A Model-Based STEM-Focused Interactive Virtual Reality Toolkit for K-12 Students

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Abstract
A model-based virtual reality toolkit (VRT) for smartphone applications is developed to provide a "serious-game" interactive learning environment for K-12 students with focus on engineering design of an unmanned flying vehicle (UFV) exploring various planetary objects with different atmospheric conditions. Using a multi-level game approach progressing from heuristic to simplified mathematical descriptions of fundamentals of engineering design process, flight physics and atmospheric science, the students are guided through various stages of the craft design, with results visualized in VRT toolkit to validate success of the design process and further encourage iterative redesign by taking into account various planetary atmospheric conditions and desired vehicle parameters.

Keywords
STEM, K-12, Virtual Reality, Interactive, Serious Game, UFV, Design, Planet, Atmosphere

Introduction

The use of Virtual Reality (VR) and Augmented Reality (AR) has a high potential to transform Science, Technology, Engineering and Math (STEM) education through introduction of computer-game environment in interactive learning process, which is particularly important for K-12 students. Such "serious game" (a term recently coined to differentiate the educational game from a typical arcade or computer game) can be highly successful in motivating students to learn. Thanks to the use of meaningful contextualization and optimized experience, serious games integrate the engagement of well-designed games with serious learning goals. As stated in Ref. [1], "the gaming environments offer exceptional potential for teaching cognitive and behavioral skills by providing opportunities for simulating the real-life situations and conditions, under which the development of these skills occurs. Games motivate learners to take responsibility for their own learning, which leads to intrinsic motivation contained by the game-based learning method itself. While engaged in a serious game, the learners tend to retain a significant amount of information by building cognitive maps."

The VR environment may be installed either on computer or smartphone and requires a VR headset displaying an (often 3D) image that changes dynamically with head motion. While most of VR games accessible on the market are focused purely on entertainment, the serious-game VR toolkit is designed to combine entertainment features with educational objectives. Several examples of such learning environments are currently available online. For instance, "View Master Experience Pack: Space Game" [2] uses VR-360 view to explore the solar system or examine 3D models of spacecraft upclose. ZSpace is a technology firm specializing in VR systems for educational market, with one of its serious games, "Newton's Park" [3], allowing learners to deepen their knowledges of Newtonian mechanics through VR experiments. Another team from Harvard University has developed a set of tools, EcoMUVE and EcoMOBILE [4] , that combines a curriculum-based virtual learning environment with complementary augmented reality. Overall, we are approaching a new era in STEM education where, as mentioned in Ref. [5], "the classroom no longer feels like a classroom for taking courses; it feels like some kind of laboratory or incubator where [students] get to explore, collaborate, and discover at the same time [they] learn about science."

The current work focuses on the development of educational, interactive, modular VR toolkit that employs both empirical and mathematical descriptions to aid a K-12 student in the design of an unmanned flying vehicle (UFV) for space explorations. Each educational module includes a detailed introduction with description of the mission background, motivation and assigned exploratory tasks, supplemented with outline of physical and mathematical models presented in a simplified form to accommodate the level of student preparation but also to challenge and motivate the "space cadet" in STEM education. In particular, the multi-disciplinary design tasks require students to use various modules (illustrated in Table 1) to integrate all stages of the design process to eventually develop a virtual UFV prototype visualized in VR toolkit along with the exploratory mission flight.

			6 to 11	12 to 15	16 to 18
Design of a plane		Airplane parts and functions	X	X	X
		Flight forces identification	X	X	X
		Balance of flight forces		X	X
		Wing shapes and area		X	X
		Airflow on known foil design		X	X
		Use of flow conditions to calculate lift/drag			X
		Introduction to propulsion			X
Discovering the atmosphere		Science facts about Earth/Mars/Moon atmospheres	X	X	X
		Difference of atmospheric parameters on Mars/Earth		X	X
		Impact of atmospheric changes on aerodynamic variables		X	X
		Mathematical description of planetary parameters and flight conditions			X
Flying in VR		Introducing the different phases of flight	X	X	X
		Heuristic validation of the design flight process	X		
		Rigorous validation of the design flight process		X	
		thorough assessment of the design complexity and its validity, using mathematical formulas			X

Table 1. Modeling approach for various age groups.

