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Board 158: Design, Fabrication, and Testing of Lego-neered Vertical Flight Dynamic Systems: Using Custom Lego Models to Inspire the Next Generation of Innovators (Work in Progress)

Mr. Alex Richard Duffy, Penn State University

Alex Duffy is a current undergraduate student majoring in Aerospace Engineering at Penn State University. His work involves the design and creation of custom Lego models which showcase vertical flight fundamentals. He has been building with Lego for almost his whole life and wishes to inspire the next generation of engineers using his educational models.

Edward C. Smith, Pennsylvania State University

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Abstract:

Engaging the next generation of technical thinkers is crucial for ensuring our society continues to innovate into the future. There are many possible methods for engagement that can be used to spark an interest in Science, Technology, Engineering, and Mathematics (STEM) for students in primary school and middle school. Most of these students are already familiar with LEGO bricks. By using custom built LEGO models to demonstrate engineering principles, interest in engineering can be generated and a lifelong passion for the discipline could be developed. This paper will examine the development of several novel LEGO models and their demonstration to students. These models were custom built to teach the fundamentals of vertical lift aircraft design such as power transmission, structures, and aerodynamics. Alongside the models, students were shown infographics which relate the LEGO designs to comparable real-life aircraft.

Funding from the Penn State College of Engineering was used to build three educational LEGO models which demonstrate the dynamics of various vertical flight aircraft. Two of these models demonstrate the technical characteristics of coaxial helicopters with a pusher propeller. One of the models uses a single engine, and the other is in a dual engine configuration. A LEGO tiltrotor aircraft model was also built to display the functional components of that type of aircraft.

All LEGO models were designed, fabricated, and tested until they were suitable for an educational environment. Each model was designed using the Bricklink Studio 2.0 software, which allows users to create custom LEGO models and order the pieces for such creations. All models provide insight into the inner workings of dynamic systems from various real-world aircraft.

The LEGO models were shown during a preliminary classroom presentation to middle school students. This was meant to assess the effectiveness of the presentation format. In the future, student engagement with the LEGO models will be quantitatively assessed during other similar demonstrations. A quiz is to be administered before and after each presentation. These quizzes will gauge the engineering knowledge and interest of listeners before and after the presentation was given. Results from the two surveys will be compared and used to assess newfound engineering knowledge and interest. Ideally, students will exhibit an improvement in engineering knowledge and more interest in the discipline after listening to the presentation.

Utilizing custom built LEGO models to demonstrate the function of various real-life aircraft systems is novel in pre-college STEM education. With the success of this method of engagement, the usage of custom LEGO models to demonstrate complex mechanical systems can be implemented by STEM educators on a broad scale. This method can inspire a lifelong interest in STEM for students.

Introduction

The acronym STEM refers to four different technical subject areas: Science, Technology, Engineering and Mathematics [1]. Individuals working in STEM-related careers have been credited with creating some of the most important contributions to societal advancement [2]. Therefore, there will be a need for a substantial number of STEM professionals in the future. This demand has been reflected in future employment projections. The Bureau of Labor Statistics estimates that the total employment in STEM occupations will grow 10.8% between 2022 and 2032. This figure far outpaces the overall employment growth rate of 2.3% [3]. The substantial growth of STEM careers highlights the importance society places on individuals working in this field. Efforts should be made to recruit individuals who can fulfill the future demand for STEM professionals. Inspiring an interest in STEM has been shown to be effective if it takes place early on in children's lives, even as early as middle school [4]. Generating an interest in STEM among students at an early age can increase their desire to become professionals in this field.

This paper outlines a STEM engagement method that can be used to inspire the next generation of STEM innovators. Emphasis will be put on generating interest and building knowledge in the engineering branch of STEM. The methodology outlines a process where educators can create custom LEGO models to teach students about engineering concepts. The intention behind using LEGO models specifically is to educate students about engineering through a familiar medium (LEGO bricks). This can make the topic more relatable to students and will ideally make it something they would become interested in learning more about or pursuing in their future careers. This paper also details a STEM outreach presentation where custom LEGO helicopter models were demonstrated. These models were designed to teach students about vertical flight concepts. In the future, a similar type of demonstration will be used to assess the effectiveness of using LEGO models to inspire interest and knowledge in engineering.

