Recent advances and problems

F.Miralles

IMAG, Université de Montpellier, France,

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Introduction

Motivation of this work

- Separation of boundary layer is not caugth using classical turbulence model using integration to the wall.
- We would like to catch aerodynamic coefficient and pressure distribution over a NACA0018 at multiple angles of attack
- we would like to reproduce separation and reattachment
- In a second time we want to simulate the noise generated by the flow.
- All mentioned above could be take into account in a rotating frame.

Part 1 : Current status on $k - \varepsilon - \gamma$

Transition $k - \varepsilon - \gamma$

- We introduce Re_θ which means laminar boundary layer based on Blasius and $Re_{\theta,S}$ is a function of turbulent kinetic energy.

- For a flat plate if $Re_\theta \leq Re_{\theta,S}$ the flow remains laminar, otherwise its is in transition and finally turbulent. [1]

- We consider transition factor defined below :

$$\widetilde{\gamma}(\gamma, Re_\theta) = \begin{cases} \min(\gamma, \alpha_1)\ , & \text{si } Re_\theta < Re_{\theta,S}, \\ \max(\gamma, \alpha_1)\ , & \text{otherwise} \end{cases}$$

- Consider $\alpha_1 < 0.5$, note that in laminar boundary layer :

$$0 < \widetilde{\gamma}(\gamma, Re_\theta) \leq \alpha_1$$

and in turbulent boundary :

$$\alpha_{\leq}\widetilde{\gamma}(\gamma, Re_\theta) \leq 1$$

1. B. J. Abu-Ghannam et R. Shaw. "Natural Transition of Boundary Layers—The Effects of Turbulence, Pressure Gradient, and Flow History". In : *Journal of Mechanical Engineering Science* 22.5 (1980), p. 213-228. doi : 10.1243/JMES_JOUR_1980_022_043_02.

Transition $k - \varepsilon - \gamma$

Properties

- When $\gamma = 1$, turbulence model should be conserved and $\mu_t^* = \mu_t$
- For a initial $0 \leq \gamma_0(\mathbf{x}) \leq 1 \ \forall \mathbf{x} \in \Omega_f$, we should have $0 \leq \gamma(\mathbf{x}, t) \leq 1$

- Transport equation on γ remains the same

$$\frac{\partial \rho \gamma}{\partial t} + \nabla \cdot (\rho \mathbf{u} \gamma) = C_{g1}\gamma(1-\gamma)\frac{P_k}{k} + \rho C_{g2}\frac{k^2}{\varepsilon}\nabla\gamma \cdot \nabla\gamma, \text{on } \Omega_f$$
$$\nabla\gamma \cdot \mathbf{n} = 0, \text{on } \partial C \tag{1}$$

- Transition model interact with $k - \varepsilon$ turbulence model as follows :

$$\frac{\partial \rho k}{\partial t} + \nabla \cdot (\rho \mathbf{u} k) = \max(\widetilde{\gamma}(\gamma, Re_\theta), \alpha_2) P_k + \nabla \cdot [(\mu + \mu_t \sigma_k) \nabla k] - \widetilde{\gamma}(\gamma, Re_\theta) D_k, \tag{2}$$

