Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Low Cost 2D-Hover Puck

IOP Conf. Series: Journal of Physics: Conf. Series **1076** (2018) 012025 doi:10.1088/1742-6596/1076/1/012025

Low Cost 2D-Hover Puck

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Abstract. The present contribution presents the development of a teaching tool for two-dimensional mechanics. A *Low Cost 2D-Hover Puck* has been designed and engineered, with which gravitational effects are locked out and motion in two dimensions can be shown. A horizontally aligned fan is mounted on top of the Hover Puck and provides constant acceleration. Now, experiments about motion with initial velocity and a constant acceleration in an arbitrary direction can be conducted by students or teachers. Due to the simple and inexpensive design, the Hover Puck can be assembled by students, by almost only using household objects and is therefore ideal for school.

1. Introduction

In traditional physics lessons, gravitational force is often used to teach constant accelerated motion. Free fall, an inclined plane or a horizontal throw, for instance, are typical settings for this teaching purpose. Gravity, however, as we know from literature (Stadler 1996), comes with a number of misconceptions and learning barriers for students (Müller *et al.* 2011, Wiesner *et al.* 2011).

> *Gravity is pervasive, acts invisibly, is not a subject to control, and is often invoked by students as a name without a well-defined concept behind it.* (Morse 1993)

As outlined by Morse, the two main learning barriers with respect to gravity are, that it acts invisibly and that it is not a subject to control.

Knowing the drawbacks of gravity as a source for acceleration, Morse (1993, 2005) developed a different approach towards teaching accelerated motion. Instead of the classical experiments, he introduced low-friction carts on rails, on a tabletop plane, to show constant accelerated motion, so that gravitational effects are locked out. In these carts acceleration is realized with one or more horizontally aligned fans. Using fans for acceleration brings a number of advantages over gravity. The accelerating effect no longer acts invisibly; it can be seen and even heard. Students even can roughly anticipate the thrust of two fan units, by comparing their pitch when operating (Morse 2005, p. 162). Contrary to traditional experiments, experiments with Morse's carts can manipulate and analyze mass, force and time of acceleration independently. Carts can be loaded with additional weights, or several carts (without fans) can be stacked onto each other to increase the total weight. The number of fans can be adapted, as well as their direction of thrust. Fans can be aligned to provide thrust in one direction, as well as they can be mounted onto the cart in an opposing way. These possible adjustments offer a range of possible experiments concerning one-dimensional accelerated motion, by simultaneously locking out gravitational effects (Morse 2005).

However, literature shows (Tobias 2010), that teaching motion in two dimensions is superior to teaching motion in a one-dimensional setting. Students show a significantly better understanding of the vectorial nature of motion, if a dynamical, two-dimensional approach towards mechanics is offered.

By creating a two-dimensional setting for teaching motion and simultaneously locking out gravitational effects, we can enhance Morse's carts to provide a beneficial learning environment for students in introductory mechanics.

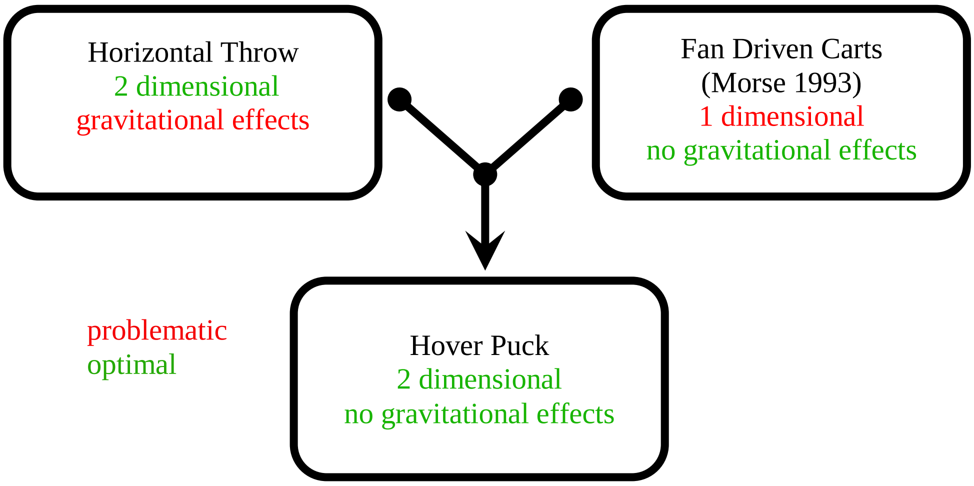

Fig. 1. Benefits of the Hover Puck

Fig. 1 shows the advantages and disadvantages of the traditional approach (Horizontal Throw) and Morse's (1993, 2005) more modern approach towards teaching motion with fan driven carts. Fig. 1 additionally depicts the idea of combining the advantages of two ways of teaching mechanics (throw and carts) to create a teaching material, which accommodates both, the exclusion of gravitational effects and a two-dimensional way of operation.

