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Simulation of transient start-up and operational performance of natural draft ACCs under varying wind conditions

Department of Mechanical & Mechatronic Engineering
Stellenbosch University

ACCUG Clarksville, USA
14-16 July 2026

Prof Hannes Pretorius

Photo by Stefan Els

Motivation

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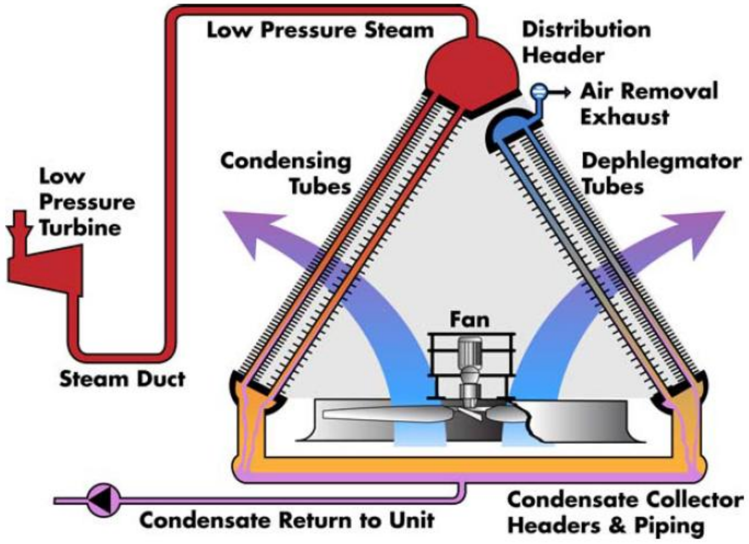
- Traditional dry cooling systems
  - Mechanical draft ACCs
  - Indirect natural draft dry cooling system

crown.co.za

Lennon (2011)

Motivation

- Mechanical draft ACCs
  - Thermally efficient "direct" system
  - Lower capital cost compared to indirect natural draft dry system
  - High aux power consumption
  - Multitude of motors, gearboxes and fans
    - Maintenance time and cost



(EPRI, 2009)

(Pretorius, 2012)

(Lennon, 2011)

(Augustyn, 2017)

(power-technology.com)

Motivation

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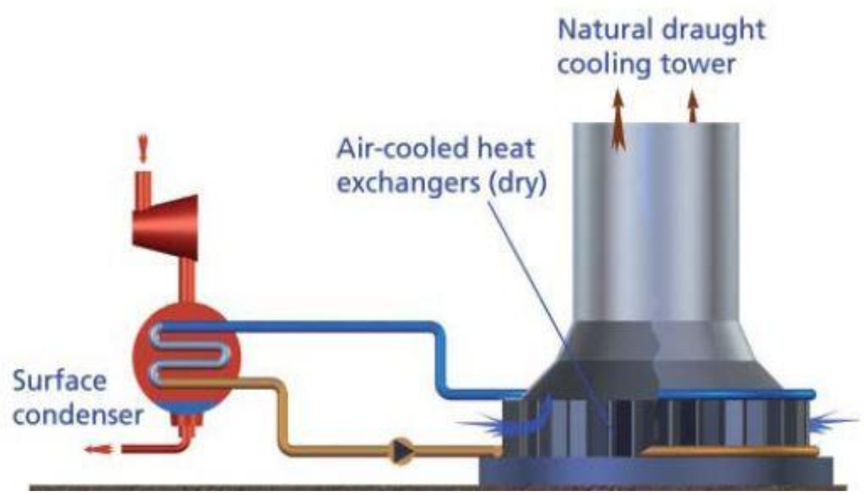
- Indirect natural draft dry cooling system
  - Less thermally efficient "indirect" system
  - Higher capital cost than ACC
  - Lower aux power consumption
  - Lower number of moving parts
    - Lower maintenance time and cost than ACC



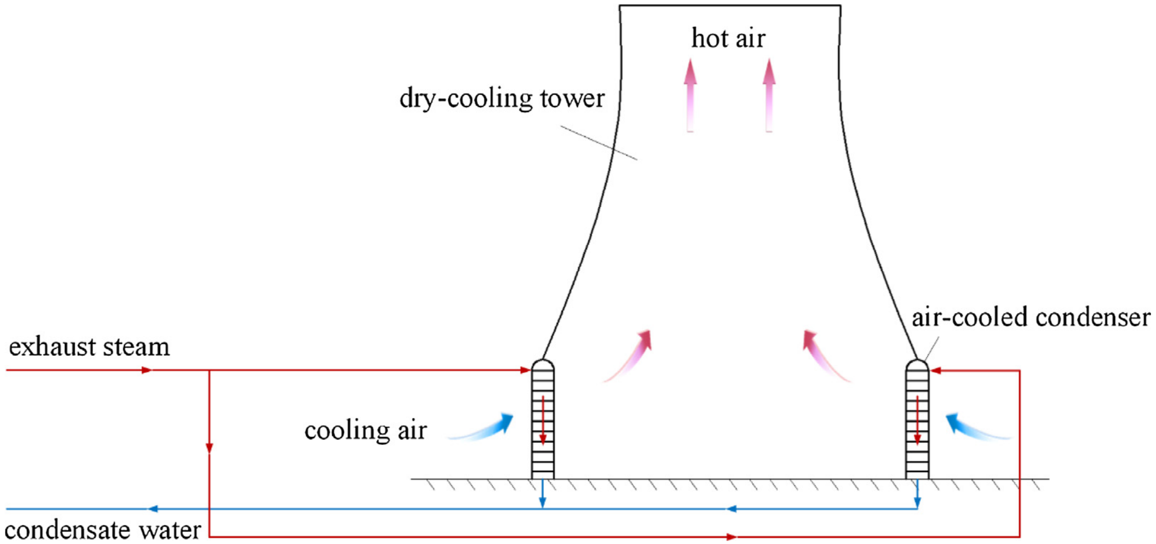
(Guan & Gurgenci, 2009)

(Lennon, 2011)

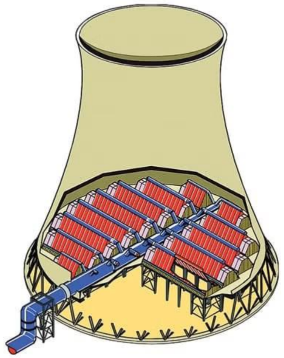
(EGI, 2005)

Motivation

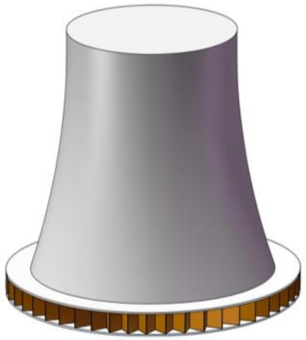
- Natural Draft Air-cooled Condenser (NDACC)
  - Aims to combine advantages and minimize disadvantages of indirect natural draft dry and ACC systems
  - Thermally efficient “direct” system
    - Lower capital cost than indirect natural draft dry system
  - Eliminates aux power consumption
  - No moving parts
    - Eliminates corresponding maintenance time and cost



Kong et al. (2018)



powermag.com

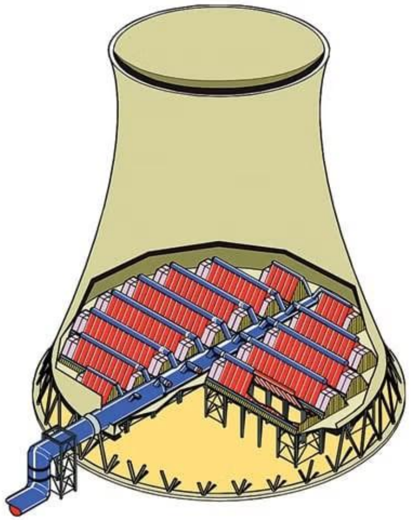


Kong et al. (2018)

The NDACC idea

- Idea for NDACC originated with Hammon-Lummus in the 1990's
  - Combined with new single-row flattened finned tubes
  - Mention lack of economic incentive for earlier adoption
  - Mention expected lower life-cycle costs and positive outlook

- Concerns about the NDACC
  - Lack of driving force
  - Resulting poor vacuum and steam distribution
  - System would not want to "start up"



(powermag.com)

Our research aims

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- Explore the expected performance of the NDACC
- Use validated simulation
- Consider different system scales
- Quantify effect of wind
- Evaluate transient start-up and operational scenarios

Our research approach and scope

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- PhD study by Dr Wian Strydom
- Simulate the performance of the NDACC, using
  - 1-D steady and transient numerical models (Python)
  - 3-D steady computational fluid dynamics (CFD) models (ANSYS Fluent)
  - Transient co-simulation model (1-D steam-side, 3-D CFD airside)

- Consider:
  - No-wind and windy conditions
  - Various systems scales: 900 MWth (coal), 100 MWth (CSP) and 1 MWth (desalination)
  - Cold-start load step and ramp, as well as islanding operations

Main system components

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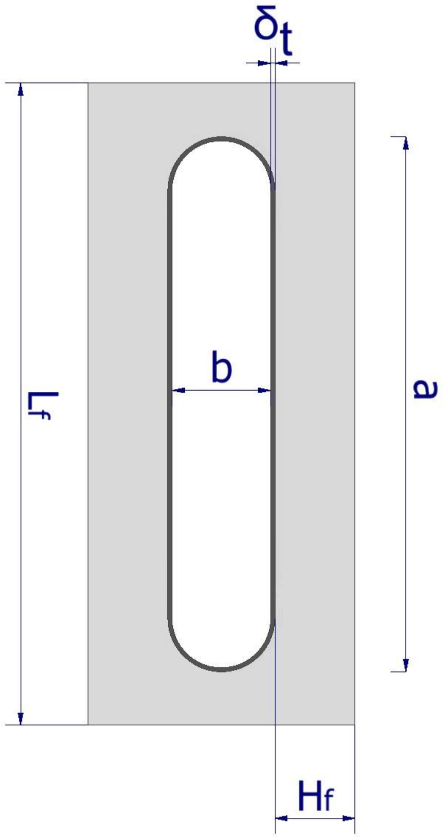
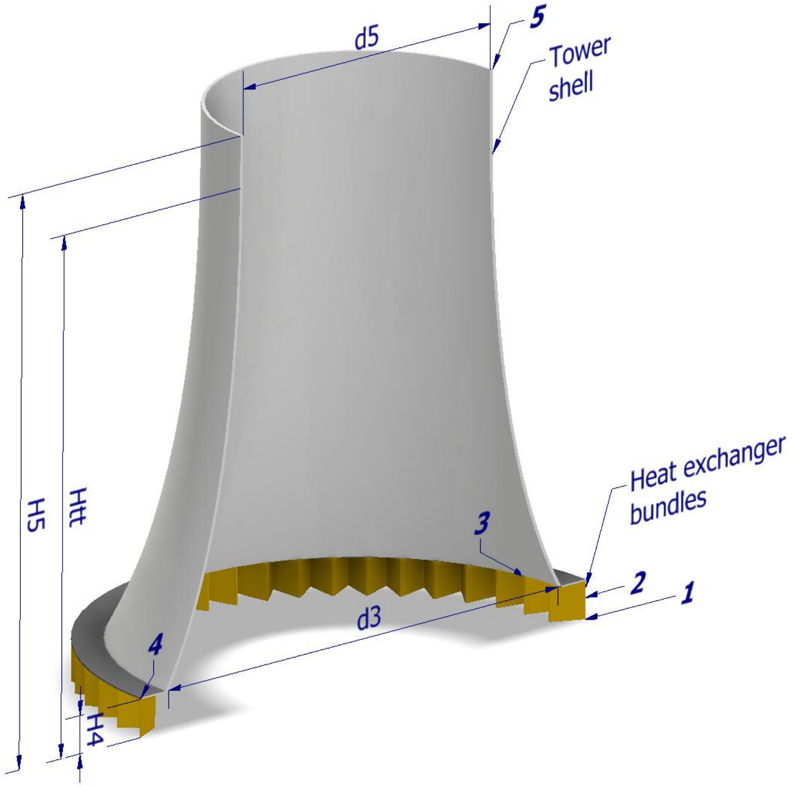


Effective single-row tube schematic



NDACC schematic for current work

Reference component sizing (large-scale)

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Description	Symbol	Value (m)
Tower dimensions		
Total tower height	H_5	165.0
Height of tower throat	H_{tt}	150.3
Inlet height	H_4	16.5
Inlet diameter	d_3	165.0
Outlet/Throat diameter	d_5	82.5
Tower shell thickness	δ_s	1
Finned tube dimensions		
Base tube major axis	a	0.15
Base tube minor axis	b	0.026
Base tube thickness	δ_t	0.0015
Tube pitch	p_t	0.067
Fin length	L_f	0.18
Fin height	H_f	0.0195
Fin thickness	δ_f	0.00025
Fin pitch	p_f	0.0023