- When $\widetilde{\gamma}(\gamma, Re_\theta) = 1$ turbulence model is conserved

- Turbulent viscosity comparison

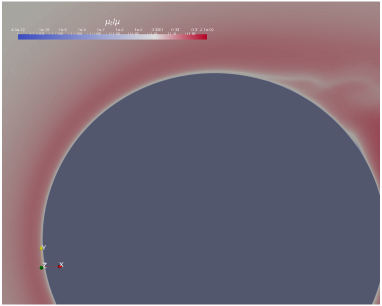

Figure – Without transition model, Re=1M

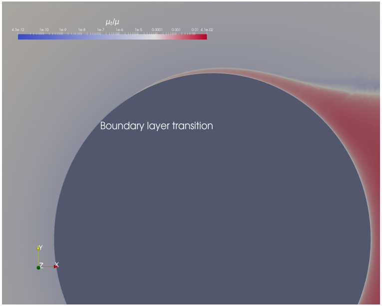

Figure – With transition model, Re=1M

	Mesh	$\overline{C}_d$	C_l'	$-\overline{C_{pb}}$	$\overline{\theta}$	
Present simulation Re=1M						
URANS k - ε / DVMS WALE	4.8M	0.48	0.11	0.55	109	
URANS $k - \varepsilon - \gamma$/ DVMS WALE	0.6M	0.31	0.12	0.33	130	
Present simulation Re=2M						
URANS $k - \varepsilon$/DVMS WALE	0.6M	0.48	0.27	0.60	109	-
URANS $k - \varepsilon - \gamma$/DVMS WALE	0.6M	0.25	0.03	0.26	135	-

Table – Bulk coefficients of the flow around a circular cylinder at Reynolds number 2×10^6.

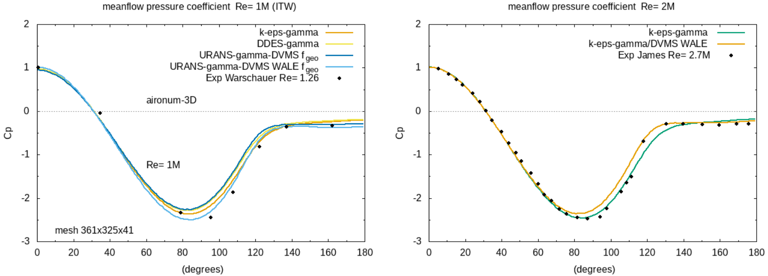

Figure – Integration to the wall meanflow pressure distribution, with $k - \epsilon - \gamma$ model

■ Recent modification :

▶ tref was hardcoded like tref = 0.012, I did :

```
 IF ( iadim .EQ. 1 ) tref        = lref4tref/vref !0.012
 IF ( iadim .EQ. 0 ) tref        = 1.0
```

▶ Initialized ε

$$\frac{\mu_t}{\mu} = \frac{\rho k^2}{\mu \varepsilon} \Rightarrow \varepsilon = \frac{\mu}{\mu_t} \frac{\rho k^2}{\mu} = \frac{\mu}{\mu_t} Re \frac{\rho k^2}{tref * rhoref * vref^2} \tag{3}$$

```
BUG #2 FIX aironum_v1.0 27/11/2010 roepsin  = rokin/10./tref
       roepsin  = rokin/10./tref

cMiralles mu/mu_t = (1/rey)*eps/(ro*kin**2)-----------------
       IF (musmut .GT. 0.0) roepsin  = musmut*rey*rokin**2/(tref*rhoref*vref**2)
c-----------------------------------------------------------
```

This implementation allows to initialized ε using a given ratio μ_t/μ

- NACA0018 set up :
  - chord = 0.08[m]
  - $\rho_0 = 1.225[kg/m^3]$, $P_0 = 101300[Pa]$
  - $U_0 = 30[m/s]$
  - $Tu = 0.3\%$,
  - $\frac{\mu}{\mu_t} = 10$
  - $tref = \frac{chord}{U_0}$
  - Mesh non dimensional $y_w^+ = 1$ 200x200x3, quasi 2D.

- Problems in the case of flow over naca0018, we should have a separation with rattachments :

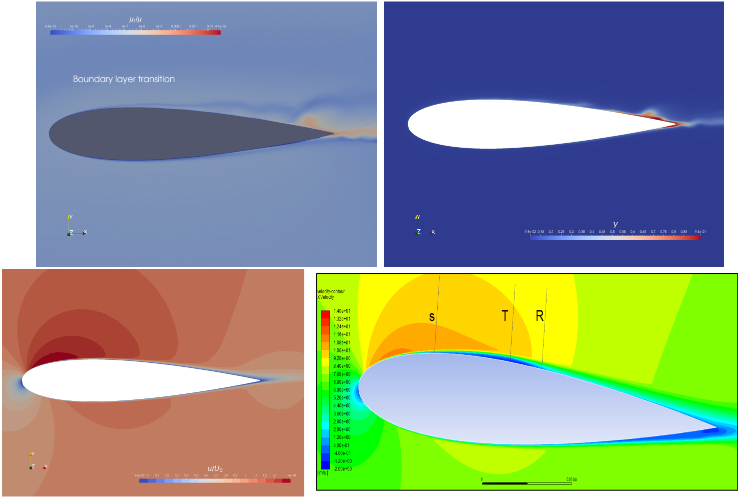

Figure – X-velocity field over NACA0018 at 5 degree angle of attcak [2]

