Democratic and Popular Republic of Algeria
Ministry of Higher Education and Scientific Research
University of BECHAR

Printed from

Journal of Scientific Research

http://www2.univ-bechar.dz/jrs/

Detached-Eddy Simulation Applied to Flow over an Elliptic Airfoil Near Stall

[1]A.Benazza, [2]E.Blanco
[1]*Djillali Liabes University of Sidi Bel-Abbès, Algeria – Laboratory of materials and reactive systems*
abdel_benazza@yahoo.fr
[2]*Universidad de Oviedo, Dpto. de Energía. Campus de Viesques, 33271-Gijón, Spain.*
eblanco@uniovi.es

Published on 30 December 2012

Journal of Scientific Research
ISSN 2170-1237

Scientific Research Journal of

The Editor, on behalf of the Editorial Board and Reviewers, has great pleasure in presenting this number of the Journal of Scientific Research. This journal (ISSN 2170-1237) is a periodic and multidisciplinary journal, published by the University of Bechar. This journal is located at the interface of research journals, and the vulgarization journals in the field of scientific research. It publishes quality articles in the domain of basic and applied sciences, technologies and humanities sciences, where the main objective is to coordinate and disseminate scientific and technical information relating to various disciplines.

The research articles and the development must be original and contribute innovative, helping in the development of new and advanced technologies, like the studies that have concrete ideas which are of primary interest in mastering a contemporary scientific concepts. These articles can be written in Arabic, French or English. They will not be published in another journal or under review elsewhere. The target readership is composed especially of engineers and technicians, teachers, researchers, scholars, consultants, companies, university lab, teaching techniques and literary ... The journal is obtainable in electronic form, which is available worldwide on the Internet and can be accessed at the journal URL:

http://www2.univ-bechar.dz/jrs/.

Journal of Scientific Research

P.O.Box 417 route de Kenadsa
08000 Bechar - ALGERIA
Tel: +213 (0) 49 81 90 24
Fax: +213 (0) 49 81 52 44
Editorial mail: jrs.bechar@gmail.com
Submission mail: submission.bechar@gmail.com
Web: http://www2.univ-bechar.dz/jrs/

Journal of Scientific Research
ISSN 2170-1237

Detached-Eddy Simulation Applied to Flow over an Elliptic Airfoil Near Stall

[1]A.Benazza, [2]E.Blanco
[1]Djillali Liabes University of Sidi Bel-Abbès, Algeria – Laboratory of materials and reactive systems abdel_benazza@yahoo.fr
[2]Universidad de Oviedo, Dpto. de Energía. Campus de Viesques, 33271-Gijón, Spain. eblanco@uniovi.es

Abstract – *Predictions of the flow around an elliptic profile are obtained using Detached Eddy Simulation at chord Reynolds number of 7.21x10*^{6}. *Lift and drag coefficients (*C_l *and* C_d*) are computed from zero lift to angles above stall and compared to experimental data and to those obtained from RANS S-A model. The analysis focuses on the 3D unsteady effects and the influence of RANS zone size on the DES predictions. The accuracy of DES predictions is superior to that of S-A model and the computed values of* C_l *and* C_d *are in good agreement with experimental data up to stall point. Flows visualizations demonstrate unsteady flow structure dominate by Von Karman vortices. The shedding process and forces modulation appears to be represented reasonably at least in relation to adequate value of Strouhal number (St=0.25) for this Reynolds number. The DES is observed to provide sufficient unsteady information in the resolved range.*

