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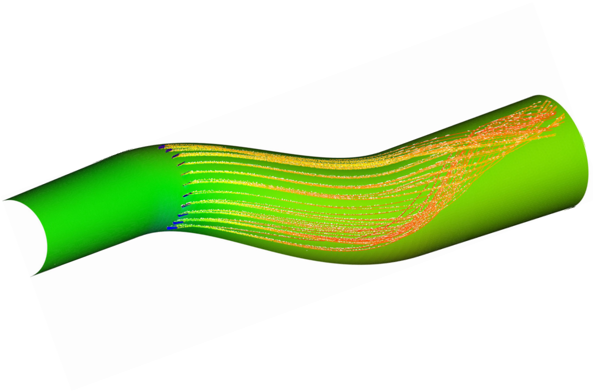

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A Modified Vortex Generator Model and its Application to Complex Aerodynamic Flows

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Abstract

This report describes the development and verification of a vortex generator model for the FOI CFD code Edge. The proposed vortex generator model removes the need to physically mesh the vortex generator. Instead the appropriate lift force normal to the local flow direction is added to the system of Navier-Stokes equations. The source term is based on an existing model in which the local force in the source term is dependent on local flow quantities and vortex generator characteristics. Several main issues were kept in focus during the development of the vortex generator model; the model must be able to treat many vortex generators as accurately as possible; the model should not contain a large number of unknowns which must be supplied by the user; the model should, to a certain extent, be grid and model constant independent and last but not least, the model must be user friendly. The proposed vortex generator model was implemented and tested for flow over a flat plate with a single sub-boundary layer vortex generator and for the RAE M2129 S-duct with four different vortex generator installations. The vortex generator model is easy to use, does not require a great deal of user input and is able to treat different types of vortex generators.

Nomenclature

AIP	Aerodynamic Interface Plane
$\vec{b}$	unit vector in the direction of the span of the vortex generator
ΔV_i	mesh cell volume
ΔV_m	sum of volumes of cells where the vortex generator source term is added
DC_{60}	pressure distortion index
C_{VG}	vortex model constant
$\vec{n}$	unit vector normal to vortex generator planform
S_{VG}	vortex generator area
$\vec{t}$	unit vector tangential to the vortex generator planform and normal to $\vec{b}$
$\vec{u}$	velocity vector
$\vec{v}$	vector of velocity tangential to the vortex generator planform

Introduction

Vortex generators are highly efficient aerodynamic devices widely used in both external and internal aerodynamics as means of flow control [3, 6, 5, 8, 11, 19]. They are local geometrical imperfections which cause the formation of longitudinal vortices giving rise to local mixing of the flow, energizing the boundary layer and consequently delaying or preventing separation or inducing secondary flow motion which restructures entire flow-field. The geometrical characteristics of vortex generators as well as the characteristics of vortex generator installation strongly depends both on the flow characteristics and on the type of problem. It is therefore desirable to use advanced CFD methods combined with experimental results and enveloped by statistical methods (for example Design of Experiment, *DOE*) in order to find the best vortex generator installation. Such an installation should be both efficient and insensitive to changes in the flow. This process is usually very time consuming. From a CFD point of view the biggest problem connected with vortex generators is the amount of time required to generate grids around the vortex generators and the large number of grid points required to obtain an accurate solution. One way to overcome this difficulty is to model the vortex generator effect using a vortex generator model thus removing the need to grid the geometry of each individual vortex generator. To my knowledge there are two types of vortex generator model - Vortex Source Model and Lifting Force Model (notation according to May[14]) .

The Vortex Source Model constructs the source term based on either adding a specific circulation Γ, or by adding another source term which is based on the velocity induced by this specific circulation according to the Biot-Savart law. The vorticity or other source term is usually added to the system of flow governing equations at the plane normal to the vector of vorticity at the vortex generator position. The key problem with this kind of model is that the value of the initial specific circulation of the vortex generator must be known. Research effort in this area aims at defining the specific circulation as well as other characteristics of circulation induced vorticity[13, 5, 9, 18, 14]. The model must be combined with appropriate boundary condition which on a wall usually is a mirror vortex boundary condition.

The Lifting Force Model is a newer model and was developed by Bender, Anderson and Yagle in 1999[7]. It is based on adding the lift force induced by the vortex generator to the system of Navier-Stokes equations. This lifting force spins the flow giving rise to the formation of vortices. In the model the lift force is estimated from the Prandtl lifting theory. This model has attracted a great deal of interest particularly in the U.S. The model has been tested for flow over a flat plate with a single vortex generator. To enable model verification and validation detailed experimental testing and fully-gridded analysis has been made[11, 3, 16, 7]. More complex flow as the flows through the RAE M2129 S-duct have also been computed[7]. The model has however some limitations. In particular it is quite difficult to define the points in the computational mesh where the vortex generator model should be applied. One consequence of this is not able to accurately treat multiple vortex generators separately. In the author opinion the lifting force model is the more promising of the two vortex generator models described here and it is this model which was chosen as the base for development of the modified vortex generator model.

1 Vortex generator model

1.1 The Bender-Anderson-Yagle (*BAY*) model

The vortex generator model which has been developed for Edge is based on vortex generator model developed by Bender et al.[7] in which the generated vorticity is induced by a lateral force which is dependent on local flow quantities and the vortex generator shape. The source term and its derivation as written in the original article of Bender et al. is repeated here for completeness:

$$\Delta V_i \frac{\Delta \rho \vec{u_i}}{\Delta t} = \sum_j \vec{F_M} \Delta S + \vec{L_i} \quad (1)$$

$$\Delta V_i \frac{\Delta \rho E}{\Delta t} = \sum_j \vec{F_E} \Delta S + \vec{u_i} \vec{L_i} \quad (2)$$

$$(3)$$

The source term $\vec{L_i}$ is a function of the lifting force caused by the vortex generator and is corrected for losses due to deviation of the flow from the vortex generator surface. This side force is approximated by

$$\vec{L_i} = C_{VG} S_{VG} \frac{\Delta V_i}{V_m} \alpha \rho u^2 \vec{l} \quad (4)$$

where C_{VG} is the vortex generator constant, ΔV_i is the volume of the cell where the force is calculated, V_m is the sum of volumes of cells where the force term is applied, α is the angle of local velocity $\vec{u}$ to the vortex generator and $\vec{l}$ is the unit vector on which the side force acts.

