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Research and Development

Cross-Stack Optical Convolution Velocimeter

Development and Evaluation of a Breadboard Design

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CROSS-STACK OPTICAL CONVOLUTION VELOCIMETER
Development and Evaluation of a Breadboard Design

by

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ABSTRACT

A new type of instrument has been designed and evaluated for the measurement of a line average of a stack gas velocity. The light output from a lamp is collimated and projected across the stack. A shadowgraph image of the turbulence in the stack is produced on the far side and this image is convected by the stack gas flow. A grating is placed over the image and the light transmitted falls on a photodetector. The frequency output from the photodetector is the rate at which the shadowgraph image crosses the grating.

A breadboard design of this cross stack optical convolution velocimeter (OCV), as it is called, has been built. It was tested in the EPA Stationary Source Simulation Facility (SSSF) over a wide range of environmental conditions. Agreement was obtained with a corrected pitot tube with a root mean square error of 1.3%.

Position sensitivity of the OCV has been extensively studied and a configuration has been found which is completely insensitive to position.

The cross stack OCV has demonstrated itself as an effective, accurate velocity monitoring instrument which is simple to build and operate.

This report was submitted in fulfillment of Contract 68-02-2786 by Bolt Beranek and Newman, Inc., Contractor, under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from October 1977 to March 1978, and work was completed as of March 1978.

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ACKNOWLEDGMENT

The author wishes to gratefully acknowledge the help and suggestions from G. Dubro and D. Kim of the Air Force Flight Dynamics Laboratory of the Wright Aeronautical Laboratories since they were the original inventors of the Optical Convolution Velocimeter. The author also wishes to acknowledge the aid of J. Nader and T. Ward of the Stationary Source Emissions Research Branch, EPA, for their support during the tests in the Stationary Source Simulation Facility.

SECTION 1

INTRODUCTION

THE OPTICAL CONVOLUTION VELOCIMETER (OCV)

The optical convolution velocimeter was conceived by DuBro and Kim* (U.S. Patent No. 3,953,126) as a noninvasive method for measuring aircraft speed. Its principle has been extended here for stack flow measurement.

The output of a light source is collimated by a lens, and projected through the turbulence onto a grating. The turbulence is generated naturally in the stack. As the light passes through the turbulence, it is refracted, and a "shadowgraph" pattern of bright and dark bands is formed on the grating. As the turbulence is convected with the mean flow, the shadowgraph pattern is convected over the grating. We can describe the light transmitted by the grating as

$$\int I(x-y)G(x)dx = F(y)$$

where I(x-y) is the shadowgraph pattern that is convected in time by distance y, and G(x) is the grating transfer function. The function F(y) is the convolution of the shadowgraph and the grating. By Parseval's theorem, the spectrum of this convolution is equivalent to the product of the spectra of I(x) and G(x). If the spectrum of G(x) is narrow, the spectrum of the convolution function F(y) is narrow, and it will be sinusoidal with a frequency equal to that at which the turbulence crosses the grating. Hence, the velocity can be found by measuring this frequency.

The purpose of this report is to describe the development of the OCV for making in-stack velocity measurements. The OCV has a number of inherent advances over the pitot tubes which are currently employed. First, it is an absolute instrument and never needs recalibration once it has been set up. Secondly, it is unaffected by ambient conditions such as pressure and temperature. Thirdly, it just measures one component of the velocity. Fourthly, it can be given a digital readout very inexpensively: The OCV promises to be a much more accurate and convenient to use instrument than the pitot tube.

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*D. Kim and G. DuBro, 1974, "The Optical Convolution Velocimeter" presented at the second Project Squid Workshop, Purdue University, Lafayette, IN, Mar. 26-27.

SECTION 2

CONCLUSIONS

A breadboard version of a cross stack OCV has been successfully designed, fabricated and tested in the EPA Stationary Source Simulation Facility. Good agreement was obtained with a pitot tube over a wide range of environmental conditions; temperatures up to 204°C and dust loadings up to 0.25 $gm/in.^3$; the root mean square discrepancy was 1.3% of reading.

A configuration for the cross stack OCV has been devised which should give perfectly uniform sensitivity across the stack. The light beam is retro-reflected across the stack to a grating of pitch 1.9 $(\text{stack width})^{\frac{1}{2}}$ millimeters. Drawings for the suggested cross stack OCV design are attached in Appendix B.

The cross stack OCV has shown itself to be a simple and accurate instrument for the measurement of the line average velocity in a stack.

SECTION 3

RECOMMENDATIONS

Now that the basic performance of the cross stack OCV has been demonstrated, it is ready for the next stage in its development. This will consist of:

1. Fabricating a properly packaged version which can be installed in the field.

2. Incorporating the double pass feature to give uniform sensitivity.

3. Incorporating air curtains over the lenses.

4. Investigating the sources of electronic noise and improving the signal-to-noise ratio.

5. Investigate the possibility of using a low power Helium-Neon Laser as a light source instead of a tungsten lamp. This has a much smaller source size which may well eliminate much of the low frequency noise due to the flow. Further, the Laser has a very low power consumption (15 watts) and, therefore, does not require convection cooling. Finally, gas Lasers have a very long life, many thousands of hours.

Such an improved instrument would be suitable for field testing.

SECTION 4

SENSITIVITY OF THE OPTICAL CONVOLUTION VELOCIMETER

The optical convolution velocimeter measures the convection velocity of a shadowgraph pattern across a one-dimensional grating. From Townsend (1965) the the spectral intensity of the shadowgraph image due to a thin sheet of turbulence and transmitted by the grating is

$$I(\ell,0) = 8\pi N^2 \sin^2(\ell^2 z/2N) F(\ell,0,0,)\delta z \cdots \qquad (1)$$

where
ℓ = wavenumber of the grating
N = wavenumber of light employed
z = thickness of turbulence
$F(\ell,m,n)$ = three-dimensional spectral intensity of turbulence refractive index variations
δz = thickness of turbulence.

It has also been shown by Batchelor (1959) that for fully developed flow of large Reynolds number, the theory of local isotropy gives

$$F(\ell,0,0) = 0.1\varepsilon_N{}^{-\frac{1}{3}}\ell^{-\frac{11}{3}} \cdots \qquad (2)$$

where ℓ >> mean scale of fluctuations $\leq 0.2\varepsilon^{\frac{1}{4}}\nu^{-\frac{3}{4}}$
ε = rate of energy dissipation per unit mass by viscosity
ν = kinematic viscosity
ε_N = rate of destruction of mean-square refractive index fluctuations by molecular diffusion.

Substituting Eq. 2 into Eq. 1, we obtain

$$I(\ell,0) = 0.8\pi N^2 \varepsilon_N \varepsilon^{-\frac{1}{3}} \sin^2(\ell^2 z/2N)\ell^{-\frac{11}{3}}\,\delta z \cdots . \qquad (3)$$

In our arrangement, ℓ, the wavenumber of the grating, is held constant, and z, the position in the stack, varies. Therefore, if ε_N and ε are constant across the stack,

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A.A. Townsend (1965), "The Interpretation of Stellar Shadow-Bands as a Consequence of Turbulent Mixing," *Quart. J. Roy, Met. Soc.*, 91, pp. 1–9.
G.K. Batchelor (1959), "Small-Scale Variation of Convected Quantities Like Temperature in Turbulent Fluid, Part 1, *J. Fluid Mech.*, 5, pp. 113–133.

$$I(\ell,0) \propto \sin^2(\ell^2 z/2N) \cdots \quad (4)$$

This dependence of $I(\ell,0)$ on 2 is shown in Figure 1. For small z,

$$I(\ell,0) \propto z^2 .$$

For z approximately between $\pi N/3\ell^2$ and $2\pi N/3\ell^2$

$$I(\ell,0) \propto z$$

and for z around $\pi N/\ell^2$

$$I(\ell,0) = \text{independent of } z .$$

This relationship will apply if a heater wire across the stack is used to generate the signal. In this case, ε and ε_N are independent of position across the stack.

In typical turbulent processes, Batchelor (1953) gives the following values for ε and ε_N,

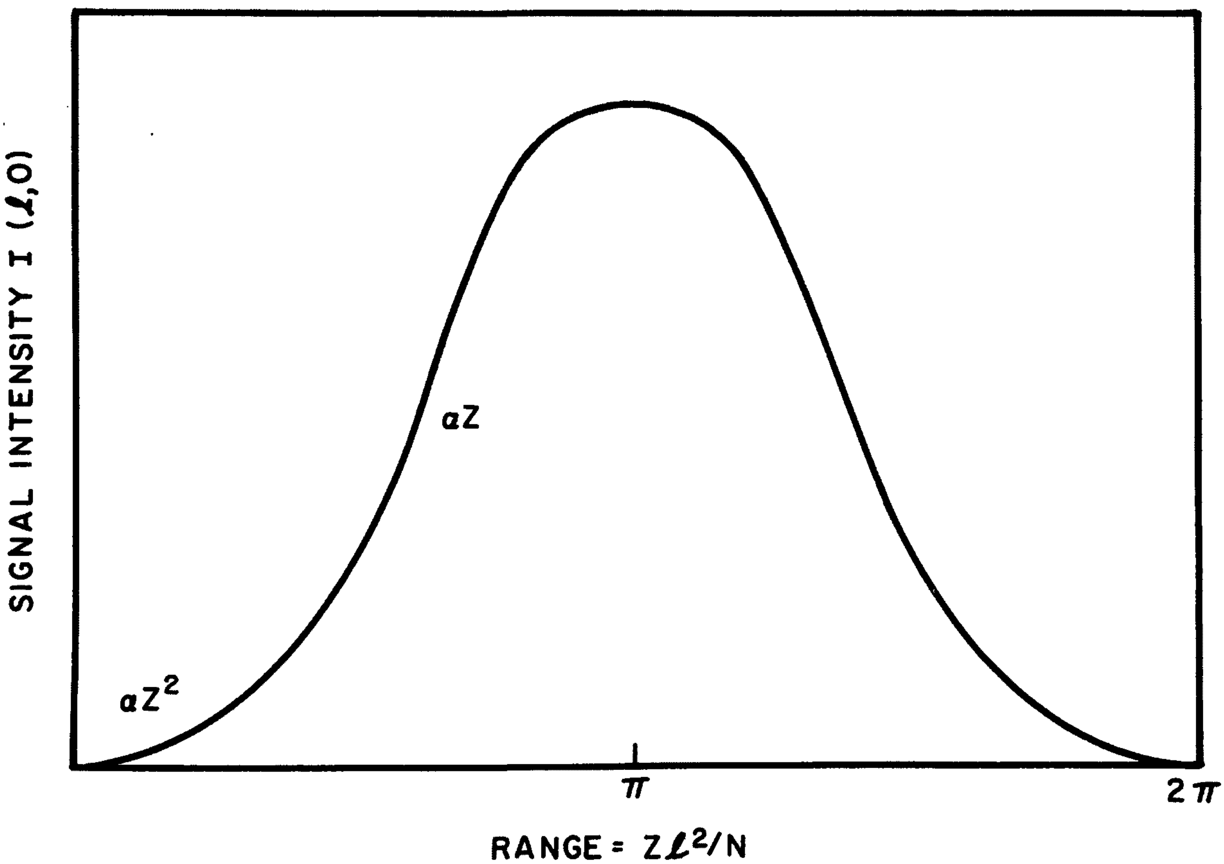


Figure 1. Range of sensitivity of OCV

G.K. Batchelor (1953), "Homogeneous Turbulence," Cambridge University Press, London.

$$\varepsilon = (\overline{U})^{\frac{3}{2}} L^{-1}$$

and

$$\varepsilon_N = \frac{1}{2} (\overline{u^2})^{\frac{1}{2}} L(\overline{d\mu/dz})^2$$

where $\overline{u^2}$ = root mean square fluctuating velocity
L = integral scale of the turbulent motion
and $\overline{d\mu/dz}$ = mean refractive index gradient = $\rho/T\ d\mu/d\rho(\overline{dT/dz})$
where ρ = density of flow, T = absolute temperature
and $\overline{dT/dz}$ = mean temperature gradient.