VR Platform and Game Development

A cross-platform VR game development tool, *Unity* [6] is employed in the design and visualization of the current serious game. This virtual reality toolkit is currently created for download on Android smartphones and can be used with a Google cardboard or other VR glasses.

The game is divided into 3 different modules (Fly, Build/Design, Learn Planet), as shown in Fig. 1. Each module represents a part of the game that can be linked to another one through graphical user interface (GUI) commands. In the current preliminary version, each module has 3 task levels addressing pools of students with different level of STEM preparation. In particular, the first (elementary) level targets a pool of students aged approximately 6 to 11, the second (intermediate) level may fit students between 12 to 15 years old, while the third (advanced) level is designed for students aged 16 to 18.

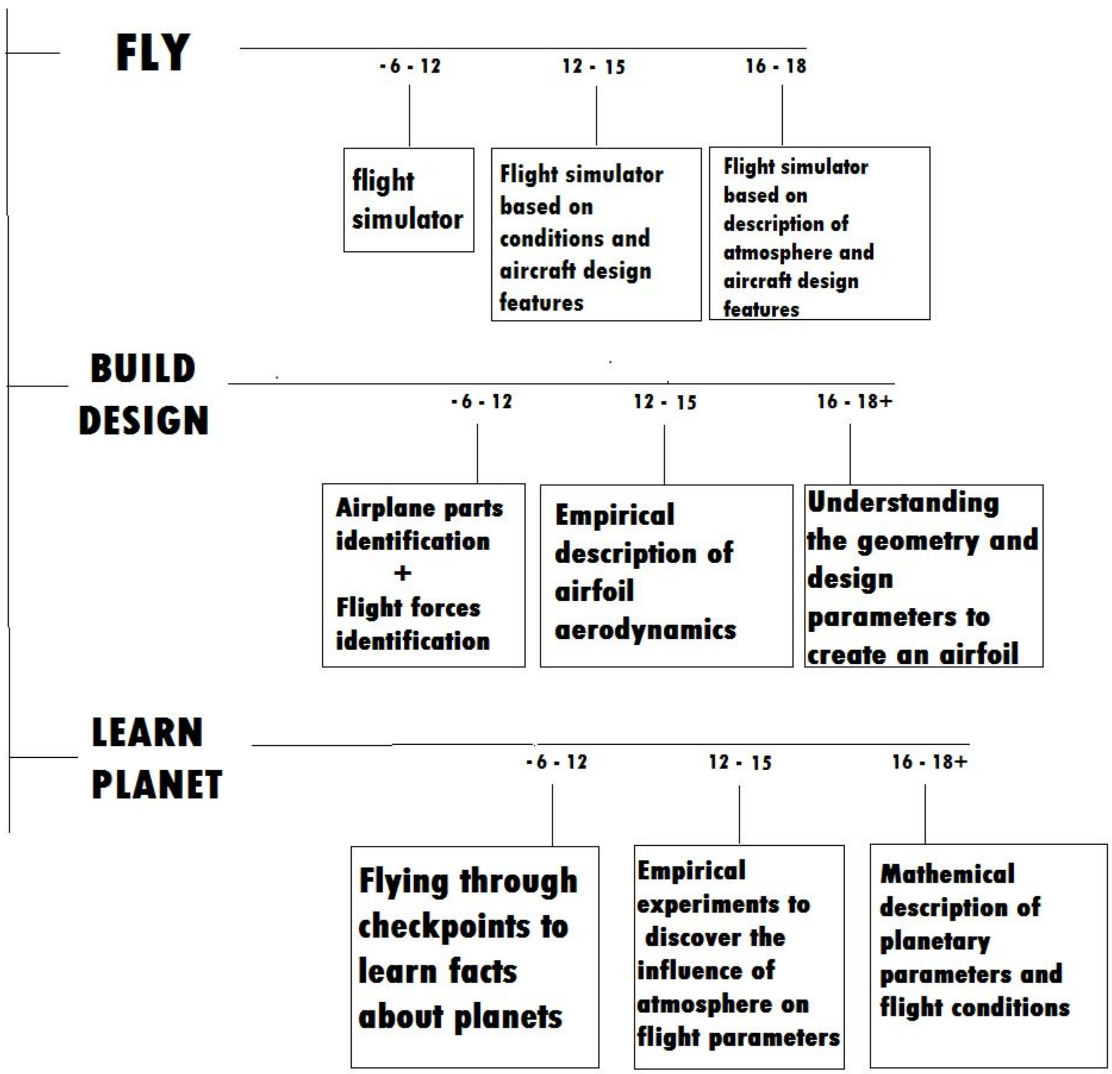

Figure 1. Fly, Build/Design, Learn Planet game modules and age-specific learning objectives.

Game Scenarios

The main menu describes 4 options corresponding to the categories of "level selection", "planetary object selection", "plane design", and "flight simulator". The design stage itself is branched into "shape design ", "foil design" and "atmosphere simulator", only available for intermediate and advanced levels. The level selection menu allows the user to select the level of difficulty matching his age and preparation. Once a level has been selected, the UFV design process starts. Following the step-by-step design process, the user eventually accesses the flight simulator for a specific planetary environment to visualize and evaluate success or failure of his design iteration, as described in detail below.

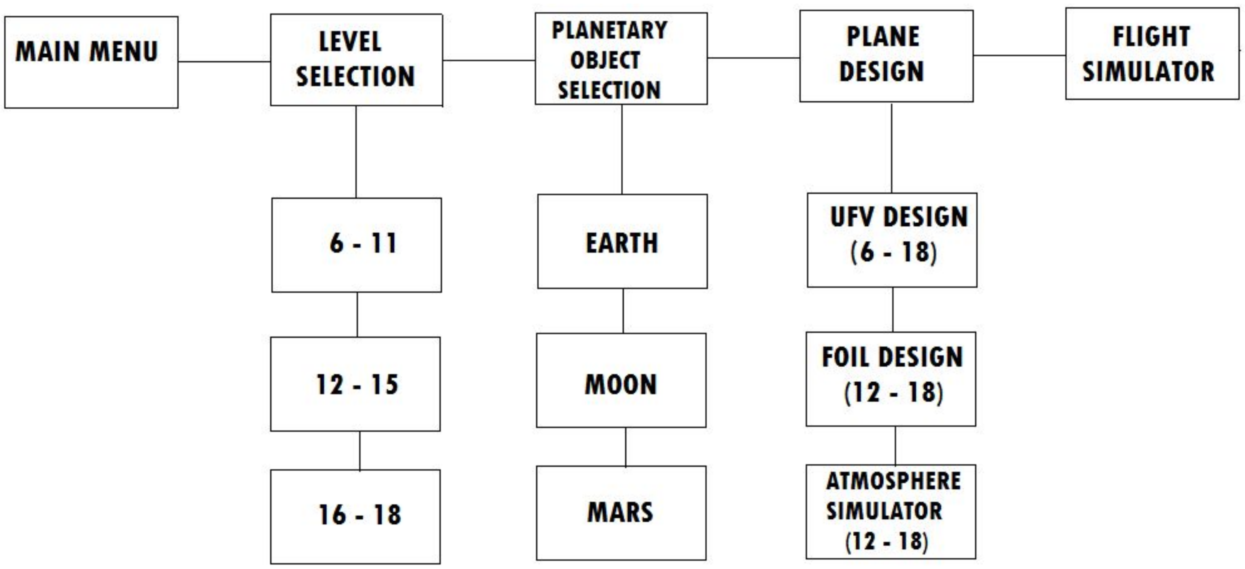

Figure 2. Selection of game displays.

