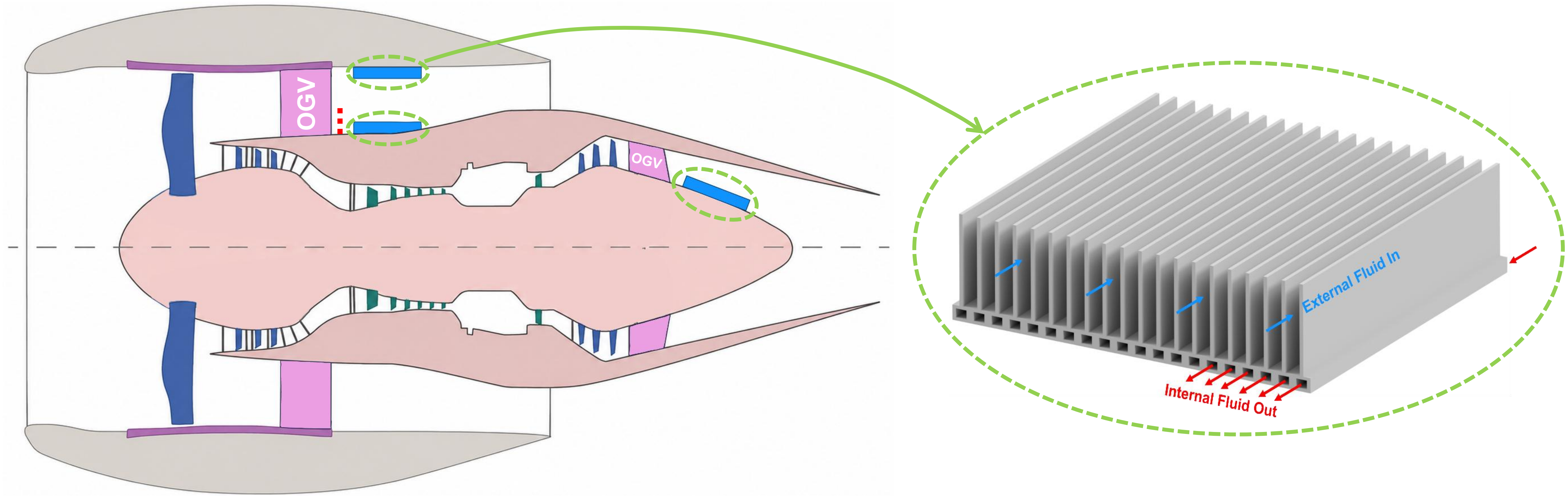
The Effect of Turbofan-Representative Distortion on Surface Heat Exchanger Performance



ID: AIAA-2026-4433

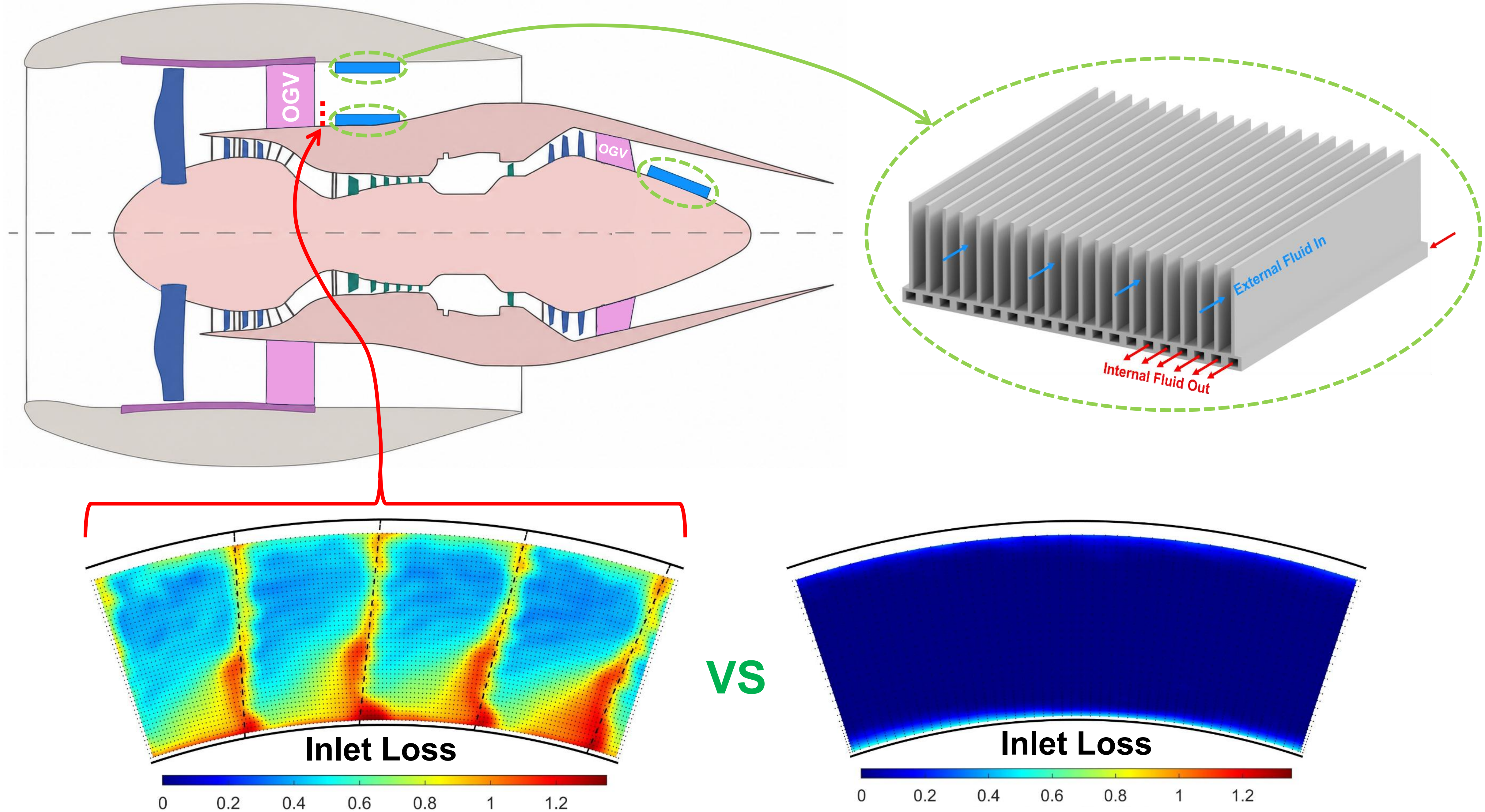
David Stewart, John Coull, Peter Ireland

University of Oxford

How does Turbofan representative distortion affect HX performance?