Therefore,

$$\varepsilon_N \varepsilon^{-\frac{1}{3}} = \frac{1}{2} L^{\frac{4}{3}} \frac{\rho}{T} \frac{d\mu}{d\rho} (\overline{dT/dz}) \qquad (5)$$

which is only a function of the temperature gradient and scale of turbulent motion for a particular fluid at a particular temperature. Typically, the temperature gradient is greatest at the wall of a stack and the mixing length is greatest in the center. Generally, for *fully developed* turbulent flow in a stack, the Prandtl hypothesis (Goldstein, 1965) is that $L \propto z'$, the distance from the wall. Similarly by the Reynolds analogy (Goldstein, 1965) between temperature gradient and velocity gradient $\overline{dT/dz} \propto 1/z'$, the reciprocal of the distance from the wall. These relations apply to the bulk of the turbulent flow in the center of the stack, but not to the region very close to the wall, the so-called viscous sublayer. Thus, over most of the region of the stack,

$$L\ \overline{dT/dz} = \text{constant} . \qquad (6)$$

Hence, $\varepsilon_N \varepsilon \propto L^{\frac{1}{3}}$, which is a very weak relationship to mixing length. Therefore, over most of the flow in a stack where the turbulence is fully developed, the OCV has a very weak dependence on the structure of the turbulence. However, it is not clear that this applies to all flows such as highly skewed velocity distributions after a bend.

The most important parameter affecting the sensitivity of the OCV is the distance between the turbulence and grating. If we are to place the grating one stack diameter beyond the grating and choose the grating spacing accordingly, $(2\sqrt{z/N})$, then there will be less than a 25% variation in sensitivity across the whole stack or 10% variation over the central 60%.

S. Goldstein (ed.) (1965), *Modern Developments in Fluid Dynamics*, Dover Publications (New York), p. 208.

S. Goldstein (ed.) (1965), *Ibid*, p. 649.

SECTION 5

POSITION SENSITIVITY OF OPTICAL CONVOLUTION VELOCIMETER

In the previous section the signal strength $I(\ell)$ of the OCV with a grating of wavenumber ℓ was given by

$$I(\ell) = 0.8\pi N^2 \varepsilon_N \varepsilon^{-\frac{1}{3}} \sin^2(\ell^2 z/2N)\ell^{-\frac{11}{3}}\ \delta z \tag{7}$$

where N = wavenumber of radiation
ε = rate of energy dissipation per unit mass by viscosity
ε_N = rate of destruction of mean-square refractive index fluctuations by molecular diffusion
z = distance of turbulence of thickness δz from grating.

Previously, a single pass OCV system was considered with the transmitter and receiver on opposite sides of the stack. It was shown that if the receiver was placed one stack diameter beyond the stack, then the sensitivity of the OCV did not vary more than 25% across the stack. However, placing the receiver so far beyond the stack is rather inconvenient. Accordingly, another scheme is considered here whereby the light is reflected back across the stack, by means of a retro-reflector and the transmitter and receiver are side by side (see Figure 2). We now have one signal from the outward beam and another signal from the return beam and we can add the two together. Thus, we obtain

$$I(\ell) = A\{\sin^2(\ell^2 z/2N) + \sin^2[\ell^2(2z_{max}-z)/2N]\}\delta z \tag{8}$$

where $A = 0.8\pi N^2 \varepsilon_N \varepsilon^{\frac{1}{3}} \ell^{-\frac{11}{3}}$
z_{max} = OCV to retro-reflector distance.

Of these two terms, the second represents the outward beam and the first the return beam. z is always less than z_{max}.

Now, if we choose the grating wavenumber ℓ such that

$$2\ell^2 z_{max}/2N = \pi/2\ . \tag{9}$$

Then the above expression reduces to

$$I(\ell) = A[\sin^2(\ell^2 z/2N) + \cos^2(\ell^2 z/2N)]\delta z \tag{10}$$

$$= A\delta z \tag{11}$$

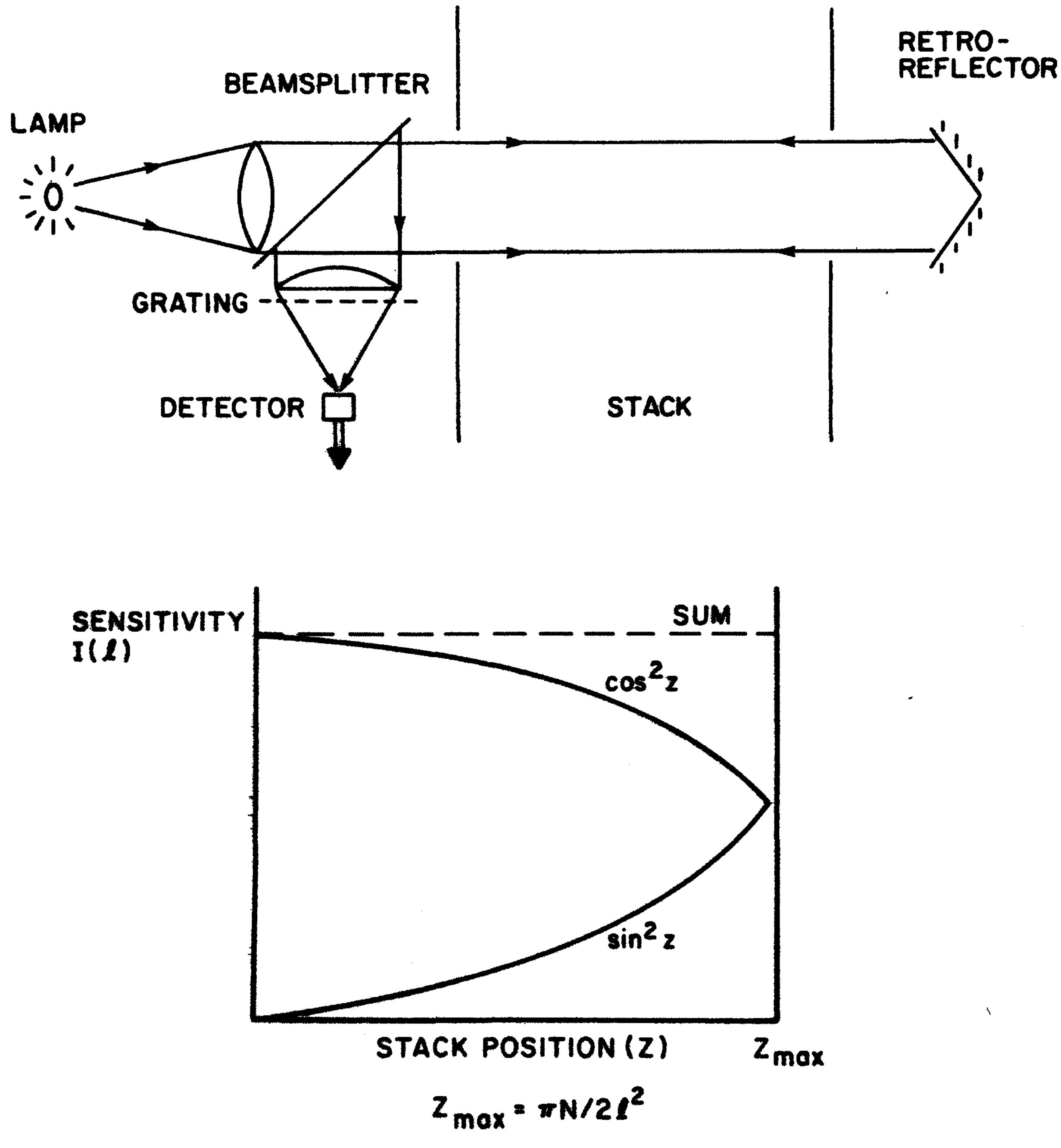


Figure 2. Retro-reflecting OCV

which is independent of z! The contributions from the outward and return beams are shown in Figure 2.

We are operating a light wavelength λ, and the grating pitch, p, is given by 3 as

$$p = 2\sqrt{\lambda z_{max}} .$$

Thus, for a wavelength of 0.9 μm and a stack width of 2 m

$$p = 2.7 \text{ mm} .$$

A grating of this pitch will then give a uniform weighting to the velocity across the stack, independent of velocity profile. This analysis does assume, however, that the turbulence intensity and scale are uniform across the stack.

SENSITIVITY ANALYSIS

It is important to know not only the performance of the optimum grating described above but also how coarser gratings may perform. This is because, in order to maximize signal strength from the OCV, it may be necessary to use a less fine grating than 2.7 mm. Accordingly the velocity weighting function, $I(\ell)/A$, has been computed for two other grating pitches, 4.9 mm and 7.6 mm when used in a 2 m stack. The results are shown in Figure 3.

These gratings tend to weight the flow next to the transmitter/receiver more heavily than that next to the retro-reflector. In the case of the 7.6 mm grating, the velocity next to the transmitter/receiver is given a 40% higher weighting than the average.

However, because we are averaging across the whole stack, the error on the average velocity measured will be much less than this. We have computed this error for a highly skewed velocity profile with a 1:1½ variation. The flow was 80% of the average at one wall and 120% of the average at the other wall. Table 1 shows the errors for the average velocity measured with the three different gratings for the two cases when the maximum velocity is next to the transmitter/receiver and when it is next to the retro-reflector. It will be seen that in no case is the error greater than 3%. Therefore, the OCV is not very sensitive to nonoptimum gratings or nonuniform velocity profile.

