



Optical Scientific Inc.

**Calibration of Optical Flow Sensor (OFS)**

**Using NIST Traceable Data**

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## 1. NIST Wind Tunnel Test Set-up

Optical Scientific Inc. (OSi) submitted an Optical Flow Sensor (OFS) to the National Institute of Standards and Technology (NIST) for wind tunnel testing. The test and calibration of the OFS was performed in the 1.5-m by 2.1-m rectangular test section of the NIST Dual Test Section Wind Tunnel. In this tunnel, the air speed is measured by NIST Standard sensors.

The test was conducted at a location 7-m downstream from the entrance area of the wind tunnel test section. During the test, the air stagnation temperature, stagnation pressure and the relative humidity were measured in the tunnel settling-chamber. The air temperature, barometric pressure, and relative humidity were measured at the location where the NIST standard was positioned.

To determine the reproducibility of the OFS under test, two calibration cycles were done separated by a tunnel shutdown. During each calibration cycle, each air speed was measured five times to ascertain the repeatability of the OFS under test.

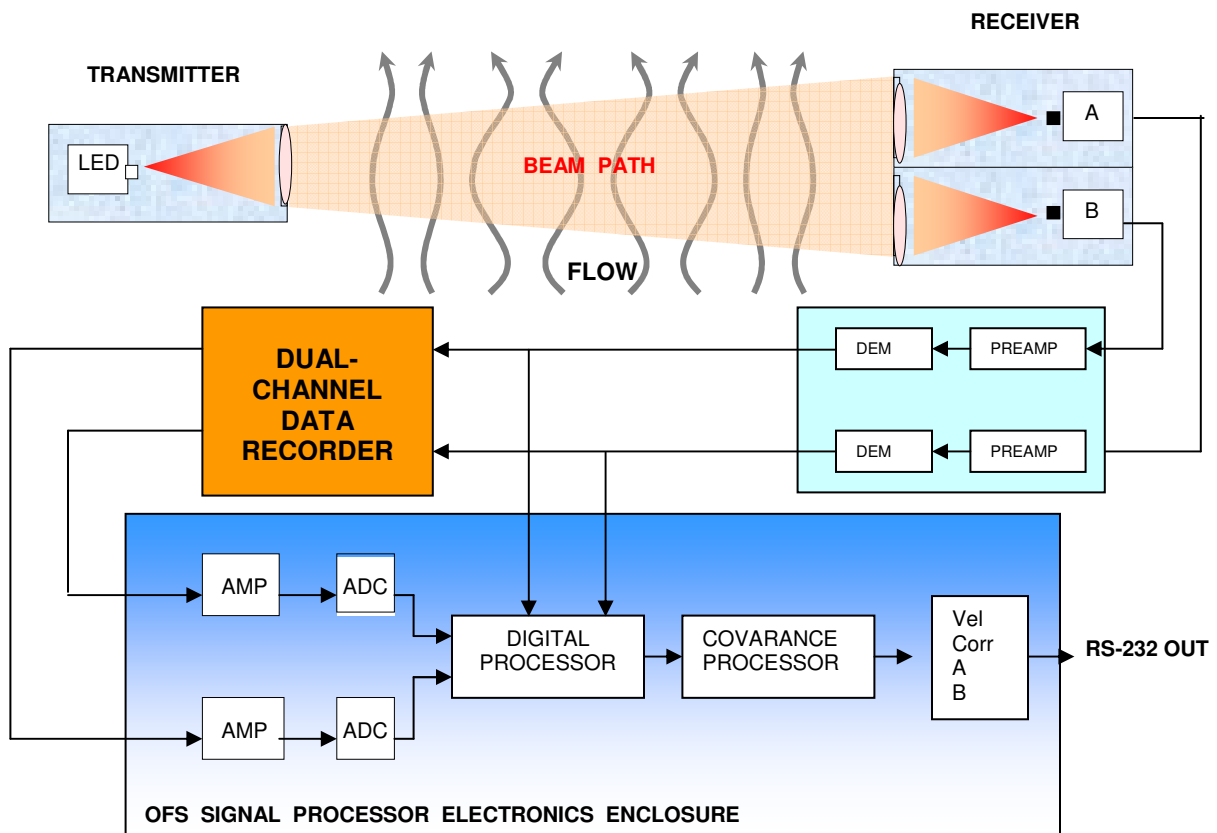


**Figure 1.** OSi's Optical Flow Sensor Receiver Heads (top view) as installed in the NIST Wind Tunnel.

## 2. NIST Wind Tunnel Test Results

As shown in Figure 1, the OFS was placed outside the tunnel. The light beam is perpendicular to the flow and roughly 4-m apart from transmitter to receiver. The width of the tunnel at this location is 2.1-m. The transmitter emitted a visible beam of light which entered the Dual Test-section Wind Tunnel through one of its Plexiglas windows. The NIST standard was placed in the tunnel nearby the sensing area of the OFS under test. Temperature and humidity sensors were placed in the area where the NIST standard made its measurements. These parameters were used to calculate the air velocity at this position.

