THRUST COMPARISON OF CONVENTIONAL JET FANS AND FANS WITH SHAPED SILENCERS IN AN ITALIAN ROAD TUNNEL BASED ON IN-SITU MEASUREMENTS

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ABSTRACT

This paper presents the results of an extensive in-situ measurement campaign aimed at quantifying the performance of conventional jet fans and using fans with shaped silencers. The tests were conducted at the Verta Tunnel, an existing 3.5 km long road tunnel with an arched cross-section operated by the Italian road authority (ANAS).

A detailed velocity grid measurement was undertaken within the tunnel, capturing the airflow profile across the entire cross-section. This measurement allowed for an evaluation of the flow distribution resulting from fan operation, as well as a calculation of the effective thrust generated by the two different jet fan types. Additional parameters, such as pressure differentials, were recorded at strategic locations to support the overall analysis.

The results demonstrate differences in thrust and flow development between conventional jet fans and those with shaped silencers. The findings not only provide insight into the in-tunnel thrust of each jet fan type, but also highlight the impact of tunnel geometry and installation layout on the actual ventilation performance.

Keywords: Jet fans, thrust, installation factor, aerodynamics

1. INTRODUCTION

Due to its versatility and modest construction cost implications, longitudinal ventilation using jet fans is an increasingly popular option for ventilating tunnels worldwide. Indeed, the use of jet fans has been the de-facto standard for the ventilation of Italian road tunnels for several decades. Despite their widespread use, jet fans are generally inefficient at producing airflow in tunnels because of aerodynamic friction with tunnel surfaces. It has been estimated that typical jet fan installations waste over half the supplied electrical power [Ref. 1]. On that basis, there has been significant interest in improving the efficiency of jet fan installations, in order to present a more sustainable and cost-effective solution to the issue of longitudinal tunnel ventilation [Ref. 2]. One of these methods is the use of shaped silencers attached to the fans, designed to deflect the jets away from the tunnel soffit and thereby enhancing the in-tunnel thrust [Refs. 3, 4]. This is the method that was considered in our measurement campaign, in which we compared back-to-back measurements using conventional jet fans and fans with shaped silencers.

2. TEST ARRANGEMENTS

2.1. Verta Tunnel

The Verta Tunnel, managed by ANAS, is a two-lane, 3.5 km long tunnel in the municipality of Omegna, within the Italian region of Piedmont. A cross-sectional view of the tunnel, showing one bank of jet fans, is provided in **Figure 1**.

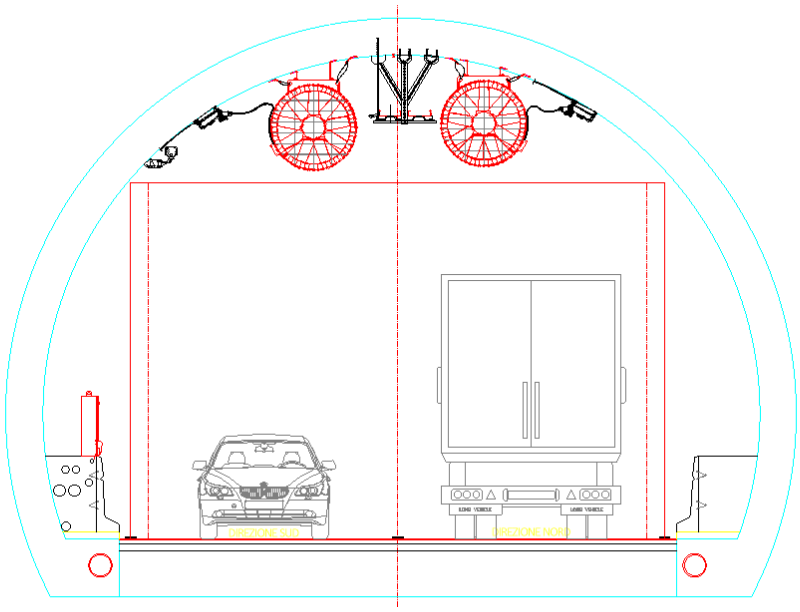


Figure 1: Cross-section of Verta Tunnel, showing jet fan installations

The Verta tunnel is equipped with 10 pairs of jet fans, each pair installed as a bank of fans. 5 pairs of jet fans are installed close to the north portal and a further 5 pairs of jet fans are located near the south portal. The first bank of jet fans is located 100m from each portal, and subsequent banks of fans are separated by 100m.

