# INVESTIGATION OF BOUNDARY CONDITIONS FOR THE SIMULATION OF SUCTION BY HBRID LAMINAR FLOW

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**Abstract**

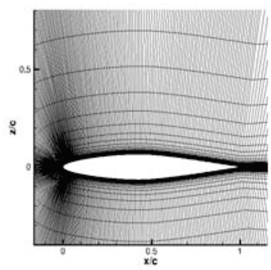
The aim is the numerical investigation of boundary conditions for suction through porous surfaces for hybrid laminar flow at the leading edge of an infinite sweep wing. Four different boundary conditions are tested. By boundary condition 1 (BC1) and BC2 the velocities at the boundary condition are set and the difference between this two boundary condition is the setting of the pressure. By BC3 and BC4 the suction velocity is set by the pressure at the boundary condition and the pressure is as long as iterated until the target mass flux is reached. In BC4 the tangential velocity is set to zero in contrast to BC3. Only the simulation with BC2 gives good results of suction in comparison to experimental data.

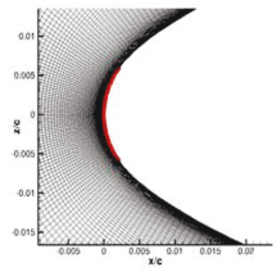
## 1. INTRODUCTION

In the project VERSUS the hybrid laminar flow with suction through a porous leading edge of a vertical tail plane (VTP) is investigated with windtunnel tests and numerical analysis with computational fluid dynamics (CFD). The leading edge sweep angle of the VTP is $\varphi$=40° and so it is important to check the laminar flow to attachment line transition as a transition mechanism. Because of the sweep angle of the leading a boundary layer develops at the attachment line along this line and this boundary layer can change from laminar flow to turbulent flow. The criterion for attachment line transition is $Re_\theta$>100 according to Pfenninger [1]. $Re_\theta$ is the Reynoldsnumber, calculated with the momentum thickness. To calculate $Re_\theta$ in CFD a boundary condition for suction through a porous surface is needed. In the DLR Tau Code boundary conditions for suction in the frame of flow control is implemented. For simulation of flow control the geometry of the actuator is most resolved, but for porous surface this is impossible because of the number of holes. This boundary conditions are used and modified for the simulation of suction through a porous surface. The aim of this work is the selection of a boundary condition, which can calculate the influence of suction to $Re_\theta$. To reduce the numerical effort the assumption of an infinite sweepted wing is used and so a two dimensional airfoil is adequate to investigate the different suction boundary conditions at the attachment line.

## 2. TESTCASE

As test case a cut normal to the leading edge of the VTP at dimensionless spanwise position of $\eta$=0,55 is selected. The airfoil is shown in PICTURE 1 and the suction boundary condition is set up to x/c=0,002. The suction boundary condition is only near the leading edge, because the aim is to investigate the influence of suction to $Re_\theta$ at the leading edge and so a small suction plane is sufficient. Only an airfoil is selected for this investigation, because only the influence of the suction boundary to $Re_\theta$ should be calculated and it is possible on a two dimensional airfoil. So the numerical effort is reduced. To consider the sweep angle of the leading edge the airfoil is staggered with one cell in the spanwise direction, periodic boundary conditions are set in spanwise direction and the yaw angle of the incoming flow is set to 40°. In the structured grid 160 points in wall normal direction are used and 128 points are near the wall to resolve the boundary layer fine enough for calculation of displacement thickness. The transition of laminar flow to turbulent flow is set at x/c=0.05, because laminar flow is only needed in the region of the leading edge. The freestream velocity is $U_\infty$ =105m/s.





PICTURE 1. Grid of the airfoil with 88000 cells and on the left side the leading edge with the red marked suction panel is shown.

