THE INFLUENCE OF HEAT TRANSFER EFFECTS ON TURBINE PERFORMANCE CHARACTERISTICS

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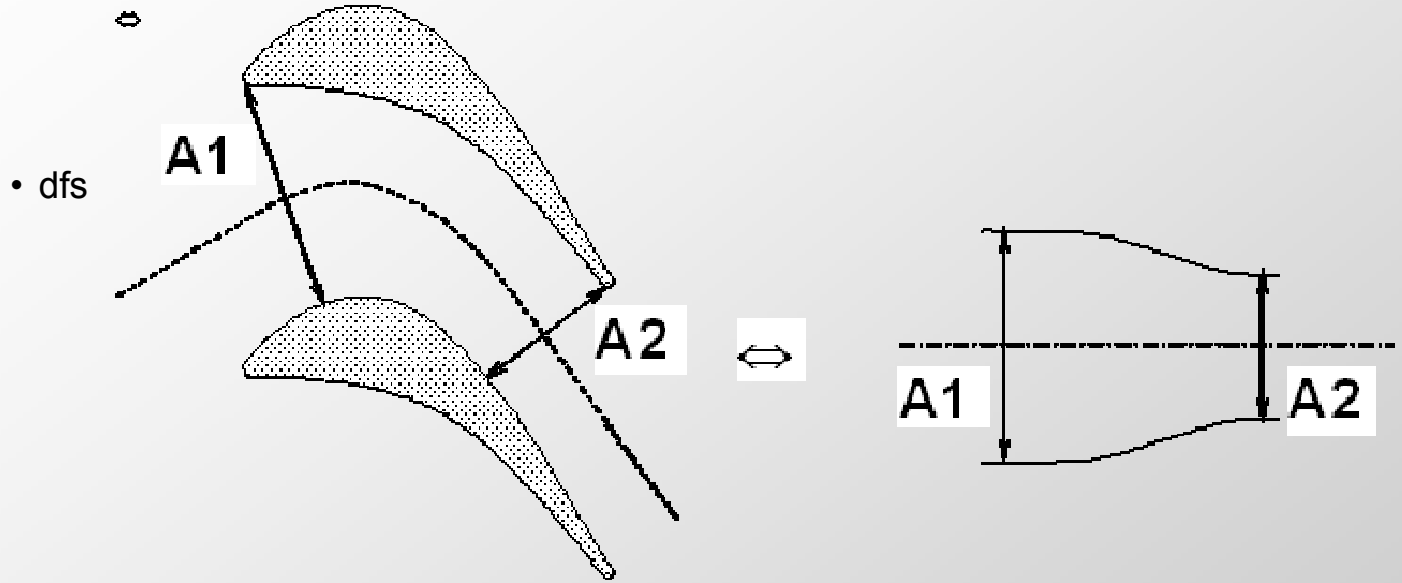
The Influence Of Heat Transfer Effects On Turbine Performance Characteristics

- **Physical reasons for Map Alteration**
- **Dilatation effect estimation**
- **Altration of the flow-field**
- **Application Example**
- **Summary-Conclusions**
- **Acknolwdgements**

The physics for turbine map constitution

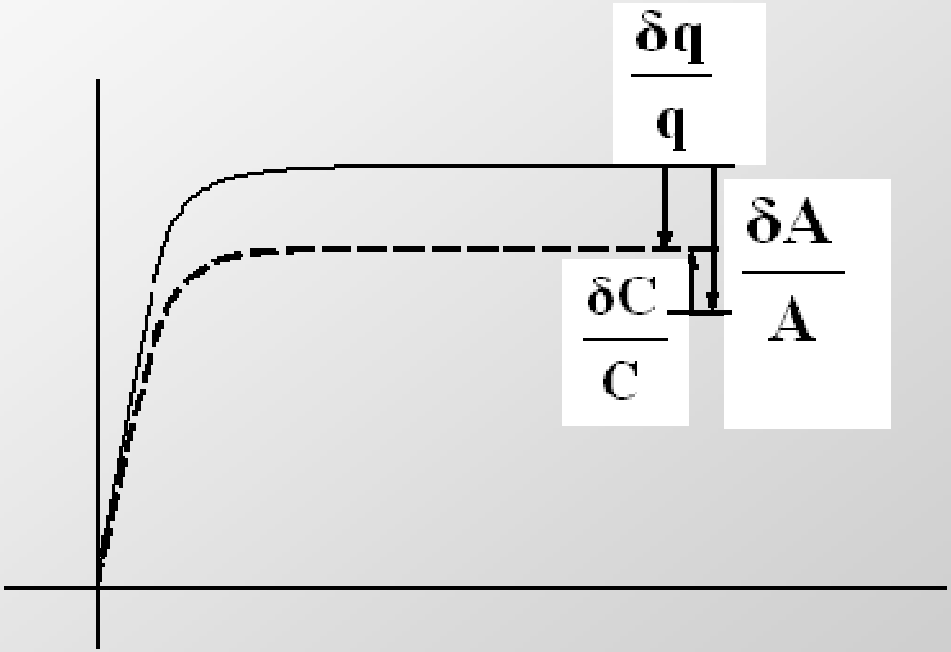


- dfs

$$\frac{m\sqrt{T_t}}{p_t} = C_D A \sqrt{\frac{2\gamma}{(\gamma-1)R}\left[\left(\frac{p}{p_t}\right)^{\frac{2}{\gamma}} - \left(\frac{p}{p_t}\right)^{\frac{\gamma+1}{\gamma}}\right]^{\frac{1}{2}}}$$

