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Imposing Resolved Turbulence by an Actuator in a Detached Eddy Simulation of an Airfoil

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Introduction

Previous work shows, c.f. [1]

- By resolving the freestream turbulence in a Detached Eddy Simulation (DES) of an airfoil the agreement with experimental results is improved
- The cost of resolving the freestream turbulence is an increase in number of cells required to resolve the turbulence as it is convected from the inlet to the airfoil

The purpose of the present work is

- To reduce the computational cost by reducing the required number of cells
- This is done by imposing the freestream turbulence directly upstream of the airfoil by an actuator. This reduces the demand for small cells in the entire upstream domain as only the mean flow has to be resolved by the upstream grid

Method

The forces applied in the cells crossed by the actuator disc are determined from the pressure required to accelerate the flow by Δu, [2]

$$\Delta p = \tfrac{1}{2}\rho((U_\infty+\Delta u)^2 - U_\infty^2) \quad \Rightarrow \quad F_c = \tfrac{1}{2}\rho A_c(U_\infty+\tfrac{1}{2}\Delta u)\Delta u \approx \tfrac{1}{2}\rho A_c U_\infty \Delta u$$

for small values of Δu. ρ is the density of the fluid, U_∞ is the freestream velocity and A_c is the area of the disc crossed by the cell. This can be generalized to include velocity changes in three dimensions

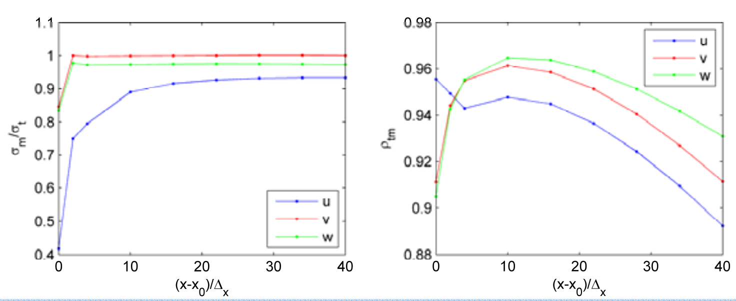
$$\mathbf{F}_c \approx \tfrac{1}{2}\rho A_c U_\infty \Delta\mathbf{u}$$

where **u** and **F** are the three-dimensional velocity and force vectors, respectively. The forces are imposed in the cells using the method described in [3] and [4].

The CFD code EllipSys3D is used.

Validation

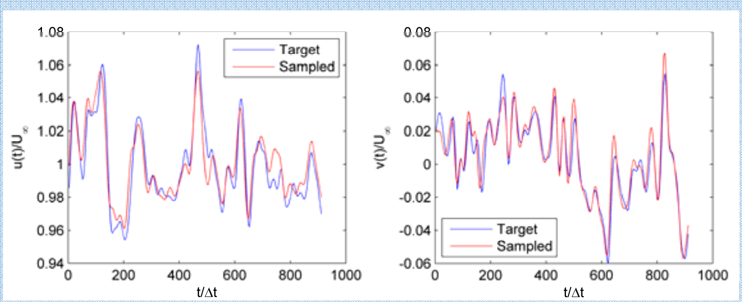
To verify the method a turbulence field from a precursor simulation is imposed in an empty tunnel. In a series of planes downstream of the actuator the field is sampled and compared to the turbulence prescribed at the actuator. Below, the standard deviation and correlation coefficients are plotted.



$(x-x_0)/\Delta_x$ is the streamwise distance from the actuator measured in number of cells, σ_m/σ_t is the ratio of sampled to target standard deviation, and ρ_{tm} is the correlation coefficient between the target and sampled time series. It is seen that

- The full intensity of the u-component is obtained approximately 25 cells downstream of the actuator. It is much faster for the v- and w-components
- The standard deviation of the streamwise component is about 8% too low
- The correlation peaks at 0.95 to 0.97 around 10 cells from the actuator
- The resolved part of the turbulence generated with this method is very similar to the prescribed turbulence field

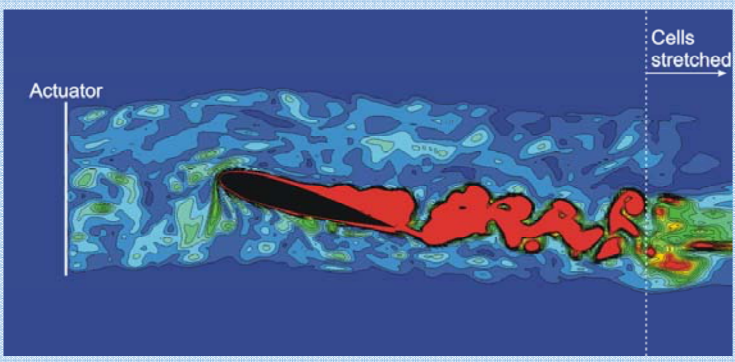
An example of time series is given below



Example

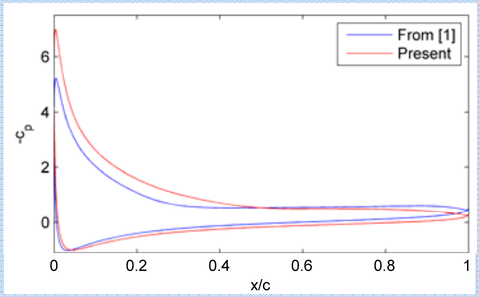
A DES of an airfoil is run with the same numerical setup as in [1]. The airfoil is a NACA 0015 and the Reynolds number is 1.6 million. The angle of attack is 16°.

Below, the contours of instantaneous vorticity close to the airfoil are shown. The resolved turbulence is seen to enclose the airfoil and the wake.



The mesh consists of 6.8 million cells vs. 21 million cells in [1]. The resolution close to the airfoil is the same in both meshes and the sizes of both domains are equal. Further, the same freestream turbulence field is used in both simulations.

Below, the computed surface pressure is compared to the results of [1] where the freestream turbulence was imposed at the inlet boundary.



The results are seen to be quite different. The reason for this is suspected to be different subgrid parts of the freestream turbulence. In [1] the eddy viscosity is in the order of 10 times the molecular. With the present approach a much lower value is obtained. The eddy viscosity builds up slowly in the turbulence field downstream of the actuator, but equilibrium is not reached before it hits the airfoil.

This will be investigated in the future.

Conclusions

From the results it can be concluded that

- The resolved part of the turbulence can successfully be imposed on the computational domain by use of this simple method
- The generated resolved turbulence is highly correlated with the input and for the present purpose the difference is neglible
- By use of an actuator to generate the turbulence it is possible to reduce the number of cells in a DES of an airfoil to about one third
- The subgrid part of the turbulence appears to have a large influence on the surface pressure. This will be investigated in the future.

Acknowledgments

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