Prediction of Subsonic Wind Tunnel Mounting System Interference

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This paper describes the use of an advanced aerodynamic low-order panel code (VSAERO) in predicting the effects of various model mounting system components in the Boeing Vertol low-speed wind tunnel. A long static probe, mounted on the wind tunnel centerline, was used in obtaining the experimental data. In general, there is good agreement between the theoretical and experimental changes in pressure due to the mounting systems. This analytical technique can now confidently be used to estimate mounting system pressure gradient effects on a static probe that can be applied with the other known tunnel corrections in producing higher quality experimental results for new configurations.

Introduction

THE purpose of this paper is to validate the use of advanced aero methods in estimating the wind tunnel interference effects of various model mounting system components. This marriage of analytical and experimental methods will permit the evaluation of new configurations more rapidly and with greater confidence. In recent years, computational aerodynamics has been applied to all phases of aerodynamics. Numerous computational tools for the aerodynamicist exist. One tool is the panel-type influence coefficient method. Panel methods are in widespread use and have proven useful for numerous configurations.[1,2] Though based upon restrictive linearized potential flow theory, panel methods are extremely accurate in predicting pressures and forces over many complicated configurations.

In the hierarchy of computational fluid dynamics, panel methods, which deal with linearized subsonic or supersonic potential flow, rank well below the sophisticated finite-difference approximations of the Euler or full-potential equations. Rapid progress is being made in solving the Euler and full-potential equations for complex three-dimensional configurations. This, however, is still a long way off due to the body-fitting grids and complex conformal mappings necessary in the solution of these equations.[3-5] At present, the surface singularity panel method represents the most versatile and efficient approach for solving the flow about arbitrary and complex three-dimensional configurations.

Another tool commonly used by the aerodynamicist is the wind tunnel. Both the panel codes and the wind tunnel are analysis tools and are used to obtain pressure and force data over aerodynamic shapes. The wind tunnel and panel method codes have their advantages and disadvantages and are restricted by physical and numerical limitations. Panel methods, which are based upon potential flow theory, cannot handle flows where viscous effects are dominant. However, for most flows of practical interest, panel methods do an adequate job in predicting flow characteristics. The wind tunnel, on the other hand, also has limitations. While the tunnel solves with undeniable accuracy the equations of flow, it has long been recognized that the flow in the tunnel is influenced by various geometric features. The relationship among these features and the flow is not perfectly understood and is the subject of continuing investigation. Wall interference effects, model support system interference, ventilations (intended and otherwise), boundary and shear layers, wakes, and secondary flows all are solved by the tunnel, but with only varying degrees of control or understanding by the tunnel operators or users. To a varying degree, the calibration of tunnels and the correction of data accounts for the gradients and offsets of angularity, velocity, pressure, and their timewise change.

The panel code cannot predict all aerodynamic parameters with accuracy that is comparable to experimental results because it deals with the solution of an idealized mathematical problem. For example, one parameter that cannot be accurately predicted by the panel code is the absolute drag coefficient. The inviscid theory behind the panel code prohibits the calculation of boundary-layer effects on the drag coefficient. The panel code can never replace the wind tunnel as an absolute aerodynamic analysis tool. Most tunnels are not used as an absolute aerodynamics tool either because after making the known corrections, there is often concern about the unknown influences. However, the panel code and the tunnel together promise an even closer approach to the absolute aerodynamic tool in understanding aerodynamic phenomena.

This paper compares the computed and measured horizontal pressure gradient over a static probe induced by the wind tunnel mounting system components. The wind tunnel experiments and numerical analyses are conducted for a mounting system in a subsonic flow, in which case the disturbances propagate upstream from the mount to the model. Therefore, the interference effect of the mounting system on measured pressures can be quite significant. This pressure gradient or buoyancy can cause an erroneous drag force to be measured on the body in the region of the gradient. If the data is not corrected for the buoyancy effect, the drag level measured by the force balance will be different from the true level. This correlation provides the basis for correcting the experimental data for mounting system effects. The use of these computational aerodynamic tools combined with well-designed wind tunnel tests will improve the desired end products.