Our tests involved operating fans from the first four banks of fans closest to the north portal – the first two banks of fans installed with shaped silencers, and subsequent two banks of fans installed with conventional silencers.

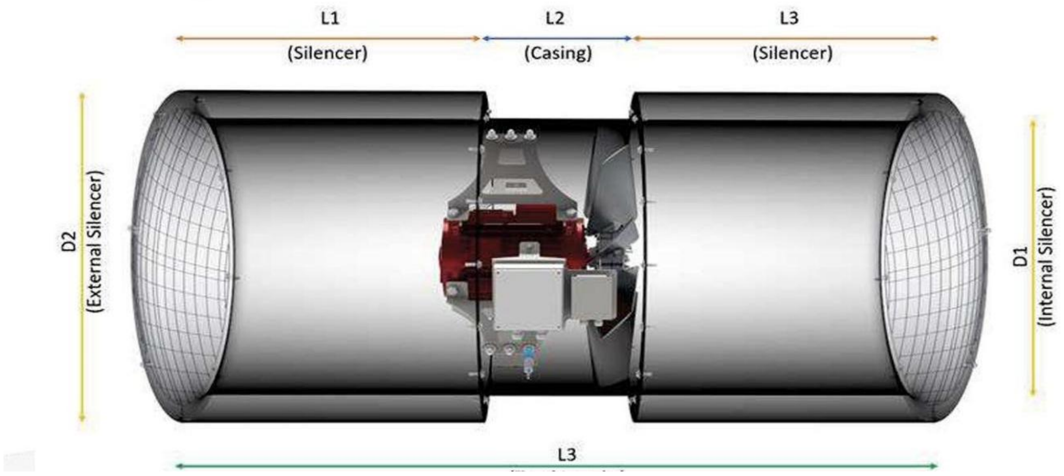
During the test, an operator located inside the electrical substation alternately operated either the two banks (four jet fans) with shaped silencers, or the two banks (four jet fans) with conventional silencers. The data was saved on a tablet that communicated with the anemometers via Bluetooth.

2.2. Jet Fans

All jet fans used in this test had the following specifications:

- Reversible fan operation
- Volumetric flowrate: 24.3 m^3/s
- Discharge velocity: 30.9 m/s
- Bench thrust: 900 N
- Rotational speed: 1480 rpm
- Absorbed power: 26 kW
- Sound pressure: 71±3 dB(A) (measured 10 m away, at a 45° angle from the fan axis)

There were no differences between the bench thrust, absorbed power or sound pressure values for the fans equipped with conventional or shaped silencers (within the measurement tolerances defined in ISO 13350:2015). The deflection of the discharged jet was therefore achieved by the shaped silencers without a reduction in thrust or an increase in power or noise, in contrast with deflection vanes which can cause a reduction in thrust and an increase in power and noise [Ref. 5]. The dimensions of the conventional jet fans are indicated in **Figure 2**. The lengths of the shaped silencers were the same as those of the conventional silencers. **Figure 3** shows a photograph of a bank of two jet fans, with shaped silencers.



L1 [mm]	L2 [mm]	L3 [mm]	D1 [mm]	D2 [mm]
1000	500	2500	1010	1210

Figure 2: Dimensions of Conventional Jet Fan

Figure 3: Bank of Jet Fans with Shaped Silencers

2.3. Measurement Locations

The longitudinal location chosen for the air velocity measurements was approximately 600 m from the north portal, and approximately 100 m after the second vehicular lay-by which is encountered on the left-hand side when traveling south through the tunnel. This section was located after the five pairs of fans in the vicinity of the north portal, and was sufficiently remote from the upstream fans and the lay-by to ensure a reasonably homogeneous flow profile.

The spatial distribution of measurement points across the tunnel cross-section was selected on the basis of EN ISO 5802_2008 +A1:2015. This standard requires that 36 measurement points be undertaken, with locations set in accordance with log-Tchebycheff rules. The area-averaged velocities were estimated on the basis of weighted coefficients defined in EN ISO 5802.

Figure 4 shows the locations of measurement points used in the tests.