Keywords*: Detached-Eddy Simulation, Lift, Drag, Stall, Vortex shedding*

I. Introduction

Elliptic profile provides a canonical flow behaviour characteristic of typical engineering flow configurations that include adverse pressure, streamline curvature and boundary layer separation. On the other hand, these symmetric airfoils are generally used in axial reversible jet fans and some vertical wind turbines. In such flows, parameters such as angle of attack and Reynolds number can greatly influence the nature of separation and the unsteady wake structure. Current engineering approaches for unsteady flows prediction rely primarily on the Reynolds-Averaged Navier-Stockes equations. While the most popular RANS models appear to yield predictions of acceptable accuracy of a relatively broad range of attached flows, it does not appear that RANS turbulence models are sufficiently accurate for reliable prediction of inherently unsteady separated flows. Techniques such as Large Eddy Simulation (LES) are attractive for flows regime with significant effects of separation. When applied to boundary layers, however, the computational cost of whole-domain LES does not differ significantly from that of Direct Numerical Simulation [1]. Therefore, the approach pursued here is one based upon the detached eddy simulation (DES) which is a hybrid RANS/LES method.

This approach aims at entrusting the boundary layer to RANS while the detached-eddies in separated regions are resolved using LES.

The DES method has proven to be especially effective for prediction of massively separated flows ([2], [3]) in turn motivating extension of the method to

the accurate prediction of flows exhibiting shallow separation, either unclosed or a bubble.

In “natural applications” of DES the entire boundary layer is treated by the RANS model and the detached regions away from the wall are handled by an LES model. There is a trend, at least in fundamental studies, to predict parts of boundary layers with LES [4]. DES is a strategy that depends on the grid not only for accurately resolving the turbulence in the regions of interest, but also in determining the switch between RANS and LES. This motivates extension of method to investigate the influence of RANS zone size on the DES predictions.

In literature few studies of flow over elliptic profile have been performed. Mittal and Balachandar [5] have performed Direct Numerical Simulation of 2D and 3D flows at low Reynolds numbers. They found that the values of Strouhal number agree well with experimental values of St for flows over circular cylinders at the same Reynolds numbers.

William and Brown [6] have tested an elliptic cylinder over range of Reynolds number from 0.3×10^6 to 7.21×10^6. Lift, drag and pitching moment were measured from zero lift to angles above stall. The values of C_l and C_d are given for the model of aspect ratio 6 as tested, corrected for wind tunnel interference, and for infinite aspect ratio, using the usual aerofoil formulae.
In this study two and three dimensional Detached Eddy simulation of incompressible flow over an elliptic airfoil of aspect ratio 6 was performed. The predicted values of drag and lift coefficients are compared to experimental results of William and Brown [6] and to those obtained from RANS simulations using S-A model [7].

II. Flow description

The specific flow of interest is that over an elliptic airfoil at chord Reynolds number of 7.21×10^6 and Mach number of 0.07. The general characteristics of flow are illustrated in figure1.The flow is evidently separated from the round trailing end; and the two separation points move, together with the wake, steadily around the end from the pressure towards the suction side, as the angle of attack is increased. At high Reynolds number, it is assumed that the transition occurred at small value of x/C very close to leading edge and that conditions are favorable for a study of a turbulent boundary layer of considerable length.

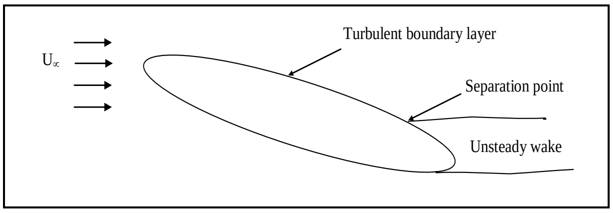

Figure1. Flow configuration around elliptic airfoil

The governing equations for viscous incompressible flow in Cartesian coordinates can be expressed as:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\rho\left(\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j}\right) = -\frac{\partial p}{\partial x_j} + \mu \Delta u_i + \rho g_i \tag{2}$$

II.1 Computational methods

II.1.1 Turbulence model

The DES approach used is based on the Spalart-Allmaras turbulence model [8]. To obtain the model used in the DES formulation, the length scale of the S-A destruction term is modified to be the minimum of the distance to the closest wall and a length scale proportional to the local grid spacing.