The initial level selection in the current version of the game corresponds to different age groups. Next, the students select one of 3 planetary objects (Earth, Moon or Mars, as seen in Fig. 2). Each of them have different (or none) atmospheric parameters, thus allowing a user to understand differences in flight conditions and design requirements for unmanned flying vehicles that exist between these objects. Based on the outcome of the design iteration in the Plane Design stage (Fig. 2), the flight simulator validates success or indicates failure of the prototype design for specific atmospheric conditions. If the design process is successful, the student will be able to "fly" the unmanned vehicle in the selected VR environment to "explore" the surface of the selected space objects. If the design is not validated, the plane will not take off and a "crash" animation is displayed. Once the student's design iteration has been validated and the vehicle has successfully taken off, he or she will fly through specific flightpath checkpoints to learn various scientific facts about the space objects, displayed on the screen (Fig. 3).

Game Modules

Flight Simulator Module

The elementary version of the flight simulator is used to introduce students to different phases of flight and trigger their interest in learning fun facts about space objects. The design validation is heuristic and takes into account only a few basic parameters discussed in the HELP section of the design process' description. The information displayed at the flight checkpoints includes only basic facts about the planetary objects.

The intermediate version of the flight simulator module (Fig. 1) examines parameters selected by the student during the design process. Taking off may require more iterations and encourages a student to be more rigorous in the design analysis. The science facts displayed at the checkpoints will help the student learn more about the physics of the planetary object that they are exploring.

Finally, the advanced version of the flight simulator includes a thorough assessment of the design complexity and its validity based on mathematical formulas (Table 1). The information displayed at the flight checkpoints will help student to learn more rigorous scientific facts about the planetary objects.

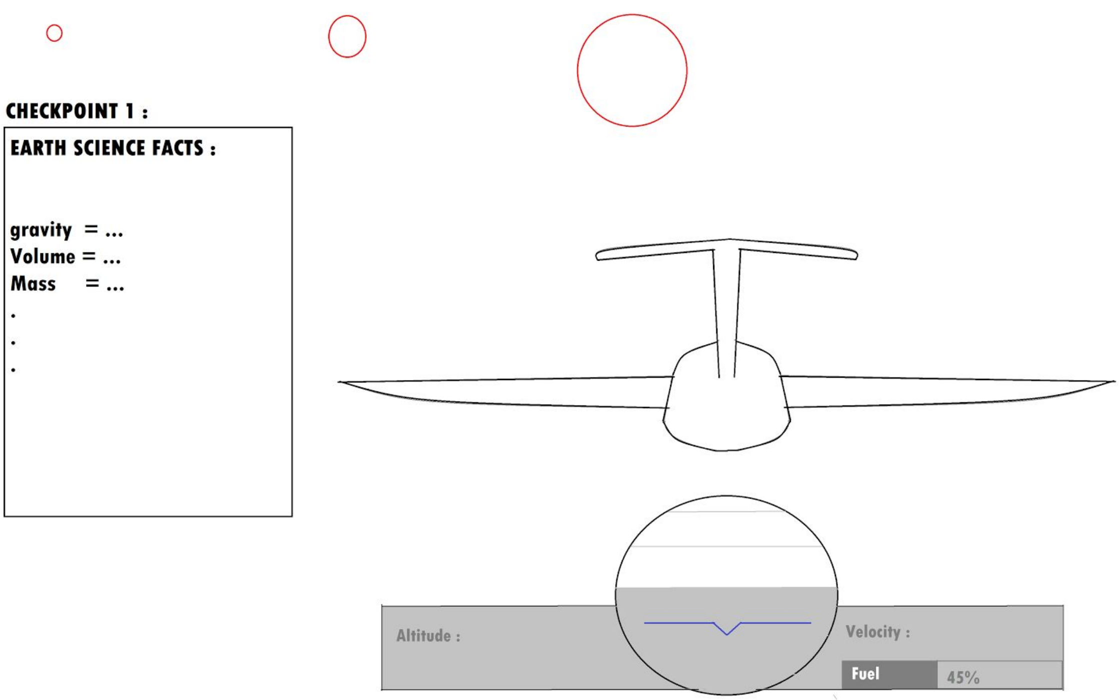

Figure 3. Flight simulator display.

