Design, Testing and Application of an Energy-Efficient Longitudinal Ventilation System

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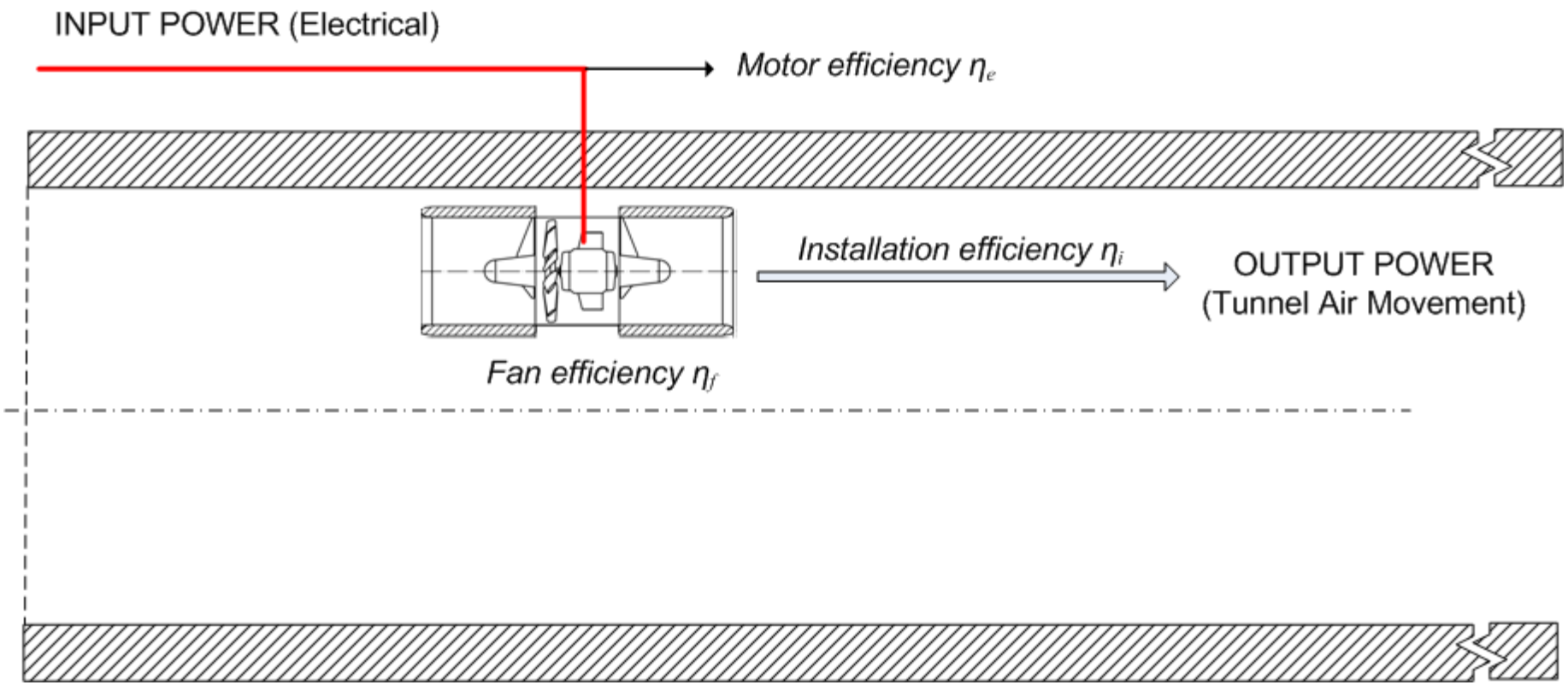
Energy Efficiency – Why Bother?

- Ventilation is usually the single highest load in tunnels
- Cost of power – rising over time
- Standing charges – payable even if fans are not operational
- Duty of public authorities to promote energy efficiency
- Ethical behaviour – climate change, responsibility for future generations.