The relatively simple geometry of the static probe is chosen to demonstrate how even subtle changes in the mounting system configuration can affect the pressures over the body. To this end, experimental calibration tests and a panel method computer code simulation are used to determine the influence of the mounting system on the pressures. The experimental calibration tests were conducted at the Boeing Vertol 20×20-ft subsonic wind tunnel. The numerical simulation for all cases was done using a low-order surface singularity panel method computer code. The code,

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designated VSAERO (Vortex Separation Aerodynamics), was developed by AMI Inc. The computed results are compared to measured data to ascertain the accuracy of the calculation. The accuracy, flexibility, and usability of the code in modeling the mounting system and wind tunnel are discussed.

Experimental Approach

Initially, a centerline static probe was used to measure the static pressure gradient in the Boeing Vertol 20×20-ft subsonic wind tunnel. However, the influence of the probe geometry and mounting system provisions prompted a second test with a modified mounting system. The test body used was a 14-ft static probe borrowed from David Taylor Naval Ship Research and Development Center (DTNSRDC). The first calibration test involved the use of the static probe on a mounting system that consisted of telescoping steps, a short cannon, and a floor-mounted strut. Figure 1 is a representation of the static probe and the major geometric components of the telescoping mounting system (wind tunnel calibration I). The second test was done with an extended static probe to minimize the influence of shoulder pressures and with the probe suspended by wires so that the influence of the model mounting system could be assessed by the removal and installation of those components. Those components include the large, retractable, vertical strut; a cannon-like sting support; and a pitch-yaw knuckle. Figure 2 is a representation of the wire-suspended static probe and the major geometric components of wind tunnel calibration II.

Numerical Simulation

VSAERO is a low-order surface singularity panel code in which the singularities (sources and doublets) are piecewise constant on each panel. VSAERO does not contain any strict requirement for the paneling along the boundary from one patch (local grouping of panels) to another. However, if the configuration of interest is complex and severe panel mismatches occur, the code has provisions for breaking panel neighbors to control velocity calculations. VSAERO has a direct matrix solver for configurations with fewer than 630 panels and a blocked Gauss-Seidel iterative technique for configurations of greater than 630 panels. The surface velocities are calculated by taking the gradient of the doublet strength. The code has provisions for avoiding the differencing of potentials across a jump in local flow characteristics (e.g., wake). Surface pressure coefficients are calculated using the isentropic relation, and the force and moment data is obtained by summing up the contribution from each panel in the configuration. VSAERO has several special capabilities, including relaxed wake calculations and viscous/inviscid interactions (not used in this study). Detailed explanations of the mathematical formulation and all available options in VSAERO are beyond the scope of this study. Several excellent documents provide detailed information.[6-8]

From an applications point of view, the most important (and time-consuming) part of obtaining a panel method solution to an aerodynamic problem is obtaining point data that represent the configuration. For complex configurations, the use of a numerical three-dimensional lofting system is almost essential in obtaining accurate surface geometry. For simple configurations, however, many panel codes possess input preprocessors that can handle simple geometric shapes. VSAERO possesses multiple automatic geometry generation schemes that can quickly and easily (with minimum input) generate simple geometric shapes. Also, VSAERO has the flexibility of accepting points as corner points of panels or in constant station (X), buttline (Y), or waterline (Z), from which surface panel geometry is interpolated. This allows for the rapid repaneling of a configuration to obtain greater resolution in a specific region.

Figure 3 is a representative panel model representation of the static probe, telescoping mounting steps, short cannon, and floor-mounted strut. Figure 4 is a representative panel model representation of the static probe, pitch-yaw adapter, tapering cannon, and floor-mounted strut. The static pressures were surveyed between the tip and root region indicated in the previous figures. The configurations depicted in these figures were depaneled for the purpose of illustration. The circular cross section of the static probe and cannon were generated using an automatic geometry scheme internal to the code. Dense paneling in the chordwise and spanwise regions of the static probe was used to obtain detailed pressure data over the static probe. The rectangular cross sections of the pitch-yaw adapter and floor-mounted strut were generated through the input of base corner point data, which the code then interpolated to generate surface panels. Moderate paneling (without sacrificing geometric detail) was used on these components of the mounting system, as detailed answers on these surfaces were of no importance.