Aerodynamic Performance ↑ 22%

Thermal Performance ↓ 2%



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Contents

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- Approach
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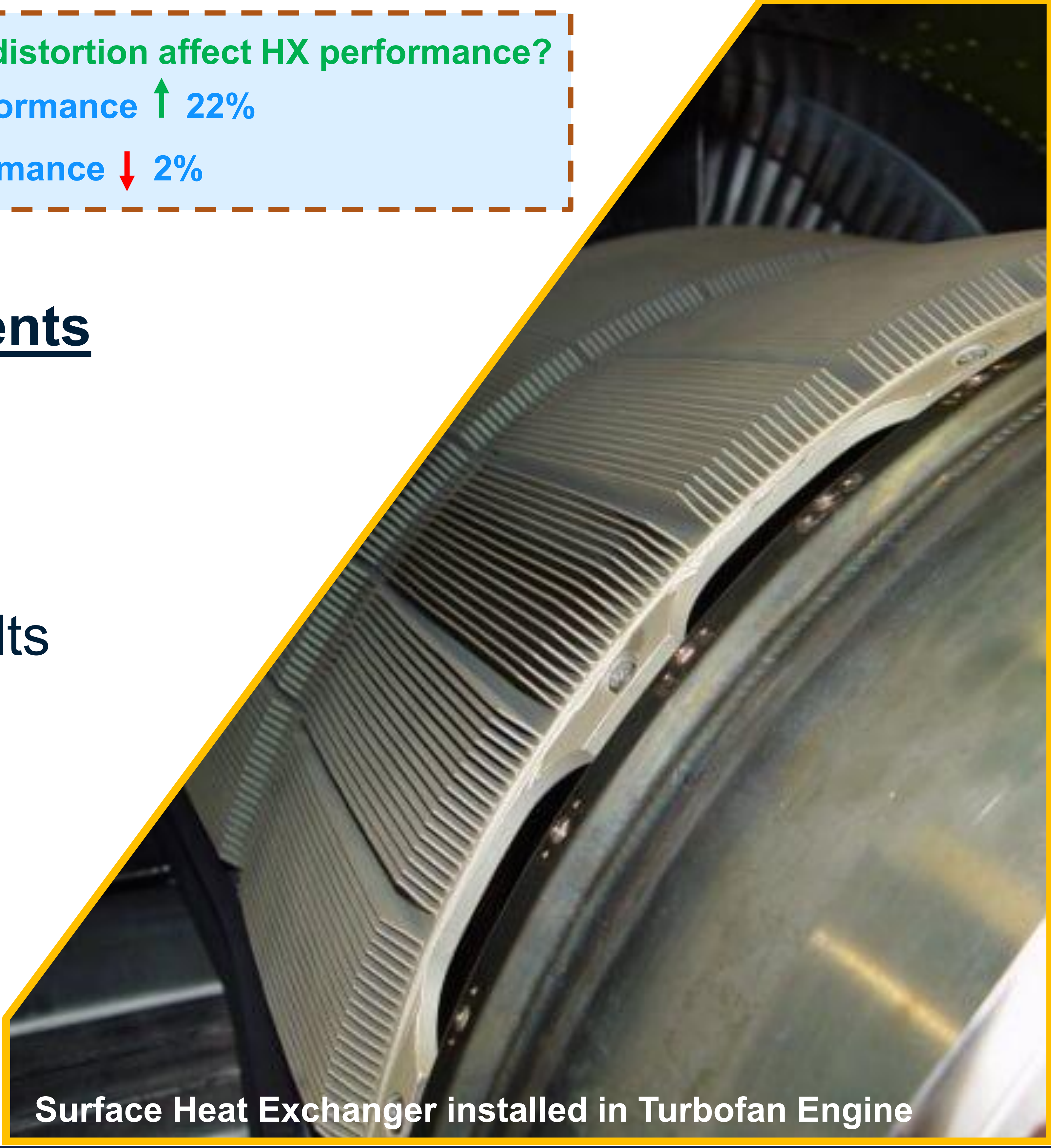
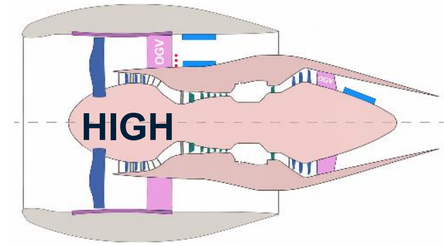
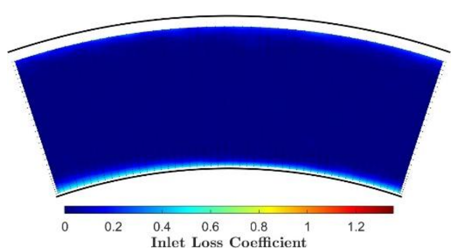
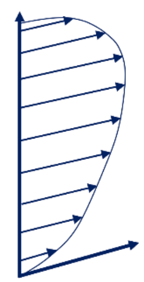
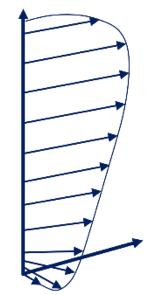
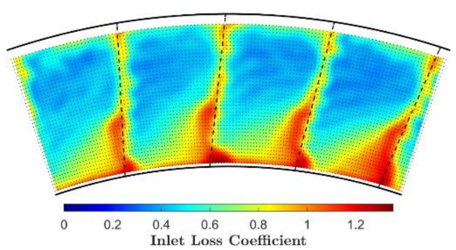
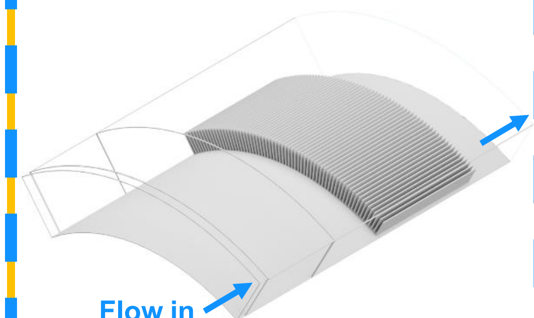
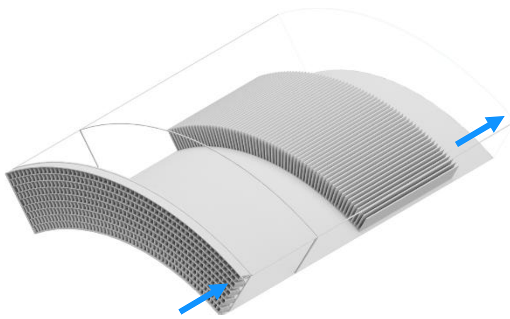
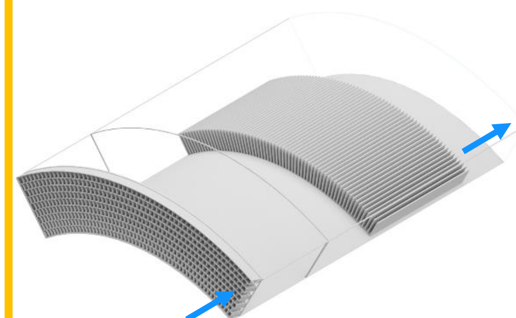
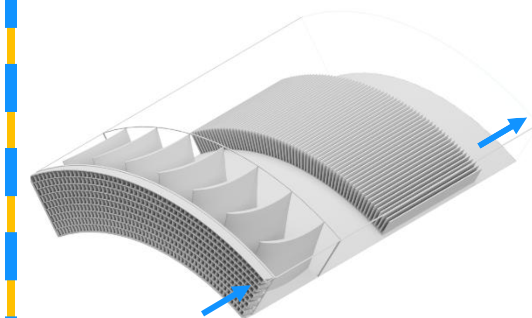
- Conclusions



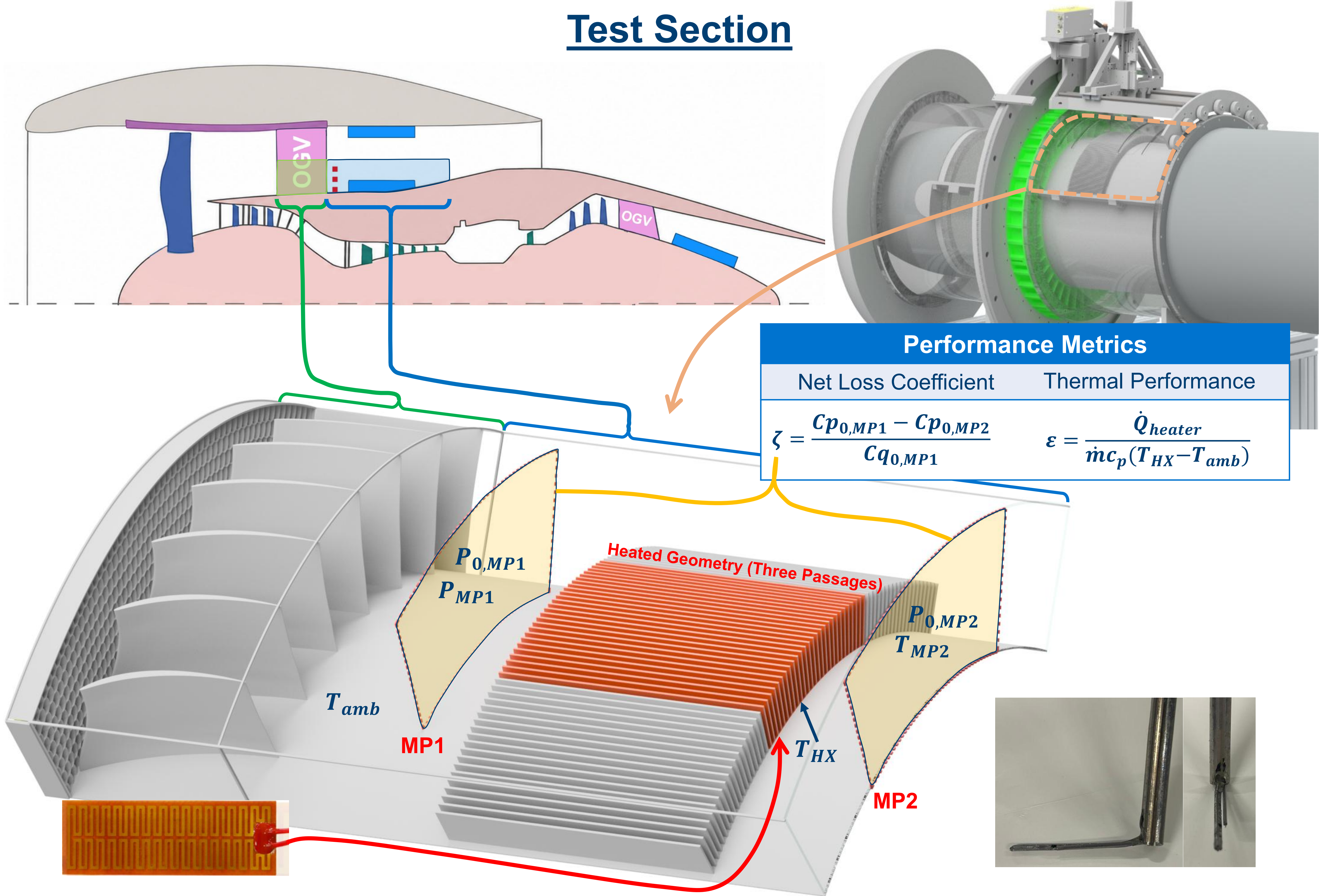
Surface Heat Exchanger installed in Turbofan Engine