Build/Design Module

The objective of this module (Fig. 1) is to assemble different UFV parts to make it flight-ready, with the design iteration validated in the flight simulator module. On the left of the UFV design interface (Fig. 4), different parts of the craft are listed. The student can add these parts to complete the vehicle design. Once the parts are added to assemble the vehicle, the user can resize them to the desired proportions by using arrows. Note that for the Earth and Mars flights, the corresponding planetary atmospheres are used to design the aircraft wing for adequate lift production, while on the Moon with low gravity, the wings are not needed because of the lack of atmosphere and the lift is created through a generic micro-propulsion device. In general, the propulsion system designs for various UFV crafts will be elaborated in the future game versions.

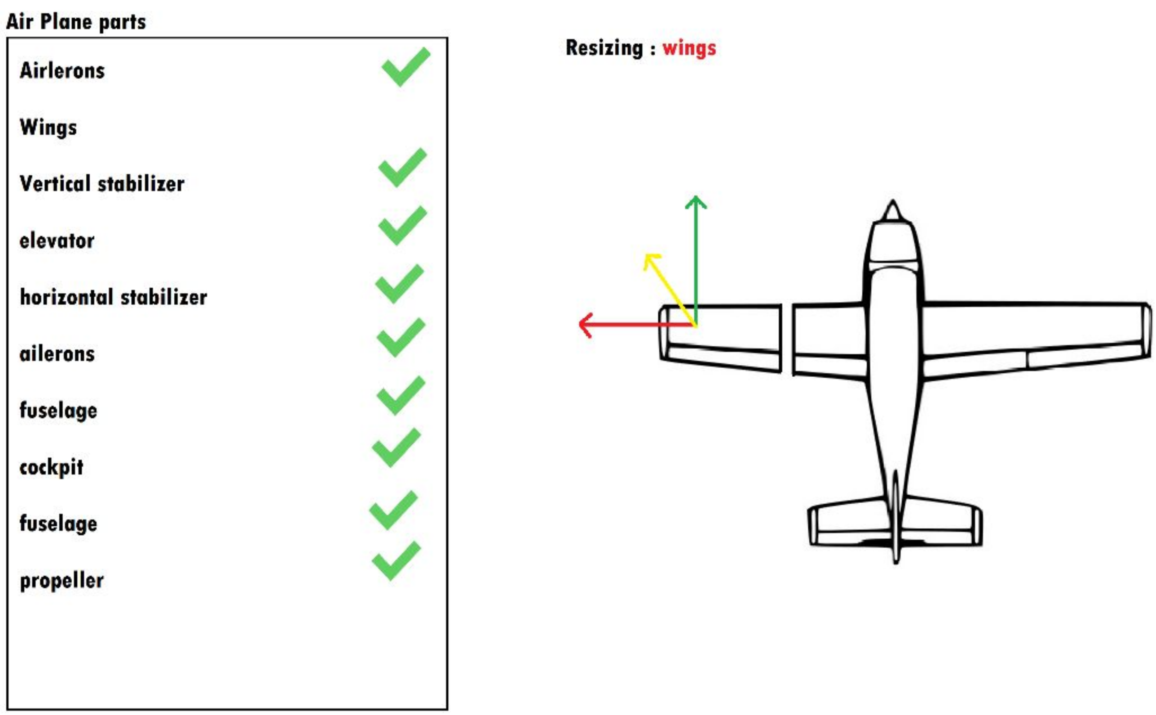

Figure 4. UFV design display.

While the intermediate and advanced levels incorporate foil design and atmosphere simulator (Fig.2), a lego-style virtual UFV configuration assembly is required at the elementary level. An interactive foil simulator tool (Fig. 5) is designed to aid in learning and understanding the classical airfoil theory. In particular, the tool provides with aerodynamic solutions for various atmospheric flow conditions for various airfoil designs. This tool is based on NASA's Interactive Educational Tool for Classical Airfoil Theory [6]. In particular, the foil simulator allows student to understand the effects of airfoil camber, thickness and angle of attack. As the student varies design conditions through VR graphical interface, a new flow field is calculated and displayed. An interactive plotter is used to record the flow variations, allowing the results to be displayed on the user's headset screen. The student has an option to select an airfoil to learn more about the geometry and airflow of some known airfoil designs. At the intermediate level, the student works with the displayed input boxes and graphs. For advanced students, the foil simulator offers a version to learn more about airfoils and wings in terms of mathematical descriptions. The latter version allows user to employ input of flow conditions and wing geometry to calculate lift and drag. The design output is provided and analyzed through a variety of plots, performance graphs, as well as text and mathematical fields.