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2. Mohannad Y. Al Orabi et Ahmed M.R. Elbaz. "Computational modeling of transitional flow over NACA-0018 airfoil at low Reynolds Number". In : 2020

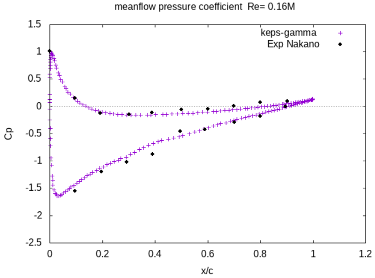


Figure – Integration to the wall meanflow pressure distribution, with $k - \epsilon - \gamma$ model

Part 2 : Recent advances of flow over a NACA0018

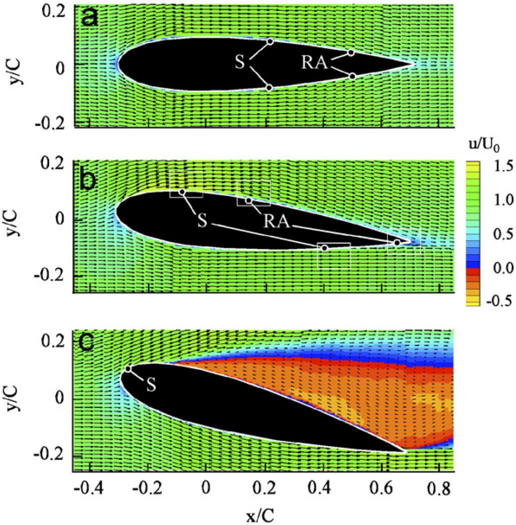


Figure – X-velocity field at 0, 6 and 15 degrees angle of attack [3].

3. T. Nakano et al. "Experimental study on flow and noise characteristics of NACA0018 airfoil". In : *Journal of Wind Engineering and Industrial Aerodynamics* 95.7 (2007), p. 511-531. issn : 0167-6105.

IDDES $k - \varepsilon$

- Development of a Improved DDES on $k - \varepsilon$ turbulence model, we introduce the Shur[4] filter :

Shur filter

- Δ is a linear function of distance to the wall d_w.
- For any d_w we have $h_{\min} \leq \Delta \leq h_{\max}$

$$\Delta = \min\{\max\left[C_w d_w, C_w h_{\max}, h_{w\mathbf{n}}\right], h_{\max}\} \tag{4}$$

- We introduce a hybrid turbulent length scale :

$$l_{IDDES} = f_{hyb}(1 + f\,restore\Psi)l_{RANS} + (1 - f_{hyb})C_{DES}\Psi\Delta. \tag{5}$$

Note that, Ψ is set to one for low Reynolds number model different than Spalart-Allmaras model.
$f_{restore}$ is used for preventing an excessive damping of RANS model.

4. A. Travin et al. "Improvement of delayed detached-eddy simulation for LES with wall modelling". In : (jan. 2006).

- Choice of filter :

$$\Delta_1 = \min\{\max\left[C_w d_w,\, C_w h_{\max},\, h_{w\mathbf{n}}\right],\, h_{\max}\} \quad \text{or} \quad \Delta_2 = C_w \max(h_x, hy, h_z) \qquad (6)$$