$$\tilde{d} = \min(d, C_{DES}\Delta) \tag{3}$$

Where, Δ is the largest local grid spacing and C_{DES} is a model constant. Near the wall, where $\tilde{d} = d$ the model works as a standard S-A turbulence model. In the regions, far from the wall, where $d > C_{DES}\Delta$ the length scale of model becomes grid-dependent, and the closure is a one equation model for the subgrid-scale (SGS) eddy viscosity. When the production and the destruction terms are balanced, this model reduces to an algebraic mixing length Smargorinsky-like subgrid model ($\tilde{\nu}\ \alpha\ S\Delta^2$). The additional model constant C_{DES}=0.65 was set in homogeneous turbulence.

II.1.2Numerical method

The governing equations are solved by a cell centered finite volume approach using the fluent code. In LES (DES) model most of the numerical procedures are based on central differencing scheme (CDS), because of its non-dissipative and energy-conserving properties. Upwind schemes are unsuitable because of their overly diffusive nature. At high Reynolds number, it is well known that CDS can produce unbounded solutions and non physical wiggles. In LES, the situation is exacerbated by usually very low sub-grid-scale turbulent diffusivity. To overcome these stability problems the convective flux in momentum equations is computed by means of the bounded central differencing scheme. The bounded CDS scheme is a composite normalized variable diagram (NVD) scheme that consists of a pure central differencing, a blended scheme of the central differencing and the second order upwind scheme.

A Green–Gauss reconstruction of the gradient is used for all gradients calculations used to discretize the convection and diffusion terms of the transport equations. The time discretization is performed by a second order implicit scheme. Second order time stepping is an established technique for improving the time accuracy of conventional numerical schemes for unsteady flow computations. A point wise-implicit Gauss-Seidel scheme is employed for advancement of the discretized system.

II.1.3 Boundary conditions

At the inflow boundary the instantaneous velocity normal to boundary is simply set to its mean velocity counterpart. This option is suitable when the level of turbulence at inflow boundary is negligible or does not play a major role in the accuracy of the overall solution. The value of subgrid scale eddy viscosity is set to low level: $(\mu_{SGS}/\mu = 1)$. No slip velocity boundary condition is used at the wall and the turbulent viscosity is set to zero.

A Neumann boundary condition for the pressure is applied at the outflow boundary.

II.1.4 Computations tests and grid

The computations were performed using an unstructured grid with quadrilateral triangular cells. The quadrilaterals elements were clustered in the near wall region and the first wall normal spacing in a dimensional form was about $y^+<1$ (figure2). The use of quadrilaterals elements in boundary layer allows using a small wall normal spacing Δy and a large wall parallel spacing Δx, which determine the extension of RANS zone. There are positive attributes of unstructured grids that relevant to DES. It is possible, for example, to concentrate points in region of interest the "focus region" introduced in the "Young Person's Guide to Detached Eddy Simulation Grids" [9], and to rapidly coarsen the grid away from these areas. Each grid is described with only a representative grid spacing Δ in the focus region [9]. Recall that the local Δ in DES is the largest of the spacings in all directions.

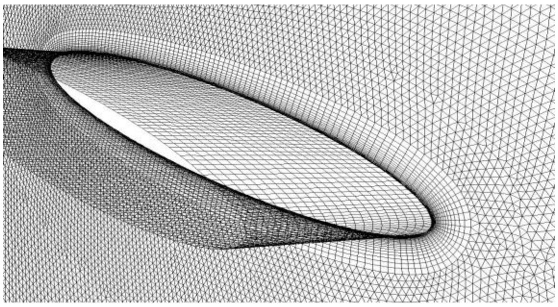

Figure 2. View of grid in vicinity of the elliptic profile

In the first computation we studied the influence of the "RANS zone" size d_R (d_R=$C_{DES}\Delta$) on the DES predictions at two angles of attack. Three values of d_R were used corresponding to three different grid sizes generated by varying the grid spacing in the wall parallel directions and applying the same resolution in the wall normal direction. For these grids the number of nodes on airfoil surface vary from N= 116 to N= 444 (see table1).