## 3. NUMERIC

In this investigation the DLR TAU code [2] is used and the Tau Code is an unstructured finite volume code, which solves the Reynolds averaged Navier Stokes equations. The code can use hybrid or hexaeder grids. The fluxes are discretisiezed by central differences with artifical dissipation. The temporal discretization is carried out with an implicit Lower-Upper Symmetric Gauss-Seidel (LU-SGS) scheme. As turbulence model the Spalart Allmaras model is used.

The boundary conditions in TAU for suction are originally implemented for flow control cases [3]. In the simulation of flow control a part of the actuator is mostly resolved in the grid, but for the simulation of a porous surface this is impossible because of the number of holes. This boundary conditions are used and modified for the investigation of suction through a porous surface in the case of hybrid laminar flow. Four boundary conditions are tested:

- BC1: Set velocity and pressure at the boundary
- BC2: Set velocity and the pressure at the boundary is extrapolated from the inner field
- BC3: Calculate the target mass flux from the given suction velocity. The pressure at the boundary is changed pointwise, until the target mass flux is reached.
- BC4: The same procedure as in BC3. The tangential velocity at the boundary is set to zero.

Two kinds of boundary conditions are implemented. By BC1 and BC2 the velocity is set on the boundary marker. The tangential velocity is set to $u_t = 0$ and the normal velocity to $u_n = \vec{n} \cdot w$, with $\vec{n}$ as normal vector and w as suction velocity. In BC1 the pressure is set to the pressure of the freestream and for BC2 the pressure is extrapolated from the field to the boundary.

For BC3 and BC4 the massflux through the marker is calculated For BC3 and BC4 the massflux through the boundary is calculated as:

$$\dot{m} = \rho \cdot u_n \cdot A$$

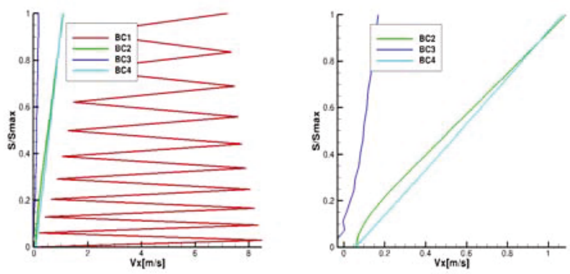
and the pressure on the marker is changed until the correct massflux is reached:

$$p_{new} = (1-\alpha) p_{old} + \alpha \frac{\dot{m}_{act}}{\dot{m}_{tar}} p_{old}$$

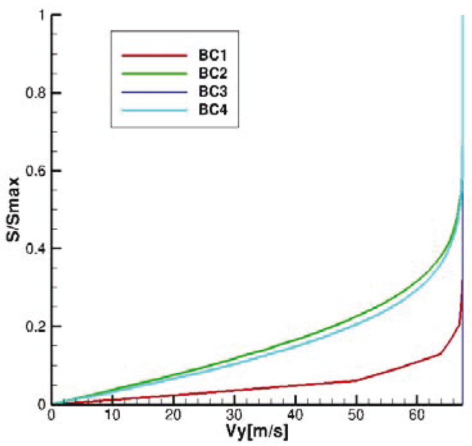
$\alpha$ is a relaxations factor, which is varies in the calculations from $10^{-6}$ to 0,0001, $\dot{m}_{act}$ is the actual mass flux through the boundary condition and $\dot{m}_{tar}$ is the target mass flux. The target mass flux is calculated through the given suction velocity. At the boundary the velocity is calculated pointwise through a similar formula like the pressure and the update of the velocity through the fluxes. In BC3 is $u_t \neq 0$, because the calculation of the velocities of the has no influence of the tangential velocity and no boundary layer profile exists for the tangential velocity in the region of the suction panel. In BC4 the original boundary condition is modified so that the tangential velocity is set to zero.