2. Beneficial learning environment

A two-dimensional curriculum for introducing motion

Building on an adapted concept of Jung, Reul and Schwedes (1977), Wiesner *et al*. (2011) developed a two-dimensional curriculum for introductory mechanics, which is already successfully implemented in Bavarian 7th grade (12 to 13 year olds). It introduces the concept of force in a dynamic way, by explicitly excluding the term *acceleration* from the equation of motion, resulting in:

$$\vec{F} \cdot \Delta t = \Delta \vec{v} \cdot m$$

By deliberately substituting acceleration by its integrative form $\vec{a} = \Delta\vec{v}/\Delta t$ and bringing the *time of interaction* to the *interacting force*, the concept uses the impulse formula as a basis for discussing the concept of accelerated motion. The focus of the mechanics curriculum lies on the vectorial nature of movement and encourages students to discuss changes in direction or speed based on a vector based understanding of motion.

A teaching tool for teaching motion in two-dimensions

A teaching tool for showing constant acceleration in a two-dimensional plane, can extend Wiesner *et al.'s* (2011) content structure in providing a simple hands-on-experiment for students to physically experience constant accelerated motion in two dimensions.

Concluding from these guidelines, a Low Cost 2D-Hover Puck for teaching motion in two dimensions has been designed and engineered.

Fig. 2. Hover Puck – view from the left (modified from Pürmayr 2017)

Fig. 3. Hover Puck – view from the rear (modified from Pürmayr)

One core point of designing the Hover Puck was to realize it as a low-cost experiment. Most of the components are household objects and the assembling can easily be done by students at home or at school.

For the wiring of the apparatus, a soldering kit is needed. The total costs of the Hover Puck sum up to about 15€, if propellers and DC-motors have to be bought.

The mount (base structure) for motors and batteries, as well as the propellers, can be 3D-printed by a data-file provided. It can be downloaded from the Website of the Austrian Educational Competence Centre for Physics[1].

If the setup and the propellers can be self-printed, the total costs of the Hover Puck are reduced to about 5€. Batteries are not included in the costs, since old cellphone-batteries are sufficient for powering the Hover Puck. They usually can be charged using an universal charger.

Fig. 4 shows the simple setup, as well as the color coded parts, which are itemized in the parts list in table 1 below. For reasons of simplicity the wires and garbage bag are not shown in Fig. 4.

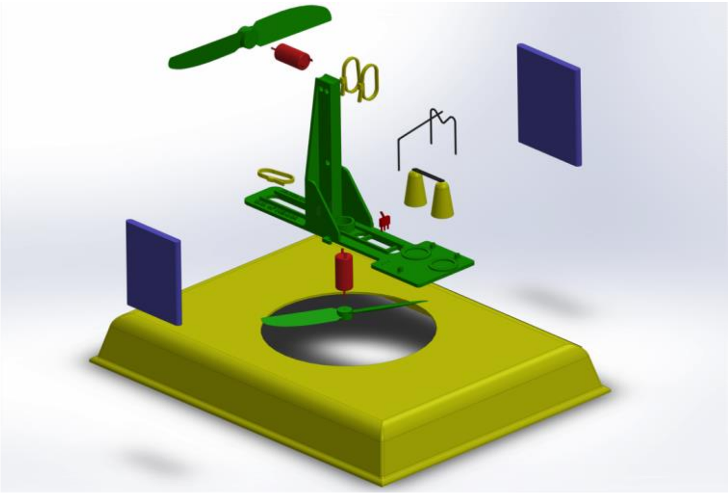

Fig. 4. Construction view of the Hover Puck (Pürmayr 2017, p. 58)

[1] http://aeccp.univie.ac.at/fileadmin/user_upload/kompetenzzentrum_aeccp/Materialen_Physik_Verstaendlich/Mechanik/Hover Puck.zip.

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Table 1. Parts of the Hover Puck. The color coded parts from Fig. 4 are labeled in the column *Color Code* (modified from Pürmayr 2017)

Component	Quantity/ Length	Cost per Piece [€]	Notes	Color Code
Styrofoam tray	1	0	Household object	yellow
Zipties	3	0	Household object	yellow
Foam ear plugs	2	0	Household object	yellow
Duct tape	1 m	0	Household object	yellow
Garbage bag	1	0	Household object	yellow
Paper clip	3	0	Household object	yellow
Base structure	1	0.25	3D-print	green
Vertical fan	1	0.05	3D-print	green
Horizontal fan	1	0.05	3D-print	green
Motors	2	0.73	Part to be purchased	red
Miniature switch	1	3.09	Part to be purchased	red
Wire	0.4 m	0,07	Part to be purchased	red
Cellphone batteries (SAMSUNG)	2	0	Picked up from recycling facility	violet
TOTAL COSTS		4.97		

We chose a three-way miniature switch to provide possibilities for expanding the current modes of operation of the Hover Puck (E.g. adding a different thrust of the horizontal fan).

