

# AERODYNAMIC MEASUREMENT TECHNIQUES

## USING LASERS

William W. Hunter, Jr.  
NASA Langley Research Center

### SUMMARY

Laser characteristics of intensity, monochromatic, spatial coherence, and temporal coherence have served to advance the development of laser-based diagnostic techniques for aerodynamic related research. Considering two broad categories of visualization and optical measurements, three techniques have received significant attention. These are holography, laser velocimetry, and Raman scattering. Examples of the quantitative laser velocimeter and Raman scattering measurements of velocity, temperature, and density indicates the potential of these nonintrusive techniques. A continued vigorous effort in the development of laser-based diagnostic techniques is expected.

### INTRODUCTION

It would be presumptuous to present this paper as a definitive survey of techniques which utilize lasers for aerodynamic research diagnostics. A fairly complete literature search of this subject field and related areas, such as fluid dynamics, reveals over 600 published references covering an approximate period of 6 years. The limited length of this paper restricts the scope and could not possibly cover all aspects presented in such a volume of references.

Therefore, the purpose of this paper is to briefly note various diagnostic techniques using lasers which have been used for or are suitable for application to aerodynamic related research. Examples of important diagnostic techniques, laser velocimetry and Raman scattering, will be given. Also near term future developments related to these examples will be noted.

### IMPORTANT LASER CHARACTERISTICS

Light Amplification by Stimulated Emission of Radiation or LASER devices have properties that provide a significant opportunity to improve or develop new diagnostic techniques for aerodynamic testing. One of the most noted properties is the ability to achieve high-intensity radiation levels. It is common to think of achieving laser radiation power levels in terms of watts with continuous wave systems and peak powers in megawatts with very short (nanoseconds) pulsed systems.

The high power property alone is not sufficient to describe the uniqueness of the laser. Lasers are monochromatic sources of radiation. That is, the laser is capable of containing its energy in several or even one narrow band of radiation. The monochromatic property coupled with the power levels routinely achieved is essential to diagnostic techniques that depend on radiation scattering and absorption processes.

Spatial and temporal coherence are important laser properties. For example, application of lasers to interferometry relieves the problem of having to closely match relative path differences to obtain good fringe contrast because of its temporal or long coherence length. The laser is also a large aperture point source because of its spatial coherence, or uniform phase front, property thereby achieving greater radiation levels than could be achieved with conventional interferometer point sources.

Properties of intensity, monochromatic, spatial coherence, and temporal coherence plus reliable and ready availability of practical laser systems with a wide range of operating frequencies have made the laser an important research tool as well as an object of research interest. The laser has provided a needed stimulus to the research and development of flow-field diagnostic techniques in the areas of fluid dynamics and aerodynamics.

#### DIAGNOSTIC TECHNIQUES USING LASERS

For convenience of this discussion, the diagnostic techniques that utilize lasers are divided into two broad groups. The first group consists of those techniques of visualization which provide qualitative and, in some cases, quantitative information. Second grouping is optical measurement techniques which are nonintrusive or probeless methods which provide quantitative information.

Included in the visualization grouping are a variety of photography, shadowgraph, holography, and Schlieren techniques. Holography has been the major benefactor of the development of laser sources.

The advantage of a laser source for direct photography is gained from the combination of intense short pulse and monochromatic radiation burst. Combined, these properties permit stop action photography of tests in which narrow band optical filters can be used to filter out unwanted background or object radiation. Such test conditions are often found in ballistic range and shock tube tests of hypersonic aerodynamic models (refs. 1 and 2).

The techniques which depend on refractive index gradients, shadowgraph and Schlieren, benefit chiefly from the same laser properties as photography. Some differences in the normal physical set-up are required because of the use of a source that produces parallel, monochromatic and coherent light. These differences are discussed in reference 3.

As noted previously, the holography technique has been a major benefactor of laser devices. This occurred because of the basic need for the laser coherence properties. Fundamentally, the holographic process is a recording

of wavefront information including amplitude and phase. Phase information is obtained through interferometric techniques. Holography is an attractive process since it can record three-dimensional spatial information on film and this information can be retrieved at a later time at the experimenter's leisure. Holography has been used in aerodynamic testing for visualization, to ascertain particle content in a flow field, to study particle interaction with model-generated shock waves, and for obtaining quantitative density information on flow fields about aerodynamic models (refs. 4 and 5).

Laser optical measurement techniques for aerodynamic testing have received considerable attention in laboratories involved in aerodynamic and related research. The reason for this interest in optical measurement techniques is several fold. First, remote optical techniques do not disturb the local flow field such as occurs with intrusive probe techniques. Second, most optical techniques determine basic individual gas parameters, e.g., number density, temperature, velocity and specie concentration, as opposed to probe measurements which are usually dependent on more than one basic parameter.

Many of the optical techniques depend on absorption, fluorescence or some type of scattering process; Rayleigh, Raman, Mie, etc. Of all of the optical techniques, most attention at this time is being directed toward the laser anemometer technique (refs. 6 and 7) which can provide velocity vector flow field measurements about aerodynamic models or any other general flow field of interest. This technique is dependent on Mie scattering from small particulates imbedded in the flow field. The ultimate limitation of this measurement process is the fidelity of the particle motion with respect to the local flow field. Analytical and experimental work has been performed (refs. 8 and 9) and it is generally accepted that in many flow fields of interest significant experimental information can be obtained before particle motion fidelity becomes a significant limiting factor.

Another optical technique receiving significant interest is the Raman scattering process (refs. 10, 11, and 12). The process provides local point measurements of the species concentration and temperature. This technique has found considerable interest in the study of engine combustion processes and engine exhaust characteristics. Also, Raman scattering has a place in aerodynamic testing, especially those found in supersonic and high enthalpy facilities.

As can be seen from the limited discussion and references cited above, a number of laser visualization and optical techniques have been investigated and used as aerodynamic testing diagnostic techniques. All of this activity has been stimulated by the development of laser devices as practical and reliable tools and the need for new and improved aerodynamic research diagnostic techniques.