3-D CFD model setup

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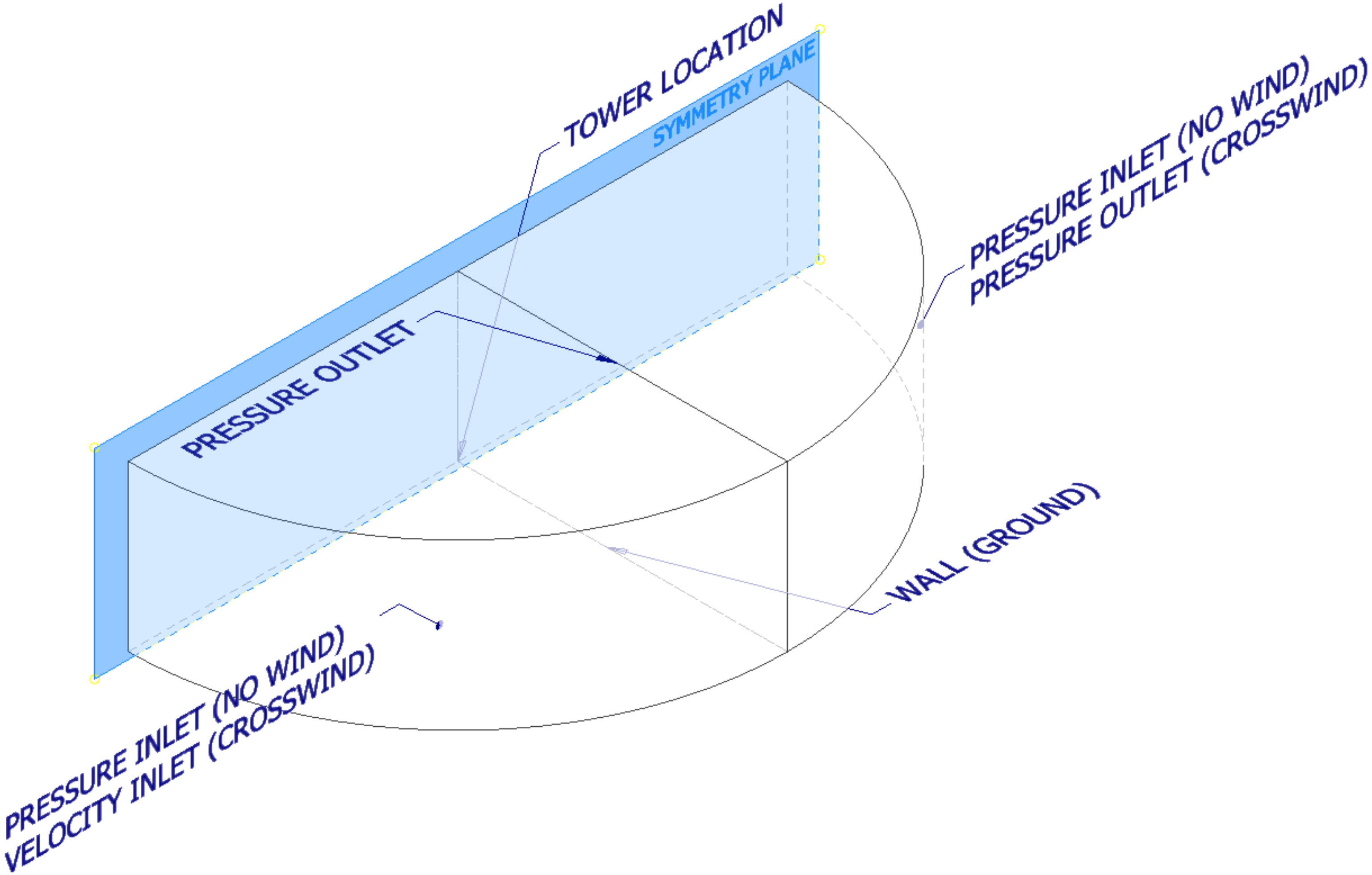
- Large-scale domain radius 2 km x 1 km half cylinder
- k-ω SST turbulence model with enhanced wall treatment
- Atmosphere modelled as ideal gas
- Pressure gradient in atmosphere modelled, assuming constant temperature atmosphere
- Heat exchanger modelled as porous zone, with energy and momentum source terms



CFD domain

3-D CFD model validation

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Condition	No-wind			6 m/s crosswind		
Variable	Kong et al.	3-D CFD	Δ%	Kong et al.	3-D CFD	Δ%
Heat transfer rate (MW)	1136.4	1080.4	-4.9	1055.3	971.0	-8.0
Air mass flow rate (kg/s)	32557.9	32926.2	+1.1	29499.6	29439.4	-0.2

- Overall, compares well
  - Differences linked to implementation of porous zone vs radiator model (Kong)
- Similar differences between no-wind and 6 m/s wind

Steady-state 3-D CFD model: no-wind results

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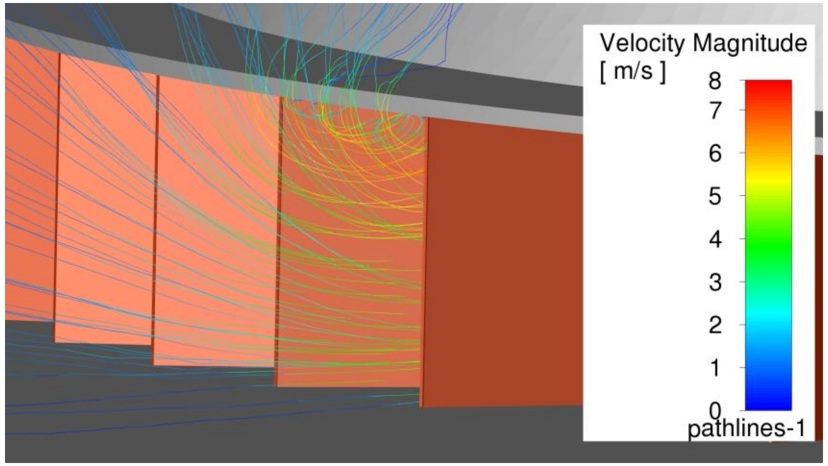
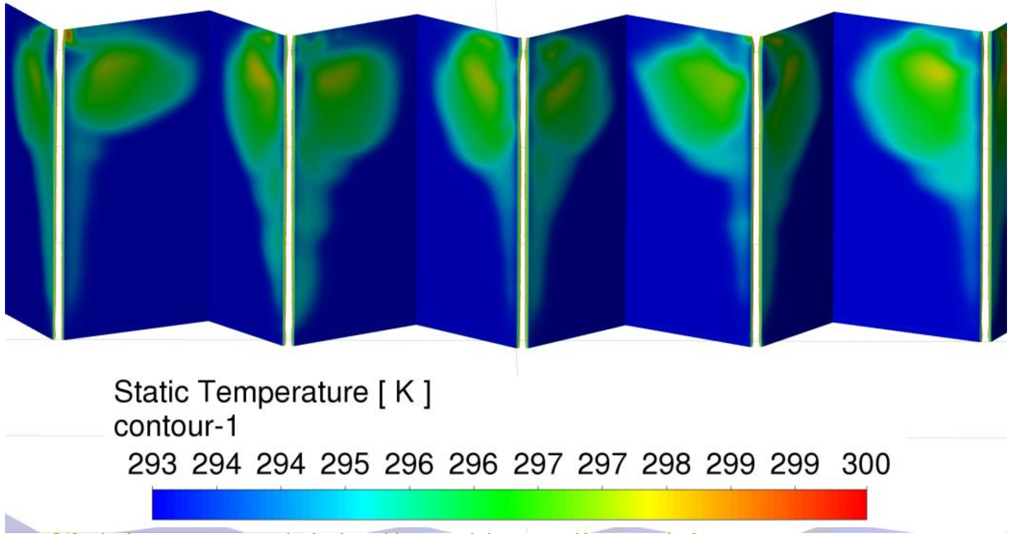
Recirculation

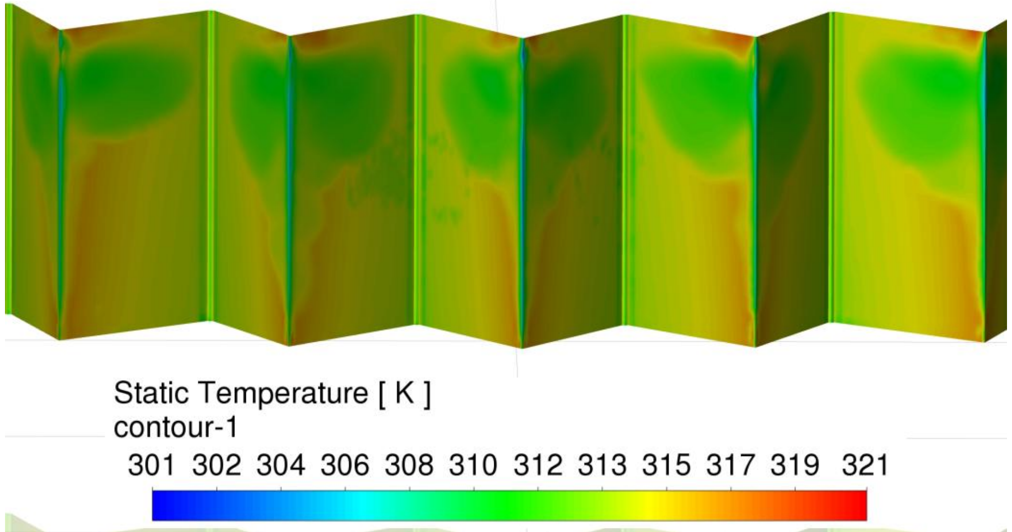


HX inlet air temp



Mirror plane

HX outlet air temp



Steady-state 3-D CFD model: no-wind results

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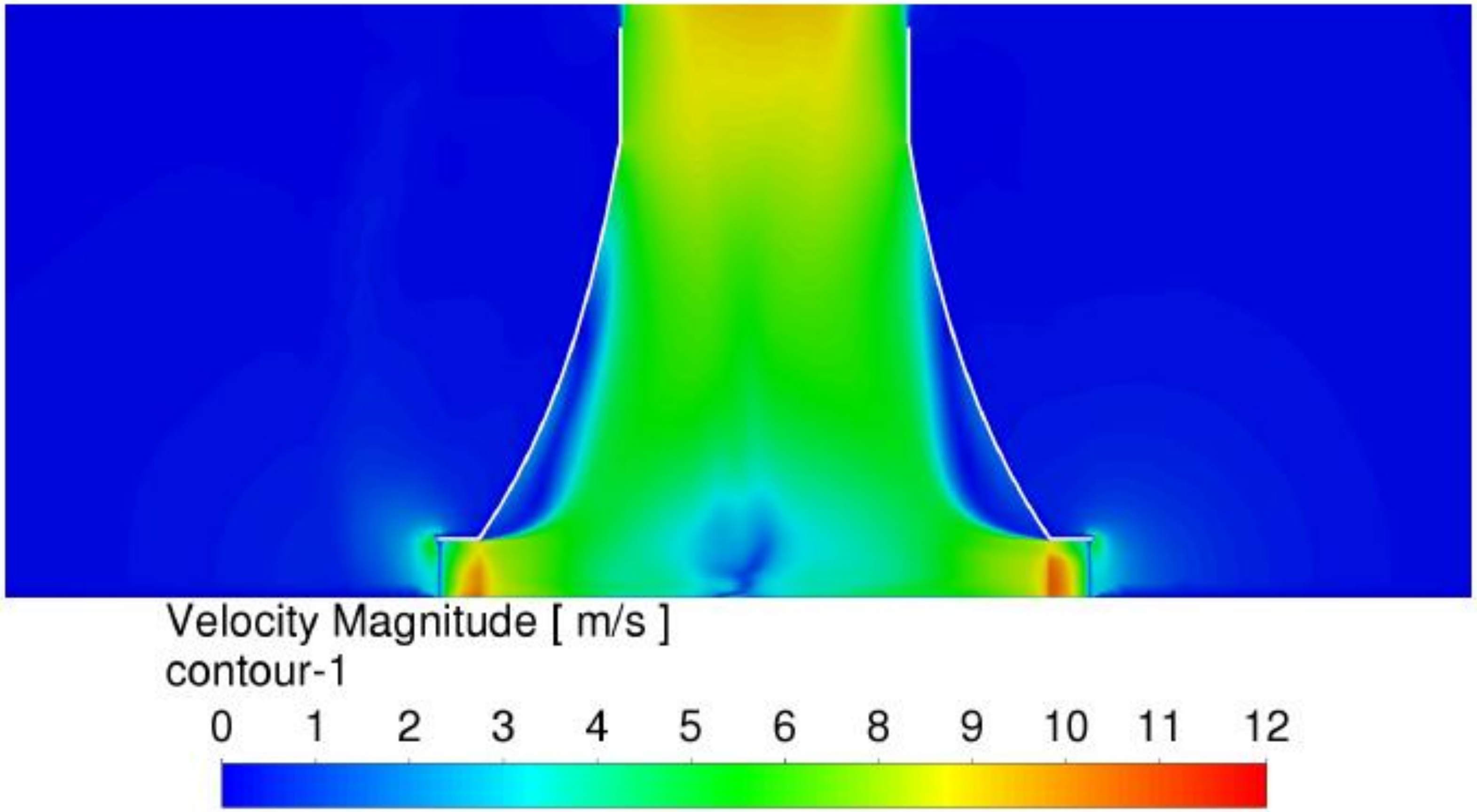

