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## **Development of Attachments for the Quanser Qube**

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# Development of Attachments for the Quanser Qube

## Introduction

The Quanser Qube is an integrated servomotor lab hardware platform [1], shown in Figure 1. This platform includes not only the direct-drive brushed DC motor, but also two encoders as well as the data acquisition system. One encoder is used to measure the rotation of the DC motor's shaft itself. It is supplied with two standard items, an inertia disk and an inverted pendulum. The inertia disk is a small aluminum part, which mounts to the equipment using magnets. The inverted pendulum also mounts to the equipment with magnets, with an encoder that plugs into the equipment to provide an additional sensor input to the system. The system includes an amplifier and other necessary components in order to be controlled with either LabVIEW or with MATLAB/Simulink, with the LabVIEW control requiring the National Instruments myRIO device [1].



Figure 1: Quanser Qube

In this work, a set of new attachments for the Quanser Qube was developed. The attachments have been fully designed, and some of them (the inertial disks) have been produced and tested; the remaining attachments will be fabricated and tested when the ongoing COVID-19 pandemic has abated and full access to the necessary facilities and labs is possible.

## Background

The value of lab exercises in system dynamics and controls has been widely acknowledged for some time, e.g., [2], [3]. At times, equipment is designed and produced exclusively by the lab

instructors or others at the university, as in [4], [5], [6]. In other cases, an existing, commercially available solution is used for modeling or experimental labs, as in [7], [8], [9]. It is also possible to have a combined approach, in which an existing solution is used, with some enhancements or additional attachments developed, as described in [10].

At the authors' institution, the Quanser Qube is used in the senior-level controls lab, with the National Instruments myRIO used as the controller. Students are provided with LabVIEW files to run the Qube, which allow them to save their data for later analysis and plotting. The labs conducted with the Qube all utilize the inertial disk. The inertial disk is chosen because this allows a linear model to be used, which aligns with the knowledge level and course content appropriate to this class; the inverted pendulum is occasionally used for demonstration purposes, but no labs utilizing this attachment are performed.

Currently, the labs carried out with the Qube focus on model validation and on control. In the area of model validation, students have a purely simulation-based lab where they compare first and second order models of the device, to determine under what conditions the motor inductance could be neglected, and are given the Qube's inductance and asked to justify their choice of model for it. In the next lab, they utilize the device itself, and compare experimental data to the theoretical performance that they expect, then are asked to reflect on the reasons for discrepancies. In a later lab, students develop a controller for the Qube. They are given a set of specifications that the controller should achieve; these differ from one term to the next, but typically involve parameters such as overshoot and settling time. They are then asked to calculate values of gains, then apply those gains to the device, determine how well it meets specifications, and attempt to use their conceptual knowledge of what different gains accomplish to tune the controller appropriately.

Use of the inertial disk allows a number of labs to be performed, involving system identification, model verification, and control, but there are limits to the range of what can be done. The DC motor can be approximated as a first order system, due to the low value of the motor's inductance, which leads to a second-order system for the angular position of the disk. Furthermore, with only one possible inertia for the disk, all students will have the same values for the lab both within the class and across terms. This reduces the ability to easily change labs to detect incidents of copying from "crib files", and does not allow for a model that is validated for one set of circumstances (the original disk) to be tested for a different case. Therefore, it was decided that additional attachments of varying types would be developed for the Qube. These would allow for a greater range of lab exercises, as well as the possibility of using the Qube for more open-ended projects.

### **Design of New Attachments**

A variety of new attachments were created, ranging from a variety of simple disks of varying inertia to more complex devices. The various inertial disks are described first, followed by the other types of attachments.

## Alternative Disks

Four disks were designed which varied in size, mass, and inertia. These disks were produced using 3D printing, and then had the appropriate magnets glued into recesses in the bottom of the disks in order to mount them on the Qube. The disks are summarized in Table 1, with isometric views of them shown in Figures 2 – 5.

