Resection methodology for PSP data processing: Recent experiences in NAL

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Abstract. PSP data processing, which primarily involves image alignment and image analysis, is a crucial element in obtaining accurate PSP results. There are two broad approaches to image alignment: the algebraic transformation technique, often called image-warping technique, and resection methodology, which uses principles of optical photogrammetry. Resection is found to have higher resolution, especially when large gradients in pressure or significantly three-dimensional regions have to be resolved, and even with flat models when the camera angles are large. A processing software based on these methodologies has been successfully developed and validated and is currently in use at the Experimental Aerodynamics Division of the National Aerospace Laboratories, Bangalore.

In this paper, we show the merits of resection methodology through two examples: (a) a wing-body model in transonic flow ($M = 0.8$) and (b) a simple delta wing in low supersonic flow ($M = 1.8$). The PSP system utilized for both the cases involve Optrod-B1 paint, a specially designed UV lamp for excitation and two scientific grade CCD cameras for imaging. Typical results are shown using both the algebraic transformation approach and resection methodology.

Keywords. Pressure-sensitive paint; resection; delta-wing.

1. Introduction

The technique of pressure-sensitive paint (PSP) for measuring surface pressure fields on wind tunnel models is well known. The method, as described elsewhere (Venkatakrishnan 2004; Channa Raju & Viswanath 2005; Channa Raju et al 2005), involves coating the model with a compound of fluorescent material, which is then illuminated with light of appropriate wavelength to excite the coating material. The pressure-sensitive emission intensity distribution is imaged with a scientific grade CCD camera during wind tunnel tests. It is common practice to use a two-component paint, a pressure-dependent component (blue) and a reference component (red), which is sensitive only to excitation intensity and not to pressure, so as to account for non-uniform intensity of illumination on the model surface. PSP data processing is a multi-step process that includes (a) calibration of the paint and converting image intensities to pressure, (b) application of corrections for non-ideal, real-world effects of optical
distortions during imaging, and (c) determining and applying a transformation from image to model coordinates.

Most PSP methods using binary paint perform a “ratio-of-ratios” between a reference (wind-off) image and a pressure (wind-on) image, each of which are normalized by the illumination to compensate for spatial and temporal variation in light intensity. The images have to be aligned with each other prior to normalization and ratioing. The process of alignment is termed “registration”. This procedure is carried out using one image (usually the wind-off illumination-sensitive image) as a “base image” and warping the other images on to this image. This step is usually followed by mapping of the image co-ordinates on the three-dimensional model in a method called resection. It has long been recognised that the accuracy of a pressure-sensitive paint system depends on many parameters among which image registration is the most important. There are two approaches to obtaining the ratio-of-ratios. The first, more commonly used, is to use some form of image transformation method to warp all the images on to a base image, which is chosen from among the four images. After completion of the ratioing, map it on to the surface grid of the model using resection. The alternative is to form the ratios in model rather than image coordinates by first individually resecting all images on to the model grid using photogrammetric techniques. The first approach, more commonly used in PSP work, seems suitable and adequate when the model surface is largely flat (with minimum transverse curvature) and model deflections and deformations are small between wind-off and wind-on images. However, more accurate results can be obtained by resection prior to ratioing, particularly for three-dimensional models in general and with model deflections between wind-off and wind-on; simple image warping techniques are not sufficient and the error is shown to be significant (Venkatakrishnan 2004). Recently, a data processing methodology and software, based on the resection approach which uses principles of optical photogrammetry was developed at NAL and demonstrated to show improved results in such cases (Venkatakrishnan 2004).

However, even when the model is flat and has no curvature, large camera angles may necessitate the use of the resection approach for better results, as is brought out in results presented here. In this paper, we use two examples from our PSP experiments to illustrate the merits of resection-based approach. In the first application, we show the effectiveness of the resection method in capturing large pressure gradients on a body with significant curvature and in the second, we show how large camera angles can lead to a skewed ratioed image even on a flat delta-wing model with the transformation approach and its improvement with the resection approach.

1.1 Image processing methodology

In the following sections, the two approaches to PSP data processing are described. First, the algebraic transformation chosen for this exercise which is a third-order polynomial method is described, following which the photogrammetry-based resection approach is outlined.

1.1a Algebraic transformation approach: These methods are suited mainly for rigid body motion of two-dimensional objects with small deformations, while being reasonably good approximations for small motions of three-dimensional objects. The geometry of the model, amount of deformation, number of markers, accuracy required and computational resources determine the method chosen.

Polynomial transformations can usually account for any combination of model movement and deformation as long as the series is carried out to sufficiently high order. A first-order transformation requires only three targets, but second- and third-order polynomial transforms