A turbine blade passage and its equivalent nozzle

Area change effect on turbine map



$$\frac{\delta q}{q} = \frac{\delta A}{A} + \frac{\delta C_D}{C_D}$$

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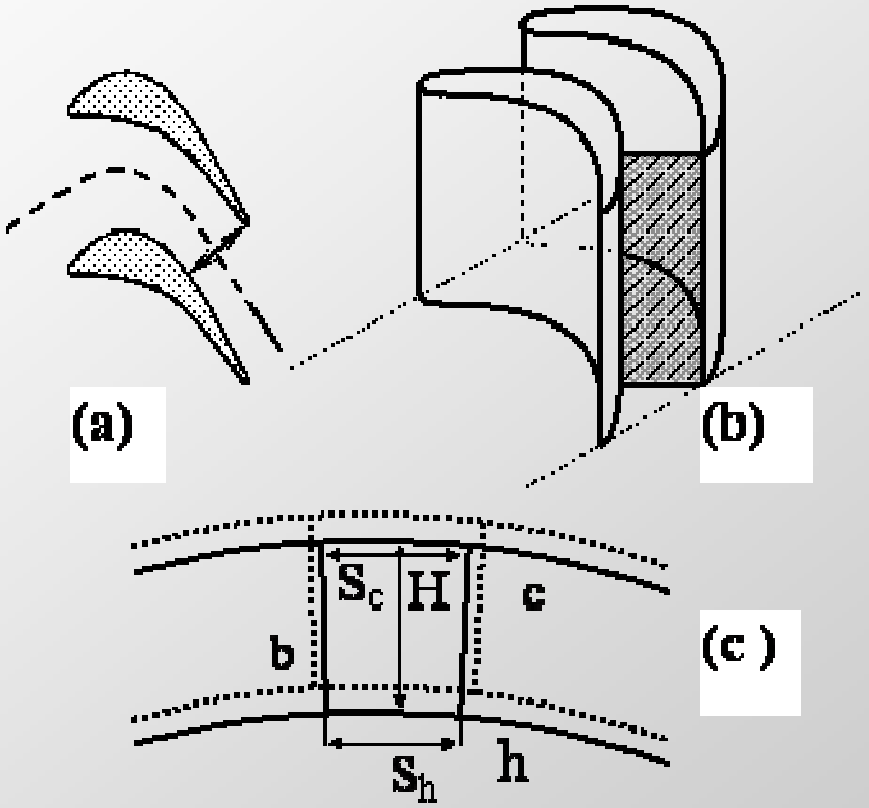
Modeling Blade Passage Geometry Change due to Dilatation

Map Change

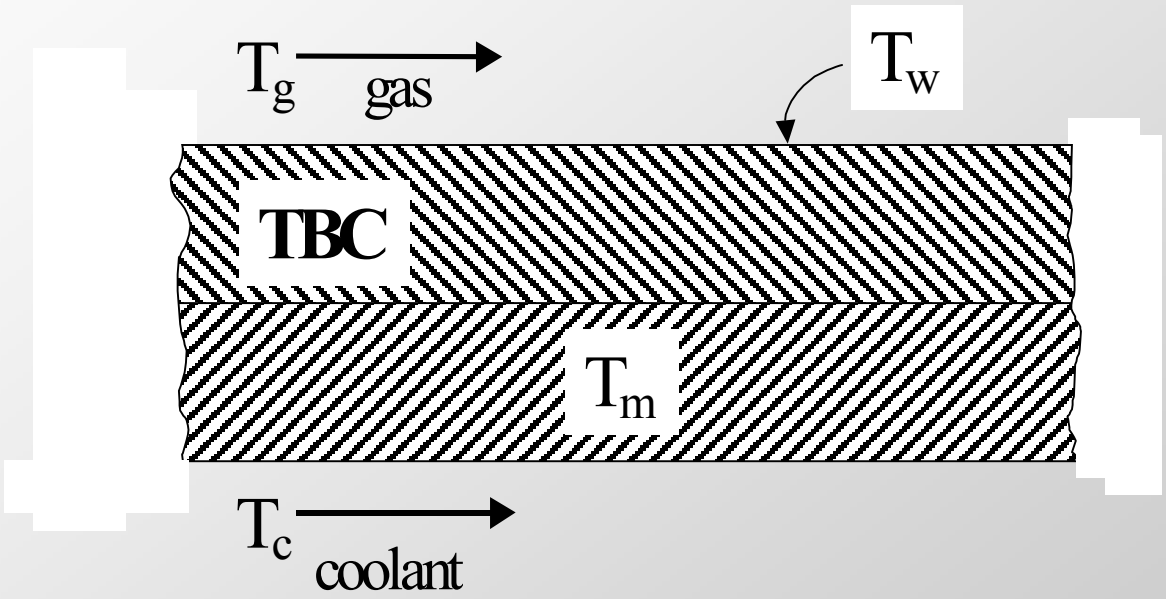
⇕

Area change



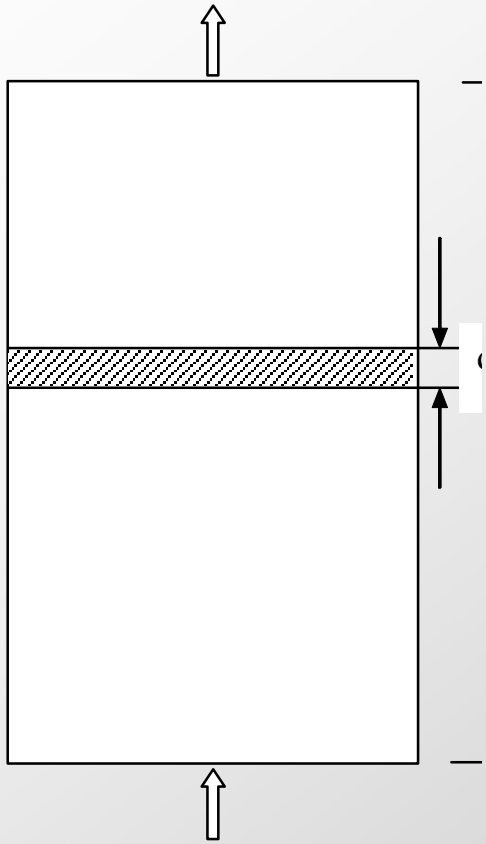
Throat area and its variation due to dilatation