The numerical simulation for the first calibration test modeled the entire mounting system consisting of telescoping steps, a tapering cannon, and a floor-mounted strut (with approximations) and was analyzed for a free-air condition. The base flow regions of the floor-mounted strut and top sec-

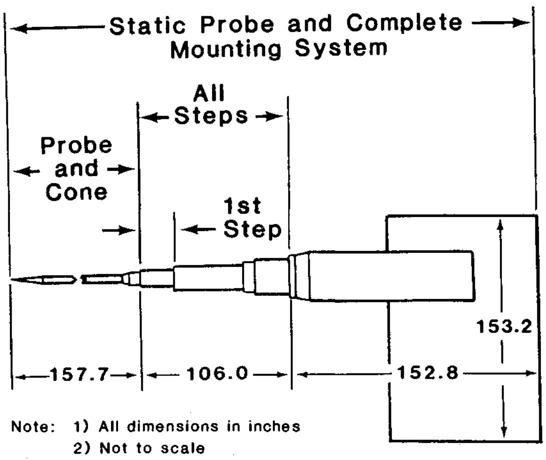

Fig. 1 Static probe and components of complete telescoping mounting system (wind tunnel calibration I).

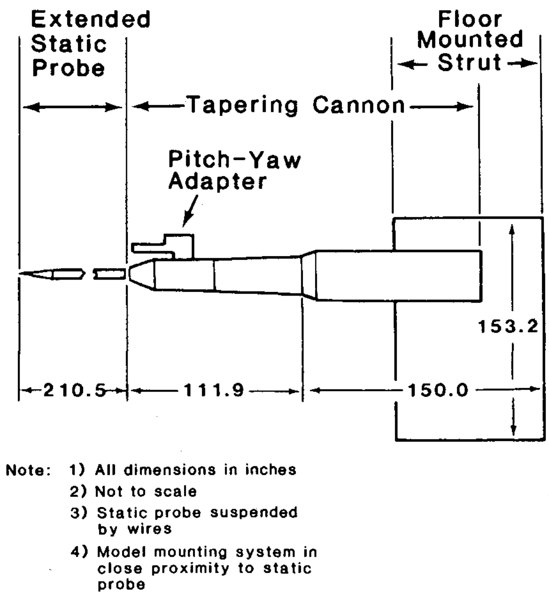

Fig. 2 Complete BVWT mounting system (wind tunnel calibration II).

tion of the yaw adapter were modeled by specifying a unit outflow from the patch (local grouping of panels) that defined the base regions. This controlled the flow at the trailing edge and prevented the flow from turning the sharp corner with infinite velocity. Since no detailed answers were required in this "jet" zone, this is an adequate model.

To isolate the effects of the mounting system, and for the purpose of comparison with the computation, the experimental results were adjusted for the known empty tunnel gradient and tunnel reference conditions. The mathematical modeling for the second wind tunnel calibration modeled the entire mounting system consisting of a pitch-yaw adapter, a tapering cannon, a floor-mounted strut (with approximations), and the tunnel walls. This case was run for both free-air and in-tunnel simulations. This was done to test the code's capability in modeling a wind tunnel wall environment.

The tunnel was modeled using the NCZONE[9] option in the code. This option is used for modeling the flow in a completely enclosed internal region. For this model, all the normal vectors must point into the region of interest. Moderate paneling was used on the tunnel walls. The inlet and exhaust plane were placed a large distance upstream and downstream (1 test section length) of the region of interest. This was done to keep the flow through these planes from constraining the flow in the test section. The flow into and out of the region is controlled by specifying normal velocities on an inlet and exhaust plane. The normal velocities on a plane specified by the analyst are then adjusted by the code to satisfy the conservation of mass.

