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Comparison of Optical Measurement Techniques for Turbomachinery Flowfields

John R. Fagan Jr.* and Sanford Fleeter†
Purdue University, West Lafayette, Indiana 47907

A preliminary set of measurements were made of the flowfield in the Purdue Research Centrifugal Compressor using a laser two-focus (L2F) velocimeter and a laser Doppler velocimeter (LDV). After a review of the preliminary results, the LDV system was chosen to continue this research due to the advantages it demonstrated over the L2F system in making measurements in this flowfield. The L2F data are compared and contrasted to the LDV data. While this comparison is not to insinuate the local features of the LDV data are universally correct, an evaluation of the global features of the compressor flowfield based upon the LDV measurements demonstrate consistency, i.e., measurements at various planes in the flowfield demonstrate conservation of mass and a reasonable distribution of work in the compressor. In addition, methodologies to determine the effect of the measurement volume geometry for the two systems are presented. Finally, the advantages and disadvantages of using the L2F system for turbomachinery flowfields is discussed in terms of measurement accuracy, applicability to general turbomachinery flowfields, and the capability to make measurements in regions of high noise due to stray reflections. Specific examples based upon this experimental work are presented.

Nomenclature

S_0 = normalized distorted L2F beam spacing
α = out-of-plane L2F angular distortion
β = in-plane L2F angular distortion
ϕ = LDV illumination beam half-angle

Introduction

THE innovation of nonintrusive optical flow measurement techniques, in particular laser Doppler velocimetry (LDV), has had a great effect on experimental fluid dynamics. Specific to turbomachinery studies, LDV measurements of the velocity field in rotating blade rows have been made. Investigations by Durao et al.[1] on centrifugal compressors and Strasizar and Powell[2] and Williams[3] on axial compressors are representative of work that has been done in this field. However, as with any measurement technique, the LDV has inherent limitations. These include 1) the entrained light scattering particles must be sufficiently small to follow fluctuations in the flow; 2) the experimental environment must be compatible with the controlled conditions required by the optical system; 3) differentiation of the Doppler signal from noise due to stray reflections and electronic equipment is often difficult; and 4) the measurements are subject to velocity bias. In turbomachinery flows, where LDV measurements are generally required to be made in backscatter mode, there are often locations in the flowfield where measurements are not possible. The laser two-focus (L2F) velocimeter was designed in response to the signal-to-noise limitations of LDV, specifically the difficulty encountered when making measurements in proximity of solid surfaces. Use of this system for measurements in a high-speed centrifugal compressor flowfield has been demonstrated by Eckardt.[4]

The overall objective of this experimental research program is to make aerodynamic measurements to quantify 1) the compressor inlet flowfield, 2) the periodic flowfield at the exit of the impeller, and 3) the steady-state (relative frame) flowfield in the impeller blade passage, to derive a more complete understanding of the fundamental physics associated with centrifugal compressors. The requirement to make measurements in the rotating blade passages of the impeller led to the decision to use a nonintrusive measurement system.

This article presents results of preliminary measurements made to evaluate the L2F system and compares them to measurements made with the LDV system, which was ultimately chosen as the instrumentation system for this research. This comparison should not be interpreted to insinuate that the local features of the LDV measurements are universally correct, but that the global features of the compressor flowfield derived from these measurements are consistent. Specifically, conservation of mass is satisfied at each of the measurement planes and the throughflow distribution of work determined from these measurements is rational and consistent with the overall performance measurements. The advantages and disadvantages of using the two nonintrusive, optical based measurement systems for turbomachinery flowfields are discussed. Specific topics considered include required signal-to-noise ratio and effective sample rate.

Optical Measurement Systems

The operating principle of the laser Doppler velocimeter is well documented in the literature with a thorough presentation given by Durst et al.[5] Examples of the application of LDV systems for turbomachinery flowfield measurements are given in Refs. 1–3. The laser two-focus velocimeter has successfully been used to make measurements in high-speed centrifugal compressors in regions where the signal-to-noise limitations of LDV systems make measurement quite difficult. The operating principle of the L2F system is thoroughly presented by Schodl.[6] The presentation of the operating principle of the two measurement systems in this article will be limited to features pertinent to the concepts discussed. The reader is referred to Refs. 5 and 6 for details not presented here.

Table 1 compares and contrasts the important characteristics of a single component LDV system (a one-dimensional

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*Research Assistant, Department of Mechanical Engineering; currently Supervisor of Turbomachinery Research, Allison Gas Turbines.
†Professor, Department of Mechanical Engineering.

LDV or a single channel of multidimensional LDV system) and single plane L2F system. Similar to the laser Doppler velocimeter, the laser two-focus velocimeter collects light from small particles convected by the flow. However, the time-of-flight of the particles between the two focused laser spots is measured rather than the Doppler frequency shift. In principle, this reduces the necessary quality of the measured signal, thus reducing the required signal-to-noise ratio. This should allow measurements to be made nearer to solid surfaces.