Steady-state 3-D CFD model: crosswind results

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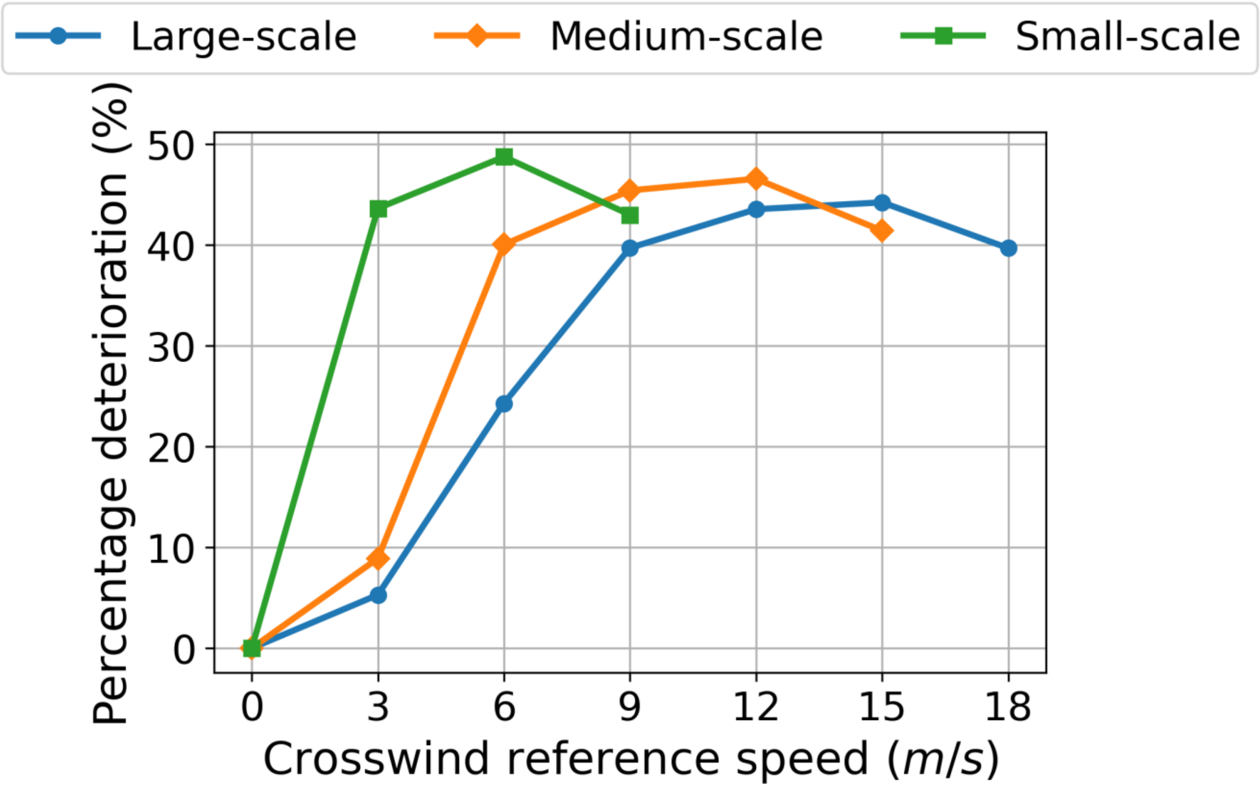

Relative $\dot{Q}$

Steady-state 3-D CFD model: crosswind results

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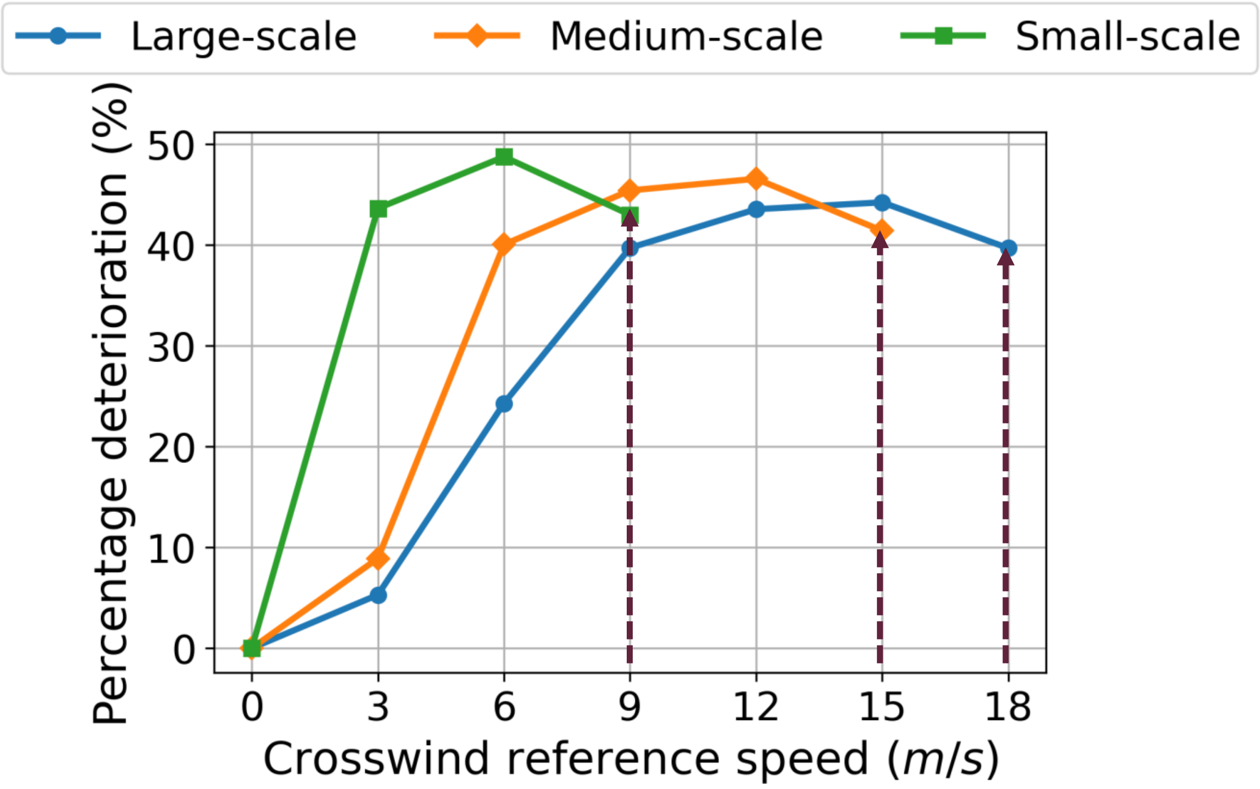
Performance recovery at 9, 15 and 18 m/s



Relative $\dot{Q}$

Transient co-simulation

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- Purpose: simulation of NDACC performance under typical transient scenarios

- Transient scenarios:
  - Cold start-up steam step input under no-wind conditions (avoid overpressure)
  - Cold start-up load ramp under no-wind conditions (typical power plant requirement)
  - Cold start-up load ramp under 9 m/s crosswind conditions (effect of high wind)
    - All cold start-up scenarios assumes 40 kPa(g) (5.8 psig) condenser pressure limit

  - Full load turbine islanding (can NDACC cope with immediate thermal load)
    - Assumes turbine back pressure protection limit of 75 kPa(a) (10.88 psia)

- To show its limitations, results of stand-alone transient 1-D model also shown (no wind)
- 1-D and co-sim model: heat load imposed, model must find corresponding backpressure

Transient co-simulation results: steam admission step input under no-wind

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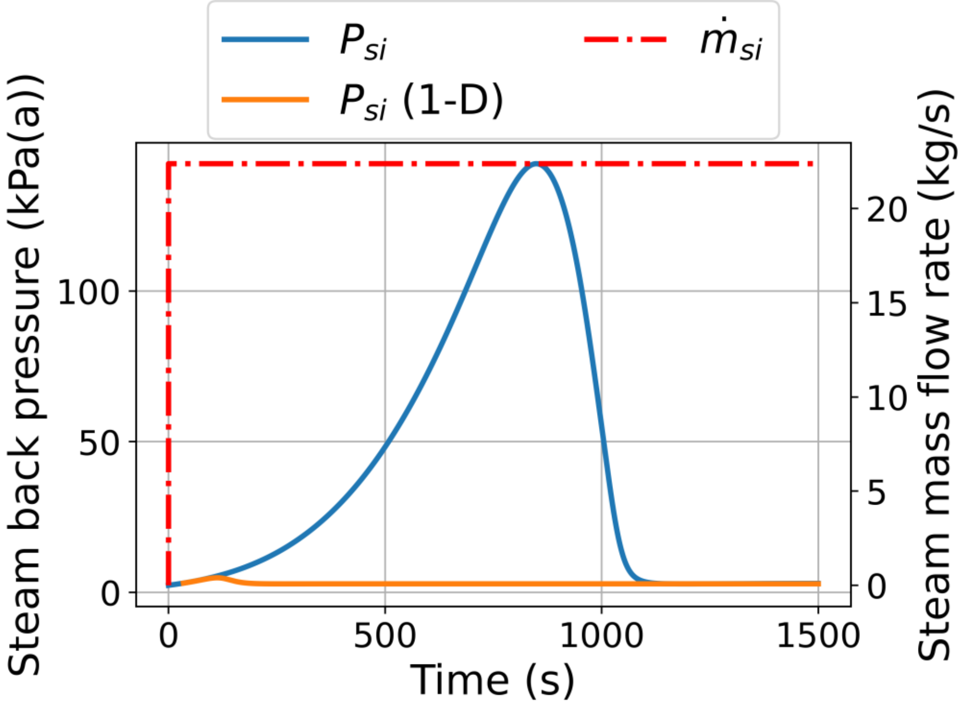
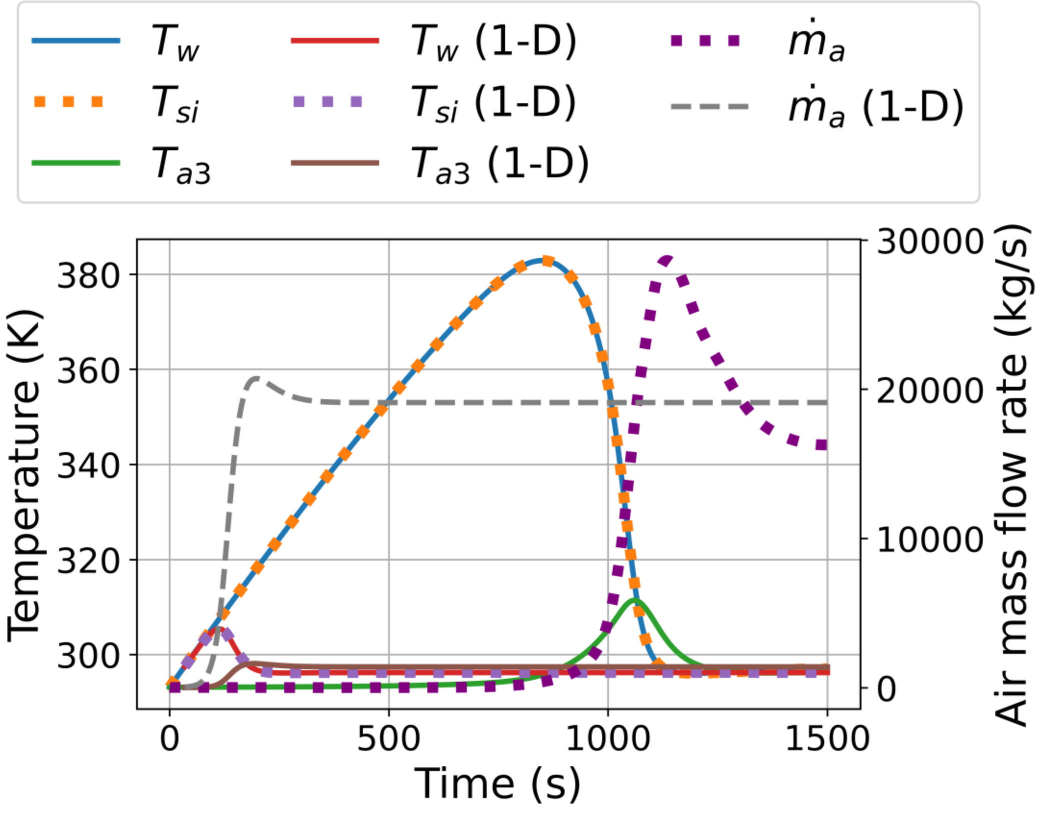
- Step input results: system can accept 5.8% of full-steam load before exceeding 40 kPa(g) limit



