TEACHER’S GUIDE

WP2.6 Teacher’s guide

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Executive Summary

This deliverable is aimed to be used as a handbook for the instructors of the various courses included into the APPLY programme.

1. Introduction

The aim of the present document is to allow instructors to adapt the curricula to their specific needs pertinent to the local Universities and delivery groups. The impact of COVID-19 pandemic has been accounted for when putting this material together by defining alternative remote delivery methods. While this has been a very exceptional situation, other unforeseen situations could arise, and this teaching guide intends to provide a framework to deal with them.

2. Specific challenges of CFD teaching

CFD involves using a set of complex mathematical and software tools and CFD teaching tends to inherit this underlying complexity. In this section, some of the specific challenges involved in teaching CFD are outlined.

Physical modelling

The application of CFD can be realized only after the physical mechanisms that arise in the relevant problems have been successfully modelled. A model is an abstraction of reality. This abstraction represents a complex reality in the simplest way that is adequate for the purpose of simulation. The best model is always that which achieves the greatest realism with the least parameter complexity (parsimony) and the least model complexity. Realism can be measured objectively as agreement between model outputs and real-world observations, or less objectively as the process insight or new understanding gained from the model.

The successful modelling of a physical process is a complicated endeavour: It requires the accurate definition of geometry and boundary conditions; the evaluation of parameters that may vary in time and space as result of complex interactions between the material properties of the surface and the flow itself; the driving forces are highly variable, often at scales smaller than the model grid; and the geometry of the problem rarely approximates to a simple, easily meshable surface. Moreover, many systems are open and should be conceived as complex assemblages of many different processes and inputs, not all of which will be well characterized in any given application. Model validation data may not be available which tests all relevant aspects of model performance to a sufficient level of detail. In fact, given that CFD models adopt finite representations of time and space that may be very different to the time and space scales over which observations are obtained, it may actually be very difficult to measure those quantities predicted by a given code. Many applications are characterized by considerable uncertainty over almost every aspect of the modelling process and it may therefore become very difficult to diagnose why a model is going wrong. For example, a mismatch between a model and available validation data may be the result of a poor choice of conceptual model given the problem in hand, lack of data to characterize the problem geometry and boundary conditions, an incorrect parameterization or just insufficient or inappropriate validation data. Most likely all these factors will apply!

Thus, the CFD teaching must address the following issues: coupling CFD with Multiphysics problems; extending process representation to consideration of coupled physical mechanisms; scale and resolution effects, including upscaling; issues over what makes sufficient process representation in terms of model simplification, model validation, complex sensitivity and uncertainty analysis, and possible model equifinality.

The first stage in simulation using CFD is model building. The goal is to move from a perceptual model, representing everything we perceive or know about a given flow problem (and which may still be incomplete), to a conceptual model that represents our best estimate of the processes, parameters and forcing functions that control the development of a flow field at a particular scale. This conceptual model may be as simple as a series of logical statements, but at some point this needs to be translated into mathematical notation if it is to be turned into computer code and solved for the problem of interest.

The instructor must therefore have an overview of the physical problem in order to make a solid assessment of the modelling strategy that will enable the students to understand the underlying physics and develop for them physically meaningful case studies, while retaining the complexity to a palatable level. A first choice that needs to be made is whether to follow a top-down or bottom-up approach. The top-down approach assumes that it is best to start with the conceptualization of the whole system and the component parts in one go. The top-down approach has led to significant progress in many areas but its reductionist focus on the component parts means that, paradoxically, it does not allow us to understand whole systems well. Now, modelling and computers are enabling us, for the first time, to follow a bottom-up approach by putting these pieces together and understanding their interactions and emergent properties as a (process, spatial and temporal) whole.

The interpretation of the bottom-up approach as a teaching strategy leads to the synthesis of the provided knowledge from the various subjects in a comprehensive and holistic way. In terms of modelling, this means that the different aspects of CFD that the students are taught in the course of their studies - such as modelling of turbulence, approximations based on the type of the flow, techniques for implementing complex boundary conditions, etc. – must become a commonplace in the examples and the case studies that will be provided.

Finally, it is imperative to encourage the students to critically evaluate the results of the simulations that they execute and to highlight any links between the modelling process and the obtained output. The goal here is to instill intuition regarding the physical mechanisms that take action in flow problems, so that a CFD solution is not perceived a stale application of numerical techniques, but as a true simulation of the natural laws that govern the real-world problems.