Case	Cells	N	Δ/C
C1	124508	444	0.0050
C2	106420	316	0.0074
C3	97172	252	0.010
C4	91846	204	0.012
C5	83432	172	0.015
C6	70432	116	0.022

Table 1. Grids details

The simulations were performed on a cluster of twenty parallel processors (2.7 GHz). The time step was estimated to Δt=0.006C/U_∞ giving a *CFL* number inferior to 1. Where C is the chord length and U_∞ is the free stream velocity. The iterations number was adjusted to I=15 in each time step to reduce the residual below an acceptable value. The lift and drag coefficients are computed for angles of attack: α=10.5 and α=17.5 and compared with experimental results.

In the second part of this study we have used a grid of 918460 cells which have given best results in the first computation. The Simulations of flow were performed from low angles of attack to angles above the stall. The extent of domain in the spanwise direction is 12 % of chord length, and periodic boundary conditions are imposed in this direction. It this acknowledged that this can potentially affect flow structures in wake, particularly if this dimension is smaller than spanwise turbulent correlation length scales, which for this problem are unknown. Three other values of span are used in order to evaluate the influence of span on the DES predictions, table 2 summarize the details of the three grids. The Computations were carried out for a single angle of attack α =21.3° on a cluster of twenty parallel processors (2.7 GHz).

Cas	L_z/C	N_z	Cells
A1	24 %	20	1.858.800
A2	36 %	30	2.788.200
A3	50 %	40	3.717.600

Table 2. Details of the 3D grids

III. Results and Discussion

Figure 3 presents the variations of the relative RANS zone size (d_R /δ) for the six grids tested. Where δ is the boundary layer thickness at the station x/C=0.5 on the pressure side of airfoil. The high values of Δ corresponds to "RANS zone" of DES that extends in great part of boundary layer, while for the low values of Δ, the "RANS zone" are in order of inner region of boundary layer. In figures 4 and 5 contours of the instantaneous vorticity magnitude for the two cases C1 and C6 are shown. Figure 4 shows that some eddy content is captured close the wall near the trailing edge and coherent structures appear in the wake, yielding unsteady fluctuations of the lift and drag coefficients. Figure 5 yields marked changes in the flow structure, with a total lack of vortices in all boundary layer and the wake. The DES predictions for this case (C6) tend to steady solution like S-A RANS computation, giving constant values of lift and drag coefficients.

The RANS zone size is relatively large and so globally the entire boundary layer is handled by the S-A model. We can say that the RANS zone size influences substantially the prediction of the unsteady features of the flow.

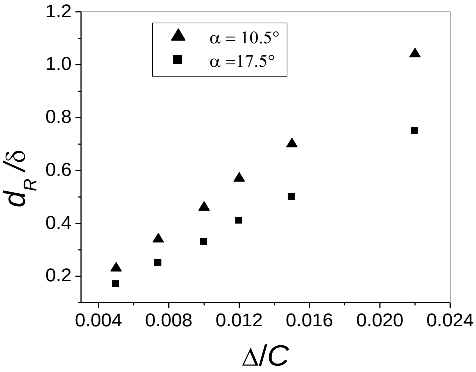

Figure3. RANS zone size versus Δ/C at x/C = 0.5 on the pressure side of airfoil

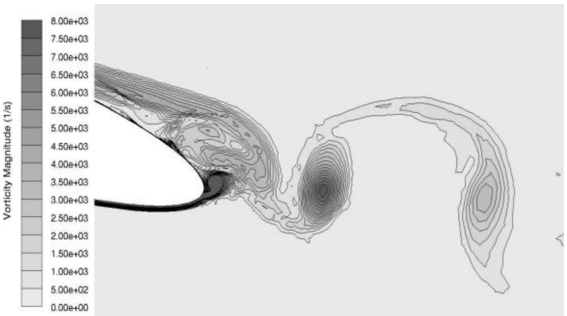

Figure4. Contours of the instantaneous vorticity (s^{-1}) magnitude for case C1 (N=124508 cells)