TABLE 1. ERRORS WITH NONOPTIMAL GRATINGS.

Velocity Profile = Linear — 0.8 to 1.2 × average across stack		
Maximum Velocity	At Transmitter/Receiver	At Retro-Reflector
2.7 mm grating	.0	.0
4.9 mm grating	.03	-.0204
7.6 mm grating	.026	.0043

MIRROR REFLECTIVITY

In the foregoing analysis, we have assumed a mirror reflectivity of 100%. In practice a value of 80 — 90% is more typical. This will change Eq. 8 and mean that perfect independence of z in Eq. 10 is no longer possible. The error is then proportional to

$$0.15 \sin^2(\ell^2 z/2N) \tag{12}$$

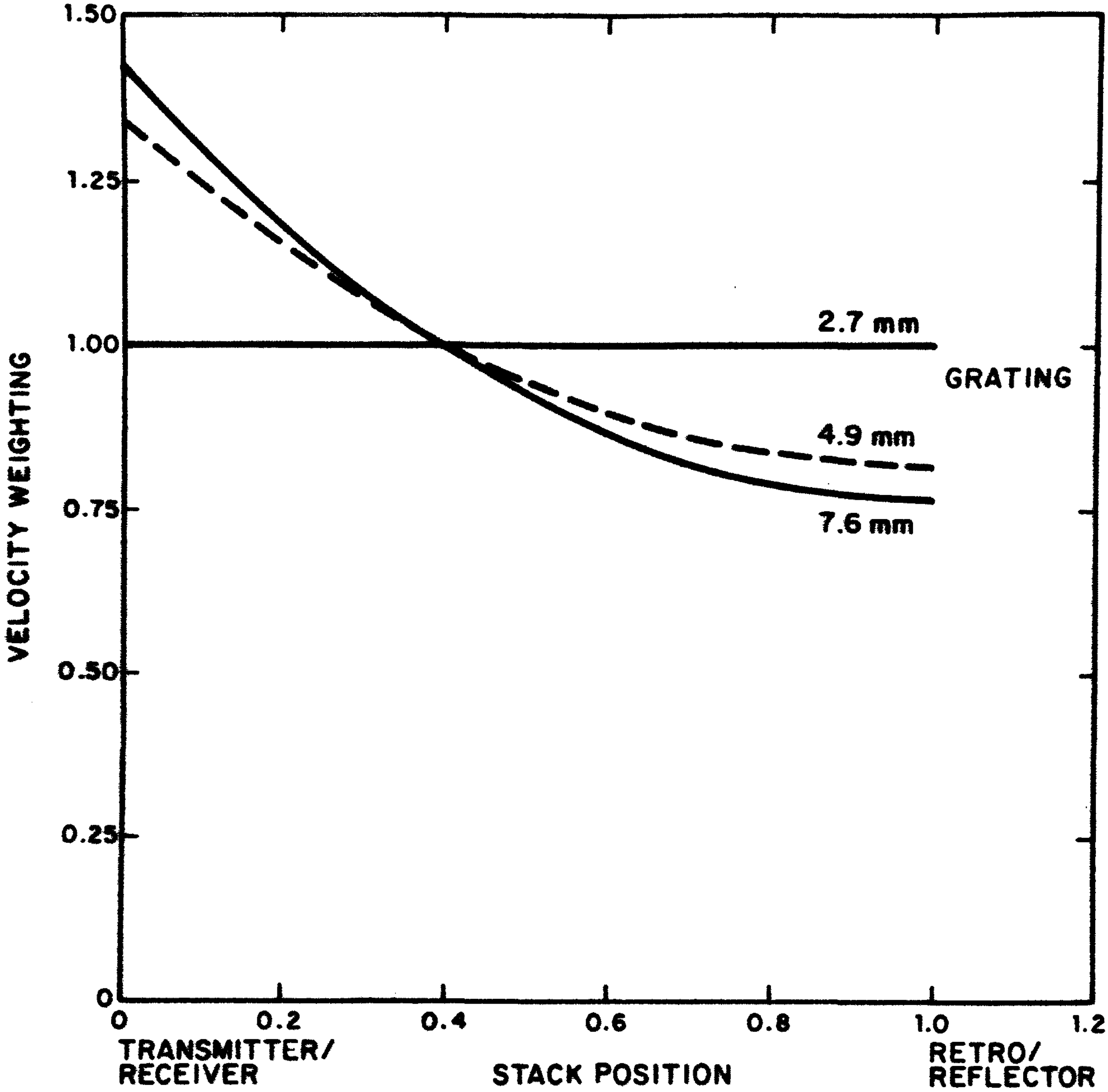


Figure 3. Position sensitivity in a 2 m stack for three gratings

which has a maximum error of 7.5% at $z = z_{max}$. However, in the light of the limited sensitivity of the OCV to grating spacing, this factor will have a much smaller effect on the overall velocity reading.

For a perfectly uniform velocity weighting across the stack, a grating pitch p should be chosen such that

$$p = 2\sqrt{\lambda z_{max}}$$

where λ = wavelength of light employed (approx. 0.9 μm)

z_{max} = transmitter - retro-reflector distance.

However, gratings which are 2 to 3 times this pitch do not show a large error, even with quite a nonuniform velocity profile.

CALCULATED PERFORMANCE OF OCV IN AN ACTUAL STACK VELOCITY PROFILE

The accuracy of the cross stack OCV has been computed for a real stack velocity profile. This profile was taken from the *Flow and Gas Sampling Manual* by E.F. Brooks and R.L. Williams, U.S. Environmental Protection Agency Report EPA-600/2-76-203 of July 1976. The profile was taken from Figure 6, page 31, and was measured in a 8.27 × 3.18 meter duct. It was supposed that the OCV would look across the duct from the center of its sides, looking either parallel to the long sides or the short sides. The velocity profiles along these lines of sight are shown in Figure 4.

If we take a linear average of the velocity on a line across the stack, we obtain a value of 101.4% of the mean on a line parallel to the long side and only 77.7% of the mean parallel to the short side. This discrepancy highlights the main source of error, that is not with the OCV itself but with the dangers of taking a line average. Since the line only samples part of the stack, serious errors can develop if a large part of the flow deviates substantially from the average. Accordingly line averages should only be taken where the flow is reasonably uniform.

The performance of different grating sizes have been compared for the profile parallel to the long side (errors associated with the profile parallel to the short side are not considered to be meaningful). The weighting functions for three grating pitches are given in Table 2. The errors for the three gratings are compared in Table 3 with that of a linear average made parallel to the long side of the duct.

It will be noted that the errors are not very large, even for the most coarse grating and are smaller than the difference between a line and true average.

SITING OF THE CROSS-STACK OCV

The main source of error which is likely to arise with the cross-stack OCV in actual use will arise from its siting, rather than any internal instrument error. The errors associated with the instrument are of the order of 1% or less, but the difference between a line average and a true average may be 20 - 30%. The flow in the duct where the cross-stack OCV is mounted should be reasonably uniform. This means that it should not be mounted downstream of a sharp bend or blockage, or even too close upstream. Whenever the cross-stack OCV is mounted on a stack, a complete velocity survey should be performed before installation and the discrepancy between the line average and true average computed. This will at least make the operator aware of any discrepancies which may arise.

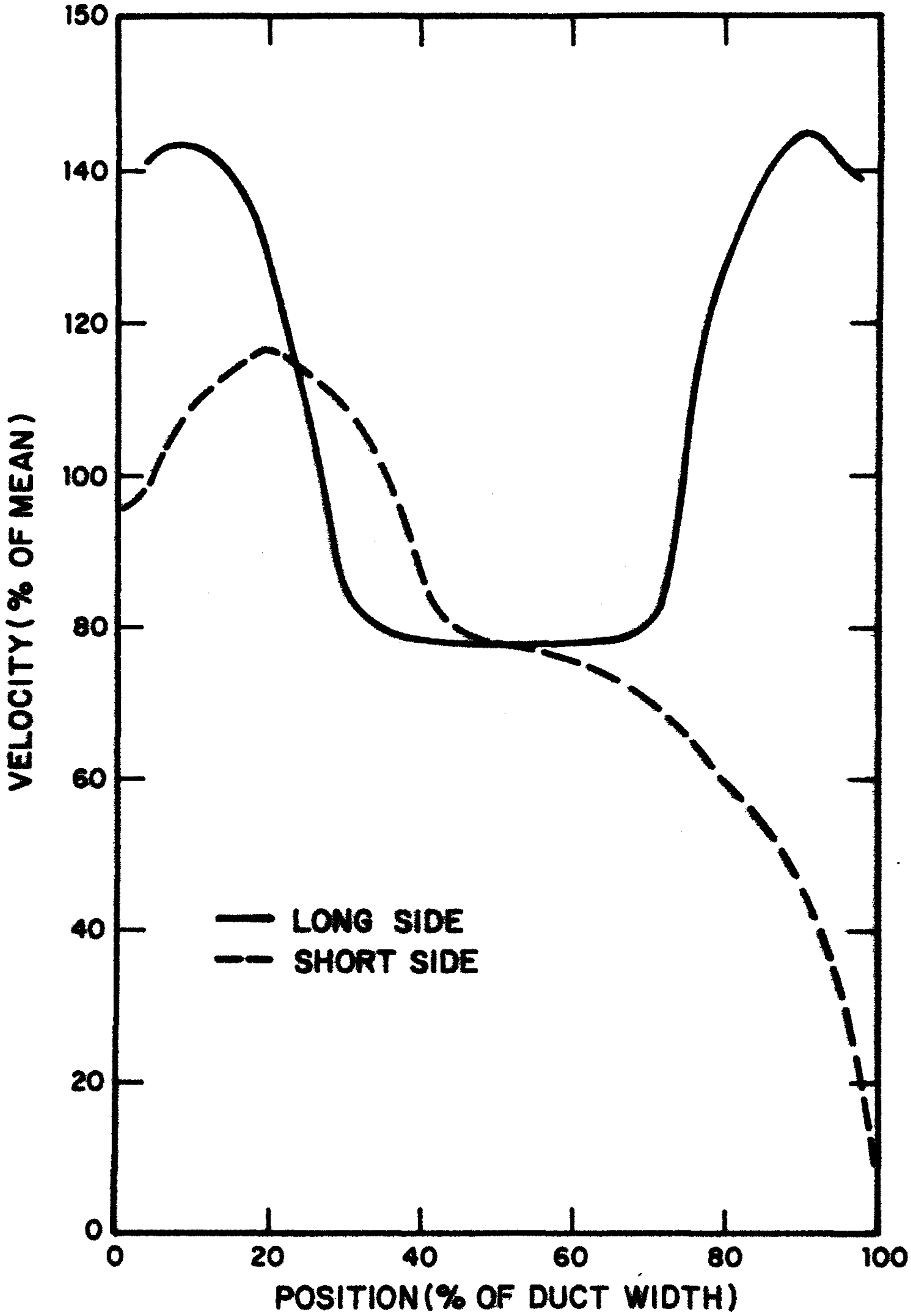


Figure 4. Velocity profile in stack (Brooks and Williams, 1976)