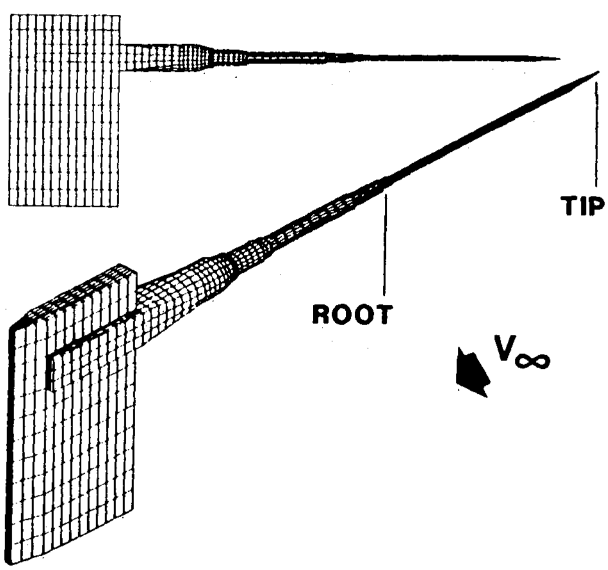

Fig. 3 Static probe with telescoping mounting steps, short cannon, and floor-mounted strut.

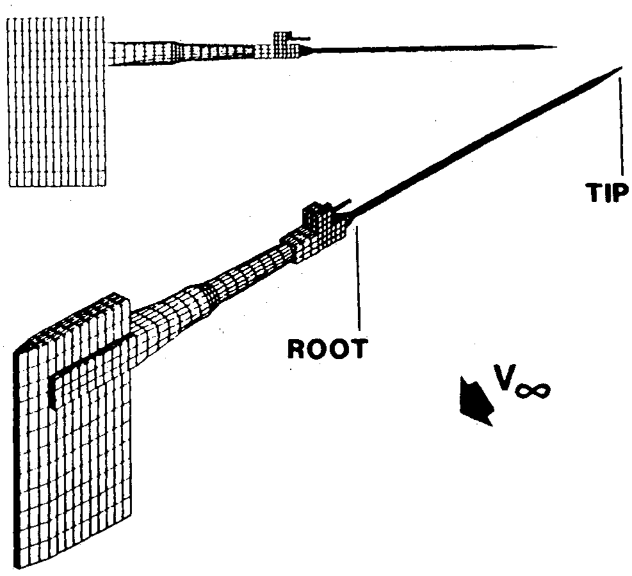

Fig. 4 Static probe with pitch-yaw adapter, tapering cannon, and floor-mounted strut.

Results and Discussion

A model buildup study was conducted (for wind tunnel calibration I) using the panel code for the configuration composed of the static probe on the telescoping mounting steps. Initially, only the static probe, mounting cone, and first telescoping step were modeled. Next, the static probe and all telescoping mounting steps were modeled. Finally, the static probe, all telescoping mounting steps, short cannon, and floor-mounted strut were modeled. Figure 5 is a superposition of the pressure distributions to show the buildup of the disturbance. The local behavior of the cone and first mounting step are easily discernable as they cause a nonlinear static pressure gradient over the aft portion of the static probe. The influence of the mounting steps near the aft end of the static probe is easily observed. Also, the disturbances induced by all of the mounting steps causes an increased gradient over the probe. The floor-mounted strut, which is well behind the static probe, increases the pressure gradient over the entire length of the probe. The increase is proportionally higher (34%) where the gradient is lower at the front and correspondingly lower (3.5%) where the gradient from local influences is highest. The increased level of the pressure coefficient with increased mounting system complexity is a result of the pressure fields induced by the planar regions of the mounting system (telescoping steps, front of