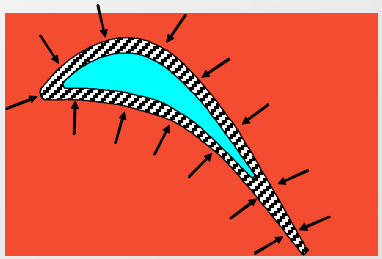
Calculation of metal temperatures (II)



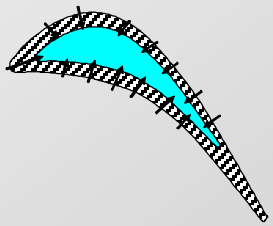
Blade wall and gas temperature configuration

Calculation of metal temperatures: Simplified 1-D model (II)

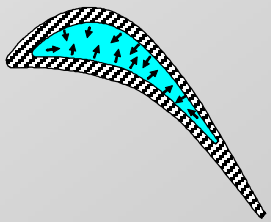




Convection

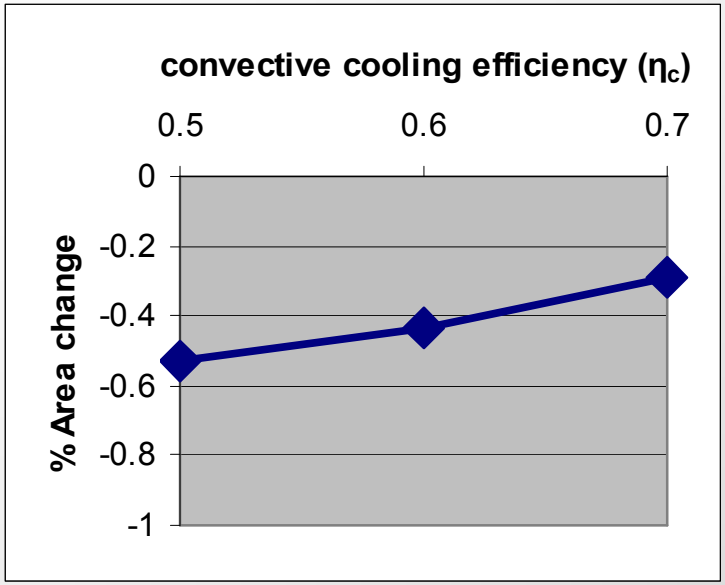


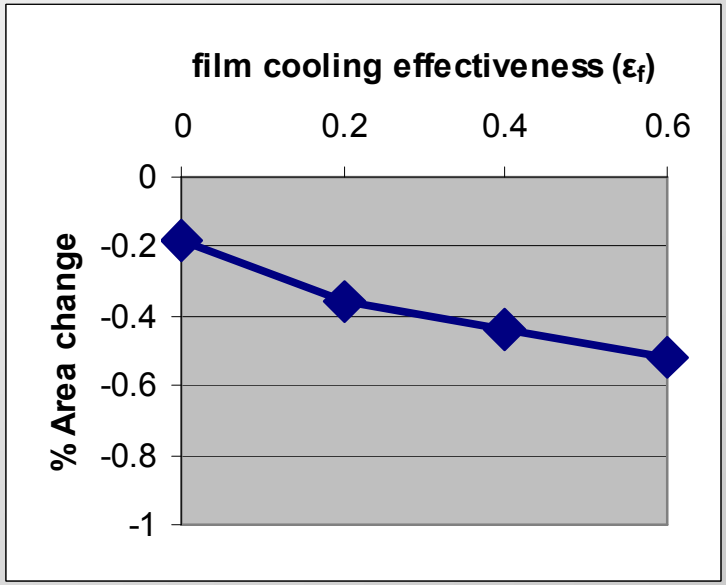
Conduction



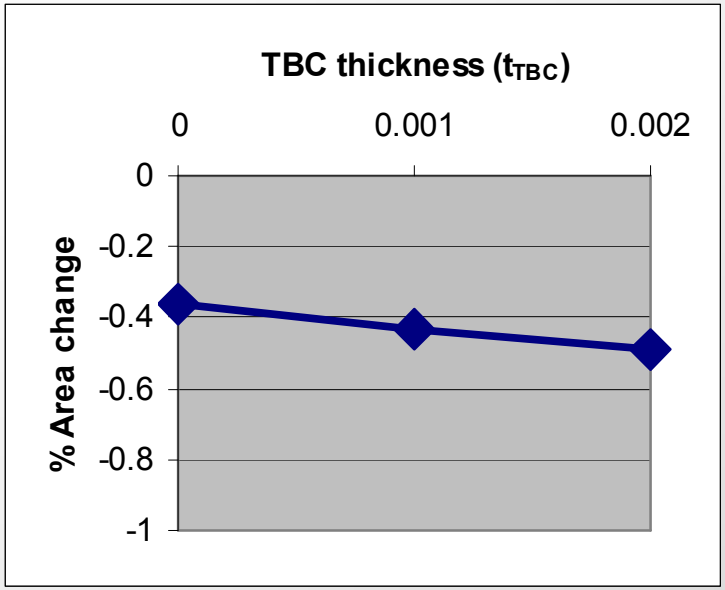
Convection

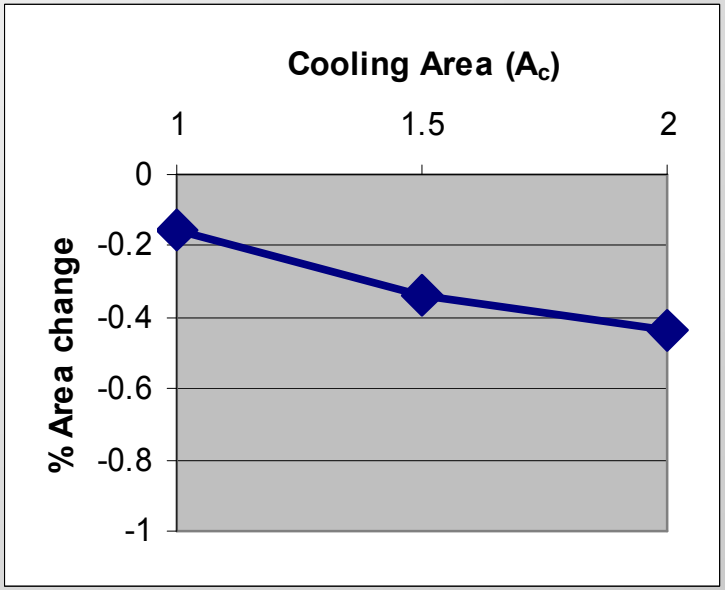
Area Change as a function of flow parameters (1)