TABLE 2. WEIGHTING FUNCTIONS FOR CROSS-STACK OCV

λ = Mean wavelength of radiation employed (0.9 μm),
d = Distance between transmitter and reflector lenses

Position Across Stack (Distance From Lamp)	Grating Pitch		
	$2\sqrt{\lambda d}$	$4\sqrt{\lambda d}$	$6\sqrt{\lambda d}$
0	1.00	1.364	1.430
.05	1.00	1.312	1.368
.10	1.00	1.260	1.307
.15	1.00	1.213	1.250
.20	1.00	1.167	1.194
.25	1.00	1.125	1.143
.30	1.00	1.083	1.093
.35	1.00	1.045	1.050
.40	1.00	1.008	1.007
.45	1.00	.976	.969
.50	1.00	.945	.932
.55	1.00	.919	.903
.60	1.00	.893	.875
.65	1.00	.872	.851
.70	1.00	.852	.826
.75	1.00	.837	.780
.80	1.00	.823	.734
.85	1.00	.813	.755
.90	1.00	.804	.774
.95	1.00	.801	.771
1.00	1.00	.799	.767

TABLE 3. ERROR COMPARED WITH LINE AVERAGE

Grating Pitch	
5.5 mm	0.0%
11.0 mm	-0.3%
16.5 mm	-1.1%

SECTION 6

TESTS OF THE CROSS-STACK OCV IN THE STACK SIMULATOR

DESCRIPTION OF CROSS-STACK OCV

The arrangement of the cross-stack OCV is shown in Figure 5. The light source was a 100 watt Quartz-Halogen Lamp with integral dichroic reflector. The lamp was driven from a 12-Volt regulated supply. The light output was focused by the reflector into a 1 cm diameter spot. An aperture (initially a 280 micron slit and later a 2 mm pinhole) was placed at this focus. A frosted glass plate was placed over the slit in order to achieve uniform illumination. The transmitted light was collimated by a 10 cm diameter, 30 cm focal length lens. The collimated light then passes across the stack to a receiver. This receiver consists of a 10 cm diameter grating and 10 cm diameter by 16 cm focal length condenser lens. This focused the light onto a 1 cm diameter silicon photo-diode which generated the signal. The signal passed through a preamplifier to the correlation discriminator signal processor and an EMR real-time spectrum analyzer.

PRELIMINARY TESTS

The cross-stack OCV was set up in the Stationary Source Simulation Facility at EPA Research Triangle Park. The first aperture used for the source was a slit 12 mm long by 0.28 mm wide. Plenty of signal amplitude was obtained but it had a very noisy character. In fact, the signal-to-noise ratio improved when the slit was misaligned by about 10° with the grating. Accordingly a 2 mm pinhole was substituted and found to give much better results. Three gratings were employed with 2.5, 5, and 7.5 mm pitch. The 5 mm worked somewhat better than the 7.5 mm grating. The 2.5 mm grating worked almost as well when a 1 mm pinhole was substituted for the 2 mm pinhole. No large changes where noted with grating pitch, although signal frequency did vary directly. The 5 mm grating was used for all subsequent tests.

EVALUATION TESTS

The stack OCV was operated under the seven test conditions detailed in Table 4 and its performance compared with a pitot tube. Readings were taken over a speed range of 6 - 22 m/sec. No data could be obtained in clean air at room temperature since the OCV did not generate any signal. However, a signal was obtained from dusty air at room temperature. No reading could be obtained either from Run 2 (10% by volume of water) since condensation occurred on the surface of the cooler lenses. Data from the six successful runs are shown in Figures 6 — 11.

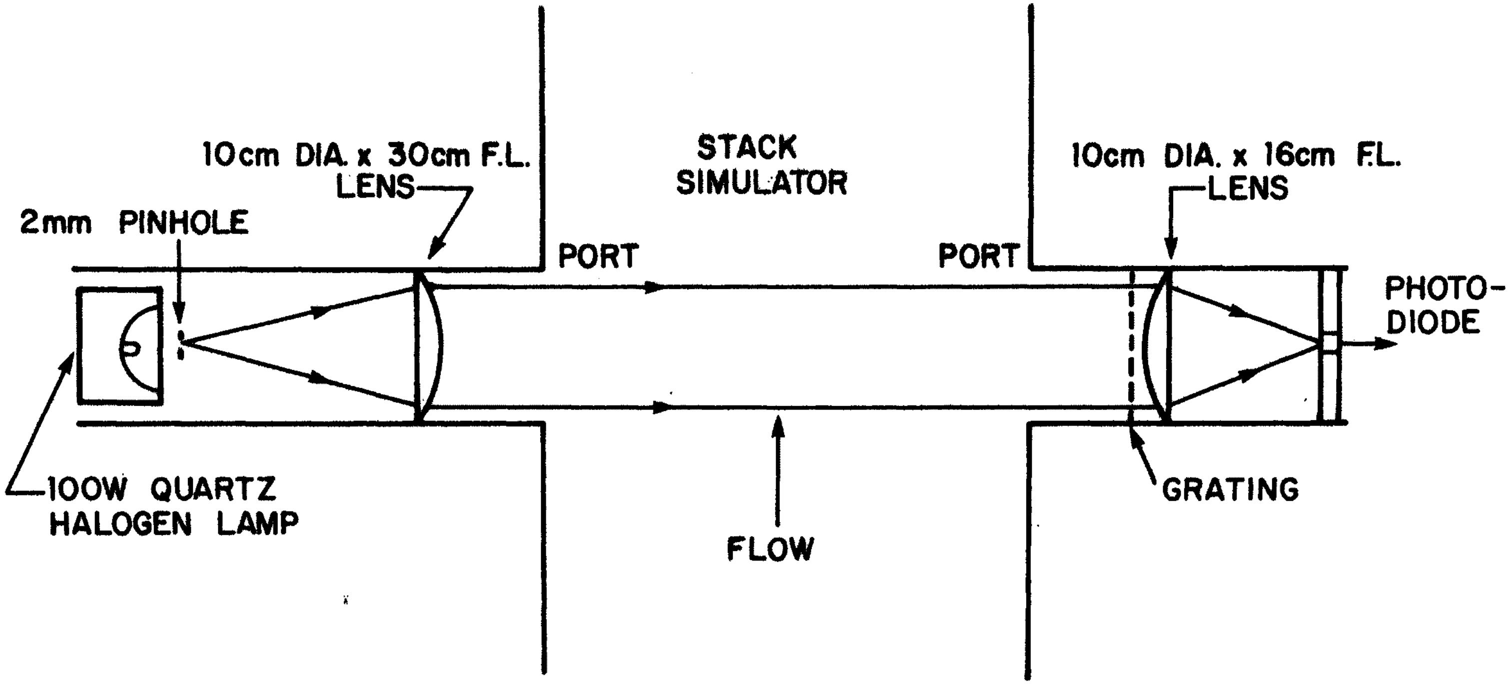


Figure 5. Schematic of cross stack OCV

TABLE 4. TEST CONDITIONS FOR CROSS STACK OCV

Run No.	Temperature	% of Water	Dust Loading
1	93°C	0	0
2	120°C	10	0
3	150°C	0	0
4	150°C	0	5 kg/hr
5	204°C	0	0
6	120°C	6	0
7	27°C	Ambient	2.5 kg/hr

For the signal analysis both the correlation discriminator and a spectrum analyzer were used. However, due to the characteristics of the signal (noise spectrum was not white) sigificant discrepancies developed between the two processors. Accordingly the spectrum analyzer data has been used in these figures. No substantial or systematic discrepancies have been found between the OCV and the pitot tube. The root mean square error for all data points is 1.3% of reading.

Good agreement has been found between the cross-stack OCV and a pitot tube over a wide range of flow and environmental conditions. However some "cleaning up" of the OCV signal is required before the correlation discriminator can be used as a reliable processor.