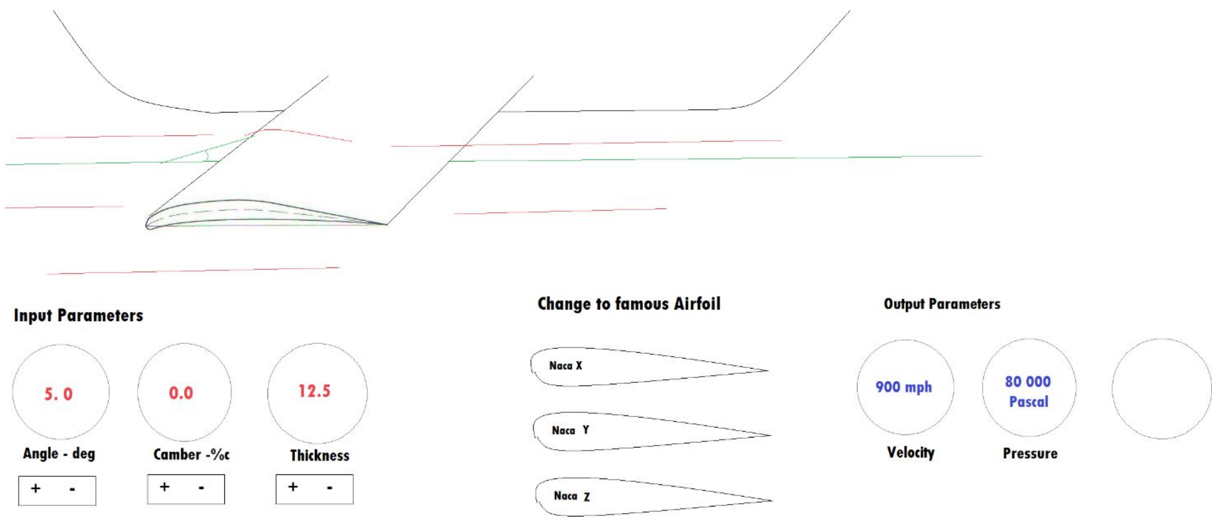

Figure 5. Foil simulator display.

Learn Planet Module

The interactive Learn Planet module employs NASA-developed AtmosModeler Simulator [7]. This tool (Fig. 6) is used to study the impact of atmospheric changes on UFV aerodynamic variables using mathematical models of the standard atmosphere for the Earth and Mars planets. More planets and other space objects will be included in the later VRT versions.

Once the user selects the initial flight parameters (altitude and velocity), he or she may control them during the UFV's VR flight. At the same time, the flight simulator demonstrates the changing magnitude of various atmospheric variables on the Earth and Mars planets. On the left, the display shows the flight altitude and the velocity (or Mach number) of the craft. Using "+" or "-" buttons will set the altitude displayed by the red arrow. The velocity is set by the same process on the right side of the interface, with the green bar selecting the desired velocity.

The selection buttons in the upper right corner of the interface allow the user to display the UFV during the flight over the selected space object. It is also possible to display the input and output in either British or metric units using the menu buttons.

The lower right portion of the simulator provides the output information. The output boxes display thermodynamic flow parameters and speed of sound on the designed craft, with the latter depending on the atmospheric gas composition and temperature of the selected planetary object.