The fundamental differences between a one-dimensional LDV system and the L2F is the information that can be derived from an individual data realization. A properly configured one-dimensional LDV system in an adequately seeded turbulent flowfield can be interpreted as an instantaneous measurement of a specified component of the local velocity vector and can be used to derive spectral information. Saxena[7] and Adrian and Yao[8] have demonstrated the use of LDV systems to obtain spectral information in turbulent flowfields. In contrast, an individual realization with an L2F is not generally a valid flow measurement. In flowfields with moderate turbulence levels (5–10%), 90% or more of the realizations contribute to the background noise level of the two-dimensional probability density distribution and provides no information about the nature of the flowfield. The two primary reasons an L2F data realization is not generally an instantaneous measurement of the velocity are due to the measurement volume geometry and ultimately the operating principle of the L2F. The first is the lack of a method to assure the particle that passes through the stop beam is the same particle that passed through the start beam, triggering the timing circuit. The second is the small acceptance angle of the L2F measurement volume, which can only make an instantaneous measurement when the local velocity vector is precisely aligned with the measurement volume. Since an individual realization is not necessarily a valid instantaneous velocity measurement, no flowfield data can be discerned until the velocity probability density distribution is constructed. Consequently, the L2F can be described as a statistical-based measurement system. In contrast, the LDV system does make an instantaneous measurement of a specified velocity component, which is the fundamental parameter. While statistical techniques are used to find the mean velocity and the turbulence parameters, the generally required engineering information, these calculations are not fundamental to the measurement system.

The dimensionality of the two measurement systems are directly related to the acceptance angle of the measurement volume. The measurement volume geometries for the two systems used for these experiments are given in Tables 2 and 3. For the LDV probe volume with a valid measurement requiring 16 Doppler beats and a velocity of 50 m/s, the acceptance half-angle ϕ for measurement is 71 deg with no frequency shift, and 100 deg with a 10-MHz frequency shift. The LDV system will measure the component specified by the probe volume orientation of the instantaneous velocity vector as long as the velocity vector is within the acceptance half-angle of the measurement direction. A multidimensional LDV system can generally be considered multiple single component LDV systems with independent probe volume orientations at a single location in space. A validated measurement requires the instantaneous velocity vector to be within the acceptance half-angle of each probe volume and a timing circuit is used to assure simultaneous measurement of each component. For the L2F, the acceptance half-angle ϕ is independent of the velocity and is approximately 2 deg. To properly construct the two-dimensional velocity probability density distribution, the acceptance half-angle must be smaller than the increment used for the angular sweep with a small acceptance half-angle required to get good directional resolution. Since the acceptance half-angle is small, valid data is only acquired when the measurement volume direction is aligned with the instantaneous velocity vector. Therefore, the magnitude of the velocity component can only be determined in the direction of the velocity vector, which completely defines the velocity vector (projected onto the two-dimensional measurement plane). Therefore, the L2F is inherently a two-dimensional measurement system, while a valid measurement with a single component LDV defines a single arbitrary component of the velocity vector.

Table 1 LDV and L2F Comparison

LDV	L2F
Light scattered by small particles convected by the flow	Light scattered by small particles convected by the flow
Doppler frequency shift is measured	Time-of-flight of the particles is measured
Measures instantaneous velocity at a point in the flowfield	Statistical-based measurement system
One-dimensional measurement system	Two-dimensional measurement system

Table 2 L2F Measurement parameters

Beam parameters	
Spot diameter, μm	8
Beam separation, μm	208
Measurement volume length, μm	450
Lens focal length, mm	350
Measurement parameters	
Number of angular positions	30
Angle increment, deg	1.50
Number of samples, each angular position	20,000
Sample frequency, Hz	200–600

Table 3 LDV Measurement parameters

Probe volume geometry	
Probe volume diameter, μm	126.6
Probe volume length, μm	1266.0
Probe volume fringe spacing, μm	2.585
Number of fringes	49
Half angle, deg	5.711
LDV measurements	
Number of samples	3,000
Number of cycles	16
Number of position bins	20
Number of histogram bins	20
Comparison, %	3
Lens focal length, mm	250

Research Centrifugal Compressor

The Purdue Research Centrifugal Compressor is a large-scale, low-speed turbomachine which features a mixed-flow impeller with 23 backswept blades and a vaned radial diffuser. The compressor is operated at 1800 rpm and has a stagnation pressure ratio of 1.03:1 at 3.33 kg/s. The shrouded impeller has an axial inlet, with the air exiting the impeller at an angle of approximately 70 deg from the axial direction. For these experiments, the compressor was fitted with an axial inlet with a meridional section of the compressor flow path given in Fig. 1. The facility is described by Bryan and Fleeter.[9]

To provide optical access to the impeller blade flow passages, the metal shroud on the impeller was replaced with a Plexiglas® shroud. The compressor case was cut away to expose 135 of the circumference of the impeller. Optical access is also provided to the radial diffuser flow path, including the vaneless space and the vaned diffuser. This is accomplished with a window which exposes three diffuser vane passages and extends to within 1 in. of the impeller exit.