Table 1: Inertial Disks

Disk #	Max. Dia. (mm)	Max. Height (mm)	Mass (g) (with magnets)	Inertia ( $10^{-6}$ kg-m <sup>2</sup> )
1	49.60	12.40	15	4.27
2	49.60	12.40	10	2.34
3	68.00	6.20	14	8.09
4	30.00	22.20	9	1.01

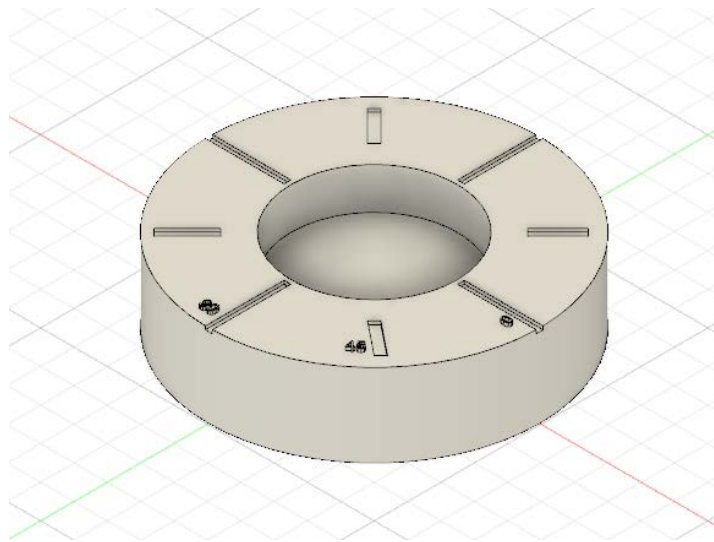


Figure 2: Disk #1 - Mass Distribution at Outer Edges

For the first disk, as shown in Figure 1, the mass is distributed to the outer edges, producing a relatively higher inertia, compared to the second disk (Figure 2). Both disks have the same outer diameter and overall height; however, the mass and inertia are different due to the mass distribution.

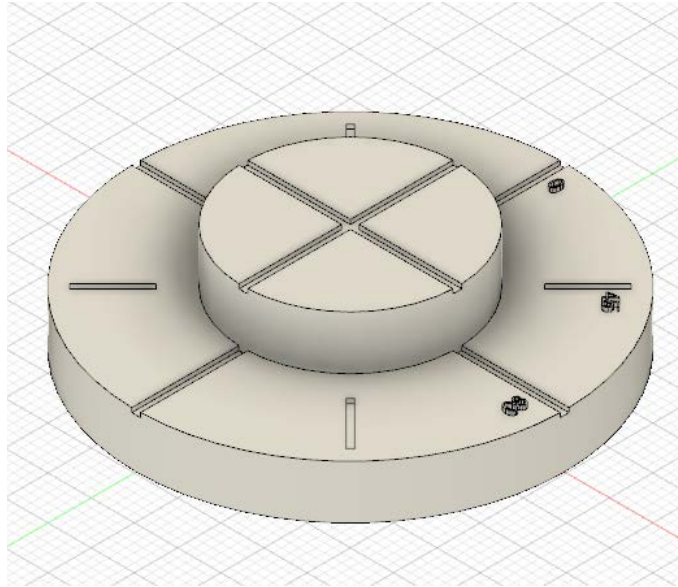


Figure 3: Disk #2 - Mass Concentrated Nearer the Center

In contrast to these two, the third disk, shown in Figure 3, is a simple flat disk with a larger diameter.

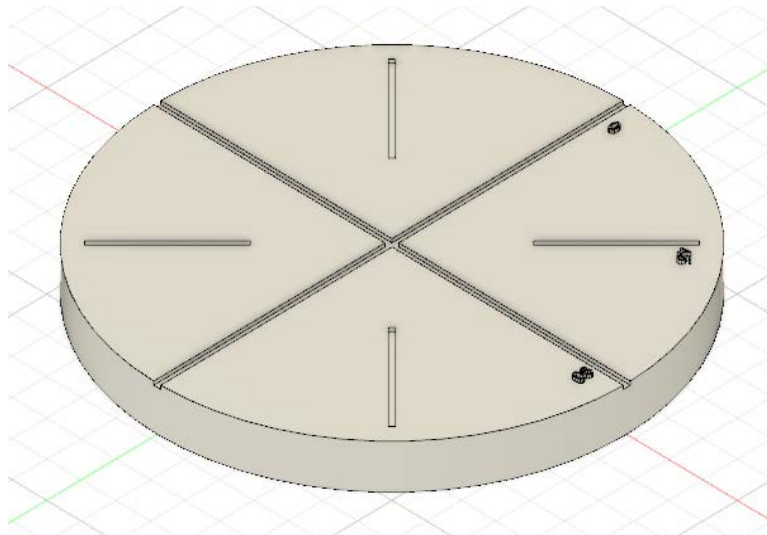


Figure 4: Disk #3 - Constant Thickness Disk

The fourth and final disk, shown in Figure 4, is also of uniform thickness, but is taller and smaller in diameter than the third one.