Literature Review

LEGO bricks have been employed in a plethora of ways to provide educational value to students. The widespread familiarity of LEGO bricks among most people aids in their usefulness in educational settings. Students at The United States Military Academy at West Point who were non-engineering majors were required to take introductory engineering courses. One such course utilized LEGO Mindstorms robots to make learning about the engineering design process more exciting for students [5]. Further, a study by Zhang and Wan describes how LEGO Mindstorms robots were used in a college level control systems course. The LEGO robots were shown to aid in students' understanding of the material, and helped hold their interest in what was being taught [6]. LEGO bricks have been used in education through the LEGO Serious Play technique as well. This method was proven to be effective in teaching various principles associated with software engineering [7], accounting [8], and management [9]. The LEGO Mindstorms and Serious Play techniques involve providing students with the ability to design their own LEGO models. However, not all applications of LEGO in the classroom involve students constructing their own creations. For example, Horikoshi details a method where LEGO bricks can be used as teaching aids in a chemistry class to demonstrate a variety of concepts, such as molecular models, density, and states of matter [10]. These models could be created by the educator and students can interact with them during class time. The stated benefits of using these models are "increasing students' enthusiasm of participating in lectures" [10]. The proposal outlined in this paper seeks to add to the work of Horikoshi and expand this type of engagement to engineering education. The authors of this paper have constructed LEGO models of vertical flight engineering technologies that may be used to generate excitement around material that is being taught and inspire an interest in engineering among young students.

Methodology

Each custom LEGO helicopter model was designed using the BrickLink Studio 2.0 software. This program was created by BrickLink, which also runs an online marketplace where LEGO products can be bought and sold. Studio 2.0 is an easy-to-understand program where LEGO pieces can be compiled to create a 3D digital rendering of a model [11]. Once a model has been created, the pieces that were used can be ordered through the BrickLink website.

The first model created by the authors was meant to showcase the internal workings of a coaxial helicopter with a pusher propeller. It features a single LEGO motor which transmits power to a gear system that allows for two sets of rotors to spin in opposite directions, in the same way a real-world coaxial helicopter functions. This model was built in an iron bird configuration, meaning it was only designed to show the internal functionality of a coaxial helicopter. There were several iterations of the coaxial model before the final design was fabricated. An initial coaxial design was constructed using the Studio 2.0 software. A limitation of this program is that it is difficult to test the structural rigidity and the gearing of Lego creations. Therefore, the parts for each design iteration had to first be ordered, assembled, and tested. For the initial coaxial model, this is the process that was followed. When this design was first built, it did not work properly. However, after deviating from the original plan, an updated version was developed. This was refined on the Studio 2.0 program, and the parts were ordered for the new model.

A second iron bird coaxial helicopter model was then designed in a similar fashion to the first. It also underwent testing and a redesign before a final version was created (Figures 1 and 2). This second model is nearly identical to the original apart from its usage of two motors instead of one. The purpose of having both the single motor and dual motor variant is to demonstrate the safety benefits of having two motors in an aircraft. The dual motor model can still function even if one of its two motors stops receiving power. The single motor version ceases to work if its only motor stops functioning. Students can see this occur during a demonstration of the two models. They can then conclude that the dual-motor version is safer than the single motor version.