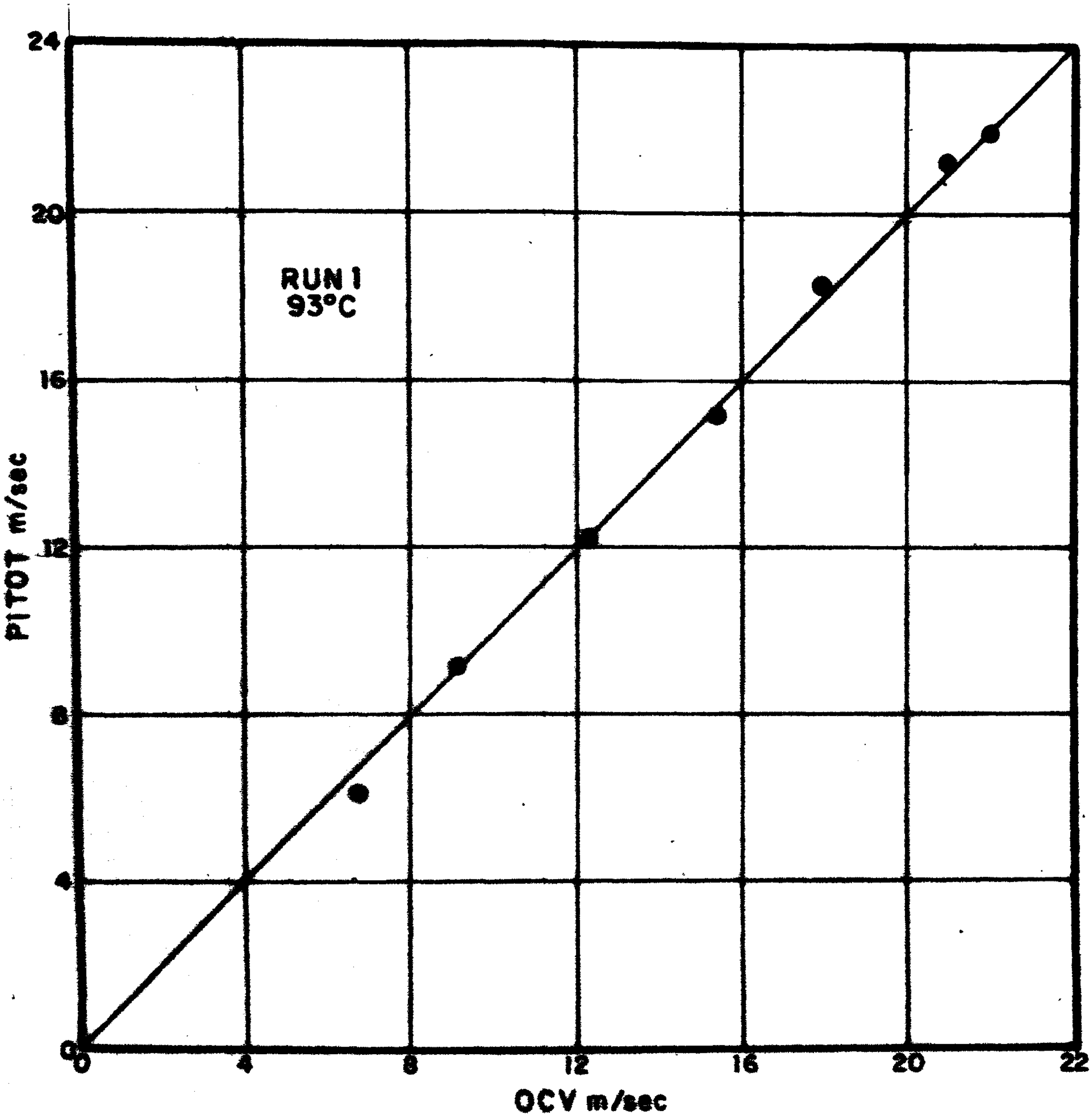


Figure 6. Comparison of OCV and pitot tube at 93°C (RMS error = 1.0%)

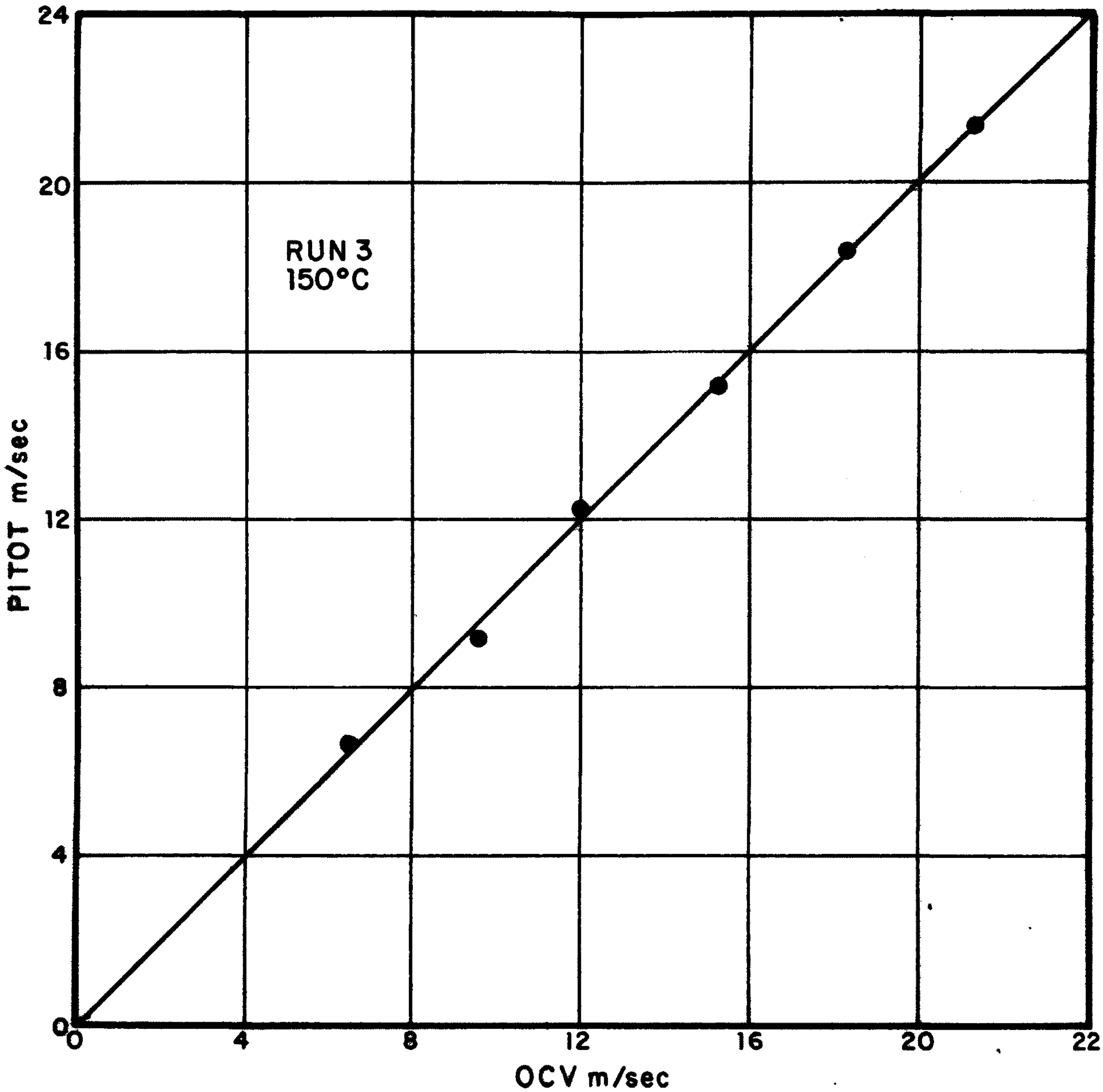


Figure 7. Comparison of OCV and pitot tube at 150°C (RMS error = 0.9%)

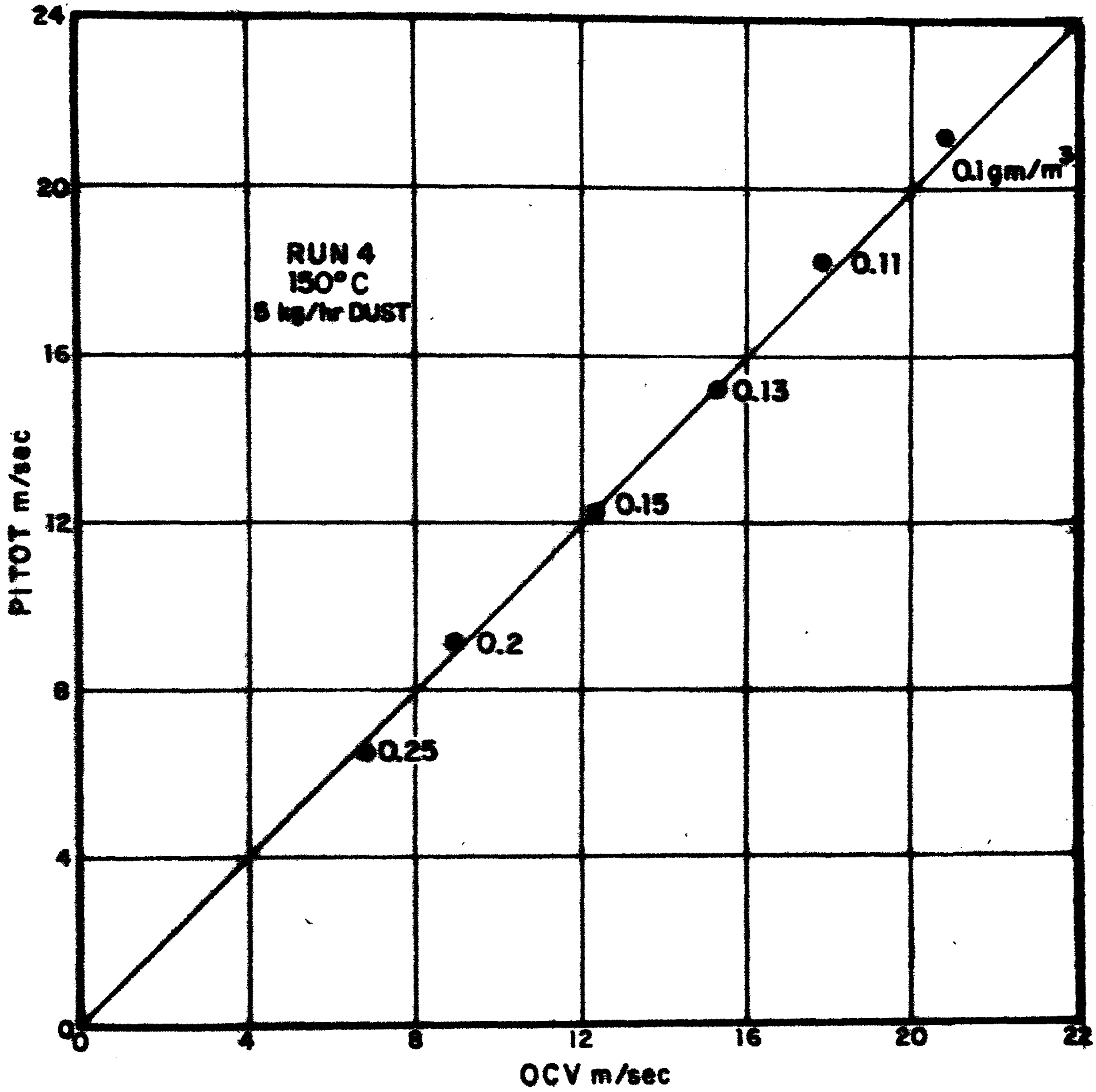


Figure 8. Comparison of OCV and pitot tube at 150°C and 5 kg/hr of dust (RMS error = 1.8%).