LOW → **Engine Realism** →



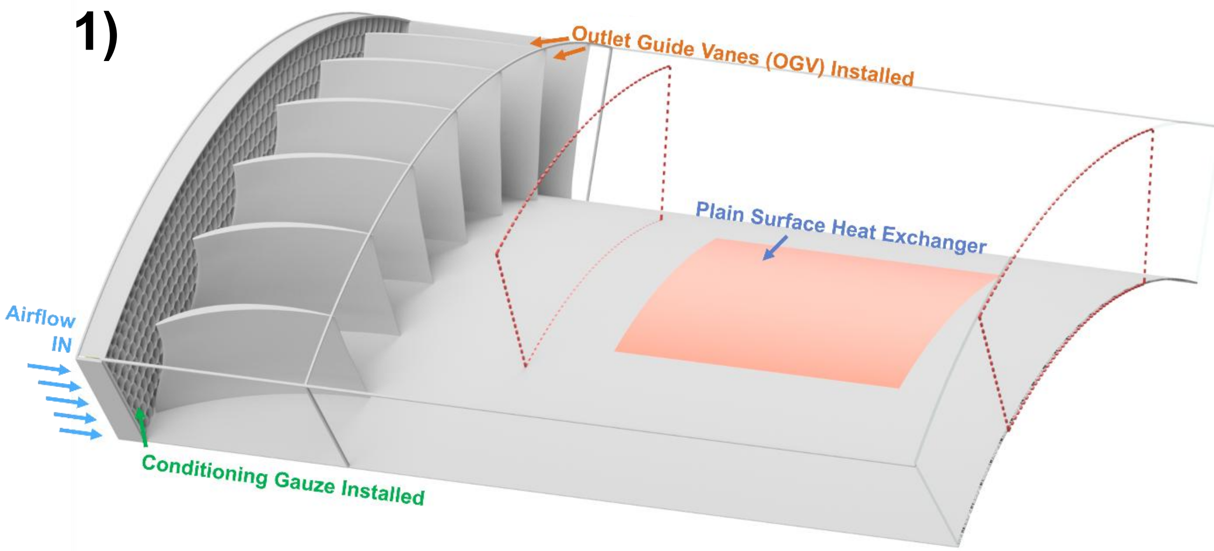
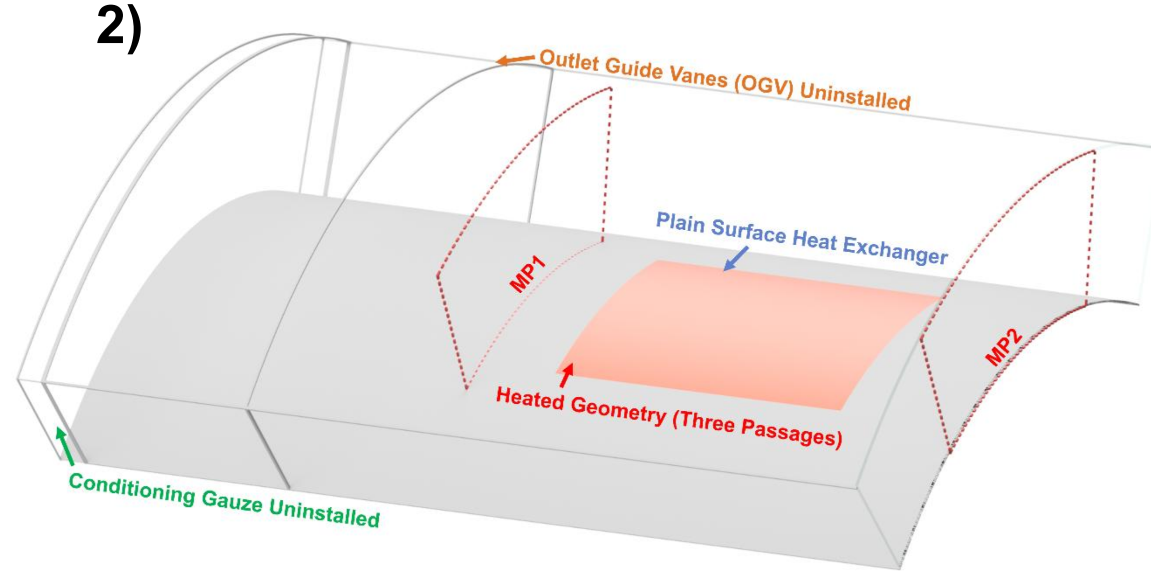
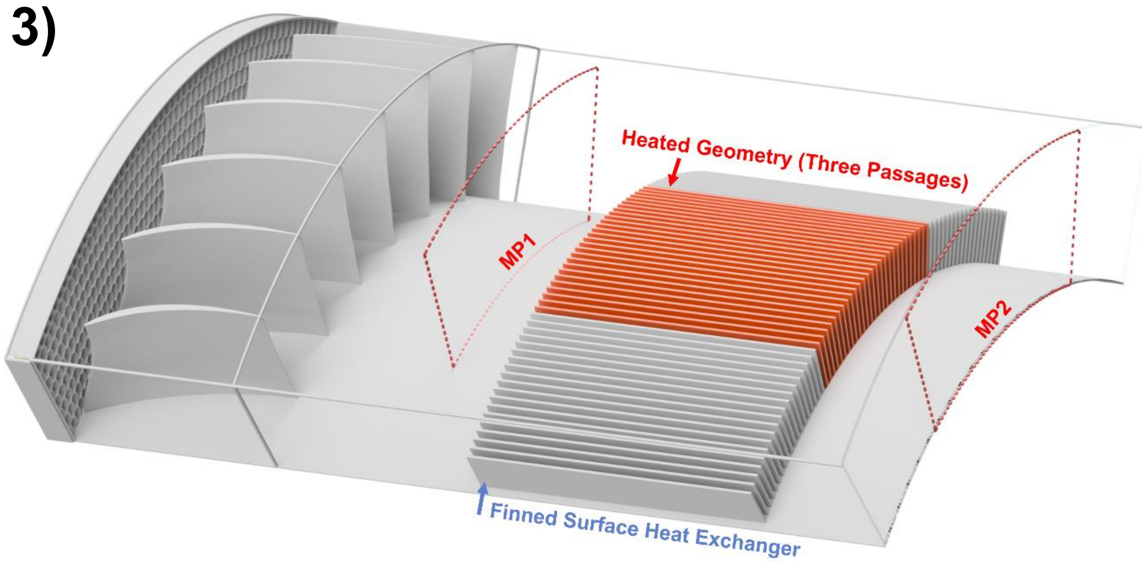
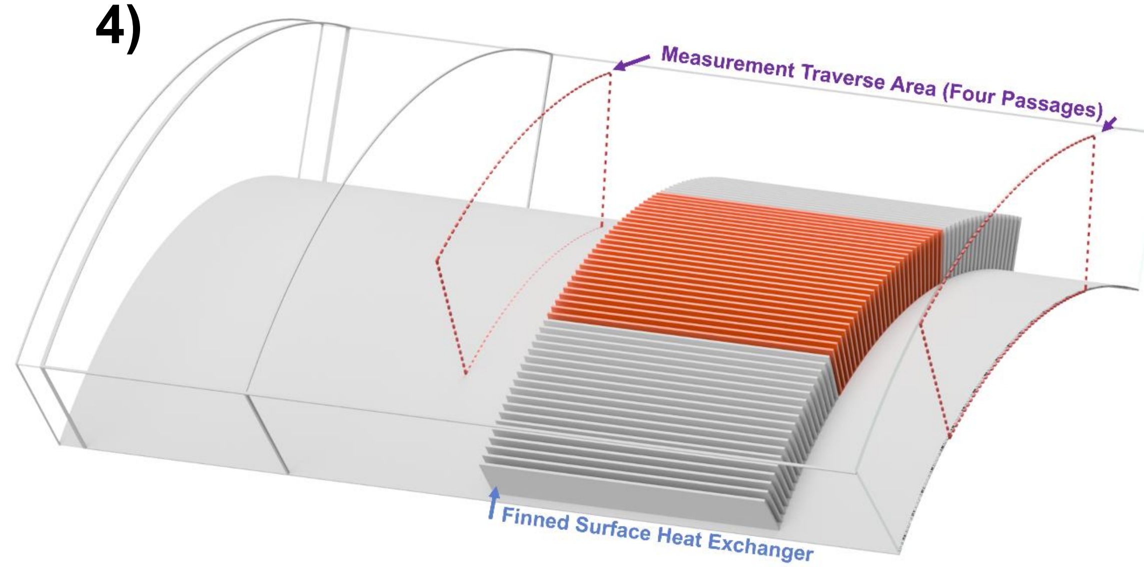
	Thin Boundary Layer (Uniform Flow)	Radial Total Pressure Profile	Full Radial Profile	Engine Representative (Distorted Flow)
P_0 Gradients	✗	✓	✓	✓
Bulk Swirl	✗	✗	✓	✓
Discrete Wakes	✗	✗	✗	✓
Inlet Profile				
Experimental Set-up	No Conditioning Grid 	Radial Cond. Grid 	Radial + Circumferential Cond. Grid 	Radial + Circumferential Cond. Grid with OGVs 
Study	Current + Rebassa et al. (Purdue Univ.)	Broatch et al. (Valencia Univ.)	Villafane et al. (Von Karmin Inst.)	Current + Gelain et al. (Safran Engines)