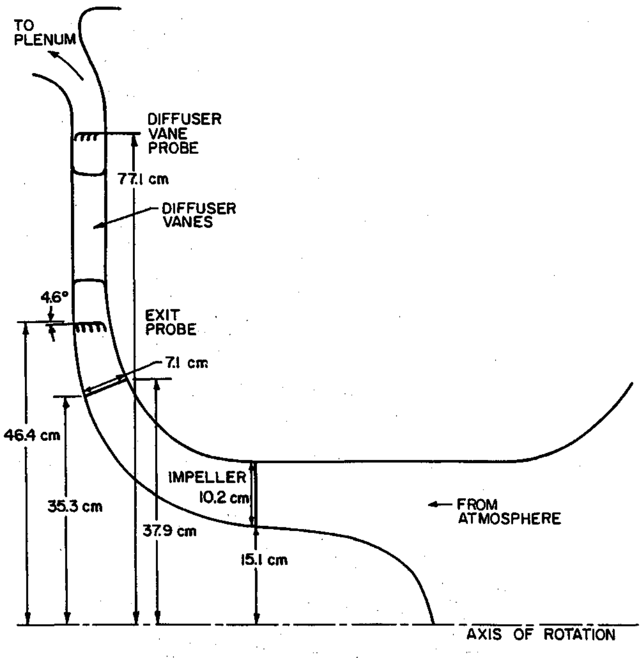

Fig. 1 Compressor flow path.

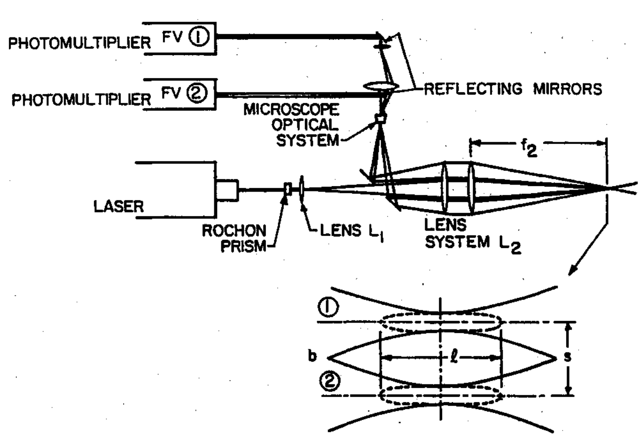

Fig. 2 L2F optical design.

L2F Experimental Technique

The L2F system is schematically depicted in Fig. 2. The dimensions of the optics housing for the L2F are 41 × 19 × 6 in. (1050 × 480 × 150 mm). The relatively large size of the L2F system restricts the locations in the flow path where L2F measurements can be made. As a consequence, measurements were limited to the inlet of the compressor, the first 20% of the impeller passage, and the radial diffuser.

The L2F system is used to make a measurement by sweeping the two focused laser beams through a range of angles about the mean flow direction in the plane with a normal along the axis of the illumination beam. The measurements are synchronized to the impeller rotation by instrumentation internal to the L2F system. A once per revolution signal is input and frequency multiplied by the blade count. Each impeller blade passage can be divided into as many as 16 windows for the measurement of circumferential velocity variations. Measurements can be taken in a single passage or ensembled over all the passages. Additionally, the laser can be strobed with a Bragg cell to eliminate the saturation of the photodetectors by reflections from the impeller blades. The flowfield was seeded with particles formed by atomizing a mixture of propylene glycol thinned with ethanol. The maximum data rate was obtained from the L2F with seed particle diameters between 0.1–0.5 μm. Typical L2F measurement parameters are given in Table 2.

LDV Experimental Technique

A single channel dual-beam LDV system operated in the backscatter mode is utilized. The three-dimensional velocity vector was derived from three independent measurements at each location. The probe volume size is given in Table 3. The flow seeding material consists of a mixture of propylene glycol and ethanol with particle diameters between 0.5–1.5 μm. As a result of the limited physical space available, a custom optics assembly was designed and fabricated in which a fiber-optic link connects the laser and preliminary optics to the final optics assembly. This enables the laser and the preliminary optics to be mounted on a fixed optical bench, with the positioning and orientation of the probe volume accomplished by traversing only the physically smaller final optics assembly.

The LDV optics assembly is shown in Fig. 3. The output from the laser is turned 180 deg by two first surface mirrors and directed into a beam splitter. The two equal power beams are individually frequency shifted, one by 40 MHz and the other by 30 MHz. These beams are directed to the fiber input coupler and transmitted to the final optics assembly through two polarization preserving fibers. The final optics assembly includes the focusing lens, probe volume positioning mirror, and receiving optics system. The fibers are connected to the output coupler which can be remotely rotated through 360 deg around the transmission beam axis. The beams pass through a thin optical window which supports the turning mirror for the backscattered signal and through the focusing lens. The probe volume is positioned in space by the mirror assembly which can be remotely rotated in two planes. The LDV system operates in backscatter mode with the mirror and lens also used to collect the scattered light. After the scattered light is collected by the lens, it is turned 90 deg and directed towards the receiving optics focusing lens which images the scattered light on the photodetector surface.

The Bragg cells are used to create a frequency shift between the two beams to eliminate velocity bias. The Bragg cells are also used to strobe the beams to prevent beam reflections from the passing blades from saturating the photodetector. The impeller angular position is determined with a timing circuit which includes a 1 MHz clock that is reset with each revolution. The timing circuit is interfaced to the LDV system as an additional counter. A timing word is passed with the LDV data for each realization. Due to large impeller mass, fluctuations in rotational speed are negligible.