Mathematical representation

Physical models in CFD are usually formulated in terms of sets of Partial Differential Equations (PDEs). The students must at least be familiar with the language of PDEs and be able to understand the different notations that can be found in the literature. Also, even if in practice CFD software will solve the PDEs for them, they must be aware of the underlying mathematical difficulties (e.g., non-linearity) and their implications.

Mesh generation

In addition to the complexity of the geometry being solved, in CFD the mesh density must be very different in each domain area due to the boundary layers, wakes, shock waves, etc. Mesh generation for CFD is therefore a disciple in its own. The students must be able to clearly differentiate between (1) The mesh requisites such as the need of different mesh densities in different areas (e.g., the so-called y+ in the boundary layers) with smooth transitions between them and (2) The specific issues of the code used for mesh generation.

In other words: while every present and future mesh generation code will have a different way to specify the size of the mesh elements next to solid walls with non-slip boundary condition, the need for such size arises from the physics of the flow and the turbulence model being used. While necessary, understanding how in practice the mesh is generated is not enough to be a good CFD engineer.

Running commercial or open CFD software

In order to be competent CFD professionals, the students must master one or more than one CFD code. However, as in the section devoted to mesh generation, the physical and mathematical aspects of the models must be clearly understood. In particular, commercial CFD tools tend to oversimplify the underlying problems and uncertainties, presenting themselves as if they were above the current limitations of technology. While this may be true -certainly, the state-of-the-art advances- it is important to provide the students with a good background so that they are not overwhelmed by the seemingly incessant advances. The opposite is also true. If all the courses are only focused in theoretical aspects, the students will have a hard time when facing industrial problems.

Developing CFD software

Years ago, it was possible for a single group or even person to write a complete CFD code valid for specific research or industrial applications. This situation has changed as the state of the art has advanced. However, while current CFD codes are far too complex to be developed from scratch in a single course, to teach software development is important for two reasons:

First, it provides a solid background to understand critical aspects of CFD such as boundary conditions, linear solvers, time advancement techniques, mesh generation and representation and so on. Second, students most likely will need to program some small applications or parts of large codes. Relevant examples can be found in post-processing area, where it is frequent to need a specific type of post-process not available in any current tool. Also, some codes are designed to be extensible and the advanced users can provide their own functions or classes.

Verification and Validation

When assessing the uncertainty in the results of a CFD simulation, the students must learn to clearly distinguish between verification and validation. First, the students must be aware that in other areas the terms verification and validation may have a slightly different meaning [1] [2].

In CFD context, the AIAA definition is typically used [1]:

- Verification: the process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model.
- Validation: the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.

In terms of Roache [1], "Verification is a mathematics and computer science issue; not a physics issue. Validation is a physical sciences and mathematics issue". The students should be able to use both terms with precision.

Verification, therefore, involves checking that the physical model, usually expressed in terms of PDEs, has been correctly solved. Validation involves checking that the model chosen is a faithful representation of the reality, and to do so one must usually perform experiments. Of course, both steps have to be performed to ensure that the CFD results are correct.

Thus, in our course we will be mainly concerned with verification. The reasons why the CFD results can be wrong or inaccurate are [1]:

Insufficient spatial discretization convergence, insufficient temporal discretization convergence, insufficient convergence of an iterative procedure, computer round-off, and computer programming errors.

Usually (but not always) computer programming errors, can be safely ignored when using readily available CFD codes, but will be stressed in the course "XXXX programming NS MANEL". The importance of the others, in particular mesh convergence has to be stressed in the different courses.

Post-processing

In the general process from the physical model to the results, post-processing is usually the last step. CFD results contain overwhelming amounts of data that have to be represented in a meaningful way. While this aspect is also addressed in section [Ivette], here we want to emphasize that the students must be aware of the importance of post-processing. As with mesh generation and CFD running, the students must be able to differentiate the underlying mathematical concepts (e.g., iso-surfaces, sections, interpolation, generation of trajectories, vortex detection methods) from the practical issues of the codes used.