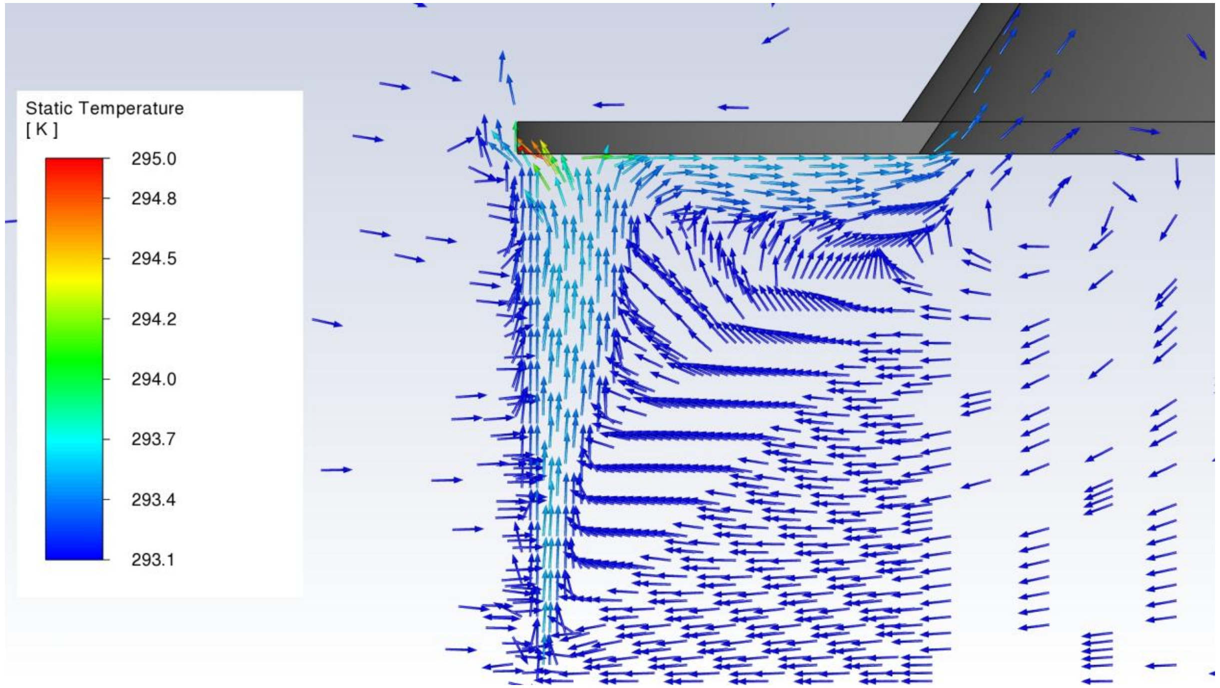
Steam back pressure

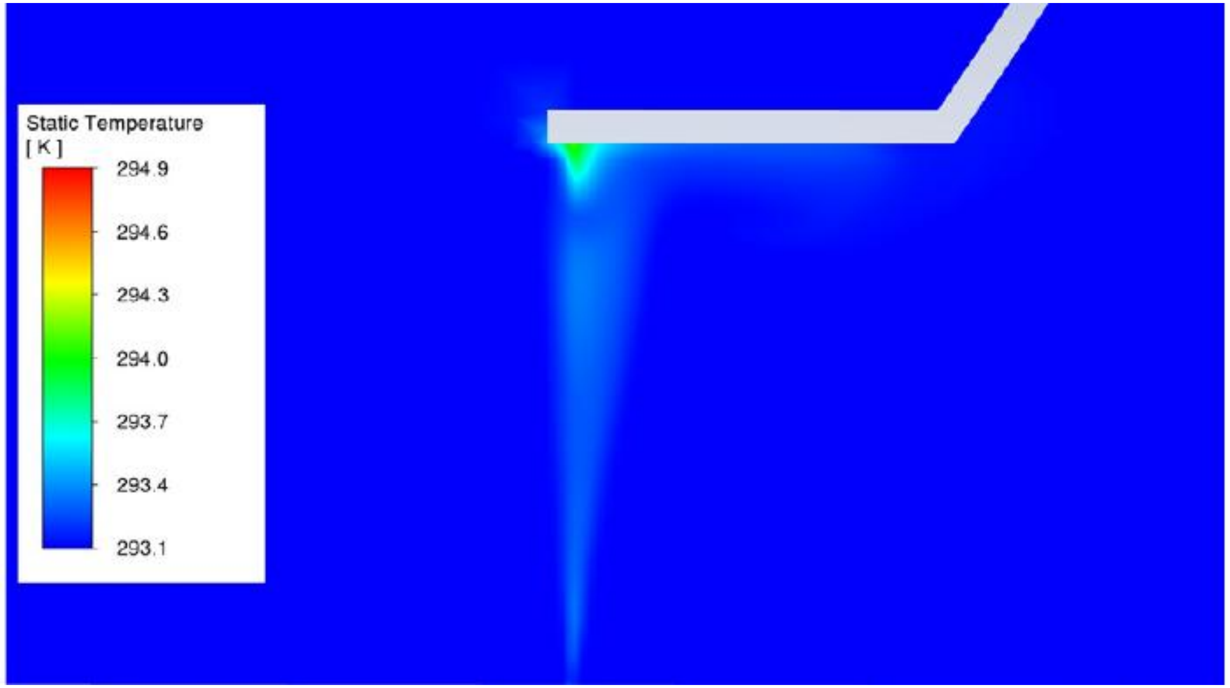


Temperatures and mass flow rate

Transient co-simulation results: steam admission step input under no-wind

Natural convection (t = 600 s)





Transient co-simulation results: steam admission step input under no-wind

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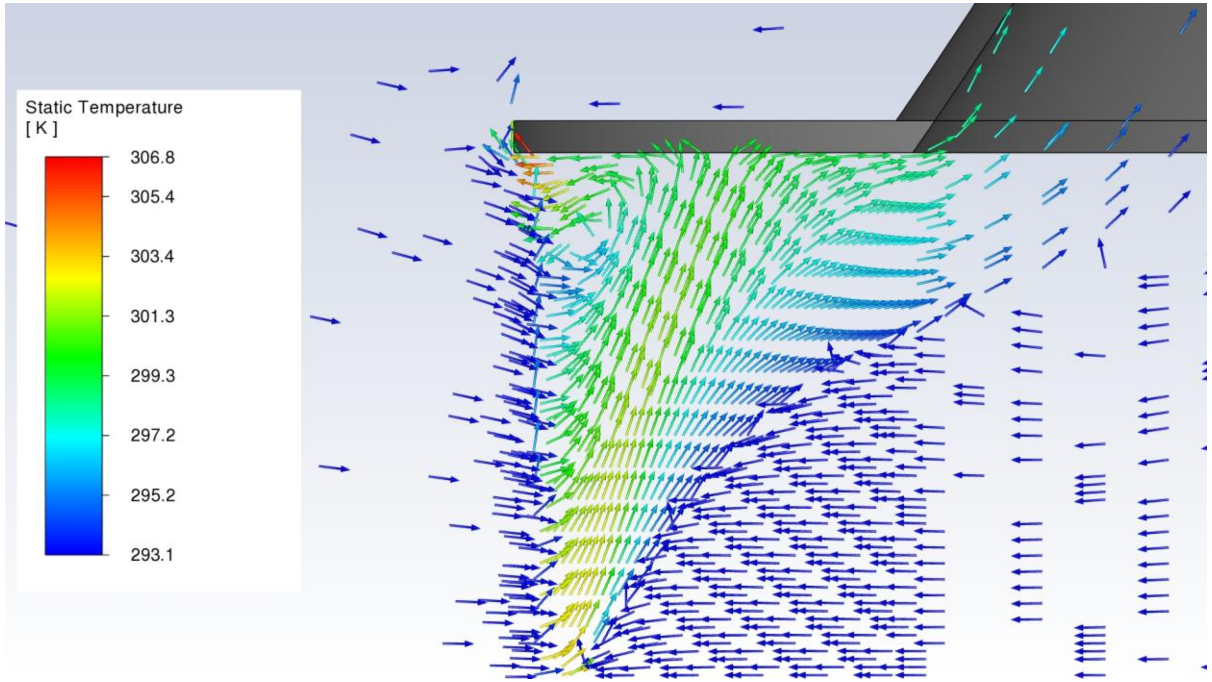
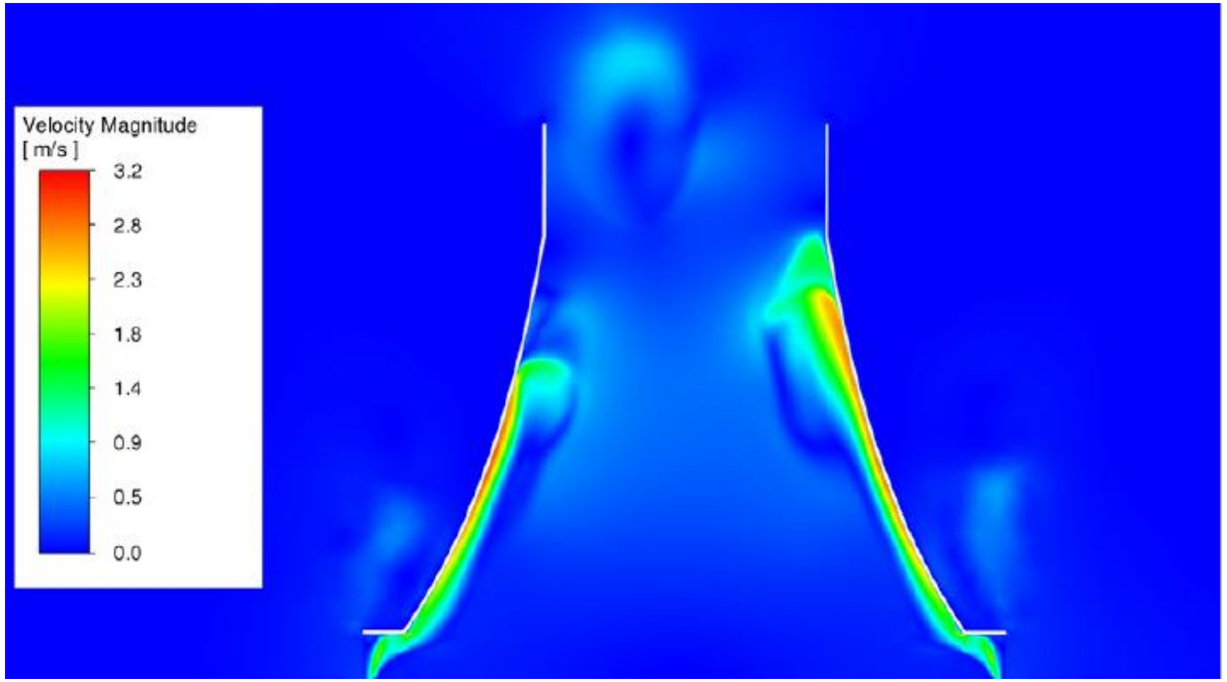
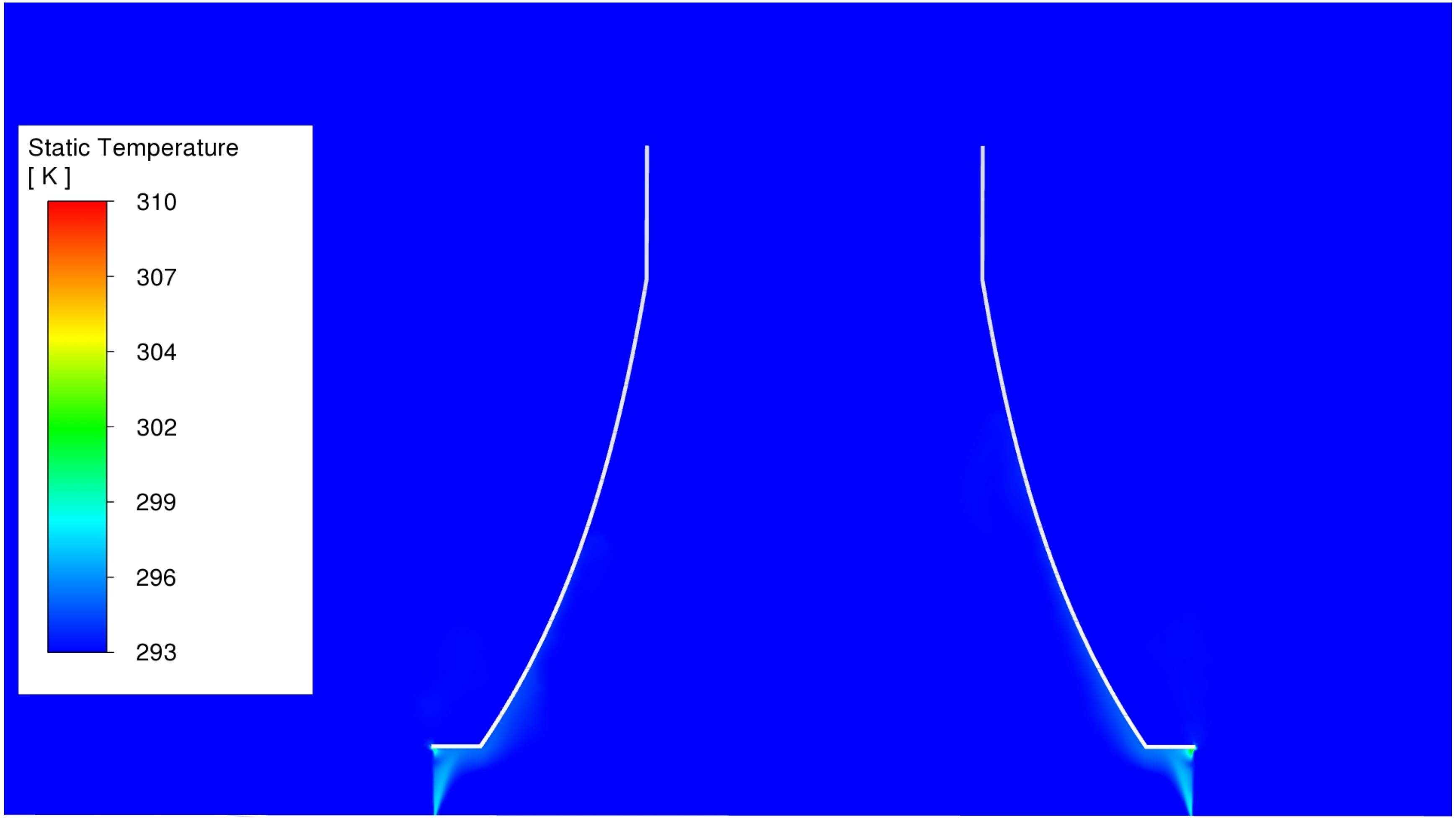
Mixed convection (t = 960 s)