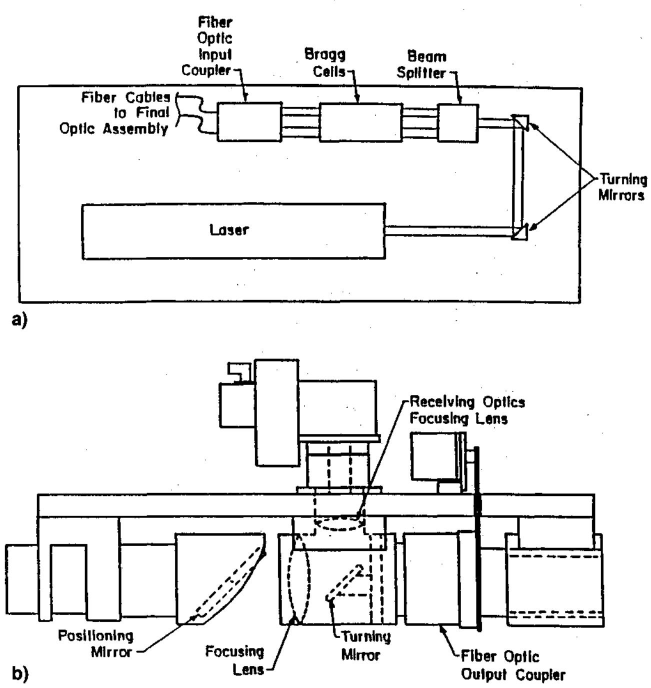

Fig. 3 LDV optics: a) preliminary and b) final.

Optical Corrections

Measurement with the optical based measurement systems in the impeller requires the illumination beams and the scattered light to pass through a Plexiglas window with a complex contour (impeller shroud). These systems are potentially sensitive to misalignment and mislocation of the measurement volume due to distortion from the window.

The small diameter, and consequently high beam intensity, at the beam waist required for laser two-focus velocimetry requires a large beam expansion. Thus, the illuminated surface area of the window can be significantly larger than for an LDV system to make a similar measurement. In the limit, this can distort the location of the measurement volume images on the photodetector pinholes making the measurement through the required range of angles impossible. It can also distort the measurement volume geometry, and a model is developed to determine the effect on measurement volume geometry of operating a L2F through a thin window of arbitrary geometry. A detailed description of the model is given by Fagan and Fleeter.[10] For this article a brief presentation of the model and the results will be presented.

The output beam of the laser operating in its fundamental mode (TEM_{00}) has a Gaussian intensity distribution. A Gaussian beam has the characteristics that the wave front is planar at the beam waist and has a spherical wavefront along the beam not near the waist. To model the L2F illumination beams, the Gaussian beam equations are used to find the theoretical wave front (location, beam radius, and radius of curvature) for the illumination beams required to produce the measurement volume geometry (waist diameter, location, orientation, and separation) for an undistorted beam path. The wave front is replaced with a finite number of rays propagating towards the beam waist. An exact ray trace is used to track each ray an equivalent optical path length through the window. The geometry is given in Fig. 4. The basis of the model is the window causes a perturbation to the original Gaussian beams resulting in new Gaussian beams with unique geometry. Assuming the distance from the beam waist to the window is much larger than the Rayleigh length, a new spherical wave front can be estimated from the endpoints of each ray. A set of equations equal to the number of rays is generated. If there are only four rays, the system can be solved exactly for the center position and radius of the sphere. However, four rays are insufficient to model the distortion to the beam by the window. The required additional relations result in an overspecified system of nonlinear equations. An optimum solution is found by using a small perturbation analysis to linearize the equations, with a least squares solution determined.

The distortion of the L2F measurement volume geometry in the impeller flow passages is estimated by using this model to calculate the distortion in a cylinder with a 19.90-in. (506-mm) i.d., and a wall thickness of 0.085 in. (2.16 mm). This is the diameter and wall thickness of the impeller shroud at the plane defined by $z = 1.5$ in. (38.1 mm). The shroud is nearly cylindrical at this location, so the analysis is presented for a cylinder; however, the model is applicable to thin windows of any arbitrary contour. The illumination beams are oriented along a ray intersecting the axis of the cylinder. Figure 5 shows the geometry and the deviation angle conventions. Due to the symmetry of the system, the distortion of any measurement volume orientation is described by the 0–90-deg results. Figures 6–8 present the predicted nondimensional-distorted beam spacing S_0, the angle from the undistorted measurement plane α, and the deviation from the undistorted orientation angle $\Delta\beta$ vs orientation angle for 5, 50, and 95% span, respectively. The maximum variation in beam separation is found to be less than 0.3% with angles α and $\Delta\beta$ less than 0.020 and 0.080 deg, respectively. The dis-

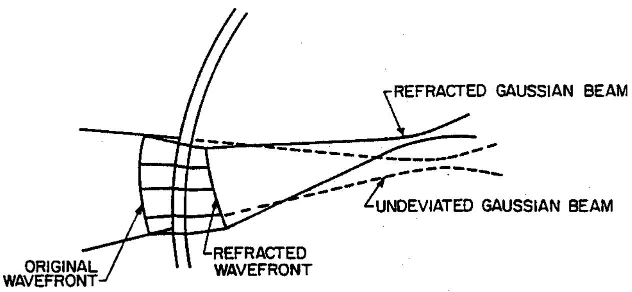

Fig. 4 Beam distortion geometry.