The side force generated using equation 4 acts so as to align the local velocity with the vortex generator. If the model constant C_{VG} is set to very high value the flow will be aligned with the vortex generator ($\alpha \rightarrow 0$), however for numerical reason the finite value must be used. As long as the model constant is sufficiently large, the side force, $\vec{L_i}$ will be independent of C_{VG}.

After some approximations the final expressions are

$$\vec{l} = \frac{\vec{u}}{|\vec{u}|} \times \vec{b} \quad (5)$$

$$\alpha \approx sin\alpha = cos(\frac{\pi}{2} - \alpha) = \frac{\vec{u}.\vec{n}}{|\vec{u}|} \quad (6)$$

The final equation is multiplied by the term $\frac{\vec{u}.\vec{t}}{|\vec{u}|}$ which represents losses of side force due to high angles of attack. The final expression for the side force according to Bender et. al.[7] is as follows

$$\vec{L_i} = C_{VG} S_{VG} \frac{\Delta V_i}{V_m} \rho (\vec{u}\vec{n})(\vec{u} \times \vec{b}) \left(\frac{\vec{u}\vec{t}}{|\vec{u}|} \right) \quad (7)$$

The original *BAY* model was applied in cells which were enclosed by the vortex geometry. For this case the user inputs are the position and orientation (vectors $\vec{t}$, $\vec{b}$, $\vec{n}$) of the vortex generator and the vortex generator model constant C_{VG}. According to Bender et. al.[7] the vortex generator model can operate in two modes - asymptotic and linear. If the sum of cell volumes V_m is close to the volume of the vortex generator (the model is applied in a limited number of cells - ie. locally) the model is insensitive to the value of the model constant provided that it is sufficiently high ($C_{VG} \approx 5)$ and higher. If V_m differs substantially from the volume of the vortex generator (as in the case of a row of vortex generators) the model behaves in linear mode and is dependent on the constant. The main difficulty with the *BAY* model is therefore the need to define points which are inside the vortex generator if it is possible since most vortex generators are flat plates with almost negligible thickness, and determining the value of the model constant or its dependency on vortex generator installation. All this makes the *BAY* model, to a certain extent, grid dependent. In order to overcome the problem with definition of grid points laying inside the very thin vortex generators, Bender et al. during their study of the RAE M2129 channel proposed to treat the row of co-rotating vanes as one large vortex generator and to apply the source term at every mesh point in this ”pseudo”-vortex generator. Their approach led to results which are in good agreement with experimental data. However, the uncertainty of the model constant remains. Another question connected with this simplification was that whilst vortices from each vane remained unresolved the secondary vorticity was predicted well. However, the author believes that in cases with complicated vane installations where some vanes are in the wake of previous ones the simplification is too restrictive and can lead to misinterpretation of the physical phenomena.

1.2 The modified *jBAY* model

The motivation behind the modified model in this study is to attempt to overcome the shortcomings of the original *BAY* model, mainly to simplify the definition of points where the side force is calculated and extend the ability of the model to treat systems of multiple vortex generators without any simplifications. The expression for the side force is thus the same as defined in the original model (equations 4-7).

The vortex generator is replaced by a mean surface with zero thickness (as in potential theory). Points where the side force is calculated are then determined by the intersection of this mean surface with grid edges. The values in cross-points are interpolated from grid nodes and the resulting side force is then redistributed back to the nodes and added to the Navier-Stokes equations.

Since the vortex generators are usually small plates glued to the wall they are located either entirely or partially inside the boundary layer. In this region, the computational grid is usually sufficiently dense so that the number of points per each vortex generator is quite high. This simplifies the search for appropriate points to define the vortex generator and allows the each vortex generator to be treated separately. It is however extremely important to keep in mind that since the model is working in a local mode, sufficient grid resolution must be retained in order to resolve vortex filaments generated by the vortex generators. We note that another advantage of applying the model locally is that the source term which is added to the Navier-Stokes equations is applied in a very limited portion of the grid and hence reduces instabilities in the solution.

2 The Edge CFD code

The CFD flow solver used for this study is Edge, a finite volume Navier-Stokes solver for unstructured meshes. Edge has been developed at the Aeronautics Division of FOI[10]. It employs local-time-stepping, multigrid and dual-time-stepping for steady-state and time-dependent problems. The data structure of the code is edge-based so that the code is constructed as cell-vertex. Edge can be run in parallel on a number of processors to efficiently solve large flow cases. It is equipped with a number of turbulence models based both on eddy-viscosity and explicit algebraic Reynolds stress model (*EARSM*) assumption. The model which was used during this study was the two-equation $k - \omega$ model combined with Wallin $\&$ Johansson EARSM model[17] with compressible corrections. The source term in the vortex generator model was calculated on the finest grid level in the first stage of the Runge-Kutta scheme and hence requires very little extra computational time. No under-relaxation was needed because all cases computed so far were stable.

3 Results

The *jBAY* vortex generator model has been used to calculate the flow over a flat plate with one sub-boundary layer vortex generator. It has also been applied to the RAE M2129 S-duct test case at two different inlet conditions with four different vortex generator installations. Sensitivity studies where both grid sensitivity as well as the sensitivity to the vortex generator model constant were carried out.

3.1 Case1: Single vortex generator on a flat plate

This test case is used to determine the ability of the *jBAY* vortex generator model to capture the vorticity induced by a vortex generator on a flat plate. Both fully-gridded computations and vortex generator model calculations were carried out. The vortex generator is $7mm$ high and $49mm$ long and is mounted on a flat plate at a position where the thickness of the boundary layer is $45mm$. The angle of the vortex generator to the free-stream velocity is $\alpha = 23^{\circ}$ and the speed of flow is $34m/s$.