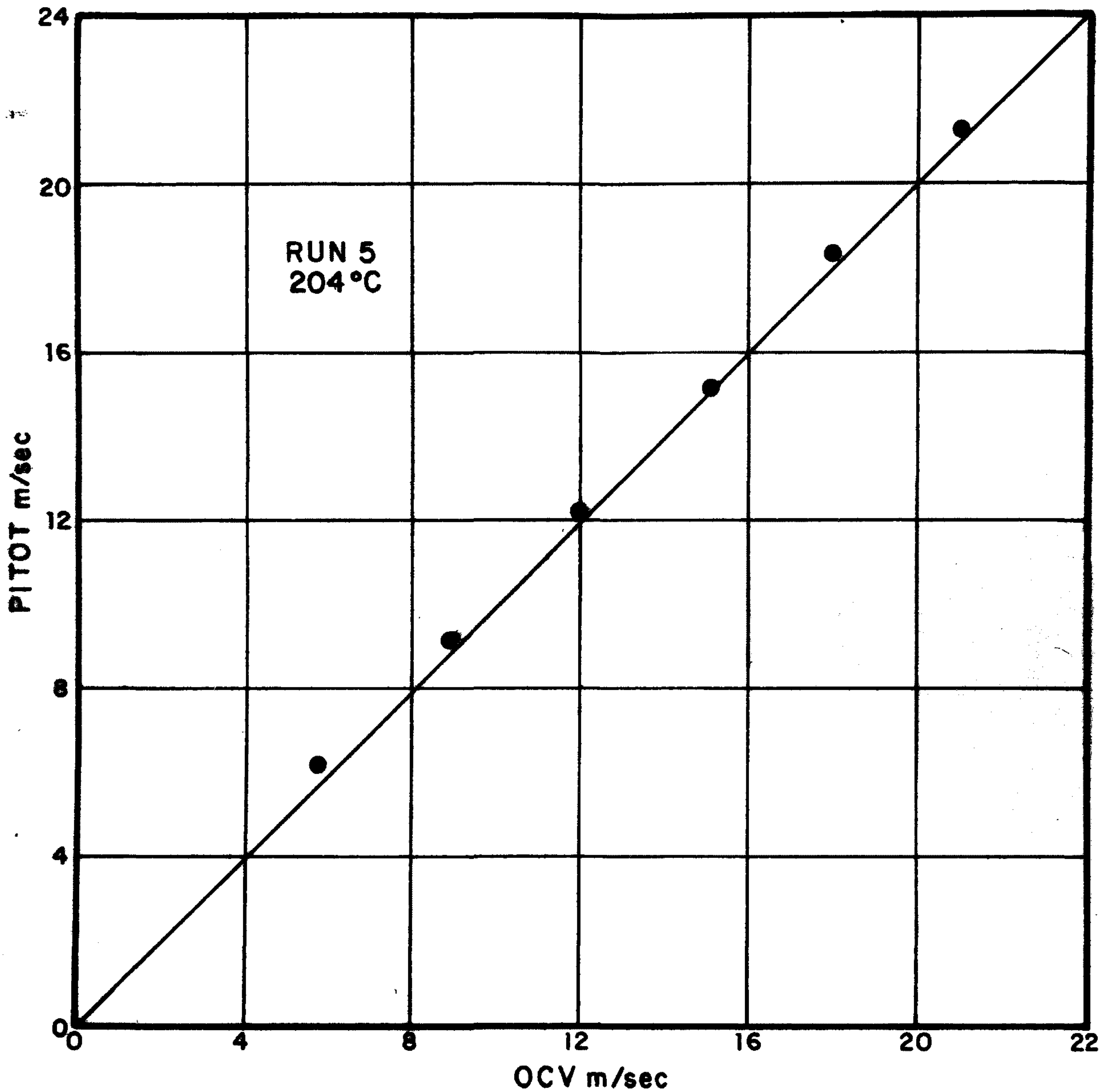


Figure 9. Comparison of OCV and pitot tube at 204°C (RMS error = 1.6%).

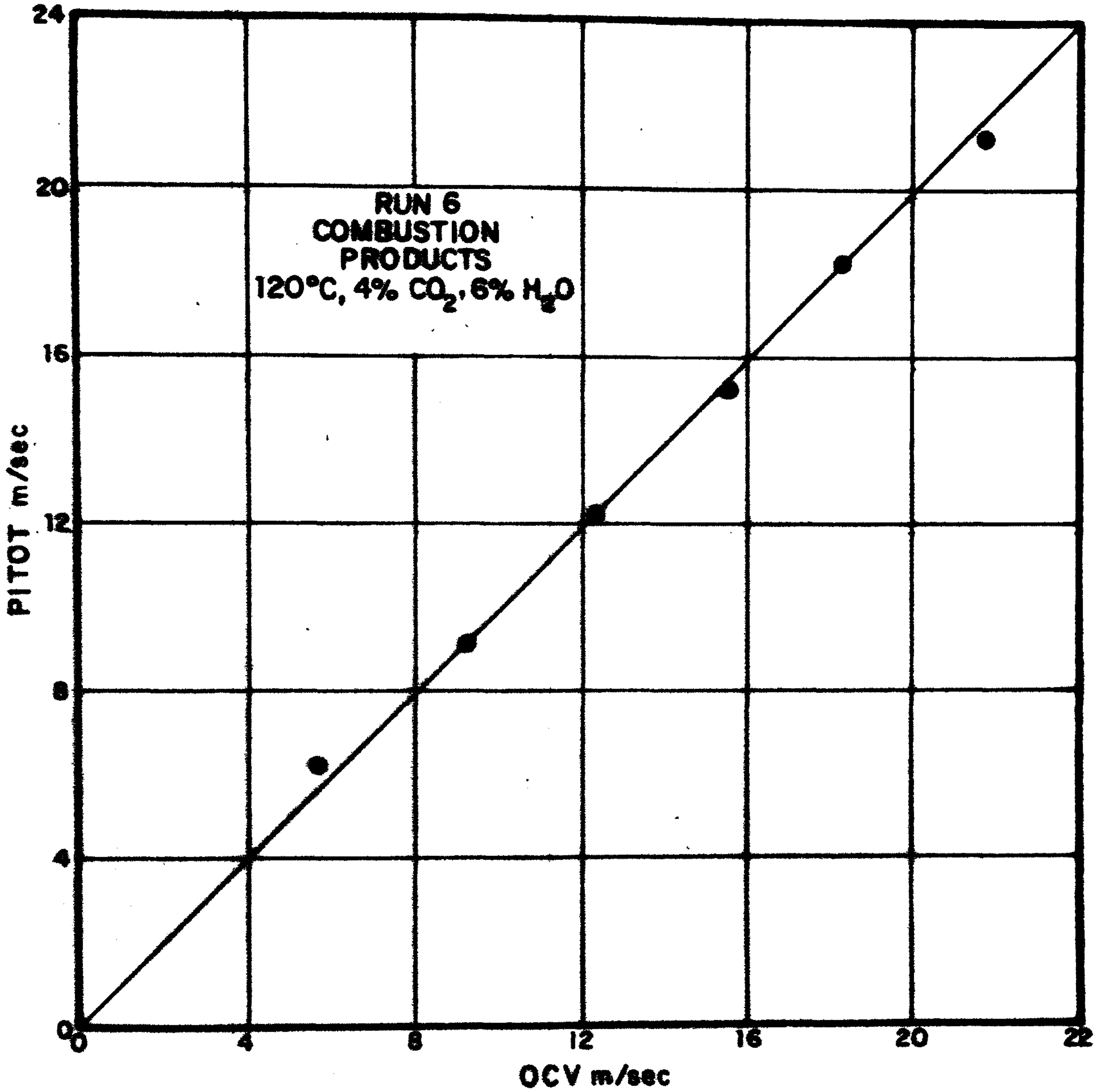


Figure 10. Comparison of OCV and pitot tube in the presence of combustion products (RMS error = 1.4%).

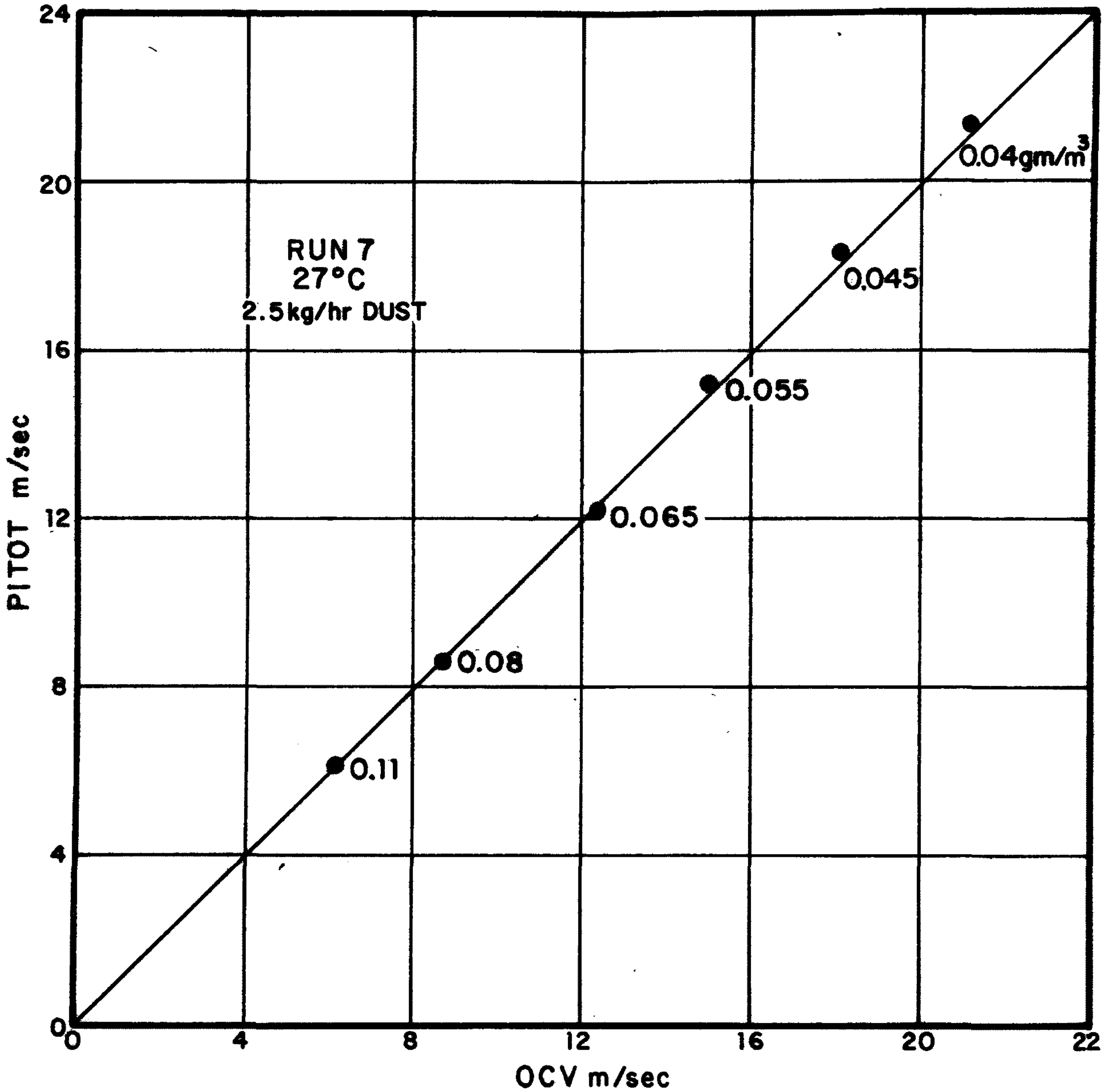


Figure 11. Comparison of OCV and pitot tube with a dust loading of 2.5 kg/hr (RMS error = 0.9%).