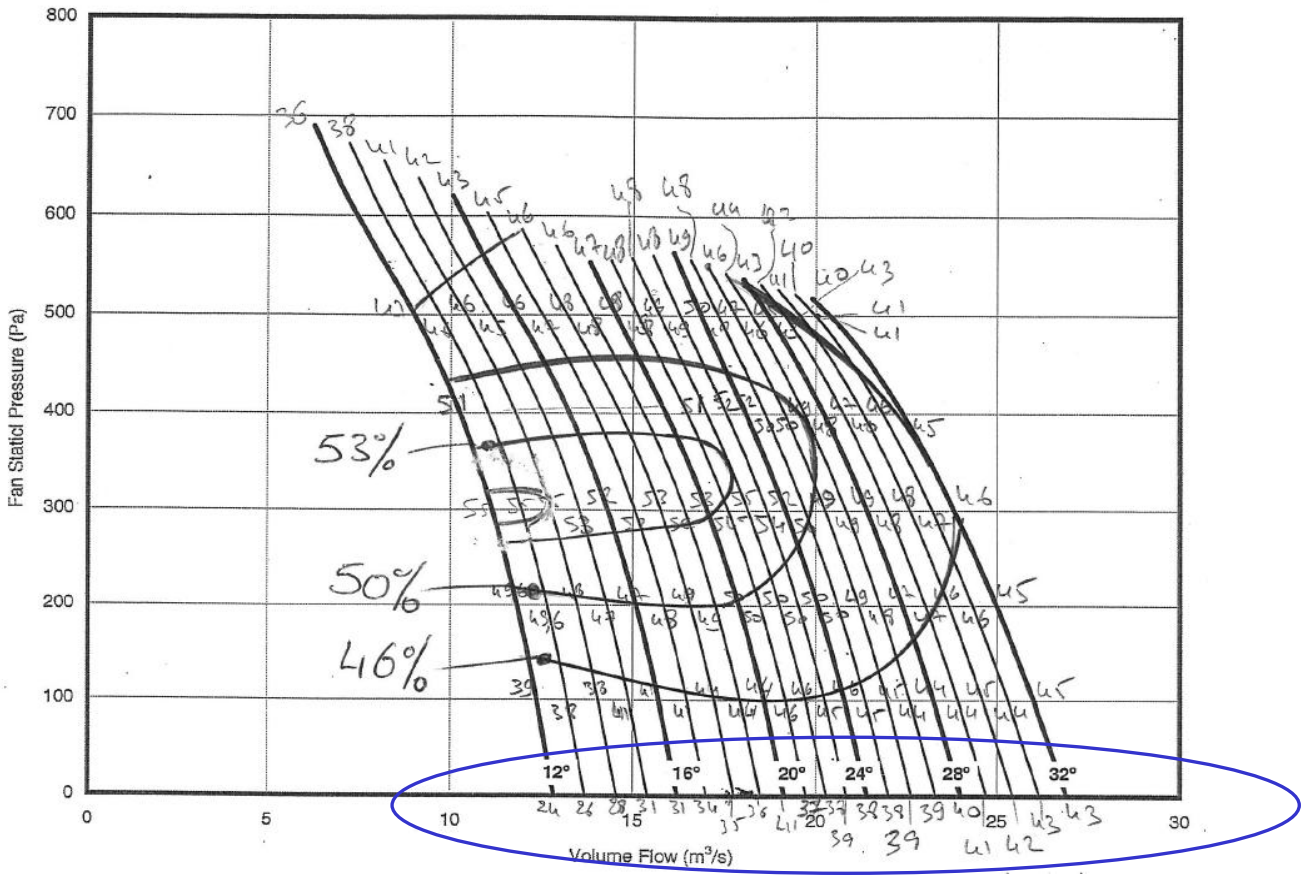
Components of Energy Losses



Typical Efficiency Values

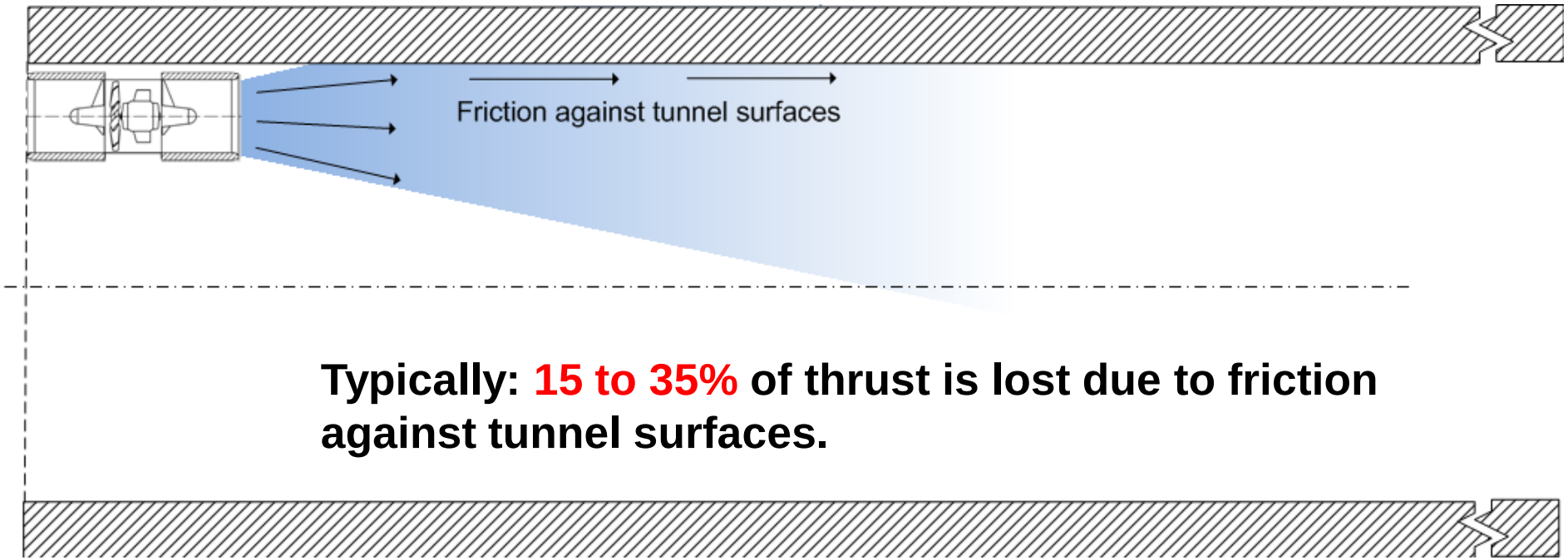
- Motor efficiency: over 90% for three-phase motors
- Fan efficiency: between 40% to 70%
- Installation efficiency: between 65% to 85%
- **Overall power efficiency can range widely, e.g. 23% to 58%**
- **Large opportunities for improvements!**

Fan Efficiency



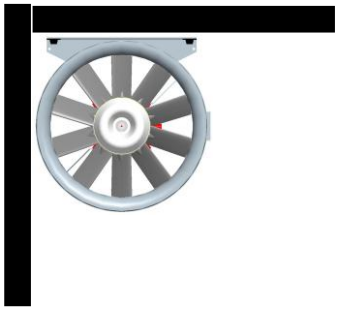
Jetfan efficiencies (poor!)

Installation Factor

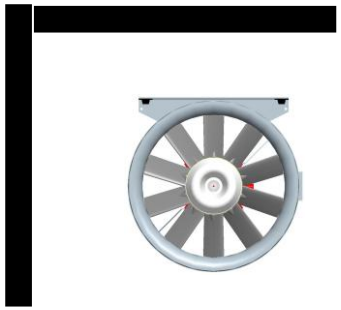


Typically: 15 to 35% of thrust is lost due to friction against tunnel surfaces.

