Augmented and Virtual Reality to enhance learning in engineering. Application to rotary wing aeromechanics.
Realidad Virtual y Aumentada para la mejora del aprendizaje en ingeniería. Aplicación a la aeromecánica de alas rotatorias

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Abstract- We present a pilot learning experience on the use of Immersive Virtual Reality (VR) and Augmented Reality (AR) to facilitate the understanding of the complex dynamics of rotors by students of Bachelor's Degrees in Aerospace Engineering. VR/AR experiences allow the visualization of the complex movements of rotor blades (airscrews, wind turbines and helicopters) as well as the vector fields of the external actions (aerodynamic, inertial and gravitational) that produce those movements. The students are surveyed about the pros and cons of using the pilot experience compared to traditional methods based on static representations of the dynamic results. The main conclusion is that both VR and AR experiences are valuable tools to complement the traditional methods.

Keywords: Immersive Virtual Reality, Augmented Reality, Rotor Dynamics, Learning Experience. Educational Innovation.

Resumen- Presentamos una experiencia piloto de aprendizaje sobre el uso de Realidad Virtual Inmersiva (VR) y Realidad Aumentada (AR), con el objetivo de facilitar la comprensión de la dinámica compleja de rotores, a estudiantes de Grados en Ingeniería Aeroespacial. Las experiencias en VR/AR permiten visualizar los movimientos de las palas de los rotores (hélices, aerogeneradores y helicópteros) así como los campos vectoriales de las acciones externas (aerodinámicas, inerciales y gravitatorias) que originan esos movimientos. Se consulta a los estudiantes sobre los pros y los contras de la experiencia piloto en comparación con los métodos tradicionales basados en representaciones estáticas de los resultados de la dinámica. La conclusión principal es que las experiencias VR/AR son herramientas valiosas para complementar los métodos tradicionales.

Palabras clave: Realidad Virtual Inmersiva, Realidad Aumentada, Dinámica de Rotores, Experiencia de Aprendizaje. Innovación Educativa.

1. INTRODUCTION

Engineering students generally show excellent analysis capabilities to solve mathematical problems. However, it's quite common for them to experience some difficulties when abstract and spatial abilities are involved. Improving this capacity has received the attention of several educators (Contero et al., 2006; Olkun, 2003).

Understanding the mechanical constraints and kinematics of mechanisms increases mental workload, and improving those skills has shown to be quite challenging (Perez-Benedito et al., 2015). Furthermore, engineering mechanisms and machinery are designed to interact with external elements. The inclusion of complex or time-dependent physics, or the inclusion of the external loads on the dynamics of those systems introduces an additional level of difficulty.

Particular fields in which students usually exhibit such difficulties, are those related to systems which involve rotary wings (i.e. wind turbines and helicopters among others). Understanding the complex kinematics, the relative motion of the fluid, and the non-steady nature of the external loads may benefit from a learning experience in which different layers of information can be superposed in an immersive environment. Indeed, the application of virtual laboratories (Balamuralithara and Woods, 2007) and Virtual Reality (Abulrub et al, 2011) to enhance the learning experience of engineering students has been around for more than two decades. Virtual Reality has also been applied to ease the understanding of abstract concepts, such as those associated to physics vector fields (Salzman et al., 1999). The increase in the computing capabilities of mobile devices has risen the popularity, and affordability, of Immersive Virtual Reality (VR) and Augmented Reality (AR). This places VR and AR as a real alternative to combine those layers into a single experience.

In what follows, the authors describe a pilot learning activity involving the application of VR and AR as complementary teaching resources in Bachelor's Degrees in Aerospace Engineering, developed in the framework of an Education-Innovation Project funded by "Servicio de Innovación Educativa", Universidad Politécnica de Madrid (UPM).

2. CONTEXT & DESCRIPTION

Understanding the complex kinematics of rotary wings systems, such as airscrews, wind turbines or helicopter rotors, is quite challenging for bachelor students in Aerospace Engineering. Three main causes have been identified. First, the kinematics associated to the mechanism (rotation, flapping,

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lagging and pitching) in combination to the different reference systems from which the kinematics of the system can be described (vehicle, blade/propeller, wind…). Second, the highly unsteady and non-uniform nature of the external actions behind the movements (aerodynamic, gravitational and inertial) which depend on the radial and azimuthal location of the considered blade section. Third, the complex dependency of the resulting dynamics on the design characteristics (blade shape, airfoil type, stiffness of the blade, etc.) and the active control of the blades (pitch control angle and rotational velocity).

First-year students are prone to show difficulties in the interpretation of the relative motion between the blade and the surrounding air. The use of static diagrams, quite useful to simplify the relevant information, can be confusing for them, even in the simplest geometric configurations (a rigid propeller rotating and moving perpendicular to the rotation plane).

