Evaluation of Interstage Water Injection Effect on Compressor and Engine Performance

I. Roumeliotis **K. Mathioudakis**

Laboratory of Thermal Turbomachines
National Technical University of Athens

Evaluation of Interstage Water Injection Effect on Compressor and Engine Performance

- §Compressor Model
- §Compressor Test Case
- §Engine Model
- §Stage Rematching
- §Effects on Overall Performance
- §Conclusions

Compressor Model

Droplet Model

- §Spalding Model
- §No Velocity Slip Assumption
- §Constant Number of Droplets

Adaptive Stage Stacking Model

- §Establishment of Compressor Stall Limits
- §Derivation of Individual Stage Characteristics
- §Determination of the Effect of Bleeds and Variable Geometry

Compressor Model

Stage Stacking Method

- **Use of mixture static properties due to not established thermal equilibrium**
- **Introduction of time dimension using rotor and stator length**
- **Unchanged stage characteristics assuming no losses of hydrodynamic or mechanical nature**
- **Introduction of entropy increase due to evaporation**

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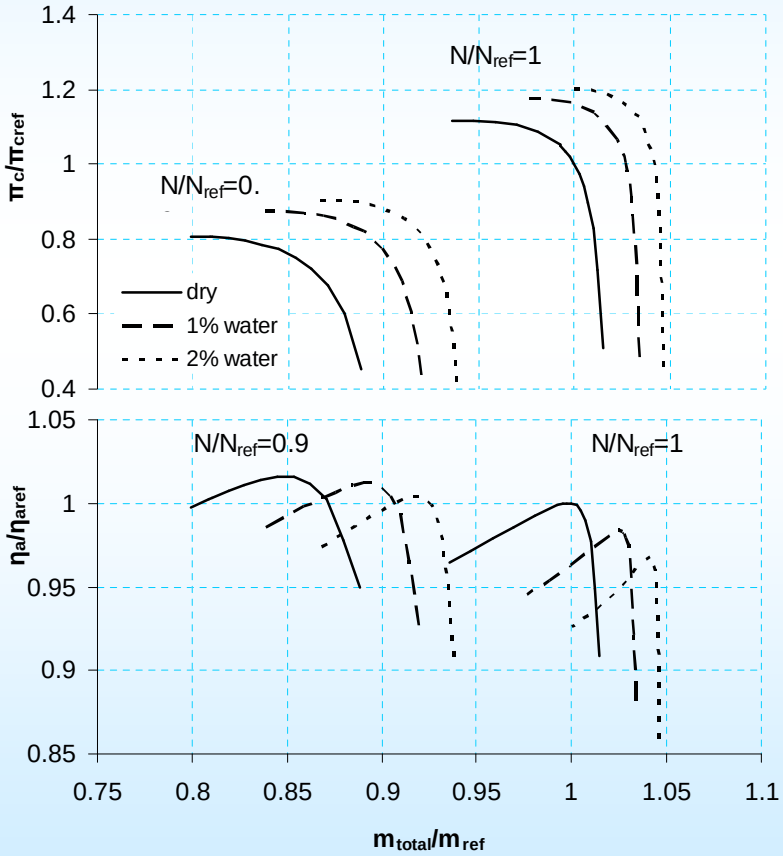
Compressor Test Case