The OFS uses optical scintillation to measure the flow rate by temporal correlation – the time-difference between optical scintillation signals detected by the two detectors aligned parallel to the flow direction. The method is non-intrusive and measures the average flow across an optical path. The OFS is designed to make measurements in turbulent airflow. The OFS measured flow rate is independent of the temperature, pressure, relative humidity and the opacity of the flowing media. Therefore, no correction is needed to the measurements of OFS.



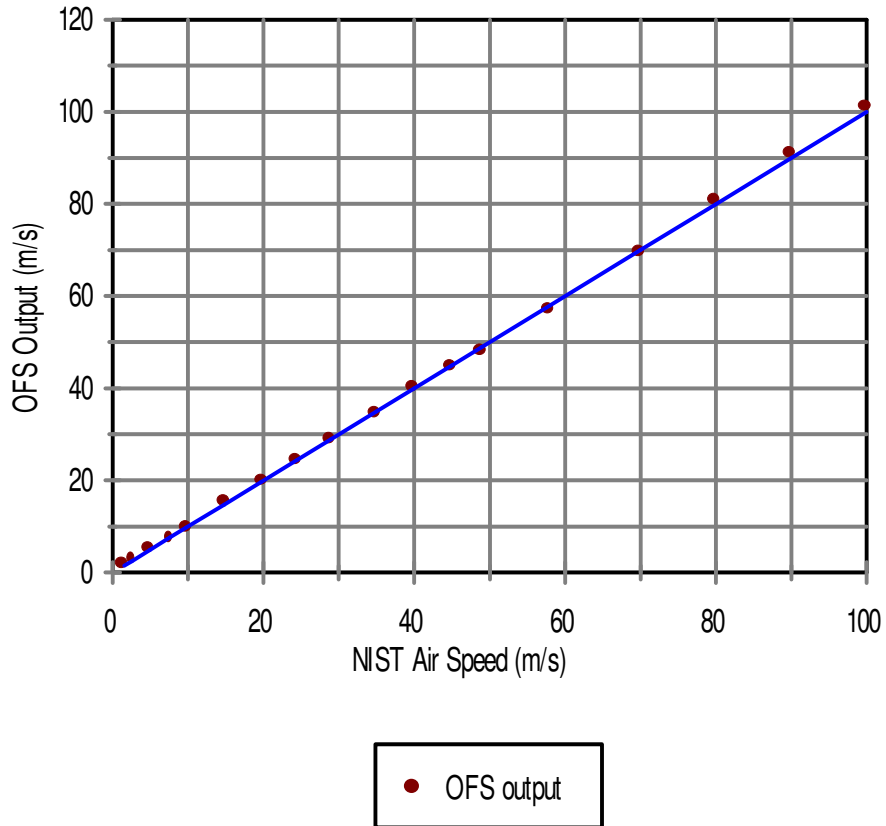
**Figure 2.** NIST Wind Tunnel Test Block Diagram

During the test, the raw signals detected by the two optical receivers were recorded on a dual-channel data recorder (see Figure 2) for different wind tunnel air velocities. These data are used as the laboratory reference OFS calibration standard. Table 1 shows that the reproducibility uncertainty of OFS. Throughout the range from 1.59 m/s to 100 m/s, the standard deviation of the reproducibility uncertainty is 1.05%. A smaller reproducibility uncertainty indicates a better repeatability of the OFS sensor. The results clearly indicate that OFS is a reliable sensor with very repeatable measurement performance. It should also be noted that the reproducibility uncertainty included not only the uncertainty of the OFS measurements but also the uncertainty of the NIST standards! Each value of air speed represents the average of 10 readings. The standard deviation of the accuracy of OFS (after calibration) is 1.25% of that of the NIST standard. A scatter diagram of the air speed measured by the NIST standard and that of the OFS is shown in Figure 3.