The most typical difficulty experienced by fourth-year students is related to the dependency of the blade basic motions (rotation, flap, lag and pitch) to the radial-time nature of the external aerodynamic actions. A correct understanding is necessary to sense their contribution to the aerodynamic thrust and torque distributions along the blade span. Traditionally, static 2D and 3D diagrams have been used to represent the influence of the flight condition, the design characteristics and the control parameters on the resulting dynamics (both, kinematic of the system and load distributions).

The experience shows that, even students of master's degrees in Aerospace Engineering and engineers working in this field of expertise may benefit from methods based in VR and AR to present the information that complement the static diagrams.

A. Main objectives

The implementation of VR and AR based experiences is being conducted in the framework of an educational innovation project supported by Universidad Politécnica de Madrid, with special focus on the incorporation of complementary resources to enhance the learning process of the students.

The main objective is twofold, first to develop VR and AR models of rotors and second to assess both, the viability and efficiency of these specialised VR and AR models, as complementary learning resources to be used by the students.

Two additional objectives are proposed by the authors. The first one is developing a library that will ease the implementation of future learning experiences, to use in other subjects or to enrich with additional functionality.

The last objective was to elaborate cross-platform resource materials that can be accessed by the students with devices that, in most of the cases, are already available to them, i.e., laptops, tablets, smartphones and similar devices. Also, the VR and AR experience should be optimized for consumer-budget headsets. The access to the more recent version of the experiences is freely available at the website (arya-XR, n.d.).

B. Framework and infrastructure.

The developments experienced by the VR and AR fields in the last decade, both in software and hardware aspects, have provided appropriate technological frameworks to achieve the project goals. Regarding the software aspects, developing a web-based experience is an easy approach to target a wide range of devices. There are several open-source JavaScript libraries focused on that functionality. Babylon.js was selected due to previous experience of the authors, and some of the advantages it provides. Babylon.js is a game engine focused in delivering smooth and interactive 3D experiences to web browsers.

Babylon.js already provides tools to include AR and VR functionality to the 3D experiences. These experiences can be delivered to any device with the WebXR device API. Two budget consumer VR headsets with similar characteristics were considered. The Meta Quest 2 was selected due to availability at the early stages of the project, and the larger developer-community support as a more mature platform. Hence the experiences have been tested and polished for that headset.

C. Rotary Wing learning experience (RWexp).

The experience was conducted with a mixed group of fourth-year students, in the last progress meeting of their bachelor's thesis on Conceptual Design of a Helicopter. This experience was focused in the viability of virtual models as complementary tools to teach rotor dynamics. A brief document was provided, to describe the objectives of the pilot experience, to propose several small tasks around a reference flight condition. The document included some of the static representations associated to the reference condition.

A browser-version and a VR experience of a helicopter rotor was provided to the students. The rotor blade was enabled to develop its kinematic movements in forward flight (rotation, flapping and pitching) accordingly to the implemented mathematical models of the Aeromechanics (Figure 1). Real time representations of the unsteady radial distributions of some external loads (such as aerodynamic thrust and tangential forces) were superimposed on the moving blade.

The students were encouraged to complete the tasks proposed in the document. They could adjust the forward flight speed, the collective blade pitch angle and the blade-to-hub stiffness coefficient, to visualise the effect in real time, both on the blade kinematics and on the load distributions. This experience was compared with the use of traditional static radial-azimuthal representations of thrust and tangential forces (see Figure 2) and line plots of the flapping angles along the blade azimuthal position (see Figure 3).

Finally, the students were invited to enter the immersive VR experience using the headset, and move across the fixed frame of reference and virtually move onto the rotating rotor and to different locations of the moving blade, to gain insight about the amplitude of the different movements along the blade.

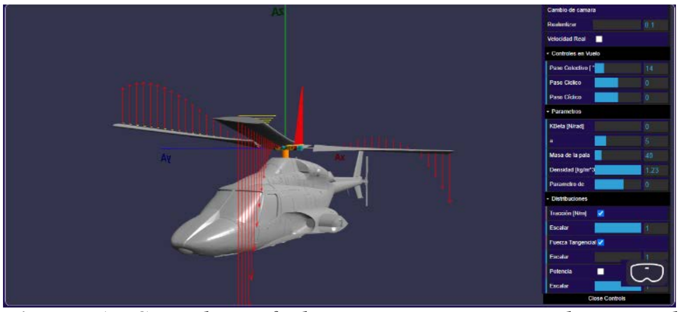

Figure 1. S*napshot of the rotor movement. Thrust and tangential forces are superimposed on the blade axis. x_A (red), y_A (blue) and z_A (green) are the axes fixed to the non-rotating part of the rotor hub. Canopy model based on (Riaanjvr_313026, 2023) (CC BY 4.0).*