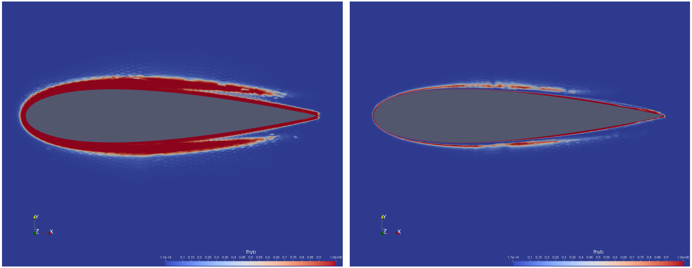
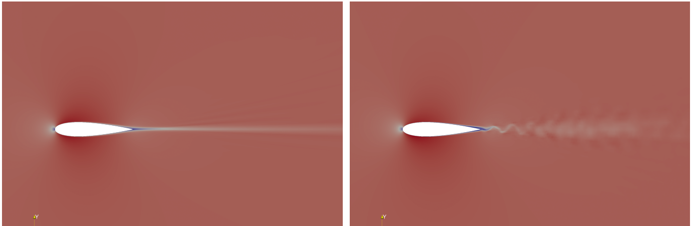


Figure – Shielding function related to Δ_1 on left and Δ_2 on the right



- Recirculation DDES Δ_2

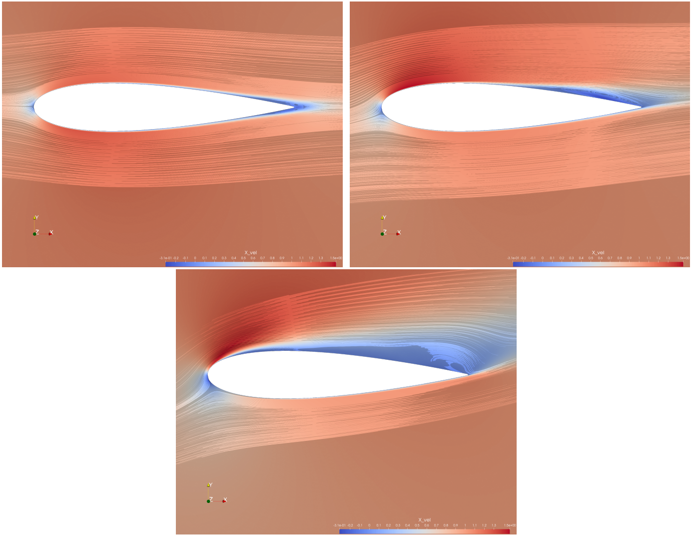


Figure – Flow recirculation at multiple angle of attack using DDES approach

- Recirculation IDDES Δ_2

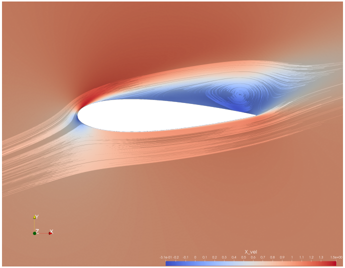
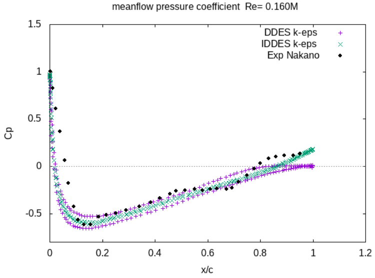
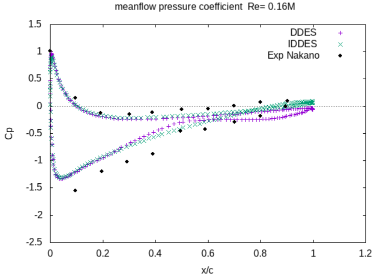


Figure – Shielding function related to Δ_1 on left and Δ_2 on the right

- Cp curves





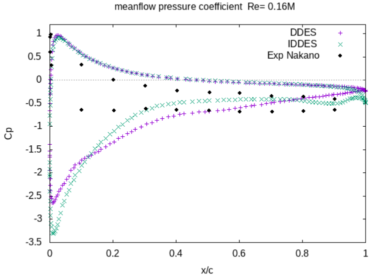


Figure – Integration to the wall meanflow pressure distribution at 0, 6 and 15 degrees angle of