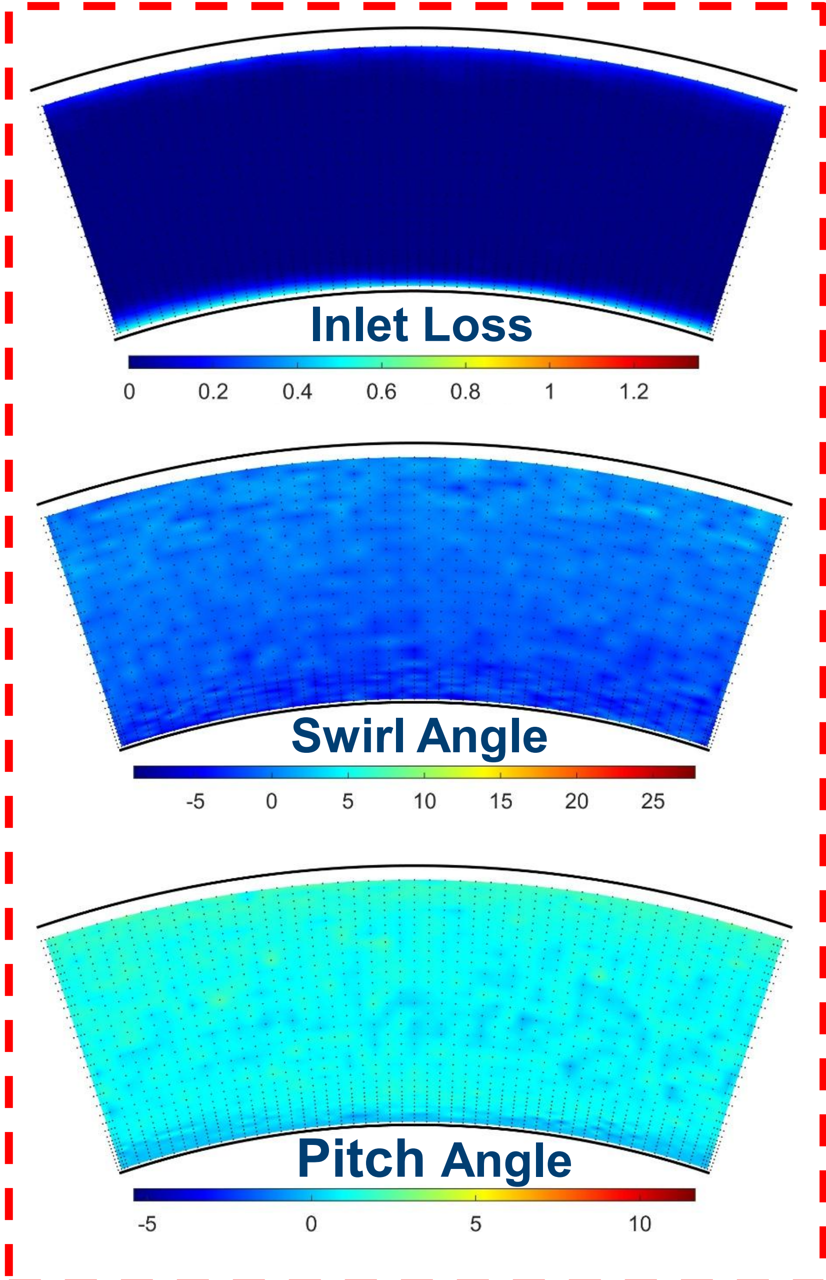
Test Section



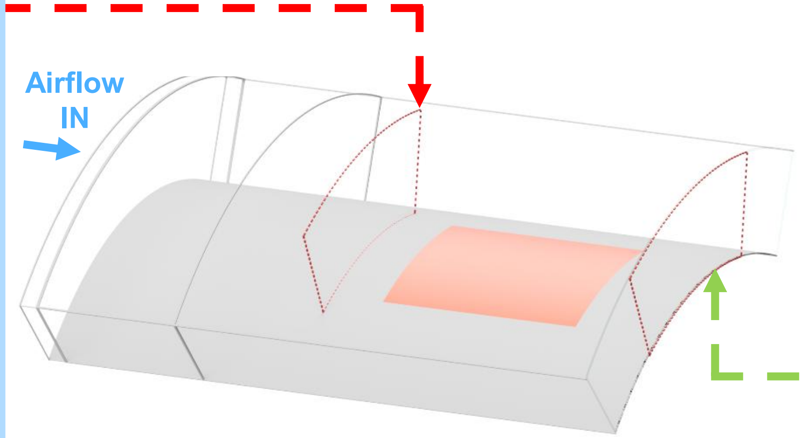
Performance Metrics	
Net Loss Coefficient	Thermal Performance
$\zeta = \dfrac{Cp_{0,MP1} - Cp_{0,MP2}}{Cq_{0,MP1}}$	$\varepsilon = \dfrac{\dot{Q}_{heater}}{\dot{m} c_p (T_{HX} - T_{amb})}$

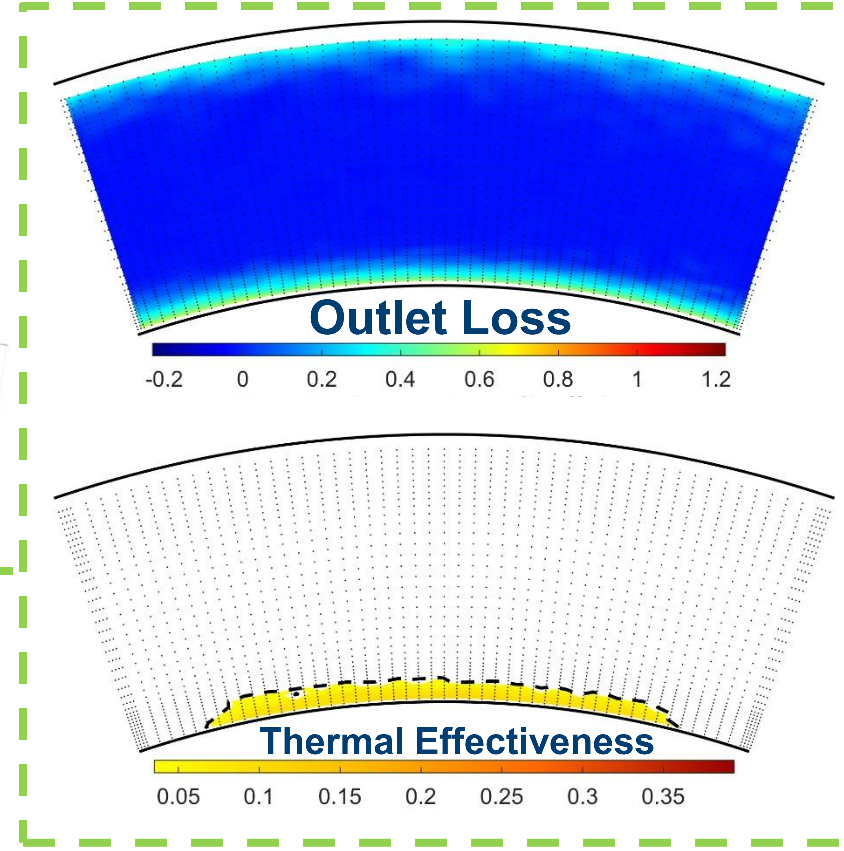
Experimental Test Configurations

	Engine Representative Inlet	Uniform Inlet
Plain HX	1) 	2) 
Finned HX	3) 	4) 