The grid for the fully-gridded analysis was created at FOI using the grid generator Icem-Hexa and has approximately $700,000$ cells. The quality of the grid on both the flat plate and the vortex generator is high and the condition of $y^{+} \approx 1$ is fulfilled. Three computational grids with different density of grid lines in span-wise direction were used for the calculation with the vortex generator model. The medium grid has twice time and the fine grid four times higher density of grid points in flat span-wise direction than the coarse grid. The grid density in stream-wise and wall-normal direction of the flat was kept the same for all three grids.

The effect of this refinement is clearly seen in figure 1 where velocity at five different cuts for all four test cases is plotted. This demonstrates the importance of having adequate grid density around the vortex generator for resolution of vorticity. When the density of grid lines is low the vortex dissipated rather quickly and its effect was under-predicted. As the grid density is increased the patterns of the flow-field grew closer to the patterns given by the fully-gridded analysis.

The vortex generator model was unable to model the core of a vortex where the velocities are around zero due to omission of viscous effects in the model. However, the effect on the flow-field is reasonably close to that obtained from the fully-gridded analysis. During this test, the different model constants ($C_{VG} = 7$ and $C_{VG} = 10$) were used and the differences were quite small, therefore the results of $C_{VG} = 10$ are shown only.

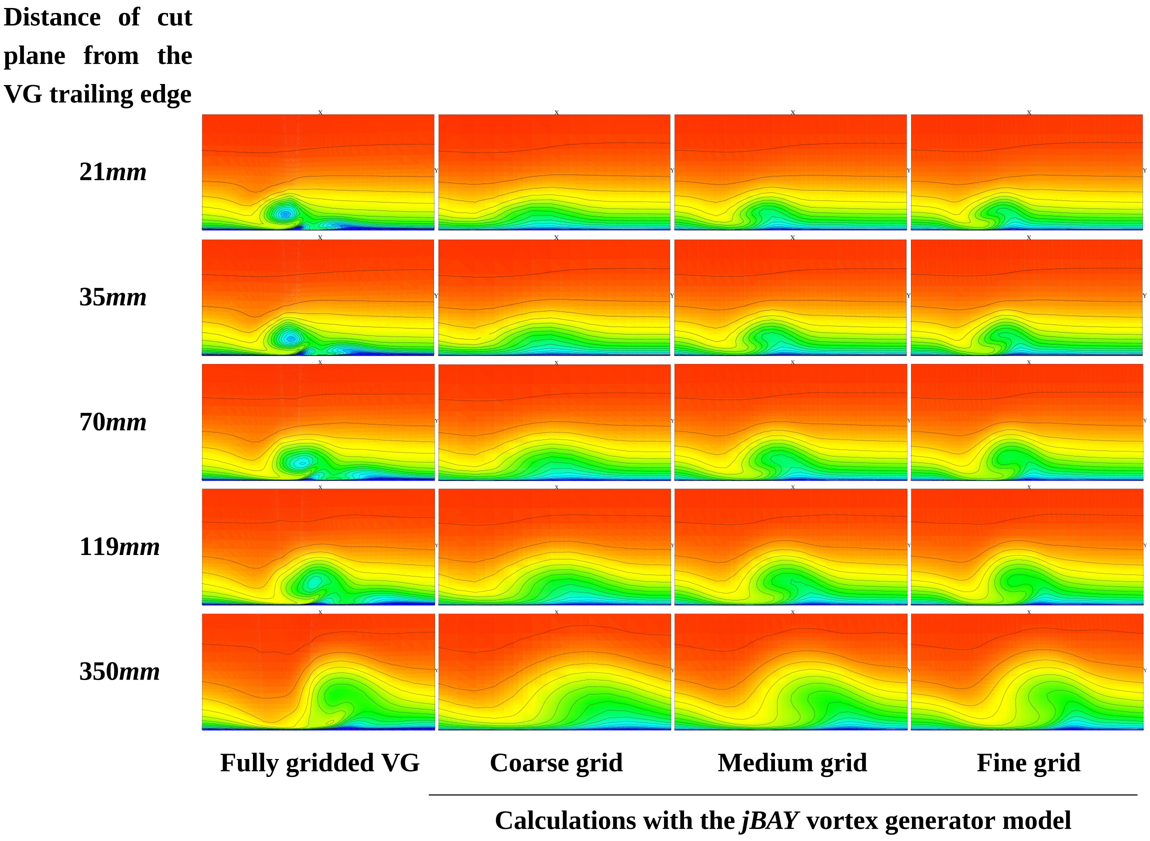


Figure 1. **Velocity contours in different cuts for vortex generated by the vortex generator on the flat plate**

3.2 Case2: RAE M2129 S-duct

The main and most complex test case used to validate the model was the flow through the RAE 2129 S-duct. The channel geometry is defined in[1, 4]. For this case it is known that, at low Mach numbers the flow separates just after the first bend. The test had two goals: firstly to find out to which extent the model is independent of the value of the vortex generator model constant and secondly to demonstrate the ability of the vortex generator model for the study of vortex generator installation.
The purpose of vortex generator installation is to restructure the flow-field inside the S-duct by inducing secondary flow motion so that flow separation is reduced or completely prevented. The figures 2 and 3 show streamlines arising from the vortex generators demonstrating secondary motion (figure 2) and streamlines of flow in the S-duct for the geometry with and without vortex generators and with visible flow separation in the smooth channel - (figure 3).