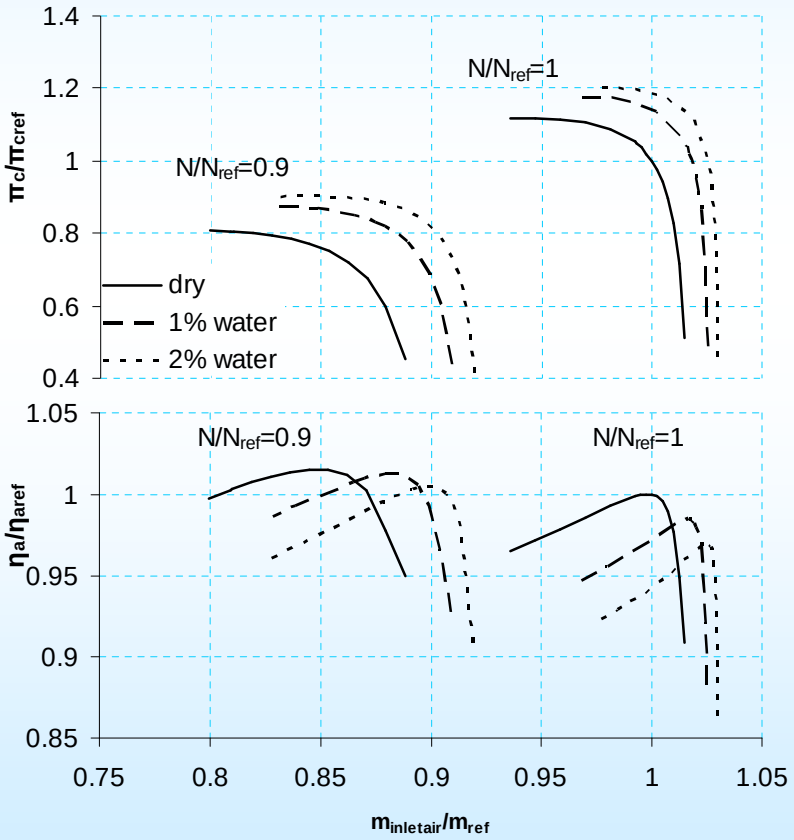
1st Stage Injection



CIT = 15°C RH=100%

Compressor Test Case

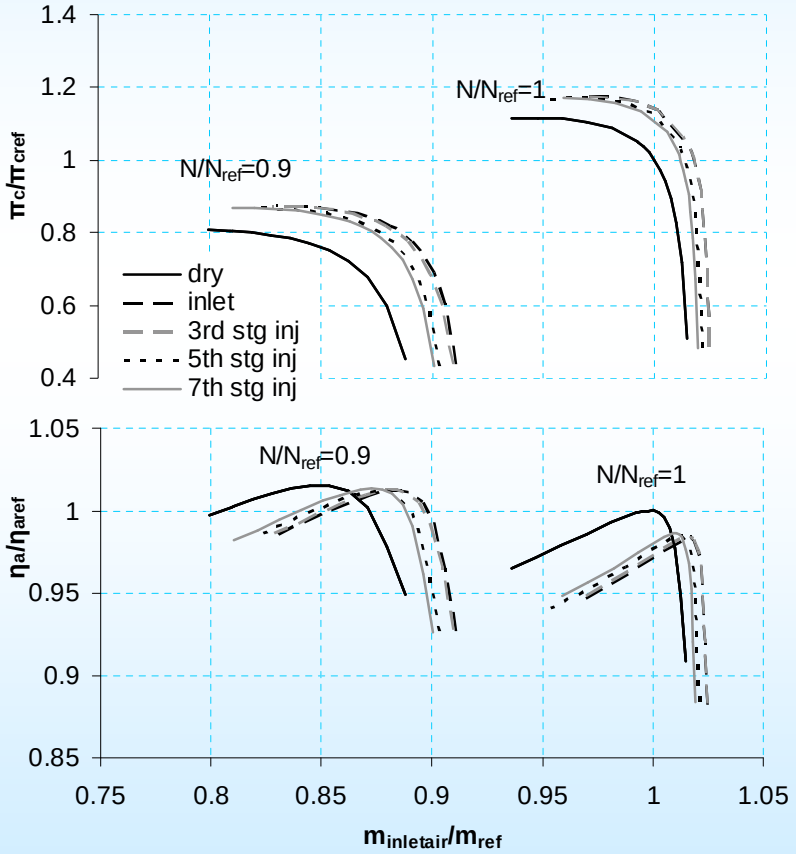
3rd Stage Injection



CIT = 15°C RH=100%

Compressor Test Case

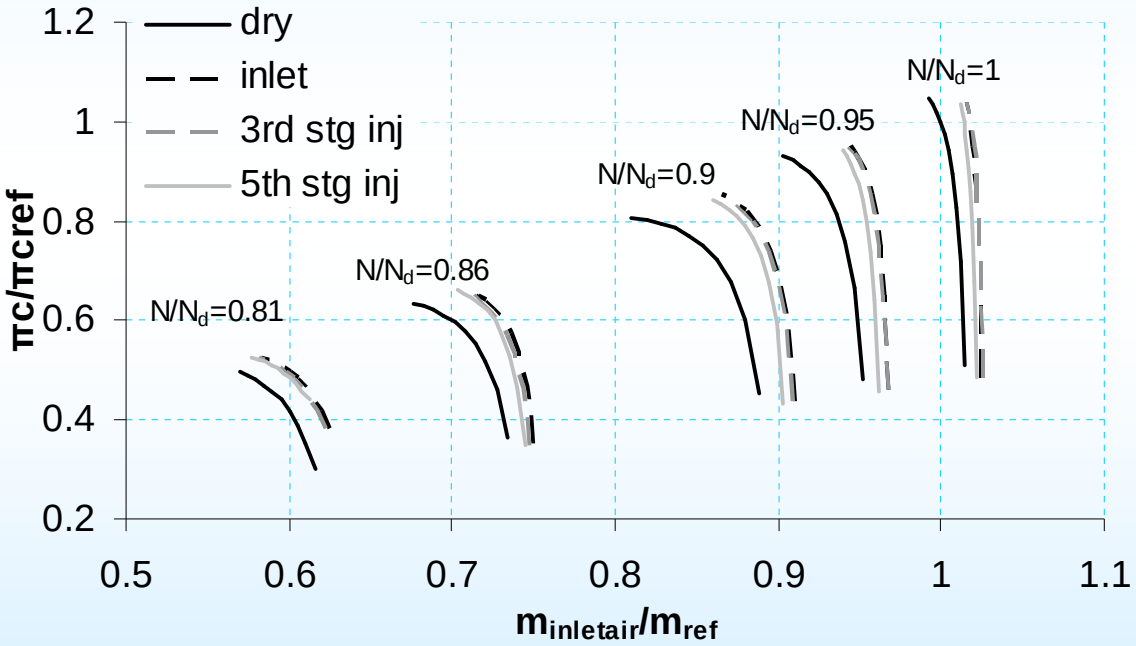
1% water injection



