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NUMERICAL SIMULATION OF LAMINAR-TURBULENT TRANSITION IN ACCELERATED FLOWS

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Introduction

A reliable prediction of turbulent flows requires both an advanced turbulence model and the model of laminar-turbulent transition. While various advanced turbulence models are routinely used the models of laminar-turbulent transition are still a matter of development and none of existing transition models is able to reliably solve all flow cases.

Mathematical model

The motion of a compressible gas is described by the set of Favre averaged Navier--Stokes equations in the conservative form:

$$\begin{aligned}
\frac{\partial \rho}{\partial t} + \nabla(\rho \mathbf{U}) &= 0, \\
\frac{\partial (\rho \mathbf{U})}{\partial t} + \nabla(\rho \mathbf{U} \otimes \mathbf{U}) + \nabla p &= \nabla \tau^{eff}, \\
\frac{\partial (\rho E)}{\partial t} + \nabla\left[(\rho E + p)\mathbf{U}\right] &= \nabla(\tau \mathbf{U}) + \nabla(\lambda^{eff} \nabla T), \\
\tau^{eff} &= (\mu + \mu_T)\,\mathbf{S}^* - \frac{2}{3}\rho k I, \\
\lambda^{eff} &= \lambda + \lambda_T = \lambda + \frac{\mu_T c_p}{Pr_T},
\end{aligned}$$

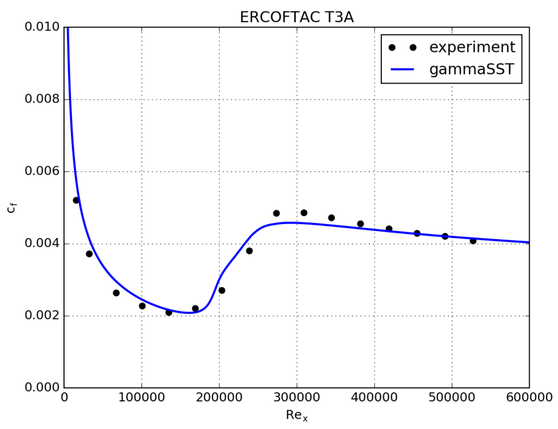
The three-equation γ-SST model of Menter at al.

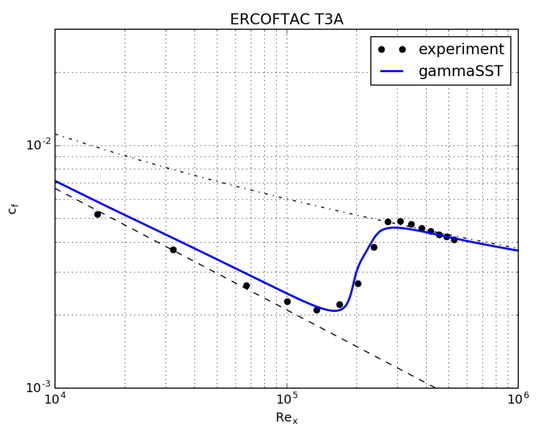
- *MENTER, Florian R., Pavel E. SMIRNOV, Tao LIU a Ravikanth AVANCHA. A one-equation local correlation-based transition model. Flow, Turbulence and Combustion. 2015, 95(4), 583–619.*

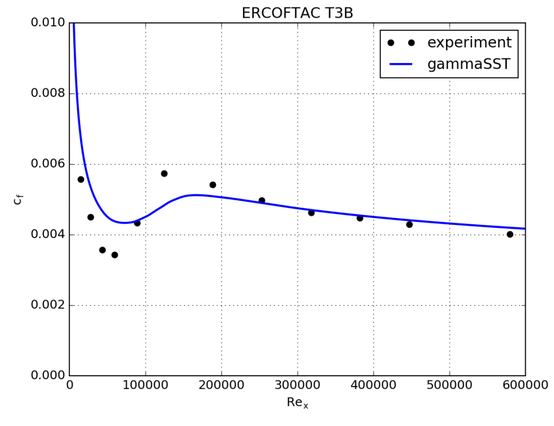
$$\begin{aligned}
\rho \frac{Dk}{Dt} &= \tilde{P}_k + P_k^{lim} - \tilde{D}_k + \nabla\left((\mu + \sigma_k \mu_T)\nabla k\right), \\
\rho \frac{D\omega}{Dt} &= \alpha \frac{P_k}{\nu_T} - \tilde{D}_\omega + Cd_\omega + \nabla\left((\mu + \sigma_\omega \mu_T)\nabla \omega\right), \\
\rho \frac{D\gamma}{Dt} &= P_\gamma - E_\gamma + \nabla\left((\mu + \mu_T/\sigma_\gamma)\nabla \gamma\right),
\end{aligned}$$