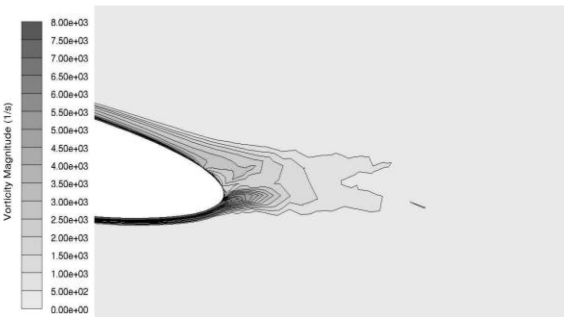

Figure5. Contours of the instantaneous vorticity (s^{-1}) magnitude for case C6 (N=70432 cells)

Figure 6 presents the variation of the lift coefficient as a function of Δ for two angles of attack studied. This figure shows that at high values of Δ the predicted lift coefficients differ significantly from those of experimental data. This corresponds to case of large “RANS zone”, as cited above; the predictions tend to steady solution. At low values of Δ the results of lift coefficients are underpredicted.

As reported by Kotapati-Apparao et al.[10], as the grid spacing in the wall-parallel directions becomes smaller than about half of the boundary layer thickness, the DES limiter reduces the eddy viscosity below its RANS level and this process can degrades predictions if mesh densities are insufficient to support eddy content in this zone of boundary layer. Both in two cases (α=10.5° and α=17.5°) studied the intermediate values of Δ allow to obtain accurate predictions of lift coefficients. It appears that for the success of DES predictions in such flow, a part of boundary layer must be treated by LES model and RANS zone must extends largely over the logarithm region. In fig.7 and fig.8 DES predicted values of drag and lift coefficients are compared with experiment results and with those from S-A model. We note that Unsteady S-A simulations tend to steady solutions. At low angles of attack both computed lift and drag coefficients agree well with experimental values for DES and S-A models. As the angle of attack increases (10<α<18), the S-A model overestimates the lift coefficients while DES predictions are in good agreement with experimental results. The differences in the S-A predictions compared to DES predicted values highlight differences in the flow evolution, especially in separation and wake. At 18.45° angle of attack the S-A model predicts separation at x/C= 0.85 and 2D DES predicts boundary layer separation at x/C = 0.80. The S-A calculations are consistent with a smaller effect of the separation compared to the DES runs. The success of DES at these angles of attack can be attributed to its LES treatment of separated region and wake zone, an outcome that contributed to improved predictions.

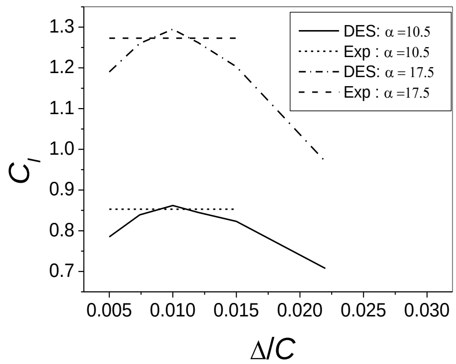

Figure 6. Lift coefficient for different grids as a function of the average cell size Δ/C