CIT = 15ºC RH=100%

Compressor Test Case

Operating Limits



Stall Criterion: $d\Psi/d\Phi=0$ for each stage characteristic

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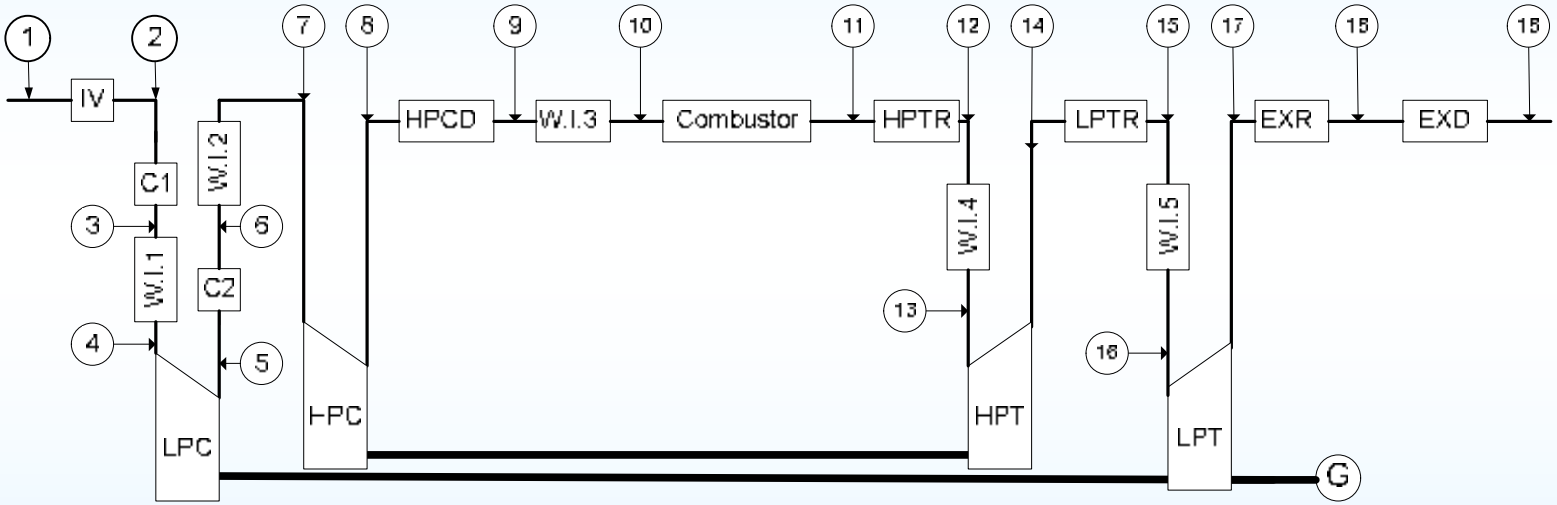
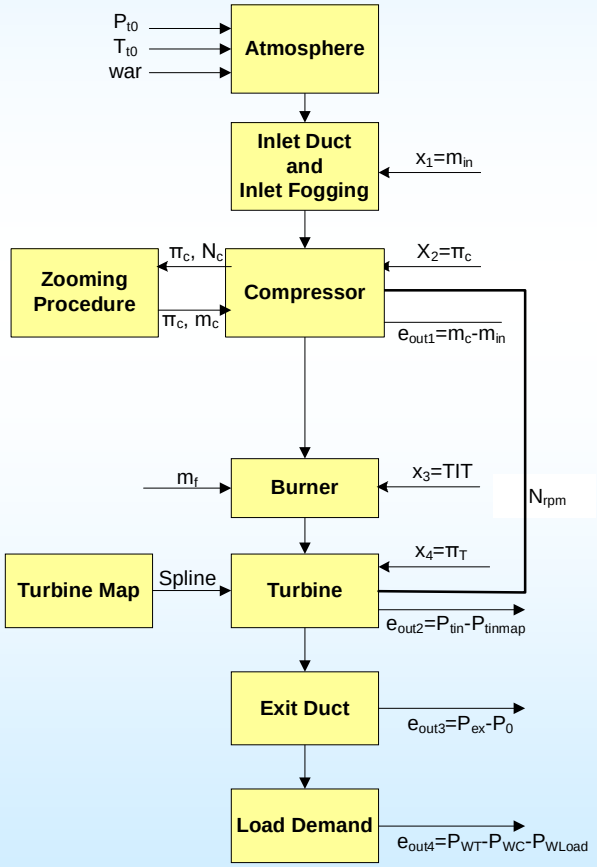
Engine Model

