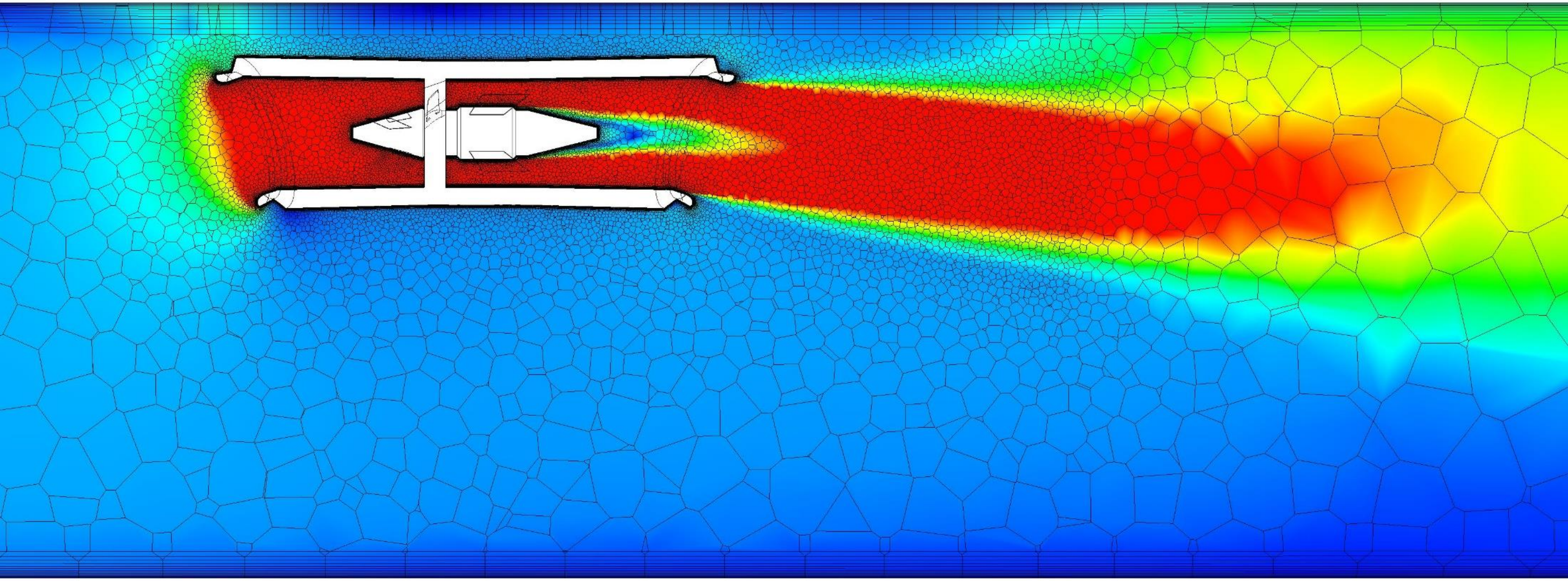
Optimising Jet Fan Thrust with Fire Suppression



Dr Fathi Tarada

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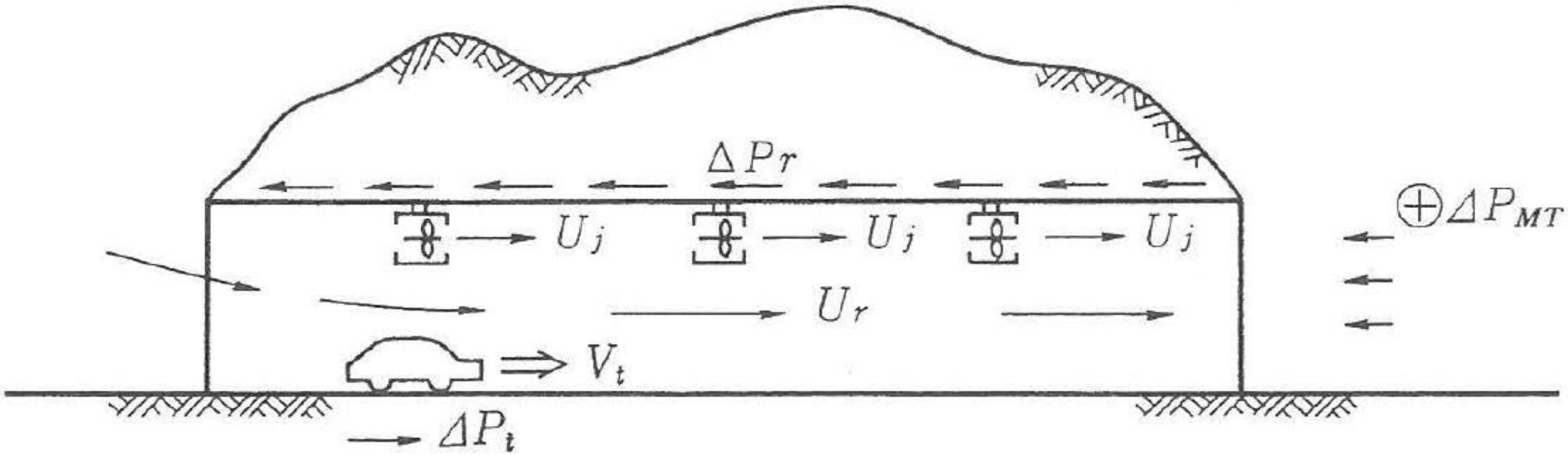
Contents

- Jet fan calculation methodologies
- Pressure drop with fire suppression
- Jet fan installation factors
- Measurements in tunnels
- 3D CFD calculations
- Summary
- Questions

Tunnel ventilation with jet fans



- Jet fans deliver a longitudinal thrust to the tunnel air
- Flow is induced from the inlet tunnel portal, and is discharged at the exit tunnel portal
- The jet fan thrust is designed to overcome aerodynamic pressure drops into, along and out of the tunnel

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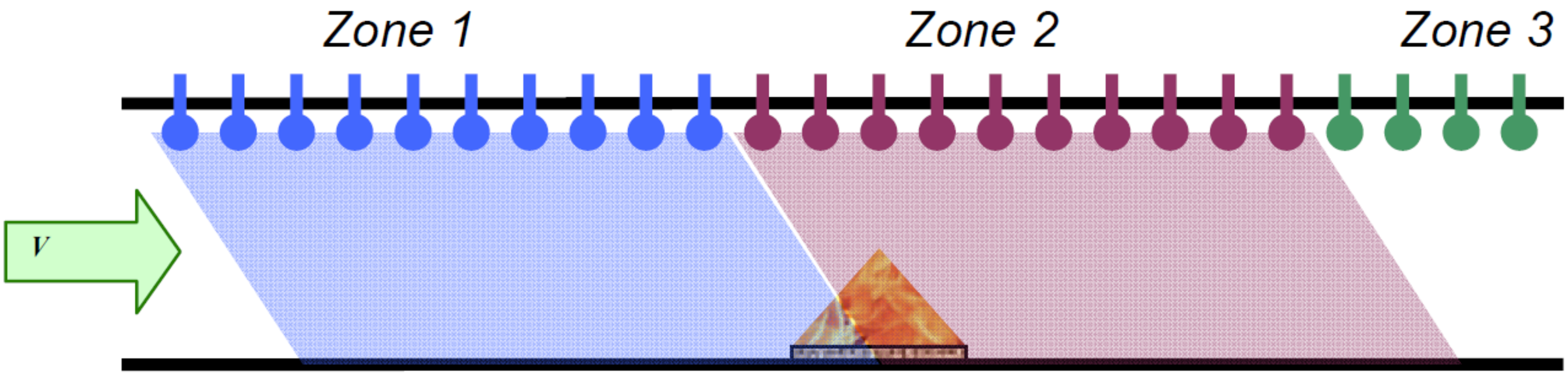
Pressure Drop due to Fire Suppression Water - 1



- The fire suppression water is accelerated to the tunnel air velocity, but this momentum is lost when the water droplets reach the tunnel floor
- The lost momentum is equivalent to an adverse aerodynamic pressure exerted by the water droplets on the tunnel air

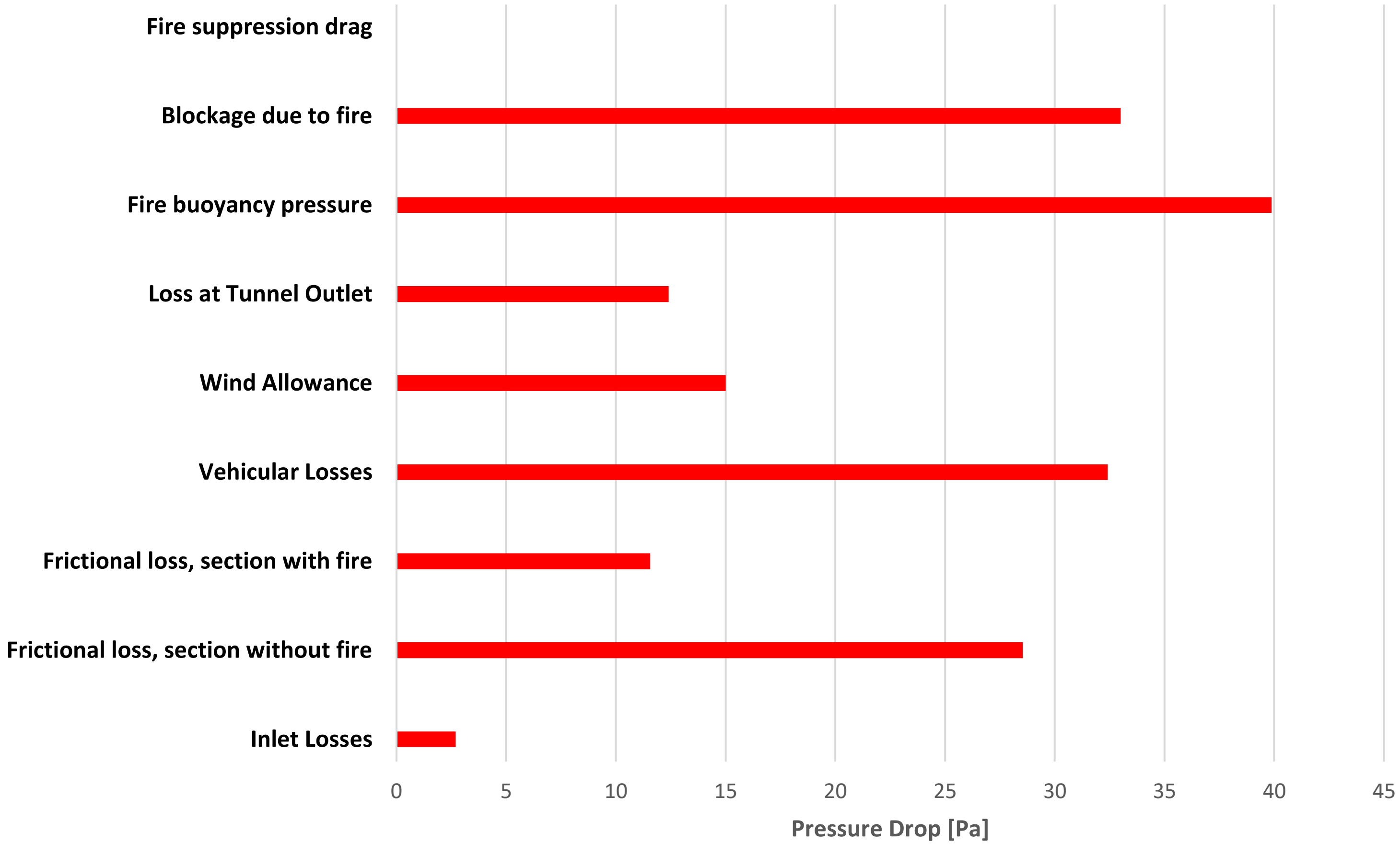
Pressure Drop due to Fire Suppression Water - 2

$$\Delta P = \dot{m}_w V_T$$

where

ΔP	Additional pressure drop due to fire suppression water [Pa]
$\dot{m}_w$	Mass flow of water over active zones - typically over 3 × 25m length [kg/s]
V_T	Tunnel air velocity [m/s]

Pressure Drop for 2 km long, 3-lane road tunnel no fire suppression, 200 MW HRR



ΔP=175 Pa

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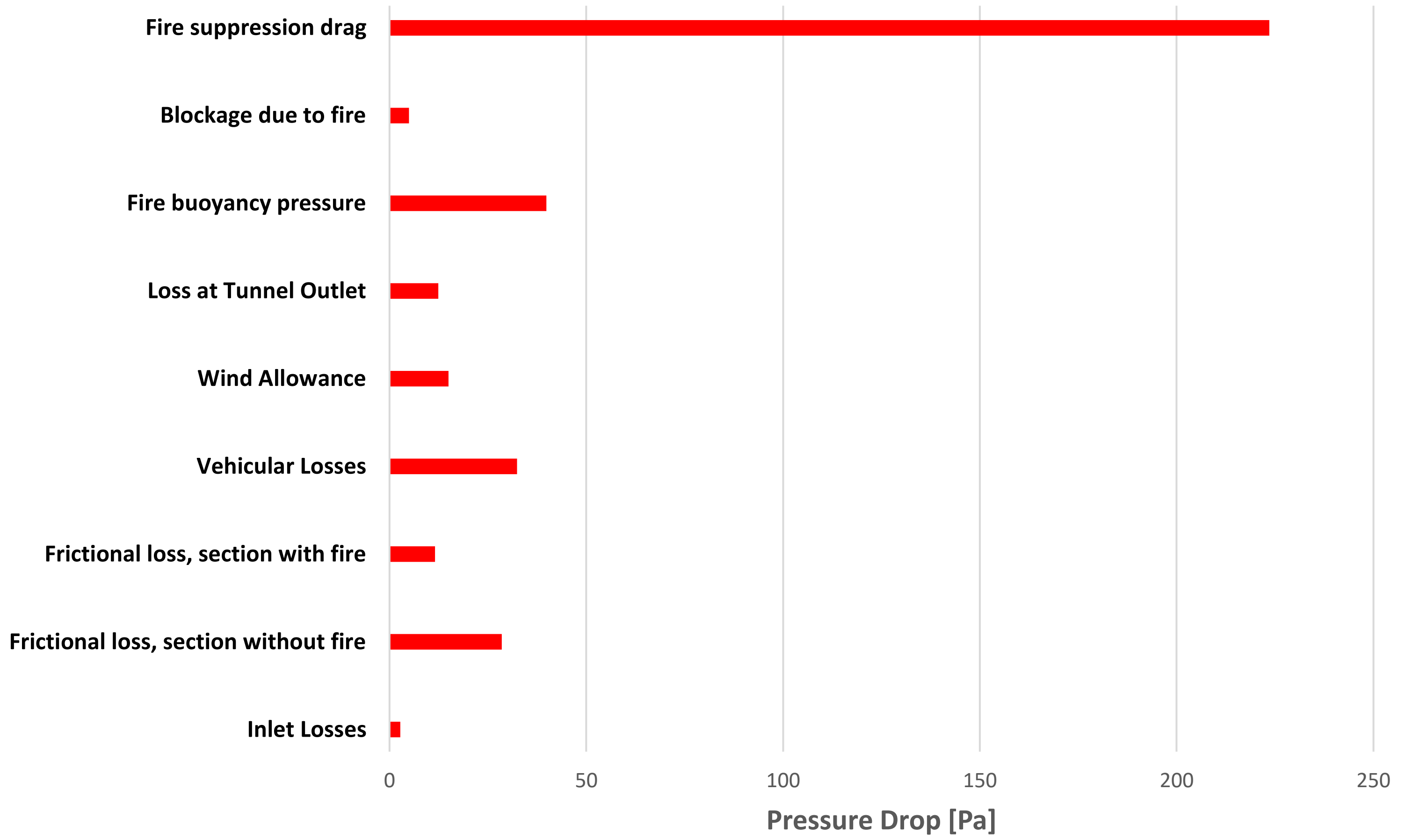
Pressure Drop for 2 km long, 3-lane road tunnel with 4 mm/min fire suppression, 30 MW suppressed HRR



$\Delta P = 371$ Pa

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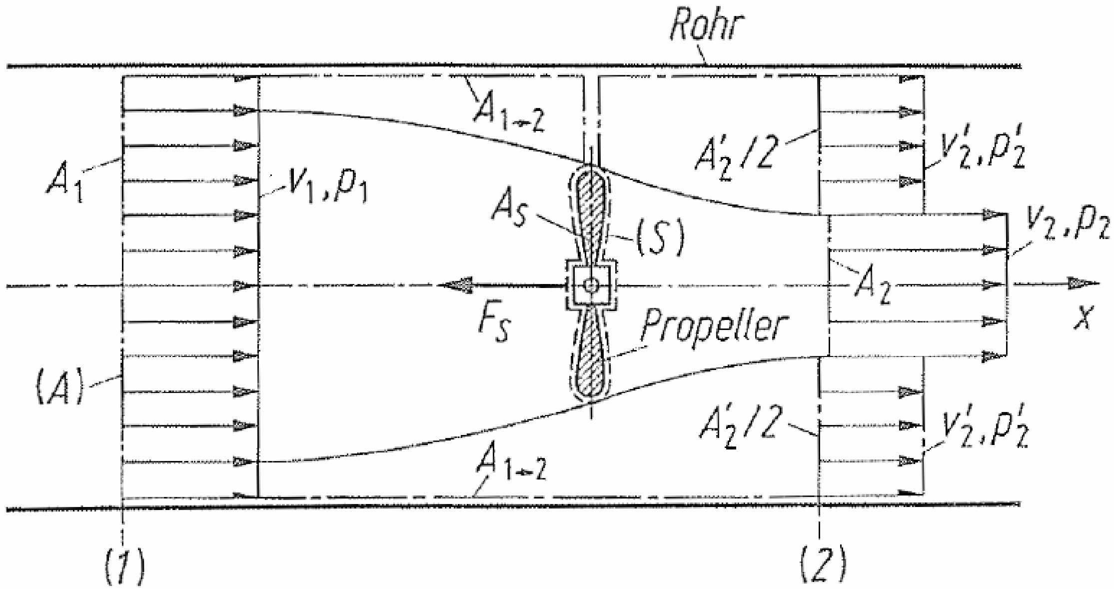
Jet fan calculation methodologies

Calculation Methodologies - 1



Truckenbrodt (1980)

$$T_{\max} = \frac{\rho}{2}\frac{A_1 A_2}{(A_1 - A_2)^2}\left[(2A_1 - 3A_2)v_2^2 - 2(A_1 - 2A_2)v_1 v_2 - A_2 v_1^2\right]$$