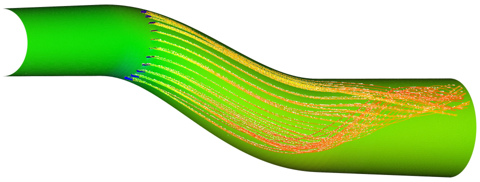
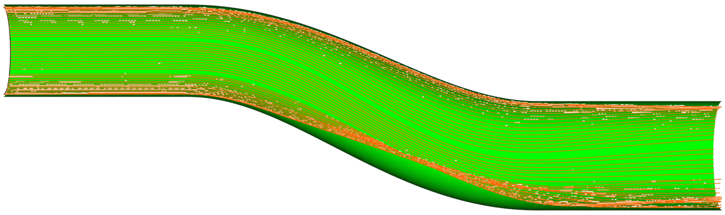
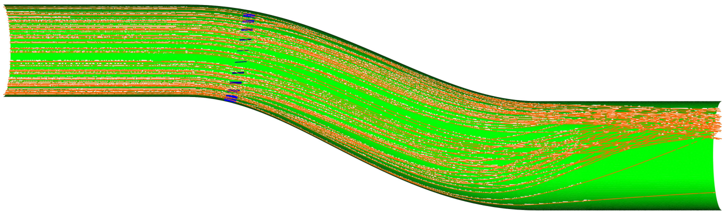


Figure 2. **Vortex filaments in flow through RAE M2129 S-duct**

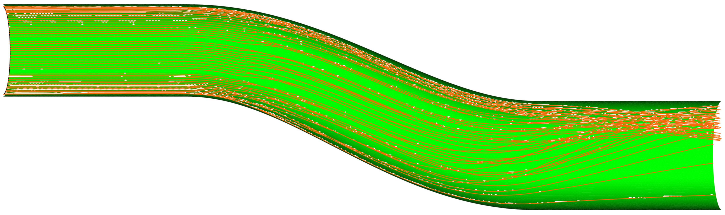
The computational grid for the fully-gridded analysis is shown in figure 4. The grid was generated using Icem-Tetra and contains about 2.25 million points with prismatic layers on both the S-duct wall and on the vortex generators. The grid has an extension upstream of the inlet in order to build an adequate boundary layer on the walls of the S-duct and is also extended downstream of the outlet. The S-duct grid without vortex generators had about $900,000$ points and has been used for all other calculations except fully-gridded computations. The size of grid is thus reduced by a factor 2.5 using the vortex generator model. Together with need to run fully-gridded analysis in parallel, the gain in computational time is of order 3. Figure 5 shows details of streamlines around the fully-gridded vortex generators and from the solution with the vortex generator model. The ability of the vortex generator model to resolve each vortex generator separately can be seen.



(a) **Baseline configuration**

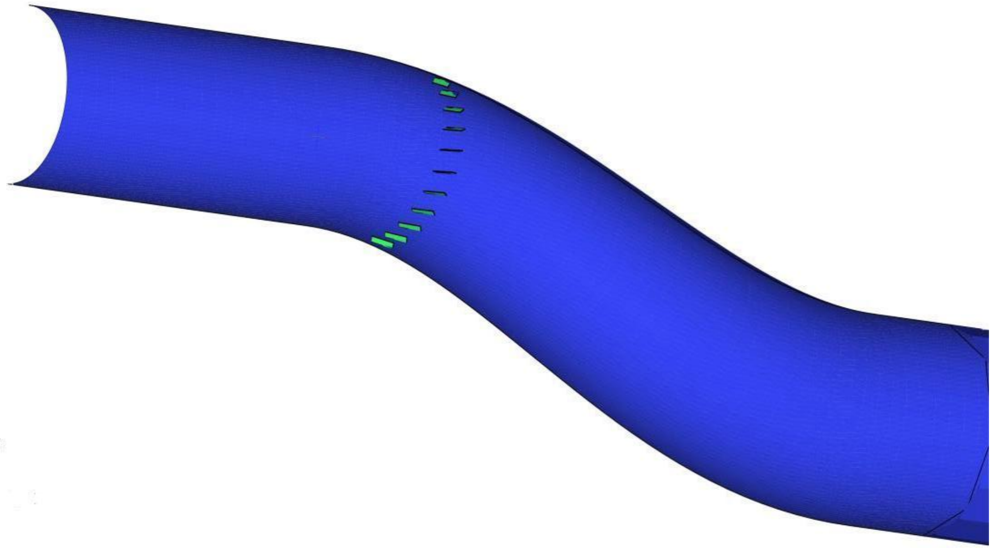


(b) **VG165 configuration - fully gridded VG**

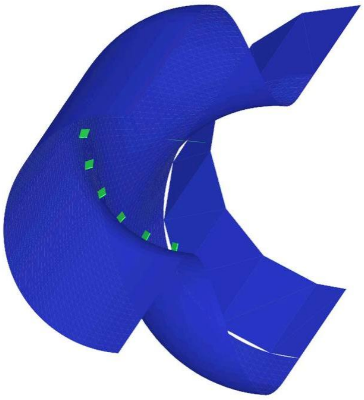


(c) **VG165 configuration - *jBAY* VG model**

Figure 3. **Streamlines of flow through RAE M2129 S-duct**

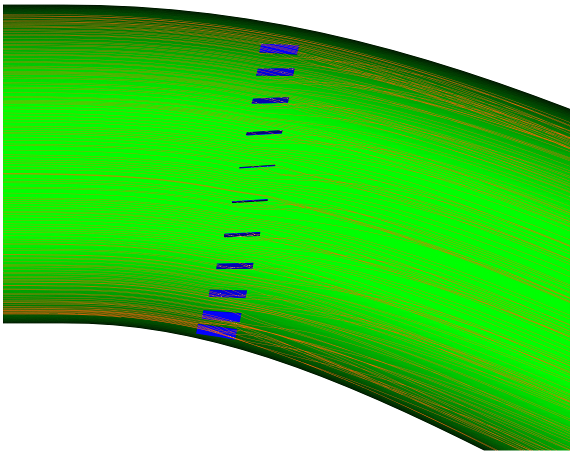


(a) **Surface of RAE M2129 S-duct**

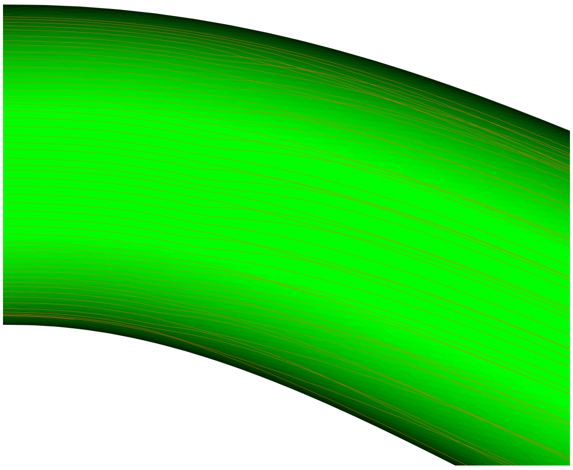


(b) **Detail of surface showing vortex generators**

Figure 4. **Geometry of RAE M2129 S-duct with vortex generators; configuration VG165**



