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CFD Applications in Long-span Bridges: An Erasmus+ Traineeship International Mobility Experience

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Abstract
An international mobility experience framed within the Erasmus+ Traineeship programme is reported. The topic of the traineeship is related with Computer Science and Engineering, more specifically, CFD applications in wind engineering studies of long-span bridges. The subject is highly multidisciplinary and therefore very adequate for the development of skills of the trainee. Topics addressed have been fundamentals of aerodynamics and aeroelasticity, CFD modelling using open source software, use of High Performance Computing facilities and wind tunnel testing, among some others. The learning plan was designed in close partnership with the trainee, since this programme offers a perfect opportunity to elaborate a tailored training that was even updated to better fulfil the demands of the intern. The assessment of the outcomes of the mobility and training experience was based in the internal review, as established in the administrative requirements of the Erasmus+ program. Nevertheless, the skills gained by the trainee were used in the frame of a research effort conducted in the field of uncertainty quantification in the evaluation of the flutter derivatives of twin-box decks. As a result, a conference paper was accepted for the AFM2021 conference, and that paper was selected for publication in an international journal.

Keywords: Erasmus+ Traineeship; International mobility; Bridge engineering; CFD; aeroelasticity.

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Una experiencia de movilidad internacional Erasmus+ Traineeship: Aplicaciones de Mecánica de Fluidos Computacional en puentes de gran vano

Resumen

En este trabajo se presenta la experiencia llevada a cabo en el marco del programa de movilidad internacional Erasmus+ Traineeship. La temática de la experiencia formativa está relacionada con la ingeniería y la ciencia computacional, de manera más específica con aplicaciones de la mecánica de fluidos computacional in ingeniería de viento aplicada a puentes de gran vano. Esta disciplina es eminentemente multidisciplinar y por tanto muy adecuada para la adquisición de nuevas habilidades por parte del estudiante. Algunos de los aspectos más fundamentales que han sido tratados en el periodo de formación han sido aerodinámica y aeroelasticidad, modelización CFD (Computational Fluid Dynamics) usando software libre, uso de computación en paralelo y ensayos en túnel de viento. El plan de formación se diseñó en colaboración con el propio estudiante, ya que esta modalidad de programa Erasmus+ permite elaborar un traje a la medida de las necesidades formativas del participante. La valoración de los resultados de esta experiencia de movilidad internacional y formación se ha realizado mediante el procedimiento de evaluación interna intrínseco al programa Erasmus+. Sin embargo, la formación adquirida por el estudiante se aplicó en una investigación desarrollada en el ámbito del estudio de la incertidumbre asociada con la evaluación de las funciones de flameo de tableros de doble cajón empleado en el diseño de puentes de gran vano. Como resultado, un artículo redactado a partir de ese trabajo de investigación fue aceptado para su presentación en el congreso AFM2021, y seleccionado para su publicación en una revista científica internacional.

Palabras clave: Erasmus+ Traineeship; movilidad internacional; Ingeniería de puentes; CFD; aeroelasticidad.

Introduction

The higher education international mobility Erasmus program, funded by the EU has been at the core of the European University system since 1987 (Erasmus Student Network web site, 2021). The main overarching goals of the programme for students are the improvement of language skills, gaining self-confidence and independence and immersing into a new culture (Erasmus+ web site, 2021). Among the available formats, the one named as Traineeship (student) offers very interesting possibilities for the student, such as improving transversal competences, international work environment exposure, immersion into a different academic culture, specific technical and scientific skills. Aeroelastic effects in long-span bridges is a very specific field of activity in engineering that in many cases stays outside the contents of standard courses in bridge engineering in civil engineering schools. The introduction in the curriculum of contents related with wind engineering applications require a good expertise in the field by the academic responsible for the contents, as well as an adequate administrative framework. Because of this, in many cases these contents are restricted to very specific courses in a handful of European universities, usually at EQF 8 level. The consequence is that interested students at EQF 7 level cannot gain exposure to the subject unless they are enrolled in a engineering studies at Master level in Institutions counting among its members with experts in the subject. In the mobility experience reported herein, a EQF 7 student with a background in civil engineering willing to improve his skills in bridge aeroelasticity and Computational Fluid Dynamics (CFD) modelling, contacted Dr. Felix Nieto, who has been working on this subject for several years. After some preliminary discussions, the duration and general scope of the traineeship was settled; and the procedure to obtain financial support and fulfil administrative requirements was completed.