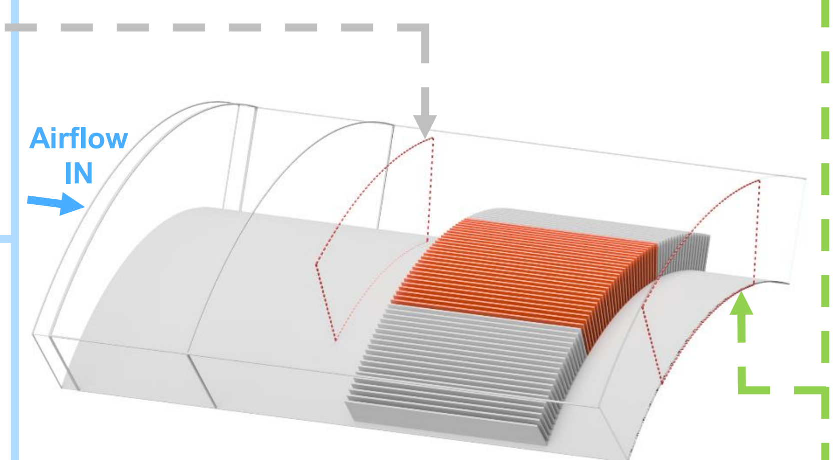


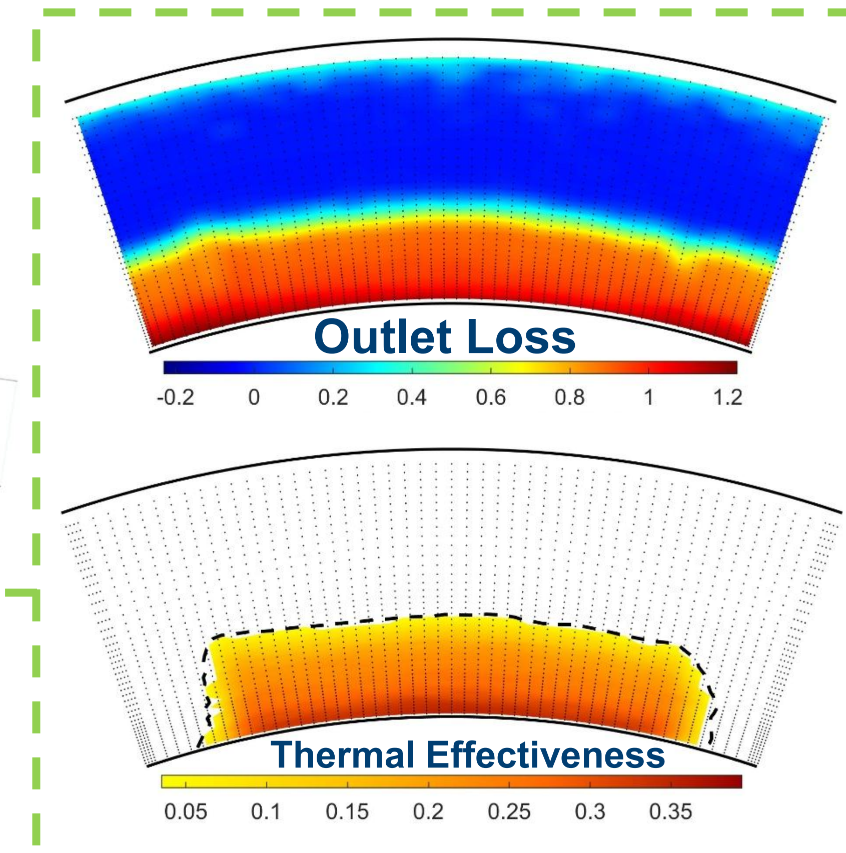
Uniform Inlet & Plain HX



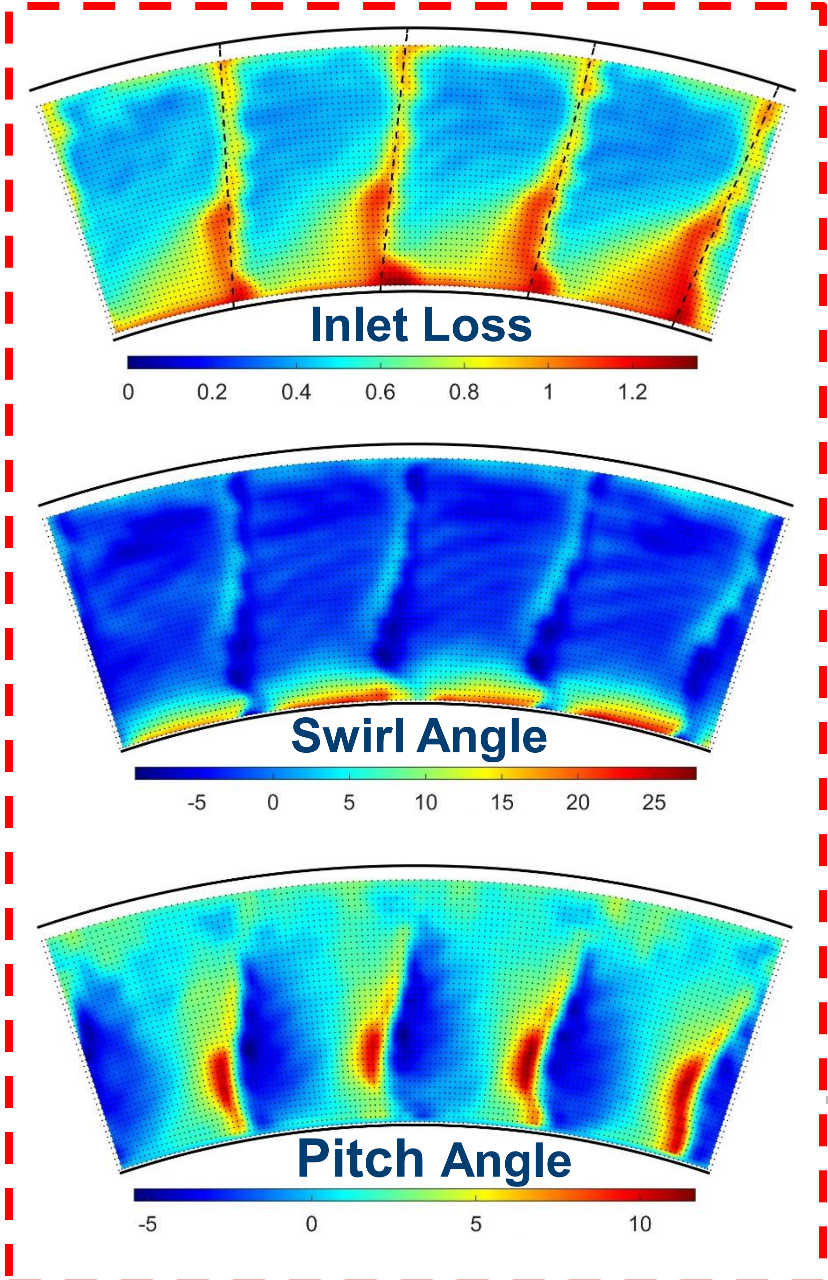


Uniform Inlet & Finned HX

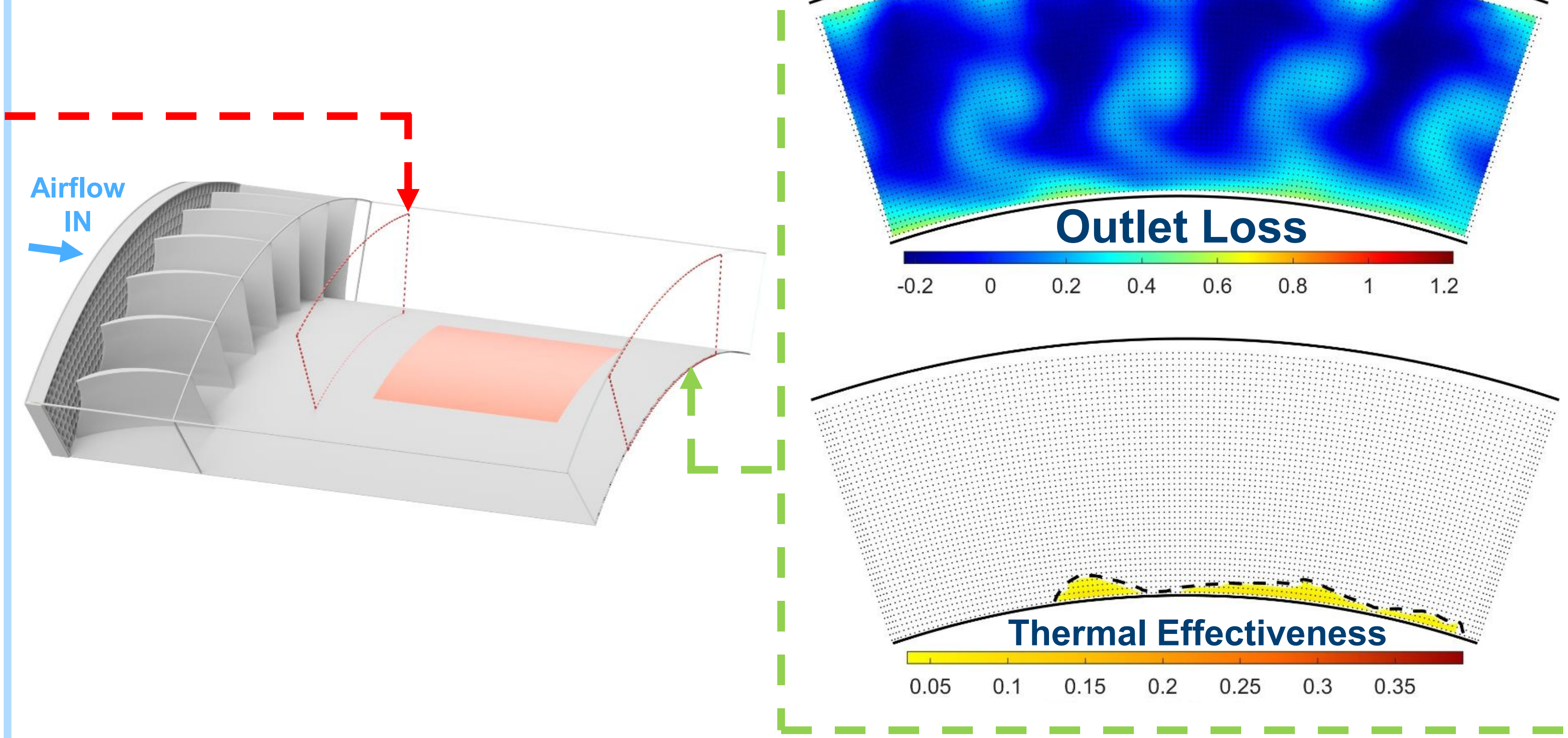




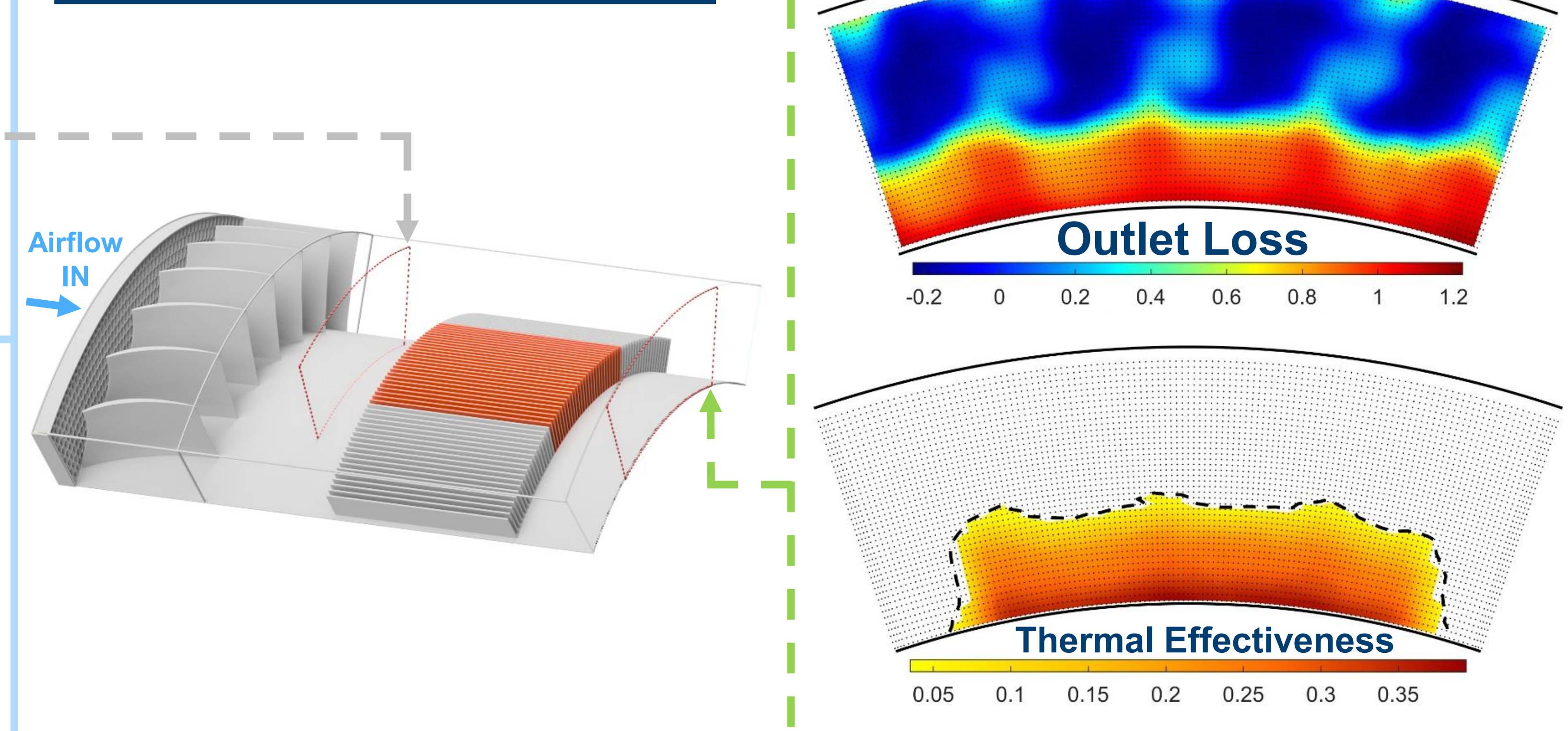
Configuration	Performance	
	Aero ζ [-]	Thermal ε [-]
Uniform - Plain	0.032	0.0047
Uniform - Finned	0.24	0.038
Distorted - Plain		
Distorted - Finned		