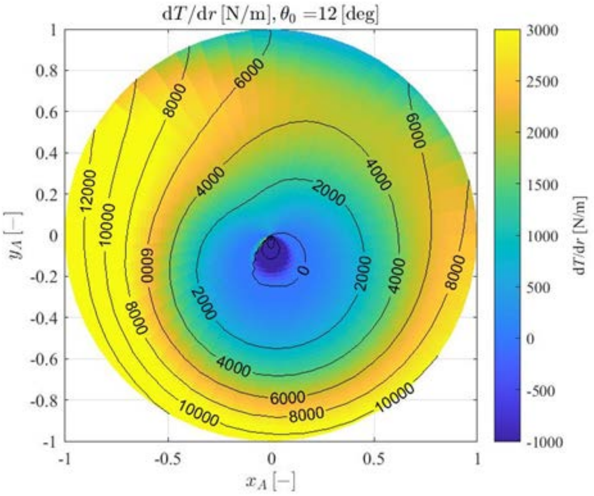

Figure 2. *Representation of the thrust per unit length of the blade in the rotation plane. Advance ratio V/ΩR=0.25 and a collective pitch angle θ_0=12 deg. V is the flight velocity, Ω is the rotational velocity and R is the rotor radius.*

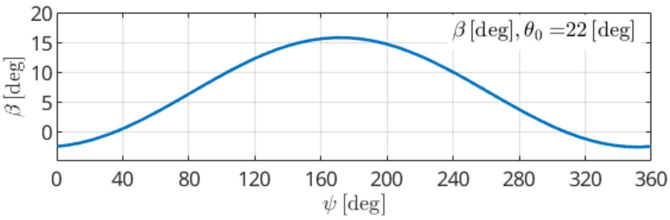

Figure 3. *Representation of the flap angle of the blade versus azimuth. Advance ratio V/ΩR=0.25 and a collective pitch angle θ_0=12 deg. V is the flight velocity, Ω is the rotational velocity and R is the rotor radius. V is the flight velocity, Ω is the rotational velocity and R is the rotor radius*

D. Wind Turbine learning experience. (WTexp).

A second learning experience was designed, considering a simpler kinematic model, to focus both on the user interface and assess different approaches to the user experience. This experience was conducted with a different mixed group of fourth-year students, in their last stage of their bachelors' thesis on Wind Turbine Conceptual Design. These students have faced the difficulties of understanding the movements of rotating and pitching blades using traditional static material.

A complete wind turbine model with rotating-pitching blades (Figure 4) was provided to the students. Three versions of the learning experience were presented, the browser-version, a VR experience in the headset and an AR experience for compatible devices. The students were asked to freely explore the relative movements of the nacelle-hub-blade in the three versions, and to focus on the user experience. There were no additional tasks, such as the comparison with classic representations.

The browser-version was used to provide a basic description of the interface, and to introduce the VR and AR environments. Students were invited to test both VR and AR versions. In Figure 4 the AR layer is used to capture a student inside the VR experience. In the VR they were capable of freely move along different camera pre-sets, associated to the reference system of different components. This virtual experience allowed a simple interaction to the environment, to keep the focus on the relative motion and amplitude of the kinematic movements.

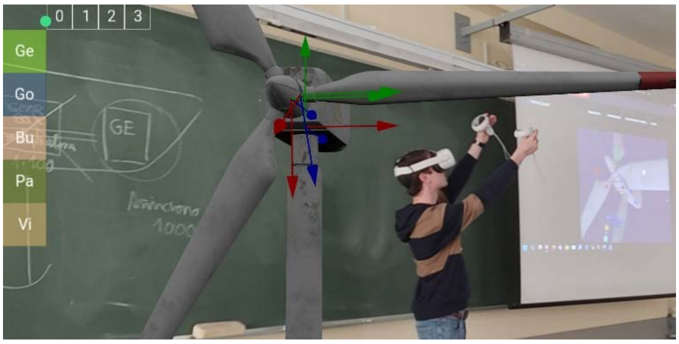

Figure 4. *WT pilot experience, AR layer in a smartphone capturing a student inside the VR experience. On the left, the Graphical User Interface for camera and parameter control. Next, global view (camera 0) of the wind turbine model. On the right, screen projection of a partial field of view of the student. The WT model is based on (Sket_h, 2023) (CC BY 4.0).*

3. RESULTS

The pilot experiences (RWexp and WTexp) were designed both to assess the viability of their application in the classroom, and to gather the students' opinions. Both experiences were presented during two progress meetings, with the use of classic study material, evaluation questionnaires and the virtual model. During the sessions, an oral presentation of the virtual model was done, and the students were allowed to use virtual reality headsets as well as virtual models on flat screens, guided by written material. And the end of the sessions, besides the verbal feedback, the students filled a survey with four simple questions and a written open feedback space. The questions were rated from 1 to 5 (lowest to highest agreement, respectively).