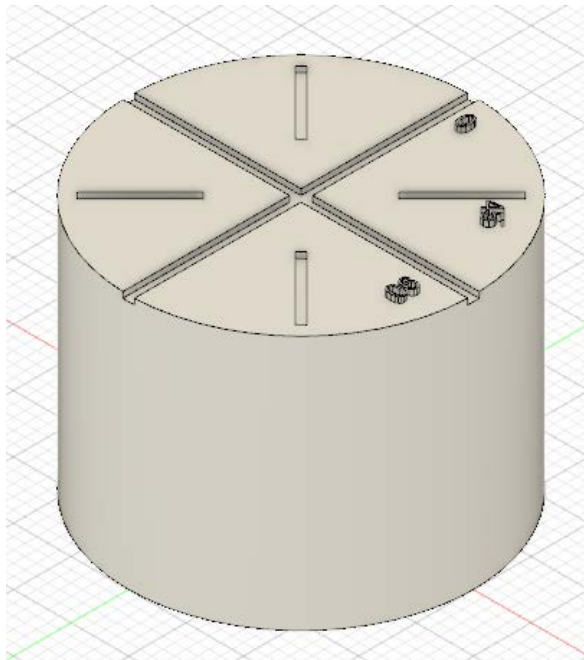


Figure 5: Disk #4 – Tall Constant Thickness Disk

Simulations were performed with these disks, in order to determine how much the results of a simple lab might vary. It was assumed that a simple square wave, varying from 0 to 2 V, would be input to the motor. The results of the simulation are shown in Figure 5. As these results show, the steady-state value of the Qube’s speed does not change; however, the time constant clearly does experience changes.

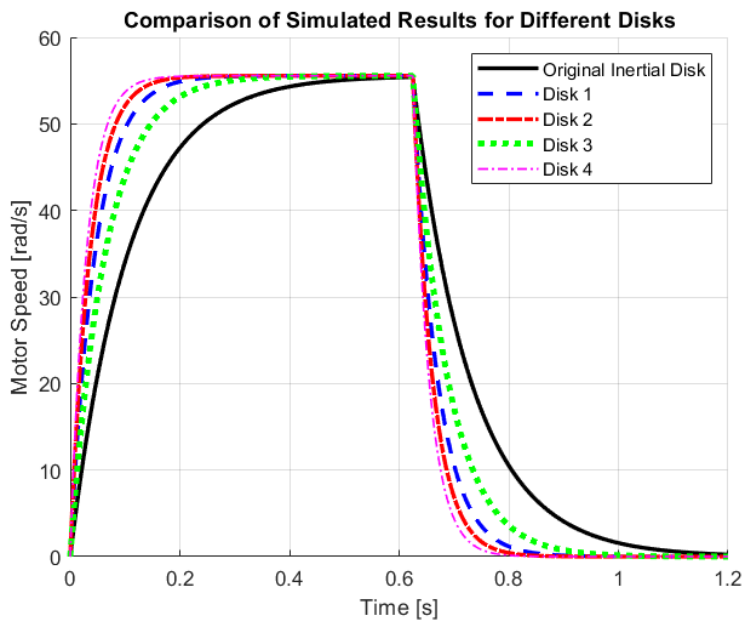


Figure 6: Comparison of Simulated Results for Different Disks

Use of these varying disks could allow a lab to be conducted in which students would be asked whether they expect the steady-state value to vary, and if so, why; and then to test their hypothesis using the disks. Other labs could be conducted based on the types of analyses conducted in [7], with other disks aside from the provided one. Additional labs could be designed to look at the impact of uncertainty; the variation from one provided aluminum disk to another can be expected to be minimal, compared to the variation seen in the 3D printed plastic disks.

### Gear Drive

The gear drive attachment is a setup that utilizes two Qubes. One is the driving Qube, and the other is driven, and is used for sensing purposes. This gear drive is comprised of four gears: a 0.7-inch diameter gear, a 1.3-inch diameter gear, a 1.9-inch diameter gear, and a 2.5-inch diameter gear. It also includes 2 custom made components that are used to attach the 2.5-inch gear and the 0.7-inch gear to the Qubes in the same matter as the standard inertia disk. The last piece is an assembly plate that secures the other two gears, the 1.3-inch and 1.9-inch, in place and keeps the Qubes at a nominal distance for the gear drive to work. This setup is shown in Figure 7.