APPENDIX A

CALIBRATION OF POINT OCV AGAINST A LASER DOPPLER VELOCIMETER

INTRODUCTION

The point OCV has previously been calibrated against a pitot tube with reasonable success.* It was now desired to check the OCV against a more absolute type of velocimeter. Such an instrument is the Laser Doppler Velocimeter. This projects a fringe pattern, generated by a laser and of well defined size, into the flow and "watches" small dust particles cross this fringe pattern. The light scattered by these particles is collected by a photomultiplier, amplified and its frequency measured. This frequency is uniquely related to the flow velocity. The particular instrument which was used employed a Helium Cadmium Laser and had a factor of 39.5 kHz/meter per second. A high speed version of the correlation discriminator was used to measure the signal frequency.

CALIBRATION TESTS

The OCV was compared with the LDV over a wide range of environmental conditions. These are detailed in Table A-1. The data are displayed in Figures A-1 — A-3.

TABLE A.1. TEST CONDITIONS FOR POINT OCV CALIBRATION

Run No.	Temperature	% of Water	Dust Loading	RMS Error
8	27°C	0	Light	5.8%
9	27°C	0	Moderate	0.9%
10	120°C	0	Light	4.7%
11	120°C	10	Light	6.4%
12	170°C	0	Light	8.5%

*M.J. Rudd, "Development of an Optical Convolution Velocimeter for Measuring Stack Flow," Submitted to Emissions Measurement and Characterization Div., Research Triangle Park, NC.

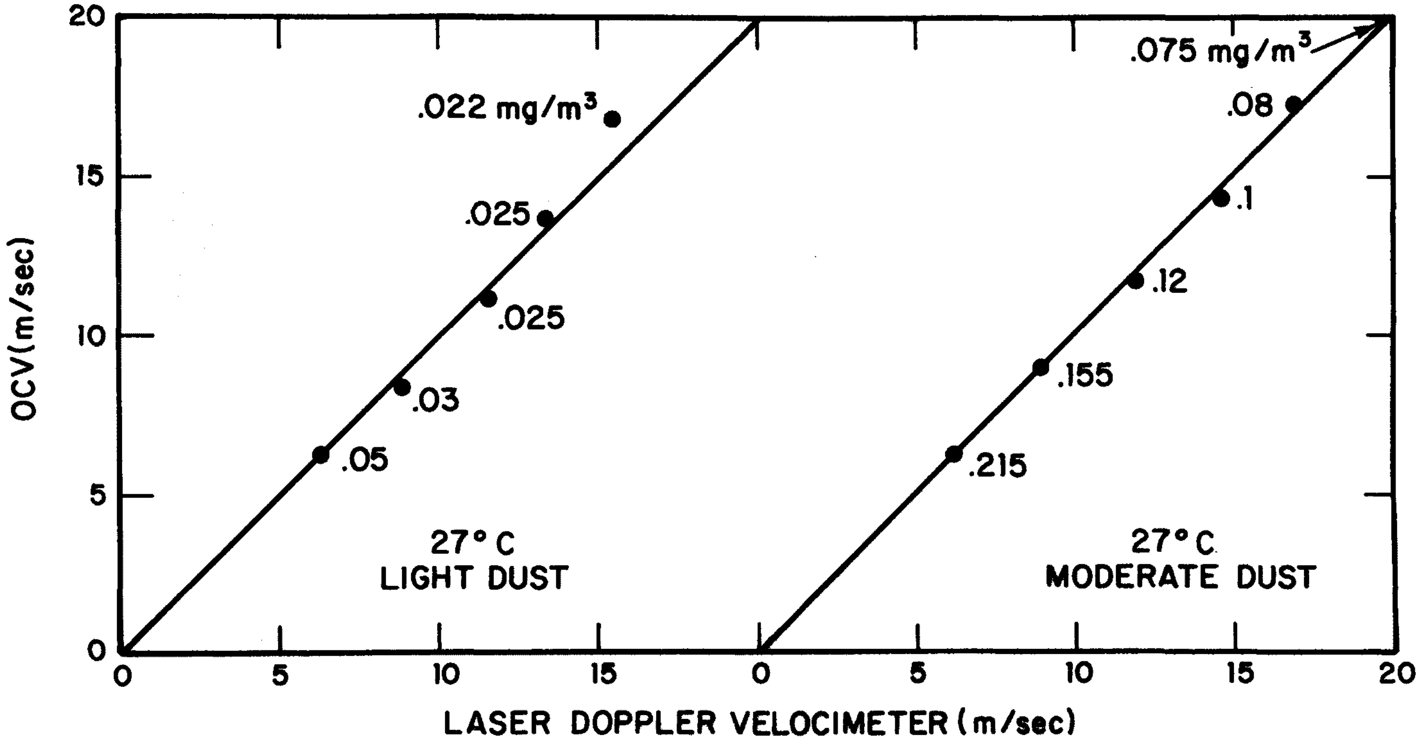


Figure A-1. Point OCV calibration

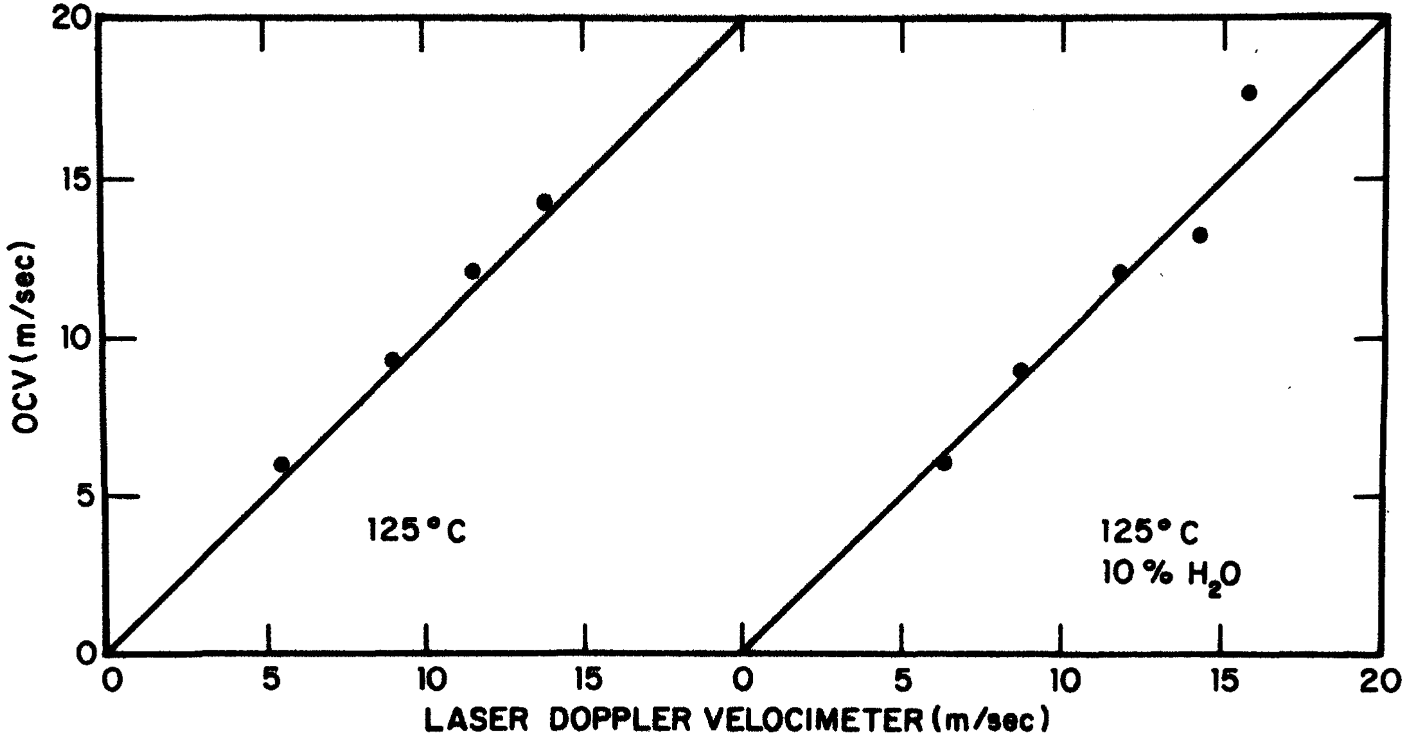


Figure A-2. Point OCV calibration

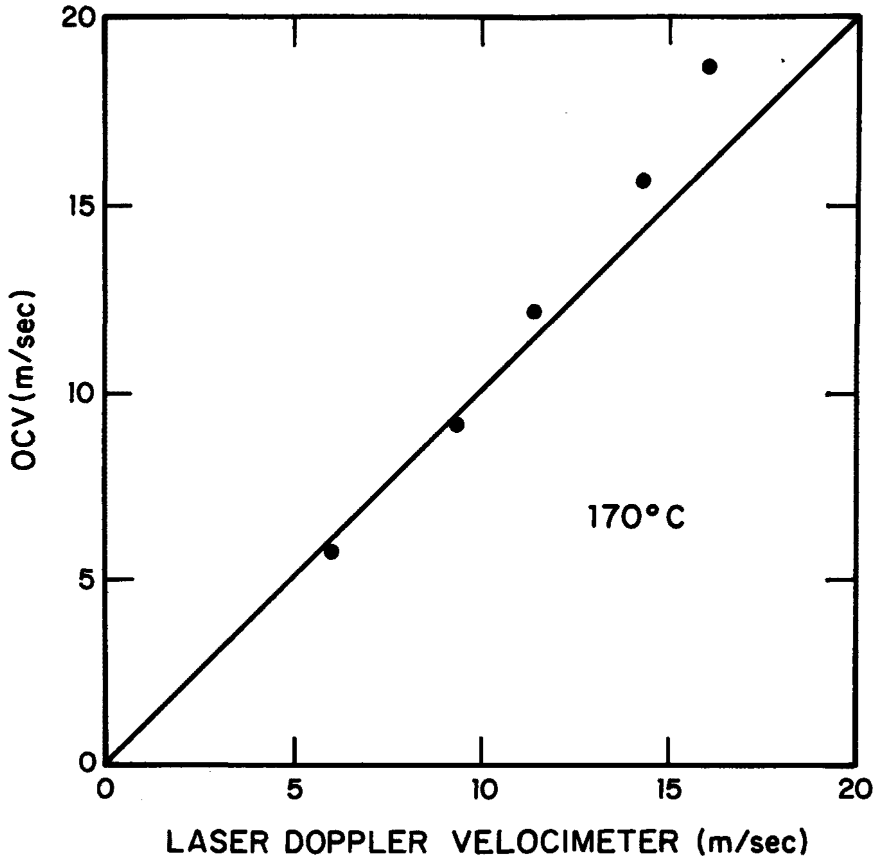


Figure A 3. Point OCV calibration

CONCLUSIONS

The calibration of the OCV probe against the Laser Doppler Velocimeter system was unsatisfactory and no definite conclusions may be drawn.