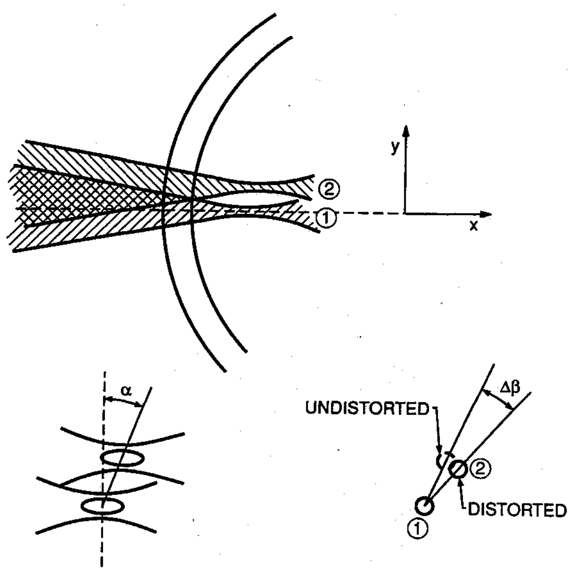

Fig. 5 Geometry for optical corrections.

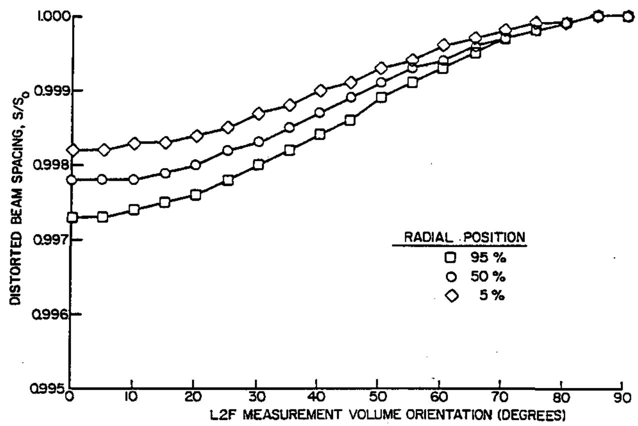

Fig. 6 Nondimensional beam separation as a function of orientation angle.

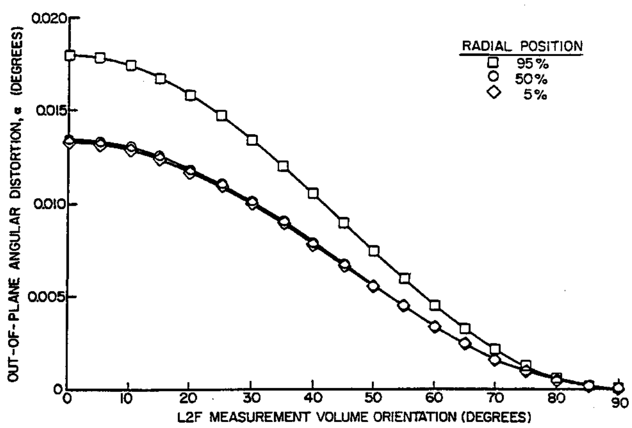

Fig. 7 Out-of-plane angular distortion as a function of orientation angle.

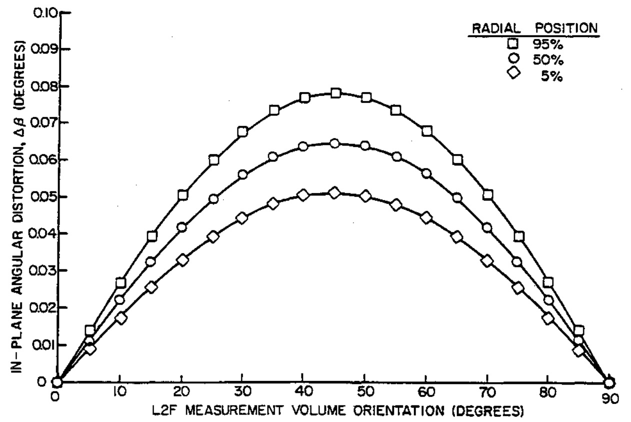

Fig. 8 In-plane angular distortion as a function of orientation angle.

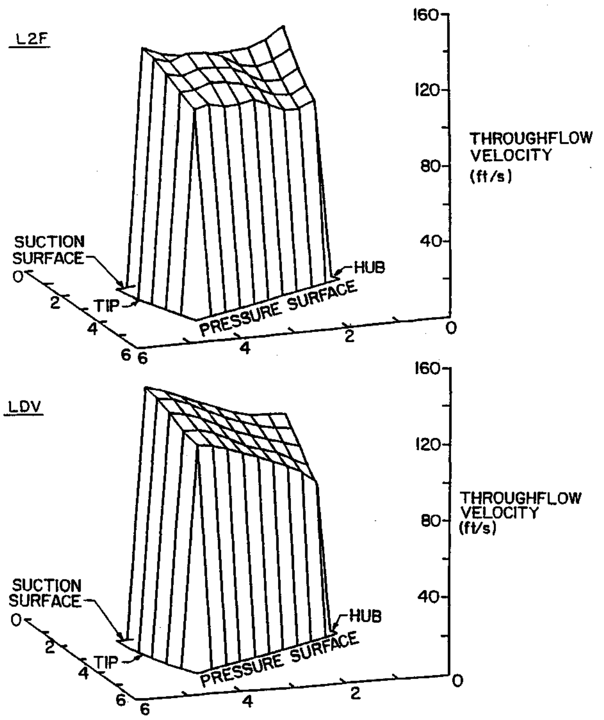

Fig. 9 Impeller throughflow L2F and LDV velocity data at plane z = 1.5 in.

placement of the measurement volume is less than 0.030 in. (0.7 mm) for all three spans. The error in the L2F measurements due to distortion of the measurement volume geometry is considered negligible for these experiments and is not corrected. The displacement of the measurement volume due to the window cannot be neglected and a correction is applied.