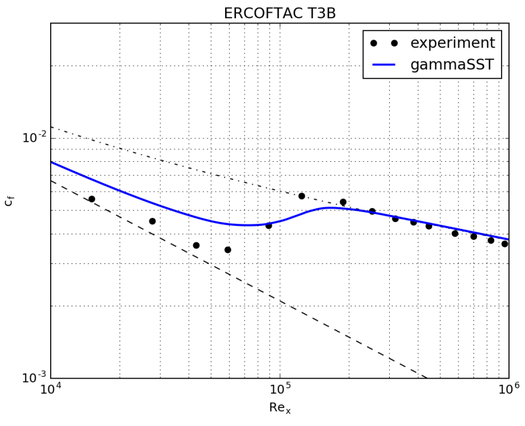
The turbulent heat conductivity is modelled using constant $Pr_T=0.9$ and the effect of the pressure gradient is included using a specific correlation for the pressure gradient parameter λ_θ.

Validation: flat plate flows









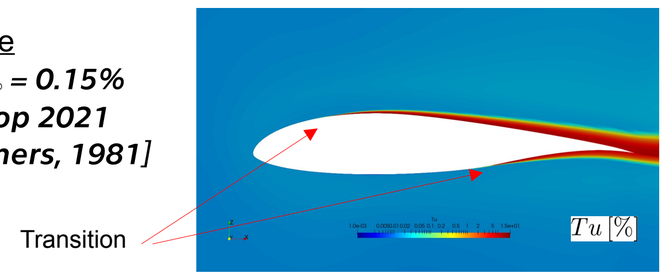
Incompressible fluid
SIMPLE algorithm

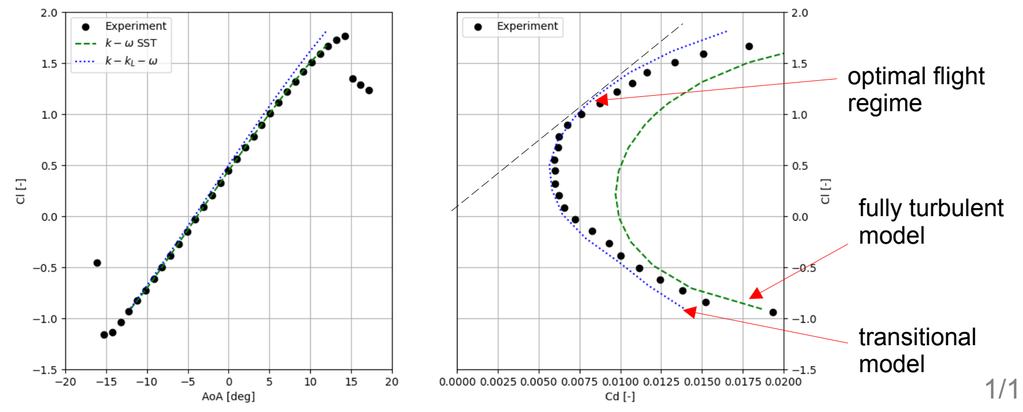
Tu = 6.6 %
v_t/v = 100 (for γ-SST)

Mesh:
- 66 675 cells,
- y^+ ~ 0.2,
- similar to mesh F

Flow over NLF(1)-0416 airfoil

Flow over NLF_1-0416 profile
- *Re = 4x10⁶, M_∞ = **0.1**, **Tu_∞ = 0.15%***
- ***AIAA Transition workshop 2021***
- **Experimental data** ***[Somers, 1981]***