**Table 1. OFS measured Air Speed vs. NIST Standard at NIST Wind Tunnel**

NIST Air Speed m/s	OFS Output m/s	OFS Accuracy m/s (%)
1.59	1.58	-0.01 (-0.56%)
2.58	2.61	0.03 (1.16%)
4.94	4.90	-0.04 (-0.84%)
7.59	7.69	0.10 (1.35%)
9.75	9.61	-0.14 (-1.44%)
14.80	15.03	0.23 (1.55%)
19.70	20.07	0.37 (1.88%)
24.50	23.96	-0.54 (-2.20%)
29.00	28.42	-0.58 (-2.00%)
35.00	34.53	-0.47 (-1.34%)
40.00	40.35	0.35 (0.88%)
45.00	44.75	0.25 (0.56%)
49.00	48.30	-0.70 (-1.43%)
58.00	57.22	-0.78 (-1.34%)
70.00	69.58	-0.42 (-0.60%)
80.00	80.47	0.47 (0.59%)
90.00	90.57	-0.57 (-0.63%)
100.00	101.10	1.10 (1.10%)

## OFS Test Result



**Figure**

**3.**

OFS Measured Air Speed vs. NIST Standard at NIST Wind Tunnel.

### 3. Using NIST Data for Factory or On-site Calibration Verification

During the NIST Wind Tunnel test, the raw signals detected by the two optical receivers were recorded on a dual-channel data recorder (see Figure 2) for different wind tunnel air velocities (see Table 1). These data will be used as the reference standards for OFS factory or on-site calibration verification.

Two separate procedures will be applied to test the performance of the OFS sensor, i.e.,

Check the optics system.

Test the performance of the electronics algorithm.

In normal operation mode, a screen is displayed in the front panel of the OFS as follows:

Vel	Corr	A	5.32
45.0 fps	247	B	4.98

where Vel is the measured velocity, Corr is the correlation coefficient. Correlation coefficient is an indicator of the quality of the measurement. The higher the correlation, the more reliable of the measured velocity. Usually a quantity of 50 represents a sufficient correlation for a reliable measurement. For any correlation coefficient higher than 100, it indicates an excellent measurement. The numbers after A and B indicate the signal strength by the two detectors respectively. A stronger light intensity will give a higher number of A or B. However, a higher number does not mean that the performance is better. As long as both A and B are in the preset range (usually between 0.5 to 8.0), OFS will operate normally. After the unit is installed for the first time and properly aligned (see details in the OFS operational manual), the value of A and B should be recorded for future reference. During normal operation, the velocity and the correlation will constantly change due to the change of the flow characteristic. However, the values of A and B should not change much. They will gradually change as the optical windows get dirty. The change of the light intensities of the two detectors will not deteriorate the performance of OFS, because the OFS incorporates a sophisticated gain control technique to automatically compensate the slow drift of the light intensities.

#### 3.1 Check the optics system

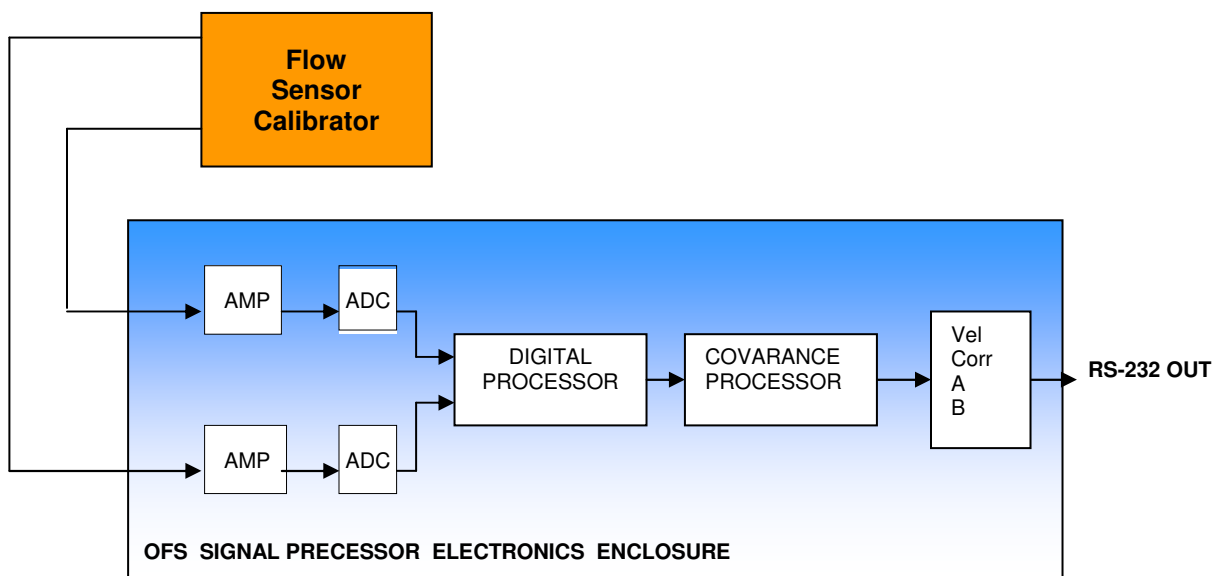
The OFS uses optical scintillation to measure the flow rate by temporal correlation – the time-difference between optical scintillation signals detected by the two detectors aligned parallel to the flow direction. The OFS measured flow rate is independent of the temperature, pressure, relative humidity, and the opacity of the flowing media. Therefore the signal strength of the two detectors is not a factor of the velocity measurement. As long as both signals are in the preset range, the OFS will operate normally.