(a) **Fully gridded vortex generators**



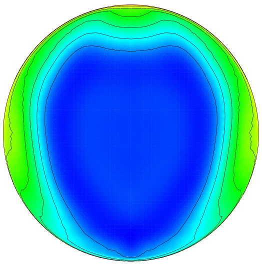
(b) ***jBAY* VG model**

Figure 5. **Streamlines of flow through RAE M2129 S-duct**

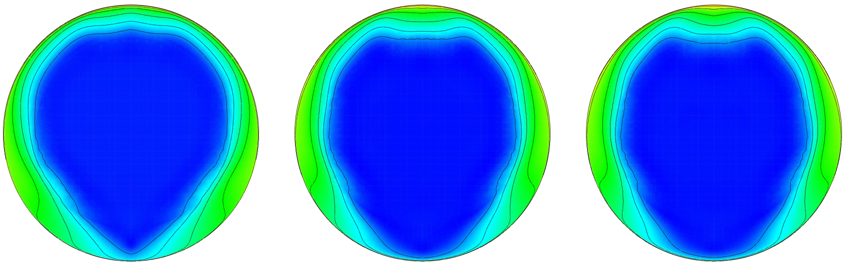
The results of the computational analysis RAE M2129 S-duct with VG165 vortex generator configuration defined in the table 2 and for flow at Mach number $M = 0.66$ and Reynolds number $Re = 0.39 \times 10^6$ are shown in figure 6 which depicts pressure recovery contours in the *AIP*. The result of flow with fully gridded vortex generators is in figure 6(a) and with vortex generator model for different model constant C_{VG} in figures 6(b) to 6(g). The pressure recovery in $60°$ sector and DC_{60} index versus radial angle of the sector in the *AIP* plane is shown on figure 7, where the pressure recovery and DC_{60} index are evaluated from all points in the *AIP* plane and their definition is in[2, 15]. Both figures show that the model is independent of the value of the model constant provided that its value is greater than or equal to $C_{VG} \geq 7$. Even the results obtained with a model with constant $C_{VG} = 5$ are still within reasonable accuracy and predict well the tendency of the distortion index. Values of distortion index DC_{60} in the ”worst” sector for the different model constants and their comparison to the DC_{60} from the fully gridded solution are given in table 1

Designation	DC_{60}	difference in $[\%]$
Fully gridded	**0.196**	**-**
C_{VG}=2	0.110	-44.88
C_{VG}=5	0.173	-11.73
C_{VG}=7	0.182	-7.14
C_{VG}=9	0.187	-4.59
C_{VG}=10	0.188	-4.08
C_{VG}=12	0.191	-2.55

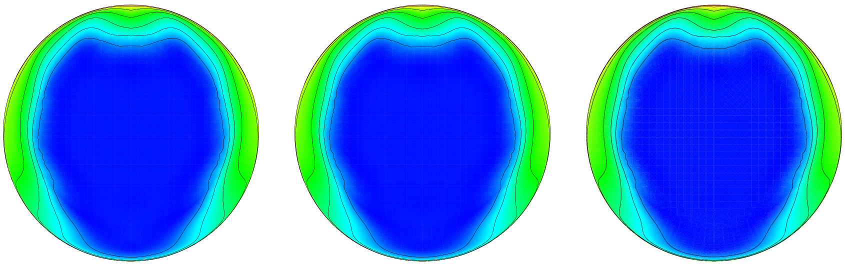
Table 1. DC_{60} **for different** C_{VG} **constants in the *AIP* plane in flow through RAE M2129 S-duct**