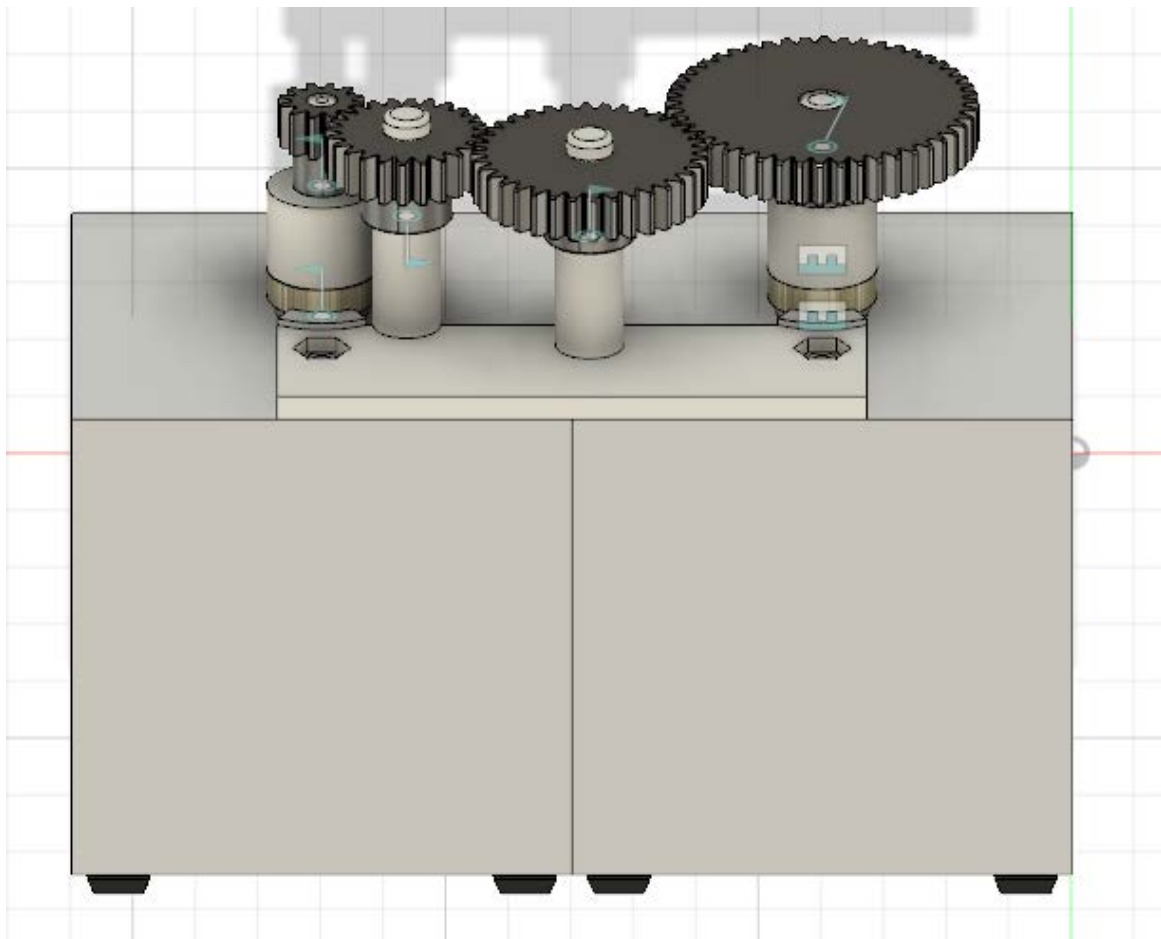


Figure 7: Gear Drive Arrangement



By creating this more complex system, students could perform a lab in which they examined issues that could be seen in a gear drive. A comparison could be performed between simulated results and actual results, with the goal of determining what the impact of backlash might be, or where there could be unmodeled losses in the system. In addition to its use in modeling exercises, a control system could be applied, allowing students to see what the impact of backlash is when a system is subject to a controller.