Dealing with the limits of computational resources available

As it is well known, CFD is very demanding in terms of computational resources (CPU, memory, disk space). The students must learn from the very beginning that, no matter the resources available to them, they will most likely be insufficient to run the simulations they would like. The professors can mitigate this problem by means of:

- Try to use less expensive models (e.g., RANS rather than LES or DNS).
- For the expensive models, use pre-calculated results that will be given to all the students, avoiding therefore the run stage and focusing on post-processing (or even in some parts of the post-processing for large scale problems).

- Focus on idealized geometries or less demanding problems for the practical exercises, while presenting more expensive techniques using available results.

Dealing with the limits of the state-of-the-art

Certain areas of scientific / technical knowledge are very well stablished and can be taught with the confidence that they won't change in the immediate future. A possible example would be Thermodynamics. But this is not the case of CFD, where very serious challenges are still to be solved, for instance in the area of turbulence modelling. It is quite possible than some of the practices that today are standard will be obsolete in a few years.

While this circumstance can be confusing for students, it can actually be used by the professors to prepare them for future innovations, by stressing best practices such as:

- Try to understand everything from the model to the solutions, don't follow blindly the recipes.
- Be critical with the results you obtained.
- Stay aware of the last developments. Develop the habit of use recent papers to search for information, and not only textbooks.

1. Didactic tools

Group-based learning

Group based learning (GBL) is based on an educational stream known as Active learning. It has been defined as: "Active learning is anything course-related that students in a class session are called on to do other than simply watching and listening to a lecture and taking notes" [9]. In the case of GBL, variants are found depending on the approach given to the course, one of the used is the project based learning, which is widely used in STEM careers. As collected by [7], this strategy is based on the different aspects of learning aiming to support the inquiry process rather than transmitting subject-based knowledge. Within the problem base learning (PmBL), there is the project base learning (PjBL) that bases its development around projects and group work, in order to acquire skills that are necessary in an environment such as today.

Table 1. PBL potential skills development [3]

PBL principles	Knowledge and competencies gained
Cognitive learning	Problem-solving Project management Contextual analysis
Contents	Subject knowledge Technical skills Cross-disciplinary knowledge Knowledge management

Collaborative learning	Collaboration Communication (oral and written) Project management and planning

GBL vs Traditional teaching

A good traditional lecture can certainly serve several useful purposes, including sparking interest in the lecture topic, raising questions and provoking subsequent discussion, and filling in gaps in people's knowledge when they already understand most of the lecture content. However, even an excellent traditional lecture on complex and relatively unfamiliar content equips students to do what the instructor is describing as well as a lecture on diving would equip them to do three and a half somersaults off a ten-meter platform. The procedure could be meticulously laid out in the lecture, but the implementation would probably not end well.

The only way a skill is developed—diving, writing, critical thinking, deducing biochemical pathways, or solving dynamics problems—is through practice: trying something, seeing how it works, possibly getting feedback, reflecting on how to do it better, and trying again. Certainly that kind of thing happens (or should happen) in homework assignments, but you have roughly 40 contact hours with students in a typical one-semester course. Why not use at least part of that time to give the students some guided practice in the tasks they'll later be asked to perform on assignments and tests? [9]

GBL aims to give tools to students since these projects resemble a real problem. This project does not have to have a single solution and allows detecting learning gaps, in this way the student is forced to seek this knowledge and discern its usefulness. All this process, supervised by the teacher, will produce in students a capacity for clinical analysis of problems. [7]

These projects can be easily transferred to our master. Theory can go hand in hand with CFD group projects, where students are encouraged to cooperate to carry out them. Care must be taken with what arises in these projects because they can be overwhelming for students due to technological or time limitations, for this reason supervision is vital so that students do not attempt atrocities and are not helpless. The working groups can be chosen among the students as well as by the teacher, since both ideas can be defended with their advantages and disadvantages. The last point of these projects is the quantity of students per group, although there are studies like in [5], given the numbers provided by the APPLY, the groups will be small of 2-3 people, so the projects should be adapted to a reasonable load for that size.