Typical Installation Factors

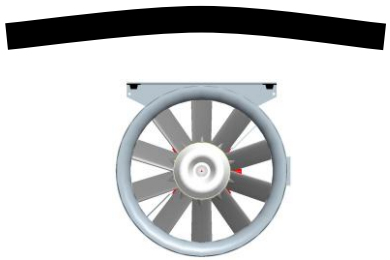


Installation Factor 0.75

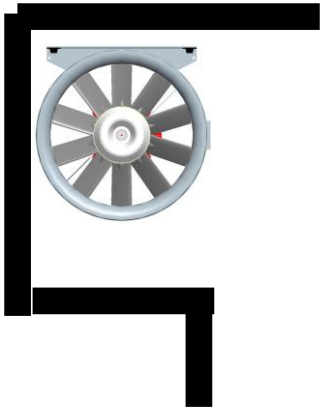


Installation Factor 0.85

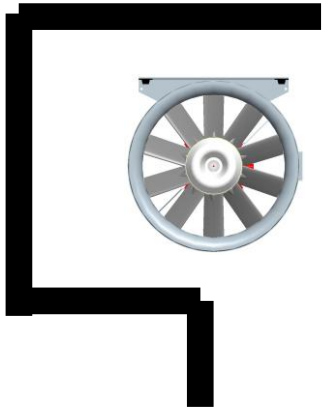
Installation Factor 0.85



Installation Factor 0.95



Installation Factor 0.65



Installation Factor 0.80

Improvements in Energy Efficiency

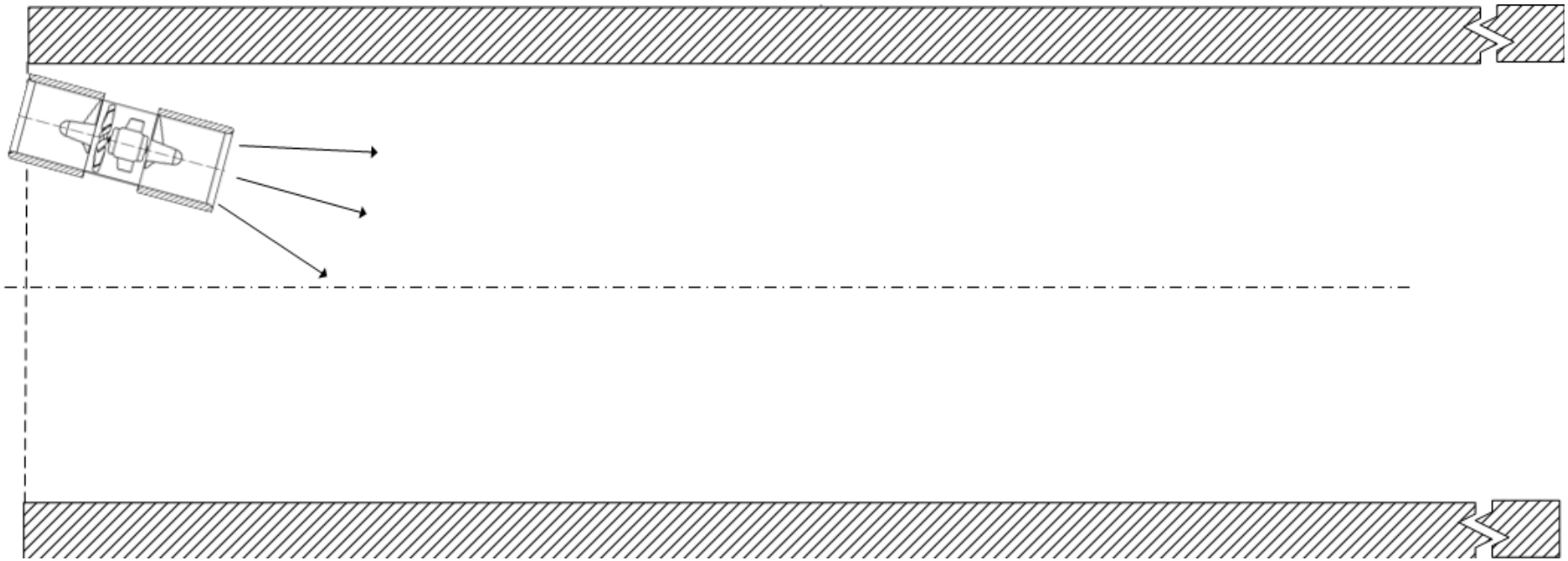
Two main potential sources of improvement:

1. **Fan efficiency**: larger fans, slower speeds, smaller pitch angles, aerodynamic blading, better operating point
2. **Installation efficiency:** direct jet towards tunnel centreline, to avoid frictional losses

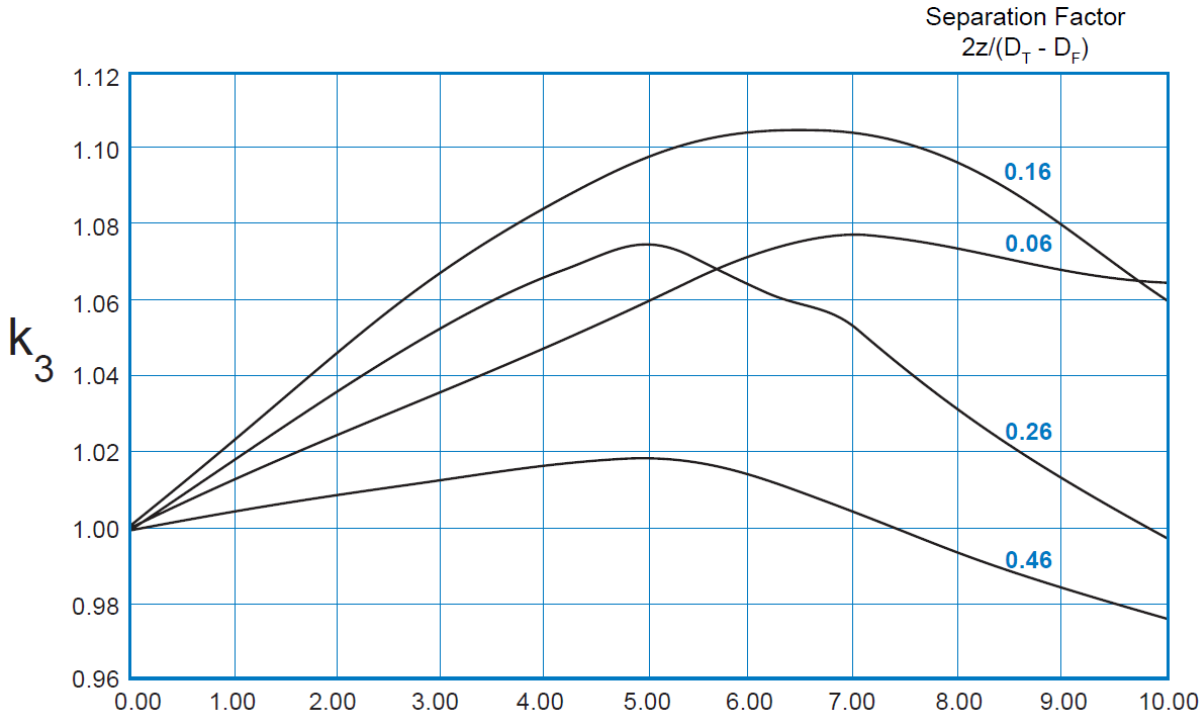
Improvements in Installation Efficiency

- Tilting the jetfans towards the tunnel centreline
- Slanting the silencers at either end of a jetfan
- Installing deflection vanes at one or both ends of a jetfan
- Converging the nozzles on or both ends of a jetfan (MoJet®)

Tilting the jetfans



Effect of Tilting Jetfans

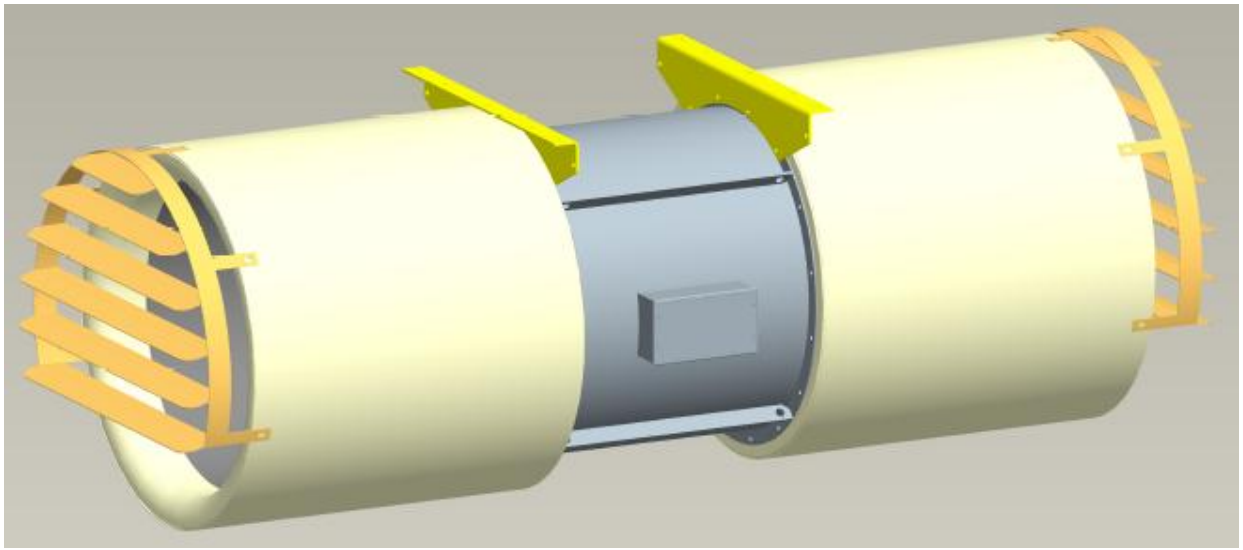


- Cannot reasonably be used for reversible jetfans.
- Additional space required for fans/silencers