Transient co-simulation results: steam admission step input under no-wind

Thermal flow field development



Transient co-simulation results: steam admission step input under no-wind

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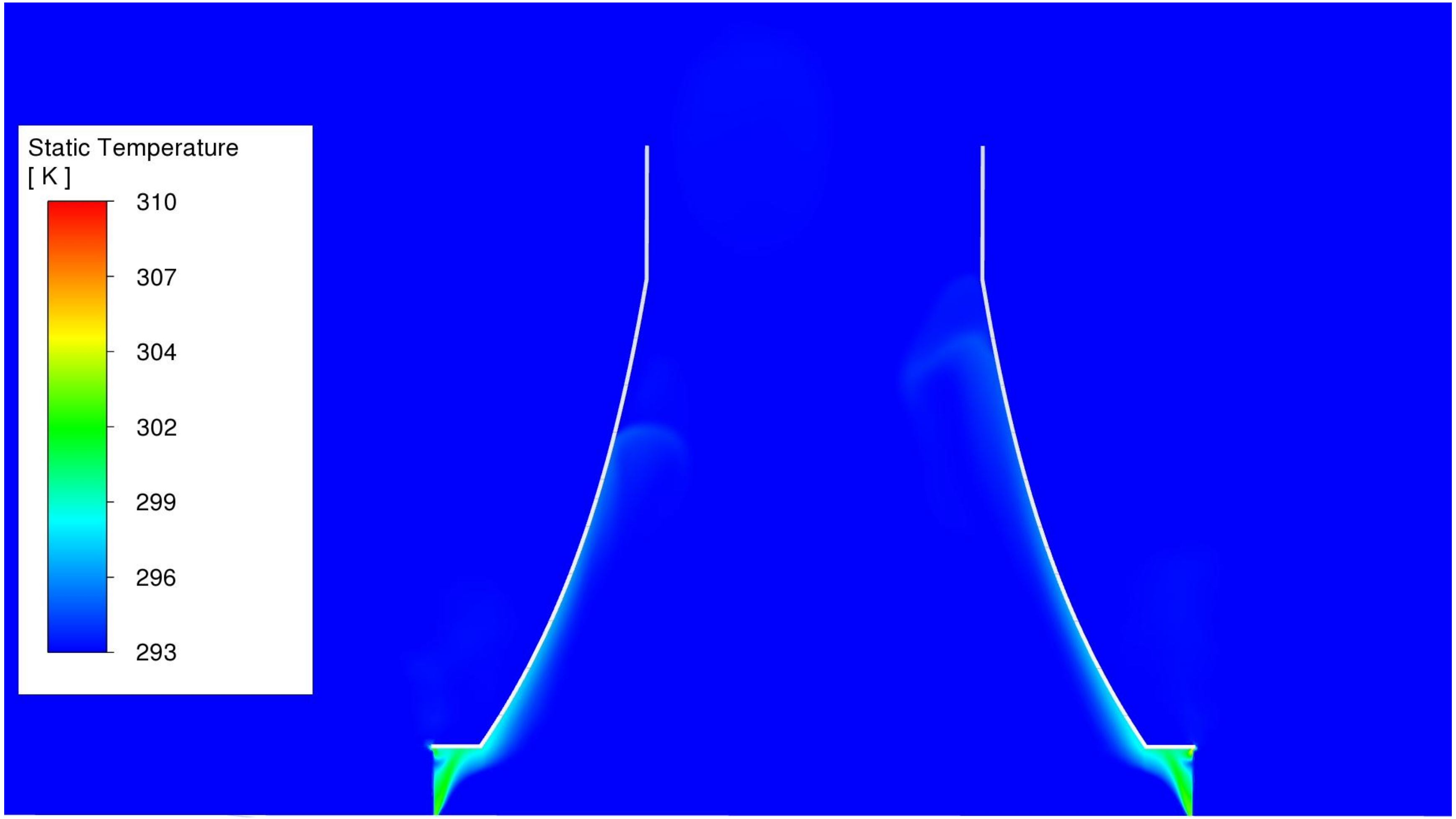
Thermal flow field development (t = 960 s)



Transient co-simulation results: steam admission step input under no-wind

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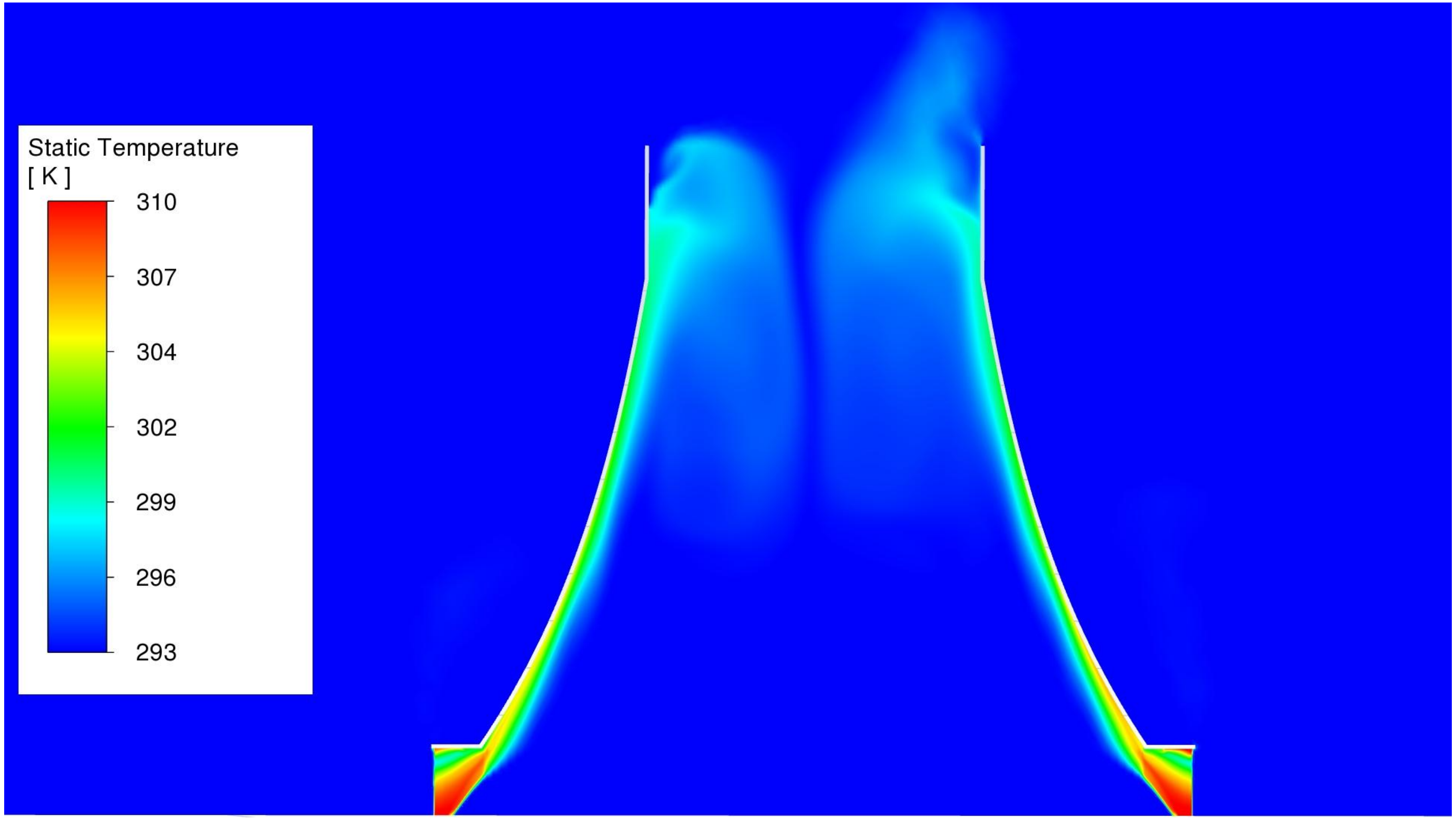
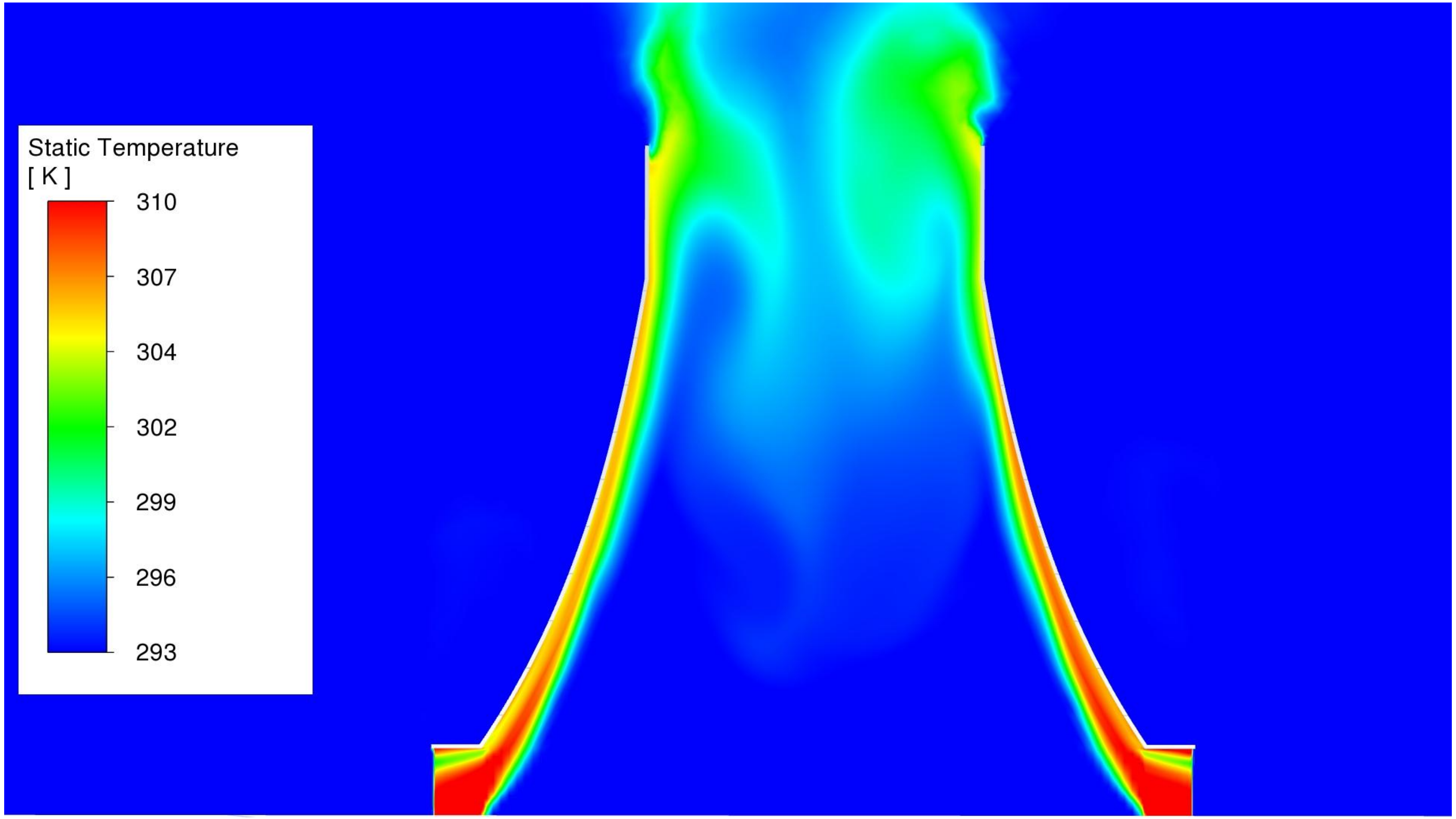
Thermal flow field development (t = 1020 s)



Transient co-simulation results: steam admission step input under no-wind

Thermal flow field development (t = 1050 s)