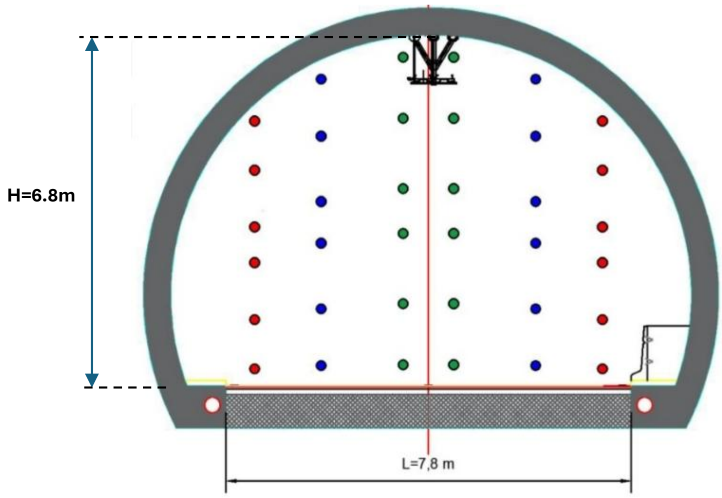


Figure 4: Velocity Measurement Locations

2.4. Measurement Equipment

The instruments used to measure air velocity were six Testo model 405i hot-wire anemometers and six Trotec model BA30WP hot-wire anemometers. The anemometers were securely fastened with hose clamps to two telescopic tripod supports at predetermined heights, which were set up during to the test preparation phase.

The six spanwise locations of the instruments were marked by chalk on the road surface, by measuring the required locations from the left-hand wall (when facing south). The vertical locations of the instruments were marked on the tripod supports.

Data acquisition was carried out with a tablet that recorded the measurements with a sampling interval of 5 seconds. Each set of measurements was undertaken for 120 seconds, after which the support was moved and the anemometers positioned at new locations.

To measure the differential pressure generated by a bank of jet fans, a Testo 400 universal instrument was used. The test consisted of placing a rubber tube across the fans, 50 m upstream and 50 m downstream of the bank (i.e. 100 m total chainage). The ends of the tube were inserted into the instrument, which detected the pressure difference at the two ends.

Figure 5 shows the tripod arrangements for the velocity and pressure measurements.

Figure 5: Tripod set-ups for velocity measurements (left) and pressure measurements (right)

3. MEASUREMENTS AND RESULTS

3.1. Test Campaign

The test campaign was carried out on 26/02/2025 and 11/06/2025. The campaign had the following objectives:

- Measure the tunnel friction factor using the rundown technique
- Measure air speed with 36 measurement points across the tunnel cross-section (as per **Figure 4**)
- Measure the installation factor of the fans using the pressure difference technique

3.2. External Wind Conditions

Wind speeds of up to 4 m/s and gust speeds of up to 5.6 m/s were measured at the north portal, as indicated in **Figure 6**. Estimates of the jet fan installation factor (as estimated by the technique described in section 3.5) are reasonably independent of meteorological conditions. The primary wind direction was towards the north, i.e. against the mechanical ventilation.