Slanted Silencers

- Improved installation efficiency, but additional space required for slanted silencers.
- No additional thrust, beyond improving installation efficiency.

Deflection Vanes

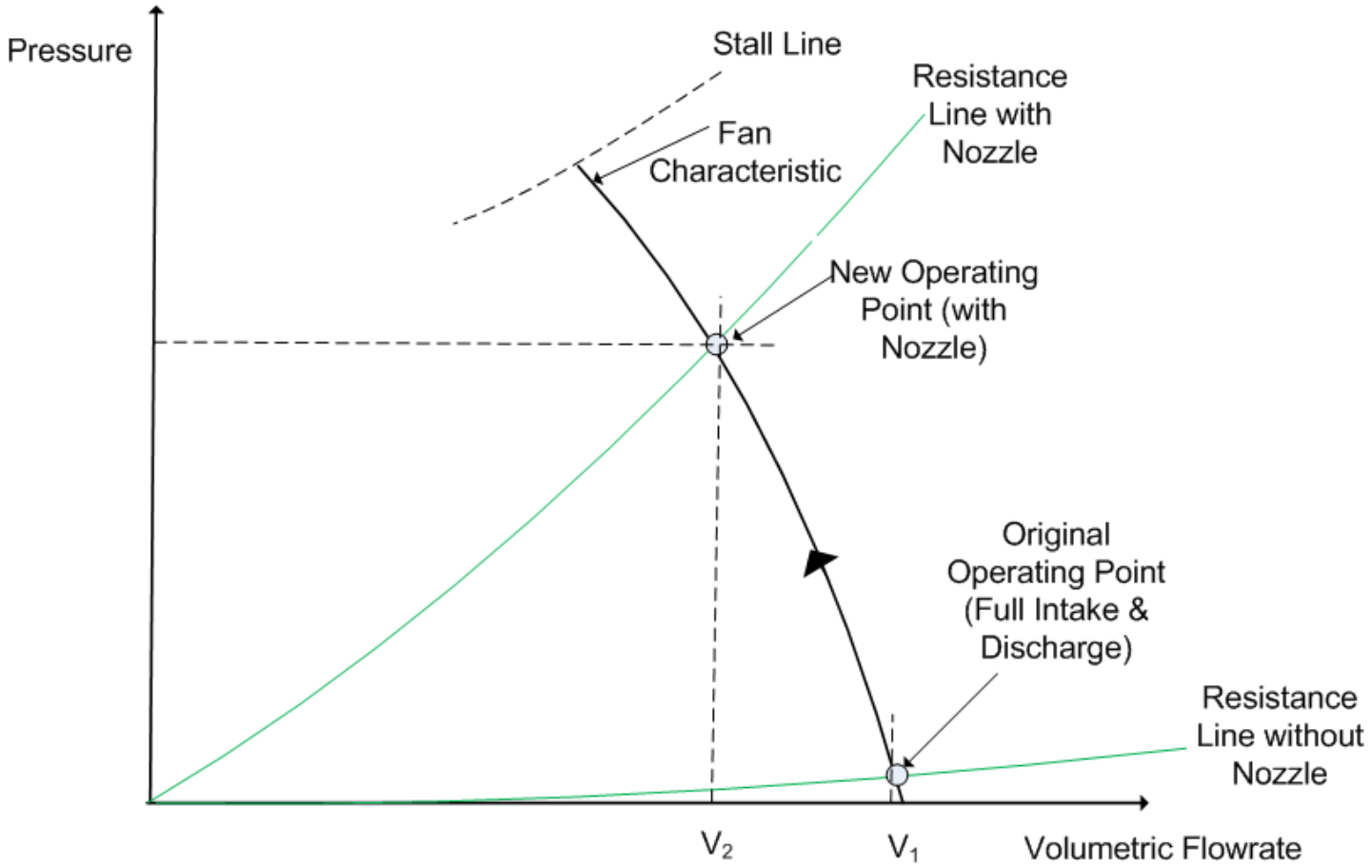


- Installation efficiency improved, *but*
- Measurements indicate a 10% reduction in bench thrust, and a 10% increase in power consumption.