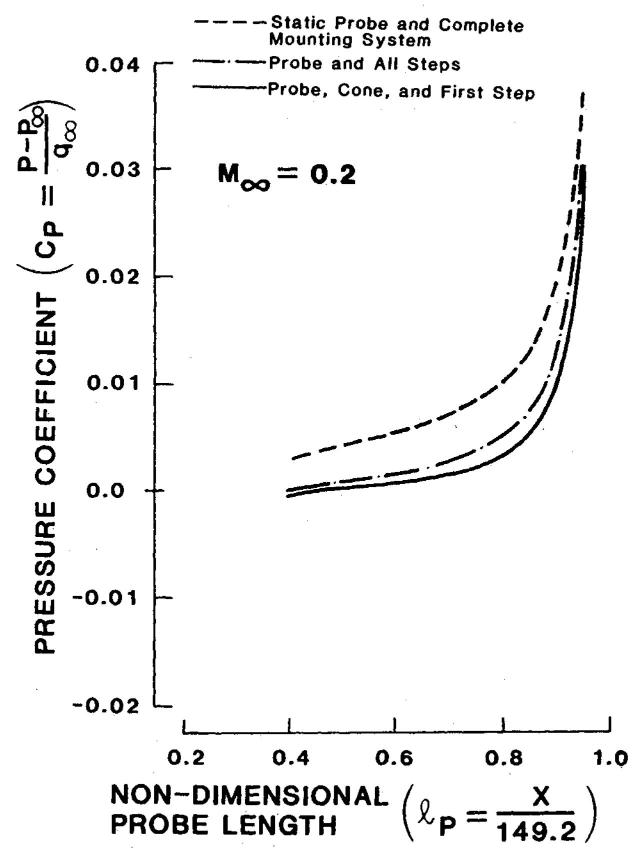

Fig. 5 Comparison of disturbance buildup for mounting system components.

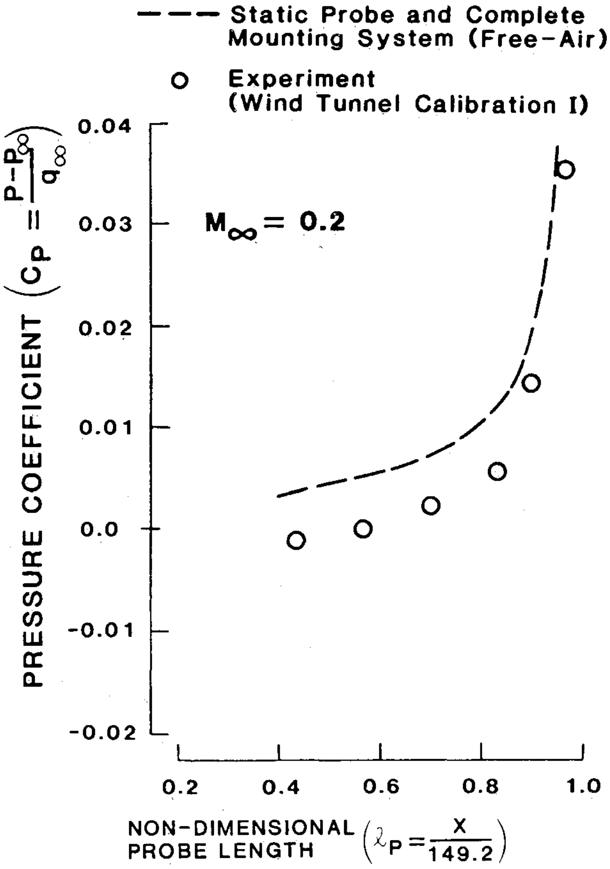

Fig. 6 Comparison of computed and measured pressure distributions for static probe on telescoping steps, short cannon, and floor-mounted strut.

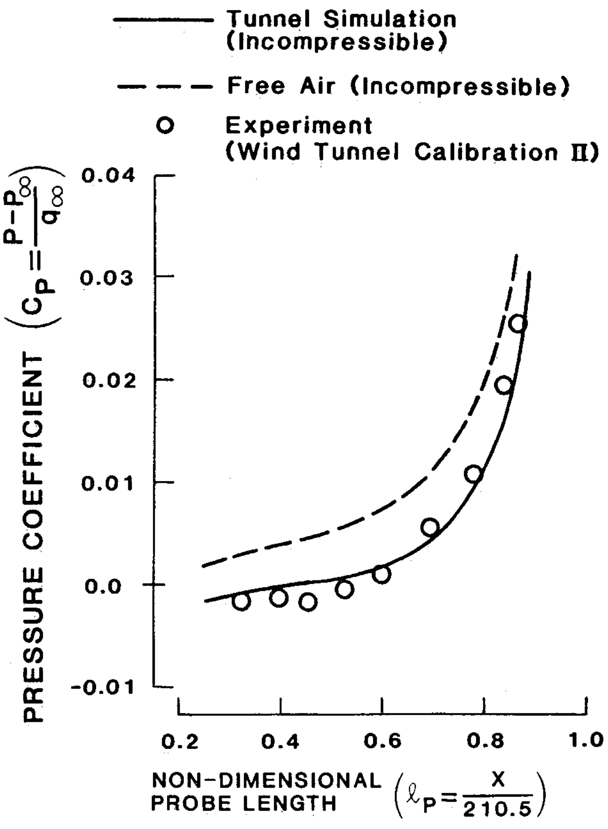

Fig. 7 Comparison of computed and measured pressure distributions for static probe on pitch-yaw adapter, tapering cannon, and floor-mounted strut.