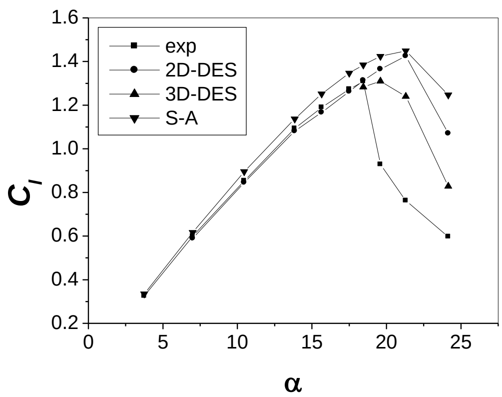

Figure 7. Lift coefficient versus the angle of attack

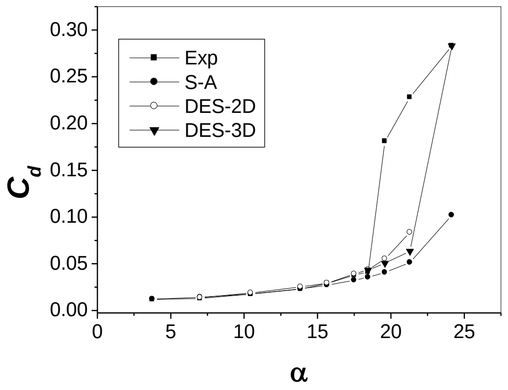

Figure 8. Drag coefficients versus the angle of attack

Figure 9. Instantaneous isosurface of the vorticity magnitude for 3D DES (α =18.45°)

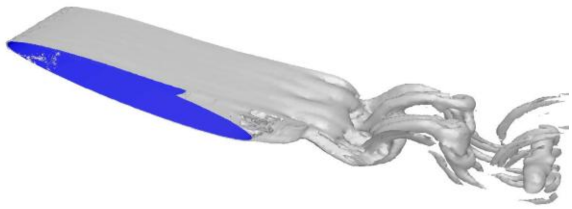

Figure 10. Instantaneous isosurface of the vorticity magnitude for 3D DES (α =21.3°)

Shown in fig 9 is the isosurfaces of the instantaneous vorticity magnitude near the trailing edge and in the wake for 3D DES predictions at 18.45° angle of attack corresponding to maximum experimental value of lift coefficient. The figure reveals dominant 2D Von Kárman vortices. A periodic vortex shedding was established, and the Strouhal number (St) based on a length scale defined as the vertical distance between points of mean separation at the trailing edge ([11]) is equal to 0.25. This value corresponds to Strouhal number for flow over circular cylinder at the same Reynolds number. 3D DES approach predicts a stall at 21.3° angle of attack, this is a relative improvement compared to 2D DES and S-A predicted values of stall angle, but it is still far from experimental result. The predicted values of C_l and C_d are largely different to experimental values. At this angle of attack are shown in figure10 isosurface of instantaneous vorticity magnitude for 3D DES computations. The figure reveals a 2D Von Kárman vortex shedding mode, but also intense vortices transverse to the Von Kárman vortices. In order to have a closer look into the details of the flow, a part of lift history is presented in fig.11 which shows very irregular variations in time. A Fast Fourier Transform (FFT) analysis of the signal (fig.12) indicates the presence of peak at frequency f=215 Hz. It is identified as a vortex shedding from the trailing edge of airfoil. In table 3 are presented the 3D DES predicted values of C_l and C_d for the three cases studied. Overall, the results show equal values of aerodynamics coefficients for the three grids. It appears that no improvements are obtained on the characteristics by increasing the span at least up to maximum value of span used.

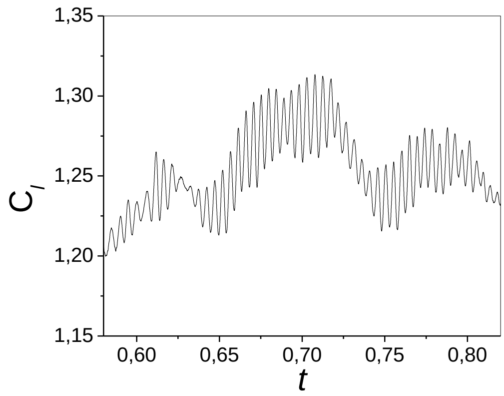

Figure 11. Time history of lift coefficient (α =21.3°)