(a) **Fully gridded vortex generators**

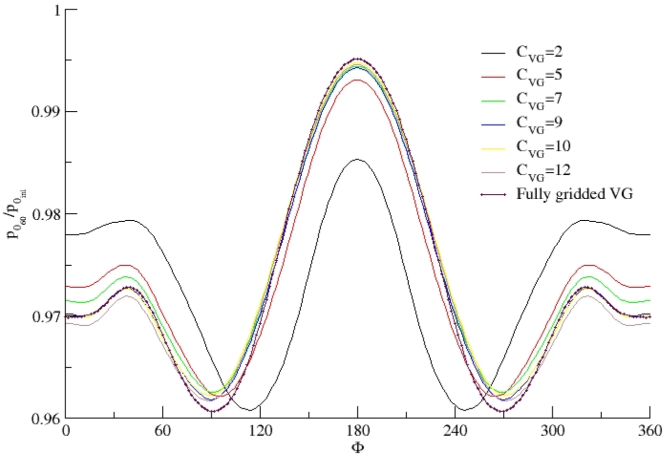


(b) $C_{VG} = 2$ (c) $C_{VG} = 5$ (d) $C_{VG} = 7$

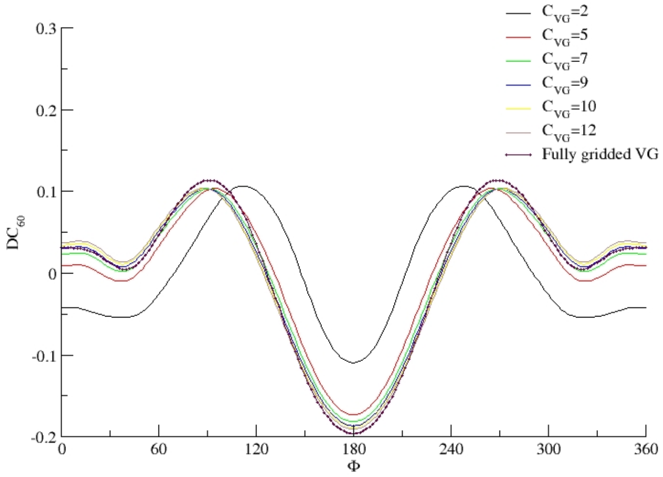


(e) $C_{VG} = 9$ (f) $C_{VG} = 10$ (g) $C_{VG} = 12$

Figure 6. **Total pressure in the *AIP* plane in flow through RAE 2129 S-duct, , VG165 configuration, different model constants in *jBAY* vortex generator model compared to the fully gridded vortex generators solution,** $M_\infty = 0.66$**,** $Re = 0.39 \times 10^6$



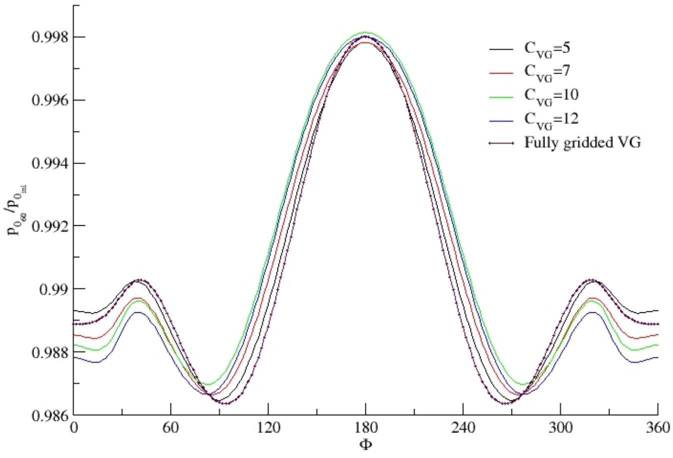
(a) **Pressure recovery**



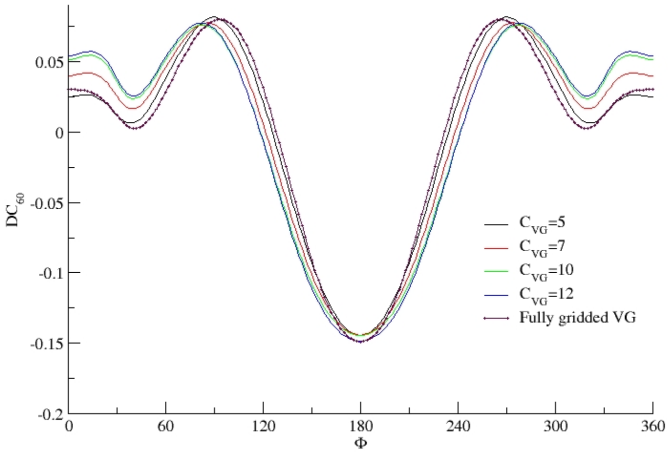
(b) DC_{60} **index**

Figure 7. **Pressure recovery and pressure distortion in the *AIP* plane in flow through RAE M2129 S-duct,** $M_\infty = 0.66$**,** $Re = 0.39 \times 10^6$

The second case the same vortex generator installation was also studied for a flow at Mach number $M = 0.4$ and Reynolds number $Re = 0.53 \times 10^6$. As in the previous case, results for model constant $C_{VG} \geq 5$ are similar and close to the experimental results. A model constant of $C_{VG} = 10$ was chosen for all other tests.



(a) **Pressure recovery**



(b) DC_{60} **index**

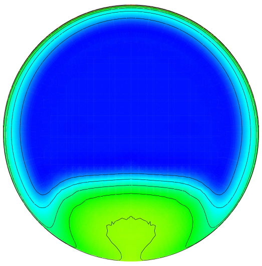
Figure 8. **Pressure recovery and pressure distortion in the *AIP* plane in flow through RAE M2129 S-duct,** $M_\infty = 0.4$**,** $Re = 0.53 \times 10^6$

Calculations were also carried out for the four different vortex generator installations as defined in Anderson[5] with the definition of geometrical characteristics given in table 2. All four vortex generator installations

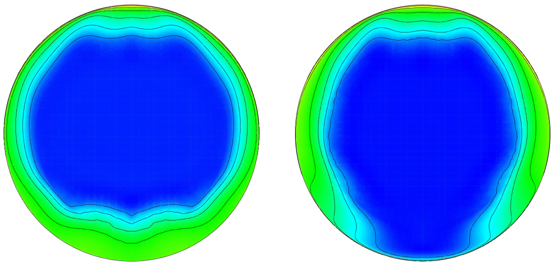
Designation	**VG130**	**VG160**	**VG165**	**VG170**
Number of VG pairs	11	13	11	11
Section location , x/R_i	3	1	1	2
Blade height, h/R_i	0.075	0.060	0.065	0.070
Chord length c/R_i	0.300	0.240	0.260	0.280
Spacing angle, α_{vg} [°]	15	12.6	15	15
Angle of incidence, β_{vg} [°]	16	16	16	16
Sector angle Θ_{vg} [°]	157.5	157.5	157.5	157.5

Table 2. **Geometrical features of different vortex generators configuration**

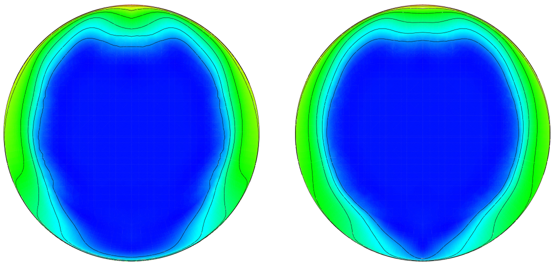
were simulated with the *jBAY* vortex generator model and with the same value of model constant $C_{VG} = 10$ and on the same grid. The pressure recovery on *AIP* plane along with smooth (baseline) configuration without vortex generators are shown in figure 9 and pressure recovery with pressure distortion in figure 10. The reduction of separation is clearly visible. The first installation VG130 is located downstream of the separation ie. part of the vortex generator row lies inside the flow separation region, which limits its effectiveness. However, even for this installation, the reduction of total pressure loss is still noticeable - figure 9(b). Other three configurations show in figures 9(c), 9(d) and 9(e) reduce separation completely.