Distorted Inlet & Plain HX



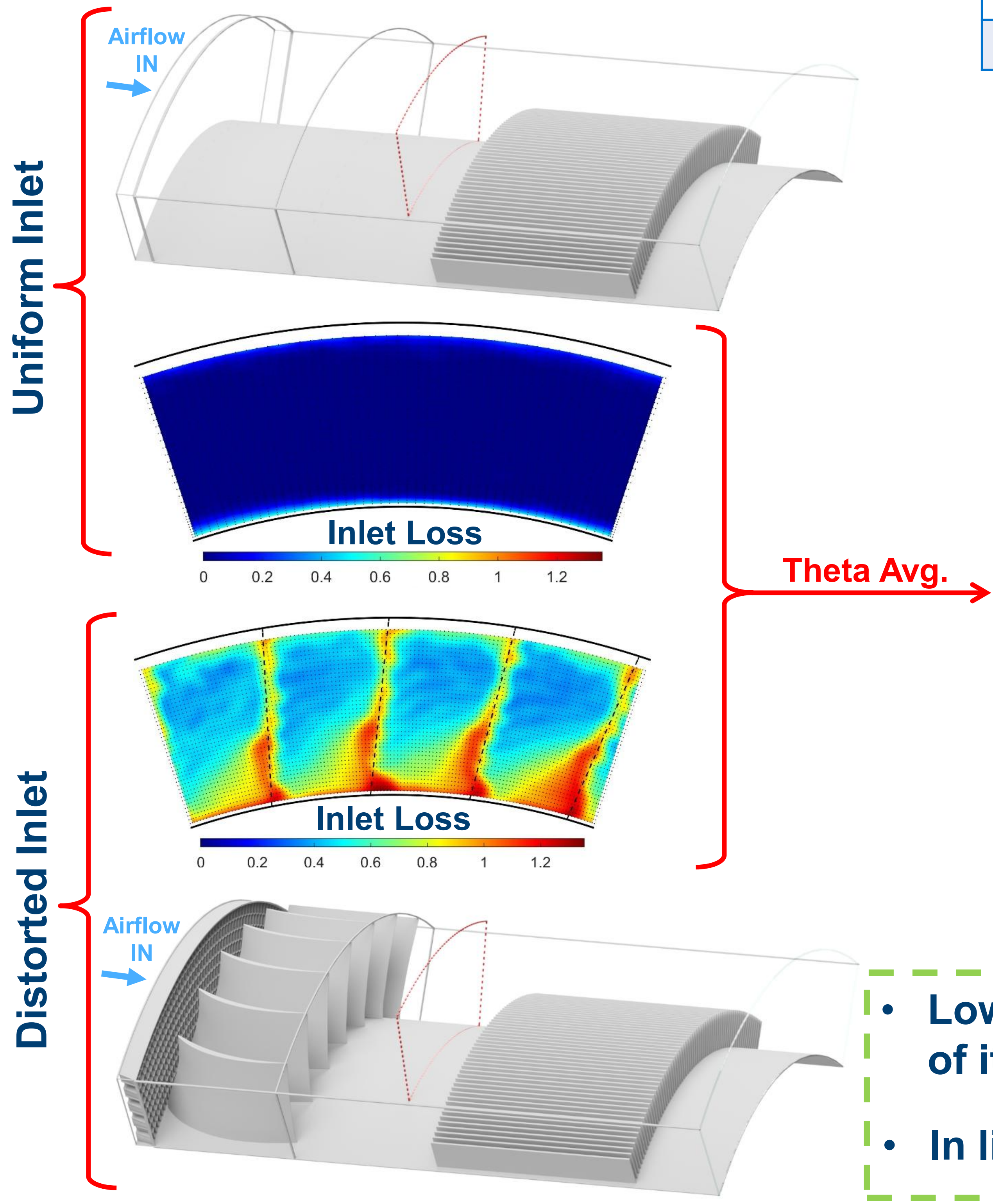
Distorted Inlet & Finned HX

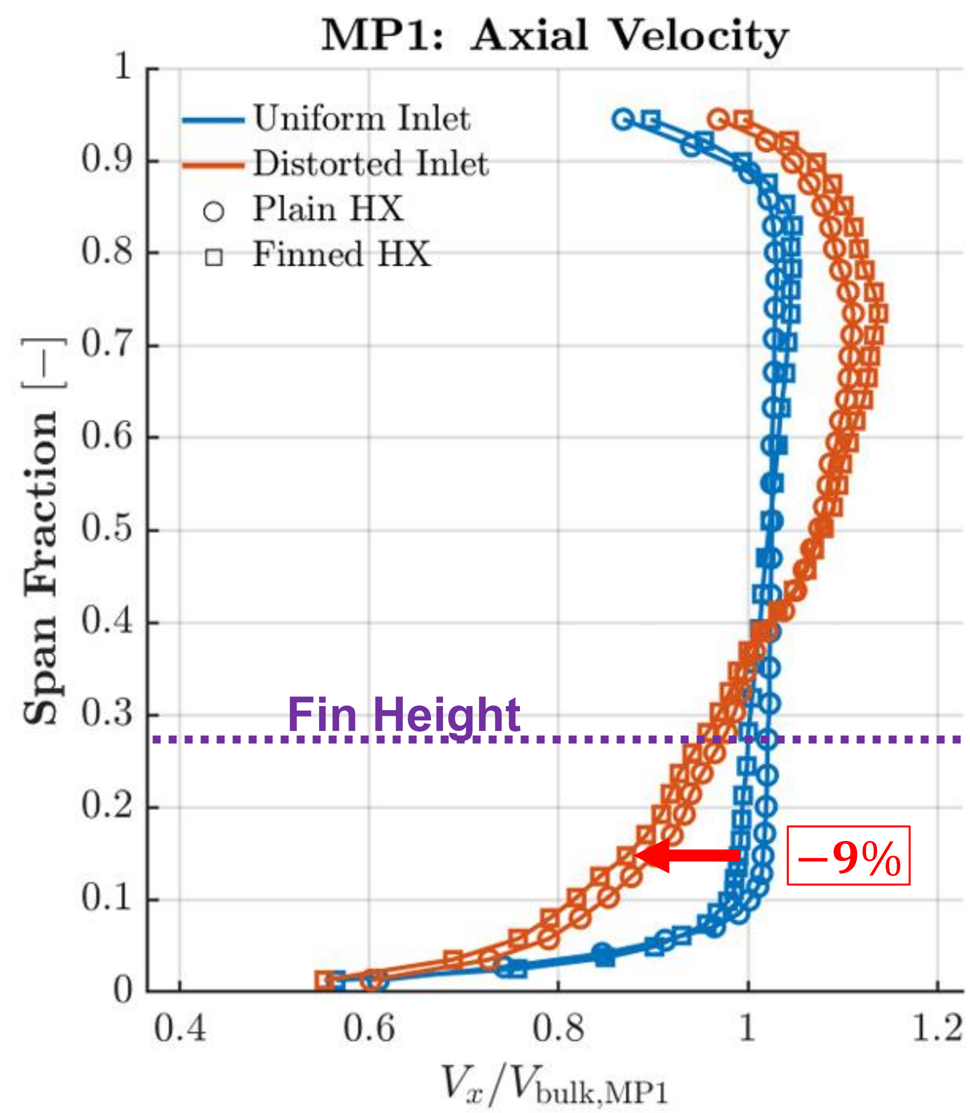


Configuration	Performance	
	Aero ζ [-]	Thermal ε [-]
Uniform - Plain	0.032	0.0047
Uniform - Finned	0.24	0.038
Distorted - Plain	0.041	0.0053
Distorted - Finned	0.19	0.037

Why is HX loss 22% lower under the distorted inlet?

Configuration	Performance	
	Aero ζ [-]	Thermal ε [-]
Uniform – Finned	0.24	0.038
Distorted - Finned	0.19 -22%	0.037





- **Lower HX loss under the distorted inlet is a result of its lower axial velocity in the finned HX region**
- **In line with $\dot{S}_{gen} \propto V^3$ (Denton et al.) (25%)**

Why is HX loss 22% lower under the distorted inlet?

- This is a result of its lower axial velocity in the finned HX region

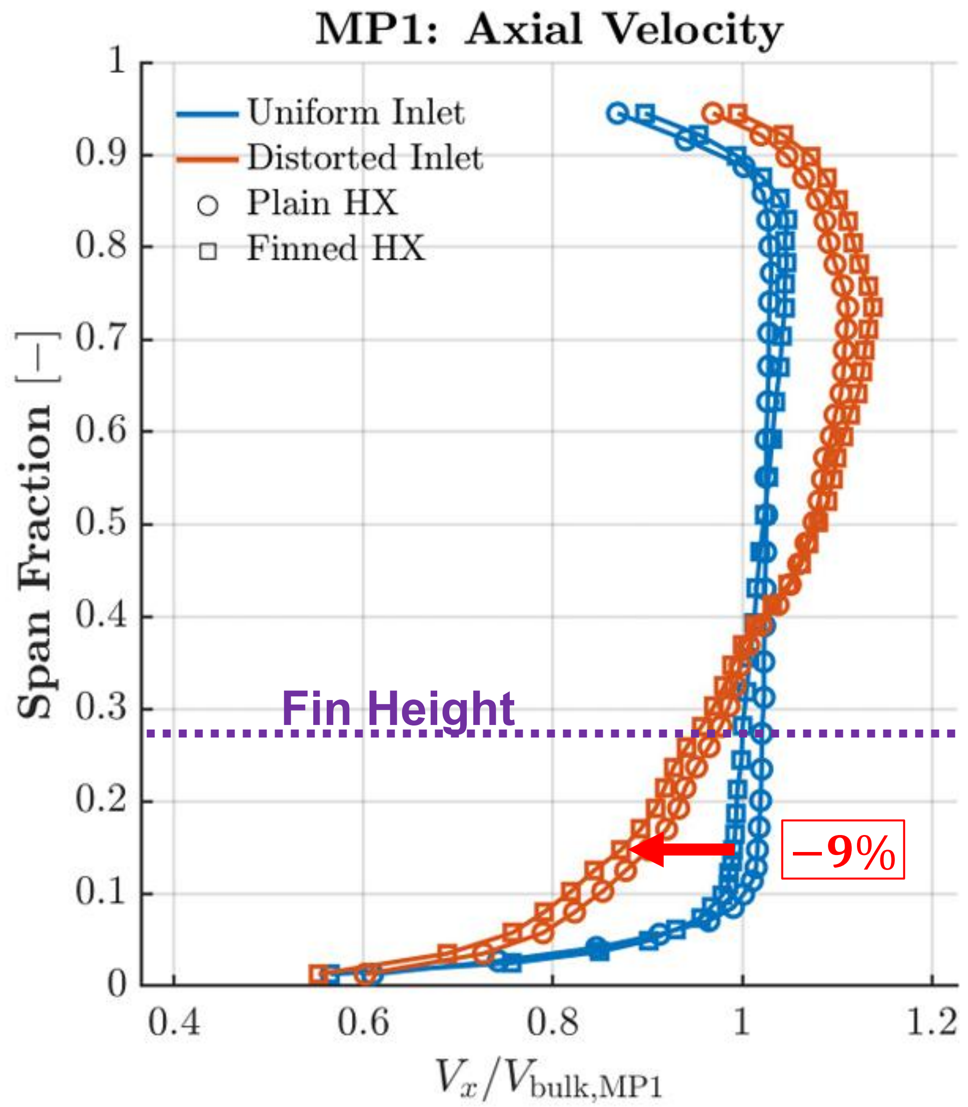
What would we expect to happen to the heat transfer?