#### Drive Belt with Synchronous Pulleys

Another configuration using two Qubes uses a synchronous belt and pulleys. This arrangement is comprised of a 1.63-inch diameter pulley, a 0.88-inch diameter pulley, and a timing belt. Much like the gear drive, there are custom made components to connect the components to the Qubes. Similarly, the first Qube will drive the system, with the second sensing the results, as shown in Figure 8.

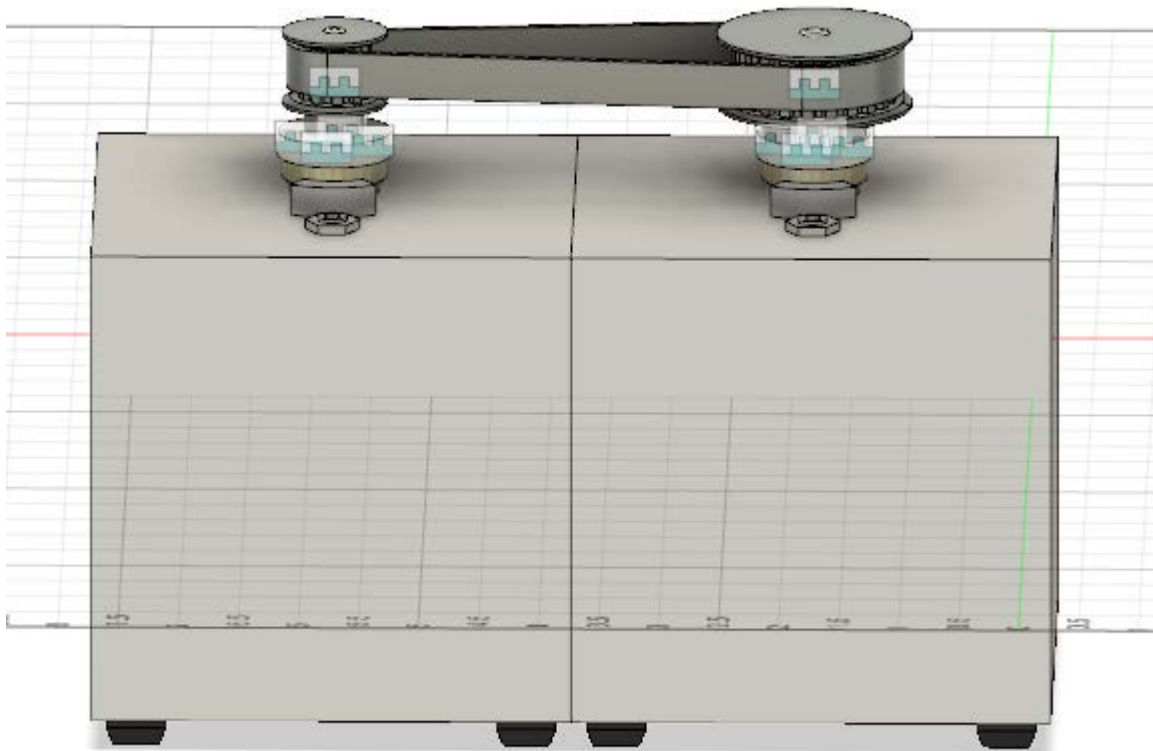


Figure 8: Belt & Pulley Arrangement

This configuration allows similar types of lab exercises to the gear drive system. In addition to asking questions about backlash with synchronous belts, students could be asked to evaluate whether belt stretch is likely to be a significant concern, and then support their evaluation with experimental data.

### Four-Bar Linkage

The four-bar linkage uses a single Qube, although an arrangement using a second Qube for sensing purposes could be designed as well. This setup consists of a 1-inch long bar segment that attaches to the rotating part of the Qube, a 2-inch long bar segment, a 1.5-inch long bar segment, and a plate that acts like a stationary 1.96-inch long bar segment, as shown in Figure 9.

