4 Large-Field and Focusing Schlieren Methods

In most cases it is unfortunately impossible to study thermo-hydrodynamic flowfields at full scale, owing to the limited dimensions of the available mirrors.

Hubert Schardin [1]

Schardin essentially overlooked the large-scale possibilities of the lens-and-grid schlieren technique which he and H. Maecker pioneered [2]. Sixty years later, this and other opportunities have emerged to free the schlieren technique from its traditional bonds of small scale. Concurrently some of these approaches allow narrow depth-of-field as well, hence the ability to focus upon a “plane” in a 3-D schlieren field. Both possibilities are crucial to the renewed vitality of schlieren imaging.

These specialized schlieren techniques are given chapter status because they are the most important and most recent developments in the field, and because they are expected to play a strong role in the future of schlieren imaging.

4.1 Large Single- and Double-Mirror Systems

4.1.1 Availability of Large Schlieren Mirrors

In Chap. 3 the cost of schlieren-quality parabolic mirrors up to about 65 cm diameter was discussed. We have amateur astronomy to thank for the larger examples of these. At about f/5 – to minimize telescope length – they are short for schlieren use. Nevertheless they make fine z-type systems of large aperture if only simple illumination is used, and if astigmatism is dealt with properly. One manufacturer, Glass Mountain Optics, has supplied very-successful twin ¼ λ 71-cm-diameter parabolic mirrors on lightweight substrates for schlieren use [174,175]. They have the ability to produce mirrors up to 2.5 m diameter (see App. D).

Such large traditional glass schlieren mirrors can be custom-made in the 1-2.5 m diameter range, but they are shockingly expensive. The conventional rule is a
6:1 diameter/thickness ratio, but some are willing to try 14:1 or 15:1 [175]. The optical fabricating industry has undergone an upheaval and several of the traditional stalwarts who once made large monolithic schlieren mirrors are no longer in business. Those who are, as of this writing, are listed in App. D.

At the same time some fresh opportunities may be on the horizon for large schlieren-quality mirrors. For example, new earthbound telescopes now achieve large aperture by way of segmented mirrors: Kodak fabricated 91 thin 1-m hexagonal segments for the Hobby-Eberly Telescope for $16,500 each [137]. Not that any such mirrors are known to be available for schlieren imaging, but the manufacturing technique and the possibility of surplus mirrors is worth noting.

The same can be said for large, light space telescope mirrors [176-178]. The 2.4-m Hubble Space Telescope mirror, for example, is a glass face-sheet with an “eggcrate” backing. Such lightweight mirrors are contemplated for meter-class amateur telescopes, so schlieren imaging cannot be far behind.

Finally, stretchable-membrane mirrors are proposed by Waddell et al. as a cheap, lightweight alternative to conventional glass schlieren mirrors [179-182]. A thin sheet of aluminized Mylar is stretched over a frame, forming an airtight cavity behind the sheet. Removing air from the cavity stretches the membrane into a spherical shape. Mirrors from 0.15 m to 1.2 m in diameter have been demonstrated, and a 2-m mirror is under development. Waddell [183] contemplates still-larger mirrors, but serious questions about their schlieren quality remain.

4.1.2 Examples of Large-Mirror Systems

A number of large conventional mirror-type schlieren systems exists, especially in government wind tunnel laboratories around the world. NASA and the US Air Force, TsAGI in Russia, and defense aerodynamic installations in Europe and Asia account for most of these. They are predominantly z-type parabolic-mirror systems not unlike the original Peenemünde wind-tunnel schlieren system described in Chap. 1. NASA’s Unitary Plan tunnels and the Propulsion Wind Tunnel at the USAF Arnold Center are mammoth facilities with schlieren equipment of similar scale. One fine example is the former NASA-Ames 6x6 Supersonic Wind Tunnel, with a 1.3-m z-type schlieren system. Images taken in this facility by the author are shown in Color Plates 6-8. In the 1950’s, the windows of this facility bested the 1-m Yerkes Refractor lens, until then the largest transmissive optical element ever cast.

Such large facilities are endangered by high energy costs, the boom-and-bust cycle of the aerospace industry, and the inexorable loss-of-ground of experimental to computational fluid dynamics. Many have already disappeared, including the NASA-Ames 6x6 and the Army BRL tunnel with its 0.9-m schlieren. Astute fans of large mirrors must always keep an eye on the surplus equipment market.

Large industrial wind tunnels typically have optics in the 0.4-0.75-m range, but these too are disappearing. New ones sometimes spring up, though, on an ad hoc basis. Mendonsa [184] describes a modern, expensive schlieren system with 0.6 m off-axis parabolas in a z-type setup, intended for a new hypersonic-flow facility.