influence more precise,show as Figure 1.

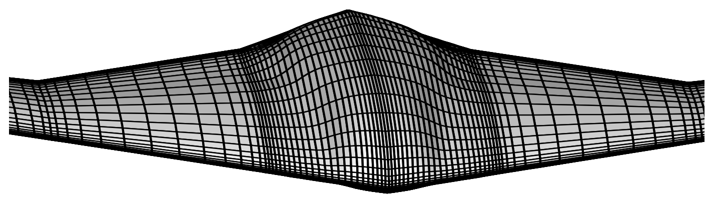


Figure 1 The grid distribution on the model surface

The far field boundary condition is used in the present computation, so the outer border of the domain field can be any shape. When we use structured grid, we should ensure the correspondences of the grids of both outer border and model surface. The space grid are created after the border grid by advancing method. We should also refine the grids where the flow changes violently while coarsen the grid near out border to reduce the amount of the grid, show in Figure 2**.**

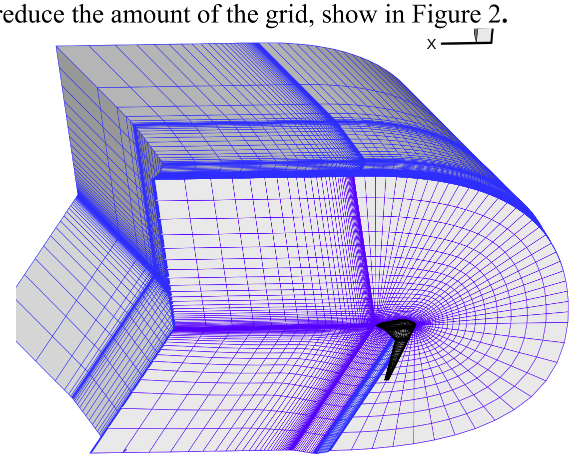


Figure 2 The grid distribution in space

To create the mesh for the model including the support system, at first, we create the grid for the model without the support system by divide the flow field in two part, one is the space occupied by the support system and the others; second, we create grid in the two part independently. Then the grid with the support system can be created by subtracting the grid in the support system and setting the surface of the support system as the wall boundary condition. In this way, the grid with support system and the without support system are absolutely identical same except the grids included in the support system, show in figure 3.

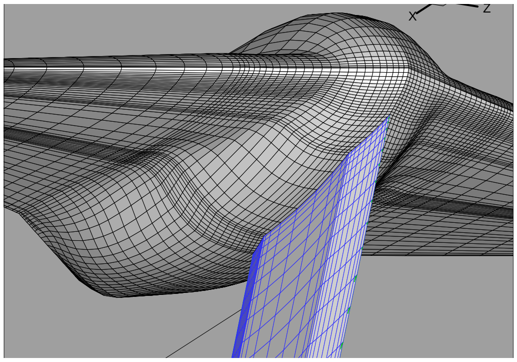


Figure 3 The grid with abdomen support

The coherence between the grids with and without support system count for much, because numerical calculation do have the numerical error, if the difference between the meshes is too large, the numerical error may mix with and overcast support interference. Such method used to refine the mesh can make the meshes same basically, thus the disadvantageous influence of the numerical error can be removed from the support interference when we compute support interference by subtract the aerodynamic force of the model without support system from the aerodynamic force with support system.

The far field boundary condition is used at outer border of the flow domain, wall boundary condition is used on the surface of the model and support system.

RESULT AND ANALYSIS

Because the support interference of the tail support mainly affects on the rear part of the model, the tail support system gearing manner and the shape of the tail support pole of the model have great influence to the pressure distribution of the tail model. Usually, most of the research has simplified the cavity used to gear the pole in the tail of the model, it is to fulfil the cavity with solid material. We have found that the cavity has important influence to the pressure distribution on the rear part of the model through our research, so the cavity is simulated in this paper to get more precise result, the mesh show in Figure 4. The pressure distribution on model surface a are shown in Figure 5, The figure depicts the surface pressure rise on the model near the support system apparently.