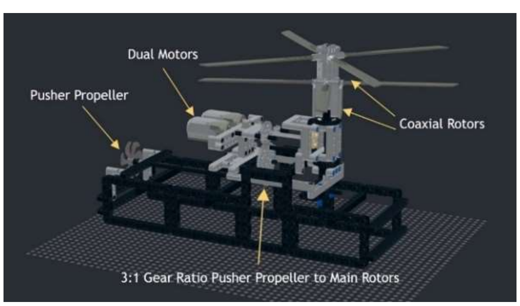

Figure 1. Digital Version of Final Dual Motor Coaxial Iron Bird

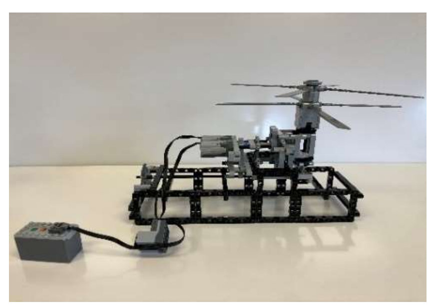

Figure 2. Physical Version of Final Dual Motor Coaxial Iron Bird

Eventually, a third iron bird model was designed, built, tested, and redesigned to display the internal workings of a tiltrotor aircraft. The final version of this model was created using the Studio 2.0 program (Figure 3) and then built into a physical model (Figure 4). At the end of each wing, there is a nacelle which houses a LEGO motor that transmits power to a propeller. As is seen on a real tiltrotor aircraft, these nacelles can rotate 90 degrees so that the propellers can face either forward or upward. When the nacelles are rotated so the propellers are facing upwards, flaps on the trailing edge of each wing also rotate to point perpendicular to the ground. When the nacelles rotate to the position where the propeller blades are facing forward, the trailing edges rotate in an orientation parallel to the ground. This functionality can also be seen on real world tiltrotor aircraft. The trailing edge flaps are connected to the nacelle by a hinge which allows for the nacelles and trailing edge flaps to move in tandem. Additionally, this model was designed to show how a tiltrotor aircraft can fly using only one engine. A driveshaft was implemented which connects the two motors on each nacelle. If one motor was made to stop working, the other motor can still power both propellers on the model.

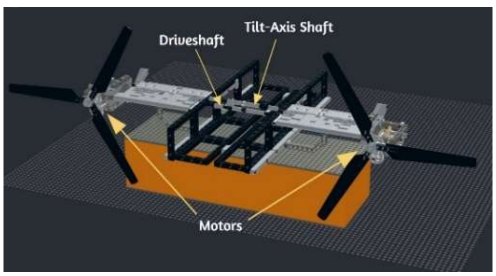

Figure 3. Digital Version of Final Tiltrotor Iron Bird with Propellers Facing Forward

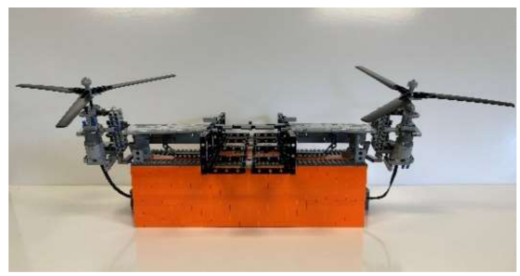

Figure 4. Physical Version of Final Tiltrotor Iron Bird with Propellers Facing Upward

Educators wishing to replicate this design methodology are not limited to creating LEGO models of vertical flight systems. Teachers could construct custom LEGO models based on any engineering concept that they wish to inform students about. The Studio 2.0 software can be used to aid in designing these models. The LEGO models are intended to be designed, fabricated, and tested by educators seeking to create an exciting tool for students to interact with and learn from. Educators can describe to students the engineering process behind creating the models and relate this process to the work of real-world engineers.

Engagement Presentation

Using surveys to collect quantifiable data is currently pending Institutional Review Board (IRB) approval. Once approval is secured, a demonstration of the LEGO models will be conducted which will utilize pre-quizzes and post-quizzes to collect data. This data will be used to determine the effectiveness of using LEGO models to increase engineering interest and knowledge among students. Before survey data could be collected, a STEM outreach presentation was given to middle school students which utilized the LEGO models. Lessons learned from this initial presentation will help prepare the authors for future demonstrations where quantifiable data will be collected. This approximately forty-minute-long presentation was given to two sixth grade classes and four fifth grade classes.

Students were shown a PowerPoint slideshow and the three educational LEGO models during the presentation. The PowerPoint slideshow consisted of general information about engineering and supplemental terminology and imagery about the LEGO models. Students were first asked to define engineering and a discussion about the definition of the term ensued. Then they were told about the future demand for engineers that has been predicted by the Bureau of Labor Statistics. Listeners were also shown biographies of one male and one female engineering student at Penn State University to show that engineering is not a gender specific career. Student listeners were also told about several common engineering disciplines and the defining characteristics of each.