The RMS error in this data is much larger than when the OCV was compared with a pitot tube previously. This can only be attributed to the unsatisfactory operation of the LDV system. No prefiltering was employed before the LDV signal was fed into the correlation discriminator. This led to large amounts of low frequency noise being admitted and may be the cause of the LDV reading low, particularly at higher speeds.

APPENDIX B

DRAWINGS OF PROPOSED DESIGN FOR A CROSS-STACK OPTICAL CONVOLUTION VELOCIMETER

Attached on the following pages are drawings for a design for a prototype cross-stack OCV. This consists of two housings - a transmitter/receiver (Figure B-1) and a retroreflector (Figure B-2). The light source is a tungsten halogen lamp powered by a 100 watt regulated supply. The light is collimated by a 82 mm dia by 300 mm focal length lens, and projected across the stack. The return beam is separated by a beam splitter, passes through a grating and falls on a photodiode. The signal is amplified and its frequency detected by two circuit boards. The retroreflector is of a cats-eye design, an achromat lens with a mirror at its focus. This minimizes the sensitivity to angular alignment.

The exposed sides of the lenses are protected by air curtains. This consists of air blown into a sleeve around the lens and then ejected around its perimeter. This prevents dust and condensation from settling on the lens surfaces.

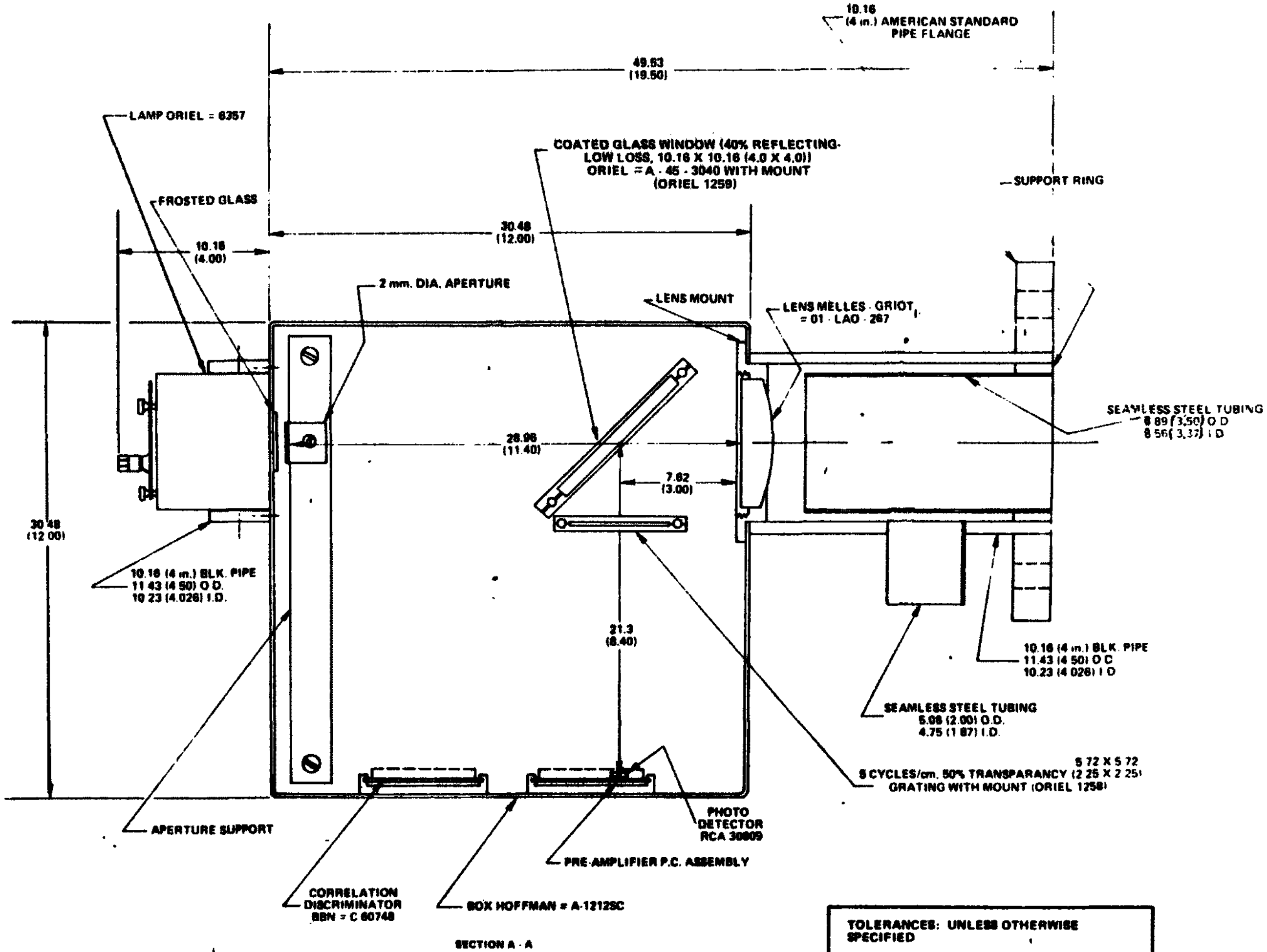
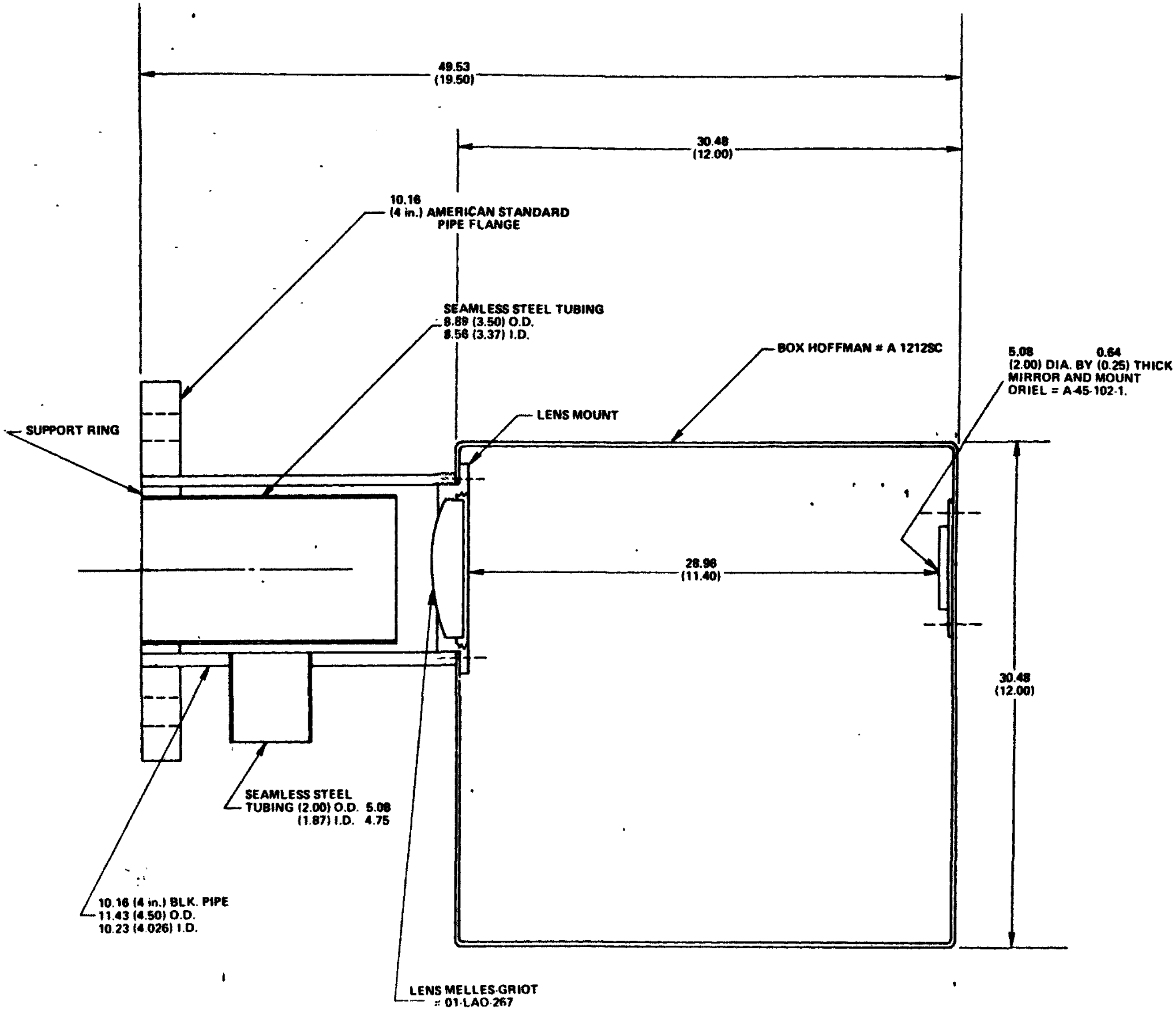


Figure B-1. Transmitter/receiver

TOLERANCES: UNLESS OTHERWISE SPECIFIED			
		ENGLISH	METRIC
DECIMAL:	.XX	(± 0.010)	0.025
	.XXX	(± 0.005)	0.013
FRACTIONS		± 1/64	
ANGLES		± 1°	



NOTES:

1 AIR SUPPLY (50 cfm) 28.3 liters/min.
PRESSURE STACK + (6" H_2O)
+ 15.2 cm H_2O

Figure B-2. Retroreflector

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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16. ABSTRACT

A new type of instrument has been designed and evaluated for the measurement of a line average of a stack gas velocity. The light output from a lamp is collimated and projected across the stack. A shadowgraph image of the turbulence in the stack is produced on the far side and this image is convected by the stack gas flow. A grating is placed over the image and the light transmitted falls on a photodetector. The frequency output from the photodetector is the rate at which the shadow graph image crosses the grating.

A breadboard design of this cross-stack optical convolution velocimeter (OCV), as it is called, was built and evaluated in the EPA Stationary Source Simulation Facility over a wide range of environmental conditions. Agreement between the OCV and a corrected pitot tube was within 1.3% (root mean square error). Position sensitivity of the OCV was extensively studied and a configuration was found that is completely insensitive to position. Laboratory tests showed that the cross-stack OCV is an effective, accurate velocity monitoring instrument that is simple to build and operate

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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