N93-16765

Interferometric Reconstruction of Three-Dimensional High-Speed Aerodynamic Flows

by
Soyoung Stephen Cha, Ph.D.
Department of Mechanical Engineering
University of Illinois at Chicago
Chicago, IL 60680

ABSTRACT

Holographic interferometry can be a very useful diagnostic tool in high-speed aerodynamic testing. It offers various merits, that is, global field capture, nonintrusive remote sensing, quantitative measurement, high spatial resolution, and excellent sensitivity. Since it detects only the phase change during two exposure, it can be easily implemented with low-quality optics. Consequently, those schlieren optical systems in the current aerodynamic testing facilities can be effectively utilized. The usefulness of the method has been well demonstrated in two-dimensional or axisymmetric flows. However, modern aerodynamics demand ever-sophisticating analyses. These frequently require global pictures of complex coherent/incoherent spatial flow structures that arise in three-dimensional steady as well as unsteady phenomena. For this purpose, it is very attractive to develop a technique that allows instantaneous capture of three-dimensional fields by inter-breeding the tomographic concept with holographic interferometry.

Holographic interferometric tomography can thus provide aforementioned various merits; however, aerodynamic wind-tunnel testing confronts formidable challenges for experimental implementation. First, the large-scale test section and the opaque enclosure inhibit instantaneous full angular scanning around the object. Second, the opaque model together with the enclosure blocks a substantial portion of probing beams, causing incomplete projections. The testing environment is also relatively harsh producing a relatively high noise level. The current aerodynamic facilities can typically provide only 30 to 40 percent instantaneous angular scanning and 60 to 80 percent data along each projection line. Under these circumstances of limited data, the reconstructions lead to erroneous results with various artifacts when ordinary computational tomographic techniques, especially those developed in x-ray imaging, are applied. In recent years (1), there have been substantial advances in computational tomographic techniques, which are tailored specifically to interferometric reconstruction of three-dimensional flow fields.

During this summer research period, various possible approaches for accurately reconstructing three-dimensional flows from limited data have been examined. The approach based on the combination of the following three techniques appears to be promising (1).

1. Continuous Local Basis Function Method: This computational tomographic method has a power to accurately reconstruct continuous regions and is appropriate from well-conditioned to moderately limited data.

2. Variable Basis Method: This computational tomographic method provides accuracy near discontinuities, i.e., shock regions, and is appropriate from moderately-limited to severely-limited data.

3. Complementary Field Method: This is a general iterative reconstructor that can be coupled with any computational tomographic techniques. Mathematically, it can be shown that this method can provide better accuracy than the direct reconstruction as in a conventional approach.

Our numerical simulation of experiments demonstrated improved reconstruction results even when these techniques were individually tested. In general, 40 to 60° angular scanning could result in

reliable reconstruction. The fully-combined power of these three methods is expected to far exceed that of any independent technique. The combination is believed to provide satisfactory accuracy even for severely-limited data with 30 to 40° angular scanning and a sizable opaque object in the field. Diffuser illumination can allow instantaneous angular scanning ranging from 30 to 50°. Hence, the combined technique can truly enable instantaneous capture of three-dimensional flows under existing aerodynamic testing environments.

During this summer research, the 15-inch Mach 6 high temperature tunnel at the Experimental Hypersonics Branch was evaluated to find the application feasibility of holographic interferometric tomography. Two typical test fields, whose interferograms might resemble those frequently appearing in practical testing, were selected. For the test fields, their approximate fringe patterns were theoretically calculated and appropriateness of interferometric testing was evaluated. The criteria for the application feasibility study were interferometric signal level and minimum facility modification in setting up experiments. In addition, the strategies for short-term, intermediate-term, and long-term plans for utilizing interferometric tomography have been formulated.

Some facilities cannot allow even the minimum angular-scanning requirement for reasonable tomographic reconstruction. For flow field reconstruction under this circumstance, a new holographic technique that is termed planar slicing interferometry has been studied (2). This technique, while requiring small optical ports, provides only limited resolution along the observation direction. The technique can be attractive for local region examination with restricted accessibility at the expense of resolution and accuracy. The schematic of the initially formulated system is shown in figure 1. The measurements in the observation planes along the optical axis yield the one-dimensional Fourier transforms of sliced sections of the test object. After reassembling and inverting the Fourier transforms, the object can be reconstructed. The accuracy and practicality of the method needs to investigated. Further modification and elaboration of the system shown here is necessary as the research progresses in the future.

1. S. S. Cha, Holographic Interferometric Tomography for Reconstructing Flow Fields; a Review, AIAA paper 92-3934, 1992

2. F. O. Weinberg and N. B. Wood, Interferometer Based on Four Diffraction Gratings, J. Sci. Instrum., 36, 227 (1959).

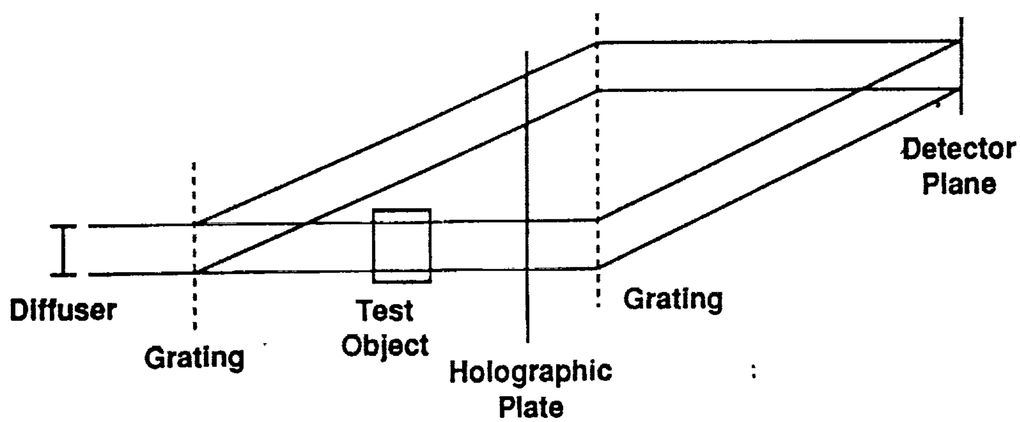

Figure 1. Schematic for planar slicing holographic interferometry