The authors would like to highlight the multidisciplinary content of the subject addressed in this internship that should provide the student with highly specialized skills such as aeroelastic effects in bridges, CFD modelling, wind tunnel testing and technical-scientific oral presentation and writing, which are highly demanded by international companies in the sector.

The traineeship took place between October 2020 and April 2021, when several restrictions associated to COVID-19 were still in place, although access to working places was allowed, as well as holding meetings with a small number of attendants.

In the next sections, the administrative framework for the Erasmus+ Traineeship program is briefly described and the main goals and tasks considered in this experience are introduced. Then, the fundamental results at educational, but also at scientific level, are reviewed and discussed. The main conclusions are summarized in the last section.

Administrative framework and methodology

The student mobility for Traineeships is organized based on the learning agreements between the "Sending Institution", that is the University in which the student is enrolled and the "Receiving Organization", that in this case is the University hosting the student for the Traineeship. In this international mobility experience, the Sending Institution is the University of Pavia in Italy (Università degli studi di Pavia) and the Receiving Organization is the University of La Coruna in Spain (Universidade da Coruña). Two learning agreements among the concerned institutions exist at different moments along the traineeship development: one is signed before the mobility, setting the goals of the training; and another is signed after the mobility, summarizing the achievements of the trainee.

Focusing on the academic content, the learning agreement before the mobility takes place must contain a detailed program of the traineeship, a list of the expected learning outcomes, a monitoring plan and an evaluation plan. The initial (August 2020) basic program for the traineeship in CFD modelling of aereolastic effects on bridges contained the following tasks:

- Review of fluid mechanics fundamentals and introduction to CFD modelling in external aerodynamics.
- Completing two tutorials about mesh generation, openFOAM solver settings and postprocessing.
- Fort the cross-section of a bridge deck, conduct 2D URANS simulations aiming at obtaining the force coefficients. Importance of verification activities must be stressed at this stage. Results to be validated with experimental data from the literature and/or wind tunnel tests at the University of La Corunna
- If progress is made at fast pace, force oscillation simulations can be done to identify flutter derivatives and/or vortex-induced vibration.

It is important to remark the last point in the list of tasks, as it allows keeping an open door for further learning along the traineeship. It is the authors' view that a traineeship should be a personally tailored learning experience; hence it is of utmost importance to design an open-ended learning path, enabling the acquisition of highly specialised skills that may help in the latter access to the labour market of the trainee.

The methodology applied in this traineeship is based on the "learning by doing concept". A pre-requisite is the understanding of the fundamental concepts in wind engineering applied to long-span bridges. Consequently, the initial weeks were devoted to aerodynamics and aeroleasticity concepts such as force coefficients, flutter derivatives, or critical flutter speed. The basic reference for the trainee was the book by Jurado et al. (2011). Similarly, the trainee required a basic training in CFD modelling,

comprising grid generation, solver settings and postprocessing. With this aim, the basic tutorials elaborated by the mentor for the course in fluid mechanics he teaches at the Master in Civil Engineering were provided to the trainee, along with access to the required open source codes Salome, OpenFOAM and ParaView. For the study of the turbulence modelling concepts, remarkably the URANS formulation, the reference of choice was Wilcox (2006).

Once the basic concepts were acquired, the trainee started to apply his recently gained knowledge in real application cases such as the numerical evaluation of the force coefficients of a mono-box long-span bridge deck and the flutter derivatives of a twin-box deck, following the procedure described in Nieto et al. (2015). It should be remarked that these real case applications required the use of cluster computing, further enlarging the scope of subjects addressed by the trainee within the frame of this internship.