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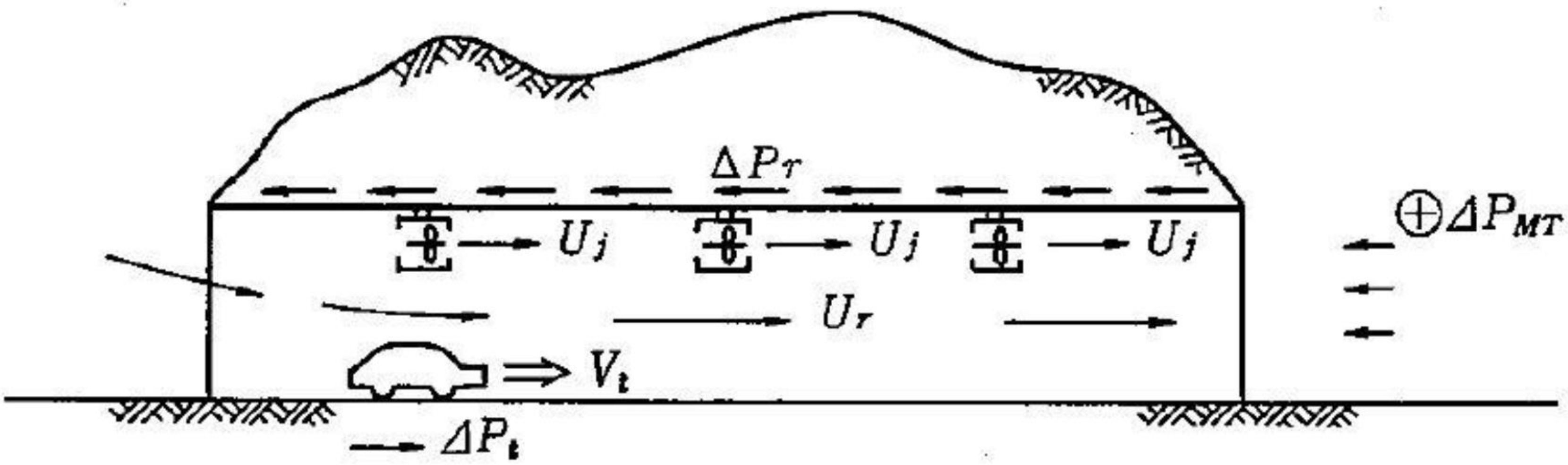
Calculation Methodologies - 2

Meidinger (1964)



$$\Delta P_j = \frac{1}{2}\rho \cdot U_j^2 \cdot \phi \cdot \frac{1-\psi}{(1-\phi)^2}(2-3\phi+\phi\psi)$$

where

Φ = Aj/Ar, Ψ = Ur/Uj

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Simplified Method

- Applicable where the jet fan cross-sectional area is much smaller than the tunnel cross-sectional area (almost always the case)
- Delivers conservative estimates of thrust, typically 2 to 3 % lower than those of the more accurate methods

$$T_{\max} = \rho A_A v_A (v_A - v_\infty)$$

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Reductions in Jet Fan Thrust

- Aerodynamic friction between the jet and neighbouring tunnel surfaces (Coanda effect)
- Jet interaction effects for downstream jet fans (jet fan spacing effect)
- Interaction effects between adjacent jet fans in a single bank (jet interference)

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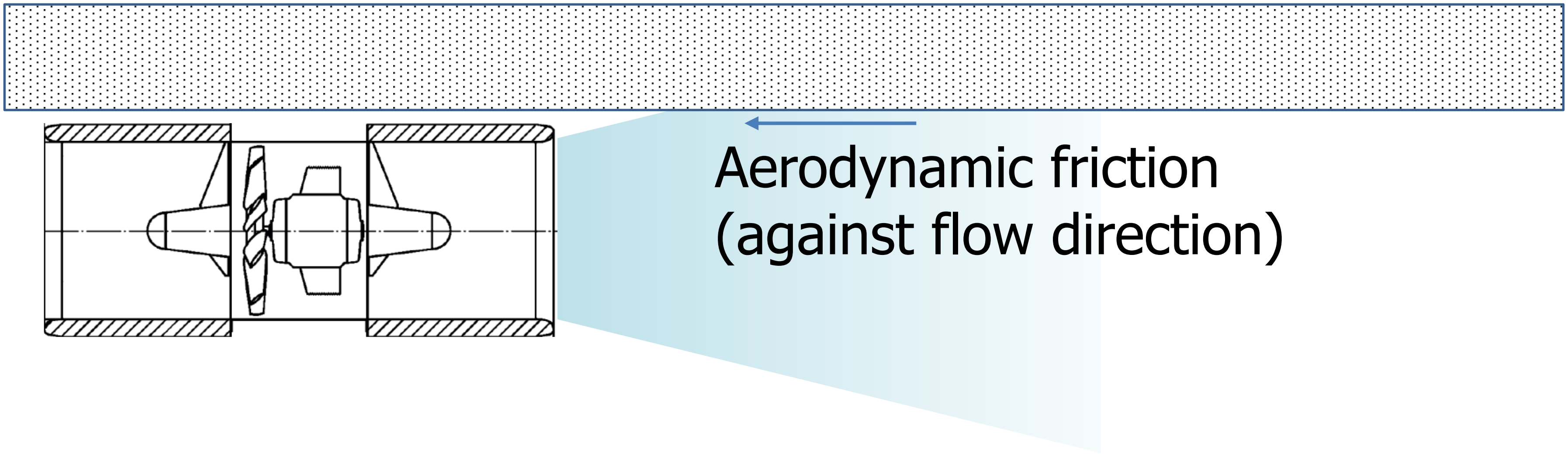
The Coanda Effect



- Discharged jet tends to stick to tunnel soffit and walls
- Typically 30% to 50% of thrust lost via aerodynamic friction
- Additional losses due to jet interaction and flow impingement

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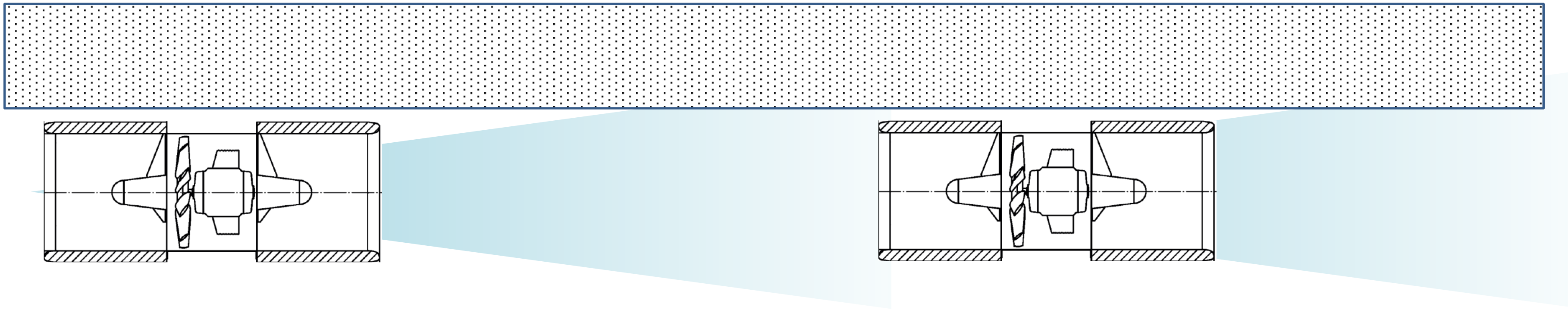
Downstream Jet Interaction Effects



- Downstream jet fan ingests high-velocity jet, reducing its thrust
- Additional form drag due to high-velocity jet flowing over downstream jet fan

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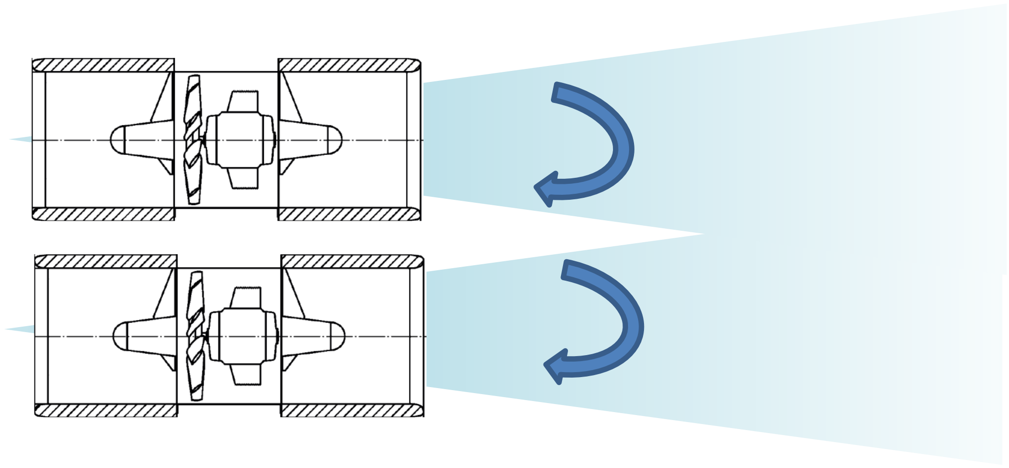
Interactions between Jets within a Bank



- Potential clash between the swirling jets on discharge
- Additional turbulence and shear causes loss of thrust

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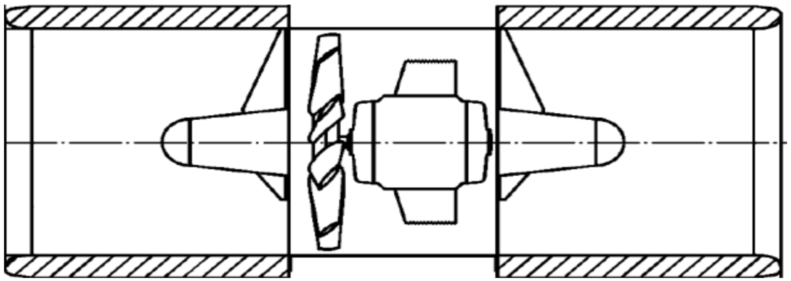
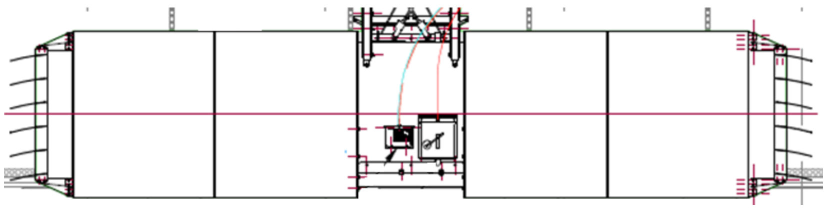
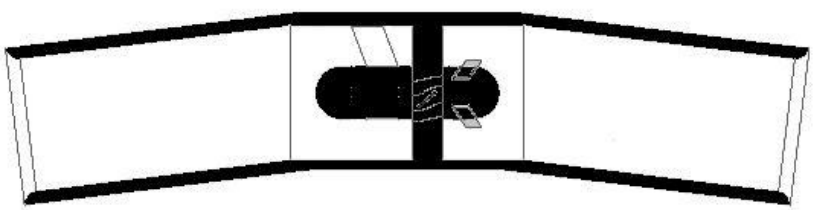
Jet Fan Technologies



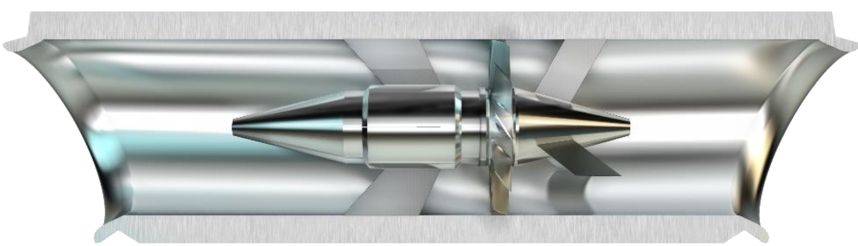
Conventional jet fan



Jet fan with deflectors



Slanted silencers



MoJet

Oldest

Time

Most recent

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Effect of Jet Fan Technology

- Corrections to the calculated jet fan thrust depend on the jet deflection technology
- Focus of this presentation is on conventional jet fans and MoJets

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Effect of Installation Details

Installation details have a significant effect on the jet fan installation factor:

- below a soffit
- within a niche
- distances to nearest tunnel surfaces
- presence of downstream impingement surfaces, e.g. tunnel headwalls and signs

Thrust Calculation accounting for Inefficiencies

$$T = \eta_i \rho A_A v_A (v_A - v_\infty)$$

where

η_i = jet fan installation factor or “boosting coefficient) (< 1) to account for inefficiencies including

- Coanda effect
- Downstream jet interaction
- Sideways jet interaction

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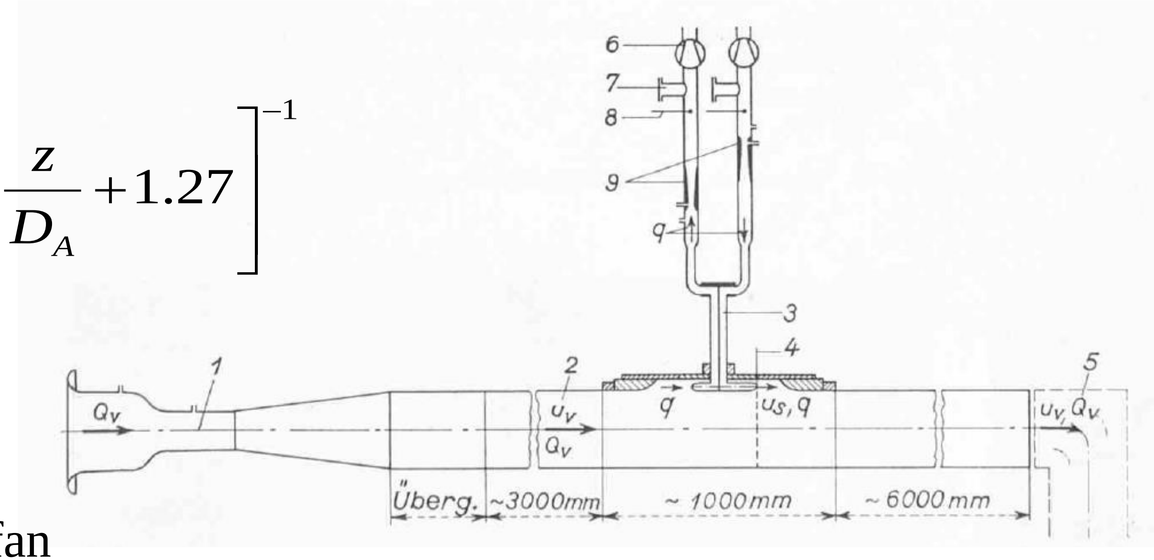
Jet fan installation factors

Installation Factor Estimation

- Correlations based on measurements by Kempf (1965) and Woods / South Bank University (1997) are widely used.
- Based upon model-scale experiments, hence Reynolds numbers are much lower than in real tunnels.
- These correlations have been shown to be too optimistic by more recent researchers, e.g. from Graz University (2016).

Kempf Measurements (1965)

$$\eta_i = \left[0.0192 \left(\frac{z}{D_A} \right)^2 - 0.144 \frac{z}{D_A} + 1.27 \right]^{-1}$$



D_A = outlet diameter of the jetfan
z = distance between the centre axis of the jet at the outlet and the tunnel wall

- Based on 1:60 scale measurements
- Reynolds number approximately 50 times smaller than reality
- Jet had no swirl, hence expanded slowly and was less likely to attach to the tunnel wall
- No jet interaction / interference effects investigated
- Measurements and correlation cannot be relied upon

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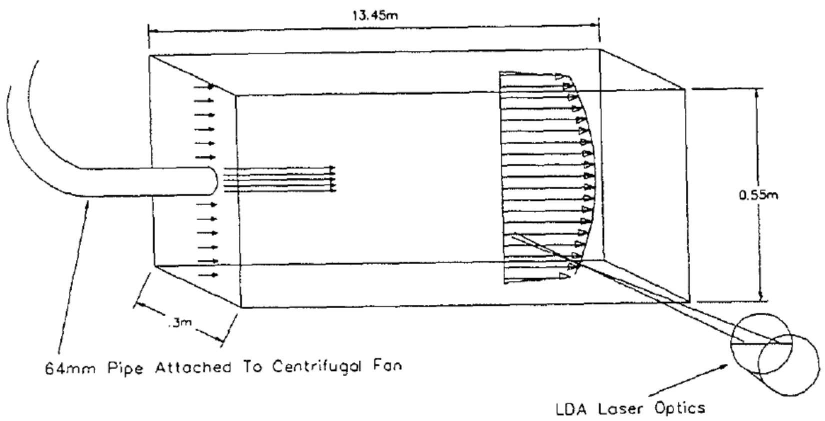
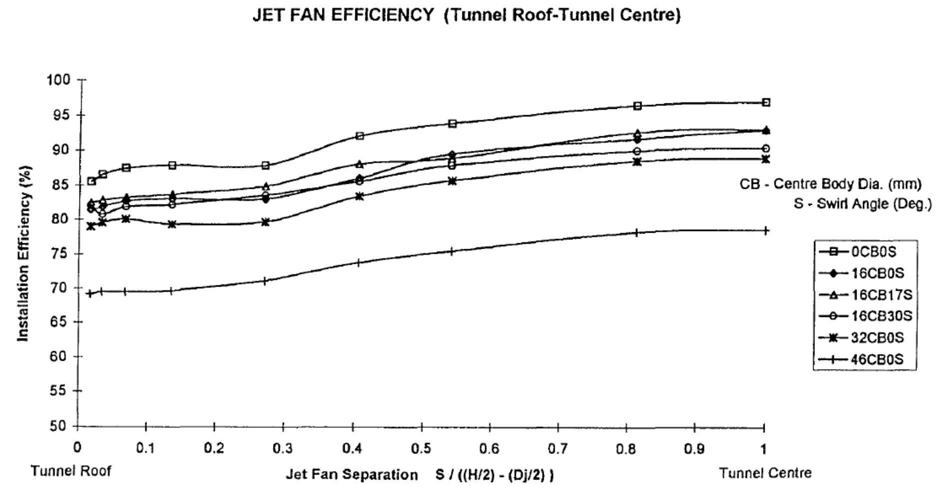
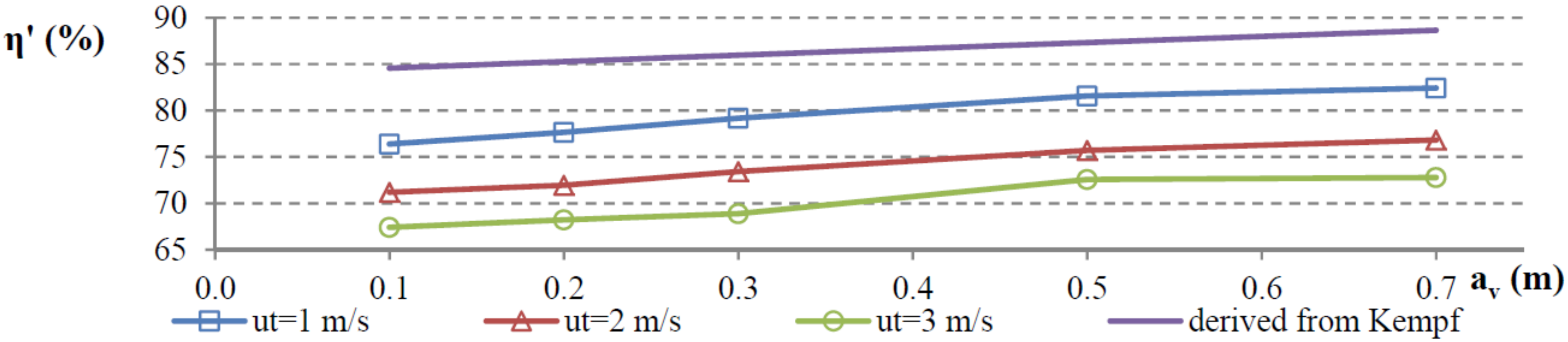
Woods / South Bank University Measurements (1997)





- 1:15 scale model
- Reynolds numbers approximately 15 times lower than reality
- No jet interaction / interference effects investigated
- Not a good basis for tunnel ventilation design

Graz University (2016)



- 3D CFD calculations validated against measurements for two tunnels, using jet fans with deflection vanes
- Installation factors reported based on 3D CFD - significantly lower installation factors than Kempf reported
- Installation factors reduce with increasing tunnel air velocity, and increase with increasing jet fan diameter
- No discharge swirl modelled – hence results are questionable for conventional jet fans (i.e. without deflection vanes)