Transient co-simulation results: steam admission step input under no-wind

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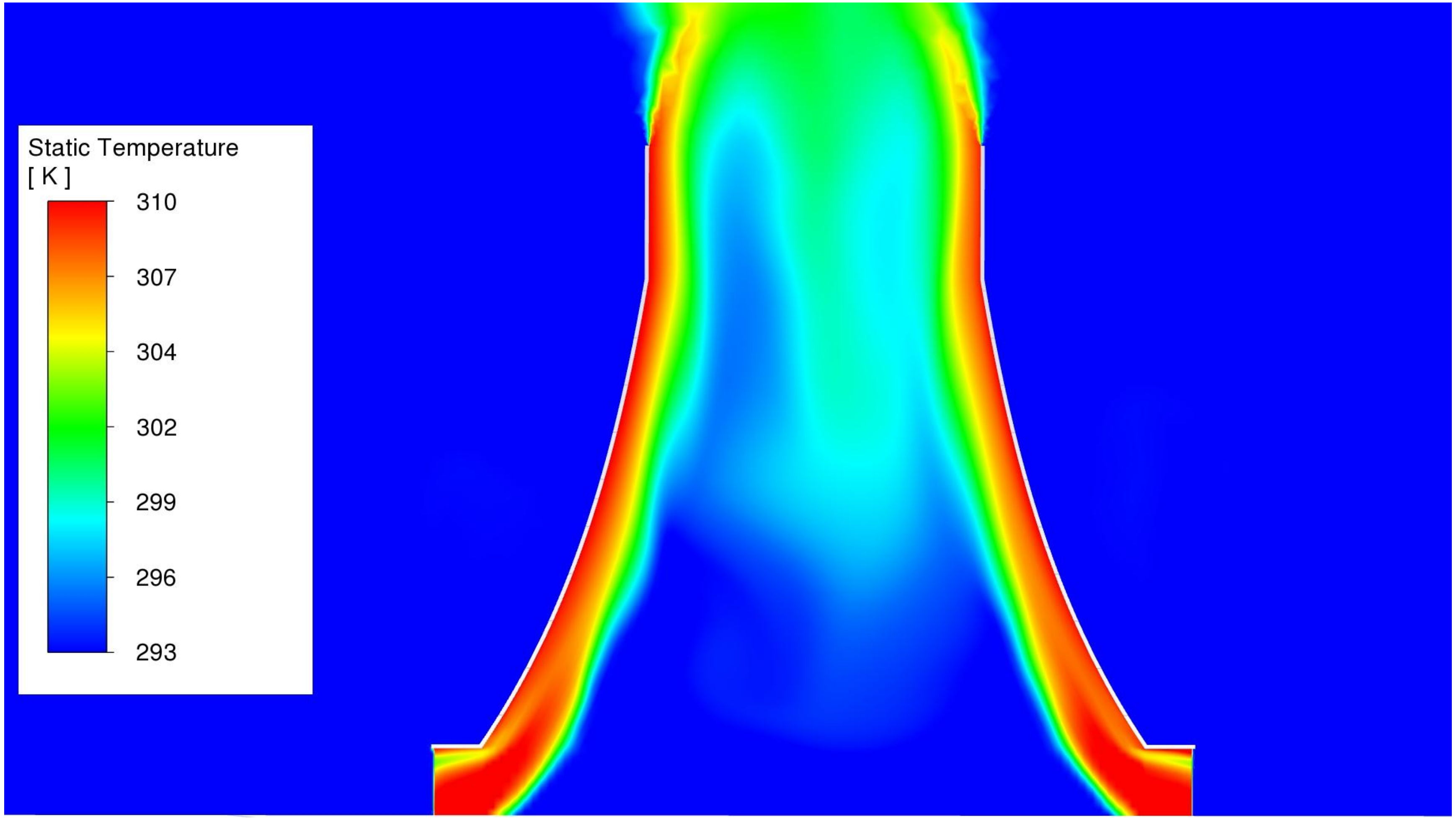
Thermal flow field development (t = 1080 s)



Transient co-simulation results: steam admission step input under no-wind

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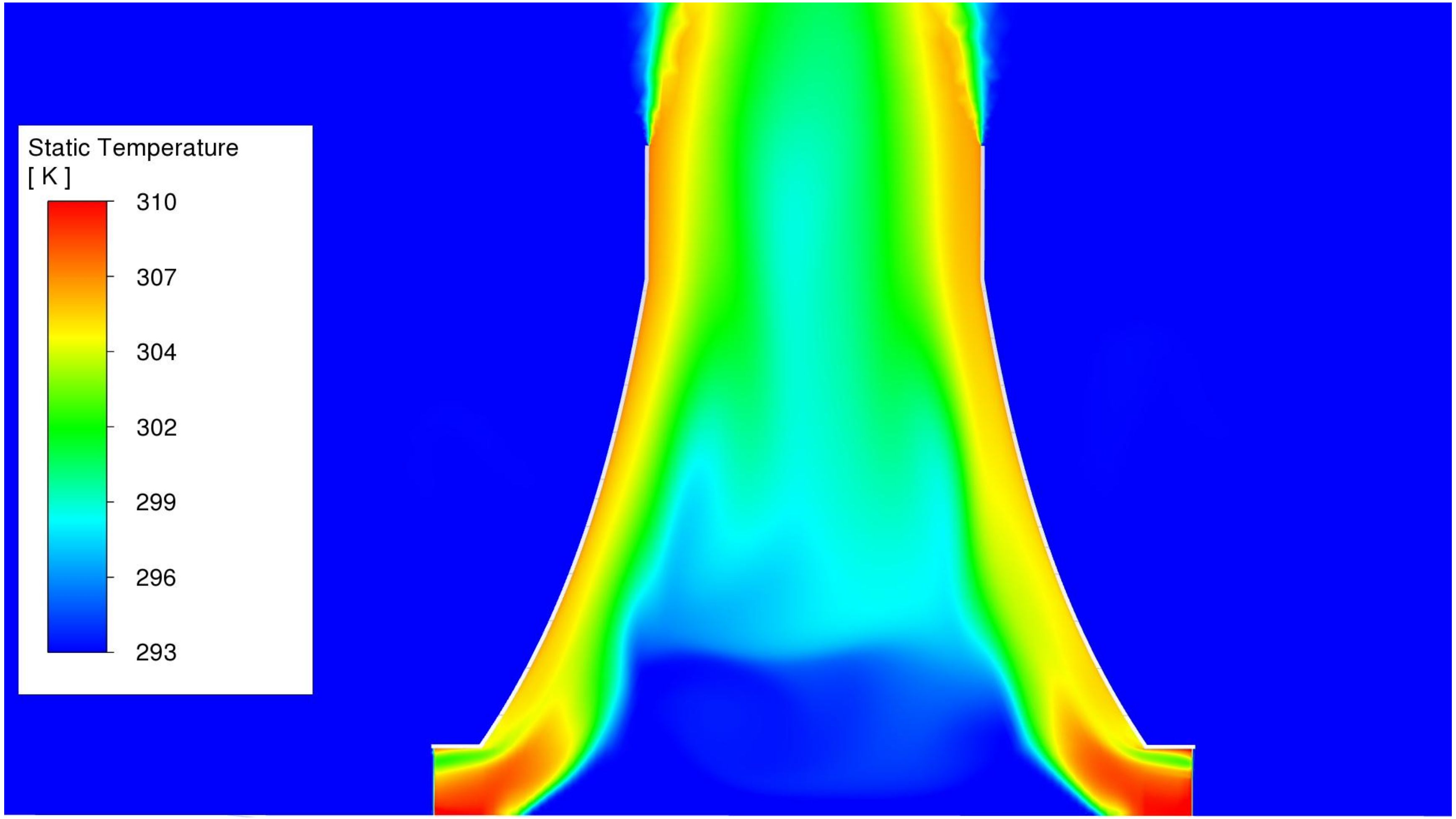
Thermal flow field development (t = 1110 s)



Transient co-simulation results: steam admission step input under no-wind

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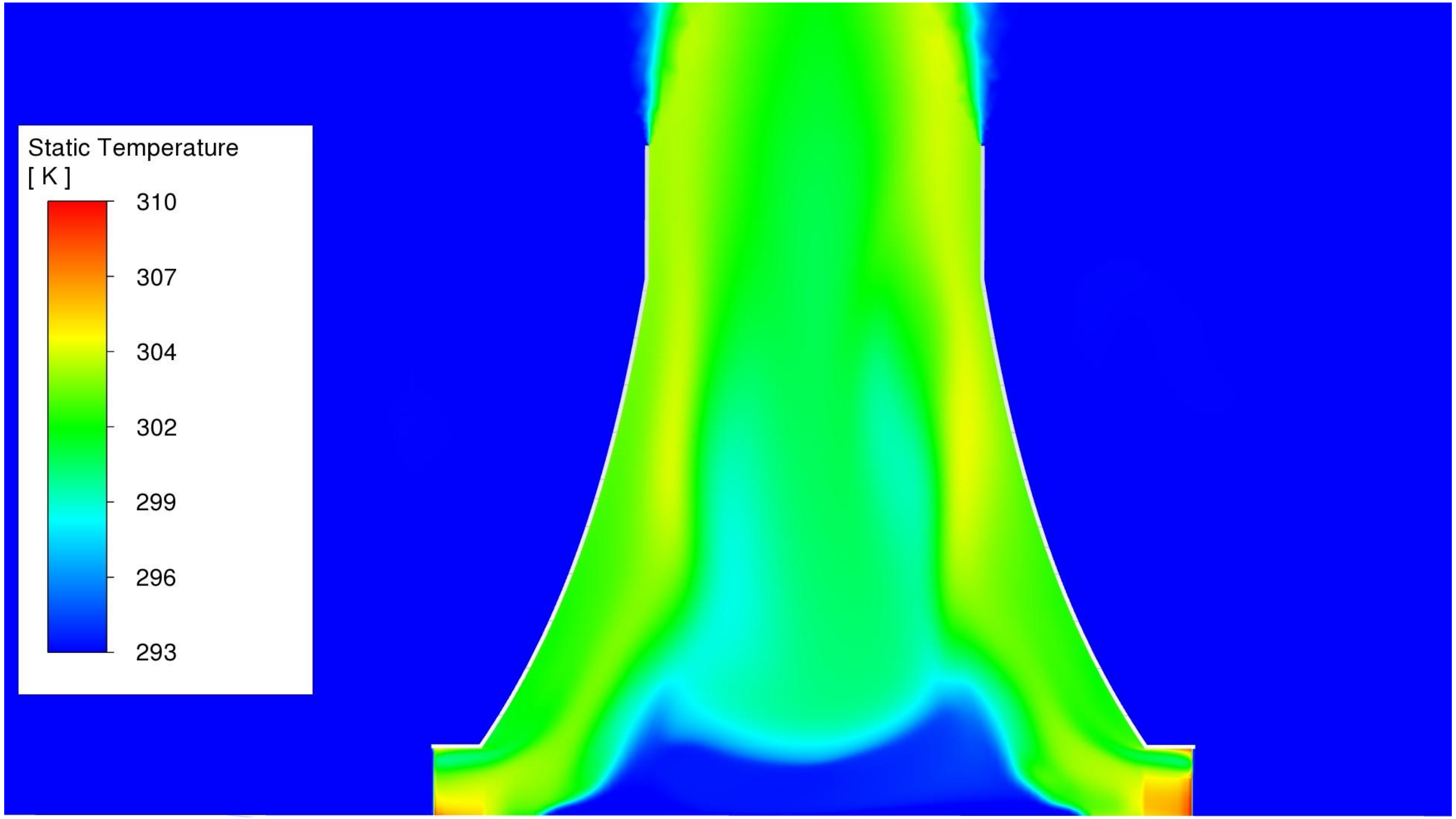
Thermal flow field development (t = 1140 s)



Transient co-simulation results: steam admission step input under no-wind

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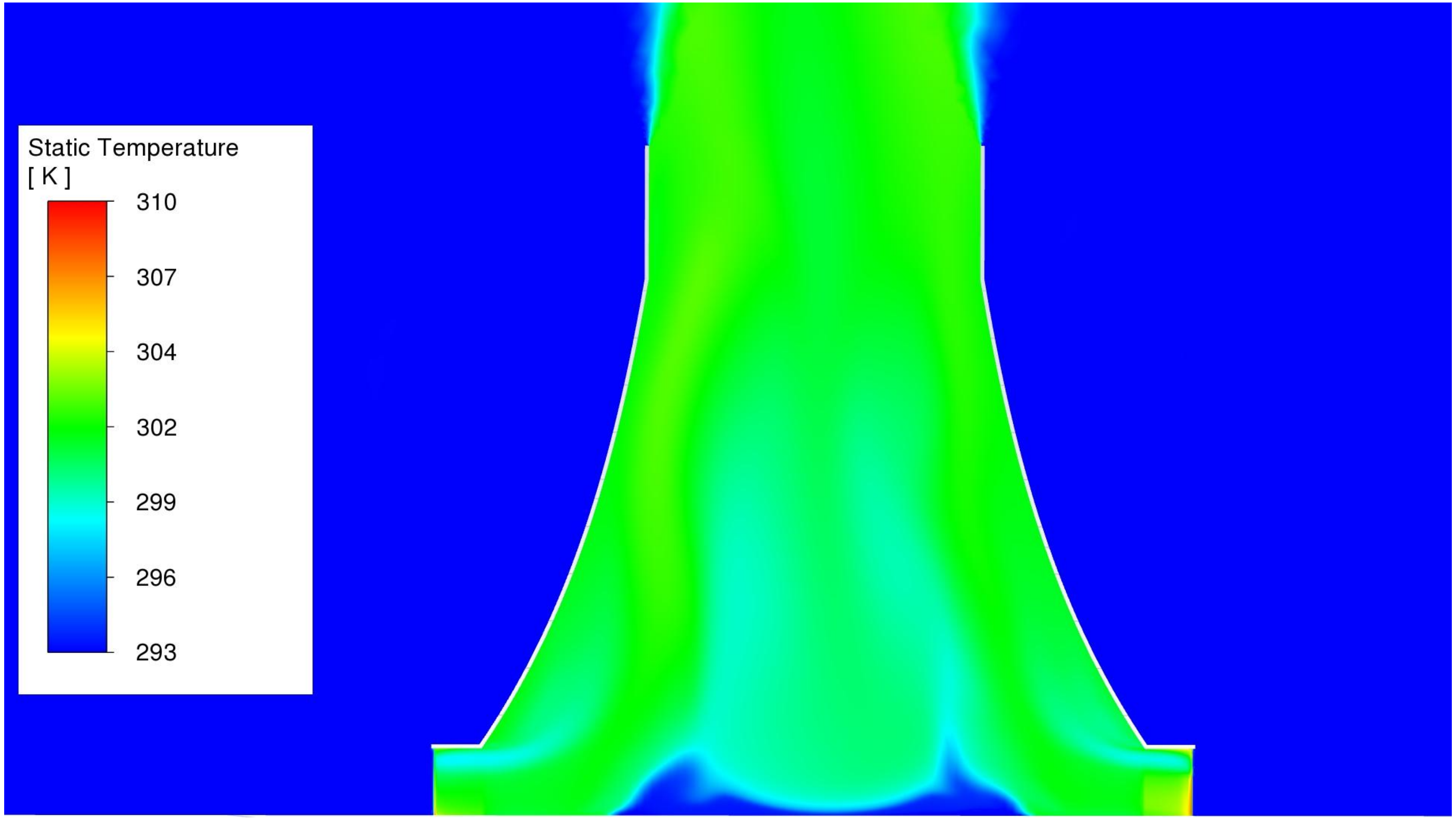
Thermal flow field development (t = 1170 s)