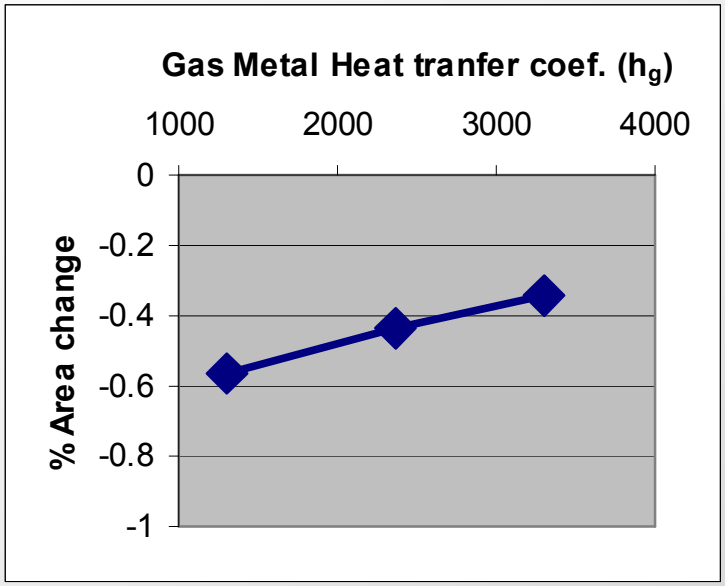


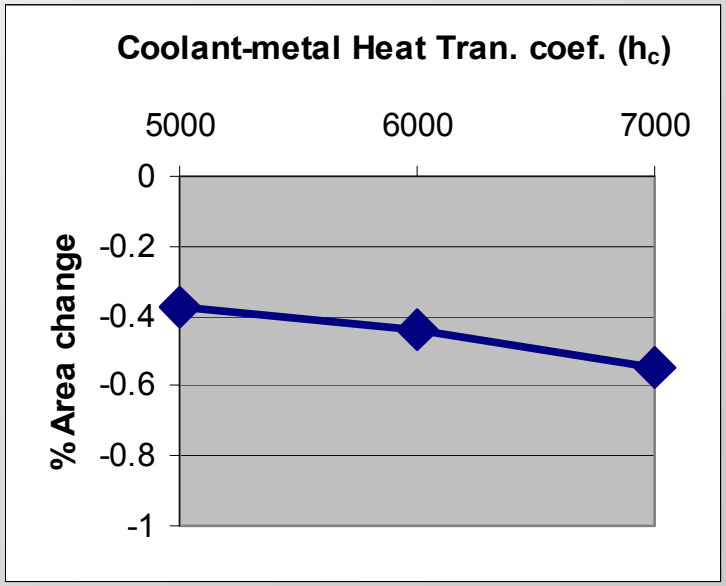
Area Change as a function of flow parameters (2)



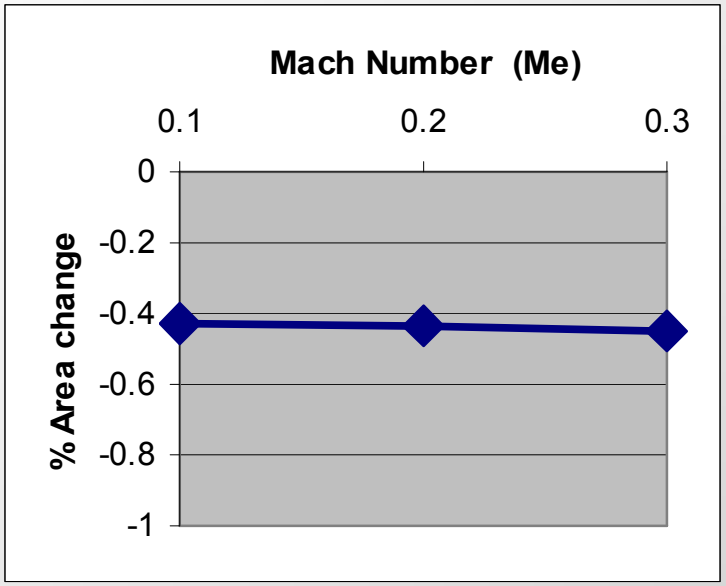


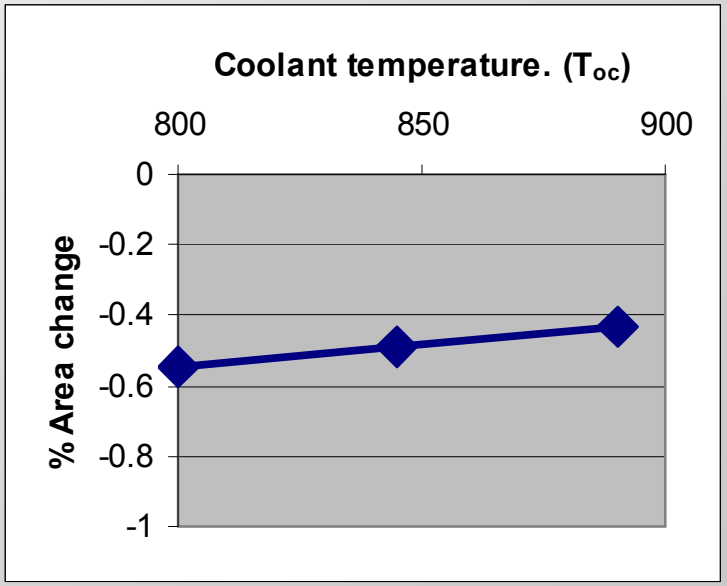
Area Change as a function of flow parameters (3)