## 4. RESULTS

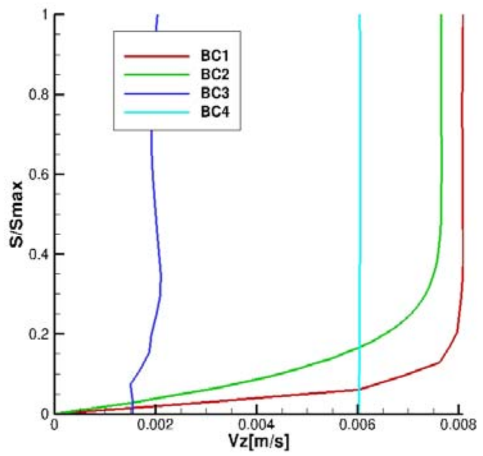
To test the influence of the four boundary conditions to the $Re_\theta$ at the attachment line three suction velocities are chosen: W=0.06195m/s, W=0.1239m/s, and w=0.2478 m/s. In pictures PICTURE 2 to PICTURE 4 the velocity profiles in x-, y- and z-direction is shown at x=y=z=0 for each boundary condition. For BC1 the $U_x$ velocity profile is noisy, because the boundary condition is over determined. For BC2 all the velocity profiles are quite good. For BC3 there is no boundary layer profile in the y-component, because the tangential velocity is not set to zero at the boundary layer and so the y-velocity is untouched and is $U_y = U_\infty \cdot \sin\varphi$. For BC4 the velocity profiles looks good and the boundary layer thickness is smaller than for BC2. For BC2 and BC4 $U_x$ at the wall is the suction velocity, because the velocity profiles are shown at the leading edge. $U_x$ is positive, because the suction is in the x direction at this position. In $U_z$ there is a difference between the two kinds of boundary approach. BC1 and BC2 show a boundary layer profile and BC3 and BC4 not, because for BC3 and BC4 $U_z$ is not direct set through the boundary condition. Because of the bad representation of a typical boundary layer profile BC1 and BC3 are not further investigated.




PICTURE 2. Velocity $U_x$ at x=y=z=0 normal to the wall. On the left sight all four boundary conditions, on the right sight without BC1

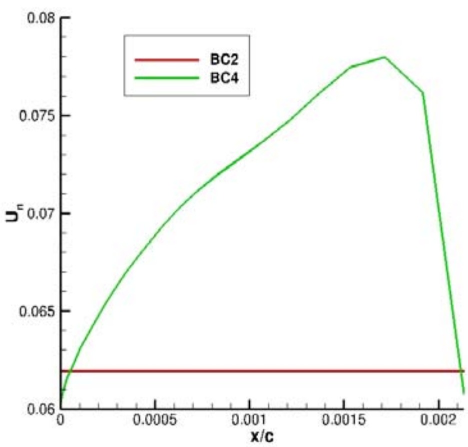



PICTURE 3. Velocity $U_y$ at x=y=z=0 in spanwise direction



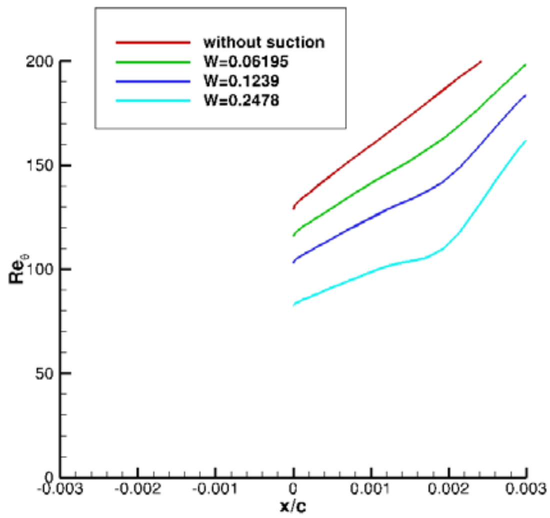

PICTURE 4. Velocity $U_z$ at x=y=z=0 tangential to the wall

The calculated suction velocity normal to the surface is compared with the given suction velocity W=0.06195m/s in PICTURE 5 for BC2 and BC4. For BC2 the calculated suction velocity is equal the target suction velocity. This was expected, because the target velocity is set directly on the boundary. For BC4 the suction velocity is not constant over the boundary marker, because the pressure is set on the boundary and the modification of the pressure is stopped when the target massflux is reached. The suction velocity is mostly greater than the constant suction velocity of BC2 and this higher suction velocity is the reason for the thinner boundary layer by BC4 in PICTURE 3.