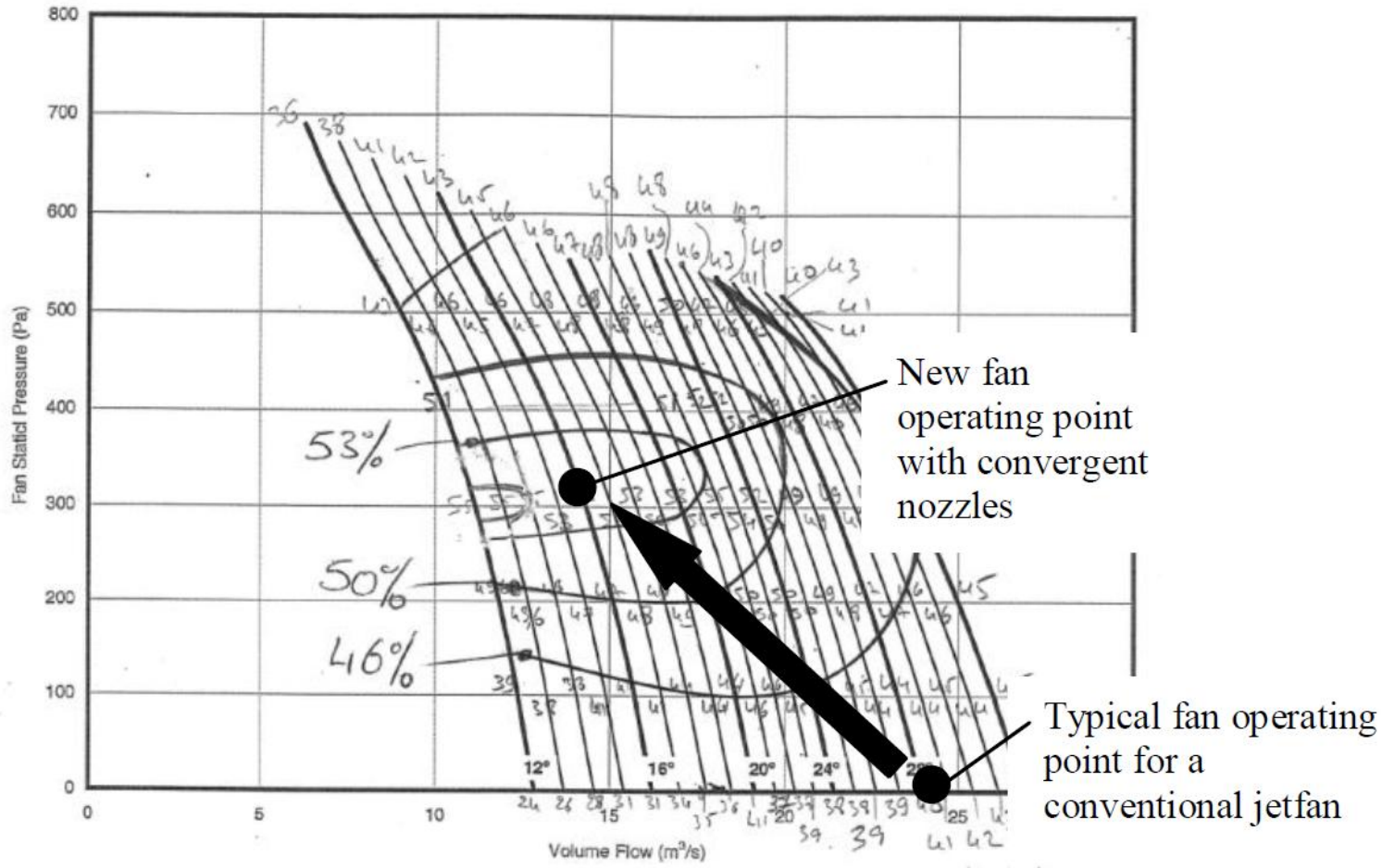
Convergent Nozzles (MoJet®)

- Improved installation efficiency
- How does the fan efficiency change?

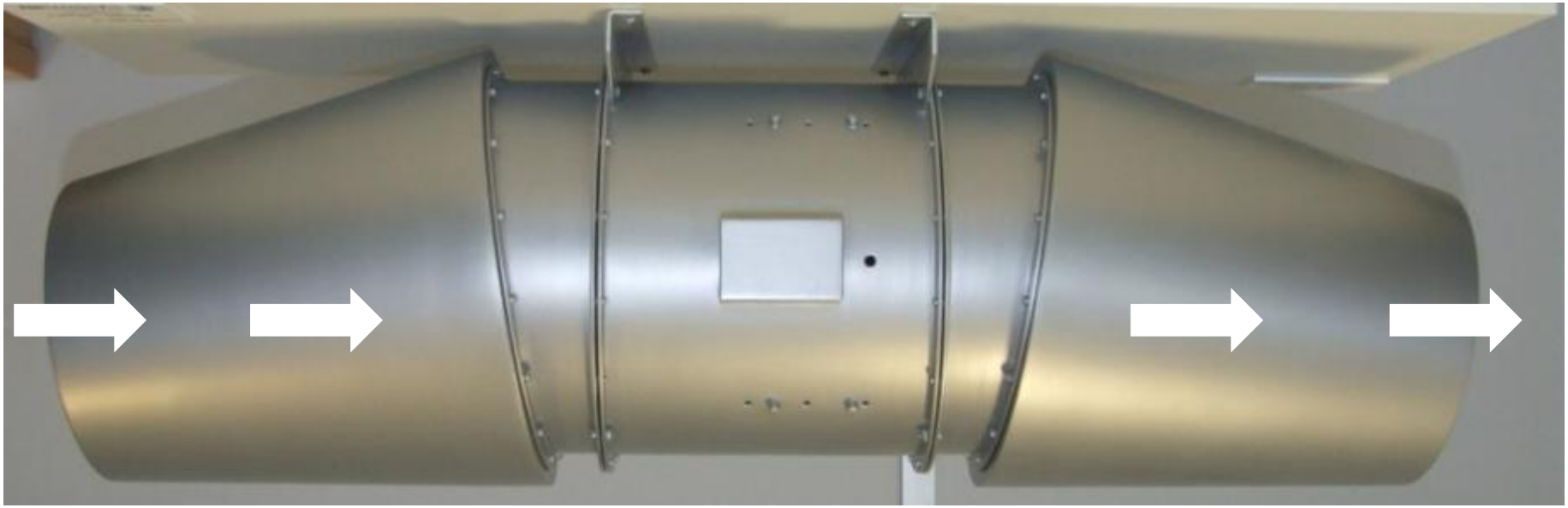
Fan Operating Points



Fan Efficiency



Typical Pressure Loss Coefficients



Inlet bellmouth: 0.25

Divergent nozzle: 0.014

Convergent nozzle: 0.012

Outlet: 1

(not an energy *loss* to the tunnel!)

MoJet® Experimental Testing

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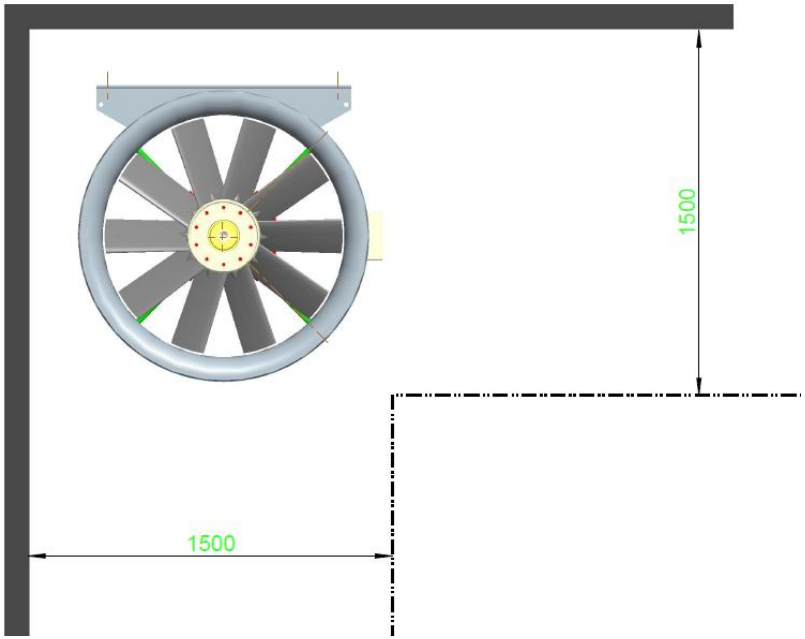
Test Results