Engine Performance Model



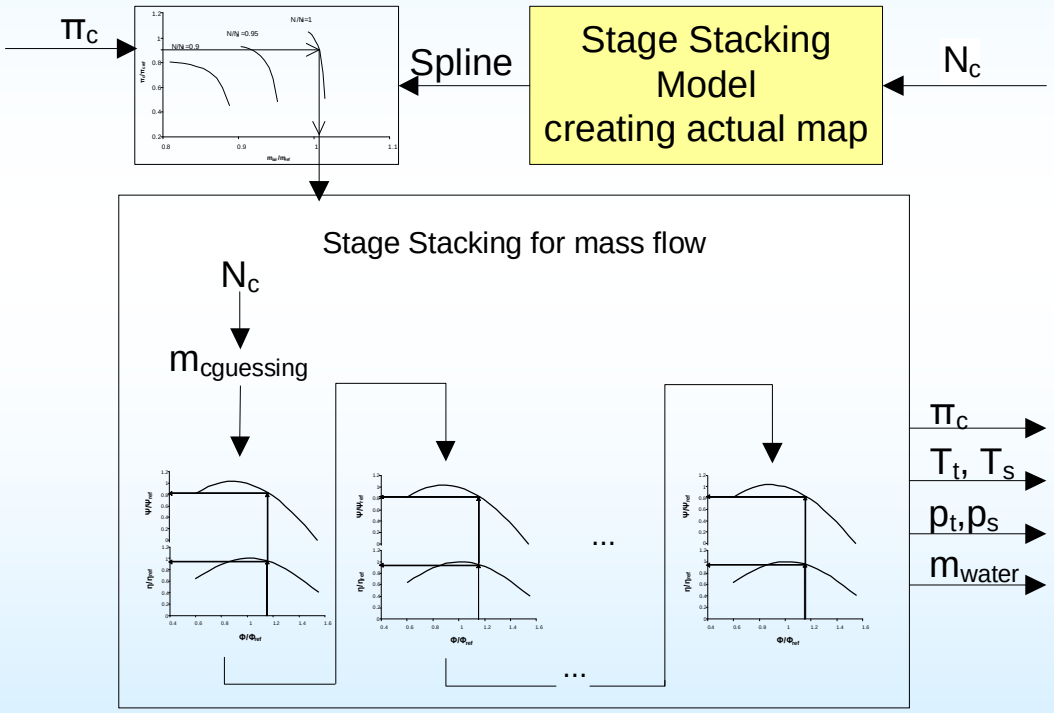
Engine Model

Coupling of Stage Stacking and Performance Model



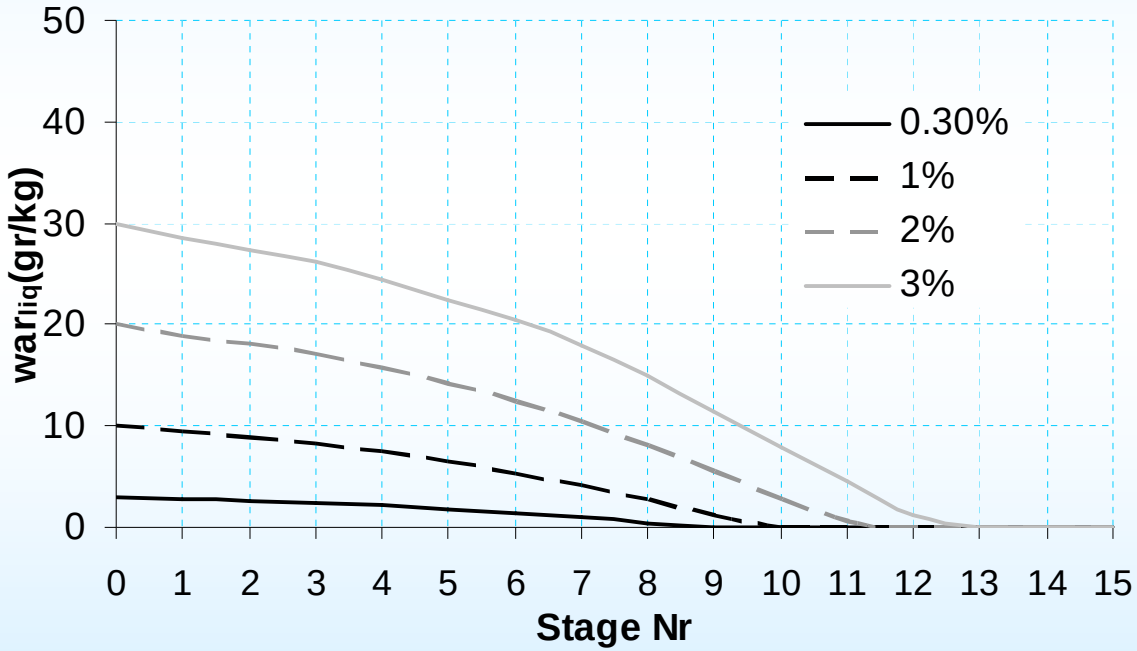
Engine Model

Zooming Procedure



Engine Model

Droplet Evaporation



No Stall Criterion

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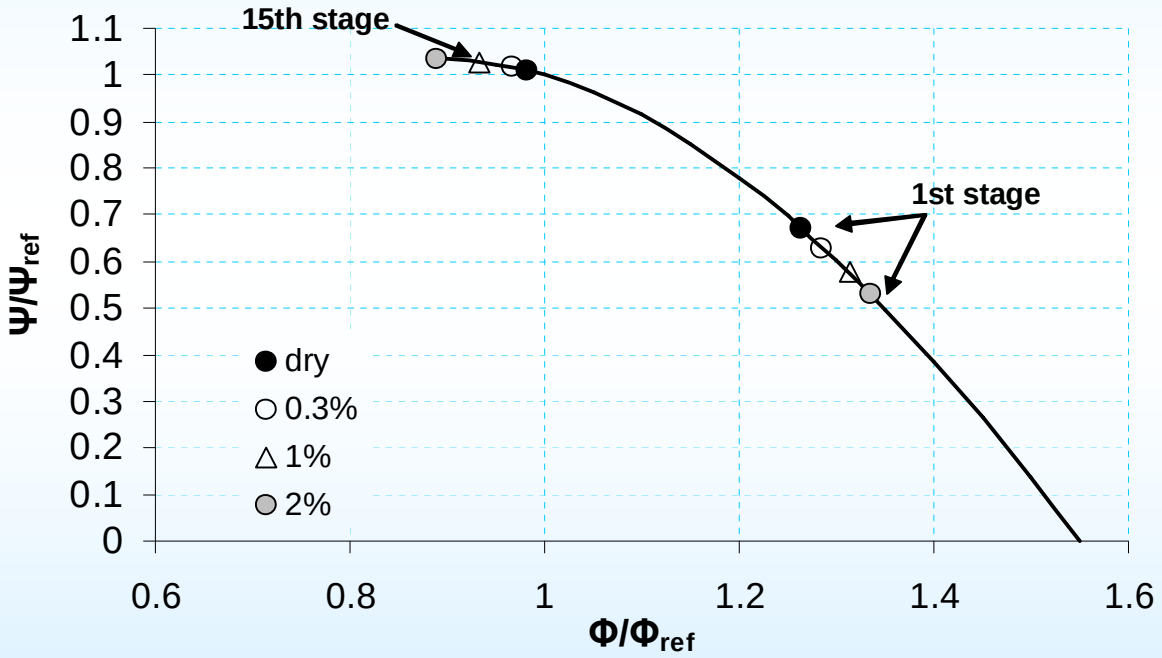
Stage Rematching