Measurements in Mersey Queensway Tunnel

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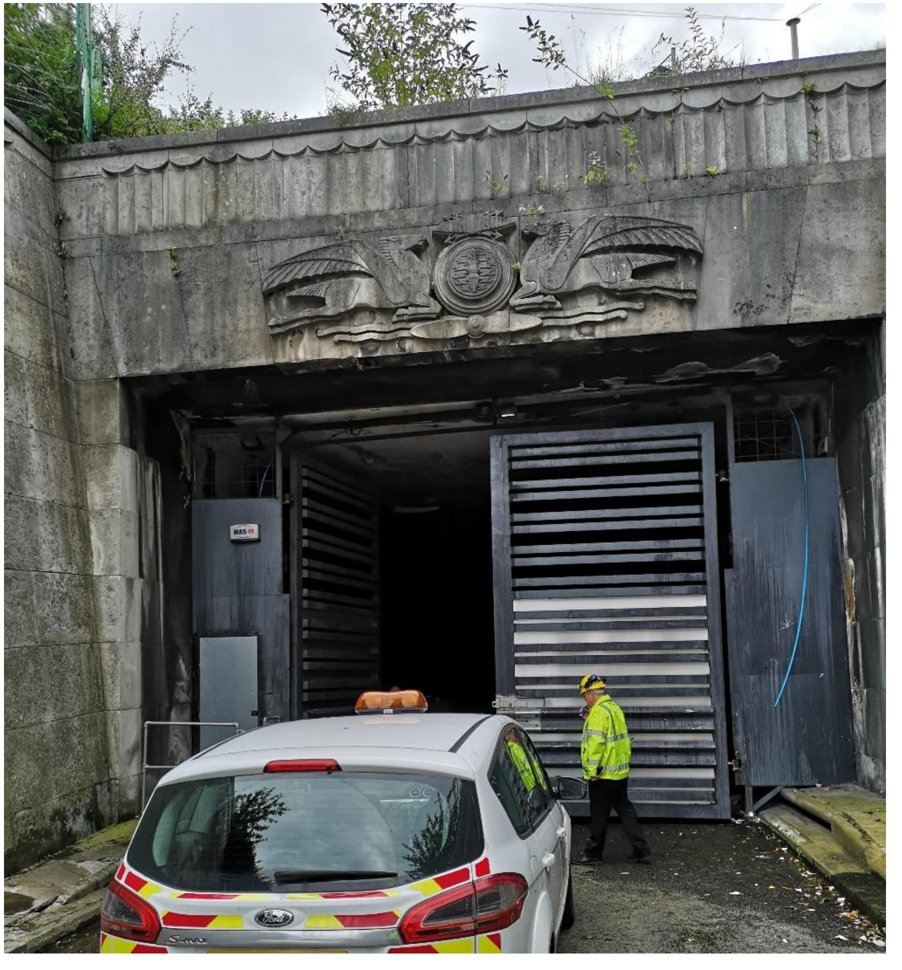
Mersey Queensway Tunnel – Rendel Street Branch



Rendel Street Branch Tunnel

(500 m long x 8 m wide approximately)

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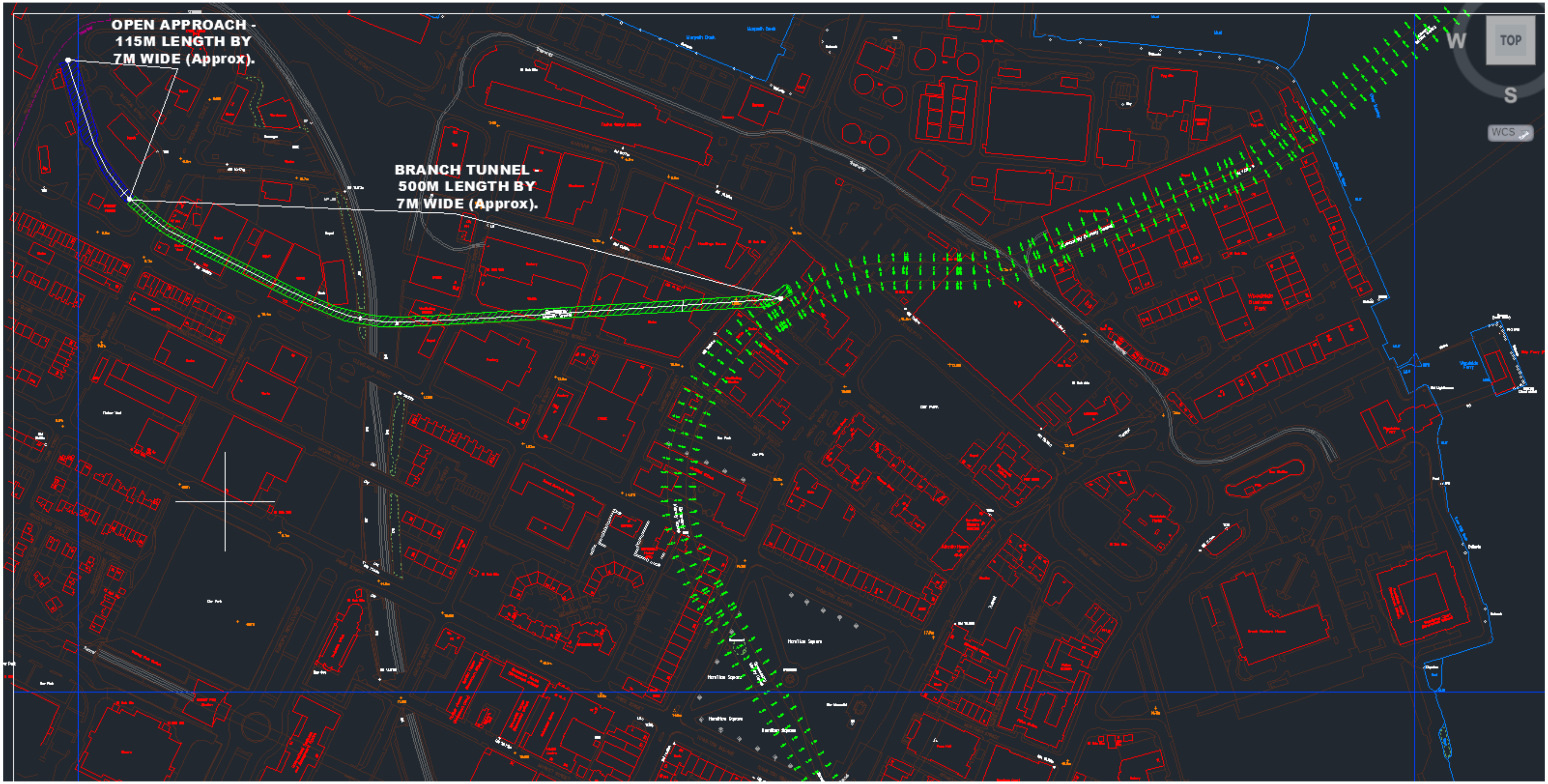
Horizontal Alignment



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Jet Fan Installation Location

jet fan position approximately 25m inside Rendel Street Branch Tunnel

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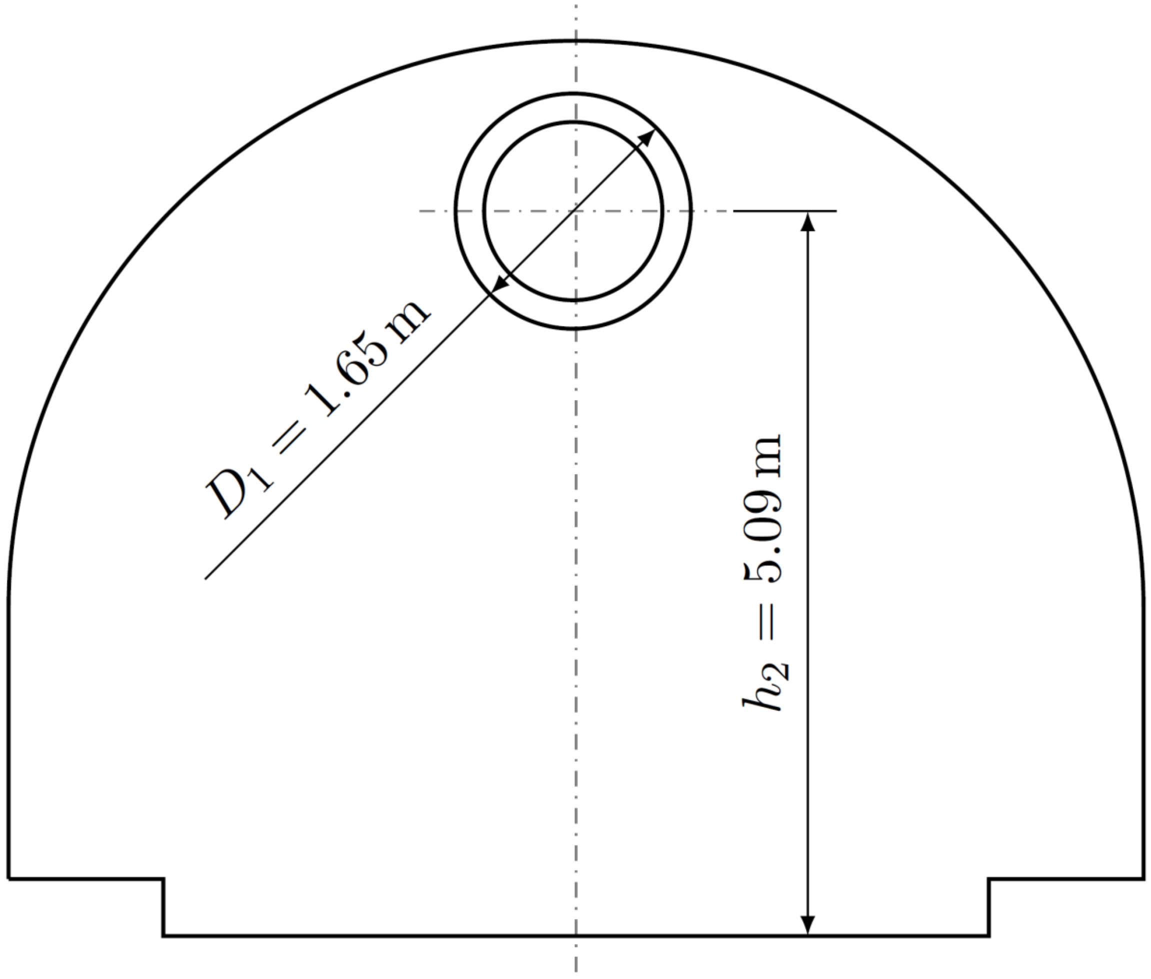
Installation Cross-Section



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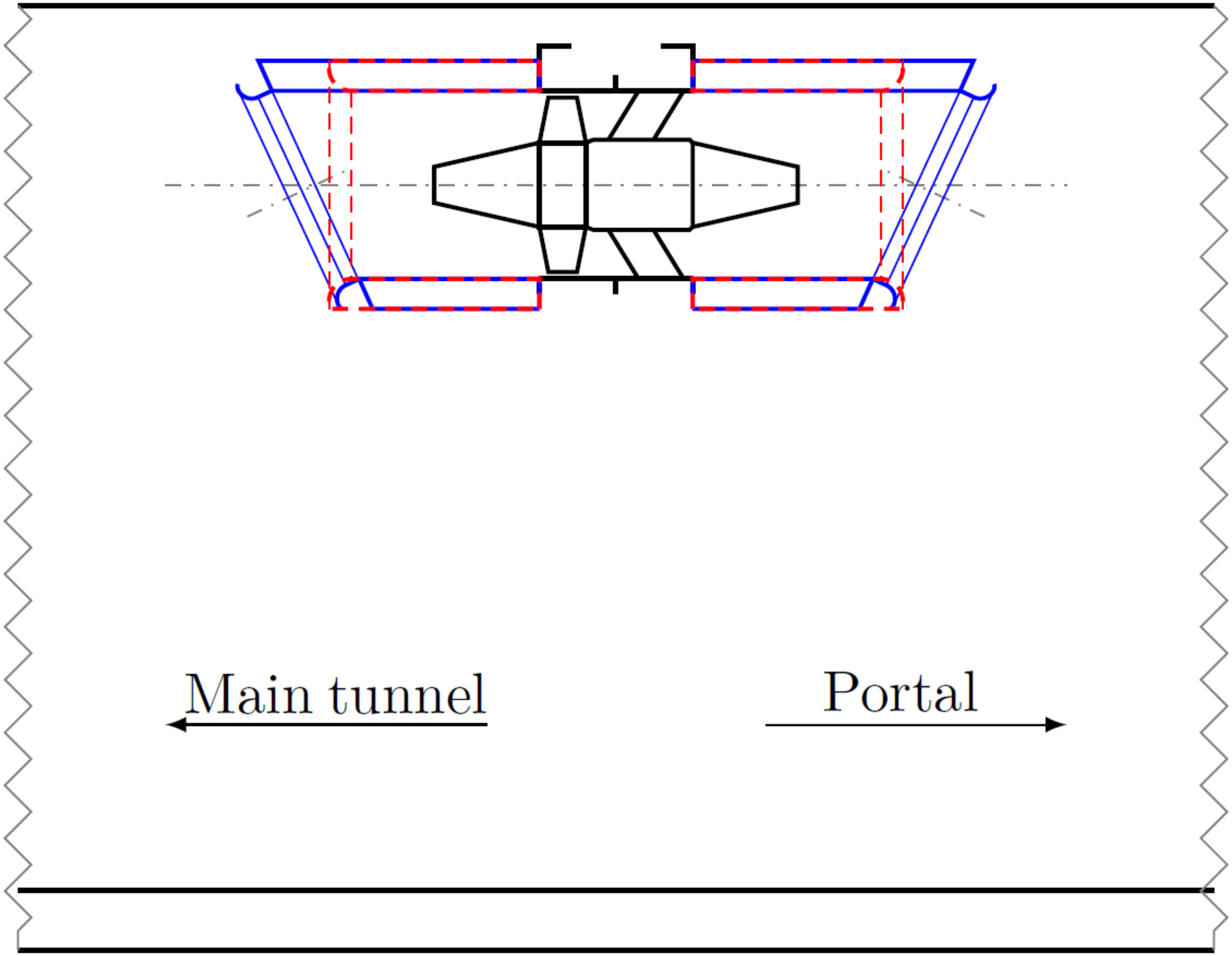
Installation Side View



Installed MoJet

Tunnel Measurements

Airflow Measurements

- BS EN ISO 5802: 2008+A1:2015
- 6 x 6 = 36 points on cross-section measured 140 m away from jet fan
- Calibrated hot wire anemometers used, with Bluetooth connection to tablet
- One minute average per reading

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In-Tunnel Thrust Increase

- Thrust increase proportional to square of velocity ratio
- MoJet increased the in-tunnel thrust by 28.6%

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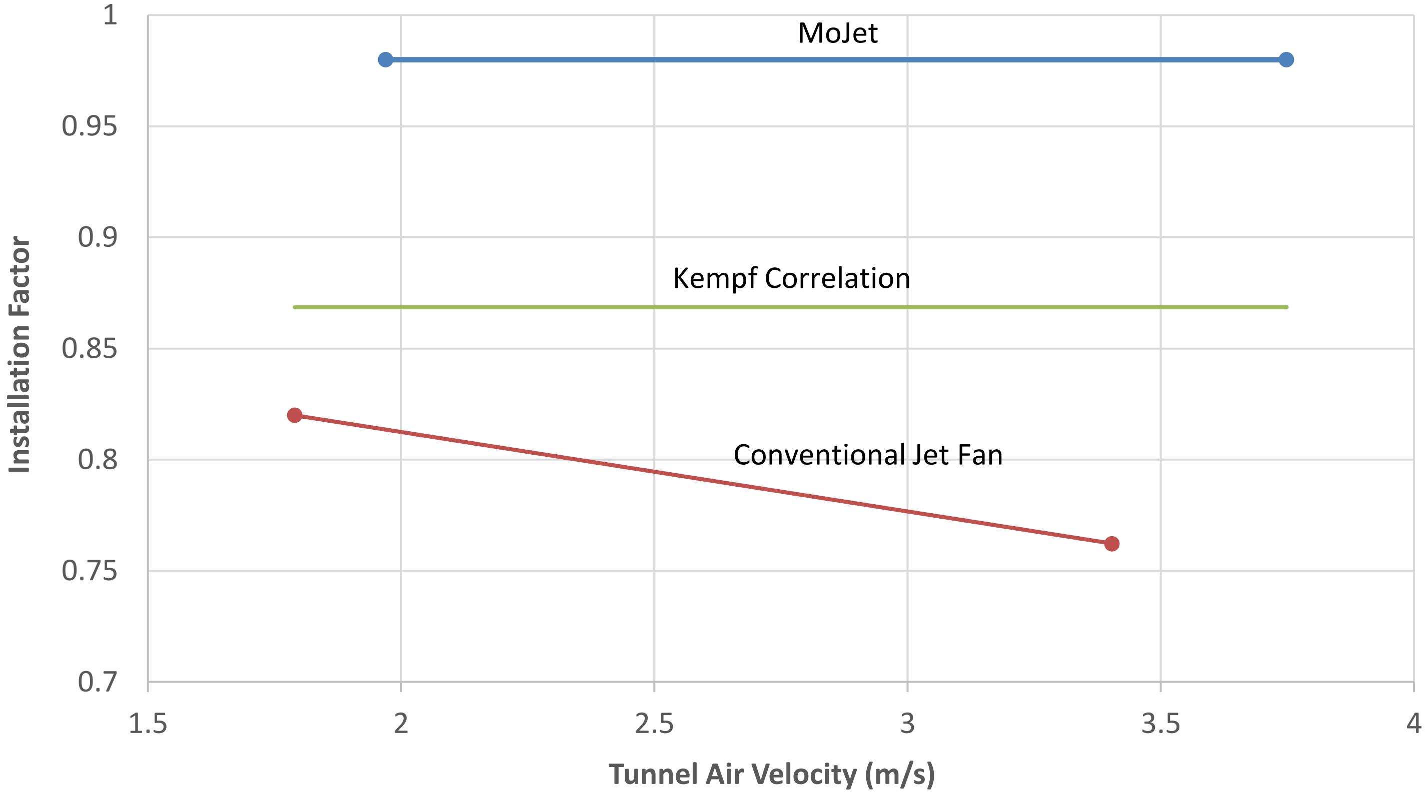
Installation Factor as a Function of Tunnel Air Velocity



