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Fluid Mechanics Education Using Japanese Anime: Examples from “Castle in the Sky” by Hayao Miyazaki

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Current K-12 and undergraduate students have grown up with constant exposure to visual popular culture (e.g., movies, TV programs, graphic novels, etc.). Because youth find pop culture references in the classroom to be engaging, many science and engineering instructors have shown that examples found in visual pop culture can be used to teach science and engineering concepts.^{1,2} One recent study on the efficacy of using pop culture for instruction found that high school students learning from graphic-novel style comics acquired deeper understanding of complex subject matter and reported higher engagement with the instructional materials as compared to students learning from traditional text materials.³ Furthermore, the increased engagement with the instructional comics was even greater for students who were less likely to self-identify as a “science person.”

Japanese animation, or anime, is one genre of visual pop culture that has steadily gained popularity in the United States,^{4,5} and many traditionally aged college students were exposed to anime as children through popular franchises (e.g., Pokémon, Yu-Gi-Oh!, Dragon Ball, and Naruto) and anime conventions held in many cities. However, compared to other types of visual pop culture, there is far less literature describing how anime can be used to curate instructional examples. In this paper, we suggest using examples found in anime for teaching fluid mechanics, a branch of physics dealing with fluids, to college students.

Anime has been incorporated into foreign-language instruction, for learning both English⁵ and Japanese.⁶ Other types of visual pop culture have been used across a range of subjects (e.g., chemistry,⁷ biology,⁸ physics,⁹ and business ethics¹⁰). Bringing visual pop culture into the classroom can help to create a common experience among students that can then be used as an anchor for learning key concepts while connecting with students’ interests and increasing engagement.² Animation can be useful for teaching physics, because although animation generally reflects reality, it is less constrained by reality than is live-action media, and this potential for separation from reality provides opportunities to test the extent to which principles of physics are bent in the “world” of the animated characters.⁹ Anime is one class of animation that has been underexplored as a source of novel, engaging examples for teaching physics. Next, we present three specific examples of how concepts in fluid mechanics can be presented and taught through scenes in one anime movie.

The most well-known Japanese animator is Hayao Miyazaki.¹¹ Through his anime movies, Miyazaki has consistently

Fig. 1. (a) Poster of “Castle in the Sky” directed by Hayao Miyazaki (© 1986 Studio Ghibli) shows that Sheeta falls with her magic crystal amulet (supine position) as Pazu watches. **(b)** Fluid mechanics forces on falling Sheeta (vertical position). F_D = drag force, F_B = buoyant force, F_W = body weight, and U = terminal speed. As the force arrows (not to scale) indicate, F_B is very small compared to F_W as shown in Eq. (2). Reproduced from “Castle in the Sky” (© 1986 Studio Ghibli).¹²

expressed his love for aircraft and things that fly. Therefore, his movies can easily be incorporated in lectures about fluid mechanics. In this paper, we introduce examples of fluid mechanics in Miyazaki’s “Castle in the Sky” [Fig. 1(a)], which is enjoyable to various age groups and contains many fluid mechanics-related scenes. In this anime movie, a young girl named Sheeta has a magic crystal amulet race with a brave boy named Pazu against air pirates and secret agents in their search for a legendary floating castle, Laputa.

Buoyancy, drag force, and terminal speed of falling Sheeta

The first example is the free fall of Sheeta. She falls from the airplane after she was kidnapped by the agents. During the free fall, she experiences three force components [Fig. 1(b)]. First, body weight (F_W) from gravity drives the free fall, which depends on the body volume: $F_W = \rho_{\text{body}}gV = mg$, where ρ_{body} is the density of her body, g the acceleration of gravity, V the body volume, and m the body mass. Second, the buoyant force (F_B) is the upward force of air displaced by the body, in which F_B also depends on V because it is equal to the weight of air displaced by the body: $F_B = \rho_{\text{air}}gV$, where ρ_{air} is the density of air ($= 1.2 \text{ kg/m}^3$). Last, the drag force (F_D) is the aerodynamic resistance from the surrounding air. F_D is estimated via the drag coefficient, C_D :

$$F_D = C_D \cdot \frac{1}{2} \rho_{\text{air}} U^2 \cdot A, \quad (1)$$

where A is the reference area of the body in the direction of the motion. U is the terminal speed (i.e., zero acceleration) of the unconscious girl, which is determined by the force balance among the three forces ($F_W = F_B + F_D$).