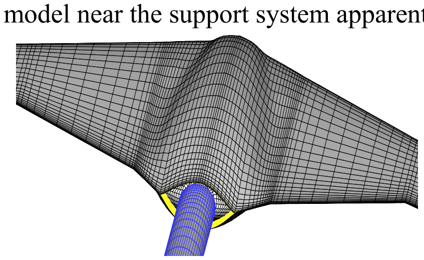


Figure 4 the mesh of the model with tail support

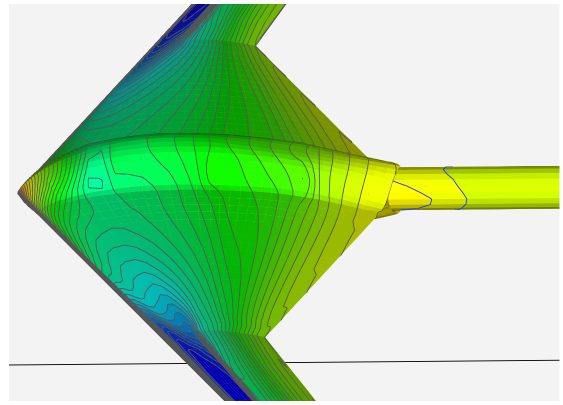


Figure 5 Pressure distribution on model surface

The aerodynamic force and moment coefficients obtained from CFD calculations and wind tunnel testing are compared in Figure 6. The incremental values reference support interferences of CFD and test are compared in Figure 7. We can see from the Figures that the curves of CFD lift coefficient and experiment lift coefficient almost overlapped, while a small difference exist in the curves of drag coefficients and pitch moment coefficients. The support interference is to calculate the difference between the aerodynamic force of the model with

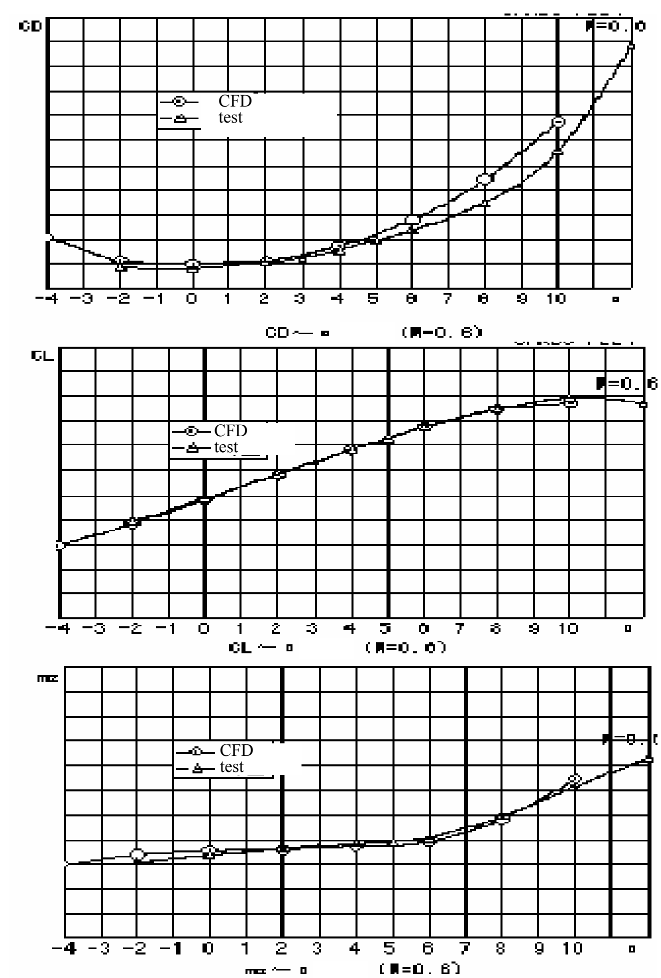


Figure 6 Comparision of numerical and experimental results

and without support system, so the difference between the CFD results and test results play little influence on accuracy of the support interference. In other words, the difference, either experimental or CFD, is acquired by results with support system minus the results without support system respectively, it also can be described by following formula:

$$\Delta Q_{CFD}=Q_{CFD\ \text{with support system}}-Q_{CFD\ \text{without support system}}$$

$$\Delta Q_{test}=Q_{test\ \text{with support system}}-Q_{test\ \text{without support system}}$$

Where, Q stands for C_L, C_D, Mz.