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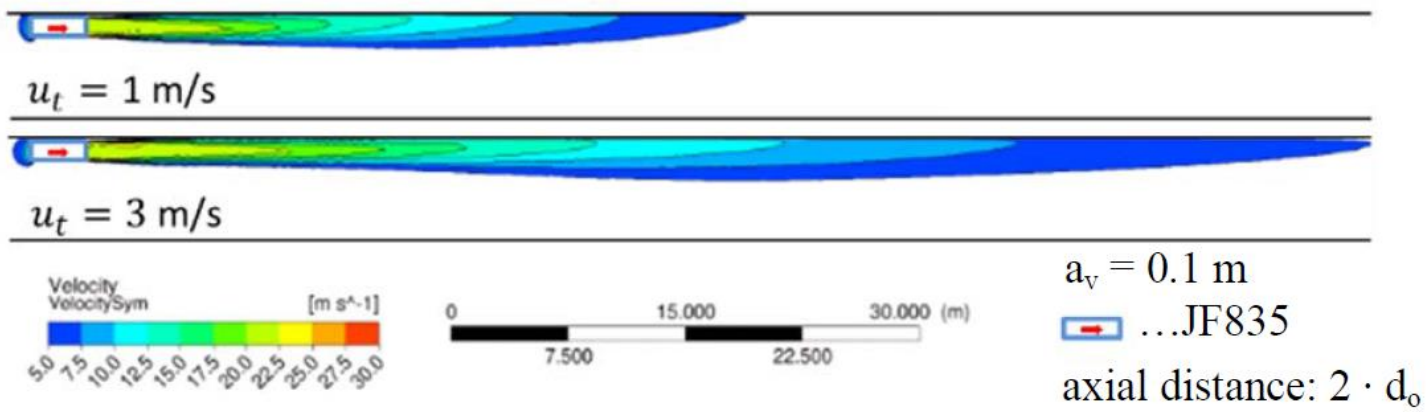
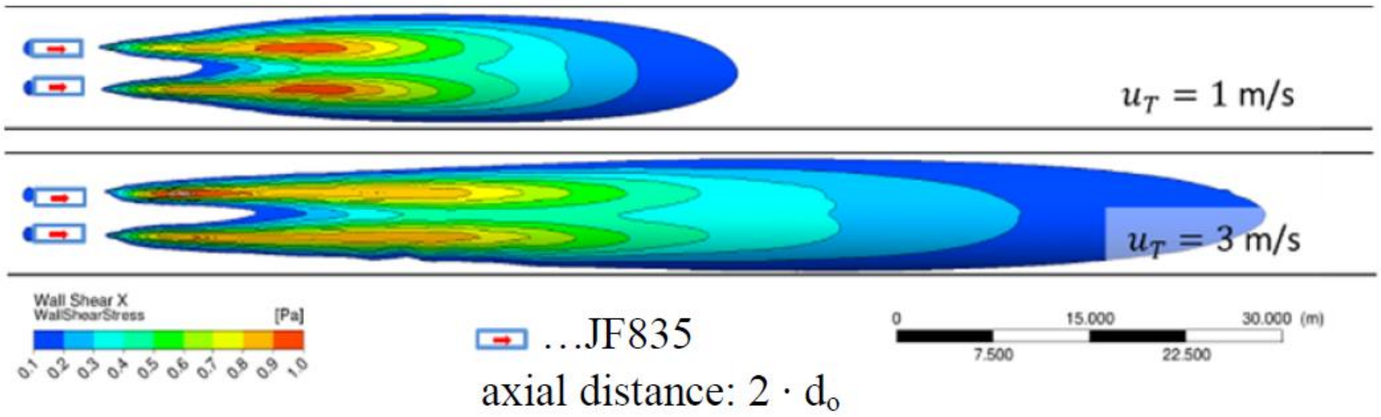
"Friction Patch" Stretching with Air Velocity Beyer et al, Graz University, 2016





3D CFD Calculations of Jet Fan Installation Factors

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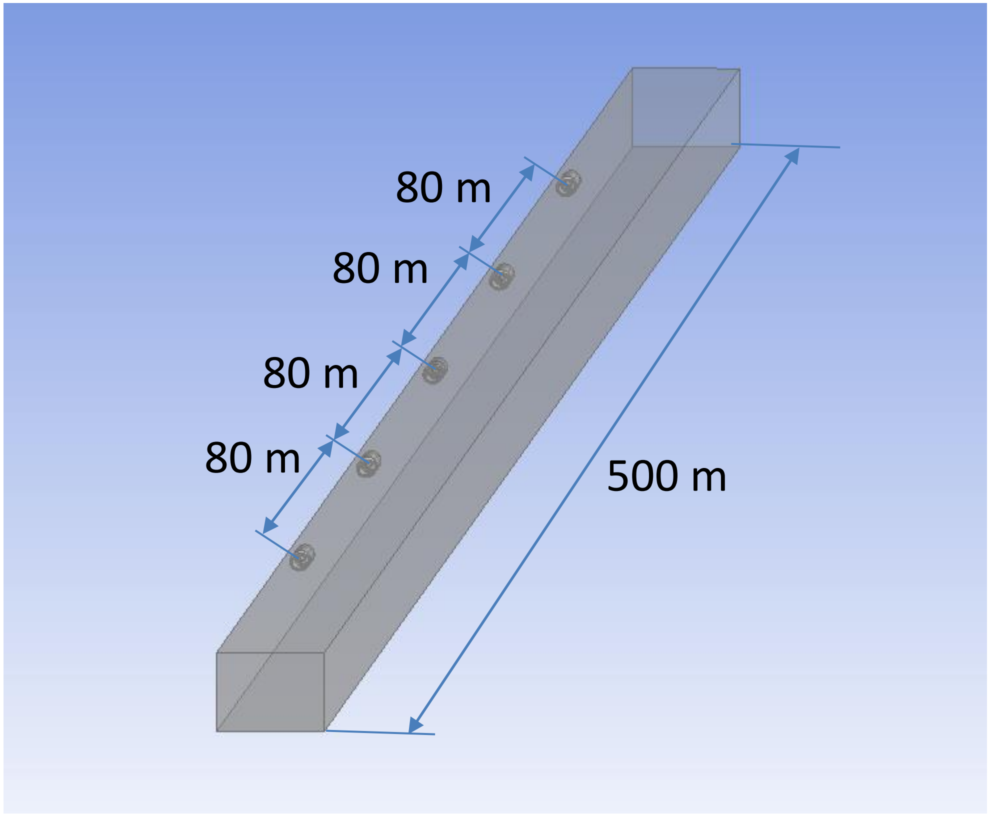
Tunnel Geometry



500 m long tunnel
2-lane road tunnel with hard shoulder
1.25m internal diameter jet fans
5 no. jet fans 80m (10 tunnel hydraulic diameters) apart

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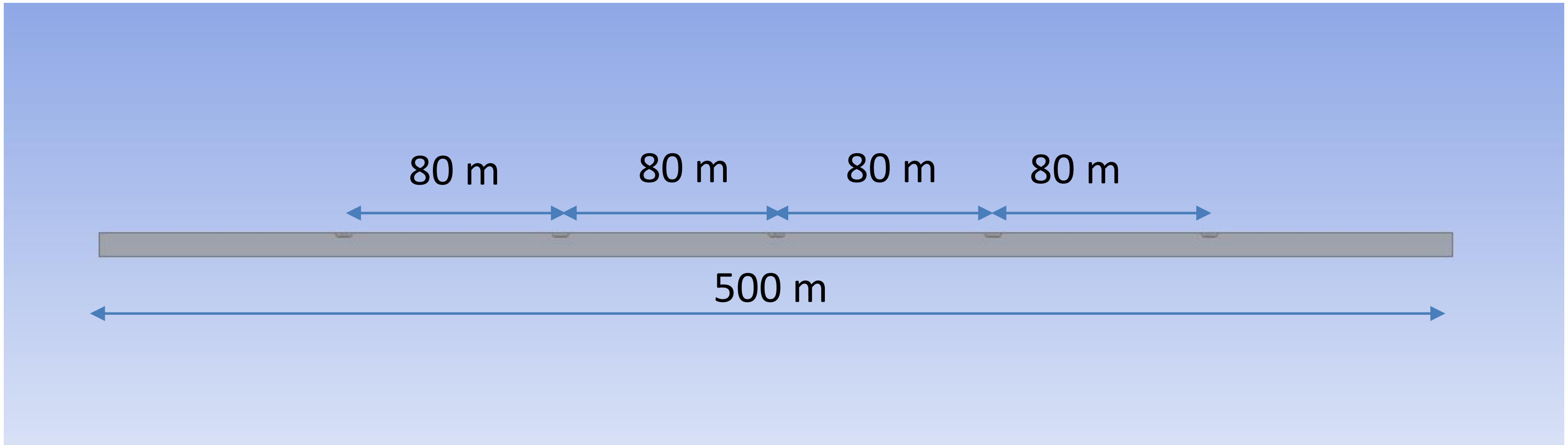
Tunnel Geometry

500 m long tunnel
5 no. Jet fans 80m apart



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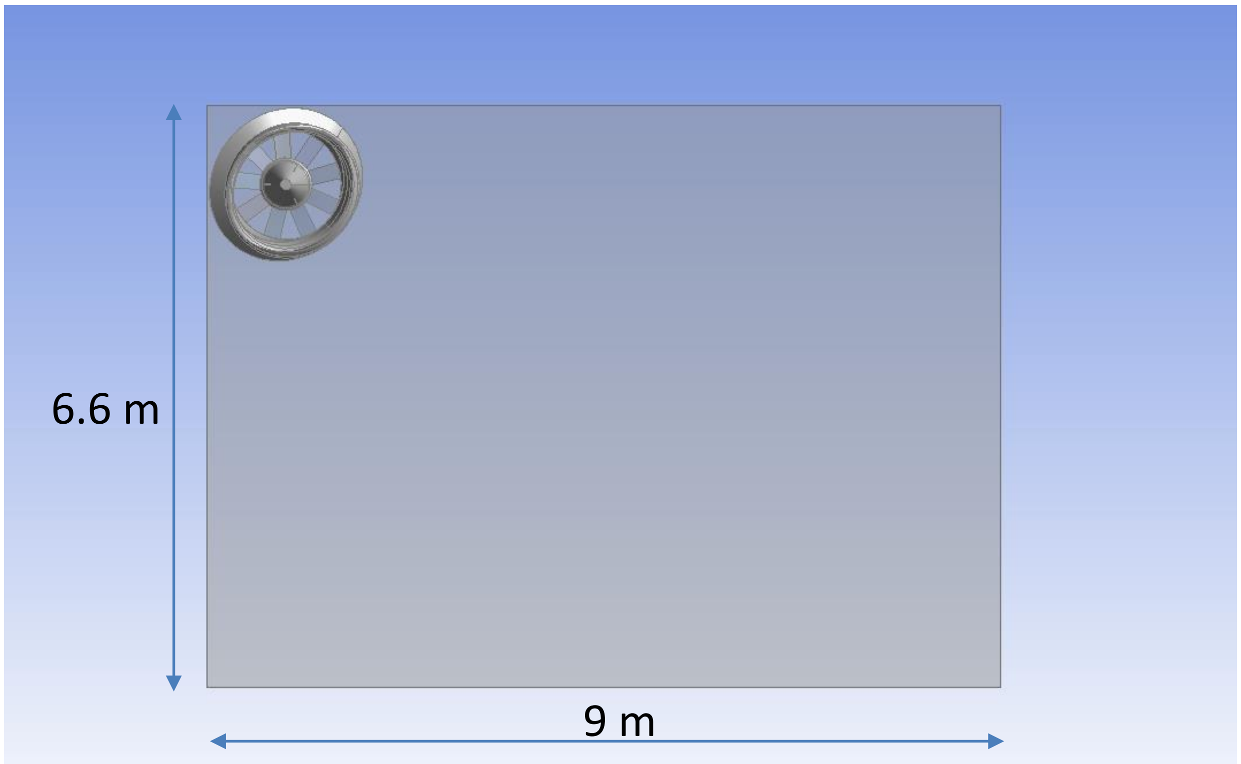
Tunnel Geometry



Tunnel Cross Section 9 m x 6.6 m

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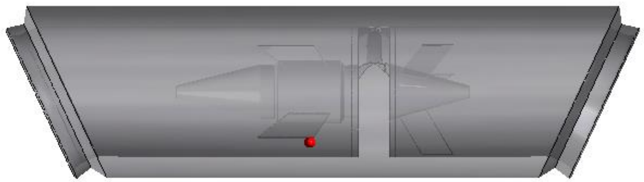
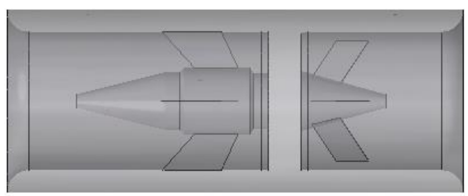
Fans



1250mm Dia MoJet



1250mm Dia Conventional Jet Fan

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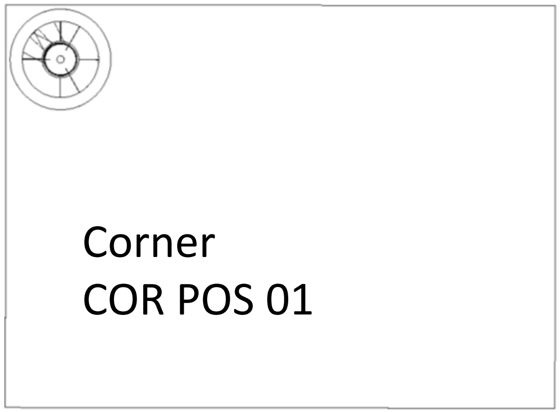
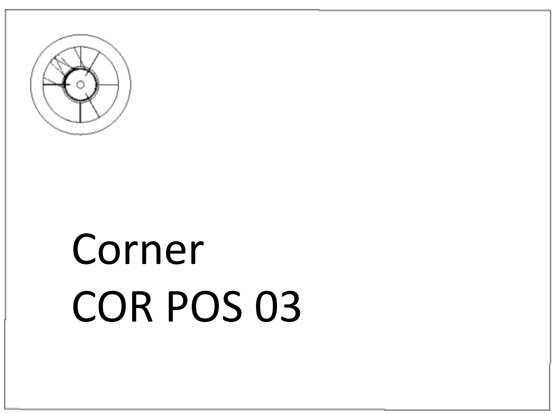
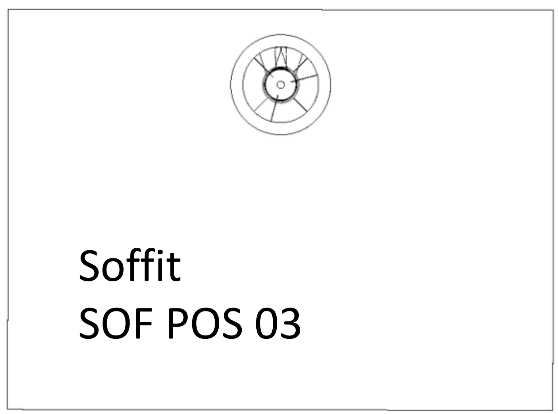
Fan Positions







POS 01 – As close as possible to nearest wall and/or soffit

POS 03 – Fan positioned 0.3 x internal fan diameter from nearest wall and/or soffit

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3D CFD Modelling

- ANSYS Fluent
- Rotating blades modelled (1485 rpm)
- Non-buoyant model
- Real gas model
- k-ω shear stress transport turbulence model
- Master/slave jet fans
- Typically 20 – 25 million cells per run

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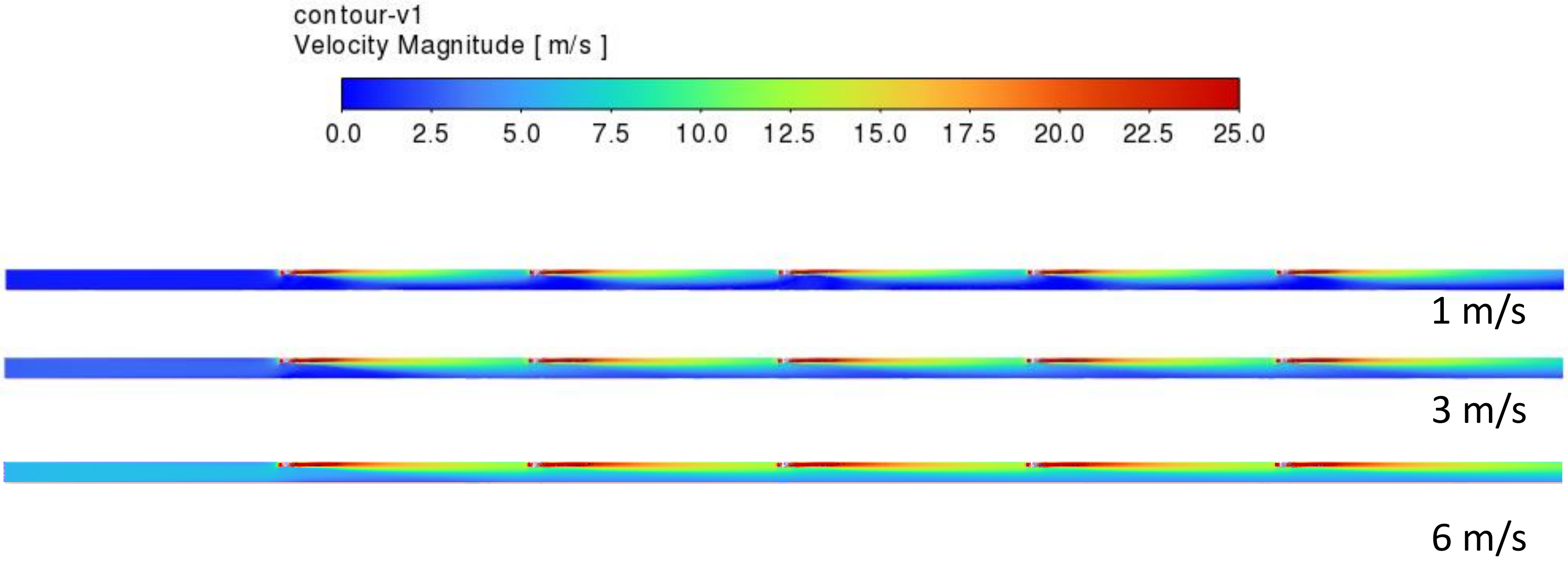
Conventional Jet Fan Corner Pos 01



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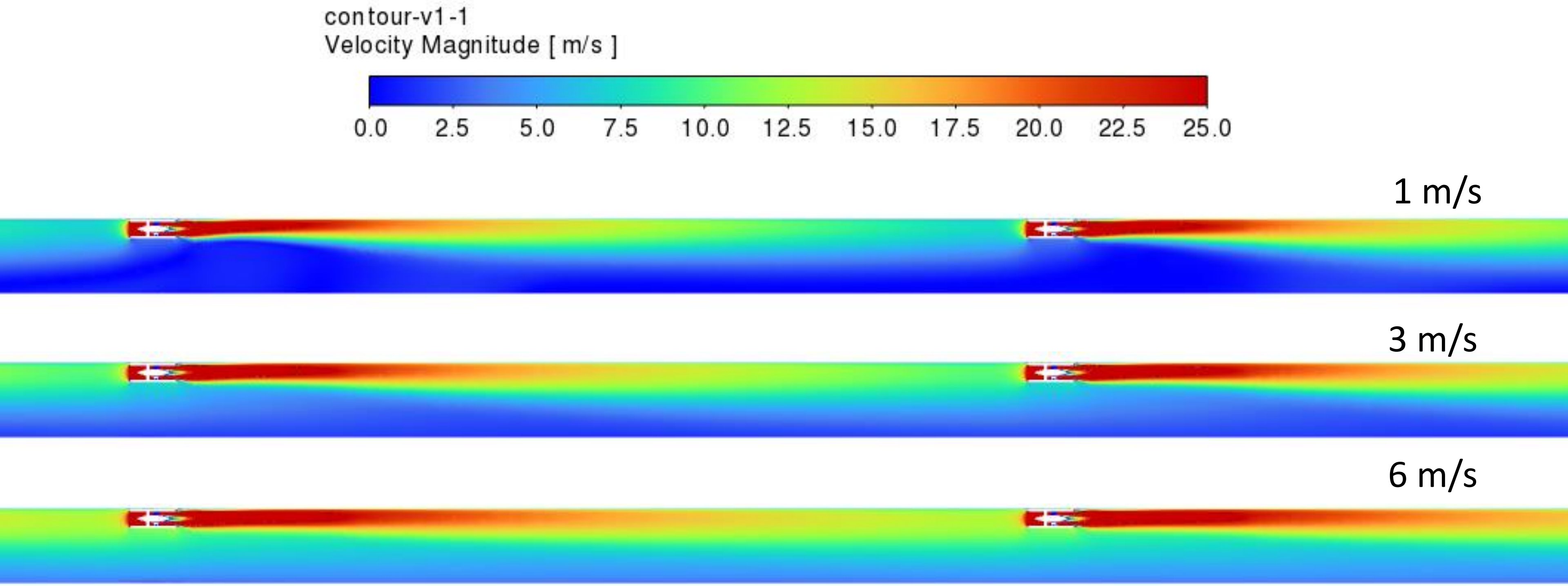
Conventional Jet Fan Corner Pos 01