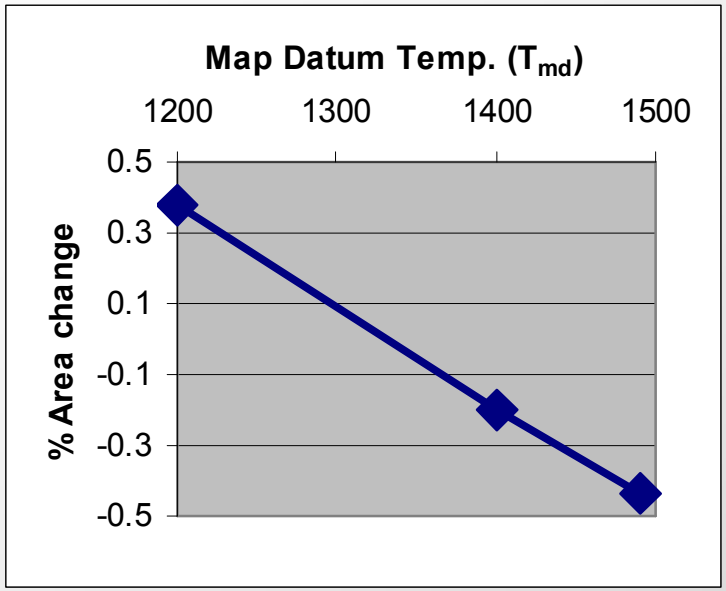


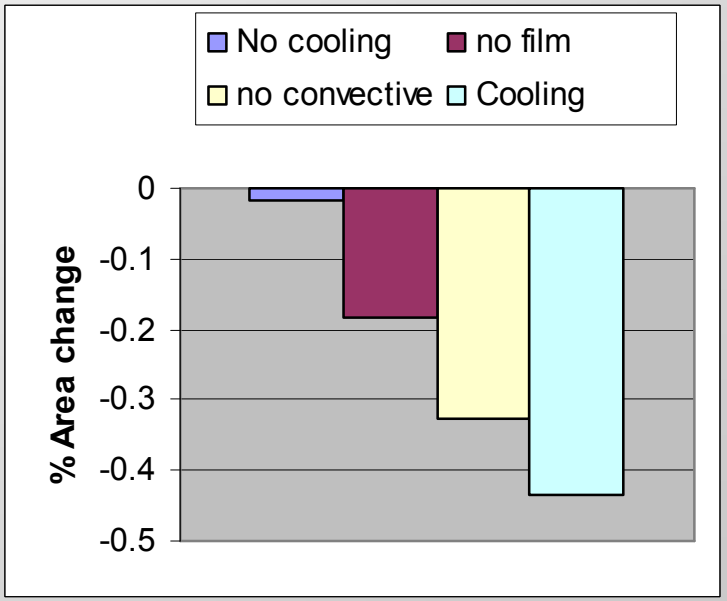
Area Change as a function of flow parameters (4)





Area Change as a function of flow parameters (5)





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Alteration of the flow-field

- **Flow filed altered due to heat addition to the flow:**
  - **Local density variation → Inviscid flow field altered**
  - **Alteration of boundary layer growth**
    - **Key parameter identified**

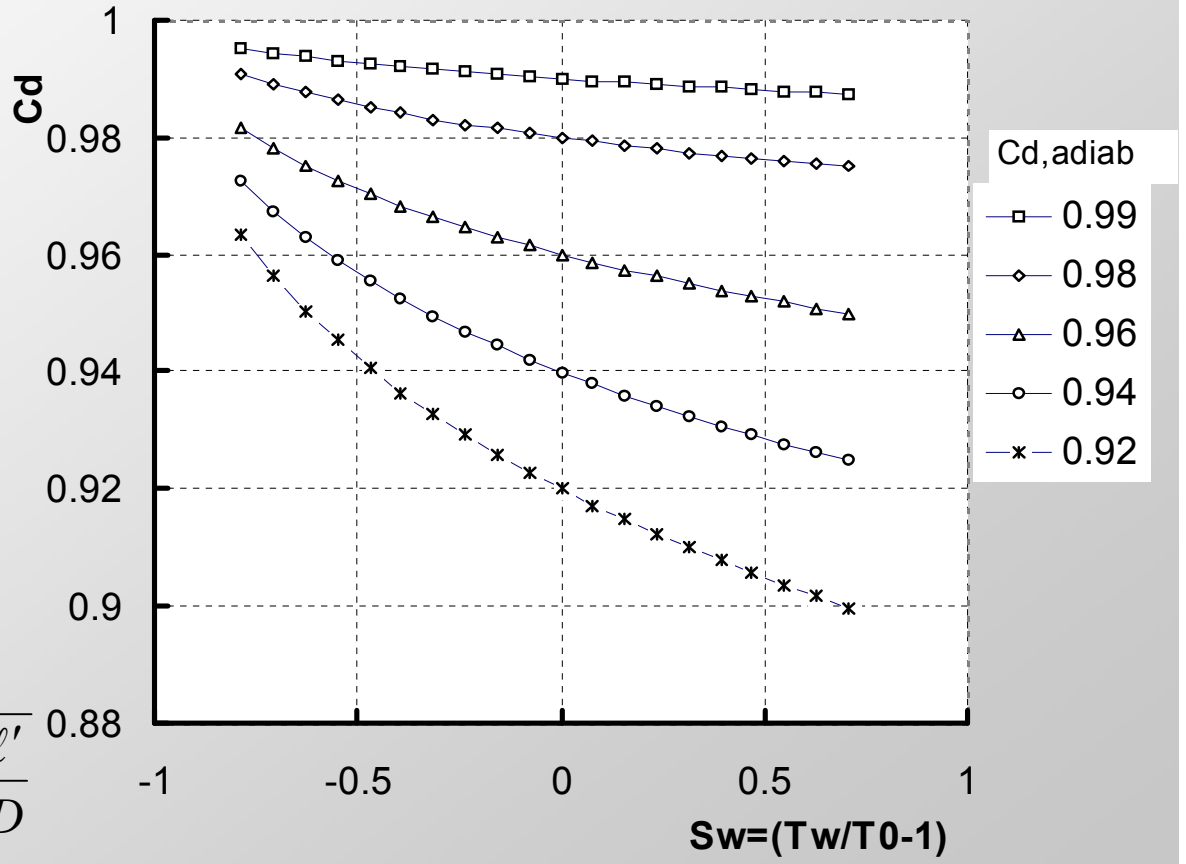
$$S_w = \frac{T_w}{T_0} - 1 \qquad (T \quad in \quad K)$$