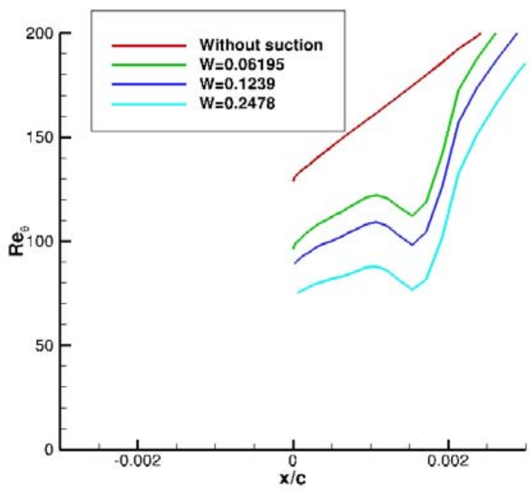



PICTURE 5. Calculated normal velocity in the suction panel for BC2 and BC4 by a given suction velocity of W=0.06195m/s

In PICTURE 6 and PICTURE 7 the reduction of $Re_\theta$ at the leading edge is shown for the three suction velocities for two boundary conditions BC2 and BC4 and for comparison with $Re_\theta$ of a simulation without suction. As expected the suction reduces $Re_\theta$ at the attachment line and increasing the suction velocity reduces $Re_\theta$. In PICTURE 6 the $Re_\theta$ is shown for BC2 and in PICTURE 7 for BC4. For the flow with out a suction velocity $Re_\theta$ at the attachment line is greater than 100 and so the flow would be turbulent because of attachment line transition. For BC2 the flow would be laminar for a suction velocity greater than W=0.1239m/s. For BC4 the flow would be laminar for all three calculated suction velocity. In PICTURE 7 $Re_\theta$ has a dip at x/c=0.0015 for all suction velocities, because the suction velocity has in this region his maximum, as shown in PICTURE 5.

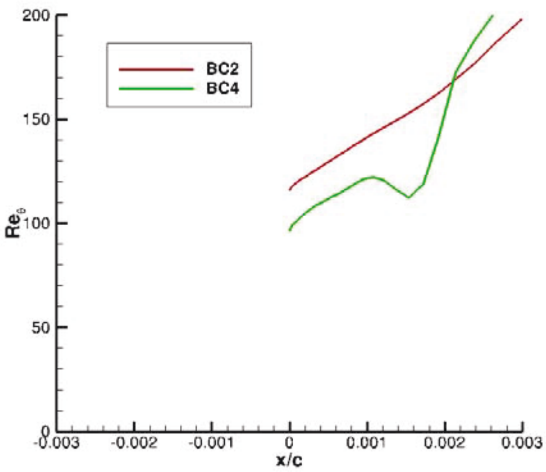



PICTURE 6. Influence of suction velocity W on $Re_\theta$ for BC2




PICTURE 7. Influence of suction velocity w on $Re_\theta$ for BC4

Because of the differences in suction velocity at the boundary and so the differences in boundary layer profiles in calculations with BC2 or BC4 the $Re_\theta$ distribution over the x coordinate is different for both boundary conditions as seen in PICTURE 8. The $Re_\theta$ distribution for BC4 is in the region of the suction boundary lower than for the simulation with BC2, because BC4 has a lower boundary thickness and momentum thickness as BC2 as shown in PICTURE 3. The difference in $Re_\theta$ at the leading edge is 17 percent. This difference can produce by a simulation with transition prediction difference in the transition position and in the transition mechanism.