The final task of this traineeship was the application of the gained knowledge, methods and techniques to generate new knowledge. To this end, a uncertainty quantification study in the flutter derivatives of a twin-box bridge deck was conducted considering the randomness in the angle of attack and the turbulence intensity in the inlet. The fundamental conclusion of the study was related with the different levels of uncertainty obtained depending on the specific flutter derivatives analysed and the reduced velocity level considered. Part of the study has been recently published, and this is explained in the next section.

Results and discussion

The precise description of the tasks carried out by the trainee are listed in the detailed programme of the traineeship, that is provided in the learning agreement produced after the mobility has taken place. In this case, in addition to the tasks set in the learning agreement before the mobility detailed in section 2, the following ones were added (April 2021):

- Forced excitation simulations were completed for the twin-box deck, obtaining the flutter derivatives for different inlet turbulence values and angles of attack, with the purpose of assessing uncertainty in flutter derivatives extraction.
- Wind tunnel testing of sectional models.

However, in this kind of training experience, is the trainee the one that must be at the centre of the programme; hence, the most important outcomes are the knowledge, intellectual and practical skills, and competences acquired by the student. In this traineeship, the following are highlighted:

- Understanding of the fundamental concepts in fluid mechanics, remarkably the Navier-Stokes equations.
- Understanding of the fundamentals in turbulence modelling in wind engineering application in bridge structures.
- Execution of finite volume meshes for CFD simulations.
- Setting up of CFD simulations using OpenFOAM.
- Completion of verification and validation studies in the frame of aerodynamics and aeroelasticity of long-span bridges.
- Postprocessing of CFD simulations
- Understanding the fundamentals of wind tunnel testing of sectional models.

Furthermore, it should be noted that a learning agreement cannot contain the whole range of expertise gained by the trainee. In fact a mobility experience, as the one briefly described herein, has provided the trainee with a wide range of the so-called soft skills, such as:

- Adaptation to a different living environment, which is implicit in a mobility action; however, it must be remarked the abnormal circumstances under which the mobility took place as a number of limitations were in place due to COVID-19-related restrictions.

- Adaptation to a different academic environment.
- Exposure of the trainee to an academic research environment that should further enlarge his professional horizon after finishing his Master Degree.
- Scientific writing and presentations skills, as the trainee was kept during his stay a kind of scientific diary, and he was making presentations in internal meetings to communicate the advancements made in the research conducted in the topic of uncertainty quantification.
- Improvement on language skills in English and Spanish.

An important point to consider when reflecting on the achievements of training and mobility actions is how to obtain an external and independent assessment of the outcomes. For this purpose, once the trainee got familiar with the subject and potential for further studying the topic was identified, a small research project on uncertainty quantification was outlined. The purpose of this was two-fold: i) Further extend the scope of the training received by the student, and ii) setting more ambitious objectives that help in the motivation of both the trainee and the hosting group. The final outcome of this small piece of research was the presentation of a research work in the international conference "11th International Conference on Advances in Fluid Dynamics with emphasis on Multiphase and Complex Flow", that took place online on 6-8 July 2021. In fact, this work was accepted as an "invited presentation" by the organizers of the conference (Wessex Institute AFM/MPF 2021), and selected for publication in the International Journal of Computational Methods and Experimental Measurements.

Conclusions

The fundamental conclusions that can be taken away are the following:

- An international mobility Erasmus+ Traineeship took place at the University of La Corunna, hosting a student from the University of Pavia in Italy.
- The topic addressed within the traineeship was highly multidisciplinary, including aerodynamics and aeroelasticity subjects, CFD modelling, cluster computing and wind tunnel testing, among others.
- A tailored learning path was developed for the trainee, given response to his demands as he was progressing over the weeks.
- The learned skills were applied by the trainee in piece of research related with the uncertainty quantification in the evaluation of flutter derivatives in long-span bridge applications.
- This international mobility experience has enlarged the horizons of the trainee for the early development of his professional career.

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