- 9% reduction in axial velocity would be expected to drop heat transfer by ~ 5 to 7%.
- First-order estimate based on forced convection velocity scaling ($h \propto V^{0.6-0.8}$)

What actually happens to the heat transfer?

- Heat transfer only drops by ~ 2%

Configuration	Performance	
	Aero ζ [-]	Thermal ε [-]
Uniform – Finned	0.24	0.038
Distorted - Finned	0.19 -22%	0.037 -2%

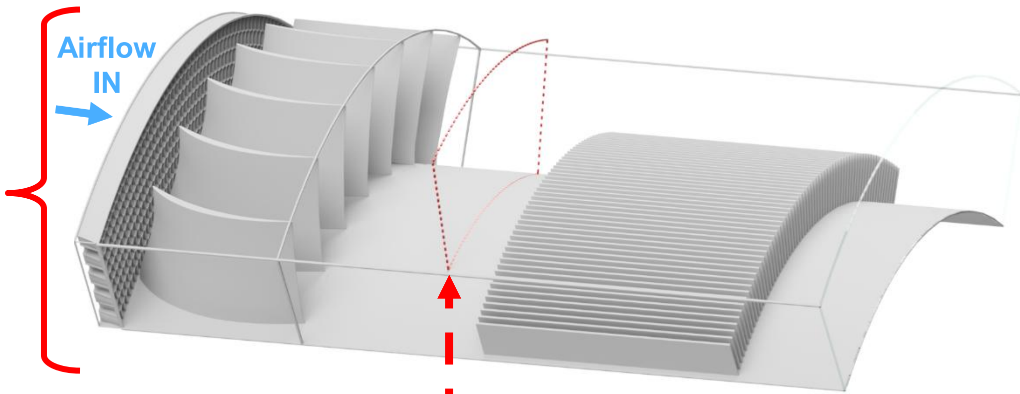


- Lower HX loss under the distorted inlet is a result of its lower axial velocity in the finned HX region
- In line with $\dot{S}_{gen} \propto V^3$ (Denton et al.) (25%)

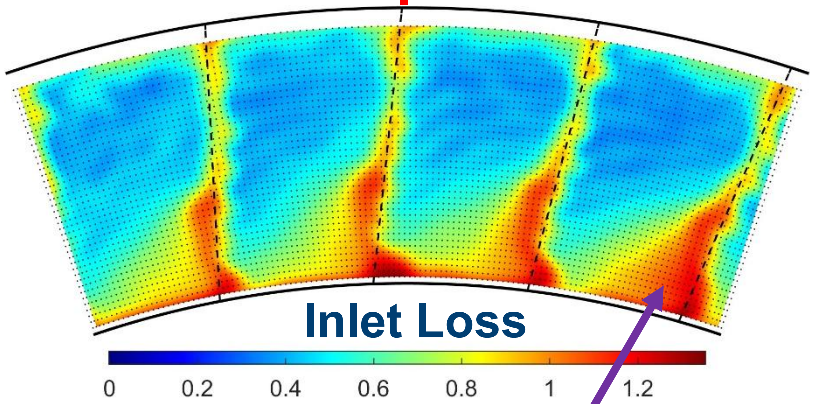
Why is heat transfer comparable between the two inlets?

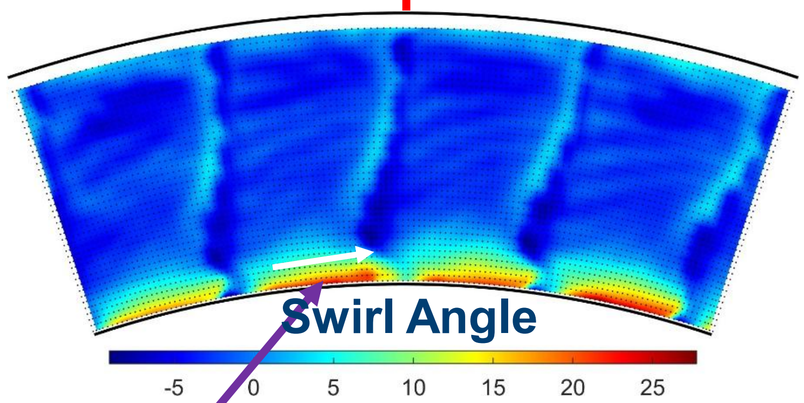
Configuration	Performance			
	Aero ζ [-]		Thermal ε [-]	
Uniform – Finned	0.24		0.038	
Distorted - Finned	0.19	-22%	0.037	-2%

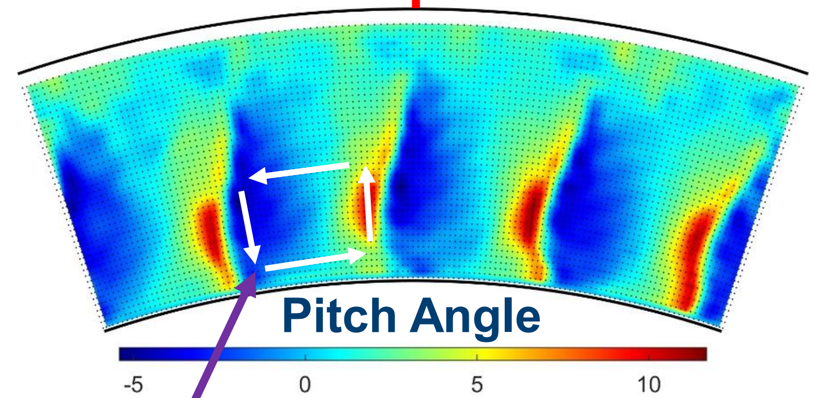
Distorted Inlet



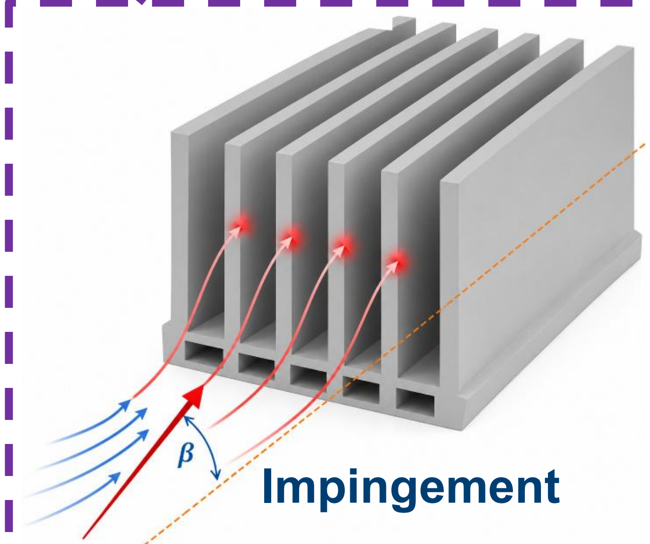
Heat transfer is comparable due to enhancement mechanisms



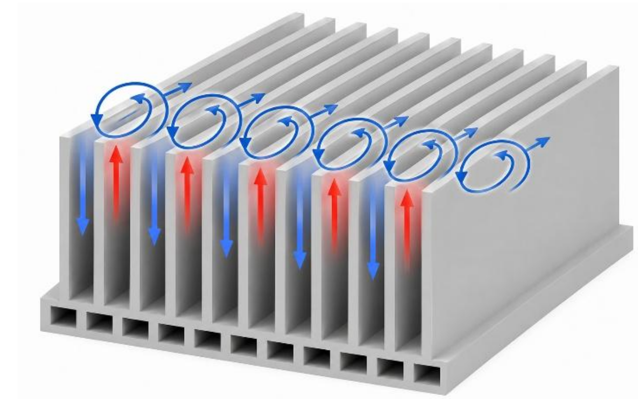




Increased Turbulence Intensity

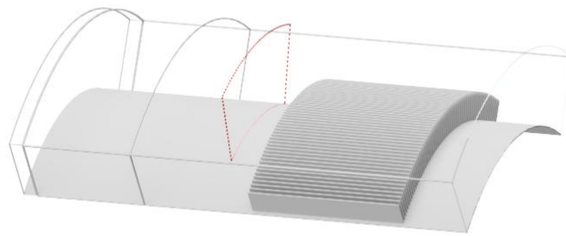


Impingement

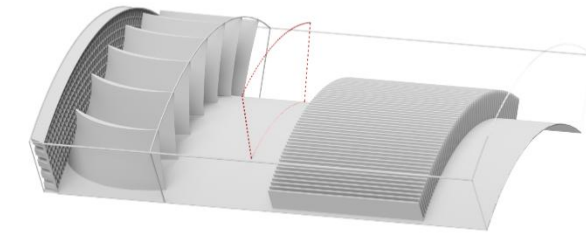


Enhanced Mixing

Conclusions

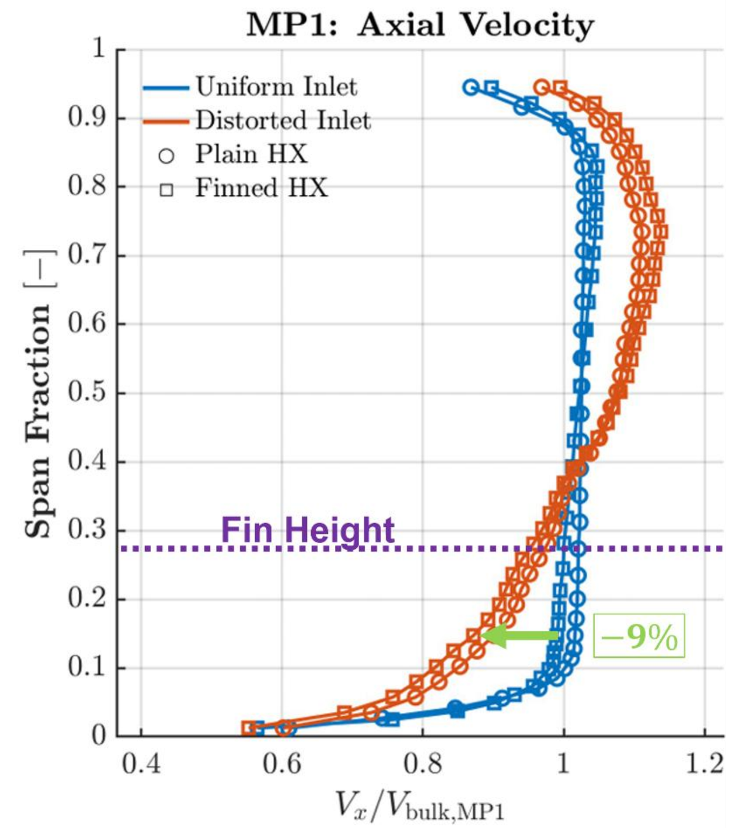


vs



How does Turbofan representative distortion affect HX performance?

