SIMULATION OF PRESSURE LOSSES FOR THE DESIGN OF TAILORED SUCTION DISTRIBUTIONS FOR LAMINAR FLOW CONTROL

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INTRODUCTION

For the reduction of drag by means of laminar flow control wall normal suction is utilized to stabilize a laminar boundary layer and, thus, remain laminarity [3, 5]. The suction is typically realized by a micro-perforated skin and some low-pressure plenum underneath the aerodynamic surface. Since the wing features a pressure distribution, also the suction distribution needs to be tailored.

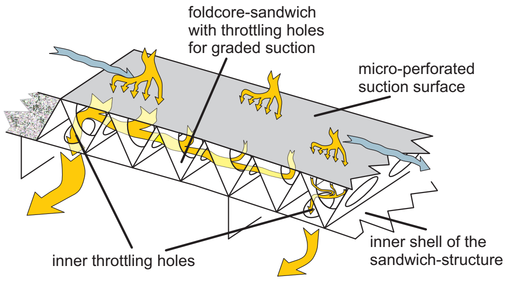

Figure 1: Sketch of the suction system with the foldcore sandwich used to generate a desired suction distribution, [1, 2].

Tailoring can be done by realizing a number of individual plenums. An idea for a smart suction surface consisting of a fully embedded possibility to create a desired suction distribution was proposed for low speed aircraft, e.g. sailplanes, [1, 2], but the system is applicable to other suction problems, too. It consists of a micro-perforated skin, which connects the outer aerodynamic surface with a foldcore structure [4]. Holes in the foldcore allow the air to flow in chordwise direction. One cell of the foldcore structure (the last cell in a row) is connected to a plenum via an inner throttling hole. The smart aspect about such system is that a desired suction distribution can be realized by sizing the holes in the foldcore. Due to the channel-type geometry foldcore and skin might be cleaned from dust and pollen.

The design of the system (for one specific design point, i.e. pressure distribution, BL data, Re, etc.) requires precise knowledge about the pressure losses in the foldcore, since these losses actually generate the suction distribution. Currently data derived by experimental means is used, where the pressure loss is measured with samples of the foldcore. The data is then used to configure a specific hole distribution in a final foldcore. As will be shown, the samples are not necessarily fully representative for the losses in the final foldcore. Therefore it is interesting to be able to estimate the pressure loss with high accuracy.

This contribution focuses on the estimation of losses by numerical simulations. Experimental validation data exists from the samples, but for the sake of conciseness the experimental method will not be covered herein. The objective is to find sensitivities for the final foldcore design. Geometrical changes (misalignment, imperfect rim shapes, foldcores with constant and increasing hole size) were simulated, each for a number of mass flow rates and hole diameters.

NUMERICAL METHOD

The incompressible Navier-Stokes equations were solved using the open source CFD toolbox OpenFOAM 2.1 with the simpleFoam solver. All Reynolds-Stresses are zero (i.e. a "laminar" computation)–this is justified by measurements with a microphone, where the flow appeared to be laminar for $Re_d < 3000$. The flow converges to a steady-state within approximately 2000 iterations.

The equations are solved on an unstructured grid, which is relatively uniform, featuring almost no clustering of cells. All results herein are based on a mesh with 480'000 cells, which is fully converged w.r.t. mesh density. The domain is 3D and makes use of the symmetry of the foldcore, as shown in fig. 2. The side faces are treated with a symmetry, all walls with a no-slip condition. The walls of the foldcore have a thickness of 0.1 mm, which is actually resolved here, to be able to vary the rim shape.

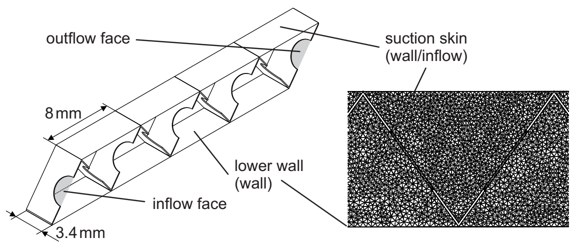

Figure 2: Domain for the simulations, consisting of eight foldcore cells.

The flow is driven by an inflow condition prescribing a constant inflow velocity v_{fc} (parallel to the upper and lower wall) over the inflow face. The outflow is a zero-gradient condition. Eight foldcore cells are resolved. The studies showed that the flow needs five cells to develop into a quasi-self-similar state. Therefore, Δp_s was determined from center of cell 6 to center of cell 7. The pressure within one cell, far away from the holes, is uniform. The pressure loss happens in the hole over a distance of only 20 % of the cell width.

The suction flow itself (i.e. the flow through the micro-perforated surface) was *not* modeled. A comparative study showed that it does not have notable influence on the pressure loss of the foldcore.

RESULTS

The approach was validated by simulating specific foldcore geometries that exist from the samples for the experiments. The geometry was verified by microscopy, modelled and the resulting pressure losses are within 4 % to the experimental values. The values from the simulations are systematically smaller than the experimental ones. Presumably this is due to (i) roughness and (ii) rugged rims, although the holes are laser cut–which effectively cannot be modelled, but will increase the losses.