As a result of the relatively small beam diameter for the LDV illumination beams, the distortion of the probe volume geometry can be calculated by a ray trace of the axial rays of the illumination beams. The ray trace is used to find the location of the illumination beam intersection and the half-angle between the beams. An inverse ray trace algorithm was developed to position the LDV system to make measurements in the specified location and direction. The calculation of the velocity magnitude from the measured Doppler frequency is based upon the calculated half-angle from the ray trace.

Flowfield Results

Comparable data at a near design operating point was taken with the L2F and LDV systems at two planes in the first 20% of the impeller blade passage, and at the impeller exit in the vaneless space between the impeller and the diffuser vanes. Figure 9 gives the through-flow velocity plots derived from

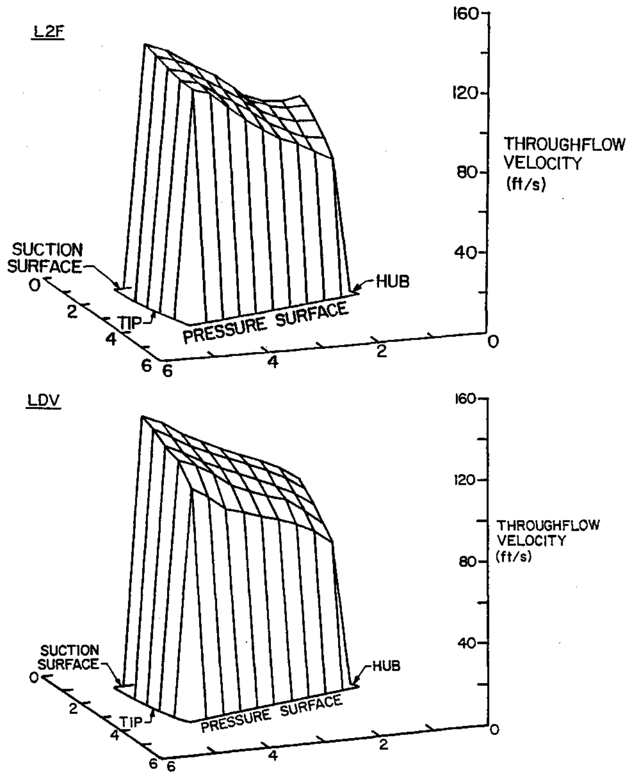

Fig. 10 Impeller throughflow L2F and LDV velocity data at plane z = 2.65 in.

the data sets for the two systems at a location 1.5 in. (38.1 mm) from the blade leading edge. The most obvious discrepancy is in the hub, suction surface corner. The L2F data indicates a much higher local velocity. A similar trend is shown in Fig. 10 for data taken at a location 2.65 in. (67.31 mm) from the blade leading edge. While it is not possible to determine the accuracy of either set of measurements based upon a direct comparison, several items lend credence to the accuracy of the LDV measurements which ultimately led to its choice for use in this study. First, the calculated mass flow based upon the LDV measurements were within 2% of the measured mass flow for the compressor while the calculated mass flow based upon the L2F results was significantly higher at each plane. Secondly, the through-flow work distribution based upon the LDV measurements is sensible and consistent with data acquired with other instrumentation. That data is described in Ref. 11. Finally, predictions with a three-dimensional viscous solver described by Fagan and Fleeter[12] do not indicate the high velocity region in the hub, suction surface corner observed in the L2F data.

Data from three spanwise locations at a single radial position is shown in Figs. 11–14. The average velocity plots show similar trends, but there are significant quantitative differences between the data from the two measurement systems. The plot of the fluctuation intensity of the through-flow velocity indicates a maximum intensity of 0.11 for the L2F data and 0.15 data. This is likely due to the limitations of the L2F system for measuring turbulent flowfields discussed in the next section.

L2F-LDV Comparisons

For this research, the LDV was chosen for use based upon a comparison of the two systems and the reasons described above. The potential benefit of the L2F for other turbomachinery applications is dependent upon the criteria used to assess its value. This discussion relates to several of the observations made about the two techniques during this evaluation, including signal-to-noise ratio, sample rate, marginal probability density distributions, and other considerations.