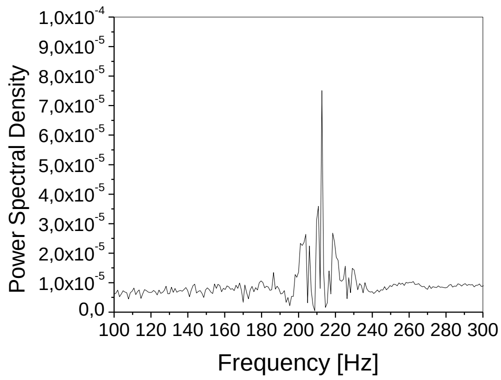

Figure 12. Power spectrum of lift coefficient (α =21.3°)

Cas	N_{total}	L_z/C	C_l	C_d
A1	1.858.800	24 %	1.256	0.0633
A2	2.788.200	36 %	1.22	0.0623
A3	3.717.600	50 %	1.253	0.0635

Table 3 Comparison of C_l and C_d results for the 3 grids

IV Conclusions

DES computations of the flow around elliptic airfoil were performed using a hybrid grid. Lift and drag coefficients were computed at various angle of attack and compared to experimental values and to those from S-A predictions. The accuracy of DES predictions is superior to that of Spallart-Allmaras model and the computed values of C_l and C_d are in good agreement with experimental results up to stall point. The complex shedding process and modulation in the forces appear to be represented reasonably adequately at least in relation to the agreement between simulation and available experimental results. The results from the six grids tested show that the "RANS zone" size influences substantially the accuracy and the quality of DES predictions. DES approach fails to predict correctly the stall for this configuration of flow. Prediction of smooth-surface separation at stall continues to strongly challenge current DES modeling approach.

References

[1] PR. Spallart, WH. Jou, M. Strelets, and S. Allmaras. "*Comments on the Feasibility of LES for Wings, and on a Hybrid RANS/LES Approach, Advances in DNS/LES"*, 1st AFOSR Int. Conf. on DNS/LES, Gredyen Press, Columbus Oh, AUG. 4-8, 1997

[2] G. Constantinescu, R. Pacheco, KD. Squires, "Detached-Eddy Simulation of flow over a sphere", AIAA Paper 2002-0425

[3] Viswanathan A, Squires KD, Forsythe JR "Detached-Eddy Simulation around fore-body at high angle of attack", AIAA Paper 2003-0263

[4] NV. Nikitin, F. Nicoud, B. Wasistho, KD. Squires, PR.Spalart, "An approach to wall modeling in Large-Eddy Simulations", Phys. Fluids 12, 2000, pp.7-10

[5] R. Mittal, S. Balanchadar, "Direct Numerical Simulation of Flow Past Elliptic Cylinders", *J. of Comp. Phys,* 124, 1996, pp 351-367

[6] DH. William, AF. Brown AF "Experiments on an Elliptic Cylinder in the Compressed Air tunnel", RM N.1817, British A.R.C, 1987

[7] A. Benazza, E. Blanco, J. Parrondo, J. Fernández, "Turbulence Models in Symmetric Airfoil Simulation", 1st International Congress of Energy and Environment Engineering and Management, Portalegre, Portugal, May 18-20, 2005

[8] PR. Spalart, SR. Allmaras, "A one-equation turbulence model for aerodynamic flows", La Recherche Aerospatiale, 1 1994, pp. 5-21

[9] PR. Spalart, "Young person's guide to Detached-Eddy Simulation grids", NASA CR-2001-211032

[10] RB. Kotapati-Apparao, KD. Squires, JR. Forsythe, "Prediction of the Flow over an Airfoil at Maximum Lift", AIAA paper 2004-0259

[11] EG. Paterson, WJ. Baker, "Simulation of Steady Circulation Control for Marine-Vehicle Control Surfaces", AIAA Paper 2004-0748

Journal of Scientific Research

P.O.Box 417 route de Kenadsa
08000 Bechar - ALGERIA
Tel: +213 (0) 49 81 90 24
Fax: +213 (0) 49 81 52 44
Editorial mail: jrs.bechar@gmail.com
Submission mail: submission.bechar@gmail.com
Web: http://www2.univ-bechar.dz/jrs/