Flow Visualization via Laser-Induced Reflection from Bubble Sheets

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Abstract

THE structure of steady and unsteady aerodynamic flows can be characterized by generating fluid markers at desired locations in the flow and tracking them in three-dimensional space. The hydrogen bubble technique allows localized injection of both continuous and interrupted fluid markers. Its advantages and limitations are described in the works of Schraub et al.[1] and Lusseyran and Rockwell.[2] The technique described herein employs multiple sheets of hydrogen bubbles in conjunction with laser sheet illumination. Arbitrary cross sections of the unsteady flow past an oscillating delta wing can be characterized. By using a phase-referencing technique, it is possible to relate the visualization at various cross sections along the wing at a given value of instantaneous angle of attack.

Contents

Experiments were performed in a transparent (Plexiglas) water channel having a cross section of 914 mm (wide) by 604 mm (deep). The sweep angle of the delta wing was $\lambda = 75$ deg; its chord was $C = 143$ mm, and the corresponding Reynolds number was $U_\infty C/\nu = 3.8 \times 10^4$. The flow structure of the upper, flat surface of the wing was visualized; the lower surface of the wing was machined at a bevel angle of 15 deg. In order to minimize spurious reflections of the laser sheet, the surface of the wing was machined to a finish of one micron. The wing system was forced in the pitching mode about its trailing edge using an integrated active control system, which allows simultaneous control of the wing position, generation of marker bubbles, and movement of the laser sheet, as described by Magness[3] and Utsch.[4] Also described therein are the laser system, related optics, and the scanning mirror used to generate the laser sheet. In essence, a 2-W argon-ion laser beam was swept at a frequency of 500 cycles/s across the flow in order to generate the laser sheet.

Figure 1 shows the conceptual diagram of the experimental system. A grid of intersecting hydrogen bubble sheets, or in this case an array of horizontal bubble sheets, is generated upstream of the delta wing in the undisturbed freestream. As the bubble sheets pass the wing, they are distorted in accord with the three-dimensional flow structure. The distorted cross section of the flow is visualized by the scanning lasersheet, which is transmitted through the optically transparent wing. An end view of the visualized cross section of the flow is obtained by reflecting the image from a mirror; it is located sufficiently far downstream such that there is no interference with the upstream flow structure. Flow visualization images are recorded on a high-speed (120 frames/s) Instar video system by Videologic Corporation.

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Central to this method is the means of generating the sheets of hydrogen bubbles. A parallel array of 25-μ platinum wires was stretched between two brass supports. On each brass support were located 2-mm-diam Plexiglas pegs spaced at an interval of 6 mm; these pegs allowed the platinum wires to be strung across the flow in the manner of a tennis racket construction. The power to the platinum wires was transmitted through a single copper wire soldered to the ends of the platinum wires, thereby insulating the platinum wire system from the brass. Effective bubble production was achieved with a custom-designed power supply providing 250 V at 7 A. It could generate bubble sheets of arbitrary duration and separation. Only the continuous mode was employed for the visualization described herein. Further details are given by Magness[3] and Utsch.[4]

The possible sources of uncertainty in employing this technique are frequency response of the bubbles to flow velocity perturbations, bubble rise to buoyancy, bubble slip arising from pressure gradients in the flow, and bubble retardation in the wake of the generating wires. All of these features are described in detail in the works of Schraub et al.,[1] Lusseyran and Rockwell,[2] Magness,[3] and Utsch.[4] For the ranges of parameters employed in this investigation, these uncertainties are minimal.

Visualization of flow past the stationary and oscillating delta wing at an angle of attack $\alpha = 10 \pm 10$ deg and a reduced frequency $K = \pi f C/U_\infty = 1.0$ is depicted in Fig. 2. In this case, the horizontal platinum wires upstream of the wing generate continuous bubble sheets, which are distorted by the unsteady wing motion. The laser sheet cuts through the wing at the indicated values of x/C. In the limiting case where the wing is stationary, these bubble sheets correspond to stream surfaces; when the wing is oscillating, they represent streak surfaces.

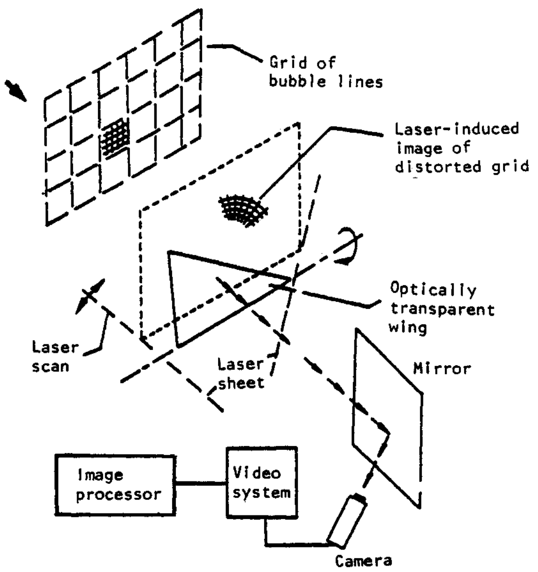

Fig. 1 Single-image technique for characterization of three-dimensional flow structure.