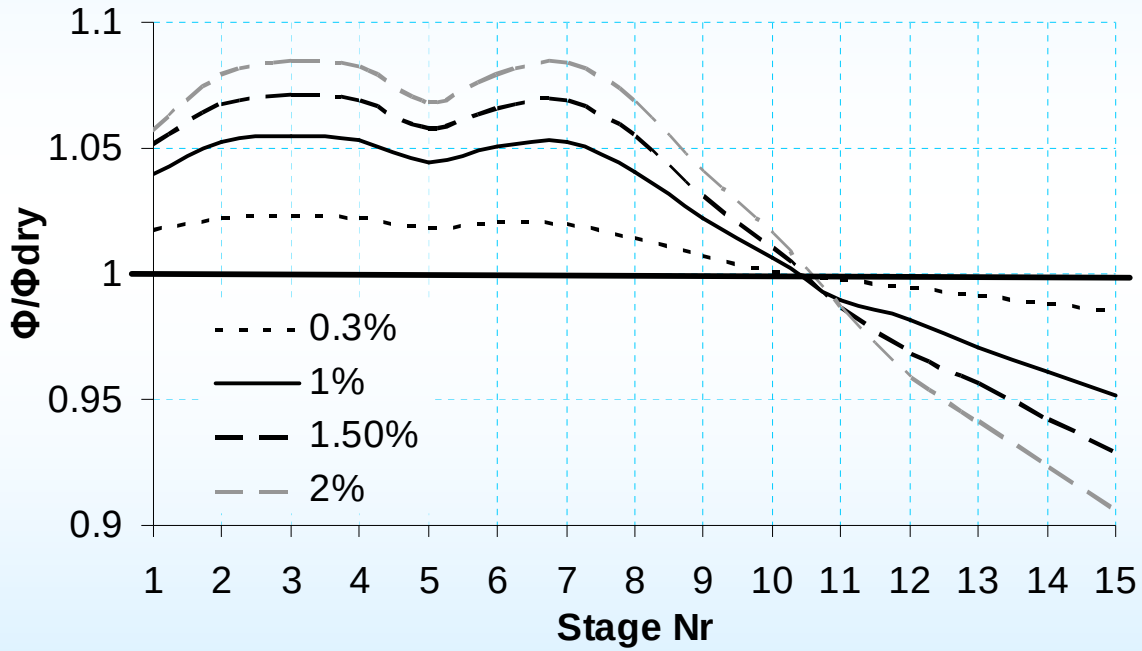
Stages Operating Point Shift



Stall Criterion: $d\Psi/d\Phi=0$ for each stage characteristic

Stage Rematching

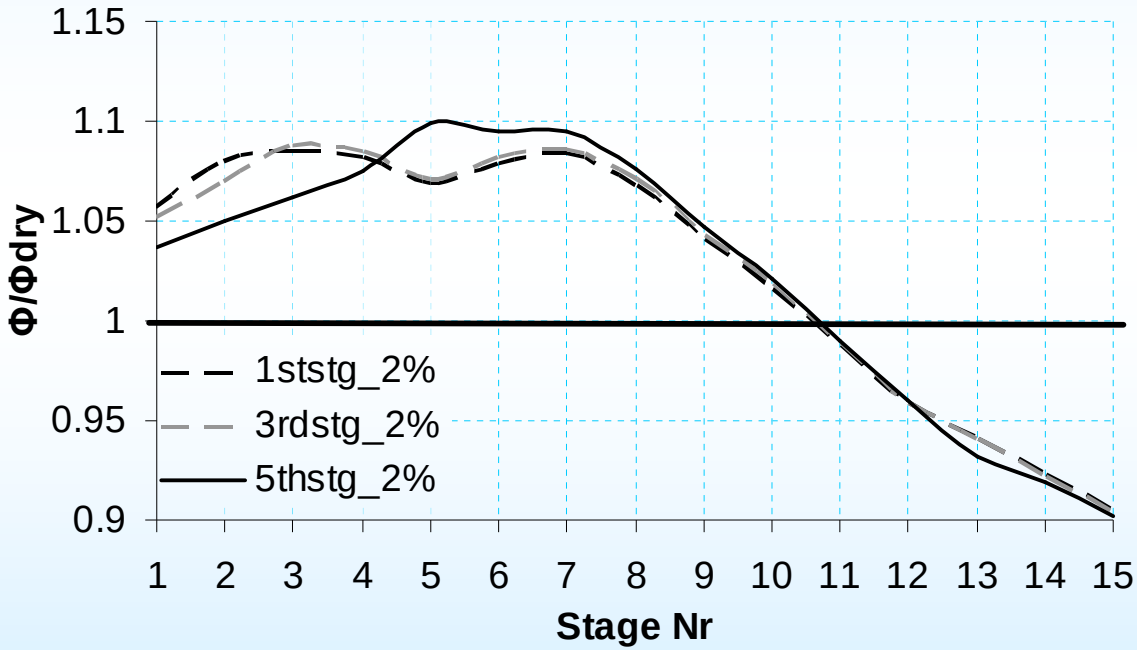
1st Stage Injection



Stall Criterion: $d\Psi/d\Phi=0$ for each stage characteristic

Stage Rematching