Mechanics of the Hover Puck

Fig. 5 shows a simplified version of the Hover Puck in a sectional view. Two fans (one vertical and one horizontal) are used to power the Hover Puck.

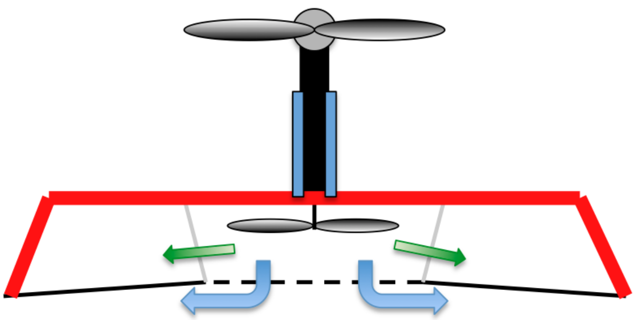

Fig. 5. Sectional view of the Hover Puck (modified from Pürmayr 2017)

Used phone-batteries provide electrical power for the motors and fans and are placed right next to the vertical structure, which serves as a mount for the horizontal motor. The placement of the batteries (Fig. 5, blue bars) has a crucial impact on a stable run of the Hover Puck, since a centered distribution of mass is required for balancing the Hover Puck.

A styrofoam tray (Fig. 5, red) is turned upside down and serves as a base. The open side of the tray is covered with a plastic bag (Fig. 5, black), which is lifted up by two threads (Fig. 5, grey). A round cutout (dashed line), right under the vertical fan, allows air flowing underneath the Hover Puck (blue arrows). The green arrows (Fig. 5) represent the portion of the air, flowing sideways and blowing up the plastic foil. Due to the increased pressure inside the styrofoam tray, the puffed up plastic foil compensates uneven patches such as joints or small gaps in the underground.

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Due to the air flow to the sides (Fig. 5, green) and under the Hover Puck (Fig. 5, blue), an air cushion forms underneath the Hover Puck, reducing friction to a minimum. The residual friction results from sliding friction between the foil and the surface material.

Now, motion in two dimensions on a tabletop plane can be shown and can even be expanded by a component of constant acceleration in an arbitrary direction. The horizontal acceleration of the Hover Puck is realized by the horizontally aligned fan (Fig. 5).

The fan can be activated manually, or by a time delay switch, allowing creation of a non-influenced setup for experiments.

Fig. 6 shows the mechanics of the time delay switch. Two blank paper clips (blue and red) are bent, serving as contacts. The wires leading to the battery are represented by the black curved lines and are soldered to the bent paper clips. In its open position, the bent paper clips don't connect to each other and therefore, the electric circuit is open. As shown in Fig. 6 on the right, foam earplugs are used to activate the horizontal fan, by pushing the blue wire up against the red wire, closing the circuit. Another paperclip (Fig. 6, black) is used as a web, connecting the foam ear plugs. The time of activation can be delayed from 1 to 20 seconds, by the amount of force applied to press down the ear plugs.

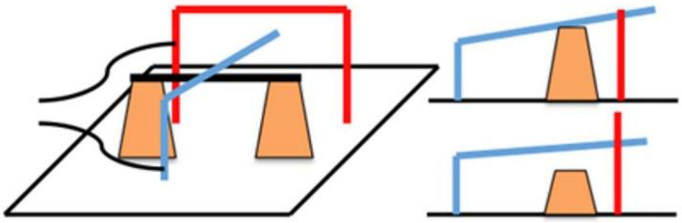

Fig. 6. Time delay switch (Pürmayr 2017)

For an adequate use of the Hover Puck for introducing motion in a two-dimensional setting, the constancy of acceleration is key. The Hover Puck has been tested for the change of acceleration over time to ensure its suitability for a two-dimensional approach towards mechanics.

Fig. 7 shows the linear acceleration of the Hover Puck over time. The x-axis shows the time in seconds and the y-axis depicts the acceleration of the Hover Puck. The unit of the acceleration in Fig. 7 is arbitrary, for the magnitude of the acceleration highly depends on the conditions of the ground's surface.