To check the condition of the optics, note the current values of A and B on the display screen. If the values have dropped significantly from the values recorded when the unit was first installed, the optics needs to be cleaned. After cleaning the optics, if the values are still too low,

realignment of the optical beam may be required. After these procedures, if the values of A and B are within 30% of the original records, the optical system is working normally.

### 3.2 Test the performance of the electronics algorithm

The critical test of the OFS is to make sure the measurements are traceable back to the NIST Wind Tunnel standards. To achieve this traceability, the raw signals of the two optical detectors have been recorded in a dual-channel data recorder for each NIST wind velocity standard and are played back for factory or on-site OFS system calibration verification (see Figure 4).



**Figure 4.** Using NIST Data for Factory or On-site Calibration Verification.

The upper range of the OFS-2000F velocity measurement is 100 m/s (328 fps). The closest NIST standards (see Table 1) of 30%, 60%, and 90% are 29.00 m/s (95.14 fps), 58.00 m/s (190.29 fps), and 90.00 m/s (295.28 fps) respectively. These data have been recorded in the OSi Flow Sensor Calibrator as standards #1, #2, and #3 respectively. These standard data are played back through the OFS and the results recorded. The reprocessed measurements must be within +/- 5% of the NIST standards (see Table 2). Otherwise, the unit is suspect and should be sent back to OSi's factory for further diagnostics. A detailed procedure for performing this OFS verification follows.

**Table 2. OFS Calibration Accuracy Requirement**

Test Data Standards	NIST Standard	OFS Output Range	OFS Accuracy
#1	29.00 m/s 95.14 fps	27.55 – 30.45 m/s 90.39 – 99.90 fps	+/-1.45 m/s (+/-5.00%) +/-4.76 fps (+/-5.00%)
#2	58.00 m/s 190.29 fps	55.10 – 60.90 m/s 180.77 – 199.80 fps	+/-2.90 m/s (+/-5.00%) +/-9.51 fps (+/-5.00%)
#3	90.00 m/s 295.28 fps	85.50 – 94.50 m/s 280.51 – 310.04 fps	+/-4.50 m/s (+/-5.00%) +/-14.76 fps (+/-5.00%)

For on-site system verification, a step-by-step instruction is as follows:

1. Disconnect the optical head cable connector from the OFS signal processor electronic enclosure.
2. Connect the OSi provided Flow Sensor Calibrator to the OFS electronic enclosure as shown in Figure 4.
3. Set the OFS time constant to 10 seconds (see details in OFS operational manual).
4. Play back each standard data set (#1, #2, and #3) for the full duration (about 10 minutes each set) into the OFS electronics enclosure. The reference data will be reprocessed to obtain the specified velocity measurements.
5. Record the stabilized velocity data for each standard.
6. Disconnect the Flow Sensor Calibrator and plug in the head cable connector.
7. Reset the OFS time constant to its desired value for normal operation.

The whole process will last about an hour. With both the optics and electronic processor checked satisfactorily, the end-user can be confident of the health and performance of the OFS. OSi recommends that the users with critical flow measurement requirements perform this calibration check on an annual basis.