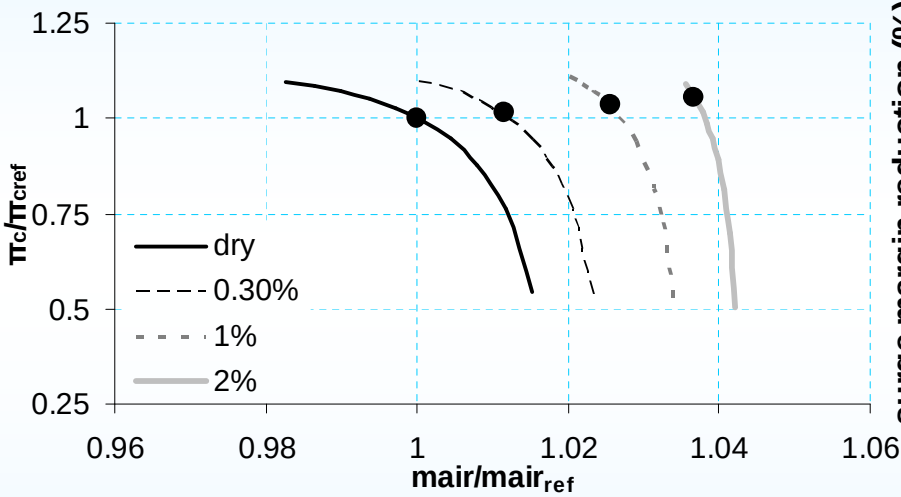
Interstage Injection

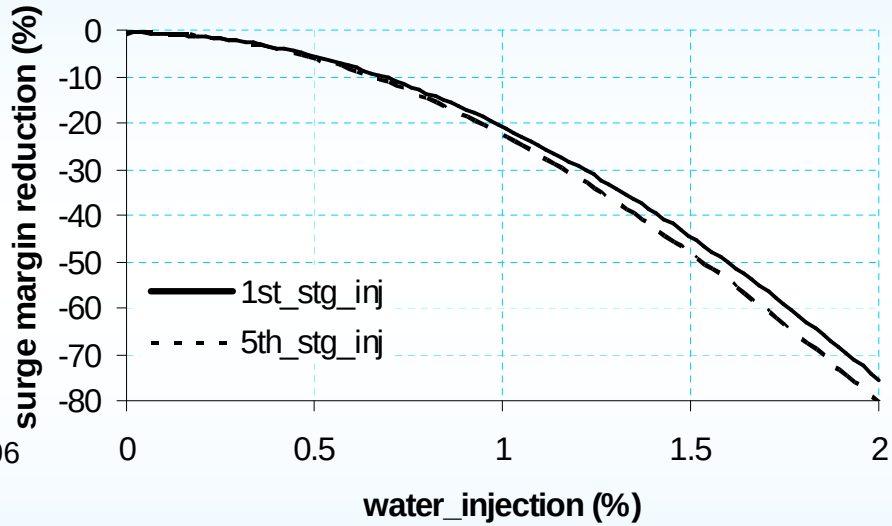


Stall Criterion: $d\Psi/d\Phi=0$ for each stage characteristic

Stage Rematching

Surge Margin





Surge Margin Definition: $\text{Surge Margin}\,(\%) = \frac{(p_{csurge} - p_{cworking})}{p_{cworking}} \cdot 100$