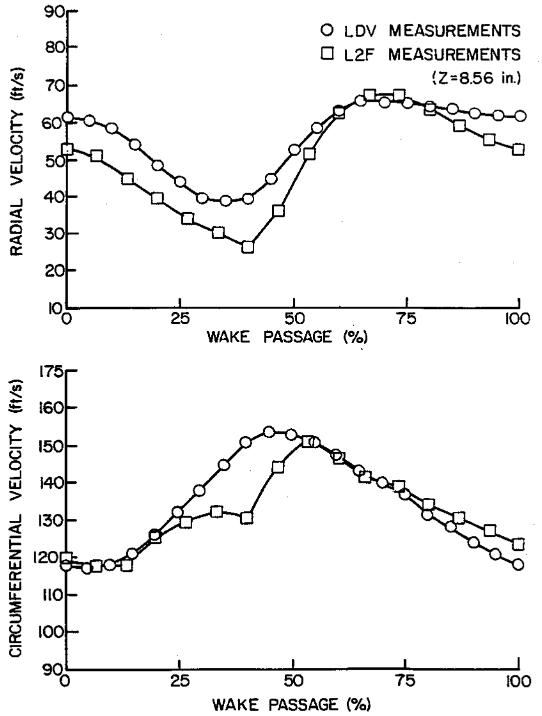

Fig. 11 Diffuser L2F and LDV data at plane z = 8.56 in.

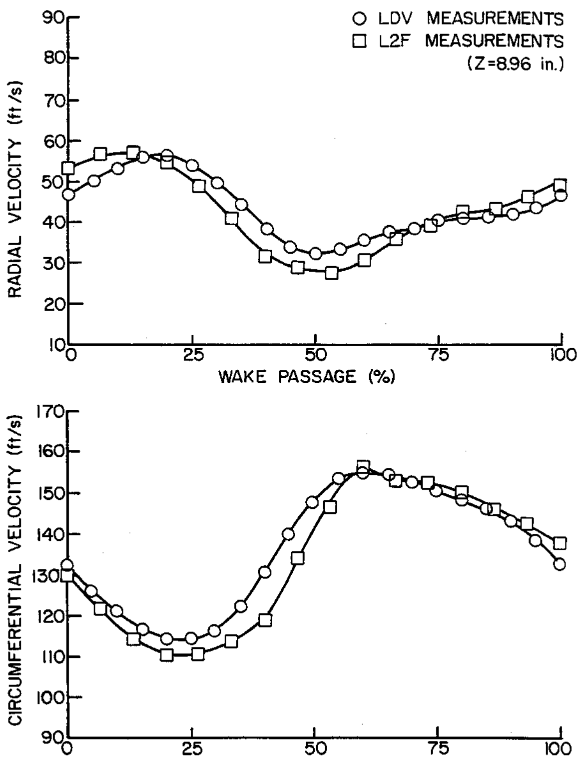

Fig. 12 Diffuser L2F and LDV data at plane z = 8.96 in.

In principle, the L2F system is capable of making measurements closer to solid boundaries than a backscatter LDV system for two reasons. The L2F illumination beam is focused to a much smaller spot resulting in a higher beam intensity. Also, the required L2F signal-to-noise ratio is less since only the presence of the particle and not the Doppler frequency needs to be determined. This can be critical in turbomachinery as the measurements are generally made in orientations nearly normal to the hub surface. Measurements made in the diffuser region with a flat window and a stationary wall and window demonstrate this. L2F data were acquired 0.030 ± 0.010 in.

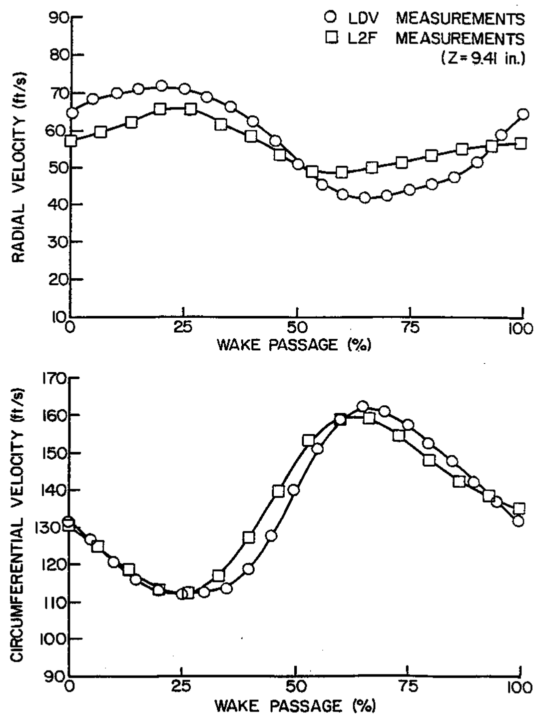

Fig. 13 Diffuser L2F and LDV data at plane z = 9.41 in.

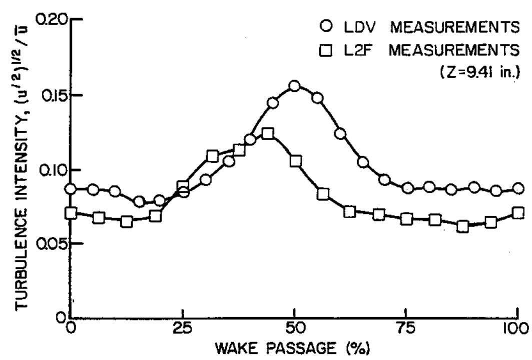

Fig. 14 Diffuser L2F and LDV turbulence intensity at plane z = 9.41 in.