floor-mounted strut), which are perpendicular to the flow. Also, this demonstrates that while all components of the mounting system have an effect on the static pressure, the local behavior of the flow in the near field is dominated by the cone and step at the end of the probe.

Figure 6 shows a comparison of the computed and measured pressure distributions over the static probe on a mounting system consisting of a telescoping step, a short cannon, and a floor-mounted strut (wind tunnel calibration I). The experimental results are for a tunnel dynamic pressure of 70 lb/ft^2. The onset condition prescribed in the code was a freestream Mach number of 0.2. The numerical simulation is for a free-air case. For the purpose of comparison, the experimental results were adjusted for the empty tunnel static pressure gradient and tunnel reference conditions. The code predicts the pressure gradient well near the aft end of the probe, but appears to underpredict the gradient nearer the nose of the probe, as the influence of the mounting system geometry becomes asymptotic. Also, this demonstrates that the wind tunnel wall environment must be simulated to obtain a more accurate estimation of the pressure gradient.

Figure 7 shows a comparison of the computed and measured pressure distributions over the static probe in free-air and a 20×20-ft closed test section wind tunnel, with a mounting system consisting of a pitch-yaw adapter, a short cannon, and a floor-mounted strut. The purpose for the free-air calculation is to again demonstrate that the tunnel wall environment must be modeled in order to obtain accurate results. The in-tunnel calculation shows good agreement with experiment. For the in-tunnel simulation, a unit velocity on the inlet face was prescribed. The tunnel simulation was run for an incompressible case. The code predicts a slightly lower gradient over the aft part of the probe ($.7 \leq \ell_p \leq .9$) and a more representative gradient over the forward part of the probe ($.3 \leq \ell_p \leq .5$). The increased nonlinearity in the static pressure distribution on the aft portion of the probe is caused by the close proximity of the pitch-yaw adapter.

Conclusions and Recommendations

A determination of the effect of wind tunnel mounting systems on a static probe has been performed. The results of a numerical simulation using the low-order surface singularity panel method code VSAERO have been compared to wind tunnel calibration experiments. The analysis consistently predicts a slightly lower gradient over the asymptotic region of the static probe.

The effect of the mounting system on the static pressure gradient can be divided into a near-field and a far-field effect. The addition of the floor-mounted strut, which causes an increase over the asymptotic region of the curve, is an example of a far-field effect. This is in contrast to the near-field effect of the telescoping steps and pitch-yaw adapter, which results in an increased nonlinear behavior of the curve.

The internal flow modeling option in VSAERO (NCZONE) is flexible, versatile, and accurate. This option requires minimum input from the user. However, the calculation does take longer to converge in the blocked Gauss-Seidel iterative matrix solver than does the external flow case. For this reason, the number of iterations specified by the user should be increased to allow for a more fully converged solution. No attempt was made to repanel the wind tunnel test section to observe the sensitivity of the calculated pressures on the probe to wall panel density. Also, a sensitivity study was not performed to determine the effect of moving the inlet and exhaust plane a larger distance away from the test section. Future studies using the option should include these sensitivity studies where absolute levels of pressure coefficient are desired. In the present study, only the gradient (slope) was of interest. Also, the far-field radius factor in the code (RFF) was set up to 100 to maintain the integrity of the solution.[10]

VSAERO has proven an accurate and reliable aerodynamic analysis tool in predicting the static pressure gradient induced by a wind tunnel mounting system. Since the effects of the mounting system can be accurately predicted, the results from modeling can be used in the wind tunnel data reduction process. Also, VSAERO (and analysis tools similar to it) should be used by the wind tunnel designer to design mounting systems that minimize interference.

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