This methodology has its drawbacks, it requires a greater effort from both parts; the teacher and the student. The first must give more time to the subject as it must transform the modules to adapt them to the methodology as well as more time waste on student's assessment. In the case of the second part, this one acquire an in-depth knowledge due to dealing with complex problems and skills such as problem solving and teamwork [6]. As it is concluded in [4]: "To be successful, teachers must provide good scaffolding, and this requires significant skills. But PBL provides an opportunity to meet the University's wider goals and the expectations of professional engineering institutions". GBL can lead to in-depth knowledge due to self-directed learning that may not always be necessary, some cases will require combining methodologies or not applying GBL. In addition, experience and flexibility are needed on the part of the instructor, since the students can go in directions that were not a priori predicted [6]. Some studies, as summarized by Hammond [4], raises that GBL do not give more knowledge to the students, however his response is that even if the knowledge is the same from both methodologies, GBL promotes other student skills and this could be its raison d'être.

In his [7], Garcia-Martin elaborates a guideline to create a course with the methodology that can be followed by the instructors if they need it:

1. Definition phase (basic information regarding objectives, restrictions, resources,…)
    a. Project proposal (Define goals and work to be developed)
    b. Project articulation (Aims, example, relation with the real-world project
2. Support phase (Detect weakness, motivation,…)
    a. Student motivation (Attention, Relevance, Confidence and Satisfaction)
    b. Design support (Where when how help students)
    c. Autonomous work (Who will do it)
    d. Project presentation (Make it attractive)
3. Organization phase (Steps of the project)

3. Online class

Online Course development – Instructional design

The term instruction design model refers to a framework or process that facilitates the development of learning/training material. Specifically, for online learning setups an instructional design model should be able to:

- Assist designers in identifying a strong course structure.
- Enable designers to visualise needs with a view to break down the educational material designing process into steps.
- Ensure linkages between material, learning objectives while meeting the intended expectations.

The following section briefly describes the most used instructional design models fitting the online environment.

ADDIE model which is an acronym five course design principles:

Analysis – it involves profiling of target students and identifications of expectations and needs of the organisation.

Design – Identification of instructions strategy, learning objectives, modes of delivery

Development – The educational material is developed according to the requirements defined in the previous steps

Implementation – Releasing the online course, delivery and monitoring of impacts or results

Evaluate – The process includes feedback from users, learning analytics from acquired data and surveys.

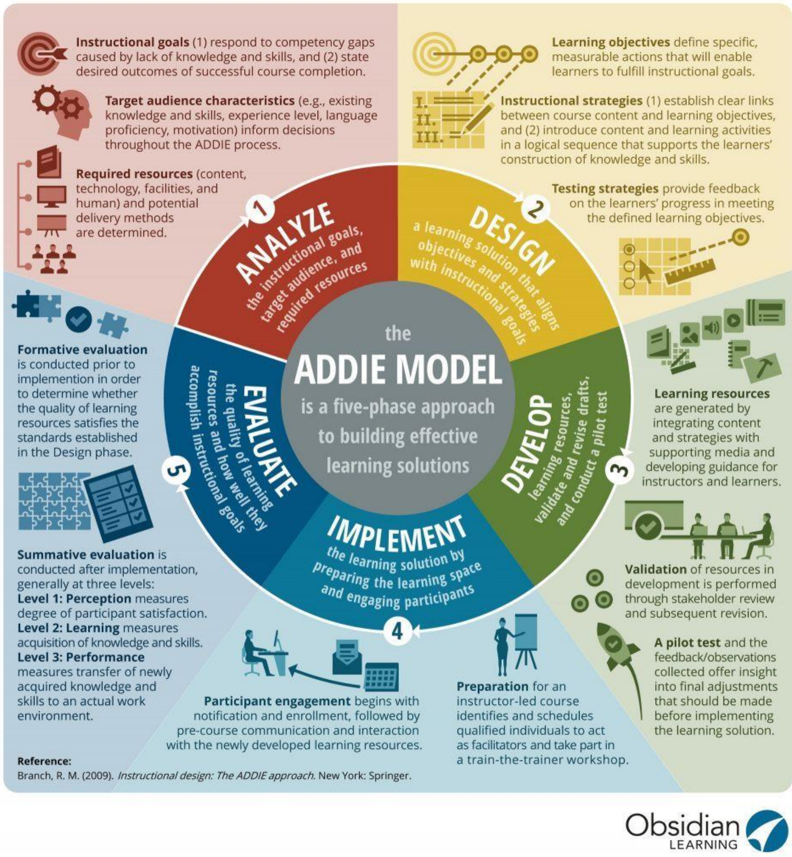


Figure 1. ADDIE model infographic [17]

Rapid Instructional Designs. This framework best applies in fast-paced eLearning environments where courses are not length in duration and can easily be modified and adapted on the fly. The four pillars to consider are:

- Prepare: Develop interest to the learners by emphasizing goals and benefits.
- Present. Provide learners required information to apply the new knowledge in the practical world.
- Practice: Follow an active learning approach through eLearning scenarios, simulations, video demos, etc. An important aspect here, is to identify the appropriate online training tool for the task.
- Perform: It refers to the evaluation process.