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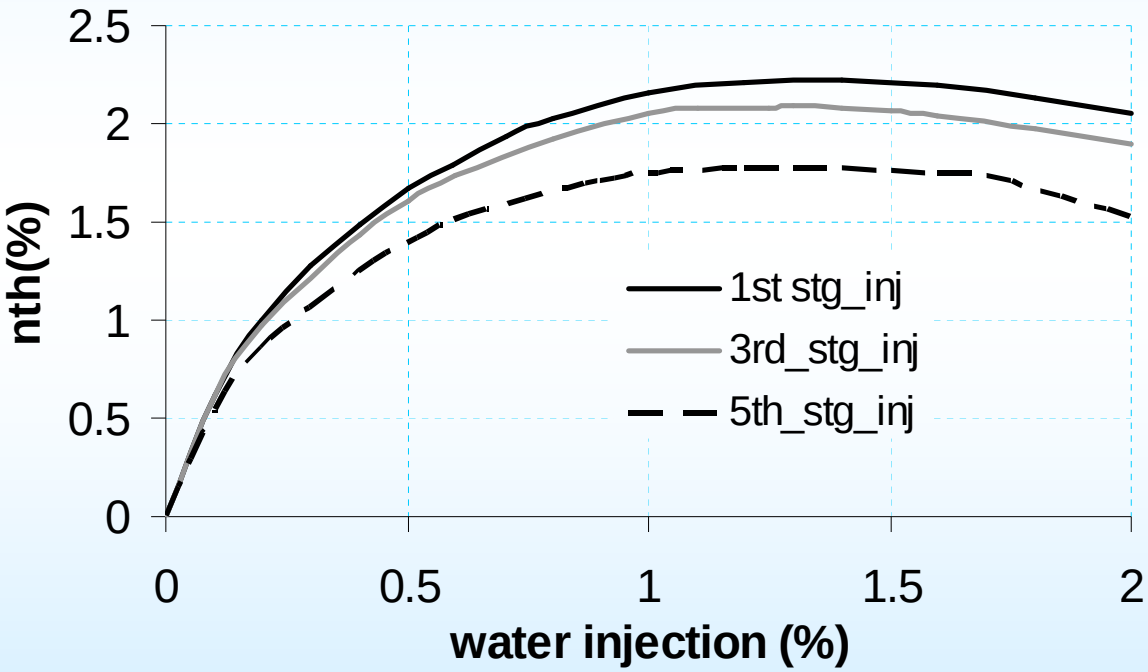
Effect on Overall Performance