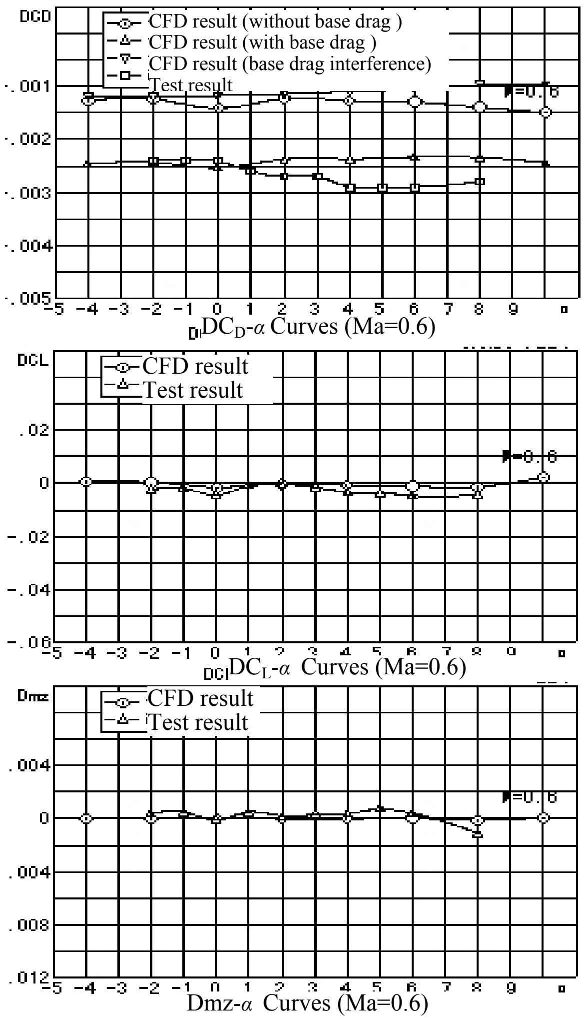


Figure 7 Contrast curves between test and CFD

From the comparison of curves of support interference shown in Figure 7, we can see, the support interference caused by the tail support system is not only smaller than the absolute error limitation, but also smaller than the square root mean error deduced from 6 repeated tests: 0.002 and 0.0005. The lift and pitch moment support interference introduced by tail support system can almost be neglected, but the support interference of drag can not be neglected because the large airplane experiments need quite high accuracy on drag. Both CFD and test results show altogether that the drag interference caused by the tail support system can not be neglected. From the comparison curves of drag support interference of test and of CFD, we can see that the calculated interference is almost identical with the tested interference for small angles of attack. The difference between the curves enlarges while the angles of attack increase, but the maximum value of the difference of drag interferences does not exceed 15% of the total value, which means that both CFD results and test results are creditable. It can also be seen from the figures of the drag interference, the interference of aft body drag and base drag introduced by tail support system is about each 50% of the total drag interference.

See from the Figure 8, the aerodynamic characteristics of the model change clearly after correction, among them, the maximum change existed in the maxim lift-drag ratio, which reduces from 30.5 to 26.5. From the above analysis, we know it is necessary to compensate the test results with tail support interference to get accurate aerodynamic characteristics of large airplane. The compensation method developed in this paper is efficient to compensating the test results and to subtract the support interference from test data.