Dick, Carey & Carey System Design Model. This is a more systematical instructional design model and similar to the ADDIE model, being sequential in nature. It evolves around the basic idea that the learner is actively involved in the learning activities and heavily relies on theoretical learning principles. The key components include:

- Ascertain learning objectives and goals.
- Carry out a thorough analysis.
- Research your target audience to figure out traits and behaviors.
- Develop some performance objectives based on specific criteria and tasks.
- Develop eLearning assessments based on needs and preferences of learners.
- Select only appropriate eLearning resources and activities.
- Evaluate the course to identify improvement areas, known as formative evaluation.

- Validate that the eLearning content properly aligns with intended outcomes, known as summative evaluation.

Conceptualisation and types of online content

Based on the target group’s knowledge and educational background the next step is to inform the learners on when, where, and how they will consume the eLearning content. Conceptualisation of the online training experience can be done through different approaches including:

- **Mind mapping** - Create a "note map" with educational material to determine the initial structure of the content and the importance of different material parts.
- **Storyboarding** - A visualized sequence of content, written in a script, comic strip, or any other form for consistent presentation.
- **Action mapping** - A handy approach for creating efficient practice activities.
- **Wireframing** - The process of creating content layouts without going deep into the design.

Ideally, this preparatory activity will help eliminate any flaws before entering the active eLearning content development phase.

eLearning content development is not only about research, writing text or creating video and presentations. It also contains an intuitive learning structure of all content, assessments or any other material throughout the course. Each time, an individual learning content/component should answer specific questions and solve well defined problems in a well structured manner (modules).

Engagement and basic types of eLearning content:

Table 2. Types of eLearning content

Type	Description
Video lecture / training video	They may include webinars, embedded videos, standalone training videos, video tutorials, and screencast
Discussion / open questions	Creation of a dedicated space encouraging the students to express their point of view, argue for it, negotiate, or come to a common ground.
Simulation related content	Under the APPLY project this could include sharing of GitHub repository codes or embedding python CDF notebooks. The employment of notebooks in eLearning experiences, is a quite interesting example since they are documents that allow the user to bring together data, code and to tell an interactive computational story. In general, through notebooks, an educator can increase learner’s engagement, participation, understanding and performance. [10] [11]
Quizzes	They help to test and consolidate the knowledge without a substantial impact on the final course result. In addition, embedding small not graded quizzes/assessments, the instructors can understand whether the teaching is achieving the needed goals.
Slide presentations	This is the most basic and familiar content that is easy to create.

HTML/online text	Online text written in HTML standard used to add and format text, links, images and more. It is quite efficient since it facilitates access from mobile devices.

The abovementioned frameworks and elements of an online learning experience shift the teacher role. This means that teachers should be able to:

- Act more as a consultant, facilitatory and resource provider rather than lecturer
- Become expert questioners rather than providers of answers
- Design the learning experience rather than just provide the content
- Present multiple perspectives on topics highlighting pertinent points
- Provide the initial structure to student work encouraging increasing self-direction
- Address students' different learning styles

Communication skills for CFD

Students must learn how to discuss and present the complex results of CFD simulations. In this section, some hints for a quality presentation of CFD results are given. The emphasis is on written communication, but all the guidelines hold also for the slides used in oral presentations. The methodology for oral presentations is out of our scope, since there are no specific hints for CFD.

After running a CFD simulation, the amount of data obtained from this might be cumbersome. Thus, in order to successfully analyse and understand the outcomes from a CFD simulation, the communication (presentation and analysis) of the results is very important, both in academia and industry. Students must learn how to present and analyse these results as part of the skills of a CFD analyst. In order to do so there are different things/steps that have to be taken into consideration.