In the RWexp 7 students filled the survey (Figure 5). The four questions, and the average of the valid answers were:

Q1. The VR user interface is user-friendly (4.86).

Q2. Dizziness / vertigo is experienced (1.86).

Q3. The virtual model eases the understanding of radial and azimuthal dependence on thrust and tangential force distributions, as well as their relative magnitude (5).

Q4. The virtual model eases the understanding of the azimuthal dependence of the flapping angle, for different values of the coupling stiffness (4.86).

In the WTexp 15 students filled the survey (Figure 6). The four questions, and the average of the valid answers were:

Q1. The VR user interface is user-friendly (3.7).

Q2. Dizziness / vertigo is experienced (1.3).

Q3. The global camera 0, aids to understand relative proportions of the wind turbine components (4.5).

Q4. The hub camera 1, aids to understand the blade geometry and the pitch motion (4.1).

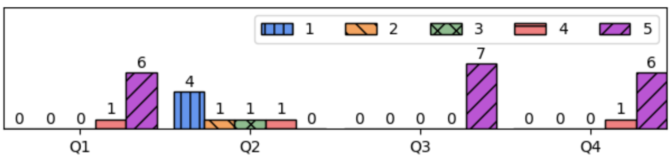

Figure 5. *Answers' distribution in the RWexp survey.*

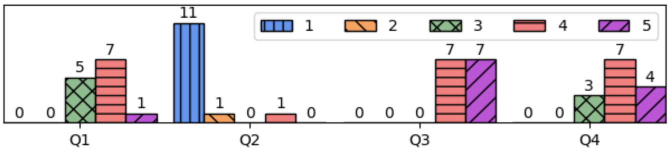

Figure 6. *Answers' distribution in the WTexp survey.*

E. Results Analysis and student feedback

The VR model and the educational experiences have been presented to the largest possible number of experienced students in a controlled environment. The purpose of this development phase is to collect information from students with experience in the learning process on rotor dynamics, with classic study material, to refine the VR model and the educational experience, prior to its incorporation as study material in regular classes. Including the students in the early stages of this educational project will enable quick modifications of the experience design, both to improve the comfort rating and optimize the learning process.

The library and the graphical user interface (GUI) were redesigned for the WTexp, with especial focus on the VR/AR environment. Some bugs appeared in the AR experience, leading to lower perception of user-friendliness (Q1). Although a better selection of the VR camera parameters influenced the comfort level (Q2), it should be noted that the WTexp is more slow-paced, with less moving elements inside the experience. Some students were prone to dizziness, but these students felt more comfortable inside the WTexp. Finally, the RWexp has a nice selection of cameras (Q3, Q4), but the positioning for the WTexp leaves room for improvement.

Most of the open feedback provided by the students was quite similar in both learning experiences. Besides the common consensus on the great potential to enhance their learning experiences, most of the students were eager to share their impressions and feedback to enhance future experiences. Most of the feedback was focused on improving the AR experience, and the inclusion of additional helpers or information layers in the VR experience. These helpers were mainly a brief tutorial on the controls (to substitute the verbal description), the inclusion of a skybox and terrain, and even additional elements as some vehicles or people to aid the scale comparison. The additional layers of information missed by the students, although are not currently implemented in the pilot experiences, were already planned in the internal roadmap.

4. Conclusions

The great level of satisfaction of the students, and the high motivation expressed during the experience, show that Virtual and Augmented Reality are promising tools to enhance the learning experience. Besides the enticing appeal to focus the attention of the students, VR and AR enable to develop feature rich experiences. One of the strong advantages, especially in the complex topics addressed in engineering studies, is the ability to superimpose different layers of information. This approach can complement the learning material in subjects in which both spatial reasoning and abstract physical-mathematical formulation are involved, such as in the case herein studied.

Once the virtual reality model has been evaluated by 4th course students of GIA-UPM, a simplified version of the experience will be presented to 1st year students (Aerospace Technology subject) facing the difficulties of being presented for the first time the dynamics of a rotor, so that they will have the opportunity to use both classic and VR study material.

Fortunately, the rise in popularity over the last years of VR and AR, has led to the availability of affordable consumer headsets. In this project, the feasibility to develop enriched experiences has been assessed with an open-source game engine (Babylon.js). Developing experiences targeting the web-browser enables the accessibility both for VR headsets and other devices (computers, tablets and smartphones).

From the experience acquired during the project, the authors have learned that early design decisions in the development of the immersive experience can complicate tuning the immersive experience to the students' reasoning, and comfort level. Thus, it seems crucial to include feedback from the students during the early stages of development.

Acknowledgements

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