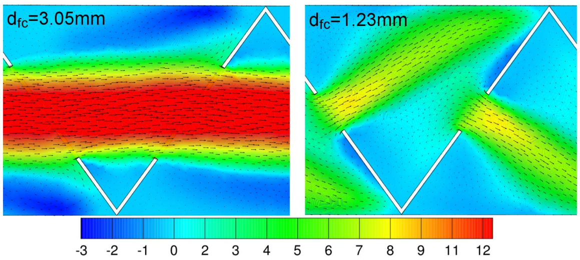

Figure 3: Flowfields for two different hole diameters at $v_{fc} = 8\,m/s$.

Fig.3 shows typical flowfields for large and small hole diameters d_{fc}. While for larger diameter the flow is more parallel to the upper and lower bounds–only slightly bend by the foldcore walls–for the smaller d_{fc} each hole creates a jet-like structure that enters the next cell almost perpendicular to the hole axis. As generally expected (not shown) the pressure loss becomes larger with decreasing d_{fc} and increasing foldcore velocity v_{fc}.

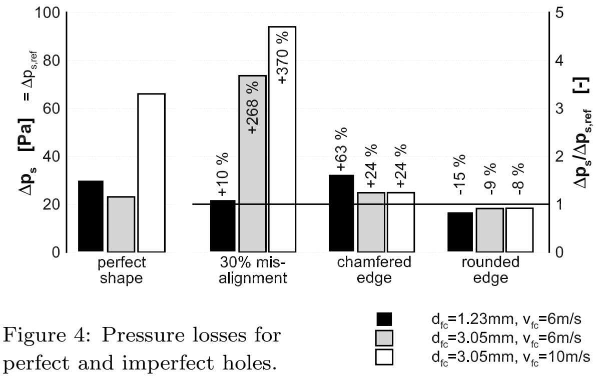

Figure 4: Pressure losses for perfect and imperfect holes.

The data in fig. 3 is an idealized case, where the rims of the holes are sharp and the geometry is fully symmetric. During the manufacturing of the folcdore holes imperfection will occur and it is of high interest to identify the sensitivities, e.g. to define manufacturing accuracy. Two different imperfections were modelled, namely misalignment of the foldcore holes and imperfect rims. Misalignment might happen, because typically (not only for foldcore systems) the holes are manufactured *before* the final structure is built up. Here, 30 % misalignment means that the hole axis' of two adjacent holes are offset by 30 % of the diameter. However, many different misalignments have been simulated (will be presented, but cannot be shown here). Imperfect rims (chamfers or radius') can easily occur, if the holes are punched, etched, etc., or if the material is exposed to adverse conditions.

Fig. 4 shows some results of these comparative simulations. Here, the pressure loss per hole for the perfect shape is in absolute values. The losses of the imperfect shapes are compared relative to the losses of the perfect shape (for the specific d_{fc} and v_{fc}). To summarize the findings: The influence of a misalignment becomes larger for increasing d_{fc}, because for small d_{fc} the sequence of "jets" shown in fig. 3 are not so sensitive to the exact hole position. In contrast, the influence of the rim shape becomes larger for decreasing d_{fc}. With respect to the flow velocity, the influence of misalignment increases progressively with increasing v_{fc}, while the change of pressure loss due to different rim shape is not sensitive to the flow velocity.

In practice, the samples for the measurement of the pressure losses are manufactured with constant hole diameter (since a desired hole distribution is unknown at that stage). The final foldcore however will have varying hole size to generate a desired suction distribution. Fig. 5 shows the difference for two velocities v_{fc}, when the diameter d_{fc} varies along the foldcore. 12 cells have been simulated and the resulting pressure is compared to the values that come from cumulatively adding the pressure loss for individual cells with the specific d_{fc}.

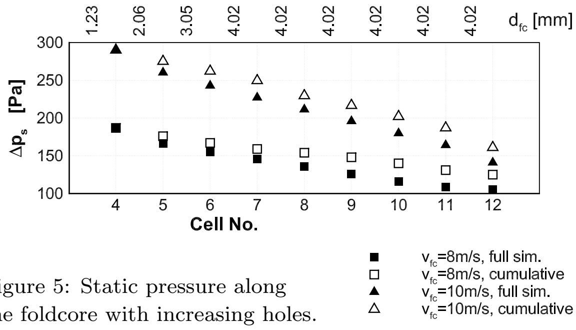

Figure 5: Static pressure along the foldcore with increasing holes.

In this case (increasing d_{fc}), the pressure loss is less. E.g. cell 5 → 6 with $d_{fc} = 3.05$ mm has 30 % less pressure loss, if it follows a smaller hole. In practice the diameter variations are much smaller than in this example and it has to be studied yet if this aspect has to be taken into account for an accurate design.

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