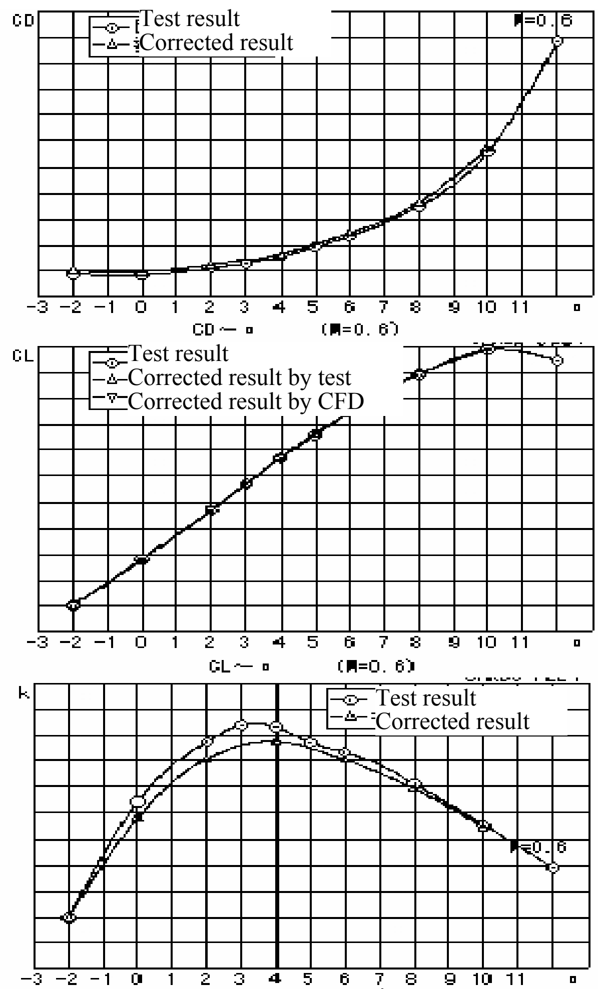
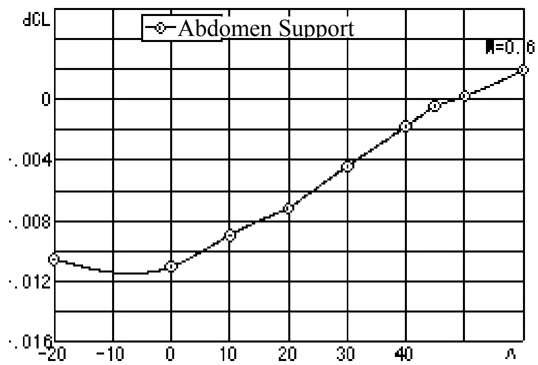


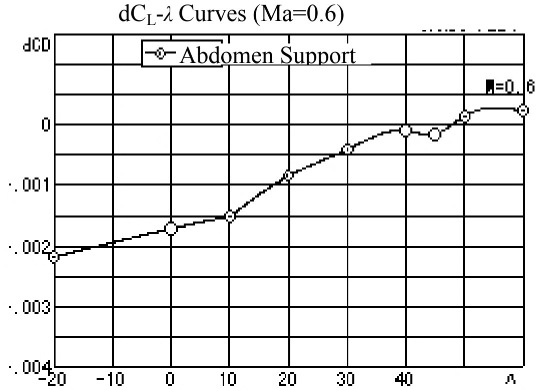
Figure 8 Comparison of curves of Corrected result and test result

THE EVALUATION OF THE ABDOMEN SUPPORT SYSTEM.