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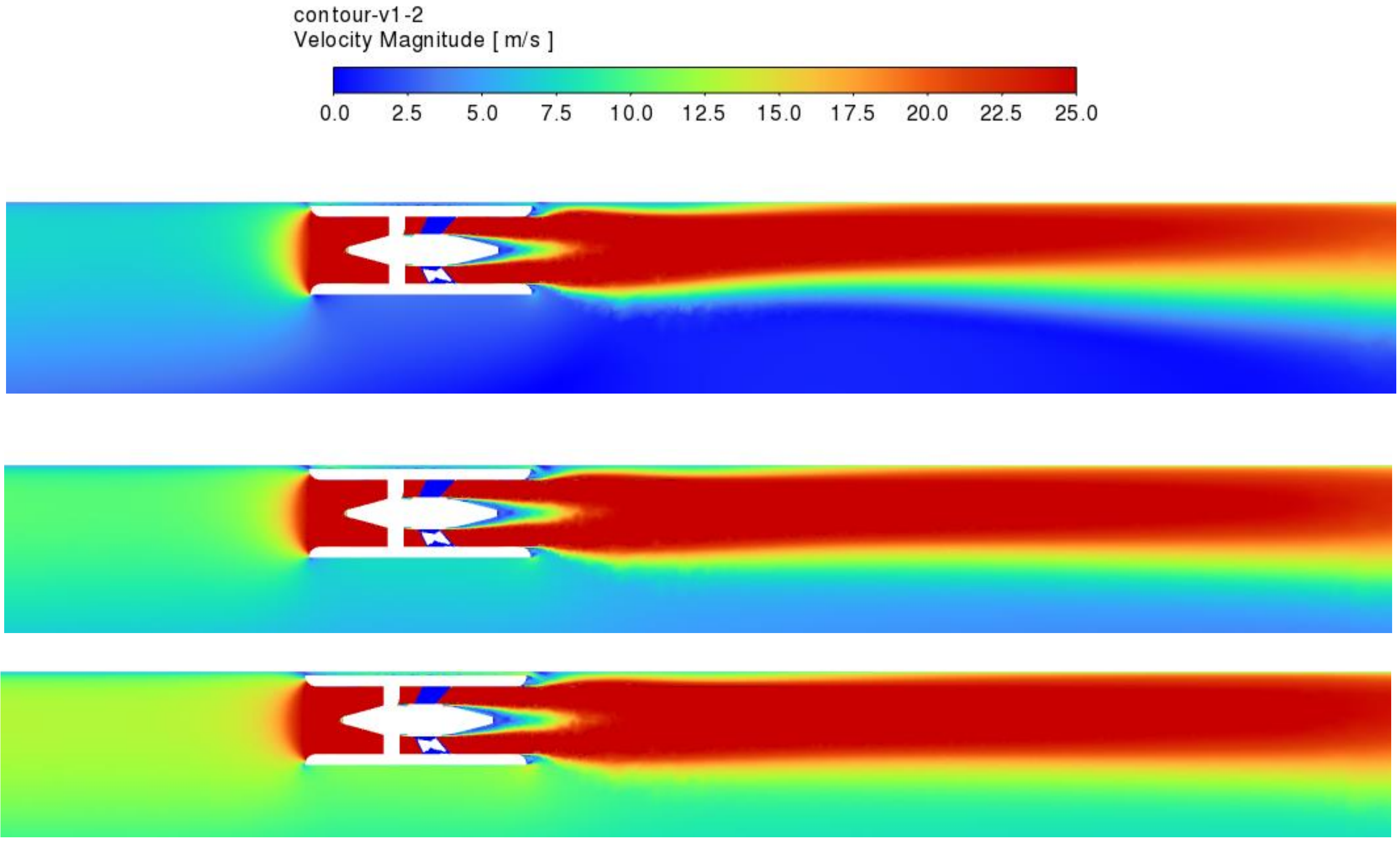
Conventional Jet Fan Corner Pos 01



1 m/s

3 m/s

6 m/s

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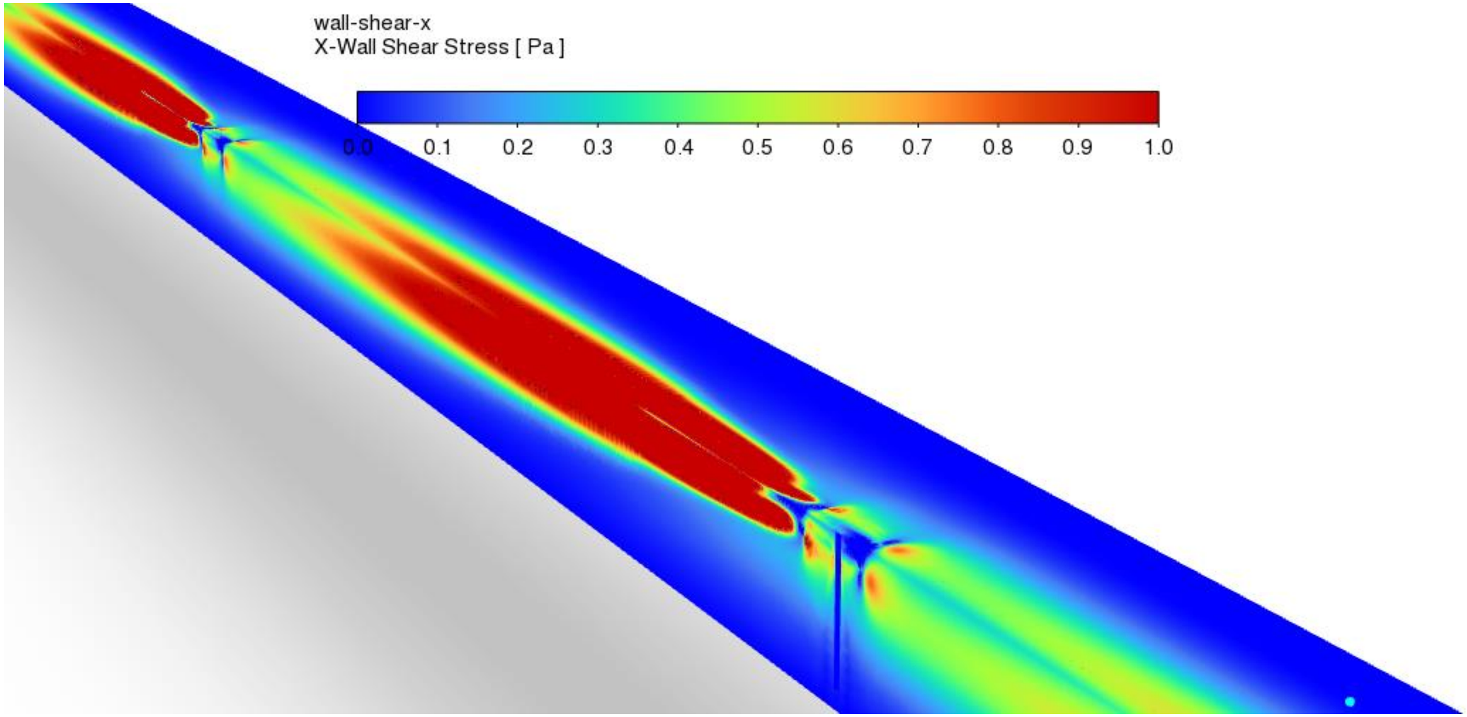
Conventional Jet Fan Corner Pos 01



3 m/s

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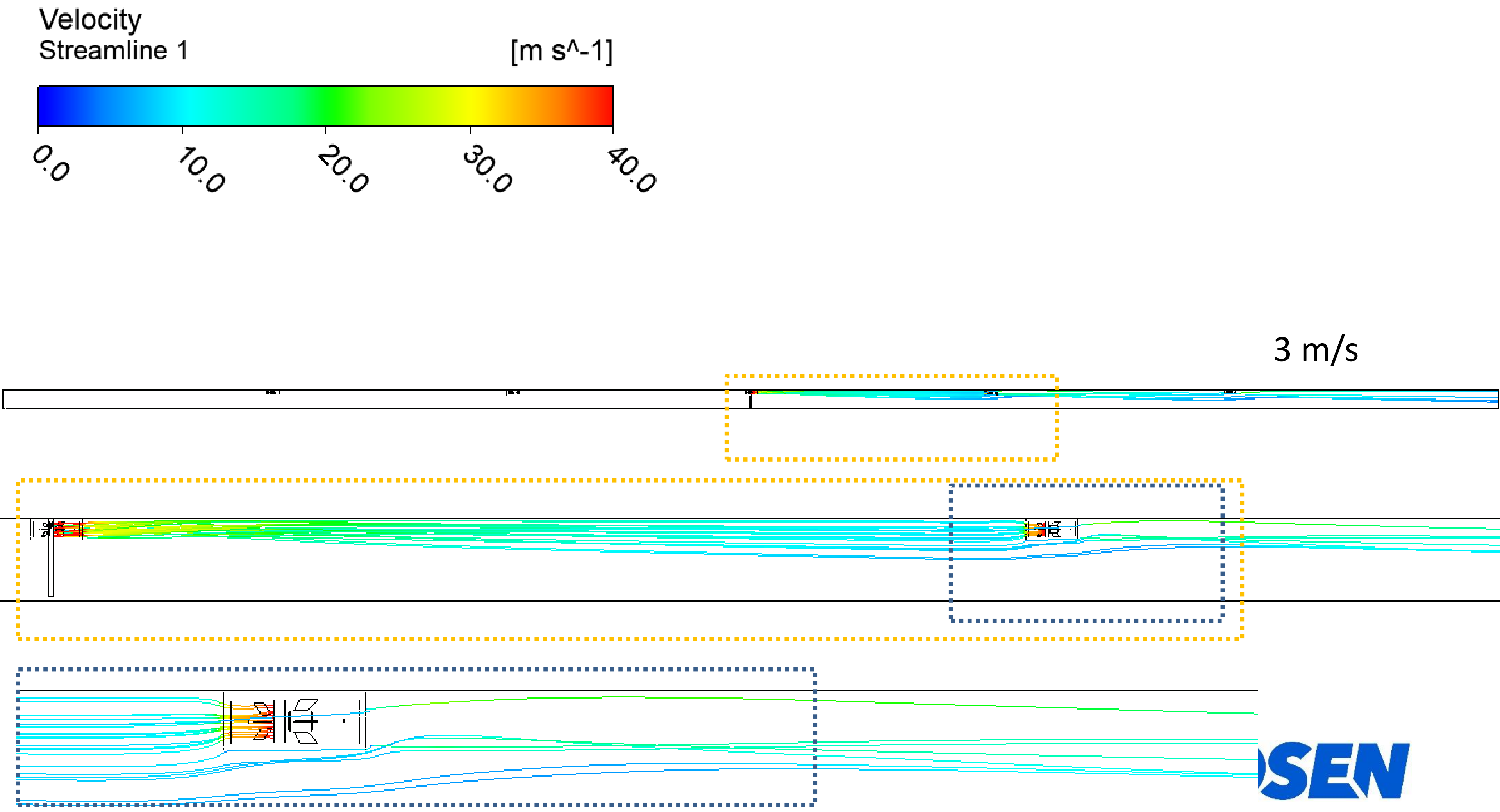
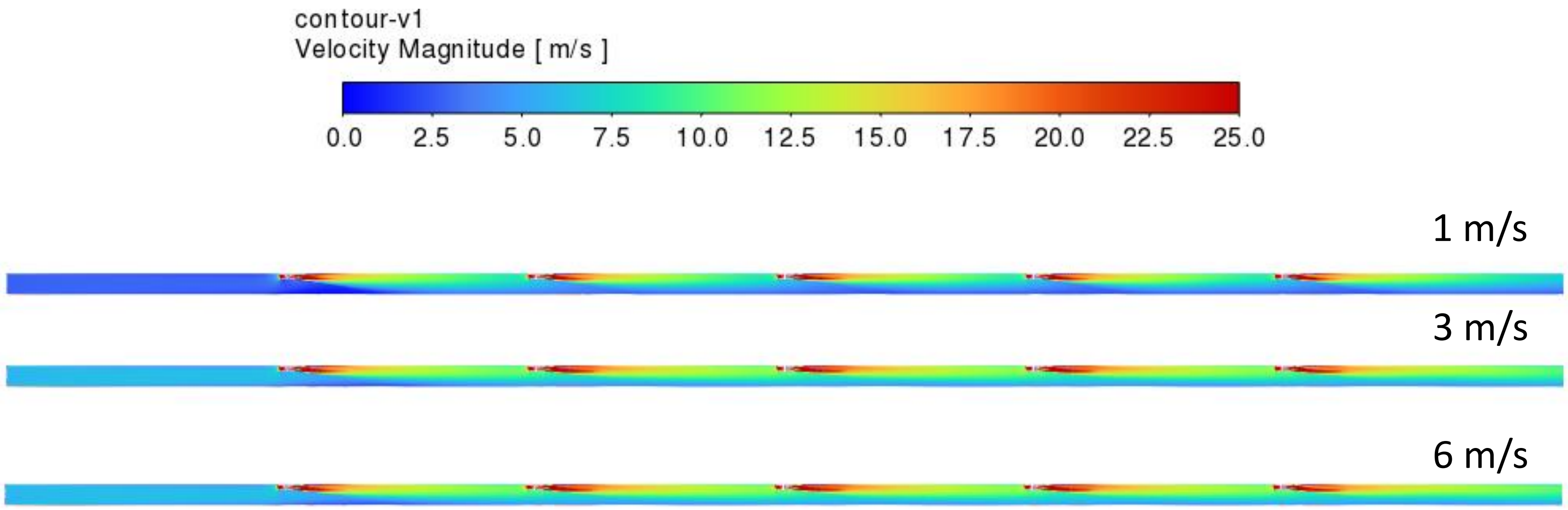
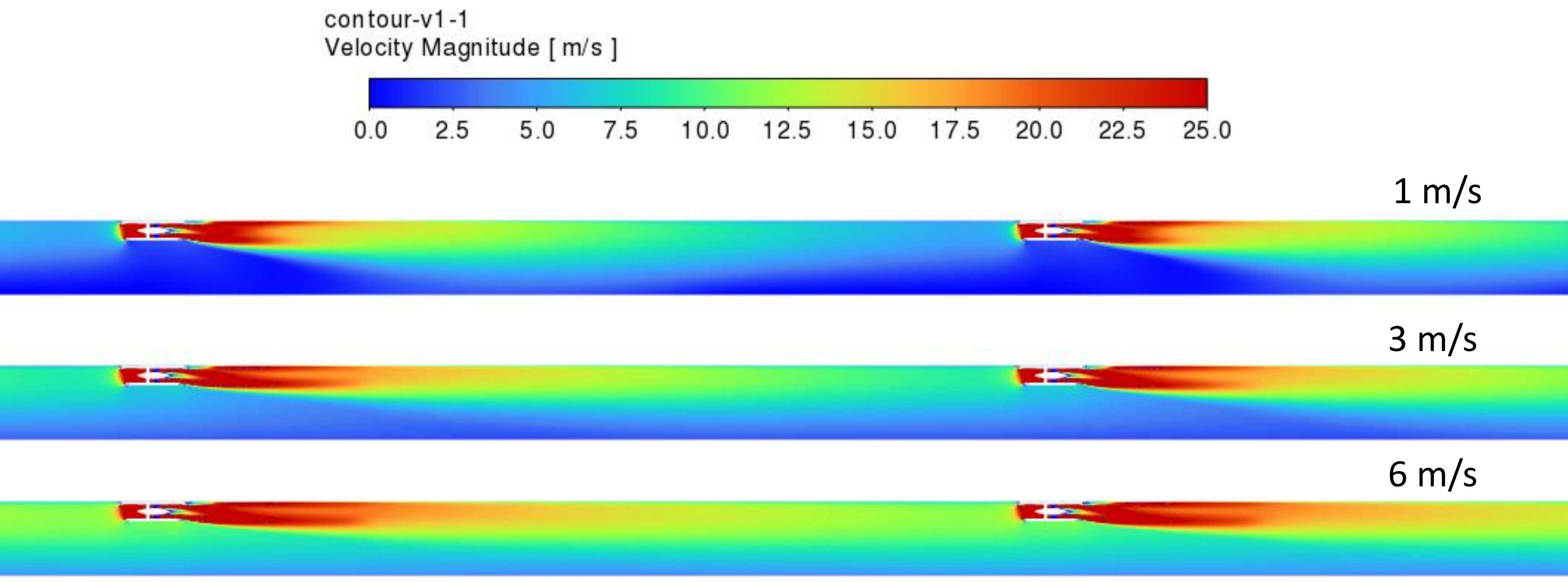
Conventional Jet Fan Corner Pos 01