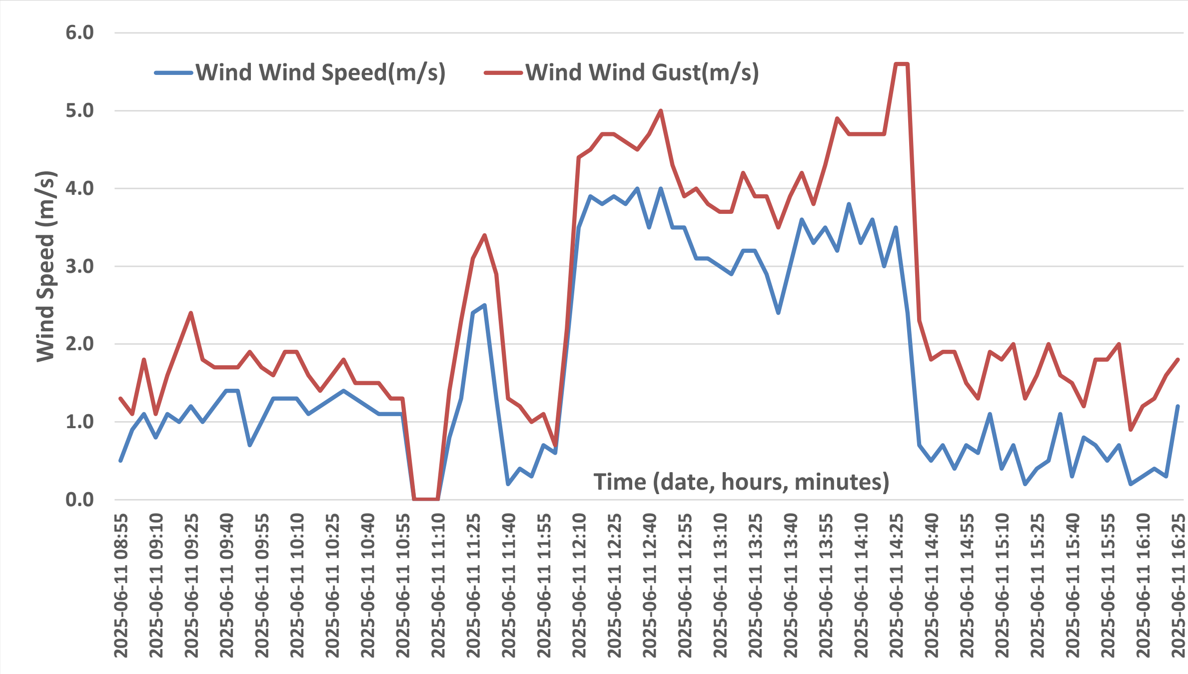


Figure 6: Wind (blue) and Gust (red) Speeds as a Function of Time

3.3. Run-Down Test

A run-down test was undertaken on 26/02/2025 to estimate the tunnel friction factor, based on the procedure proposed in [Ref. 6], initially using all jet fans on the northern side, and then using all jet fans in the tunnel. The result was a friction factor of 0.025, with a measurement uncertainty of +10%.

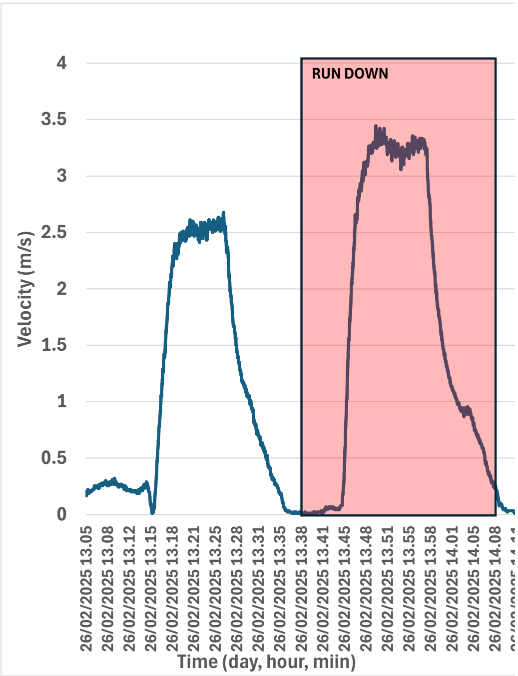


Figure 7: Run-down Test

3.4. Air Velocity Tests

Three separate sets of measurements were undertaken for the air velocities in the tunnel: one with conventional jet fans, and two with shaped silencers. The measurement periods, each of which lasted for 7 minutes, are indicated in **Figure 8**.

Table 1 reports the time-average velocity measurements for the three time periods. The thrust increase with shaped silencers can be estimated on the basis of the square of the measured velocities.