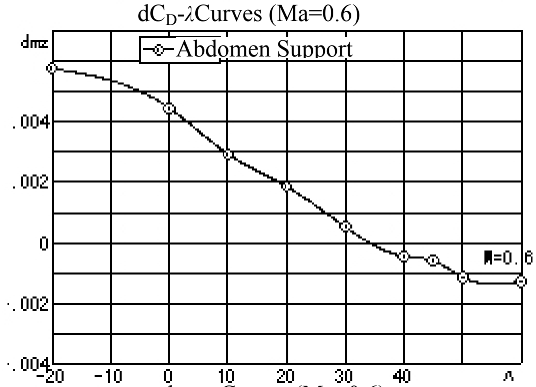
Figure 9 shows the curves of the support interference of abdomen support system as a function of the sweep back angle of the support system. We can see from the figures, the drag interference rises from -0.00219 to 0.0002 when the sweepback changes from -20º to 60º. The minimal absolute value of drag interference reaches to zero when the sweep back angle nears 45º. The lift interference rises from -0.011 to 0.0019 when the sweepback varies from -20º to 60º. The minimal absolute value of the lift interference is also zero when the sweep back angle nears 48º. The pitch moment interference reduces almost linearly from 0.00575 to -0.00128, the minimum interference nears 0 when the sweep back angle of abdomen support system nears 35º.



dC_L-λ Curves (Ma=0.6)



dC_D-λCurves (Ma=0.6)

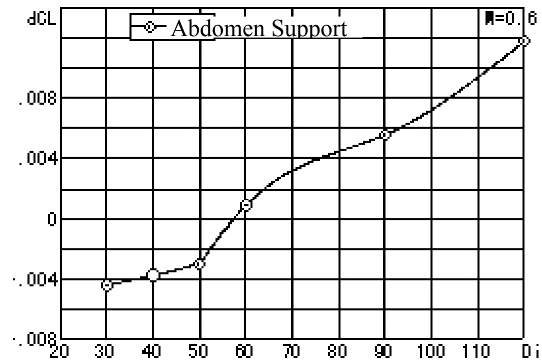


dmz-λCurves (Ma=0.6)

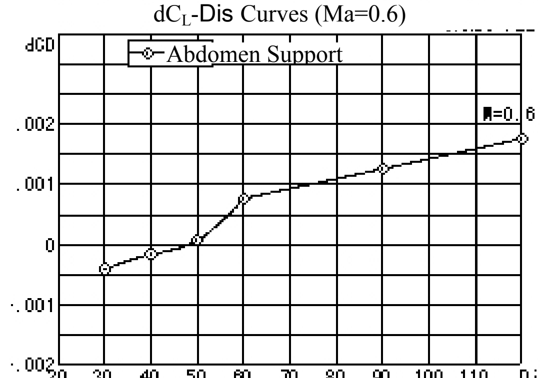
[illegible] with sweep back angle

Figure 10 presents the curves of support interference as a function of the distance between the leading edge of support system and leading edge of the model, the figure shows that the drag interference decreases from a positive value to a negative value when the support system moving away from the leading edge of the model. The distance is 49mm when the interference attains a value of zero; Lift interference decreases from a negative value to a positive value while the pitch moment interference decreases from a positive value to a negative value when the support system moving away from the leading edge of the airplane model, the distance where the lift interference attains 0 is 49mm; the position when the pitch moment interference attains 0 is 36mm from the leading edge of the model.

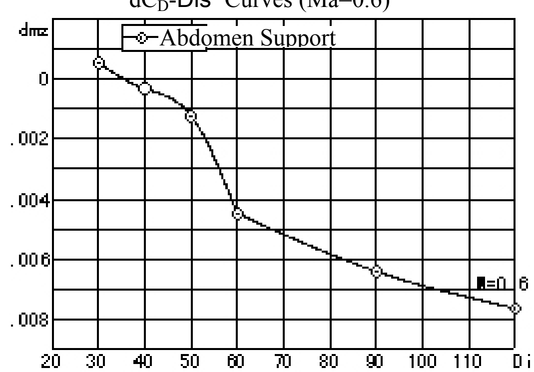
From the analysis above we can see that position and sweepback of abdomen support system have great influence on the support interference. A novel designed abdomen support system can decrease the amount of support interference greatly.



dC_L-Dis Curves (Ma=0.6)



dC_D-Dis Curves (Ma=0.6)



dmz-Dis Curves (Ma=0.6)

Figure 10 Interference variation with position

3.3 MECHANISM OF SUPPORT INTERFERENCE

To illustrate the mechanism of support interference, the isolines of pressure interference caused by the tail support system and the abdomen support system on model surface are shown in Figure 11, Figure 12 and Figure 13. We can see from Figure 11 and Figure 12 that the abdomen support system modifies the lower surface pressure distribution. Thus the abdomen support system mainly affects the lift. The abdomen support system has almost no influence on the pressure distribution of upper surface of model.