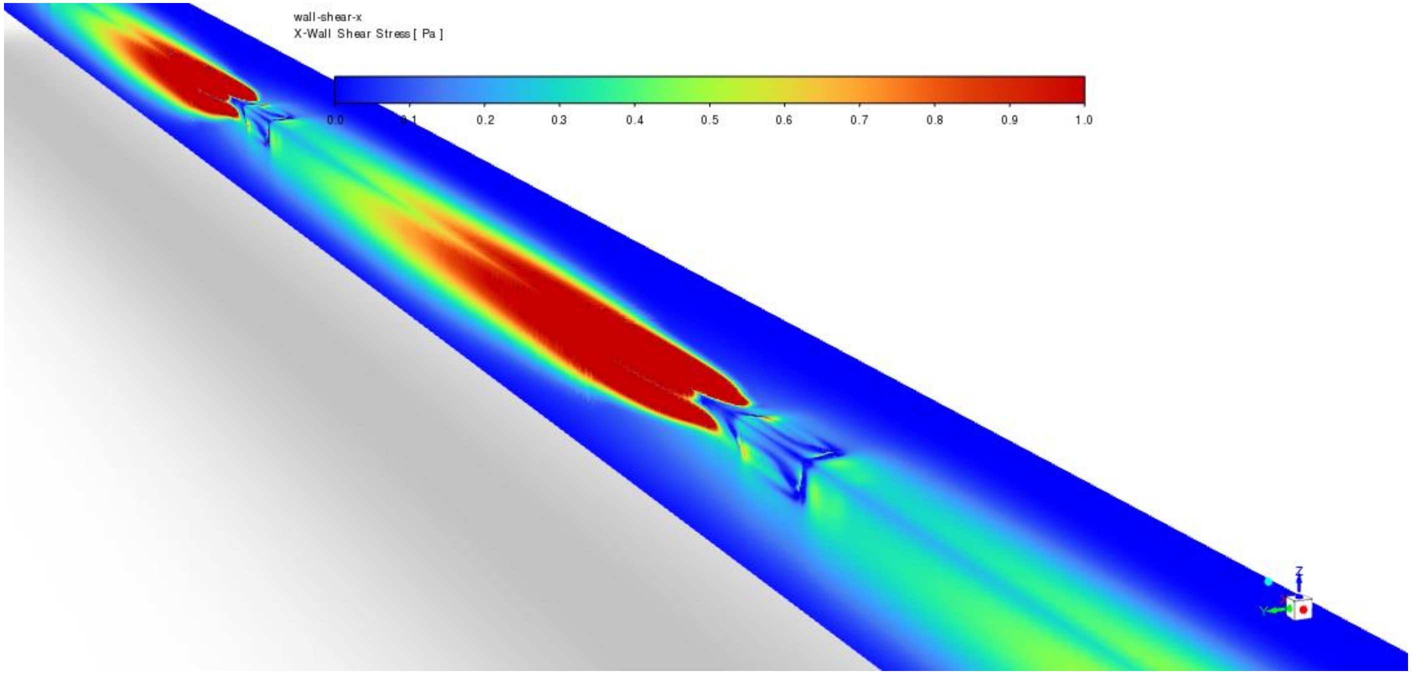
MoJet Corner Pos 01



MoJet Corner Pos 01

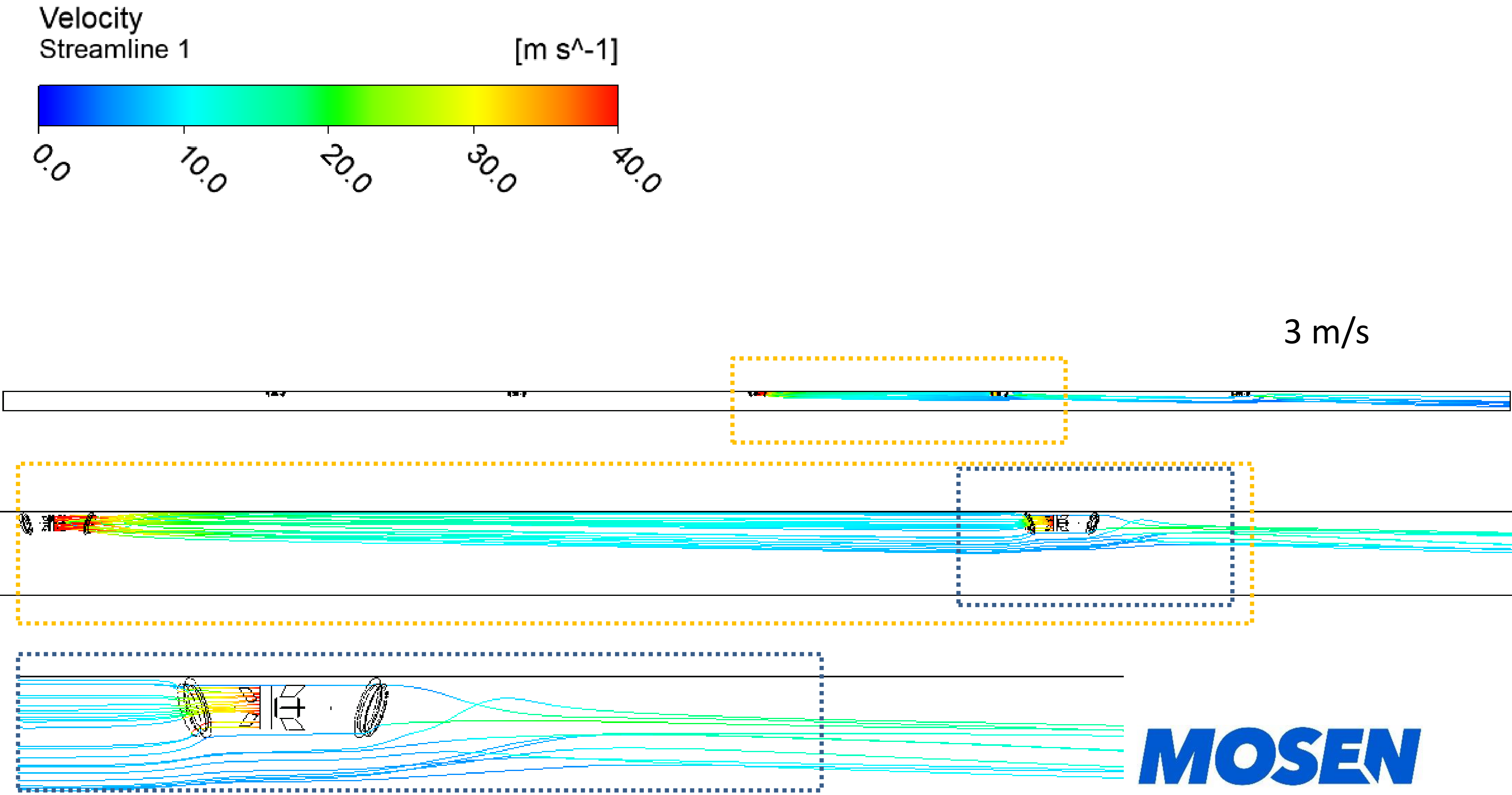


MoJet Corner Pos 01

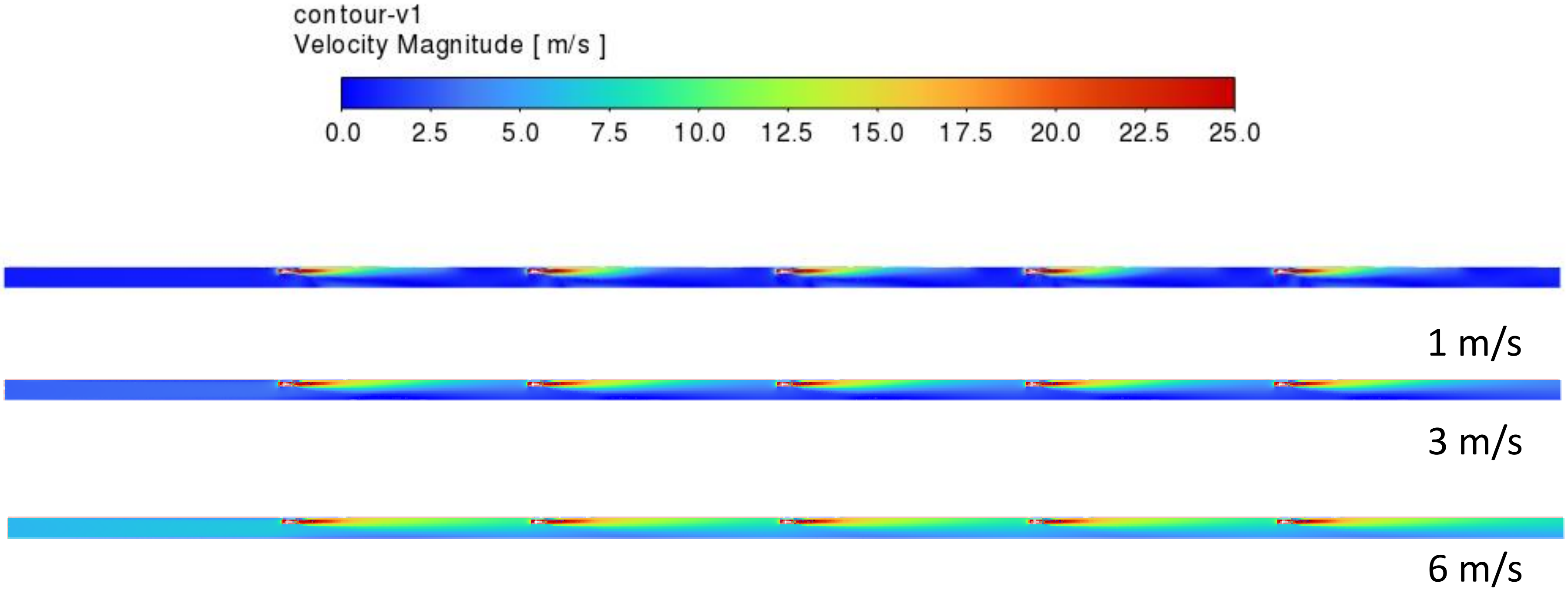


3 m/s

MoJet Corner Pos 01



Conventional Jet Fan Soffit Pos 03



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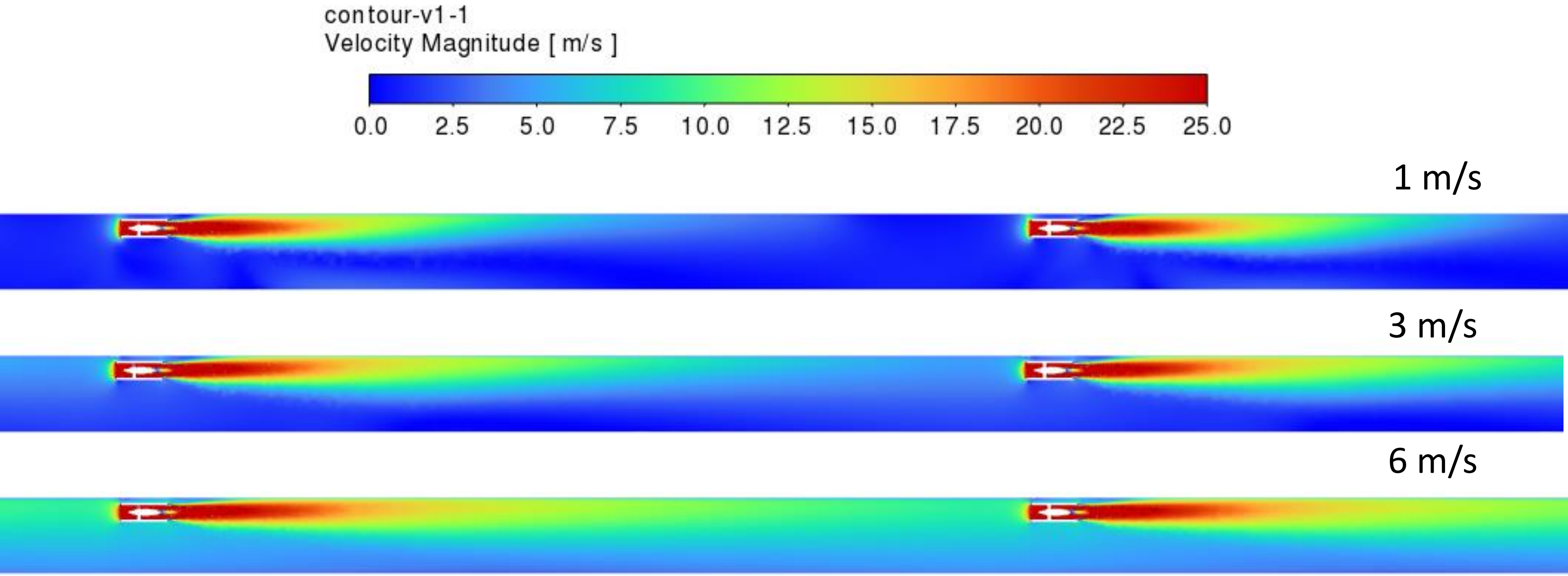
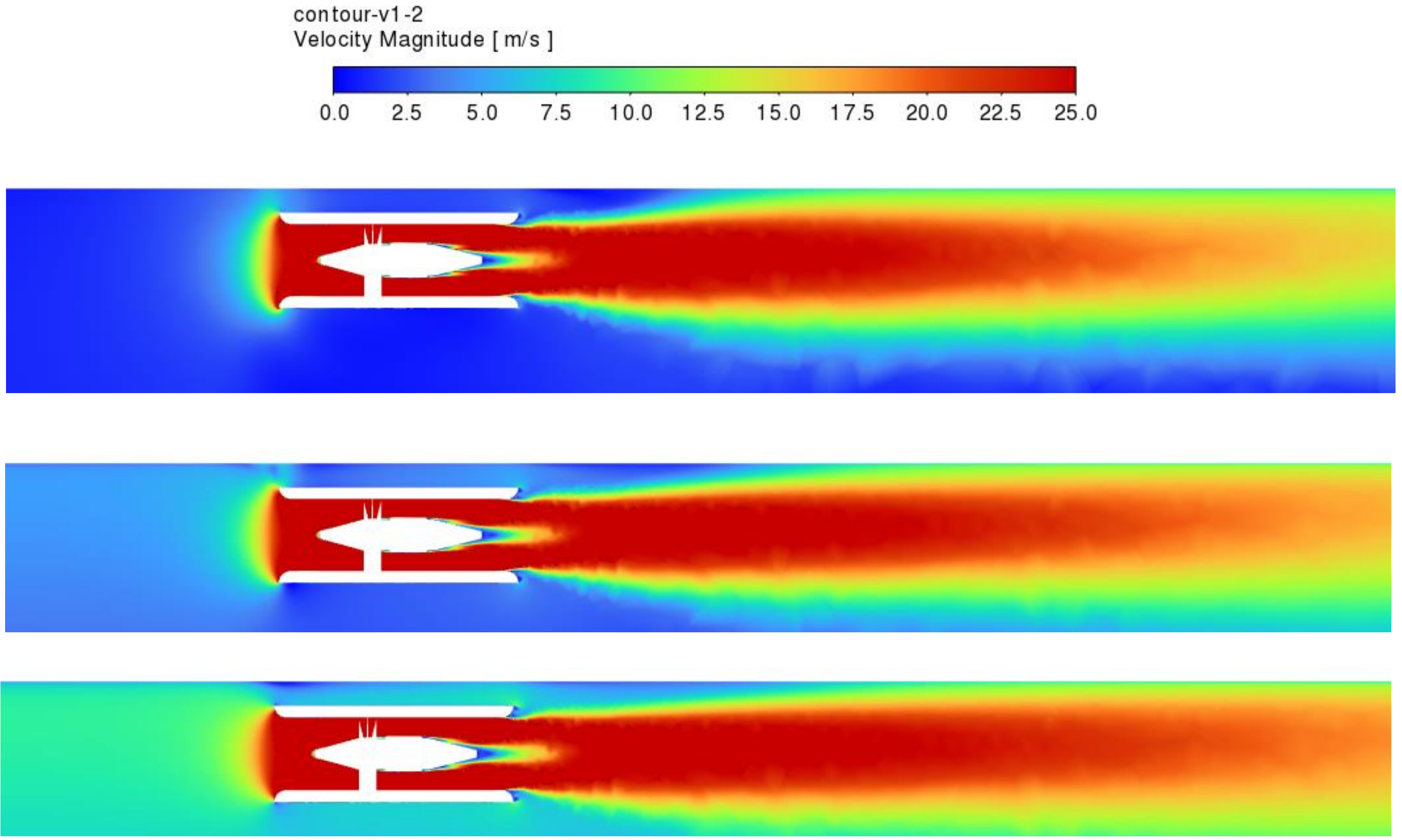
Conventional Jet Fan Soffit Pos 03



Conventional Jet Fan Soffit Pos 03



1 m/s

3 m/s

6 m/s

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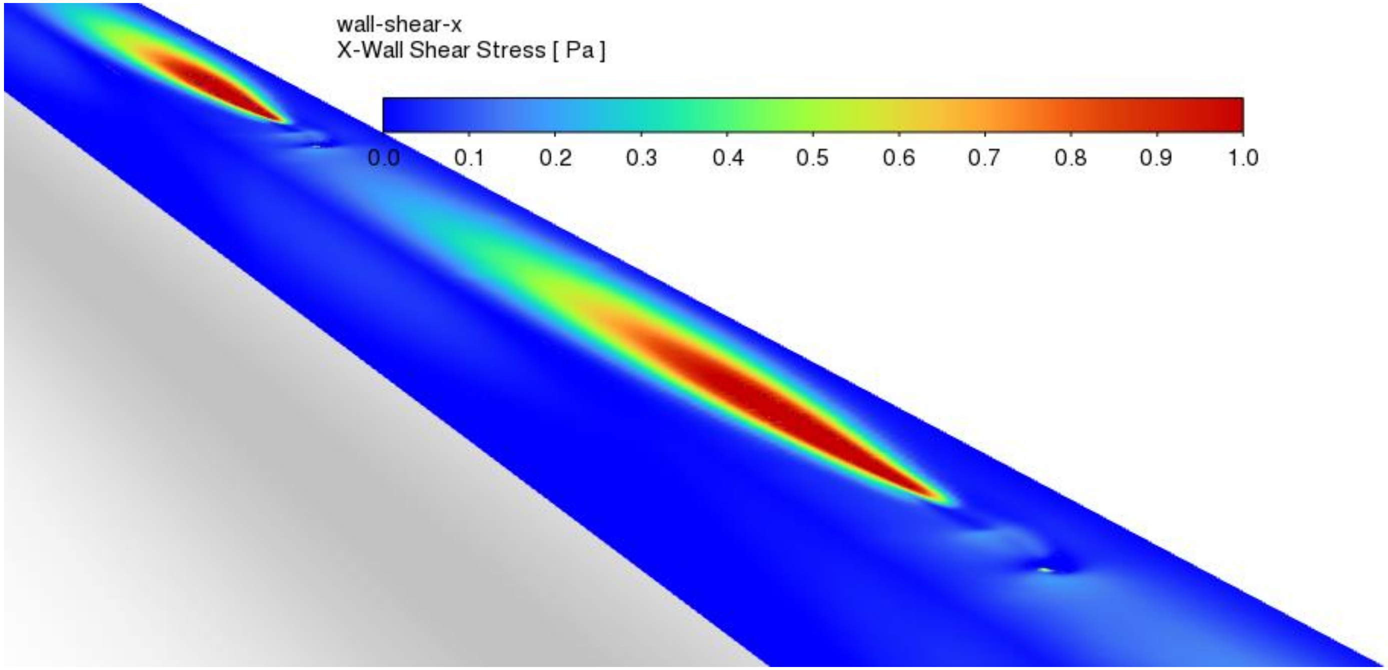
Conventional Jet Fan Soffit Pos 03