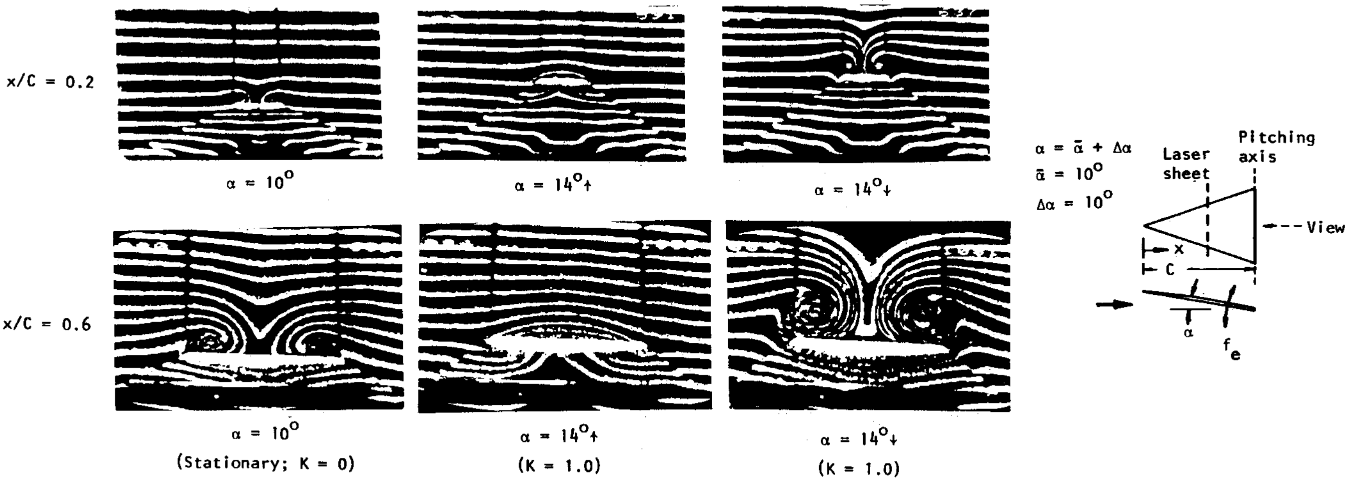

Fig. 2 Sectional views of stream surfaces (left column of photographs) and streak surfaces (middle and right columns of photographs) obtained from single-image method of Fig. 1. All views are in the upstream direction.

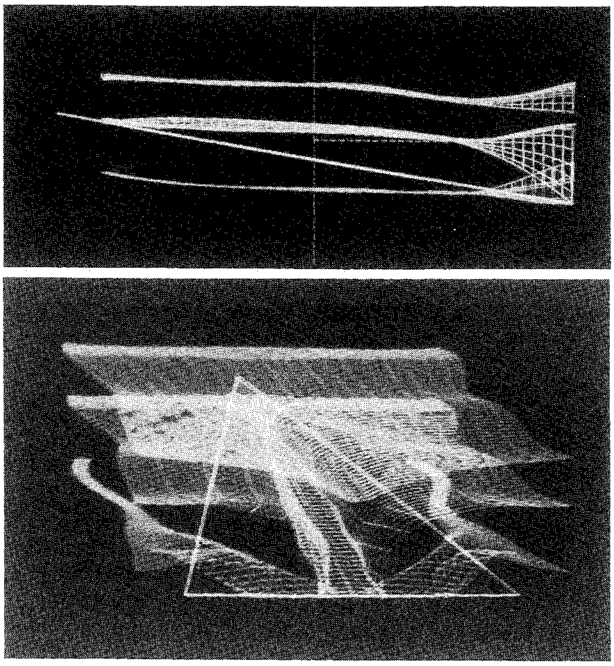

Fig. 3 Representative side and isometric views obtained from end views of the type shown in Fig. 2, $\alpha = 14$ deg

The actual thickness of the bubble sheets in the photographs of Fig. 2 is of the order of 100 μ; use of a high value of gain on the video system exaggerates the actual thickness.

The limiting case of the stationary wing is depicted in the left column of photographs in Fig. 2. The cross-sections of the stream surfaces indicate that vortex formation is detectable near the apex at $x/T = 0.2$ and is more readily evident at $x/T = 0.6$. The bubble lines located below the wing are also visible in both of these photographs; however, near the plane of symmetry of the wing, they are distorted due to substantial variations in wing thickness. Streak surfaces are depicted in the middle and right columns of the photographs of Fig. 2. They emphasize the substantial effects of dynamic hysteresis of the flow structure with respect to the instantaneous position of the wing. The upstroke motion is indicated by upward-oriented arrows and the downstroke motion by downward-oriented arrows. At an angle of attack $\alpha = 14$ deg and a streamwise location $x/C = 0.2$, the flow structure exhibits no vortex formation; the upward curvature of the bubble lines on the lower surface of the apex is due to the noncirculatory flow distortion produced by the acceleration of the wing. However, at an angle of attack $\alpha = 14$ deg and at $x/T = 0.2$, highly concentrated vortices exist along the upper surface of the wing immediately adjacent to the apex. As suggested by the visualization at $x/C = 0.6$, the dynamic hysteresis exists along the entire streamwise extent of the wing.

By phase-referencing the visualized flow with the instantaneous wing position, it is possible to obtain the instantaneous cross-sectional visualization at successive streamwise locations at a given value of instantaneous angle of attack. With these cross-sectional images at hand, it is then possible to connect them in three-dimensional space using Unigraphics CAD software. Details of three-dimensional image reconstruction are described by Rockwell et al.[5] The three-dimensional images were constructed and displayed on a McAuto D-100 color terminal allowing rotation of the three-dimensional images in real time. Representative isometric and side views of multiple streak surfaces corresponding to the oscillating delta wing are given in Fig. 3. By examining the flow structure from various perspectives, it is possible to determine the streamwise evolution of the flow at a given angle of attack. Moreover, by examining successive instantaneous angles of attack in a similar fashion, the evolution in time and three-dimensional space can be tracked.

Acknowledgments

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