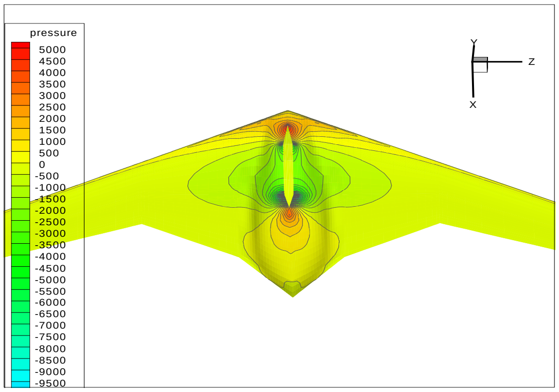


Figure 11 Pressure interference distribution on lower surface of abdomen support system.

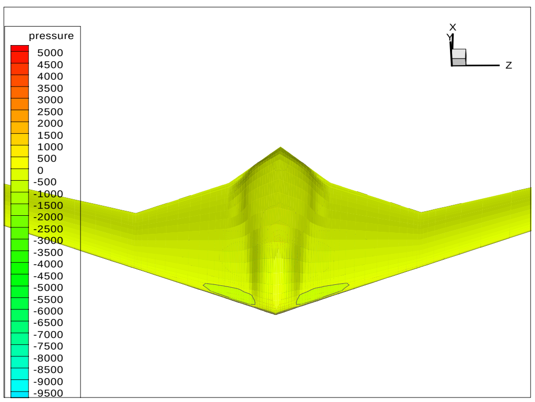


Figure 12 Pressure interference distribution on up surface of abdomen support system.

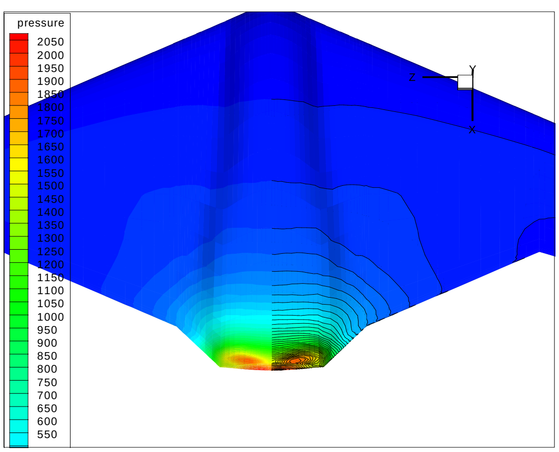


Figure 13 Pressure interference distribution on upper surface of abdomen support system.

The tail support pole make surface pressure rise regardless of the position of surface. The surface pressure increases in the vicinity of the tail support structure. The axial force will decrease because of the additional force that caused by the positive pressure interference and converged tail shape of the model. The small difference between the pressure interference on upper surface and bottom surface cause very small interference of normal force. Furthermore, the lift created by the tail contributes negligible of total normal force, thus the lift interference caused by tail support system is small.

CONCLUSIONS

The numerical evaluation and test data correction method for support interference developed in this paper is reasonable and efficient. The method can fulfil the requirement for design, the computed result is reasonable and the value is reliable. The coefficients corrected test data have higher drag and a lower lift-drag ratio.

For high speed wind tunnel tesing, the abdomen support system and the tail support system can meet the test requirement. The tail support system is comparatively better, because the lift, drag and pitch moment support interference of tail support system are all lower than that of abdomen support system.

The position and sweep back angle of abdomen support system have great influence on the support interference. Novel designed abdomen support system can reduce the amount of support interference greatly.

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