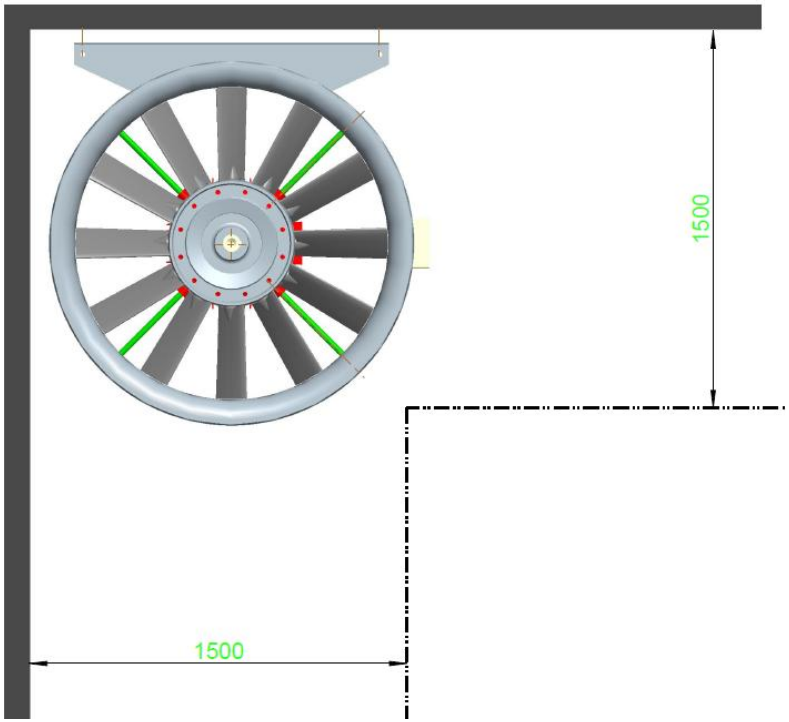
- 1 metre diameter jetfan with 20° blade pitch angle and a 50 Hz 4-pole motor
- Fully reversible fan
- Nozzle area convergence ratio of 1.6
- **Bench thrust increased by 7%**
- **Propulsive efficiency (N/kW) increased by 15%**
- **Sound pressure levels reduced by 2 dB(A)**

Design Options for Given Space



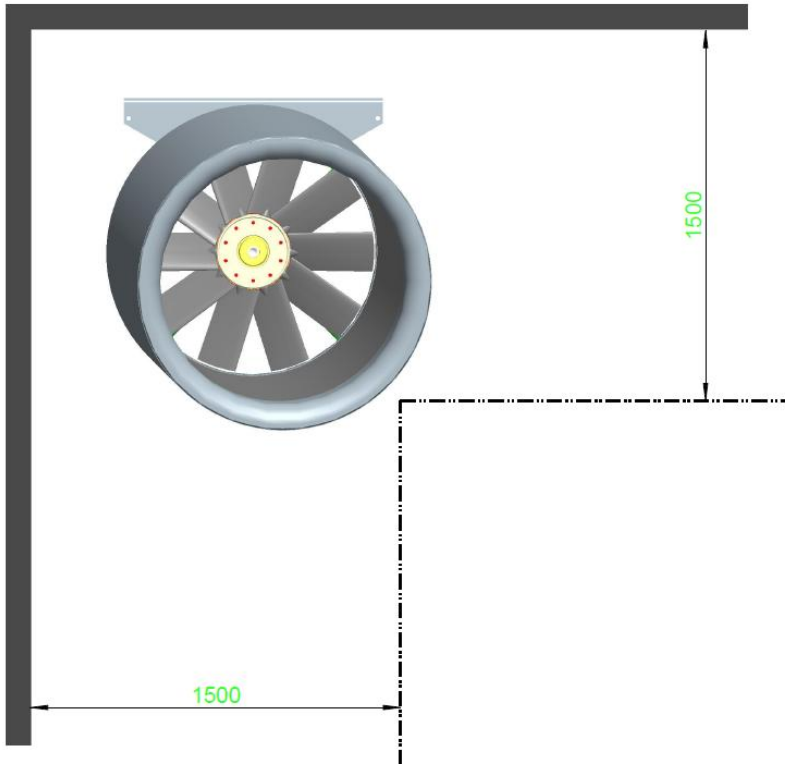
- Conventional jetfan solution (1 m diameter)
- Poor fan and installation efficiencies

Large–Diameter Fan Option



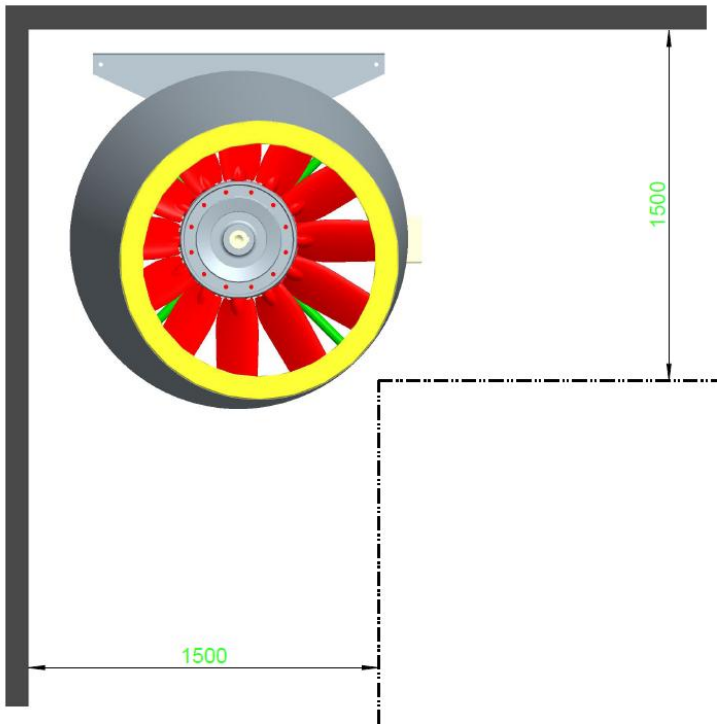
- Improved fan efficiency (fan diameter 1.2m)
- Installation efficiency worse than for conventional solution!