3 m/s



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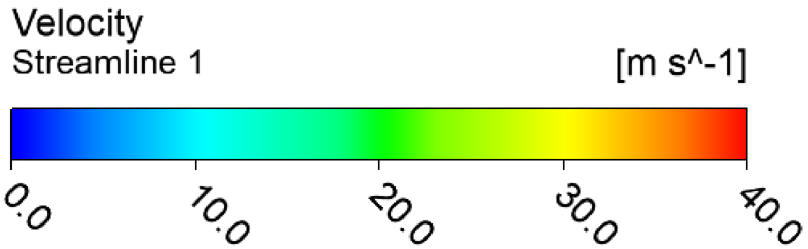
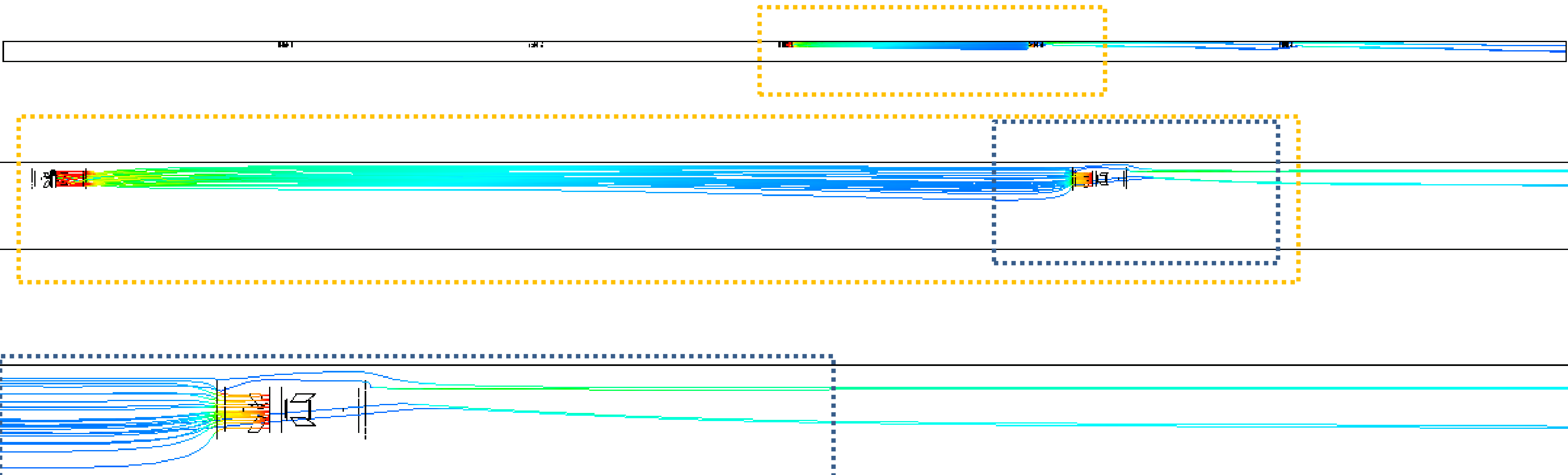
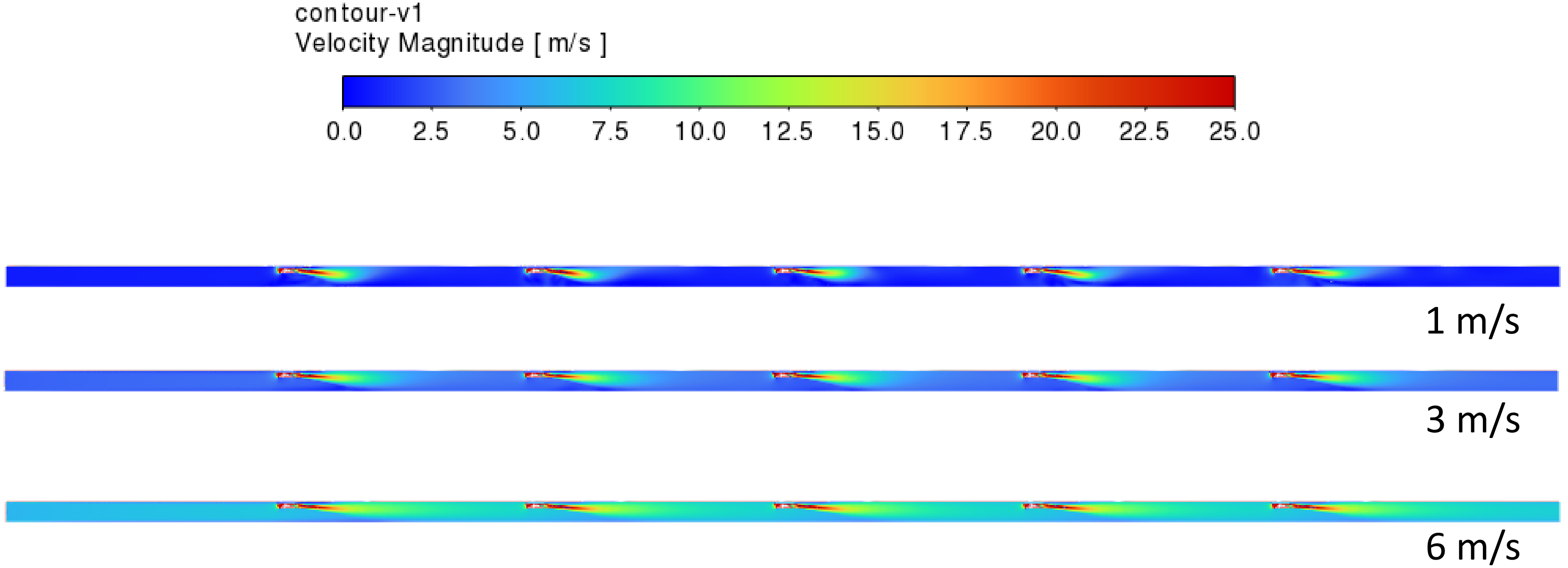
Conventional Jet Fan Soffit Pos 03



3 m/s



MoJet Soffit Pos 03



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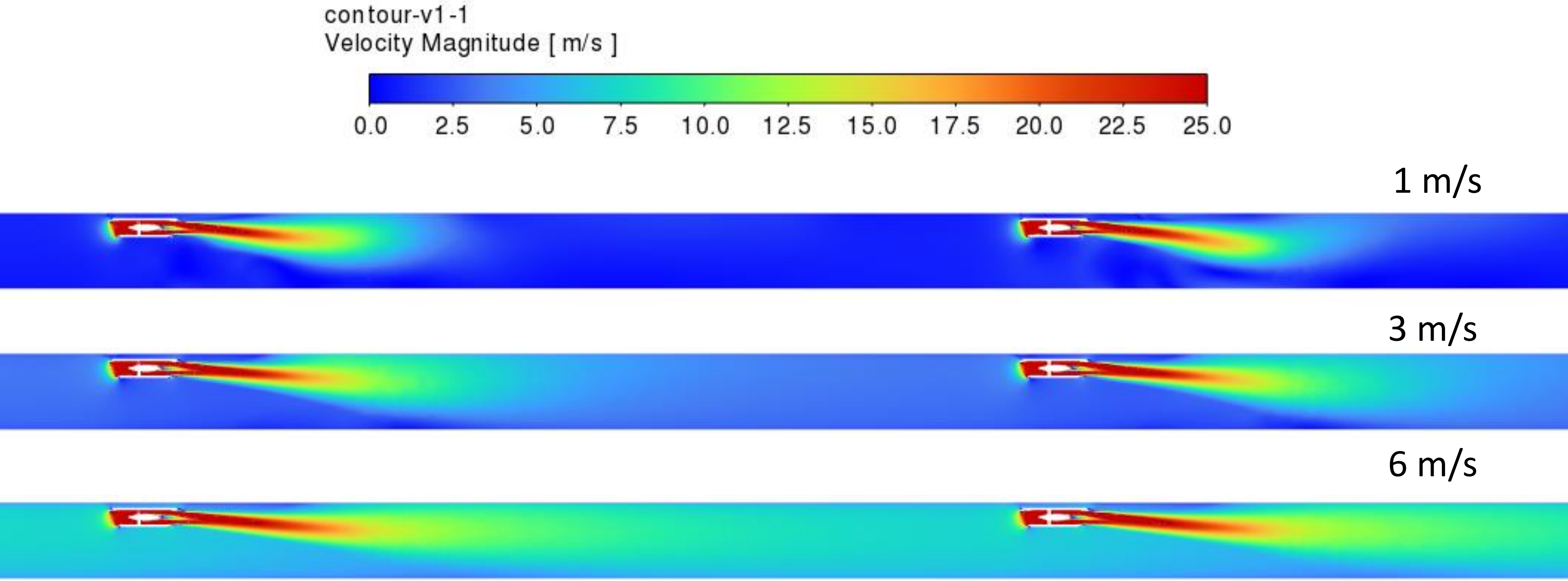
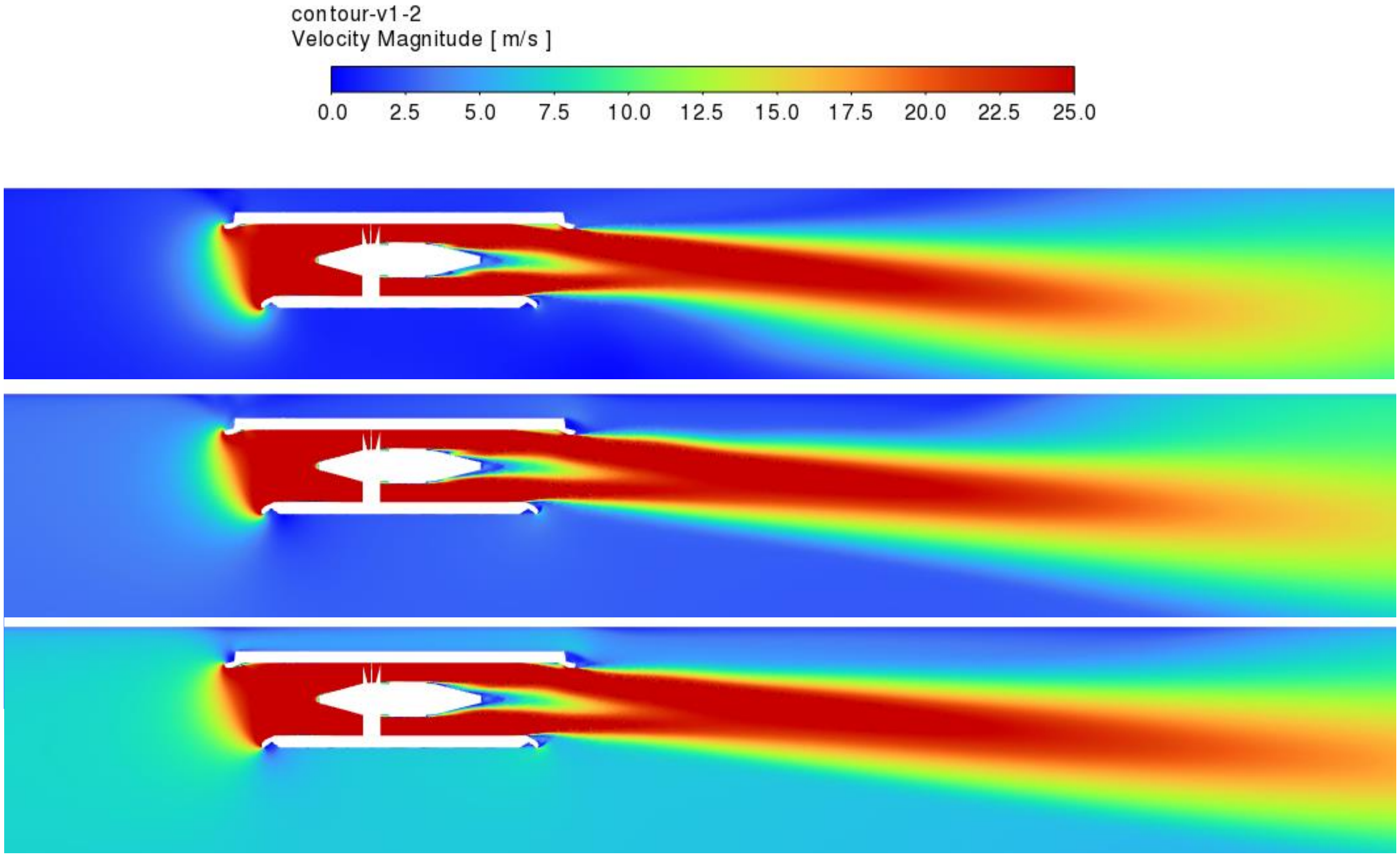
MoJet Soffit Pos 03



MoJet Soffit Pos 03



1 m/s

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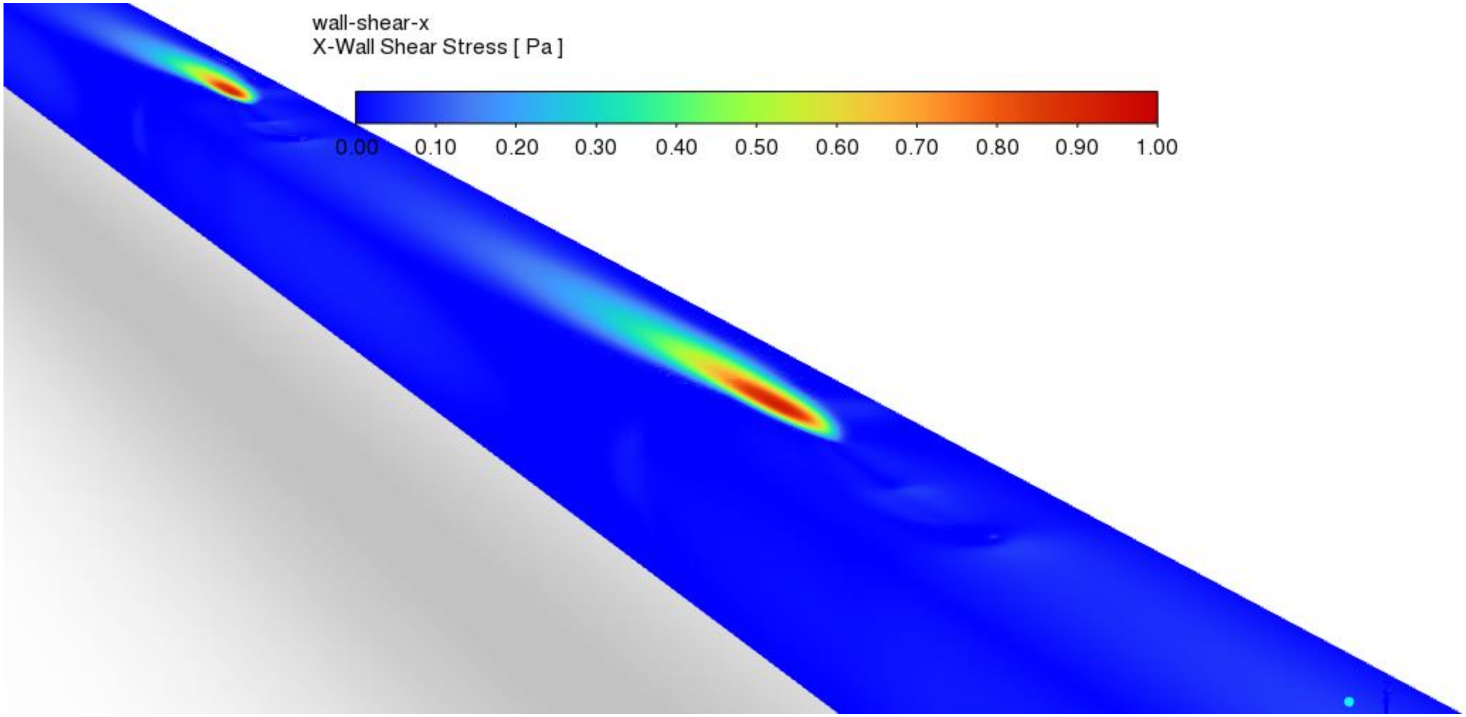
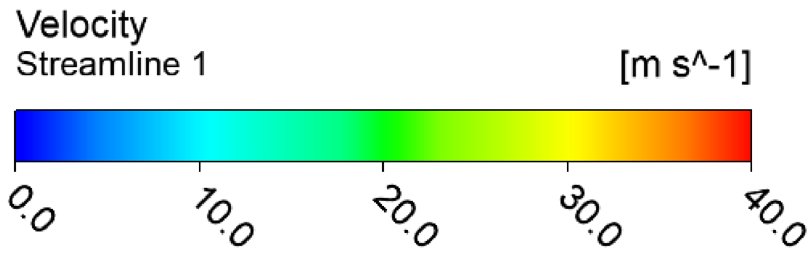
MoJet Soffit Pos 03

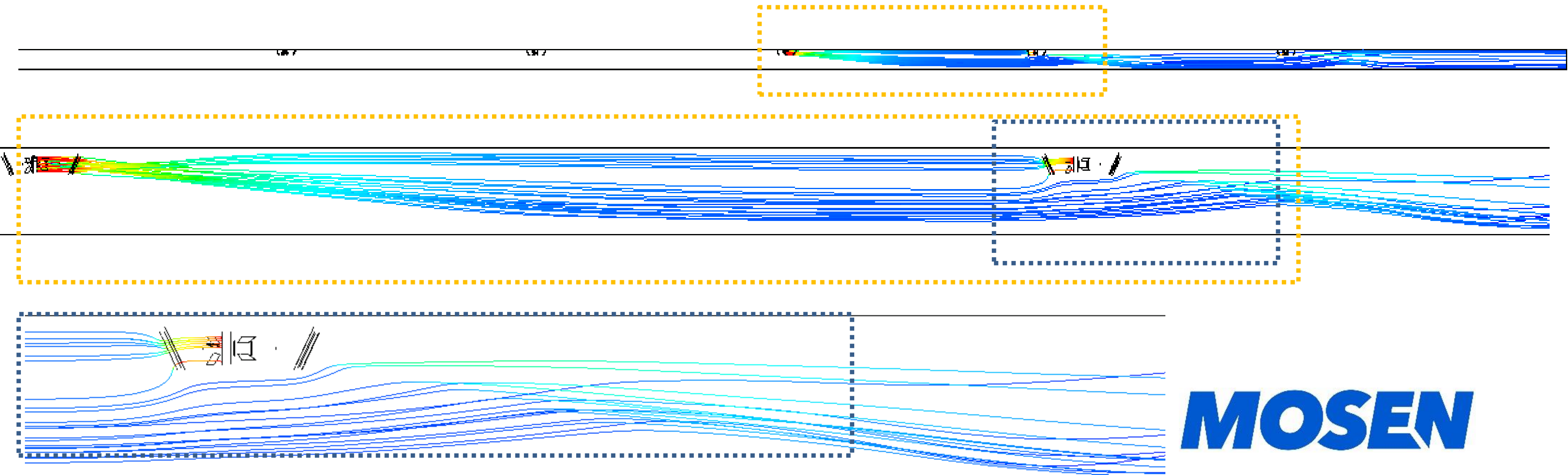


3 m/s

MoJet Soffit Pos 03



3 m/s



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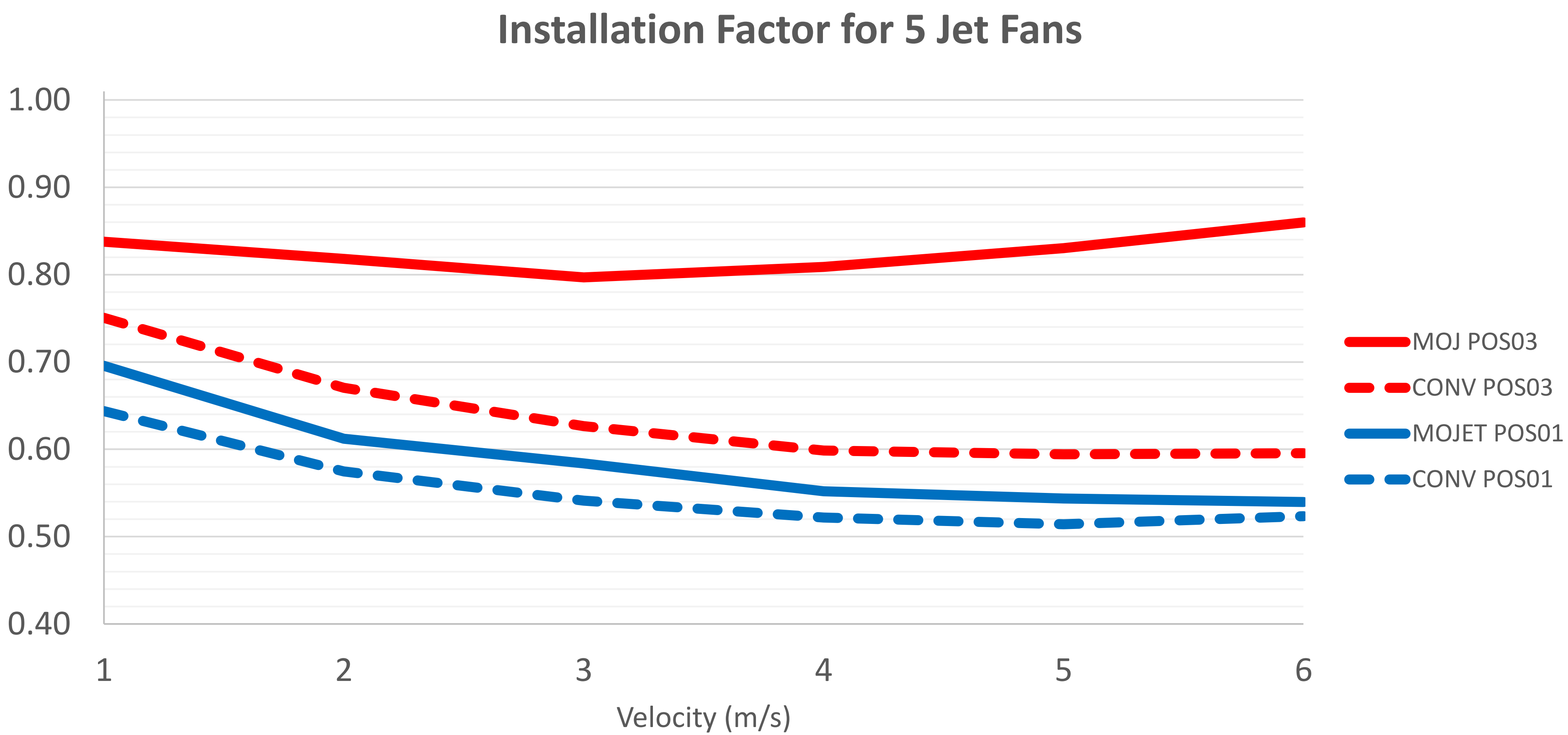
Installation Factor - Corner



