URANS and RANS

URANS and RANS

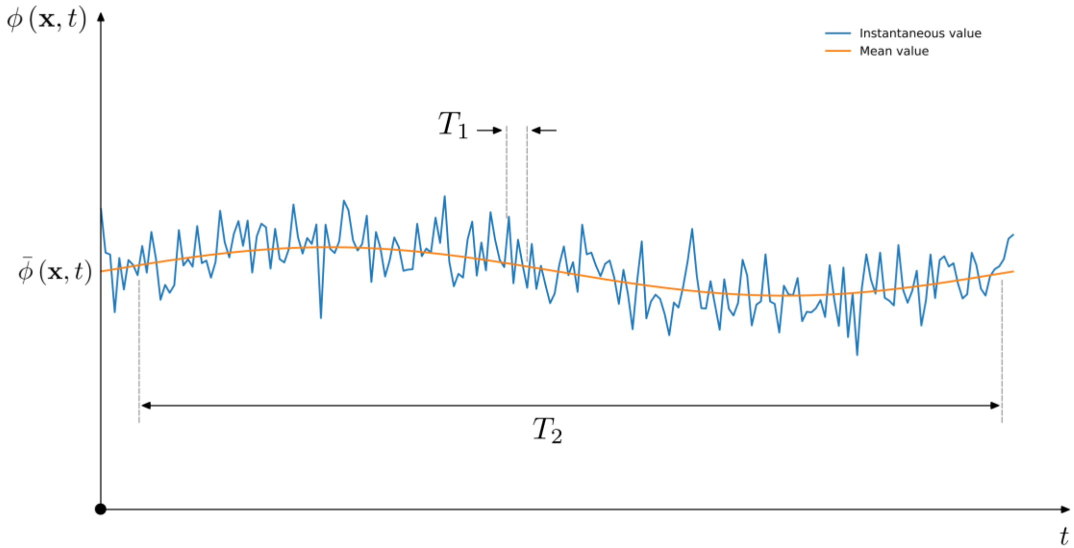
- So far, we have said that in RANS simulations we neglect the time derivative and in URANS simulations we retain the time derivative.
- It is a little bit more complicated than that, but it is a good interpretation.
- We should also take into consideration what we know about the flow physics, such as, shedding frequency or flow separation.
- The choice of the approach, RANS or URANS, strongly depends on the unsteadiness of the flow physics.
  - The unsteadiness can be due the coherent vortical structures, large scale eddies, multiphase flows, external forces, boundary conditions, moving bodies, and so on.
- Have in mind that it is possible to use RANS solvers with unsteady physics.
  - However, the results will be very questionable.
- Ultimately, it is up to the user.
- You must understand your physics, know your resources, and get a compromise between accuracy and computing speed.

URANS and RANS

- The mean flow computed in RANS simulations can be viewed as an ensemble or time averaged field.
- Any unsteadiness inherent to the turbulent eddies is removed by the averaging process.
    - Yes, the unsteadiness can be present in the steady solver, but the solution is not time accurate.
    - RANS simulations implies that the resolved quantities depends only on space.
- It is important to stress that the hypothesis of steadiness is very questionable, with results that might be even more questionable.
- But if the flow is truly steady (this is the exception rather than the rule) or mildly unsteady, the steady hypothesis is a good one.
- In many engineering applications steady solutions are acceptable and highly desirable.
- Two questions should always be asked when using RANS models,
    - How well does the model capture the flow physics?
    - How accurate are the quantitative predictions obtained in the analysis?
- If you cannot answer positively the previous questions or if you know that the flow physics is strongly unsteady, it is better to use unsteady RANS or URANS.

URANS and RANS

- In unsteady RANS or URANS, the mean flow is viewed as a results of the ensemble average or time averaging over the time period must smaller that T_2 (long period oscillations) and larger than T_1 (we do not want to solve the instantaneous fluctuations).



$$\phi(\mathbf{x},t) = \underbrace{\bar{\phi}(\mathbf{x},t)}_{mean\,value} + \underbrace{\phi'(\mathbf{x},t)}_{fluctuating\,part}$$

- In the figure, T_2 is a time scale characteristic of a slow variation in the flow that we do not wish to regard as belonging to the turbulence fluctuations.