(a) **Baseline**

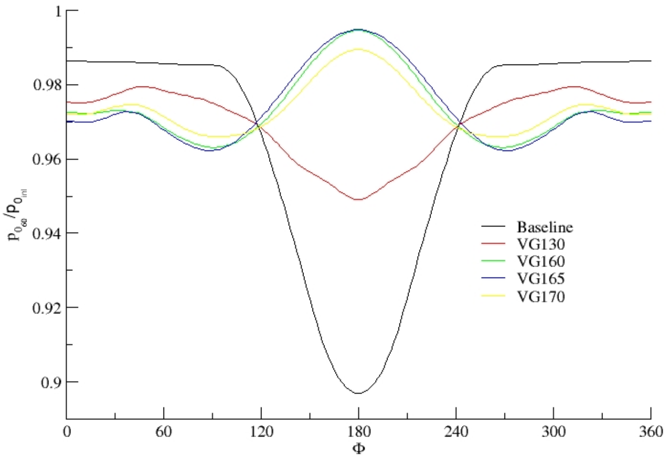


(b) **VG130 configuration** (c) **VG160 configuration**

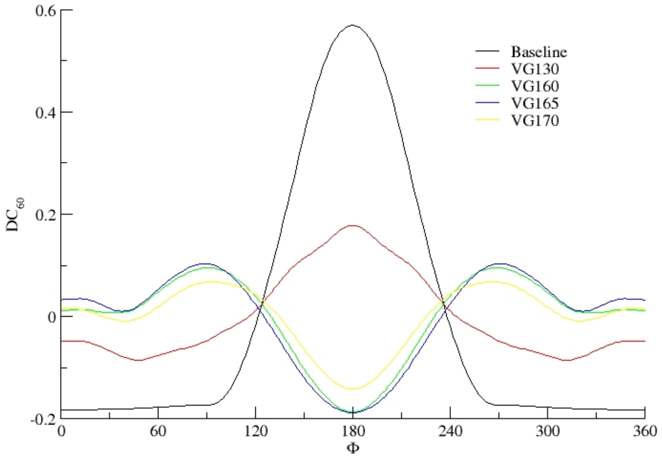


(d) **VG165 configuration** (e) **VG170 configuration**

Figure 9. **Total pressure in the *AIP* plane in flow through RAE M2129 S-duct, four different VG configurations, solution with *jBAY* vortex generator model,** $M_\infty = 0.66$**,** $Re = 0.39 \times 10^6$



(a) **Pressure recovery**



(b) DC_{60} **index**

Figure 10. **Pressure recovery and pressure distortion in the *AIP* plane in flow through RAE M2129 S-duct, solution with *jBAY* vortex generator model,** $M_\infty = 0.66$**,** $Re = 0.56 \times 10^6$

Conclusion

A modified vortex generator model *jBAY* was developed and implemented into the Edge code. The proposed *jBAY* vortex generator model enables one to solve each vortex generator separately, is independent of vortex generator model constant C_{VG}, can model the vortex generators with different shapes and curvature and is completely grid independent. It does not require too much user input and does not have any limitations concerning the number of vortex generators. The only existing limitation is that the model does not take into account the thickness of the vortex generator. However for many applications this is not a problem since most vortex generators are very thin flat plates. The model is user friendly due to the fact that it does not require complicated user input, it needs only the local cross system ($\vec{n}$, $\vec{t}$, $\vec{b}$ vectors) defining the vortex generator and the plan-parallel area S_{VG} and should be independent of the model constant. It is simple and does not require a great deal of effort to be implemented into existing codes.

The model has been tested on different cases: a flat plate case with a single vortex generator and the RAE M2129 S-duct test case with different vortex generator installations and results with the vortex generator model were compared to the fully-gridded analysis. The tests were aimed at answering two key questions: firstly to what extent the accuracy of the vortex generator model depends on the grid and how much is the vortex generator model accuracy dependent on model constant. Grid sensitivity was tested during the flat plate calculations on three different grids and it was found that sufficient grid density must be kept in order to keep the vortex ”alive” - in fact this is not a requirement of the vortex generator model but a requirement of the flow which needs sufficient grid density in order to resolve vortices which are present in the flow-field. The second question was answered during the RAE M2129 S-duct calculations where the final finding was that if the model constant is higher than $C_{VG} = 5$ then the model is insensitive to this value. In all cases a value of $C_{VG} = 10$ was chosen as universal model constant.

Current development of the *jBAY* model aims to improve modelling of the vortex generators with finite thickness and development of viscous corrections.