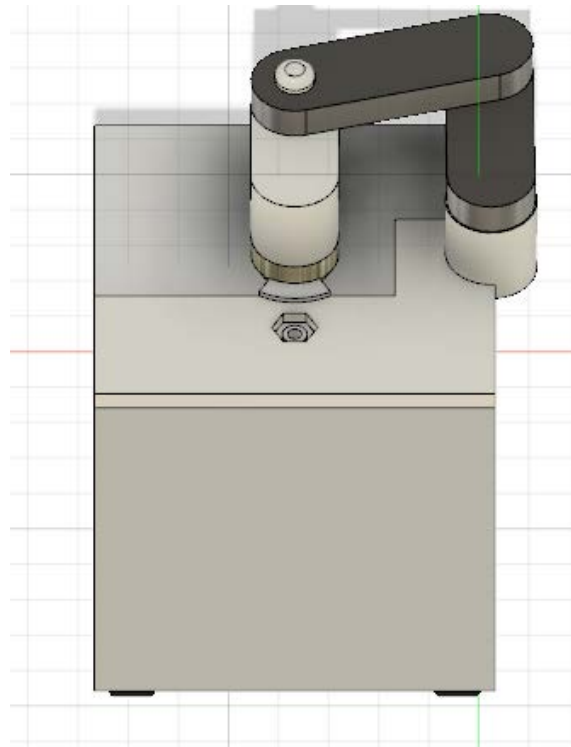


Figure 9: Linkage Arrangement

The four bar linkage differs from the previous two setups in that it is inherently a nonlinear system. This setup could be used in a more complex modeling class, with students validating a nonlinear model. It could also be used to investigate issues of linearization; if a linearized model is used, students could evaluate for what range of motion they felt it was accurate enough to be useful.

### Wind Turbine

The final attachment designed in this project is an adjustable wind turbine. This device, utilizing a single Qube, is comprised of a base plate to attach the turbine to the Qube, a vertical shaft that mounts to the Qube's output shaft, a horizontal shaft with slots for propeller poles, 6 propeller poles, and two miter gears. The propeller poles are adjustable, and additional ones could be made of different materials and with different geometries. The Qube is used not to drive the device, but as a sensing means; its internal encoder reads the rotational speed of the turbine, which could be used to compare different configurations and understand how much electricity could be generated. This setup is shown in Figure 10.

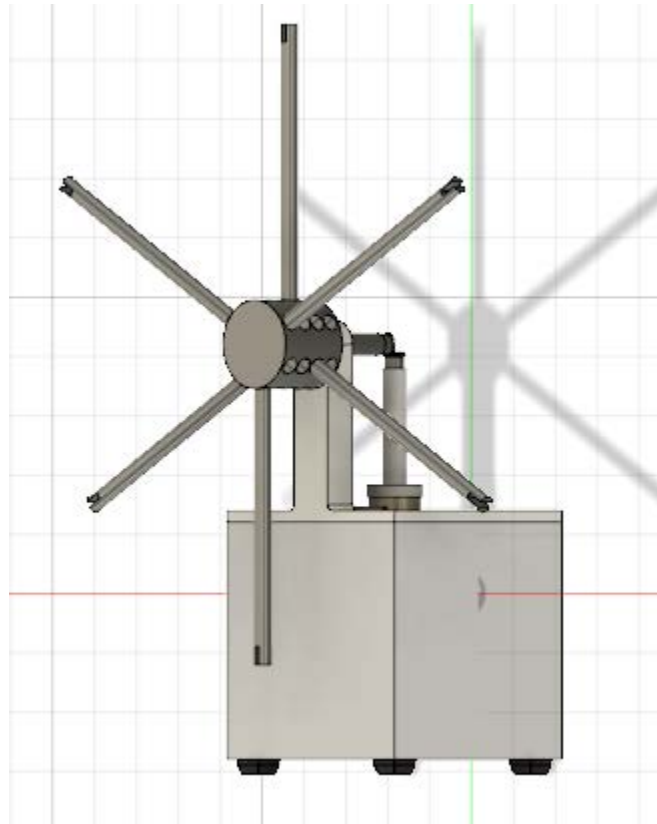


Figure 10: Wind Turbine Arrangement

This attachment could be used in labs beyond the Dynamic Systems courses in which the Qubes are often used. It could be used for a course in which the focus is on materials, on fluid flow, or on energy generation; if a university has a wind tunnel of moderate size, the Qube with this wind turbine could be placed in it for a variety of different experiments.

### **Summary and Conclusion**

In this paper, designs for a variety of different attachments for the Quanser Qube have been presented. The use of such custom designs for a purchased piece of hardware combines the advantages of a well-supported commercial platform with the flexibility of a custom-designed lab solution. The designs presented could be used for a variety of different types of labs, expanding the usefulness of the equipment. In addition, they could be used to spark student ideas, in a more open-ended lab in which students could design their own attachments and run them with the Qube. By doing so, the effectiveness of lab experiences can be enhanced.

### **Acknowledgments**

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