Tw is the wall temperature and *T0* is the temperature of the gas.

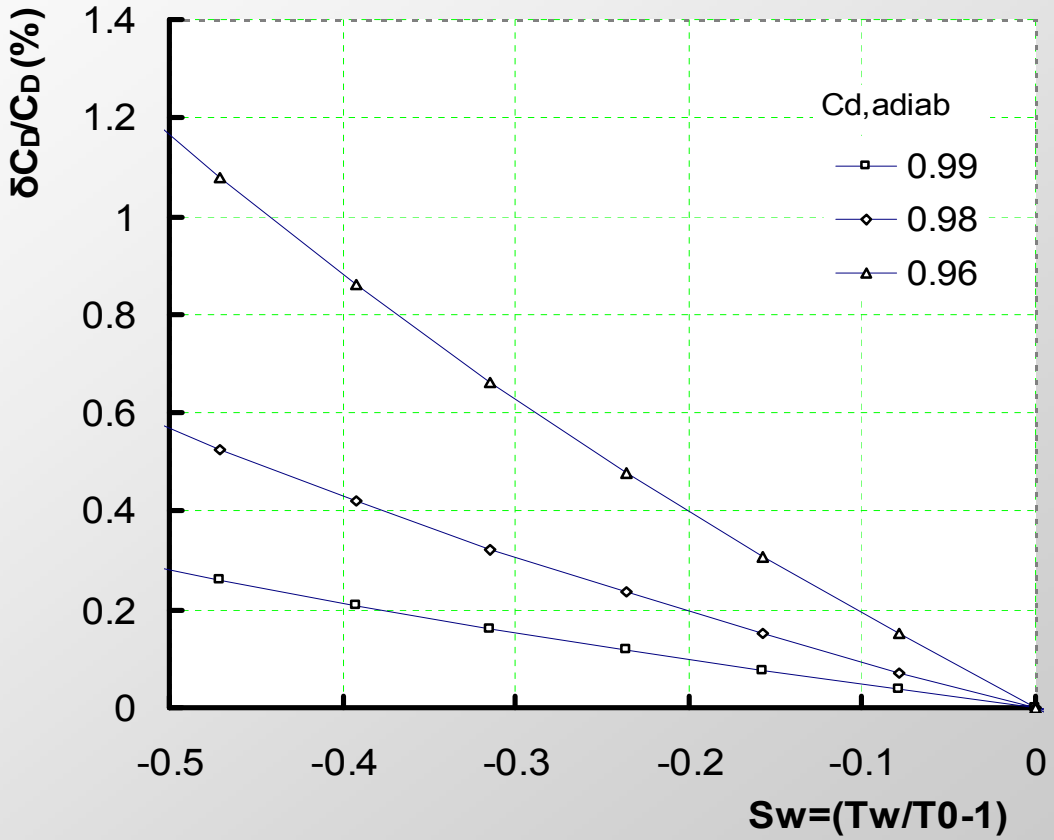
Alteration of the flow-field: encapsulated in discharge coefficient

$$\frac{1-C_D}{1-C_{D,ad}} = \frac{1-\dfrac{\ell n\left(T_0/T_w\right)}{\ell n 2}}{2-T_0/T_w}$$

$$\left(C_D\right)_{ad} = 1-\frac{7{,}08}{\sqrt{Re_D}}\sqrt{\frac{\ell}{D}+\frac{1}{4}\cdot\frac{\ell'}{D}}$$



Discharge coefficient Variation



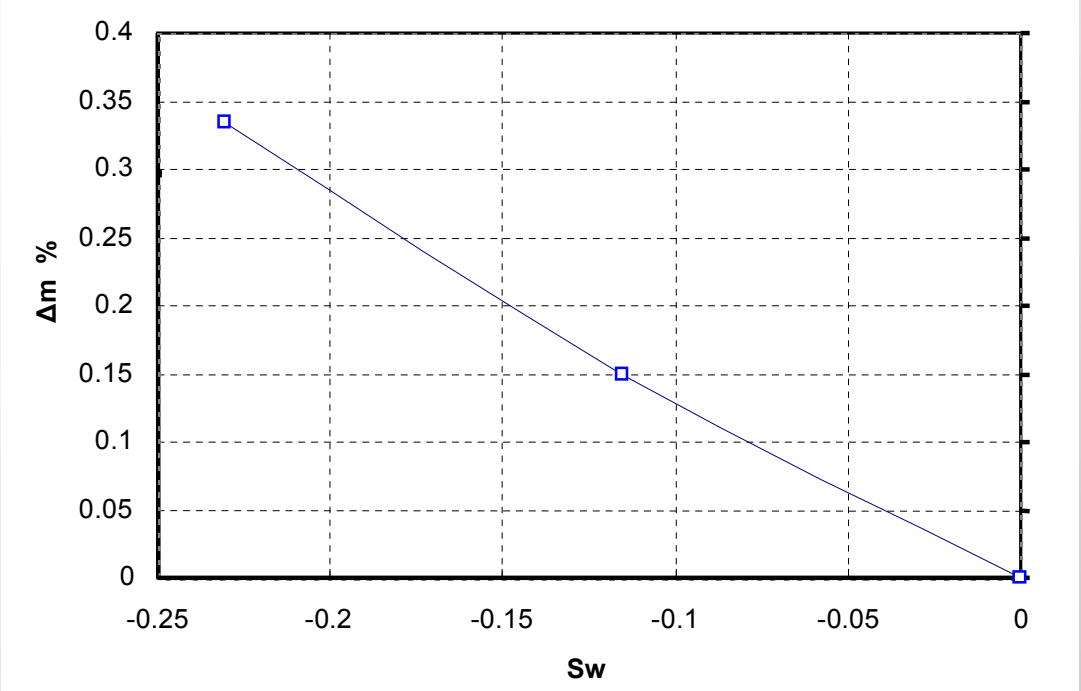
Proposed procedure for incorporating the heat transfer effect on boundary layers (I)