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References

[1] Advisory Group for Aerospace Research & Development: *Air Intakes for High Speed Vehicles*, AGARD Advisory Report 270, Fluid Dynamics Panel Working Group 13, AGARD-AR-270, 1991

[2] Aerospace Recommended Practise: *Gas Turbine Engine Inlet Distortion Guidlines*, ARP 1420, Society of Automotive Engineers, Inc., 1991

[3] Allan B. G., Yao C. S., Lin J. C.: *Numerical Simulation of Vortex Generator Vanes and Jets on a Flat Plate*, AIAA Paper 2002-3160, June 2002

[4] Anderson B. H., Reddy D. R., Kapoor K.: *A Comparative Study of Full Navier-Stokes and Reduced Navier-Stokes Analyses for Separating Flows Within a Diffusing Inlet S-duct*, AIAA Paper 93-2154, June 1993

[5] Anderson B. H., Gibb J.: *Vortex Generator Installation Studies on Steady State and Dynamic Distortion*, AIAA Paper 96-3279, 32nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Lake Buena Vista, FL, July 1-3, 1996

[6] Anderson B. H., Yagle P. J., Miller D. N., Traux P. P.: *A Study of MEMES Flow Control for the Management of Engine Distortion in Compact Inlet Systems*, FEDSM99-6920, 3rd ASME/JSME Joint FLuids Engineering Conference, San Francisco, CA, 18-23 July, 1999

[7] Bender E. E., Anderson B. H., Yagle P. J.: *Vortex Generator Modelling for Navier-Stokes Codes*, FEDSM 99-6919, 3rd ASME/JSME Joint Fluids Engineering Conference, July 18-23, 1999, San Francisco, California

[8] Bragg M. B., Gregorek G. M.: *Experimental Study of Airfoil Performance with Vortex Generators*, Journal of Aircraft, Vol 24, No. 5, pp. 305-309, 1987

[9] Bray T. P.: *A Parametric Study of Vane and Air-Jet Vortex Generators*, Engineering Doctorate thesis, Cranfield univeristy, 1998

[10] Eliasson P.: *EDGE, a Navier-Stokes solver for unstructured grids*, Proc. to Finite Volumes for Complex Applications III, ISBN 1 9039 9634 1, pp. 527-534., 2002 (also www.edge.foi.se)

[11] Lin J. C., Robinson S. K., McGhee R. J., Valerezo W. O.: *Separation Control on High-Lift Airfoils via Micro-Vortex Generators*, Journal of Aircraft , Vol 31, No. 6, pp. 1317-1323, November-December 1994,

[12] Lin J. C.: *Control of Turbulent Boundary-Layer Separation using Micro-Vortex Generators*, AIAA Paper 98-3404, 1998

[13] Kunik W. G.: *Applicationof a Computational Model for Vortex Generators in Subsonic Internal Flows*, AIAA Paper 86-1458, June 1986

[14] May, N. E.: *A New Vortex Generator Model for Use in Complex Configuration CFD Solvers*, AIAA Paper 01-31014, 19th Applied Aerodynamic Conference, Anehaim CA, 11-14 June, 2001

[15] Seddon J., Goldsmith E. L.: *Intake Aerodynamics, Second edition,* AIAA Education Series, American Institute of Aeronautics and Astronautics, Inc., Reston, Virginia, 1999

[16] Waithe K. A.,: *Source Term Model for an Array of Vortex Generator Vanes*, NASA/CR-2003-212157, NASA, March 2003

[17] Wallin S., Johansson A.: *A Complete Explicit Algebraic Reynolds Stress Model for Incompressible and Compressible Turbulent Flows*, Journal of Fluid Mechanics, Vol. 403, pp. 89-132, 2000

[18] Wendt B. J.: *Initial Circulation and Peak Vorticity Behavior of Vortices Shed From Airfoil Vortex Generators,* NASA/CR-2001-211144, 2001

[19] Yao C-S, Lin J. C. A.: *Flow-Field Measurement of Device-Induced Embedded Streamwise Vortex on a Flat Plate*, AIAA Paper 2002-3162, 1st AIAA Flow Control Conference, St. Loius, MO, 24-27 June, 2002

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Report title
A Modified Vortex Generator Model and its Application to Complex Aerodynamic Flows

Abstract

This report describes the development and verification of a vortex generator model for the FOI CFD code Edge. The proposed vortex generator model removes the need to physically mesh the vortex generator. Instead the appropriate lift force normal to the local flow direction is added to the system of Navier-Stokes equations. The source term is based on an existing model in which the local force in the source term is dependent on local flow quantities and vortex generator characteristics. Several main issues were kept in focus during the development of the vortex generator model; the model must be able to treat many vortex generators as accurately as possible; the model should not contain a large number of unknowns which must be supplied by the user; the model should, to a certain extent, be grid and model constant independent and last but not least, the model must be user friendly. The proposed vortex generator model was implemented and tested for flow over a flat plate with single a sub-boundary layer vortex generator and for the RAE M2129 S-duct with four different vortex generator installations. The vortex generator model is easy to use, does not require a great deal of user input and is able to treat different types of vortex generators.

Keywords
Vortex generator, *jBAY* vortex generator model, S-duct, CFD, Edge

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Rapporttitel

En modifierad virvelgeneratormodell och dess tillämpningar inom komplex aerodynamisk strömning

Sammanfattning

Den här rapporten beskriver utvecklingen och verifieringen av en virvelgeneratormodell för den på FOI utvecklade CFD-lösaren Edge. Den föreslagna virvelgeneratormodellen avlägsnar behovet av att generera nät runt virvelgeneratorn. I stället är en lyftkraft, vinkelrät mot den lokala strömningsriktningen, adderad till Navier-Stokes ekvationer. Källtermen är baserad på en tidigare modell där den lokala kraften i källtermen är beroende på de lokala strömningsstorheterna och karakteristiken hos virvelgeneratorn. Under utvecklingen av virvelgeneratormodellen hölls fokus på flera viktiga aspekter: modellen måste kunna hantera många virvelgeneratorer så noggrant som möjligt, modellen skall inte innehålla ett stort antal okända parametrar som måste tillhandahållas av användaren, modellen skall till en viss utsträckning vara nät och modellkonstantsoberoende och sist men inte minst måste modellen vara användarvänlig. Den föreslagna virvelgeneratormodellen är implementerad och testad för strömning över en plan platta med en ensam virvelgenerator i subgränsskiktet och för S-kanalen RAE M2129 med fyra olika virvelgeneratorinstallationer. Virvelgeneratormodellen är enkel att använda, kräver inte mycket användarinput och kan hantera olika typer av virvelgeneratorer.

Nyckelord

Virvelgenerator, *jBAY* virvelgeneratormodell, S-kanal, CFD, Edge

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