1 Introduction to the case/context of the simulation
2 Presentation of the mathematical/numerical model
3 Verification/Validation of the results
4 Presentation of the results
5 Conclusions
6 References

Hereafter a brief description of what should be expected in each of these items is given.

1. Introduction to the case/context of the simulation

The introductory section should include the definition of the case to be studied, the objectives of the study, justifying why is important and putting into context the simulations, i.e. a brief review of the literature related specifically with the studied case might be expected (for academic presentations) or the industrial context (previous runs, relevance of the problem considered and goals).

2. Presentation of the mathematical/numerical model

In a CFD simulation, both the mathematical model and the numerical approach followed are important. The mathematical model refers to the equations and hypothesis used, whereas the numerical model refers to the approach for solving these equations. For example, a CFD study by means of large-eddy simulations and using and explicit finite volume solver such as the one implemented in the open source code Open Foam might be explained as:

Mathematical model: The spatially filtered incompressible Navier-Stokes equations can be written as:

$$\frac{\partial \overline{u}_i}{\partial x_i} = 0$$

$$\frac{\partial \overline{u}_i}{\partial t} + \frac{\partial \overline{u}_i \overline{u}_j}{\partial x_j} - \nu \frac{\partial^2 \overline{u}_i}{\partial x_j \partial x_j} + \rho^{-1} \frac{\partial \overline{p}}{\partial x_i} - F_i = -\frac{\partial \mathcal{T}_{ij}}{\partial x_j}$$

where x_i are the spatial coordinates (or x, y, and z) in the stream-wise, cross-stream and span-wise directions. u_i (or u, v, and w) stand for the filtered velocity components and p is the pressure. ν is the kinematic viscosity and ρ the density of the fluid. Fi is a body force used to impose the no-slip boundary condition on the rough cylinder surface; it is non-zero only in the cells including part or all of a roughness elements. In Eq. 2 τ_{ij} is the subgrid scale (SGS) stress tensor, which must be modelled. Its deviatoric part is given by $\tau_{ij} - \frac{1}{3}\tau_{kk}\delta_{ij} = -2\upsilon_{sgs}\bar{S}_{ij}$ where is the large-scale rate-of-strain tensor, and $g_{ij} = \frac{\partial ui}{\partial xj}$ δ_{ij} is the Kronecker delta. The formulation is closed by an appropriate expression for the subgrid- scale viscosity, ν_{sgs} . In this paper the wall-adapting local-eddy viscosity model is used.

2. Numerical model: The governing equations are discretised on a collocated unstructured grid arrangement using second-order spectrum-consistent schemes. Such schemes are conservative, i.e., the symmetry properties of the continuous differential operators are preserved, and both stability and conservation of the kinetic-energy are ensured, even at high Reynolds numbers and with coarse grids. A self-adaptive two-step linear explicit scheme on a fractional-step method for the convective and diffusive terms is used for the temporal discretisation of the momentum equation, whilst an implicit first-order scheme is implemented for the pressure gradient. See more details in Rodriguez et al. [11].

Note that all the symbols should be defined and the text should be reviewed to ensure that no information is missing, such as the length reference in Reynolds number.

3. Verification/Validation of the results

It is always advisable to give credibility to the numerical solutions obtained. In order to do this one can compare the obtained results with those of the literature experimental or numerical if there are any available. Moreover, whenever possible, grid refined solutions should be checked in order to ensure the solution obtained is grid independent. If the solver used is implicit, then not only the independence of the solution in space should be checked, but also in time, by solving for different time steps. The same holds for numerical parameters such as the linear solvers tolerance. Other verification procedures, such as to ensure that the selected domain is large enough are also advisable. In an industrial context it may not possible to do this for every run, but the students shall learn the best practices.

4. Presentation of the results

The presentation of the results should be clear. It is advisable to use tables and figures to present them. All figures and tables should be clearly referenced into the text and discussed (meaning that they should not be included if not explicitly mentioned in the text) . Figures and tables captions should be self-explanatory. In the case of figures, the size of the text, line width, symbols size, colors, should be selected conveniently so as they could be clearly identified and read in the text. See for instance the examples bellow:

Table 3. Results of the effect of the free-stream turbulence on the Nusselt number

Table 3
Influence of the free-stream turbulence on the heat transfer from the sphere. Nusselt number $\langle Nu \rangle$ and the rms of its fluctuations $\langle Nu_{rms} \rangle$, minimum Nusselt number $\langle Nu_{\min} \rangle$ and its location θ_{Num}, Nusselt number at the rear stagnation point $\langle Nu_b \rangle$.