Perform calculations of Viscous flow with heat transfer in turbine passage (Navier Stokes Eqns)

to establish a correlation

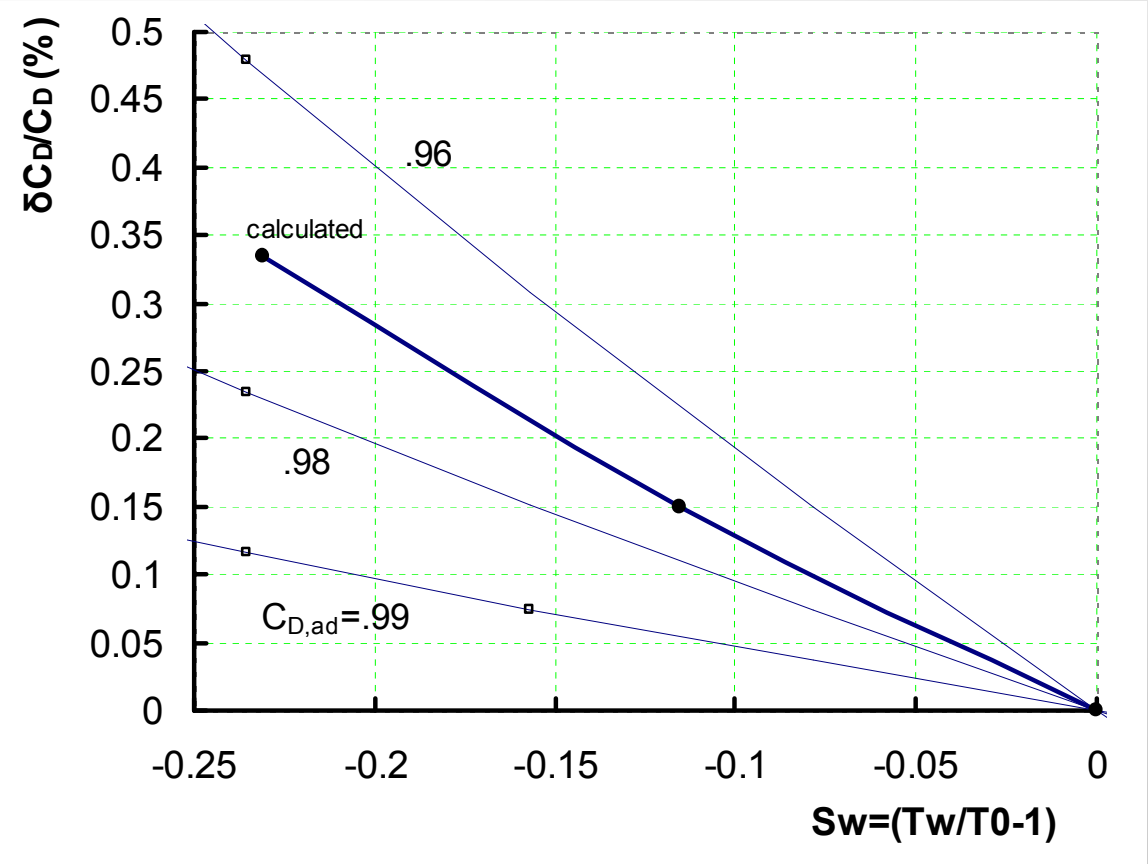
(discharge coefficient) ↔ S_w

Sample result of Calculation in Turbine Cascade



Variation of mass flow rate through a cascade, for given inlet total to outlet static pressure ratio and different wall temperatures.

Discharge Coefficient Variation



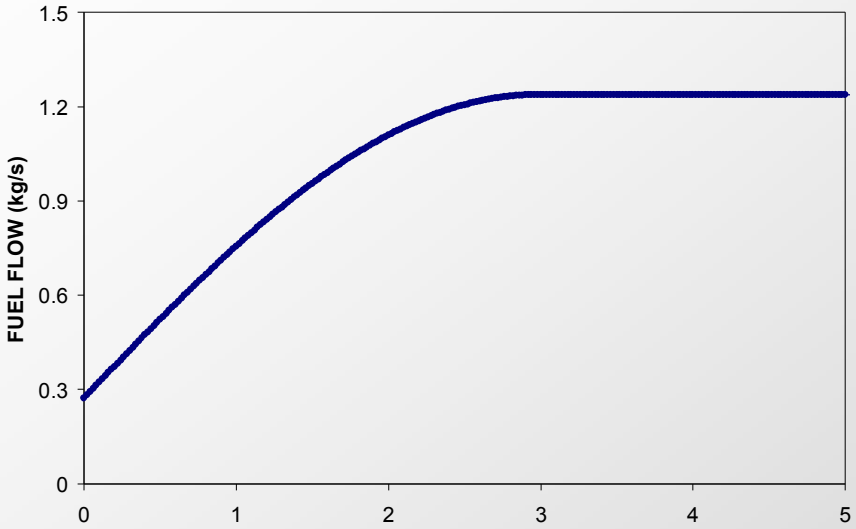
Comparison of trends established by calculations and viscous flow solutions, to predictions according to the method of [11]