- Aero Performance ↑ 22%, caused by the distorted inlet lowering axial velocity through HX by 9%.
- The loss reduction is in line with $\dot{S}_{gen} \propto V^3$ arguments.
- Despite a nominal ~ 5 to 7% heat transfer penalty from reduced velocity.
- Heat transfer is maintained within 2% due to enhancement mechanisms.
- May be beneficial to actively place these HXs in regions of high distortion, i.e. downstream of OGVs.



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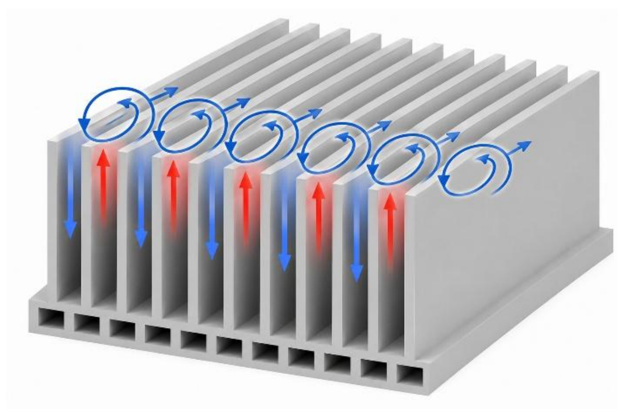

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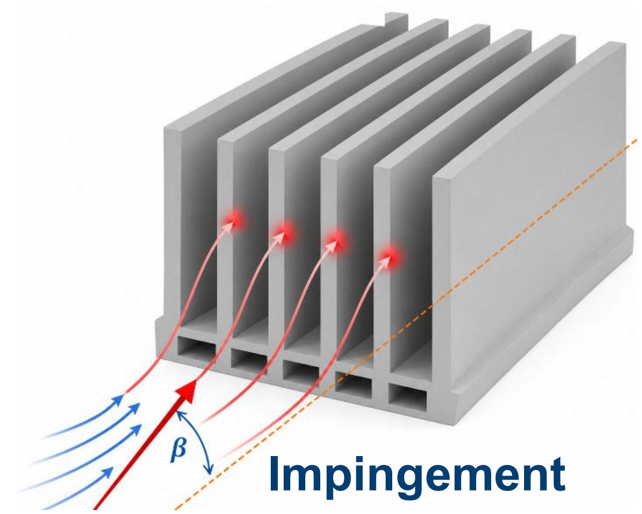

Impingement

Acknowledgements

<table>
<tr><th colspan="3">Acknowledgements</th></tr>
<tr><td>Marko Bacic</td><td>Rolls-Royce plc.</td><td rowspan="2">Guidance</td></tr>
<tr><td>Andrew Pilkington</td><td rowspan="4">University of Oxford</td></tr>
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<tr><td>James Turner</td></tr>
<tr><td>Lucy Cross</td></tr>
<tr><td>James Taylor</td><td>University of Cambridge</td></tr>
<tr><td>UK LH2GT Project</td><td>ATI</td><td rowspan="2">Funding</td></tr>
<tr><td>UKRI EPSRC iCase Studentship</td><td>EPSRC/Rolls-Royce plc</td></tr>
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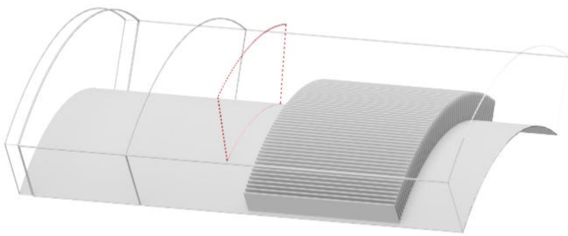
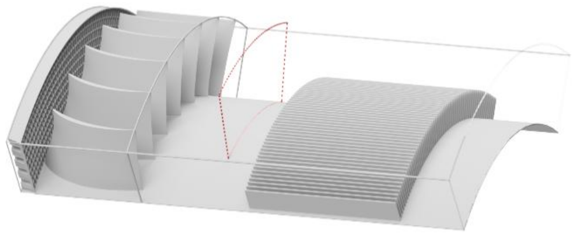
Conclusions


vs


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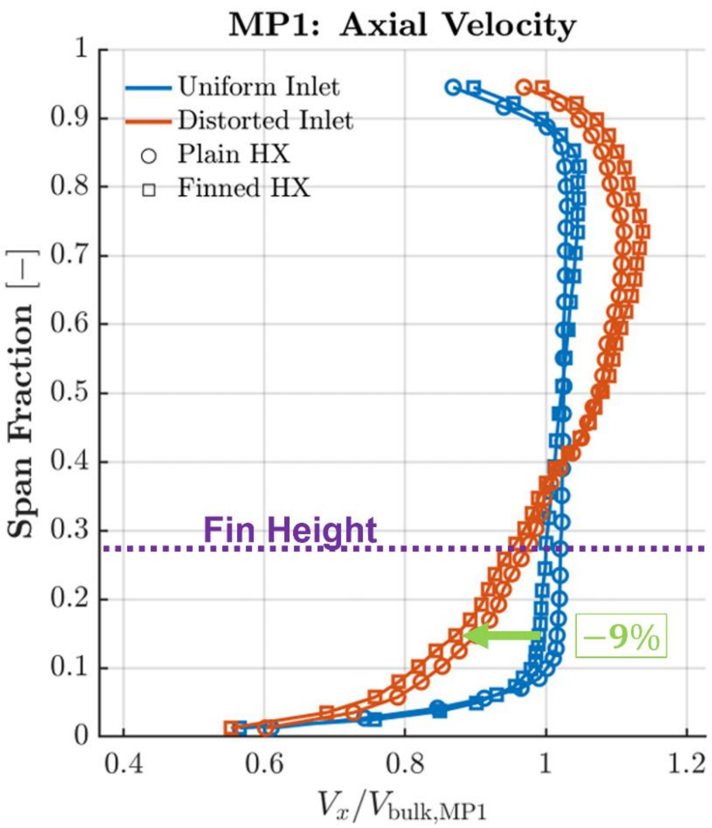

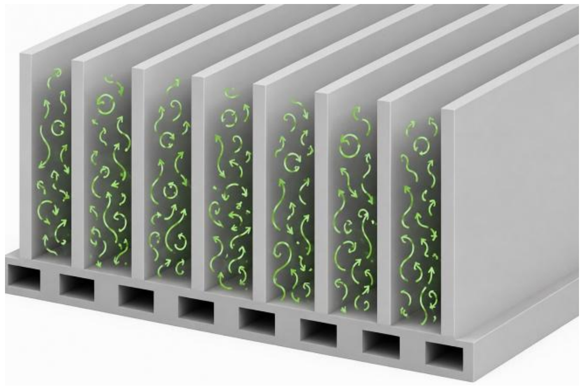

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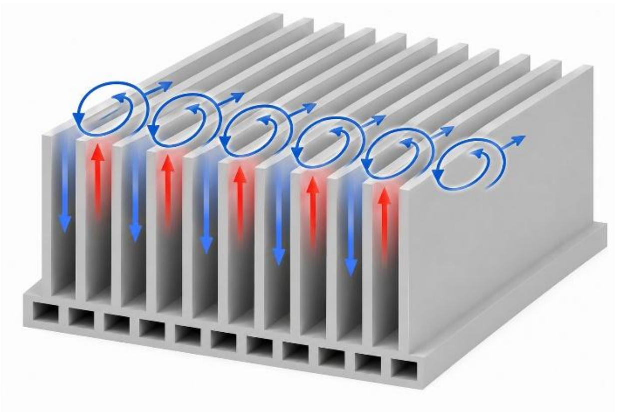
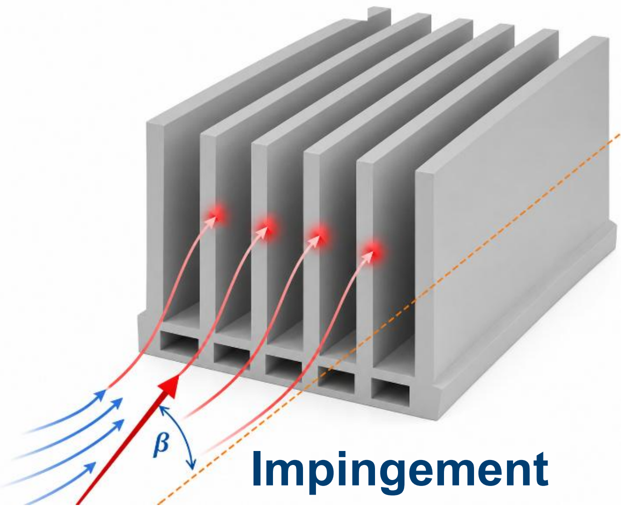


Enhanced Mixing



Impingement