TI [%]	$\langle Nu \rangle$	$\langle Nu_{rms} \rangle$	$\langle Nu_{\min} \rangle$	θ_{Num}	$\langle Nu_b \rangle$
			$Re = 1000$(DNS)		
0	17.40	0.131	4.82	113.57	9.57
1	17.52	0.141	4.84	114.59	10.47
5	17.69	0.269	5.02	115.54	11.28
10	18.08	0.444	5.54	115.68	15.08
			$Re = 10^4$(LES)		
0	54.03	1.311	13.38	94.79	44.18
1	54.72	0.989	13.87	95.33	62.06
5	58.48	1.296	16.49	96.20	79.02
10	60.70	1.716	19.72	97.28	89.89

Results of the effect of the free-stream turbulence (TI, that had been previously defined) on the Nusselt number and its fluctuations are given in Table 3. At both Reynolds numbers, just after separation, the Nusselt number reaches a minimum but its magnitude slightly increases and moves towards the aft zone of the sphere with the level of free-stream turbulence (see values reported in Table 3). Recall that all the terms should have been defined previously, and not in the caption. Moreover, the incoming turbulence level largely affects both the local heat transfer coefficient and its fluctuations in the rear side of the sphere. For more details the reader is referred to Rodriguez et al. [13].

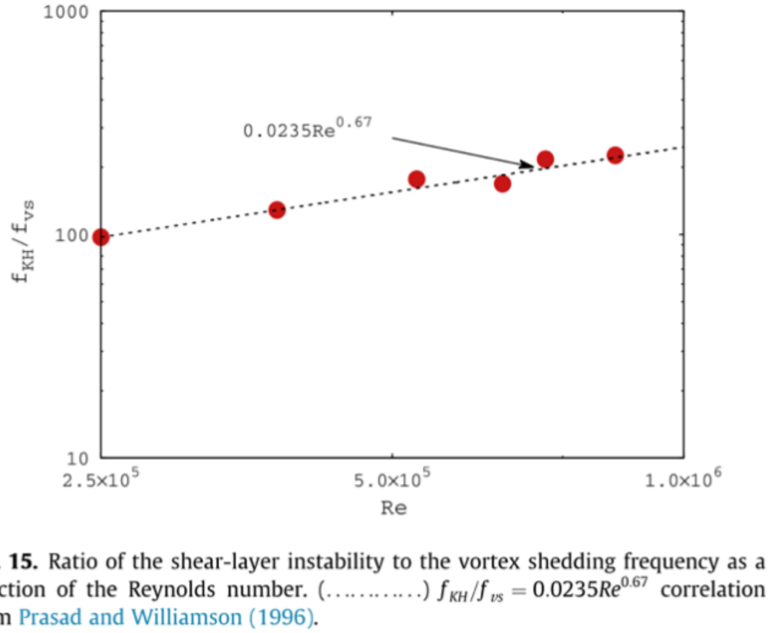


Fig. 15. Ratio of the shear-layer instability to the vortex shedding frequency as a function of the Reynolds number. (…………) $f_{KH}/f_{vs} = 0.0235Re^{0.67}$ correlation from Prasad and Williamson (1996).

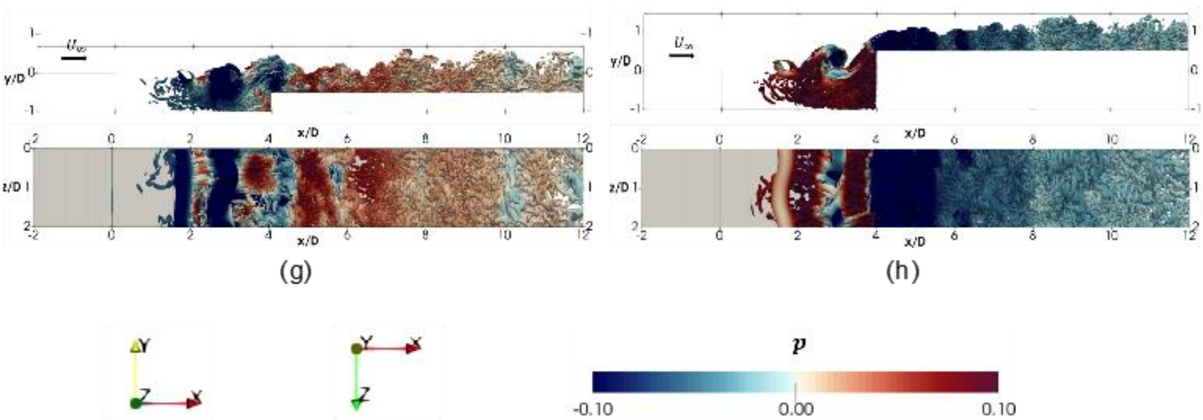
Figure 2. Ratio of the shear-layer from [14]

