Standard Test Case for a Low-Speed, Turbulent Junction Vortex Flow

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Abstract

THE mean flow structure upstream, around, within, and in the near wake of a turbulent junction or horseshoe vortex is reported for an incompressible subsonic flow. Measurements of the primitive variables of velocity and pressure are reported on all surfaces bounding the region of the vortex flow and on three transverse and one streamwise plane within the flowfield itself for comparisons between the measured and any calculated flow variables. Detailed surface flow visualizations and some direct force measurements of surface shear stress are also available. The data is a highly detailed, coherent, self-consistent set offered to the computational fluid mechanics community as a standard test case for the evaluation of the capability of numerical solvers intended for predicting the flowfield in such a complex, separated, three-dimensional turbulent flow. This data base is available for copying to user supplied tapes or for transmission via BITNET, as well as in two National Technical Information Service (NTIS) reports.

Contents

The 1981-1982 Stanford Conference on Complex Turbulent Flows[1] clearly revealed that however one may categorize and subdivide the broad class of flows generally designated as turbulent and complex, there is, in virtually any particular category, a notable shortage of data bases that are sufficiently unified, comprehensive, and detailed so as to be of broad value to turbulence modelers, flow modelers, and code/technique developers for such flows. This was made clear in the search for standard test cases in various categories where many experimental studies, which provide excellent information on one or a few aspects of a particular flow, lacked the kind of completeness required for use in objectively evaluating the predictive ability of codes. This lack of completeness in experiments allows, or even requires, flow modelers and program developers to make assumptions in their work that could have very large effects on their computed results. This latitude in assumptions clouds objectivity in evaluating flow models or predictive capability of computer codes.

This Synoptic reports on the availability of a complete, highly detailed, self-consistent and coherent data set of exceptional quality that could serve as a standard case or archive case for one particular complex, separated, three-dimensional turbulent flow.

The junction vortex flow can be arbitrarily divided into three regions:

1. The three-dimensional pressure-driven turbulent boundary-layer-like flow upstream and around the body but excluding the separated flow;
2. The three-dimensional separation region including the separation sheet/envelope and the three-dimensional horseshoe or junction vortex system that is contained between the separation sheet and the body itself, including the flow forward of and around the body sides to the trailing edge; and
3. The near-wake flow dominated by the strong mixing of the tails of the horseshoe vortex system coming off of the two sides of the body, as well as the wake from the boundary layers developed on the body sides, and mixing with the adjacent boundary-layer-like, more remote floor flow.

Extensive surface flow measurements were first made to observe surface details of the flow, to guide in the placement of surface instrumentation, and to select initial transverse stations. For the fully three-dimensional turbulent junction vortex flow of region 2, with considerable overlay into region 1, and the near wake-flow of region 3, measurements reported here include the following: 1) the floor surface static pressure coefficient, 2) the body surface static pressure coefficient, 3) the velocity field, 4) the total pressure field, 5) the static pressure field, and 6) the computed vorticity field.

Figure 1 shows the body and the surfaces over which flow measurements were made for this standard test case. This flow region includes the separated and vortex flow, as well as the near wake-flow.

The complexity of the flow through separation and in the vortex of region 2 suggests that the full, elliptic, turbulent Navier-Stokes equations would be required in a solution. A well-posed problem governed by elliptic equations requires boundary conditions on all boundaries surrounding the solution domain. Hence, measurements of the primitive variables of pressure and velocity were made, as described later. The data set is also suitable for use in evaluating numerical solution methods that march through the elliptic flow, while correcting or adjusting to account for the elliptic character of the flow.

Measurements were made on the following: 1) an upstream transverse plane at 67% chord length, 2) the upstream symmetry plane, 3) a streamwise side plane at 67% chord length away from and parallel to the body centerline, 4) a top plane parallel to the tunnel floor, at 55% body height, 5) the tunnel floor, 6) the body side, 7) a downstream transverse plane at 200% chord length, and 8) the downstream symmetry plane. These planes form a complete box-like boundary surrounding the junction vortex flow. Measurements were made on four additional planes within this flow-field to provide for comparisons between the measured data and any computed flowfield. These planes include the following: 1) a transverse plane at 43% chord distance downstream of the body leading edge, 2) a downstream transverse plane at the body trailing edge at 100% chord length, 3) a transverse plane at 150% chord distance downstream of the body leading edge, and 4) a streamwise plane at 38% chord length away from and parallel to the body centerline, and generally passing through the large junction vortex.