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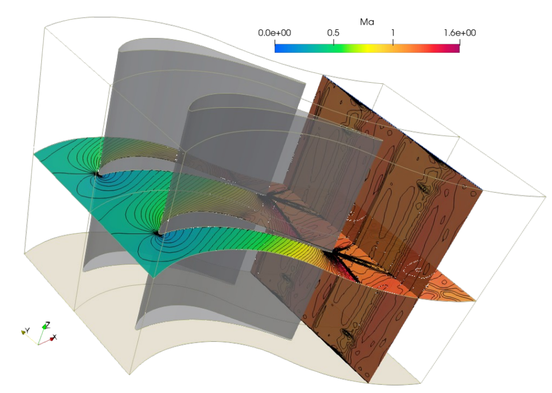
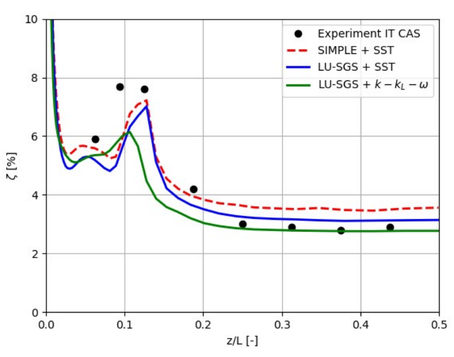
Flow over NLF(1)-0416 airfoil

3D flows in turbine cascade TR-L-1 *[Šimurda et al., 2013]*
- experiments carried out in IT CAS, *Re = 1.2x10⁶*, *M_{2i} = 1.2*, *Tu ~ 2%*
- calculation with two numerical methods and with "standard" turbulence model (SST) and with transition and turbulence model (*k-k_L-ω*)

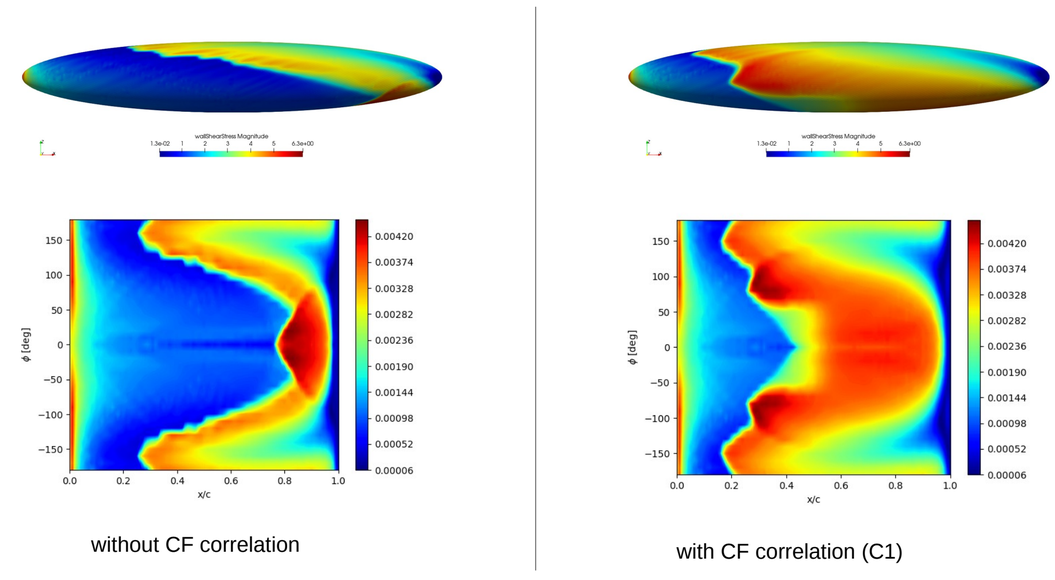


$$\zeta = (1 - \frac{\lambda_2^2}{\lambda_{2,is}^2}) \cdot 100\%$$



Flow over 6:1 ellipsoid

3D flows over an ellipsoid
- M=0.13, Re=6.5x10⁶
- Tu=0.15%
- with and without cross-flow correlation



without CF correlation

with CF correlation (C1)

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