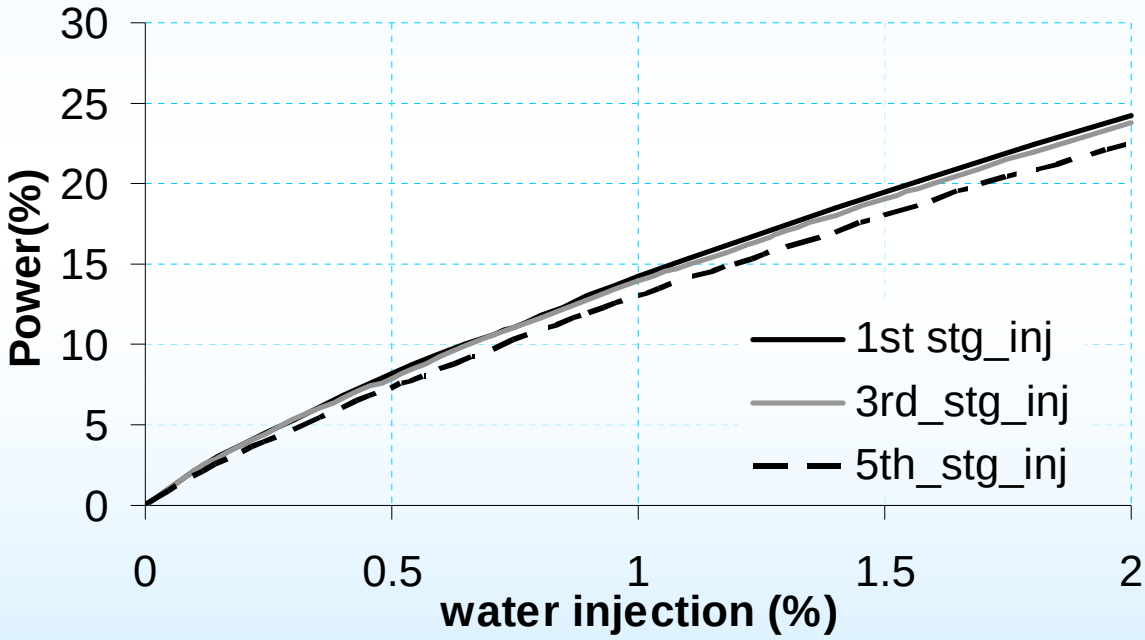
Thermal Efficiency



CIT = 30°C TIT = const

Effect on Overall Performance

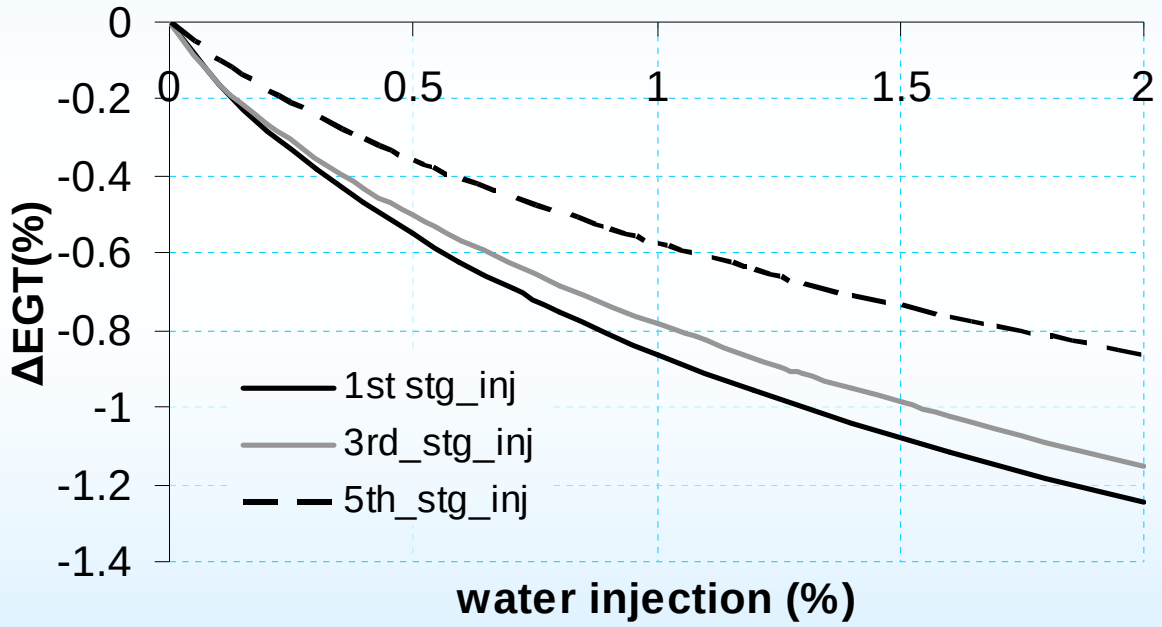
Power Boost



CIT = 30°C TIT = const

Effect on Overall Performance

EGT Variation



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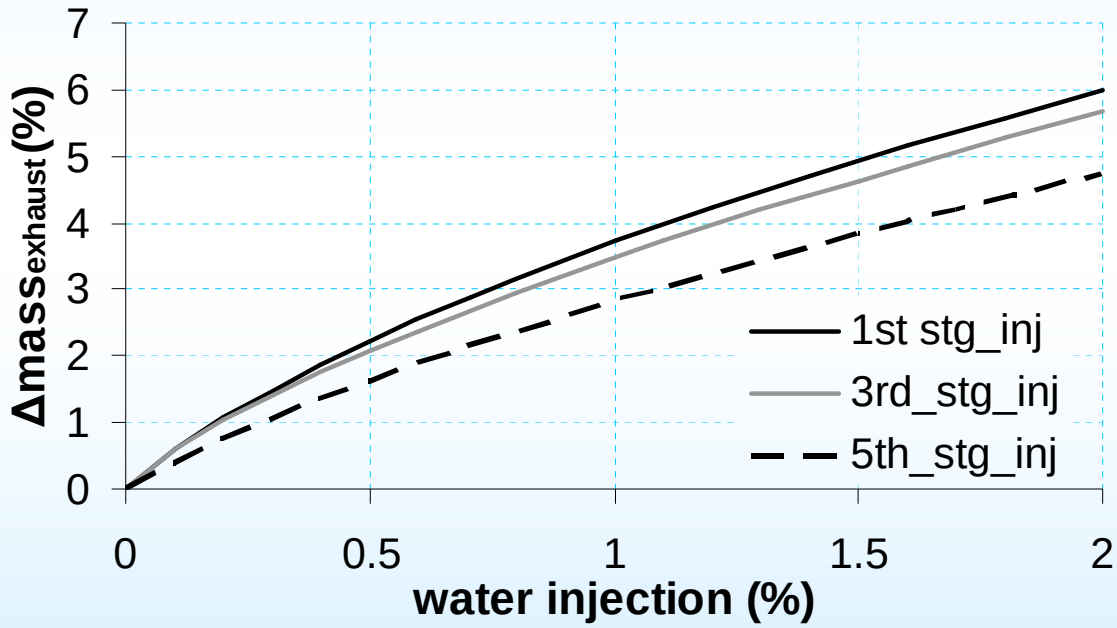
Effect on Overall Performance

Exhaust Mass Variation



CIT = 30°C TIT = const

Conclusions

- Water injection shifts the characteristics to higher mass flow ratio
- The individual stages are working off design unloading the first stages and shifting the rear stages towards stall
- A marginal thermal efficiency increase along with a substantial power boost has been predicted
- The benefits of water injection increase as the injection point moves towards the compressor inlet
- Interstage water injection may be of practical interest in regions of low ambient temperature
- The behavior of each compressor may be different with wet compression

Future Work

- Experimental work in order to examine the effect of water injection on stage characteristics and quantify any additional losses
- Experimental analysis of the compressor stability with water injection is needed in order to obtain the full benefits of water injection
- Incorporation of forced convection in the droplet model
- Investigation of the benefits of water injection through redesign of the compressor