(0.762 ± 0.254 mm) from the front window, and 0.050 ± 0.010 in. (1.270 ± 0.254 mm) from the back wall. Corresponding LDV data was acquired as close as 0.200 in. (5.080 mm) from the front window. Although it is likely an LDV measurement can be made nearer to the window by using a field stop or through the application of fluorescence techniques, the L2F system clearly has some advantage for this geometry.

In the rotating impeller, accurate measurements were acquired nearer to the hub and shroud with the LDV than the L2F system. The primary cause is that imperfections on the rotating surfaces can produce a detectable L2F signal. In fact, the L2F actually measures the surface velocity if the measurement volume is sufficiently near the surface. As the measurement volume is moved away from the wall, there is a measurement region where events are detected from both particles passing through the measurement volume and from wall surface reflections. Since the wall velocity is the asymptotic velocity of the fluid as the wall is approached, events from the wall can undetectably contribute to the velocity histogram thereby biasing the L2F velocity and turbulence data.

The effective data acquisition rate of the L2F was much smaller than that for the LDV for these measurements. It is necessary to recognize that the L2F system is making a two-dimensional velocity measurement, and the single channel LDV makes a one-dimensional measurement and requires two independent measurements to acquire nearly the same amount of information. Another option is a two-channel LDV system which requires simultaneous measurement in two directions which additionally provides the velocity correlation, but usually results in a reduced data rate.

To discuss the sample rate, some terminology must be defined. For the L2F it is important to distinguish between a sampled event, which occurs when the system is in the ready mode and a particle passes through the start beam, and a correlated event. A correlated event occurs when a single particle passes through both the start and stop beam and contributes to building the velocity probability density distribution. The rate at which events can be sampled with the L2F is limited because the mean particle separation in the flowfield must be larger than the beam spacing. For velocities on the order of 164 ft/s (50 m/s) and this beam spacing used for these measurements, the sampling rate is limited to approximately 500 Hz. For the measurements made at the exit of the impeller using the range and angular step size recommended by the manufacturer of the L2F, approximately 5% of the sampled events were correlated events. This resulted in an effective L2F sampling rate of 25 Hz (500 Hz $\times$ 0.05). Additionally, the uncorrelated events cannot be rejected until postprocessing, requiring a large amount of data to be acquired to obtain adequate sample sizes. While this rate can be improved by educated choices for the sampled range of angles, it cannot be ultimately determined until the complete histogram is built. The range of angles suggested by the manufacturer was appropriate to make measurements with these velocities and turbulence intensities.

The single-channel LDV system had a typical sample rate of 700 Hz for measurements at the exit of the impeller. As a result of the internal LDV validation circuitry, most invalid measurements are rejected by the processor and not passed as an event. During postprocessing of the LDV data, velocity measurements outside four standard deviations from the mean value are rejected. The number of rejected LDV measurements typically make up less than 1% of the total, resulting in an effective sampling rate of 690 Hz.

In principle, the L2F system builds the two-dimensional velocity probability density distribution from the time-of-flight histograms collected at each angular position. However, the Polytec instrument does not build the complete two-dimensional velocity probability density distribution because of data storage limitations in the multichannel analyzer. Rather, two marginal distributions are constructed: 1) a time-of-flight histogram which is independent of the angular position, and 2) a histogram of the number of correlated events vs angular position which is independent of the time-of-flight measurement. The mean velocity and the turbulence intensities are calculated from these two distributions, which introduce several potential problems. No rigorous mathematical treatment has been developed, quantifying the error introduced by modeling the two-dimensional velocity probability density distribution with the marginal distributions. As a consequence, the magnitude of the experimental error cannot be calculated directly. Additionally, no angle dependent measurement volume geometry correction can be applied during postprocessing if the marginal distributions are used.

During these experiments, the optimal seed particle diameter for the L2F was found to be nearly an order of magnitude smaller than for the LDV. Smaller particles are advantageous when making measurements in flowfields with large velocity gradients, high-frequency oscillations, or discrete jumps such as shock waves. Although these conditions are not relevant to measurements in the Purdue Research Centrifugal Compressor, it could be important in high-speed turbomachinery.

Finally, the L2F is limited in its capability to accurately measure flowfields with high turbulence intensity. Schodl[6] and results from this experiment suggest an upper turbulence intensity limit of approximately 15% for accurate measurements. This can be a serious limitation for high-speed turbomachinery.

Summary

An evaluation of an LDV and an L2F system was made resulting in the choice of the LDV system to continue this research. Several of the reasons for choosing the LDV system are specific to making measurements in this facility. These include difficulty in making measurements near the rotating window (impeller shroud), making measurements through a curved window, and restrictions in optical access due to the size of the L2F system. Several limitations of the L2F system for general measurements are also discussed. These include the low effective sample rate, the difficulty associated with using the marginal distributions to model the two-dimensional probability density distribution, and the turbulence intensity limitations for accurate measurements with the L2F system.

The L2F was designed to allow measurements nearer to solid surfaces, a serious limitation of LDV systems for turbomachinery flowfields. Data obtained from this research indicates the L2F is capable of making measurements nearer stationary walls than a typical LDV system. Some important limitations of the L2F must also be considered when choosing the proper measurement system for use in turbomachinery flowfields.

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