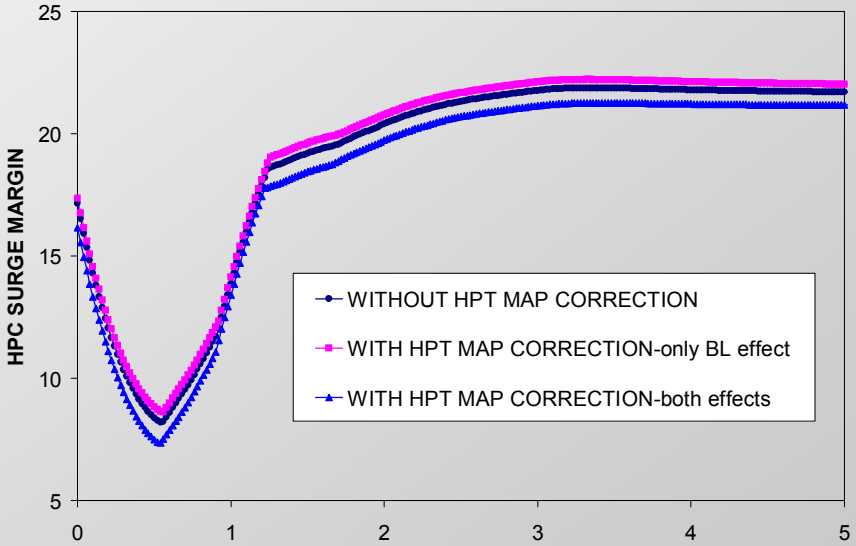
Example Application

Results from Transient performance Calculation, incorporating Heat Transfer effects

Map Change ↔Area change effect on turbine map

Effect Of Thermal Dilatation On Performance





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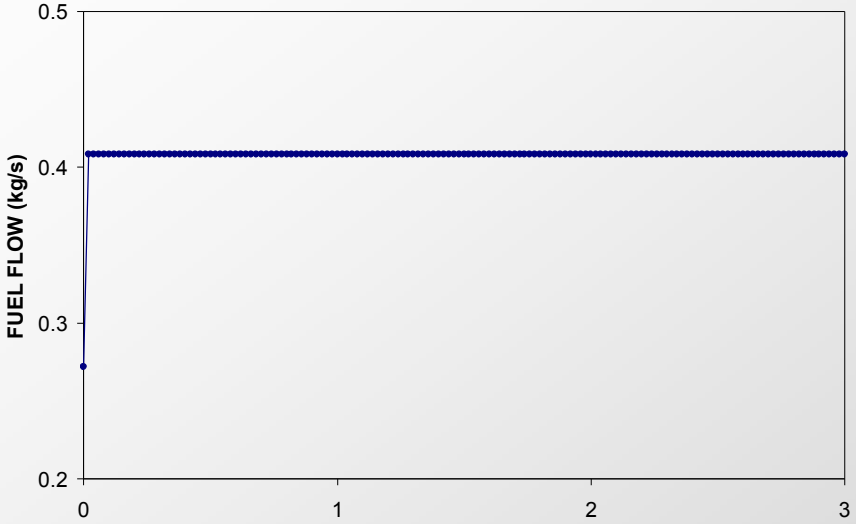

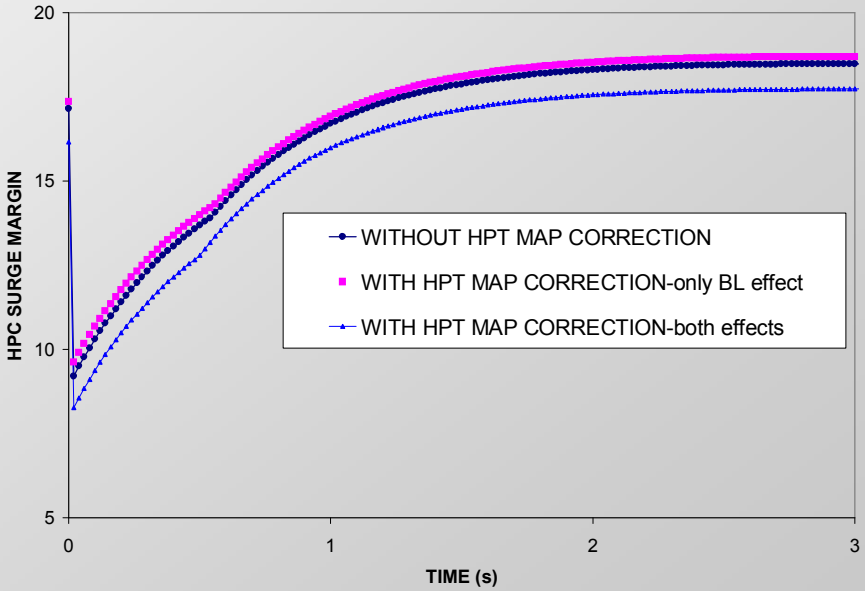

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Summary - Conclusions

- Heat Transfer Alters Turbine (mass flow) – (pressure ratio) characteristics, due to geometry changes and flow field alteration

- Geometry Changes can be estimated by assessing material temperatures (A possibility using simplified models has been proposed here)

- Flow field alteration can be expressed through change in the discharge coefficient which can be correlated to an appropriate paramter (S)

- Detailed calculation can be used to establish correlations which are easily implantable in 1-d engine performance models

Acknowledgements

- **The authors would like to express their thanks to SNECMA for financing the work that led to this paper and for allowing its publication. Thanks are expresses to X. Ruiz, for many useful comments and discussions.**