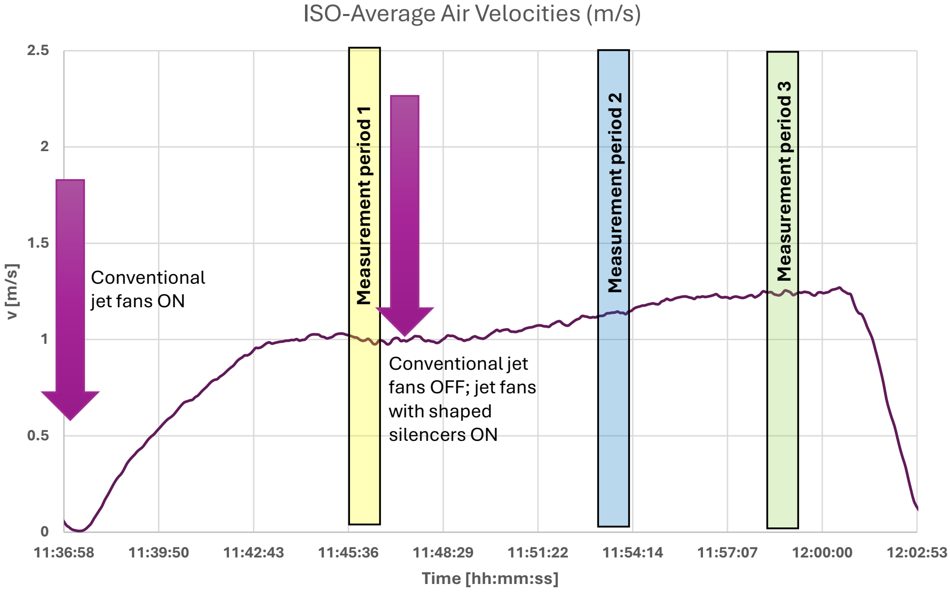


Figure 8: Variation of ISO-average tunnel velocities during the test

Table 1: Air Velocity Measurements

Measurement period no.	Jet fan type	ISO Area-Average Air Velocity (m/s)	Test average air velocity (m/s)
1	Conventional	1.016	1.016
2	Shaped silencers	1.118	1.182
3	Shaped silencers	1.246	

3.5. Pressure Difference Results

The jet fan installation factor, η, for both fan types was estimated using the measured pressure rise across the fans (Δp_{12}), as follows [Ref. 7]:

$$\eta = 100 \cdot \frac{\Delta p_{12} + \left(\frac{\lambda \cdot L_{12}}{D} + \zeta_{12}\right)\frac{\rho}{2}u_t^2}{n \cdot \rho u_s^2 \frac{A_s}{A_t} \cdot \left(1 - \frac{u_t}{u_s}\right)}$$

The measured pressure rise across a bank of fans and the estimated jet fan installation factors are listed in **Table 2**, based on the test-average results.

Table 2: Jet Fan Installation Factors from Pressure Differences

	Δp_{12} (Pa)	Installation Factor
Conventional	20.60	0.703
Shaped silencer	29.64	0.948

3.6. In-Line Jet Fan Tests

In-line arrangements of four conventional jet fans with four jet fans with shaped silencers, all installed near the north portal, were tested on 26th February 2025. These tests were conducted with the jet fans located near the south portal switched on (and blowing towards the south), in order to provide a background tunnel velocity and to counteract the effect of external wind. The installation factor results were similar to those reported here with jet fans arranged in banks of two – which increases the confidence that can be attached to the results, and suggests that there was no significant influence of external wind.

3.7. Measurement Errors

The measurements were subject to systematic uncertainties (e.g. due to anemometer calibrations, direction of probes, finite number of measuring points) and to random measurement errors. Most systematic uncertainties “cancelled out” due to comparative nature of exercise, since the same layout and measurement equipment was used for both the conventional and shaped silencer tests.

We estimate that the random errors for the velocity and pressure measurements were within 5%, to 95% confidence as described in EN ISO 5802:2008+A1:2015. One of the sources of random errors in this test was the external wind, which was moderate, but which had a temporal variability. Adding all random errors, including wind, implies an overall ±10% uncertainty to 95% confidence in the installation factor results.

4. DISCUSSION AND CONCLUSION

Measurements undertaken in the 3.5 km Verta Tunnel in Omegna, Italy sought to determine the performance difference between jet fans using conventional (cylindrical) silencers and those with shaped silencers. The latter are designed to deflect the airflow away from the tunnel soffit, and hence enhance the in-tunnel thrust.

The two types of measurements (velocity and pressure) suggest slightly different enhancements of shaped silencers compared to conventional silencers, albeit within the ranges of uncertainty.

The enhancement of jet fan in-tunnel thrust using shaped silencers has been well established from previous full-scale measurements [Ref. 3] and CFD [Ref. 8]. In particular, Ref. 3 reported a thrust enhancement of 29% in a similar arched tunnel profile, using shaped silencers. The measured jet fan installation factors align well with the results of Ref. 3 and with correlations proposed on the basis of extensive CFD calculations [Ref. 4].

In order to further reduce the measurement uncertainties, we recommend further tests with a larger number of jet fans, in order to provide additional confirmation of our test results.

5. REFERENCES

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