Slanted Silencer Option



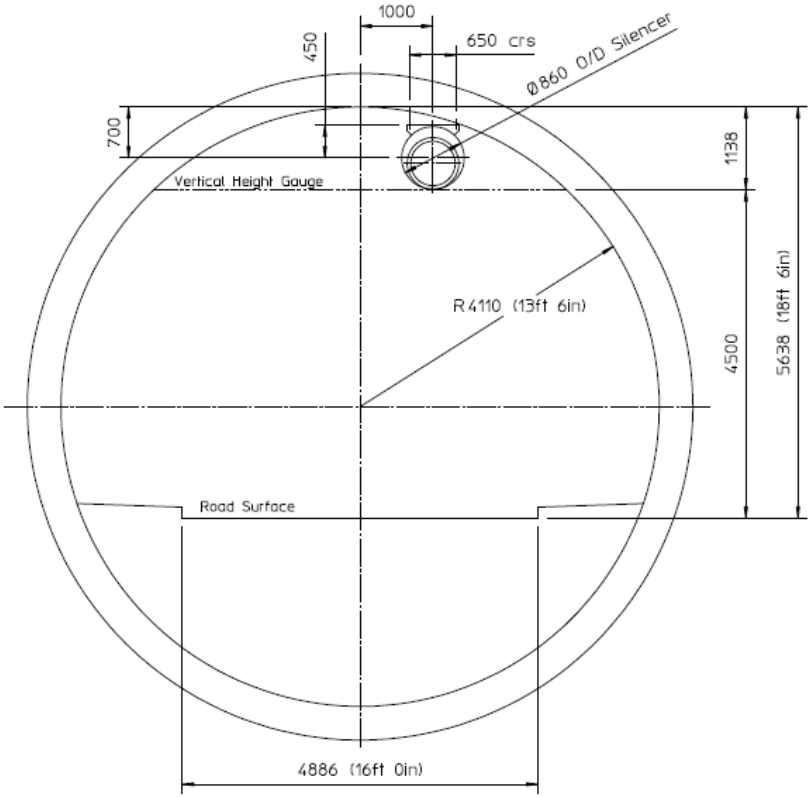
- Installation efficiency improved
- Fan efficiency poor (small diameter fan)

Convergent Nozzle Solution (MoJet®)

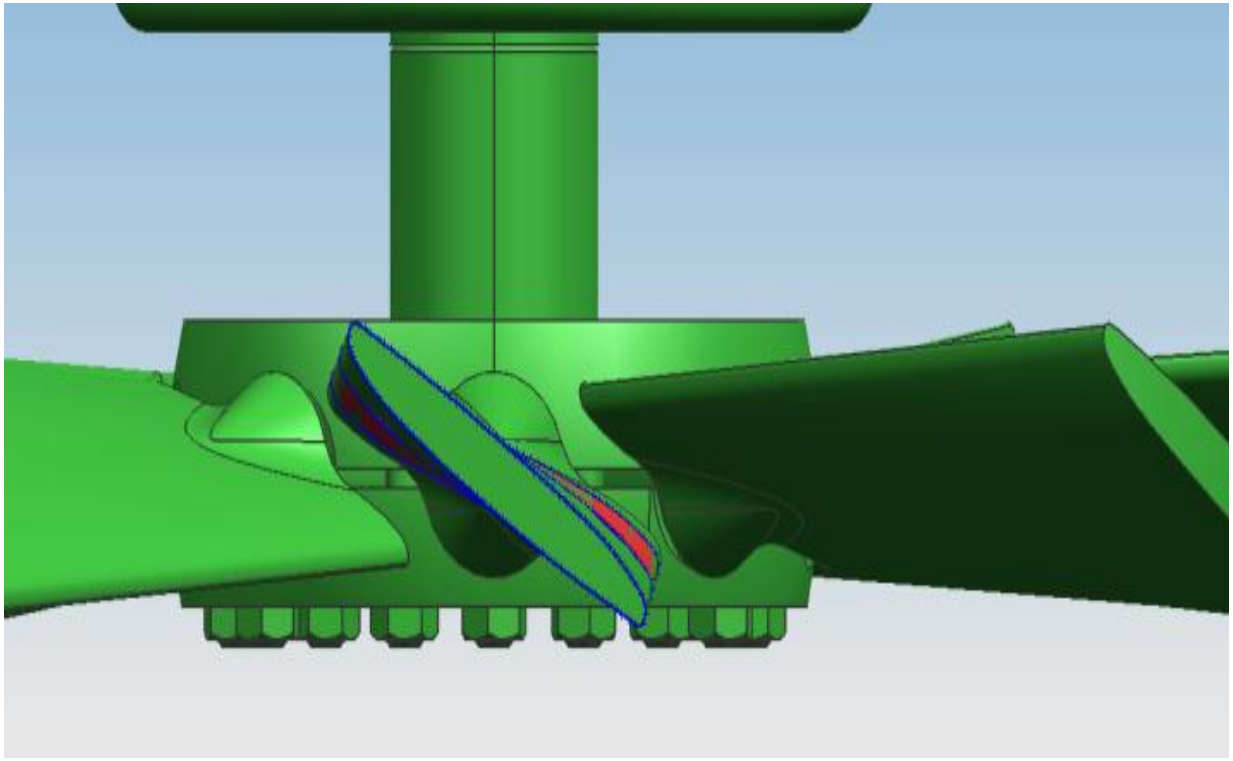


- Fan efficiency improved (optimum operating point, large fan diameter)
- Installation efficiency also improved