PICTURE 8. Differences between BC2 and BC4 in $Re_\theta$ over x/c for W=0.06195m/s suction velocity

In a first step the boundary layer profiles and the calculated $Re_\theta$ is checked for plausibility. In a second step the results are compared with experimental results von Pfenninger [1] and Arnal [4]. Both made experiments in wind tunnels. By Pfenninger the flow conditions are Re=5 million and a leading edge sweep angle of $\varphi$=45°, by Arnal the flow conditions are a freestream velocity of $U_\infty$=10-56m/s and the leading edge sweep angle of $\varphi$=40° or $\varphi$=50°. In the experiments the dimensionless parameter for suction velocity is:

$$K = \frac{W}{V_e}\overline{\mathrm{Re}}$$

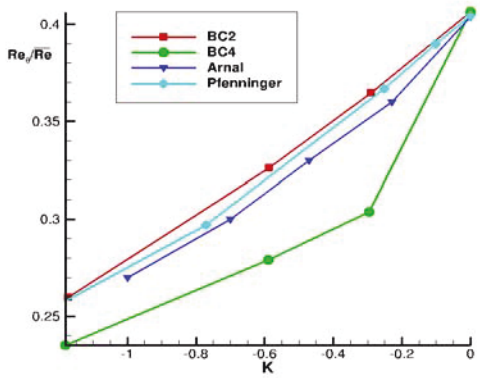
with W as suction velocity, $V_e = U_y = U_\infty \cdot \sin\varphi$ as edge velocity of boundary layer tangential to leading edge and the Reynoldsnumber

$$\overline{\mathrm{Re}} = \sqrt{\frac{V_e^{\,2}}{\nu_e \frac{\partial U_e}{\partial s}}}$$

with $\nu_e$ as viscosity and $\frac{\partial U_e}{\partial s}$ as variation of $U_e$ in streamwise direction. Per definition the parameter K is negative for suction and positive for blowing. The Reynoldsnumber $\overline{\mathrm{Re}}$ depends only on the value of the boundary layer edge and this values are not influenced by the small used suction velocity. For a flow around a swept cylinder infinite span as model for the leading edge of an airfoil infinite span the $\overline{\mathrm{Re}}$ can be written as [4], [5]:

$$\overline{\mathrm{Re}} = \sqrt{\frac{U_\infty r \sin\varphi \tan\varphi}{2\nu}}$$

with r as radius of the leading edge. $\overline{\mathrm{Re}}$ depends only on geometric parameter not on boundary layer parameter. In PICTURE 9 the ratio of $\frac{\mathrm{Re}_\vartheta}{\overline{\mathrm{Re}}}$ is shown over K for experimental data and results of BC2 and BC4. The results of BC2 have a good congruence with the experiments. The results from BC4 show lower values of $\frac{\mathrm{Re}_\vartheta}{\overline{\mathrm{Re}}}$ and the gradient has not so good congruence with the experiments as the gradient from BC2. For both simulation with the different boundary conditions $\overline{\mathrm{Re}}$ is similar and the differences in the ratio $\frac{\mathrm{Re}_\vartheta}{\overline{\mathrm{Re}}}$ depends only in the differences in the momentum thickness $\theta$. So the $Re_\theta$ values of the simulation with BC2 have a better congruence with the experiments than the values from BC4. With BC2 it is possible to calculate the influence of the suction velocity to $Re_\theta$ correct.




PICTURE 9. Comparsion of numerical results with Experiments from Arnal and Pfenninger

## 5. CONCLUSION

Four Boundary conditions are tested for suction at an airfoil. Two boundary conditions, BC1 and BC3, produce unphysical boundary layer profiles. The other boundary conditions, BC2 and BC4, produce physical boundary layer profiles. But only BC2 gives good results in comparison to experimental data.

## 6. LITERATURE

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