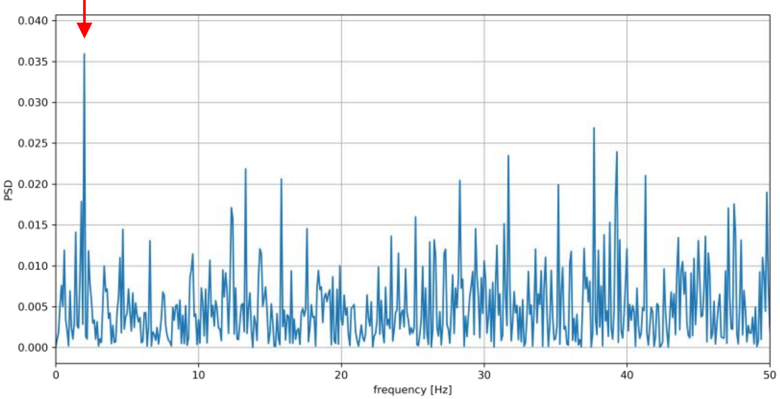
URANS and RANS

- In the previous situation, we were assuming that the time scales T_1 and T_2 exist and differ by several order of magnitude.
- But it might happen that in some situations this requirement is not satisfied.
- In such cases, the time averaging applied to the equations will remove or average these time scales.
- And this is due to the fact that there is no distinct separation between the flow unsteadiness and the turbulent fluctuations.
    - This separation between the flow scales and turbulent fluctuations is known as **spectral gap**.
- In cases where the spectral gap is not large enough, so it is not possible to distinct between the turbulent fluctuation and the flow scales, the time averaging used in standard URANS methods will add numerical diffusion to solution, and it will underestimate the physics of interest.
- In this situation the mean flow and the fluctuations are correlated.

URANS and RANS

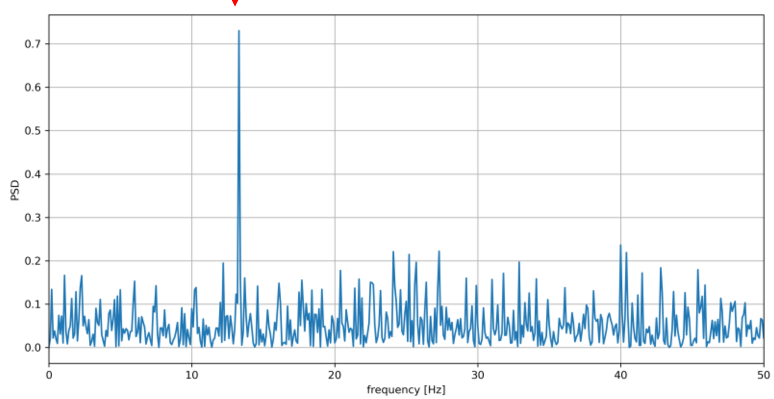
- In recent years, variations of URANS models have been developed that allow for the inclusion of transient, random large-scale structures.
- Such schemes generally are based on lowering the local eddy viscosity of the method to the point that diffusion no longer suppresses instabilities.
- Such effect can also be achieved by recalibrating the coefficients of the URANS model.
- In particular, the value of the coefficient C_μ is often decreased (and as a results μ_t) [1, 2].
- In the figure below, we show the effect of adjusting the coefficient C_μ (the specific application is not important). In this case, a lower value of the coefficient adds less dissipation.

No apparent dominant frequency – Maybe this one?



URANS with standard coefficients

Dominant frequency

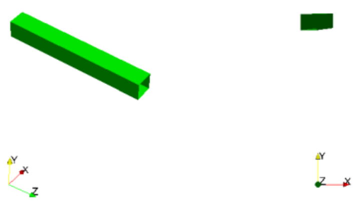


URANS with lower C_μ

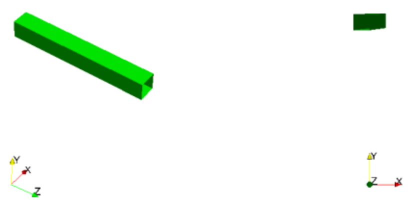
[1] F. Bastin, P. Lafon, S. Candel. Computation of jet mixing noise due to coherent structures: the plane jet case. J. Fluid Mech., 335, 261–304. 1997.
[2] P. Spalart. Strategies for turbulence modelling and simulations. Int. J. Heat and Fluid Flow, 21, 252–263. 2000.

URANS and RANS

Vortex shedding past square cylinder



URANS (K-Omega SST with no wall functions) – Vortices visualized by Q-criterion
www.wolfdynamics.com/wiki/squarecil/urans2.gif



LES (Smagorinsky) – Vortices visualized by Q-criterion
www.wolfdynamics.com/wiki/squarecil/les.gif

- The quantitative results are very similar in both cases.
- But qualitatively speaking, the solutions are very different.
- URANS simulations add a lot of dissipation to the solution.
- They do not resolve well the vortical structures in all directions, in particular in the spanwise direction (vortex stretching).
- And if there is no spectral gap between the turbulent fluctuations and the mean flow fluctuations (the vortex shedding frequency in this case), URANS will remove the mean flow fluctuations.

URANS and RANS

- Adjusting the coefficients of the URANS model, might not always be the best solution when dealing with strong unsteadiness and small spectral gaps.
- In the situations where we are interested in resolving the turbulent spectrum instead of modeling it (as in RANS/URANS), we can resort to another type of approach, namely, scale-resolving simulations or SRS.
- SRS refers to all turbulence models which resolve at least a portion of the turbulence spectrum in at least a part of the domain.
- SRS is a field of intense research, and many new formulations continue to emerge.
- Just to name a few of the approaches found in SRS:
  - Large eddy simulations (LES), detached eddy simulations (DES), scale adaptive simulation (SAS), wall-modeled LES (WMLES), hybrid URANS-LES, embedded LES (ELES), stress-blended eddy simulations (SBES).
- We will explore LES and DES in lecture 10.
- Have in mind that these approaches are intrinsically 3D and unsteady; therefore, computationally expensive.
  - The workhorse of turbulence modeling in CFD, RANS/URANS.