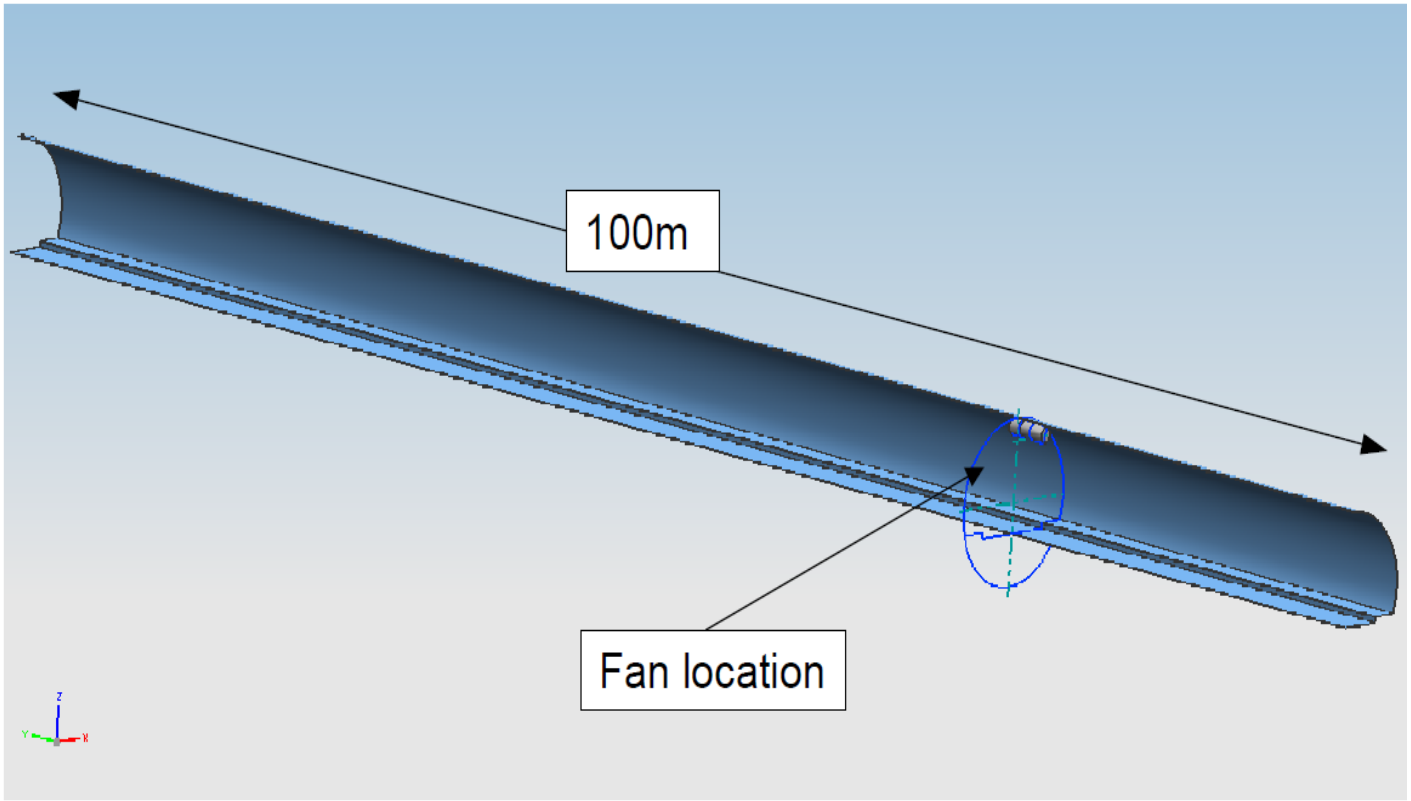
CFD Calculations – Road Tunnel



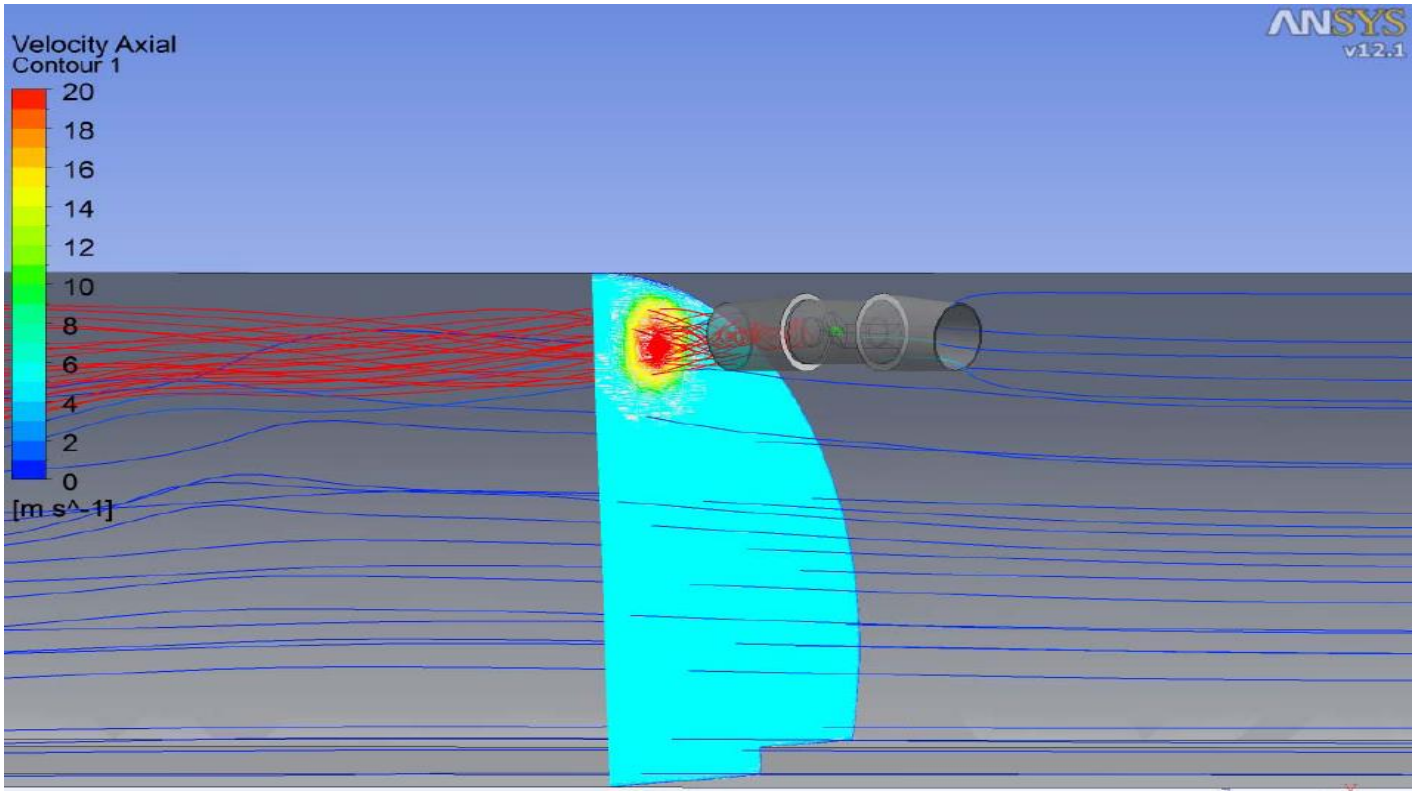
Fan Rotor



Fan Location



CFD Results



- Coanda effect is minimised
- Installation efficiency is significantly improved

Case Study – Road Tunnel

- Can we improve on the energy efficiency of a slanted silencer solution?

Slanted Silencer Selection

- 454N of external thrust
- 710mm diameter jetfan
- 2-pole motor
- Absorbed motor power 17.1 kW

MoJet® Selection

- 454N of external thrust
- 900mm diameter jetfan **(fits into same space)**
- 4-pole motor **(50% speed reduction)**
- Absorbed motor power 12 kW **(30% reduction)**

Case Study – Rail Tunnel

	Standard Jetfan	Jetfan with convergent silencers
Design Thrust Requirement (in Tunnel) incl. velocity factor	22,803 N	
Installation Factor	0.73	0.95
Static Thrust Requirement (N)	31,237	24,003
Maximum Fan size	710mm diameter	

Fan Selections

	Standard Jetfan	Jetfan with convergent silencers
Selected Fan	710TR 2P	710TR 2P
Fan Thrust (N)	822	758
Fan Quantity	38	32
Absorbed Power per Fan (kW)	32.8	28.6
Overall Power Absorbed (kW)	1246.4	915.2

- Power consumption *per fan* was **reduced by 13%**
- Number of fans **reduced by 16%**
- *Overall* power consumption **reduced by 27%.**

Summary

- Sources of Energy Losses
- Current State of the Art
- Jetfans with Convergent Nozzles (MoJet®)
- Bench Test Results
- CFD Results
- Case Studies

Conclusions

- Big potential for energy savings in tunnel ventilation
- Reduce aerodynamic frictional effects
- Operate larger fans at optimum operating points
- Convergent nozzles can help achieve energy savings of up to 30%

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