Transient co-simulation results: steam admission step input under no-wind

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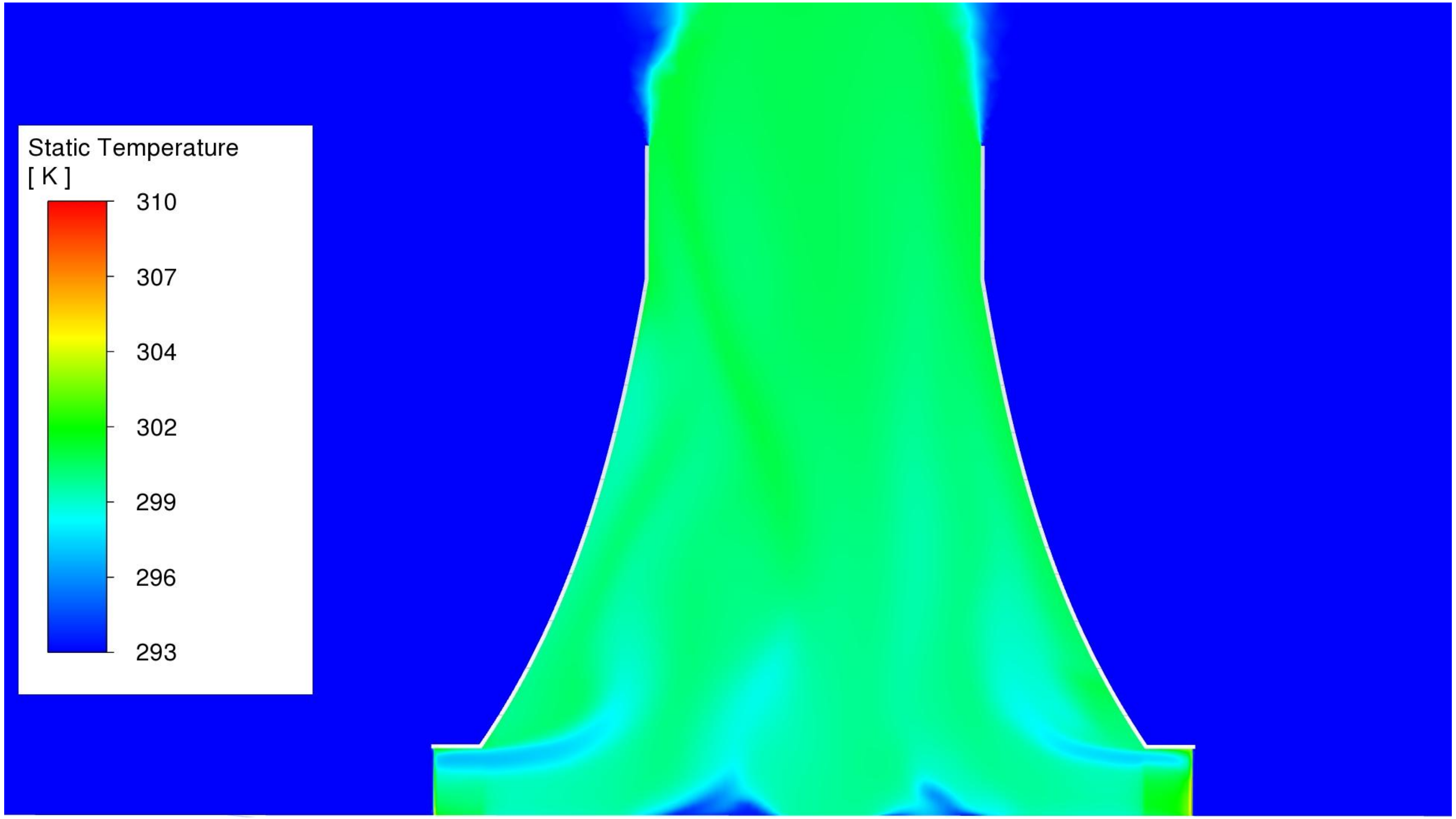
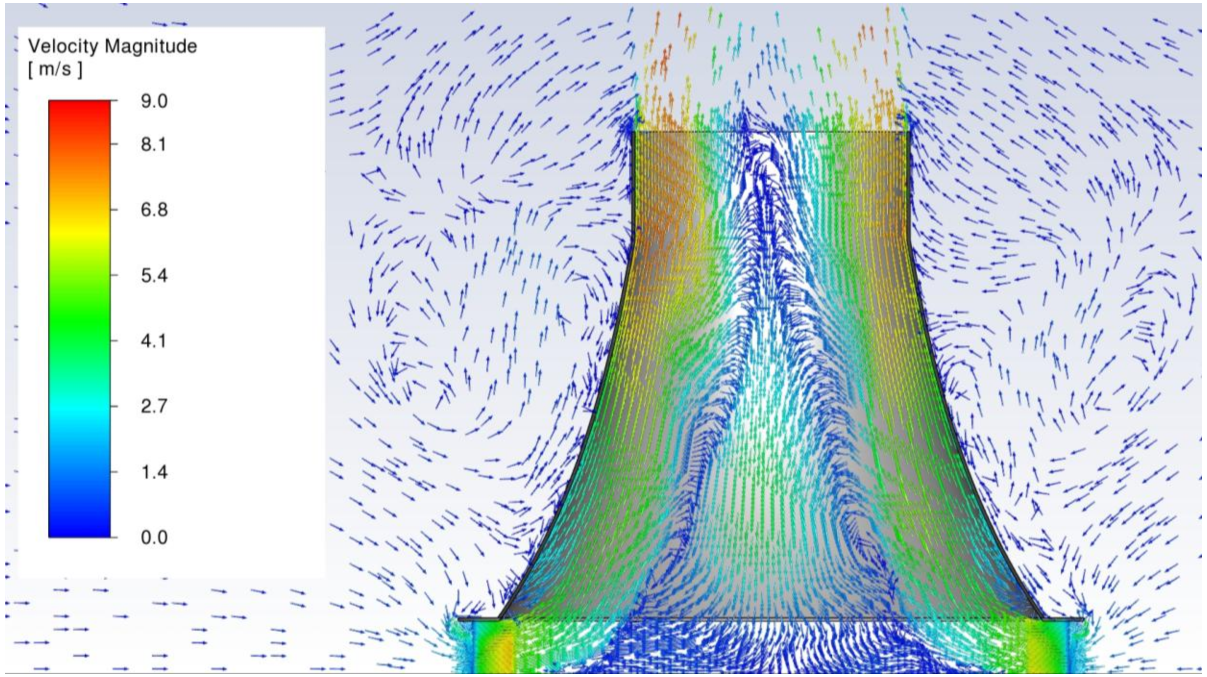
Thermal flow field development (t = 1200 s)

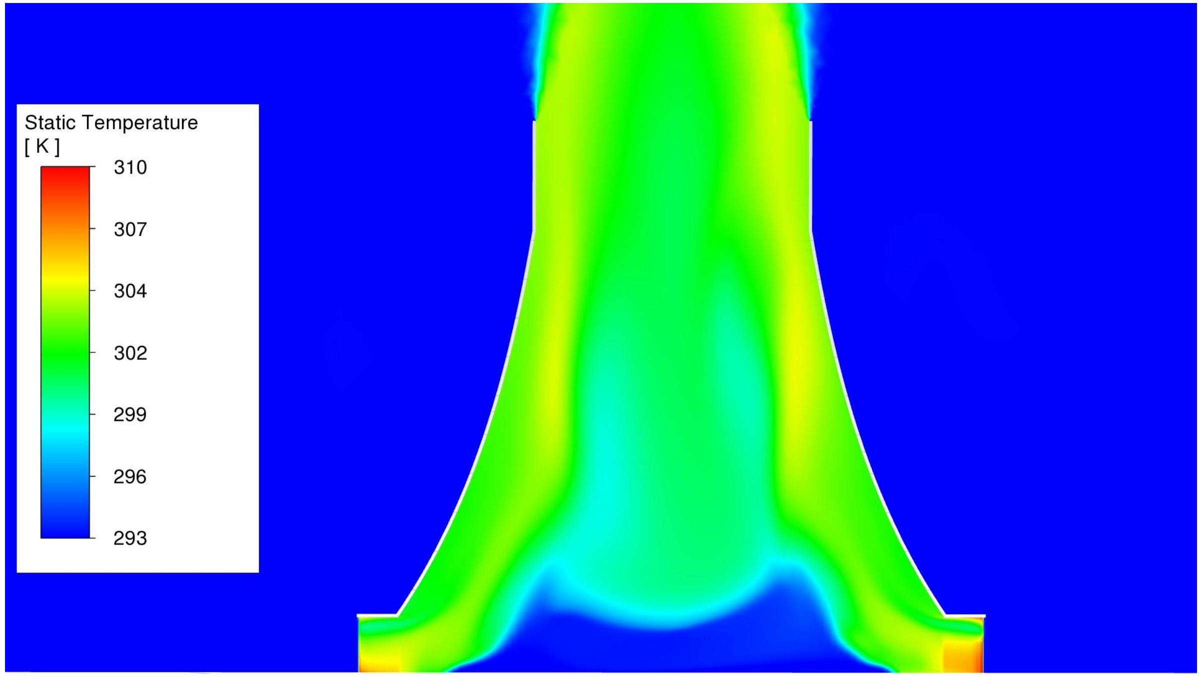


Transient co-simulation results: steam admission step input under no-wind

Velocity flow field (t = 1140 s)

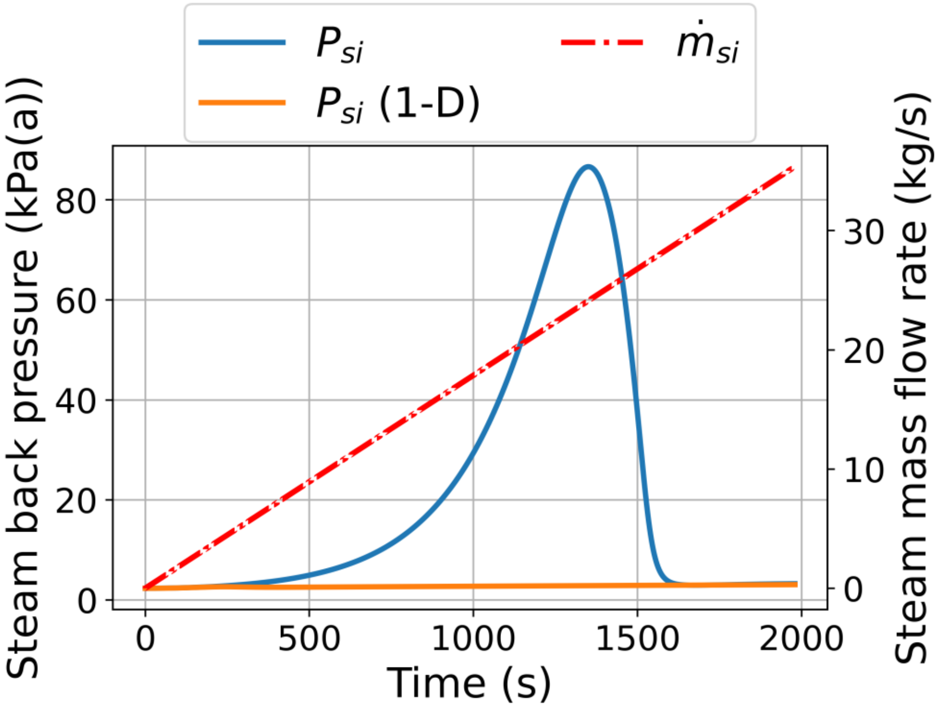


Temperature flow field (t = 1140 s)