The cylinder has a leading-edge diameter of 127 mm, a chord length of 298 mm, and a height of 229 mm. Dynamic similarity was achieved by maintaining a constant Reynolds number at the wind-tunnel throat. The Reynolds number per unit length, $Re/L = \rho V_* / \mu$, was equal to 1.34×10^6 /m, where V_* is the mean velocity at the throat of the tunnel inlet nozzle. The body Reynolds number was 1.83×10^6 based on the body thickness or leading-edge cylinder radius and 4.3 ×

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10^5 based on the body chord. The upstream transverse plane showed the presence of the body with yaw and pitch angles up to 3.5 and 1.5 deg respectively. The approach boundary layer was about 80-mm thick, with a momentum thickness Reynolds number of 1.25×10^4. Surface flow visualizations on the body suggest a laminar separation at about 90 deg with a turbulent reattachment following closely. The floor visualizations suggest a corner separation near the trailing edge, but the body visualizations do not confirm this.

All of the measurements were made with the body fixed at its reference position. An automated traverse and data acquisition system was used for probe positioning and data collection. Distributions of the three components of velocity, total pressure, and static pressure were measured by using a 3.18-mm-diam, United Sensor Corporation, type DC, five-hole biconic, Prandtl-type pressure probe. Flow visualizations and surface pressure measurements were also reported. More details about the data acquisition system, flow visualization techniques, and the five-hole probe calibration and measurement methods, as well as the dedicated open circuit, subsonic wind tunnels used for the experiments and probe calibrations, can be found in Pierce et al.[3]

Detailed results of the surface flow visualizations, the surface pressure measurements, and the five-hole probe measurements for the 13 planes shown in Fig. 1 are available in Pierce et al.[2,3] Additional details of the upstream and surrounding boundary-layer-like flow are in Menna and Pierce[4] and for the separated and junction vortex flow, in Pierce and Harsh[5] and in Pierce and Shin[6].

The surface flow visualizations generally are used to observe qualitative features of the flow, but they can provide quantitative information on such features as the location of separation points on the floor and body sides and the physical size of the junction vortex growth as sensed by the floor.

Both the surface pressure results and the five-hole probe results are presented in a variety of graphical forms and in detailed tabulations, as well. A rigorous calibration procedure was followed for the measurement system. The five-hole probe was carefully and extensively calibrated in the null-yaw method. Regression analyses, with over 30 candidate models, were used to obtain the calibration functions. A formal and rigorous error analysis gives statistically meaningful uncertainties for each tabulated data value reported for the surface pressure and the five-hole probe results.

The BITNET files also contain extensive laser Doppler velocity (LDV) measurements for the plane of symmetry flow, as described in Pierce and Tree.[7] These results also include statistically meaningful uncertainty values for each reported measurement. The LDV data were obtained using a modified DISA (now DANTEC) two-color, two-channel system with frequency shift to allow velocity direction discrimination. The LDV allowed a better spatial resolution of the flow, especially near the solid surfaces. The more dense LDV measurements were confined to the plane of symmetry where the singular separation point and vortex core velocities sometimes exceeded the limits of the five-hole probe calibration functions. These LDV data supplement the five-hole probe data.

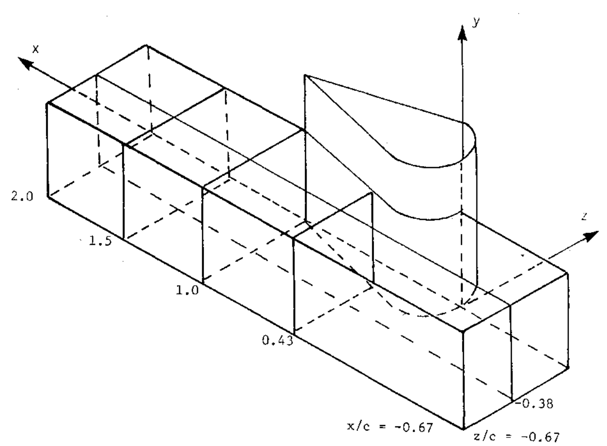

Fig. 1 Measurement planes for the junction vortex flow.

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