Previous figure depicts the ratio of the shear-layer instabilities to the vortex shedding frequency $\frac{f_{KH}}{f_{vs}}$ for all Reynolds numbers. It can be seen that $\frac{f_{KH}}{f_{vs}}$ follows the same trend in the super-critical regime as in the critical one. Thus, it would be reasonable to suggest that this correlation might be valid for the whole super-critical regime, where there is a laminar separation bubble followed by turbulent separation, up until fully turbulent separation of the boundary layer takes place in the trans-critical regime (see Rodriguez et al. [14]).

In the case of color figures, here are some recommendations:

i) Keep the colour bar simple and visible and provide appropriate value references
ii) It is always preferable to work with non-dimensional variables
iii) Show the axes and provide a scale to know the physical dimension of the plot.

The image below adapted from [16] is an example.



5. Conclusions

The discussion of the results should conduct to draw some conclusions about the case solved, which should clearly be stated on a separated section. All the conclusions extracted should previously be discussed in the section Results.

6. References

Finally, all referenced papers or documents should be included in a separated section. The students must be reminded that references should be explicitly used and that if possible, peer-reviewed journals must be used as reference. Text books can also be used with confidence. Documents produced by well-known companies or institutions (e.g., NASA) are acceptable, as well as PhD dissertations. Sometimes, it is necessary to use material from the web, but it must be done carefully and mentioning the date when the information was used. Students tend to refer to class notes but this should be avoided if possible, since they are difficult or impossible to obtain. The students must understand the reason behind this hierarchy of sources: all the information used should be of quality and available in case the readers want to review it.

4. How to teach literature reviews to CFD students

A literature review is essentially a survey of scholarly articles, books, dissertations, conference proceedings, and/or other published material. The review provides a summary, description, and critical evaluation of a topic, issue, or area of research. The purpose of a literature review is to provide foundation of knowledge on topic and identify areas of prior scholarship to prevent duplication and/or give credit to other researchers.

There are three essential types of literature reviews. The first one the simple literature review, which is a brief overview of the topic, not necessarily purely academic in scope and often uses popular sources and not extremely reliable. This kind of review is often just the start of the research process. The second kind is the applied one, which are mostly oriented in fact-finding and are used mostly in business, government and other professional environments. The last kind of literature review is the academic review. Whether stand-alone or part of a paper, study or project, the academic literature review requires accuracy, quality resources, objectivity thoroughness, quality analysis and understanding in depth the scientific area that is being reviewed.

To prepare a literature review a researcher should proceed with the following steps:

1. **Generate a list of references:** A preliminary list of statistical literature that is relevant to the research topic must be made. Sometimes it can be difficult to procure the desired copies of the scientific articles. It is advised to gather as much references as possible in the beginning, and later on decide which ones are relevant and which ones are not.
2. **Reading the literature:** After obtaining the preliminary list of references, the material must be thoroughly studied. This process can be very time consuming, depending on the popularity of the scientific topic. Not every reference will contain material that is relevant to the research problem. A researcher must keep what is relevant and ignore what is not. A good practice is to keep notes about the assumptions made and the important results, as it will be proven useful in later stages of the review. It is important to remember that the task is not just summarizing. For each reference the following questions must be adequately answered:
   - What is the author trying to say?

- Is it relevant to my research and if yes why?
- What is original about the methodology used by the author?

3. **Presentation:** There will be a point that it will be clear which are the most relevant publications to one's work. The articles that will be referenced should be grouped according to the relevance with each other (e.g. experimental/numerical articles, articles produced using the same method, articles from the same research team, etc.)

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