Following the introductory engineering information, students were shown an image of the Sikorsky X-2 coaxial helicopter next to the LEGO models that replicated the aircraft. Students were also shown an image of the Bell-Boeing V-22 Osprey tiltrotor and its LEGO equivalent. Then students were asked to crowd around the LEGO models and a demonstration of their features was given. The Studio 2.0 software files for each model were then shown to the students.

The specific design context for creating the LEGO models was summarized. This context was defined as the design, build, and test cycle. Students were told that this process can be employed while building with LEGO and can also be utilized by engineers working in industry. Thus, the connection was established that building with LEGO bricks is engineering. The presentation concluded with students being asked to answer questions about the presentation.

Preliminary Evidence and Discussion

Observations from the initial presentation indicate that it was well received overall. When students first entered the classroom, many approached the models and appeared to be fascinated by how they were made entirely out of LEGO bricks. In each presentation, almost all listeners seemed to be excited about what was being taught. Based on the presenting author's observation, the fifth grade classes appeared to be more engaged with the presentation. In each of the four fifth grade classes, more than half of the students participated in the presentation by answering questions or asking questions of their own. During the sixth grade presentations, less than half of the students participated. Additionally, in each presentation there appeared to be a higher proportion of male students who participated than female students.

It appeared that students' knowledge increased after listening to the presentation. Students were initially given the definition of an Iron Bird model and were shown the safety benefits of having two engines on an aircraft. At the end of the presentation, students had no trouble defining the term Iron Bird and explaining the redundancy associated with having two engines.

The overall positive reception to this initial presentation could have been due to the usage of custom LEGO models. However, since other information about the relevancy of engineering (such as future employment data) was shared, the presentation format would likely not be ideal for establishing a connection that custom LEGO models can be used to increase engineering interest and knowledge among students. Therefore, a future demonstration intended to measure the effectiveness of using LEGO models as an engineering engagement method should have increased emphasis on the LEGO models themselves. This future presentation format can still include a PowerPoint slideshow to provide supplementary information; however, the information provided should only concern the LEGO models and their connection to engineering. A possible PowerPoint slide that can be carried over from the initial to the future presentation is shown in Figure 5. Further, a future demonstration format could include more student interaction with the models. For example, small groups of students can have hands-on interaction with the models and try to determine for themselves why the dual motor version is safer.

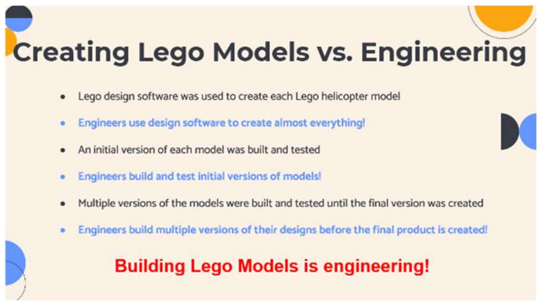

Figure 5. PowerPoint Slide from Initial Presentation

Future Research

Identified improvements from the initial presentation will be considered when developing the structure of the next presentation. Once IRB approval is secured, a demonstration will be conducted that gathers quantitative data to statistically gauge the effectiveness using LEGO models as an instrument to generate interest and knowledge in engineering. The usage of pre-quizzes and post-quizzes will measure engineering interest and knowledge before and after the presentation. These quizzes will anonymously track student responses by gender and grade level. Comparisons will be made between male and female genders to determine preconceived ideas about engineering and how these notions may have changed after listening to the presentation. Questions from pre-validated survey instruments will be implemented into the pre-quizzes and post-quizzes. This will ensure that all obtained data is reliable and can accurately measure the effectiveness of the proposed engagement method.

In the future, a program can be developed in which students follow the design process outlined in the methodology. The current presentation format that was explored was intended to be a one-time event which fits into an approximately forty-minute-long window. Due to the time constraints with this format, students can only be told about the design process behind the models rather than employ it themselves. With a longer format, students can design, test, and redesign their own models and learn about the process behind creating a mechanical system. This program would require more time than a forty-minute period and can be conducted periodically over several weeks. The effectiveness of this type of program can be compared against the one-time format.

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