Applications of the continuous adjoint method to car aeroacoustics

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Applications of the adjoint method in the automotive industry have experienced a rapid growth over the last years for the field of Computational Fluid Dynamics (CFD). The majority of these applications involve either the topology optimization of internal flows (e.g. cabin ventilation ducts, engine intake ports) or the shape optimization of external flows (e.g. drag and lift coefficients). However, CFD has been recently considered for a new field of applications, that of aeroacoustics problems. The wind-generated noise perceived by the passengers of a vehicle impacts negatively the comfort levels inside the cabin. Thus, aeroacoustics methods and procedures have been developed in order to make it possible to calculate the noise levels experienced inside the vehicle's cabin and then improve the aeroacoustics performance of the vehicles. The great potential of the adjoint method in gradient-based optimization and the experience gained over the previous years in the automotive sector, has led the efforts to couple the developed aeroacoustics processes with the adjoint method. Such an example, of coupling an aeroacoustics process with the adjoint method is presented here.

I. Introduction

The advancements in the computational power of computers have led in an ever increasing application of Computational Fluid Dynamics (CFD) in the automotive sector for improving the aerodynamic performance of a vehicle and reducing its development cycle. The negative impact of aerodynamic drag in vehicles fuel consumption has been the main driving factor for improved designs. However the next frontier for CFD is focused on passengers comfort; this time with the development of methods, which can predict the flow-induced noise levels. The aeroacoustic noise generated from the external shape of a vehicle has a great effect on the noise levels experienced inside the passengers cabin, thus requiring the development of tools to improve the acoustic performance of a vehicle.

The adjoint method has played an essential role in the shape optimization for external and internal flows and has been established as the method of choice in the automotive industry. However aeroacoustics problems cannot be tackled with a steady state adjoint method since they are inherently unsteady, based on time fluctuations of the flow fields and more importantly expressed in frequency domain. With the recent development and availability of the unsteady adjoint method at Volkswagen's Group Research[1] , aeroacoustics problems can now be addressed.

In this paper, acoustic analogy methods are considered for the prediction of aeroacoustic noise, with an integral method used to form the basis of an optimization loop,[2] . The method is applied on a test case of a simplified geometry with a sharp edge in order to introduce a separation point and broadband noise effects. The flow simulation is based on an incompressible DES approach and an objective function is formed, which quantifies the high frequency noise levels emmitted from a surface and perceived by a microphone. Thereafter, the unsteady adjoint method is applied in order to compute the gradient of the objective with respect to the design variables, which then drives the optimization loop.

All of the developed methods and simulations were implemented and conducted within the OpenFOAM® software package.

II. Aeroacoustic processes and the Kirchhoff Integral Method

There has been a long history of acoustic analogy methods used in conjunction with CFD in order to predict the flow-induced noise generated in different conditions. Amongst them, the Kirchhoff Integral

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(KI), which has been most notably used for the prediction of helicopter noise. Recently, the method has been used to predict the noise generated from the mirror of a moving vehicle, which is then propagated inside the vehicle cabin and perceived by the driver[2] .

On the other hand, the adjoint method has proved to be a robust optimization tool and has been used extensivelly to conduct gradient-based optimization in applications of CFD in the automotive industry[3] . It is therefore promising to combine the experience and knowledge acquired from the optimization of aerodynamics with the adjoint method together with the afformentioned aeroacoustics process chain.

This aeroacoustics process chain consists of 4 major steps:

1. An incompressible DES calculation of the external flow of the vehicle.
2. The acoustic pressure radiated from the mirror on the driver's window is calculated using the KI method.
3. The hydrodynamic and acoustic pressure on the driver's window computed from steps 1 and 2 are combined and provided as an input to compute the structural vibrations of the window.
4. The radiation of noise from the vibrations of the window inside the passanger cabin is calculated for some predefined locations and the noise levels are evaluated at these positions.

Since there had been no prior experience with the adjoint method for steps 3 and 4 (even though the issue has now been addressed, see[4]), a simplified process for the noise generated from the mirror and radiated towards the driver is derived from steps 1 and 2. The unsteady adjoint method for incompressible fluids is then used to tackle the optimization problem defined by this process, as it is presented in this work.

III. Results

A test case is defined and an incompressible DES simulation is used to compute the flow field. Then the KI method is used to compute the acoustic pressure emmited from the geometry towards an array of microphones. The objective function is defined as the sound pressure levels received by the microphones over a range of frequencies. Following that, the unsteady adjoint method is used to compute the flow shape sensitivities, which are then combined with the geometric sensitivities of the KI and are used to perform a morphing step. The objective function is reevaluated for the morphed geometry and a discussion follows comparing the results of the different geometries.

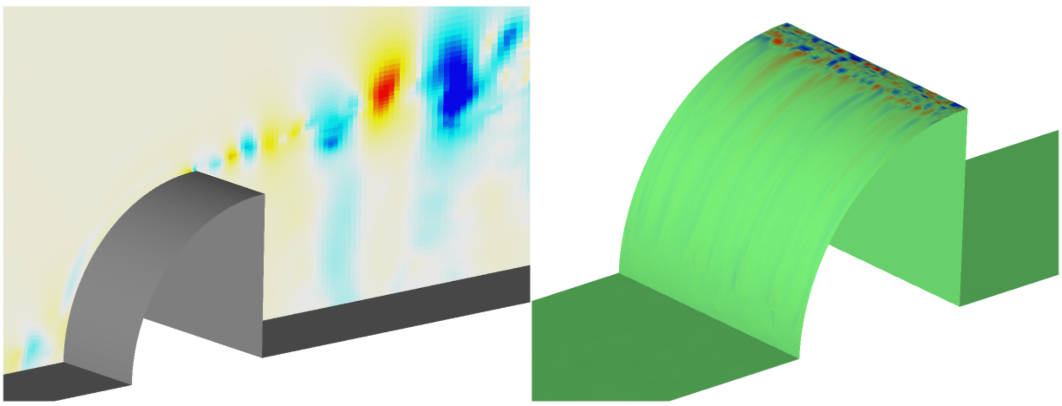

Figure 1. Left: Pressure fluctuations on cutting plane of test case. Right: Shape sensitivities of test geometry.

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