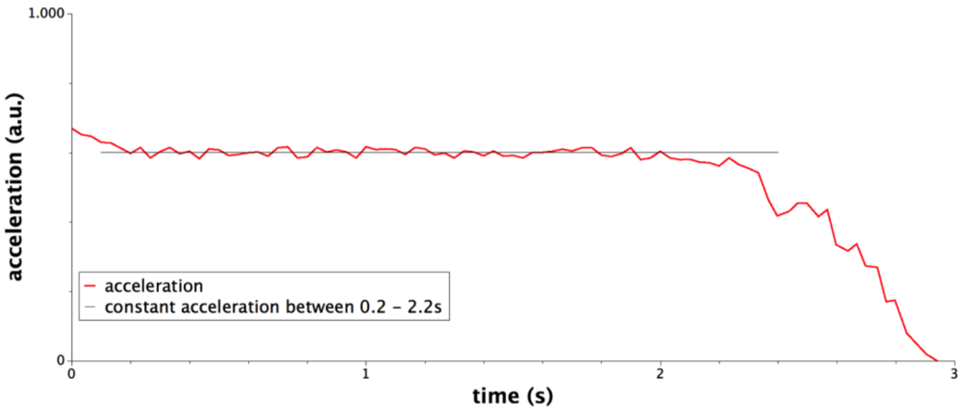

Fig. 7. Constant acceleration over time of the Hover Puck (Pürmayr 2017)

As Fig. 7 reveals, acceleration can be considered as constant between 0.2 and 2.2 seconds, creating the possibility to teach constant accelerated motion in a two-dimensional setting.

Examples for viable Experiments

Figs 8 and 10 show two examples for possible experiments with the Hover Puck.

Two-dimensional motion with an initial velocity to the left and constant acceleration in a forward direction can be shown. The Hover Puck is set in motion in a direction perpendicular to the acceleration of the Hover Puck (Fig. 8). The horizontal fan is activated right at the start, showing, in combination with the initial velocity to the left, a constantly accelerated motion.

The vectors of the velocity to the left (red) and the velocity forward (green) add together to the resulting velocity (blue) of the Hover Puck at a certain time. The construction of the vectors of velocity can be done by students, to provide an insight into the mechanics of motion. Fig. 8 has been created using a free motion shot app on a smartphone.

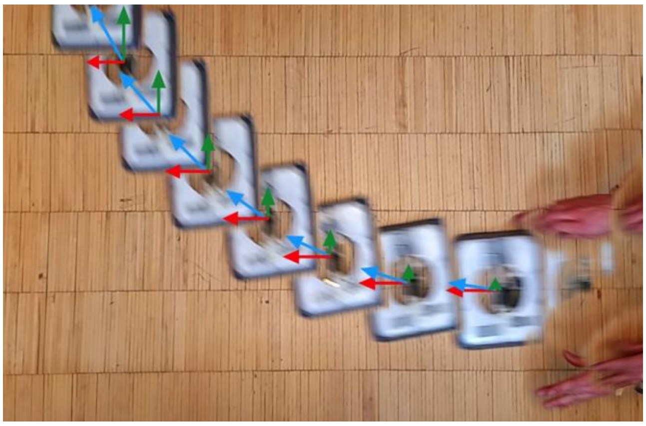

Fig. 8. Constant acceleration perpendicular to initial velocity to the left (Pürmayr 2017)

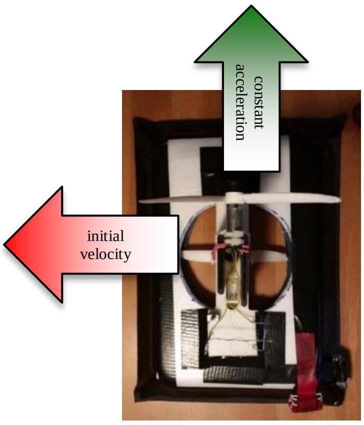

Fig. 9. Directions of initial velocity and acceleration (Pürmayr 2017)

The Hover Puck can also be used to show one-dimensional accelerated motion (Fig. 10). The time-delay switch provides a non-manipulated system by delay triggering the activation of the horizontal motor.

Just as in the previous example, the stop-motion illustration has been created with a smartphone-app to show the acceleration.

Fig. 10. Linear constant acceleration of the Hover Puck (Pürmayr 2017)

3. Outlook

For further development of the Hover Puck, Austrian teachers, with experience with Wiesner *et al.'s* (2011) mechanic curriculum have been interviewed. The goal was to gather information about possible applications and difficulties concerning the Hover Puck in Physics classes. This feedback will be used to improve the Hover Puck to become a viable teaching tool for teaching introductory mechanics, which will be tested in school for its effectiveness on learning.

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