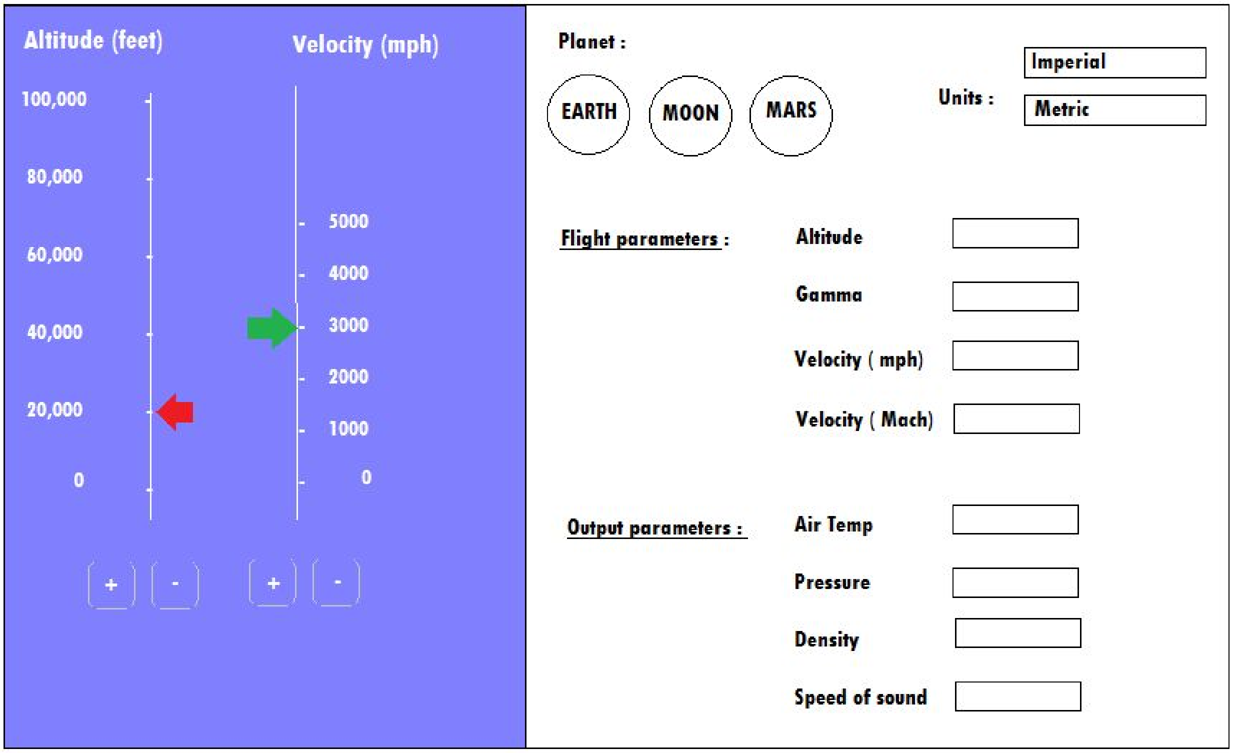

Figure 6. Selection of atmospheric parameters.

Conclusions

The paper outlined the development of a virtual-reality interactive serious game focused on space and flight science education for K-12 students. The game combines both educational and entertainment features to enhance student motivation in STEM learning. The virtual reality toolkit will be available for download on smartphones and can be used with Google cardboard or any other VR glasses. Future plans for the project include further development of various aspects of the game including enhanced complexity and variety of unmanned flying vehicle technical features and planetary object parameters incorporated in the game modules. Furthermore, in partnership with STAR, Inc [9], the use of this VRT tool in K-4 classes will help evaluate necessary adjustments in the game scenarios and age-based technical level content.

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Biographical Data

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Paul Bouché is a Master 1 engineering student at the EPF- Graduate School of Engineering in Sceaux, France. He joined the ERAU for a 4 months internship during fall 2017. His research efforts are currently focused on the development of a Model-Based STEM-Focused Interactive Virtual Reality Toolkit for K-12 Students.

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Ms. Shahinaz Millar is president of Space Training Adventure & Research Inc. She has been involved in bringing together a variety of support groups for advance studies of current STEM programs. Ms. Millar is actively involved with local college humanitarian clubs to serve the community and abroad. As a strong-minded woman in today’s business world, she recognizes the lack of women in STEM careers and is focused in driving more young women towards STEM careers. She is fluent in several languages and holds the highest teaching certification as a French linguist. She holds a dual Masters from UCL – University Catholic of Leuven in Brussels, Belgium and several certifications in STEM and Business Entrepreneurship from UCF – University of Central Florida.