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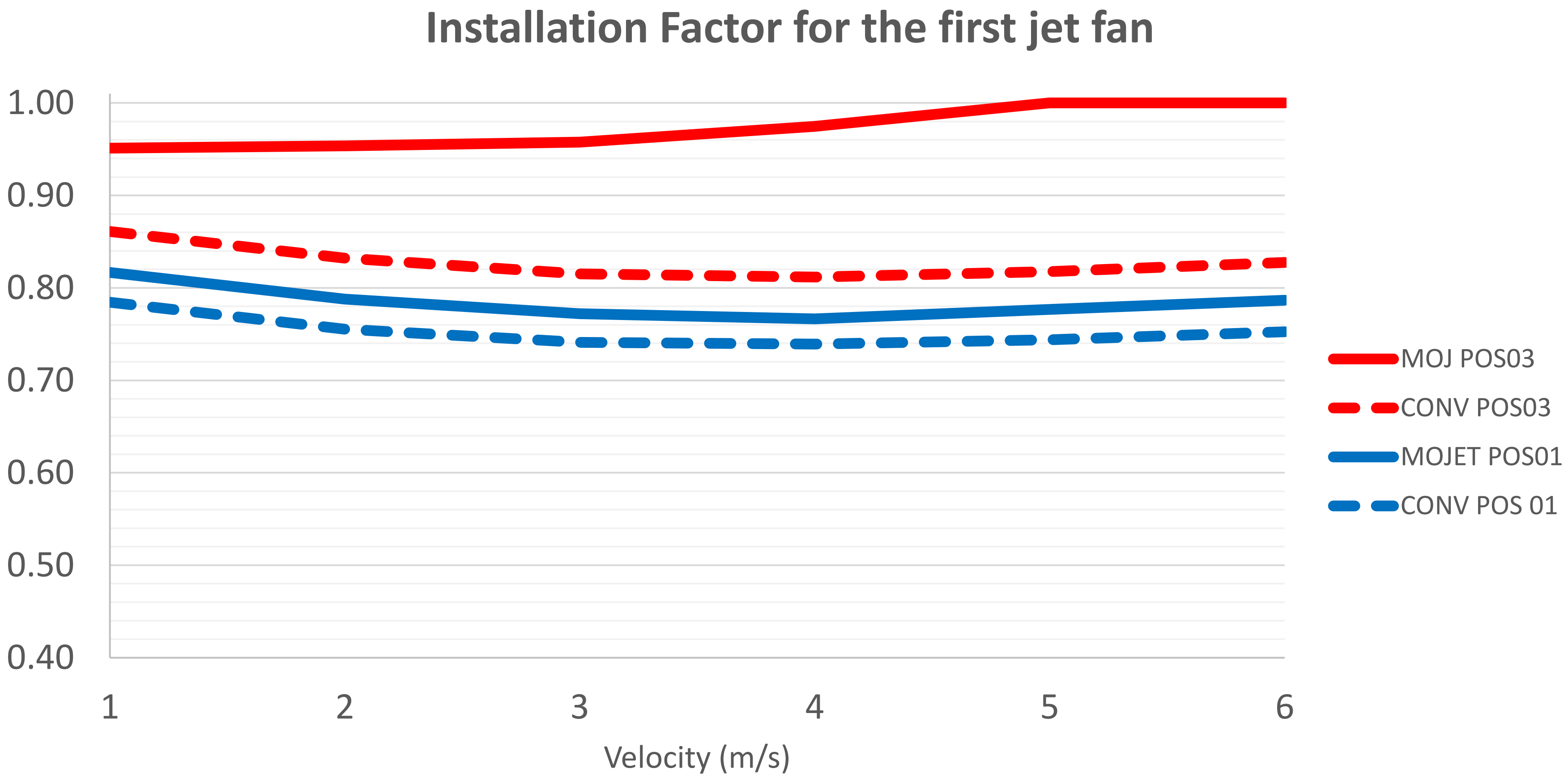
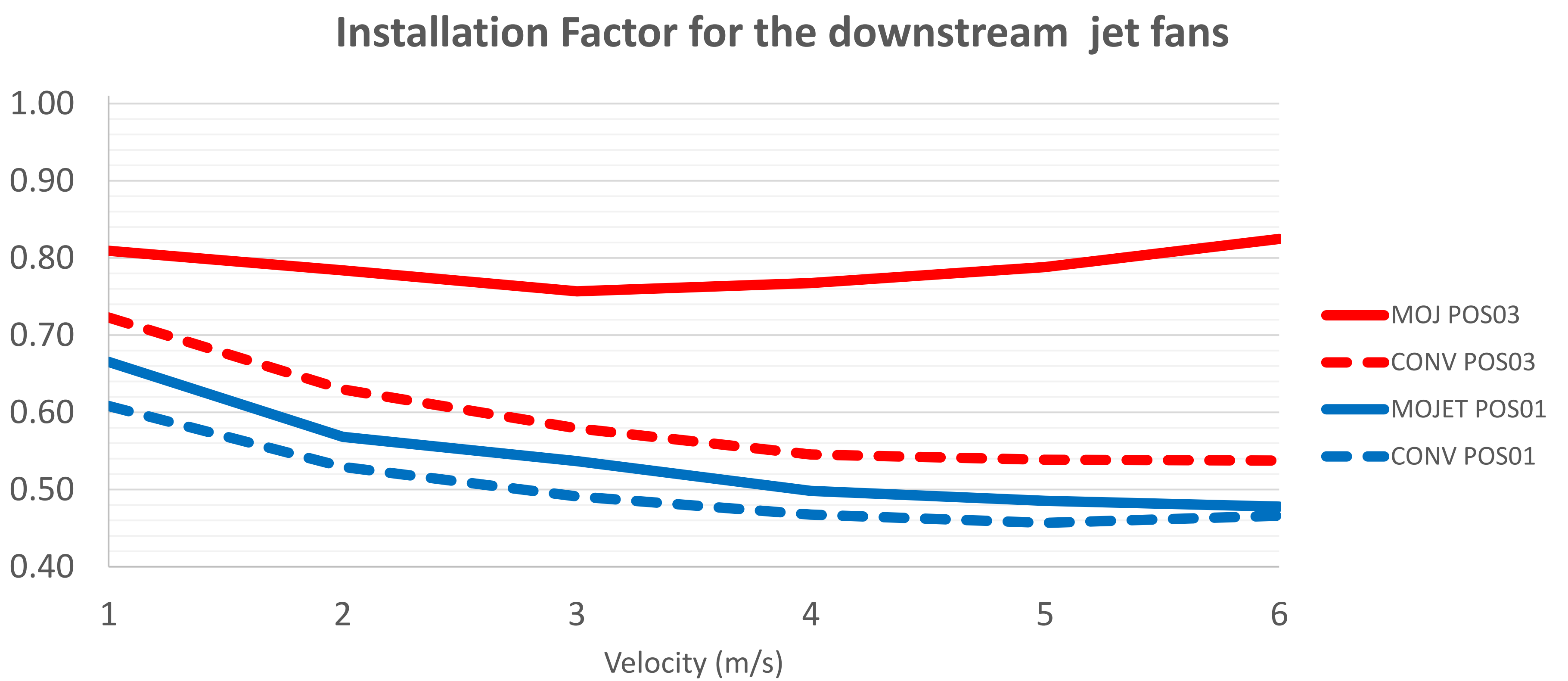
Installation Factor - Corner

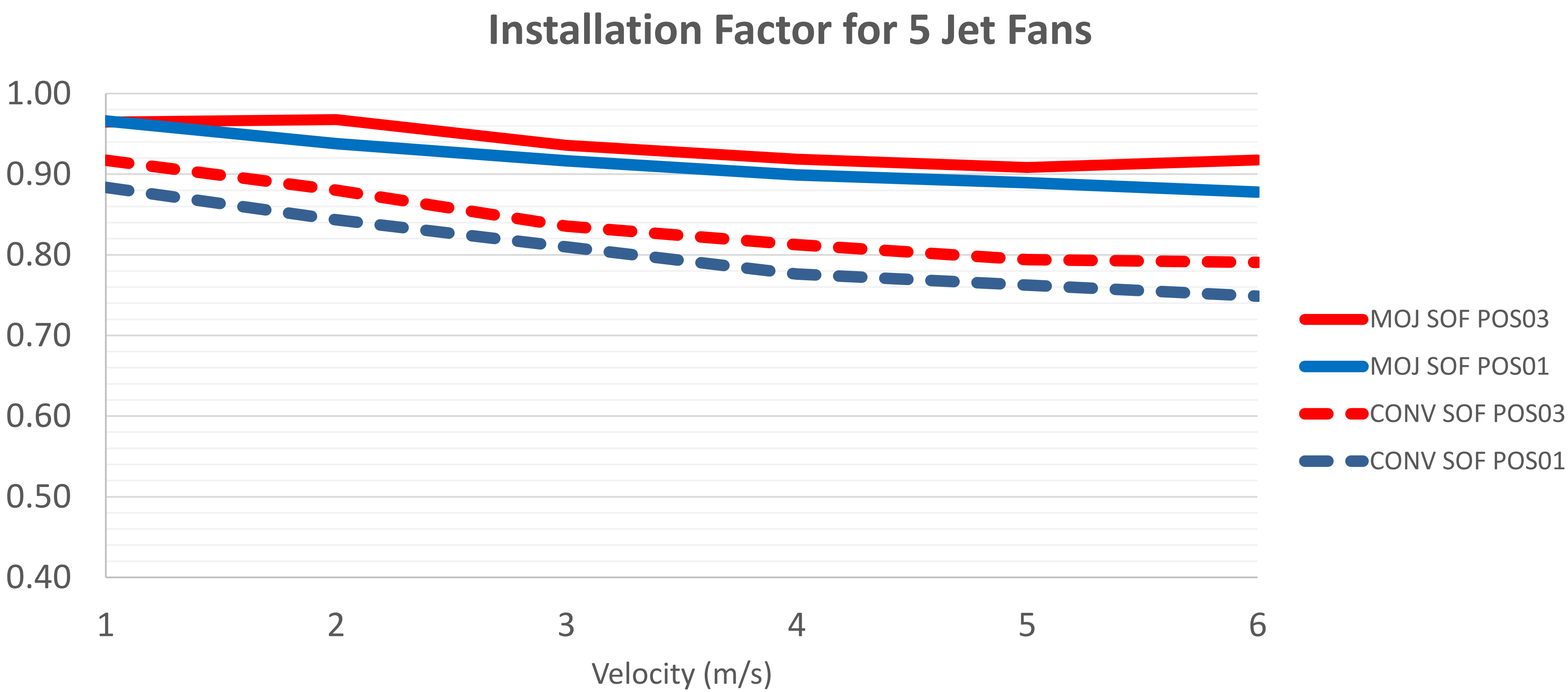


MOSEN

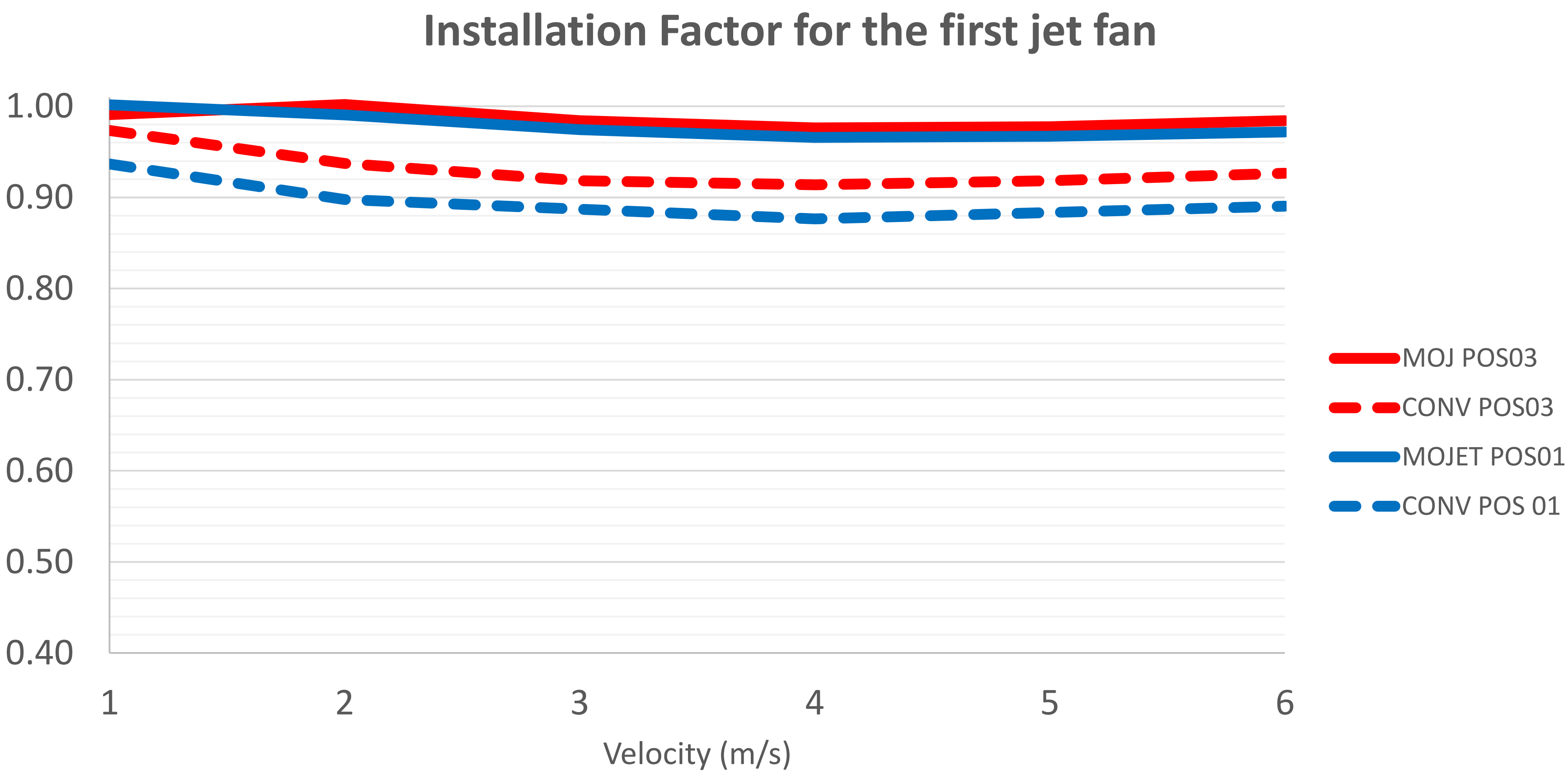
Installation Factor - Corner



Installation Factor - Soffit

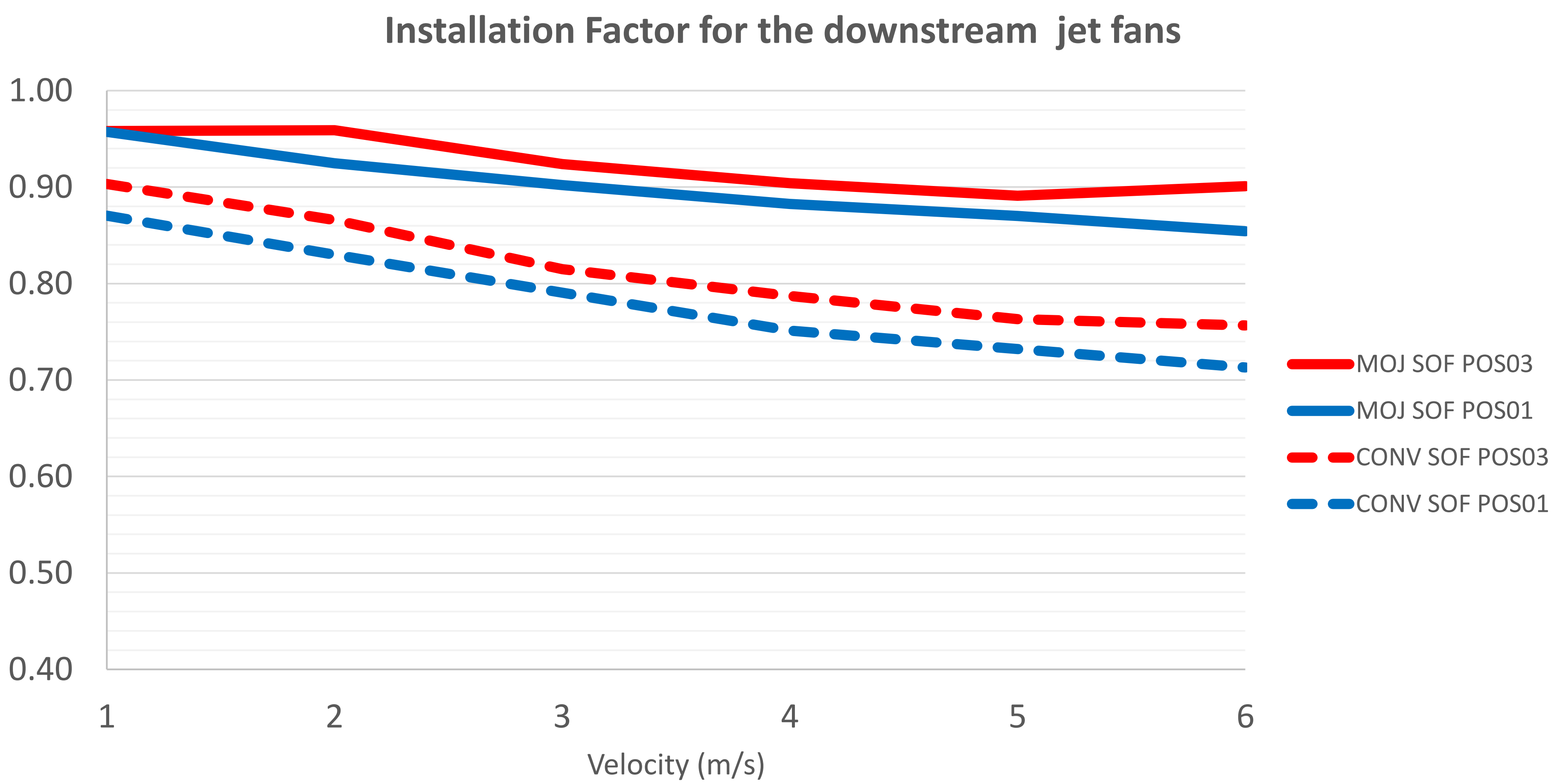


Installation Factor - Soffit



MOSEN

Installation Factor - Soffit



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Summary

- Jet fan calculation methodologies
- Jet fan installation factors
- Measurements in tunnels
- 3D CFD calculations

Any Questions?