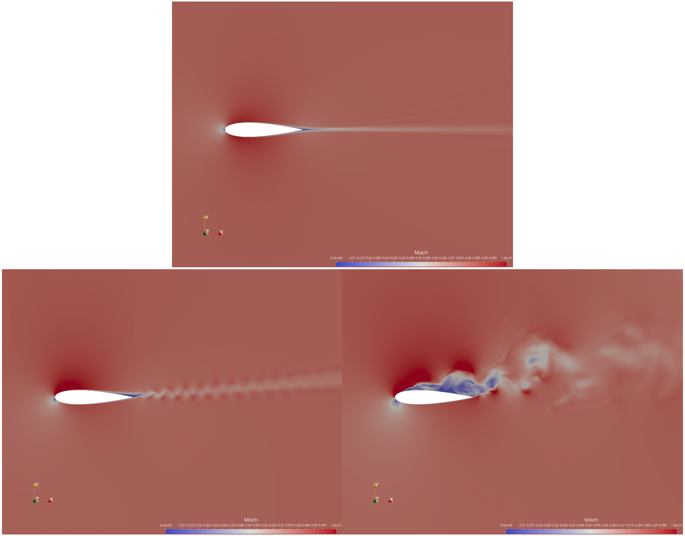


Figure – Integration to the wall meanflow pressure distribution at 0, 6 and 15 degrees angle of attack

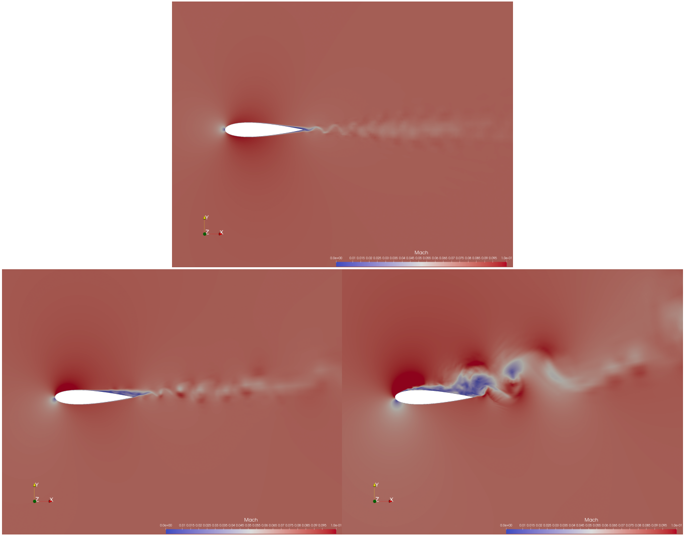


Figure – Integration to the wall meanflow pressure distribution at 0, 6 and 15 degrees angle of attack

- Aeroacoustic : Sound Pressure Level using $p_{ref} = 20[\mu Pa]$

$$d_B = 10 \log \left(\frac{(p(t) - p_\infty)^2}{p_{ref}^2} \right) \quad [dB],$$

$$p_{rms}^2 = \overline{p_\sim^2} = \overline{p}^2 - \overline{p^2},$$

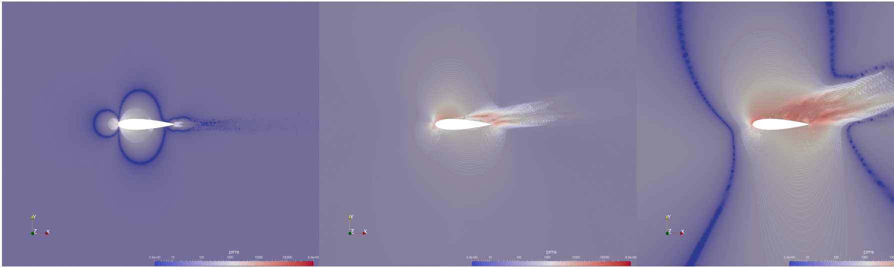


Figure – Integration to the wall root mean square pressure field at 0, 6 and 15 degrees angle of attack