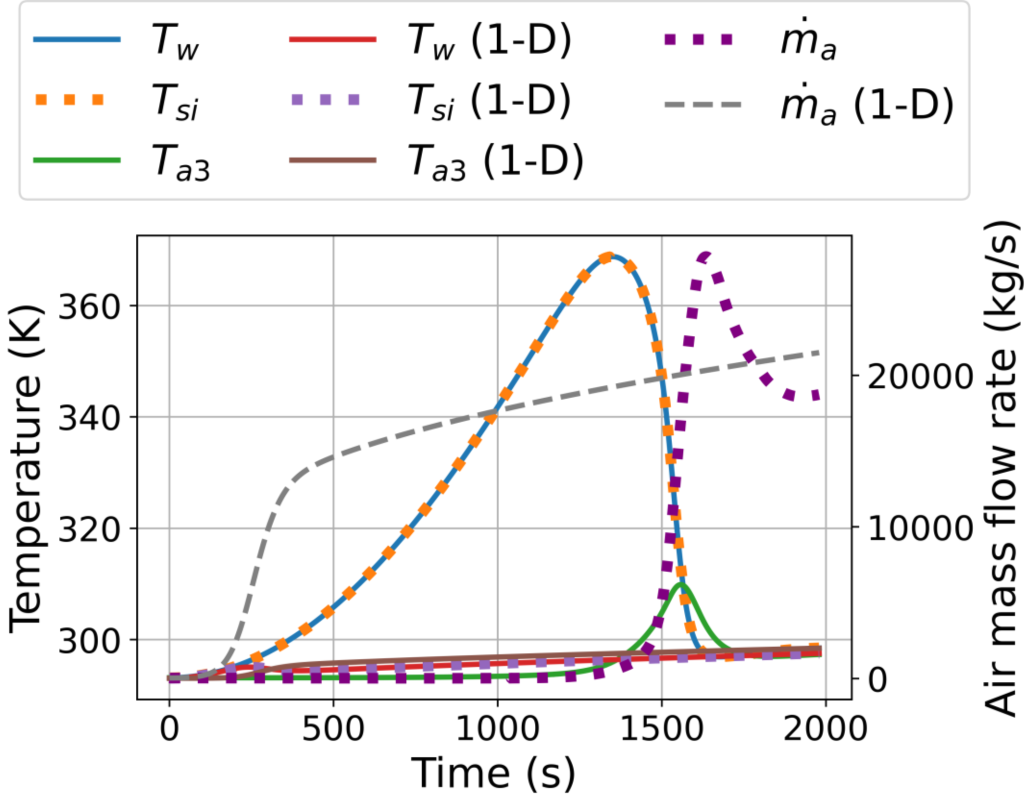


Transient co-simulation results: steam admission load ramp under no-wind

- Load ramp results (no wind): system does not exceed 40 kPa(g) limit for typical load ramp start-up scenario



Steam back pressure



Temperatures and mass flow rate

Transient co-simulation results: steam admission load ramp under 9 m/s crosswind

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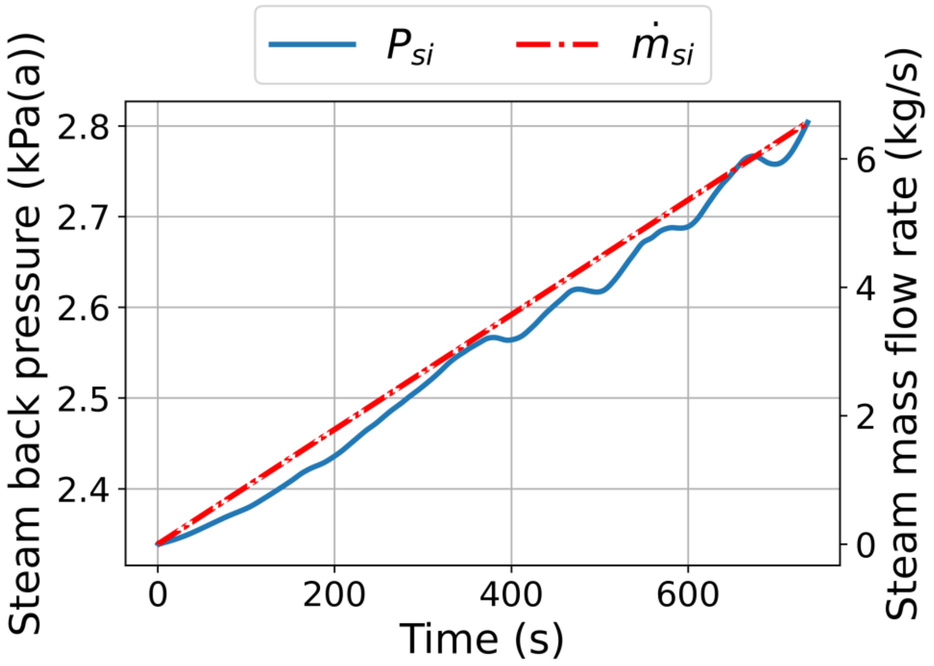
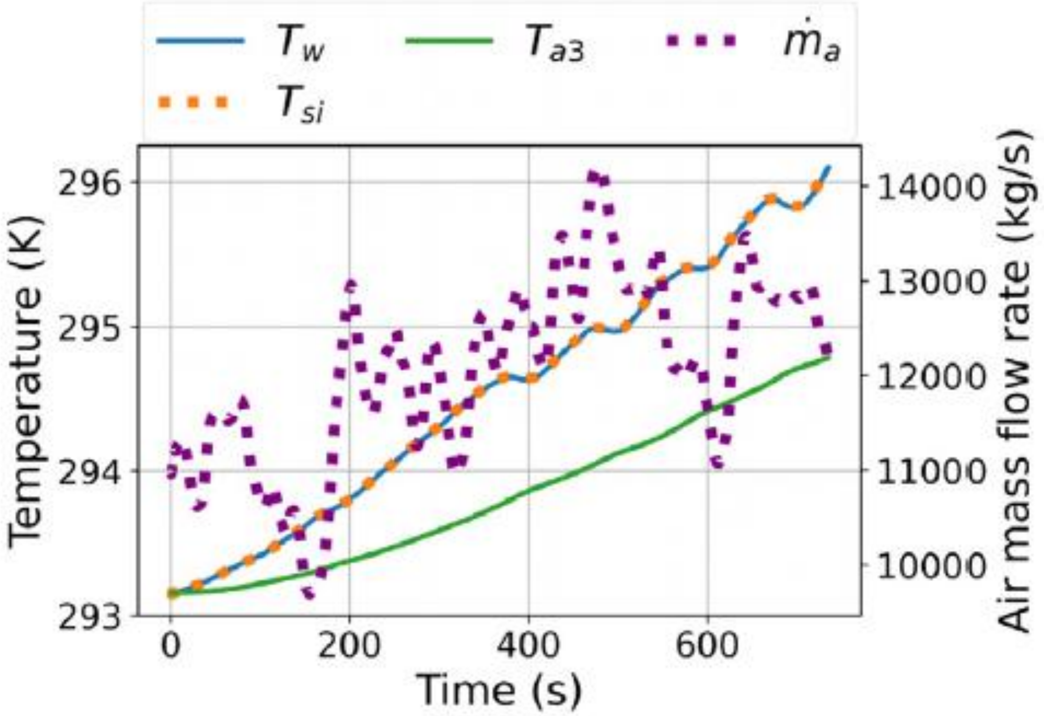
- Load ramp results (high wind): improves start-up performance compared to no wind scenario



Steam back pressure



Temperatures and mass flow rate

Transient co-simulation results: full-load turbine islanding

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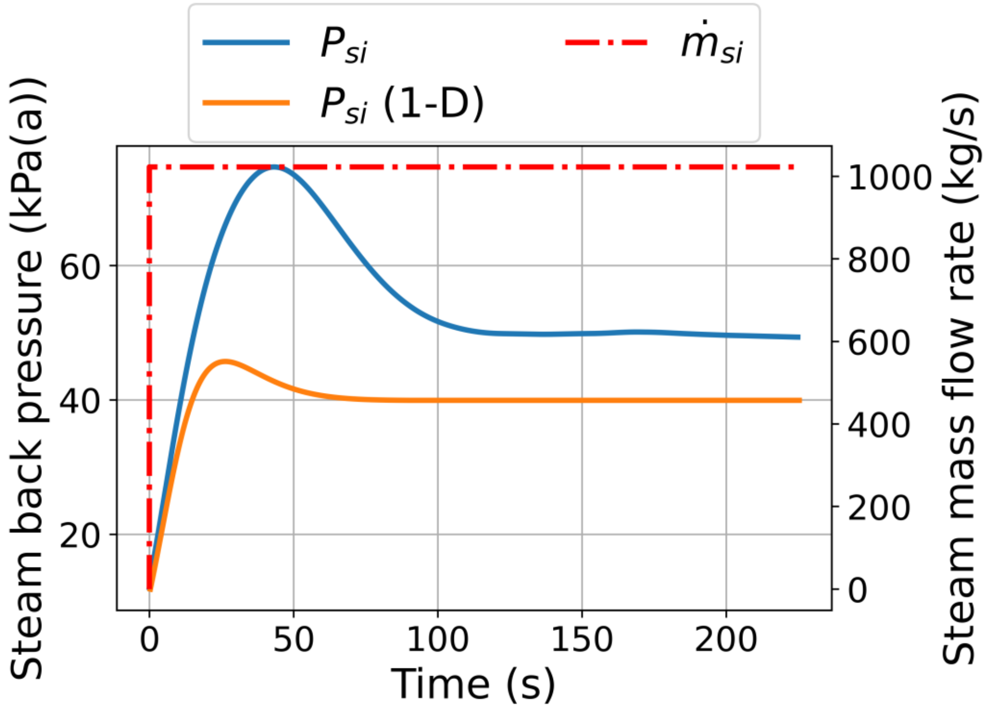
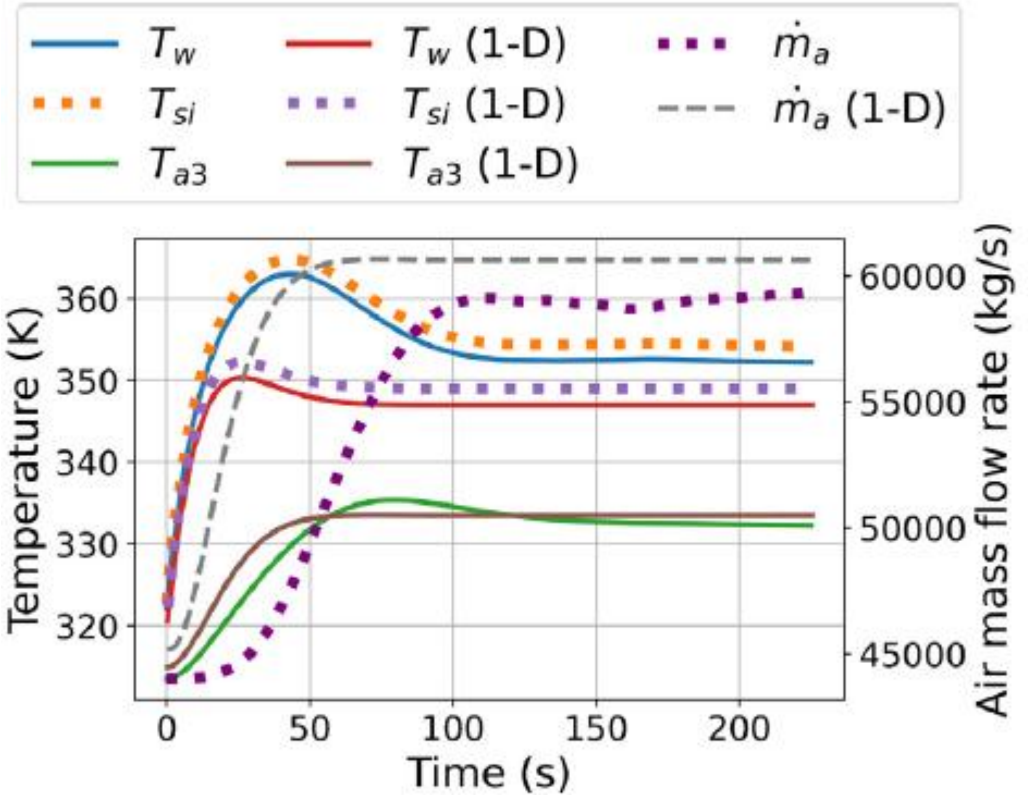
- Full-load islanding (no wind): NDACC can handle 265% load without exceeding 75 kPa(a) limit



Steam back pressure



Temperatures and mass flow rate

Conclusions & future work

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- Conclusion from transient simulations:
  - Co-sim model accounts for natural convection effects which 1-D model cannot capture
  - Under no wind conditions, NDACC has limited tolerance of steam admission step input when cold
  - For realistic scenarios, co-sim predicts NDACC does not limit cold start-up or islanding
  - Windy conditions improve NDACC start-up performance
  - For NDACCs with vertically-arranged heat exchangers, radial placement of bundles is important for start-up
- NDACC has merit
- Future work
  - Wind mitigation for NDACCs
  - Calculation of LCOEs for ACC vs NDACC for CCGT plant in South Africa
  - Integrate ROM with NDACC models – determine optimized tube design

(abengoa.com)

(spgdrycooling.com)


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Questions?
Thank you
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