Part 3 : Tournant

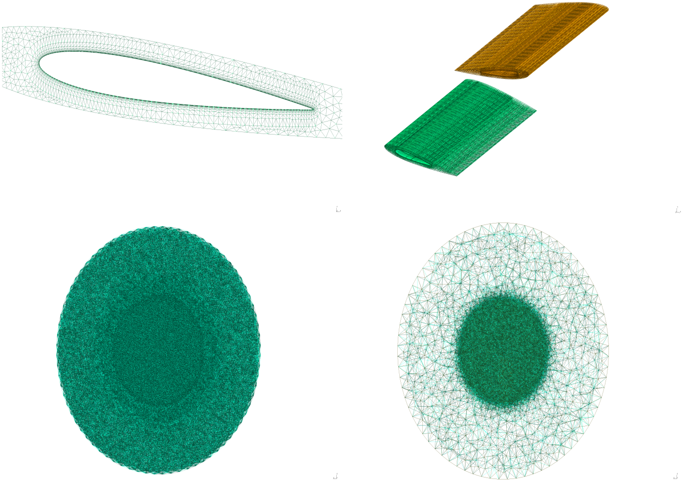


Figure – Fine versus coarse mesh.

- Set up
  - air viscosity 1.84×10^{-5}
  - Tip velocity $77[m/s]$
  - $\rho_0 = 1.225,\ P_0 = 101300[Pa]$
  - $AOA = 8^\circ$

No model simulation

Problems :

- ALE run only for inewt = 1 ARSFlu-General.f :

```
c
          IF (nordre_fluid_loc .EQ. 1) GOTO 275
C !MODIF TO REMOVE, USEFUL FOR THE FALCON
c           IF ((coor(1,nubo1).GT.7.85 .AND. logfr(nubo1).LT.0) .OR.
c     &         (coor(1,nubo2).GT.7.85 .AND. logfr(nubo2).LT.0)) GOTO 275
C !END MODIF TO REMOVE, USEFUL FOR THE FALCON
c
c

          IF (((inewt.EQ.1).and.(nexp.EQ.0)).OR.
     &       ((ialpha.EQ.1).and.(nexp.EQ.1))) THEN
c
            aix                         = coor(1,nubo2) - coor(1,nubo1)
            aiy                         = coor(2,nubo2) - coor(2,nubo1)
            aiz                         = coor(3,nubo2) - coor(3,nubo1)
c
          ELSE
c
            aix                         = coco(1,nubo2) - coco(1,nubo1)
            aiy                         = coco(2,nubo2) - coco(2,nubo1)
            aiz                         = coco(3,nubo2) - coco(3,nubo1)
c
          ENDIF
c
          IF (nordre_fluid_loc.EQ.2) THEN
            flur1                       = -(beta2*
     &          (aix*dx(1,nubo1) + aiy*dy(1,nubo1) + aiz*dz(1,nubo1)) +
     &                                  beta3*(uas1(2) - uas1(1)))
            flur2                       = -(beta2*
     &          (aix*dx(2,nubo1) + aiy*dy(2,nubo1) + aiz*dz(2,nubo1)) +
     &                                  beta3*(uas2(2) - uas2(1)))
            flur3                       = -(beta2*
     &          (aix*dx(3,nubo1) + aiy*dy(3,nubo1) + aiz*dz(3,nubo1)) +
```

- Velocity on faces not computed using Barth cells

- Average normals is not clear :

```
IF (iordtime .EQ. 2) THEN

   IF ((kt.EQ.(kt0 + 1)) .AND. avenorm.EQ.1) THEN
      DO 600 iseg=1,nseg
        sigmab(iseg)          = sigma(iseg)
        DO i=1,3
          vnoclb(i,iseg)          = vnocl(i,iseg)
        ENDDO
      CONTINUE
   ENDIF

   IF ((kt.GT.(kt0+1)) .AND. avenorm.EQ.1) THEN
      aa                      = (1.0 + 2.0*tau)/(1.0 + tau)
      ccovtau                 = tau/(1.0 + tau)
      DO 610 iseg=1,nseg
        sigmabb              = sigma(iseg)
        sigma(iseg)          = aa*sigma(iseg) -
&                               ccovtau*sigmab(iseg) !
         sigmab(iseg)         = sigmabb
         DO i=1,3
           vnoclbb                = vnocl(i,iseg)
           vnocl(i,iseg)          = aa*vnocl(i,iseg) -
&                                   ccovtau*vnoclb(i,iseg) !
           vnoclb(i,iseg)         = vnoclbb
         ENDDO
      CONTINUE
   ENDIF
```