Then, U is determined to be

$$U = \sqrt{2 \left(\frac{\rho_{\text{body}} - \rho_{\text{air}}}{\rho_{\text{air}}} \right) \frac{Vg}{C_D A}} \xrightarrow{\rho_{\text{body}} \gg \rho_{\text{air}}} U = \sqrt{\frac{2mg}{\rho_{\text{air}} C_D A}}. \quad (2)$$

Since ρ_{air} , m , and g are constant, U depends on the product of C_D and A only: as $C_D A$ increases, which means larger drag on the body, U decreases. It needs to be noted that $C_D A$ changes as the falling posture of Sheeta changes. For the vertical orientation (head-down position) shown in Fig. 1(b), $C_D A$ is 0.11 m^2 for an average adult.¹³ We converted this $C_D A$ value for Sheeta because Sheeta has a smaller A value than adults. Here, it needs to be noted C_D does not depend on the body size because it is dimensionless. Assuming an average height of 1.75 m and 1.55 m for adults and 13.5-year-old girls, respectively,¹⁴ we evaluated the area ratio between Sheeta and an average adult to be $A_{\text{Sheeta}}/A_{\text{adult}} = (1.55 \text{ m}/1.75 \text{ m})^2 = 0.784$. Then, the $C_D A$ value of Sheeta is found as follows: $C_D A_{\text{Sheeta}} = C_D A_{\text{adult}} (A_{\text{Sheeta}}/A_{\text{adult}}) = 0.086 \text{ m}^2$. Then, the terminal speed is estimated to be 95.4 m/s with the average m of 48 kg for the girl, which is worrisome for viewers.

Fortunately, Sheeta's crystal amulet is activated and changes her posture (belly-to-sky or supine position) as shown in Fig. 1(a). For this posture, the $C_D A$ of an average adult is 0.84 m^2 , and thus the $C_D A$ of Sheeta is estimated to be 0.659 m^2 .¹³ As a result, the terminal speed has decreased to 34.5 m/s according to Eq. (2). This is exactly what skydivers do to slow down their free fall. Here, it needs to be mentioned that the crystal amulet also appears to reduce the g value in Eq. (2) or to generate anti-gravity field since the material is used to keep the castle Laputa and the other flying cities aloft.

It should also be pointed out that C_D depends on the Reynolds number ($Re = \rho_{\text{air}} U L / \mu_{\text{air}}$) and Mach number ($Ma = U/a$) of Sheeta falling in the air. Here, μ_{air} is the dynamic viscosity of air ($= 1.8 \times 10^{-5} \text{ Pa}\cdot\text{s}$), L the characteristic length scale of Sheeta, and a the speed of sound in air ($= 340 \text{ m/s}$). For the head-down posture, we can assume Sheeta's shoulder width for L ($= 0.4 \text{ m}$), and the Re and Ma of falling Sheeta are calcu-

lated to be 2.5×10^6 and 0.28, respectively. These Re and Ma values show that the airflow around falling Sheeta is subsonic turbulent flow.¹³ Since the used C_D values are valid for incompressible flow of $Re > 10^4$, our calculation of U is justified.

Lift force on the *Tiger Moth*

The main ship of the air pirate is the *Tiger Moth*, shown in Fig. 2(a). This aircraft can fly based on two fluid mechanics forces. First, the main body has balloons filled with helium, which is lighter than air, so the *Tiger Moth* is similar to hot air balloons and a blimp in the sense that its flight relies on the buoyant force (F_B) generated by the lighter gas and the larger volume of the main body. However, having the balloons is not enough for the aircraft to "fly" because the buoyant force does not generate propulsion. So, the *Tiger Moth* has two wings with rotors to produce propulsion and lift force (F_L). Then, it can be questioned which force is larger between the two and whether these forces are enough to fly the air pirate ship in the air.

The *Tiger Moth* is 42 m long, 20 m high, and 54 m wide.¹⁵ Based on these dimensions and available images, we estimate that the volume of the balloon is about 1810 m^3 as an ellipsoid of the diameter and length of 12 m and 24 m, respectively [i.e., $V = (4\pi/3) \times (24 \text{ m}/2) \times (12 \text{ m}/2)^2$]. In this case, F_B is found to be about $2.13 \times 10^4 \text{ N}$. The lift force generated by an airfoil is given as

$$F_L = C_L \cdot \frac{1}{2} \rho_{\text{air}} U^2 \cdot A, \quad (3)$$

where C_L is the lift coefficient, U the flight speed, and A the area of the airfoil. Again, based on the available dimensions and images of the *Tiger Moth*, we estimate that the chord and span of one wing are 6.2 m and 15.4 m, respectively (i.e., $A = 95.5 \text{ m}^2$). The average speed of the aircraft is 65 km/h ($= 18.1 \text{ m/s}$), and the typical maximum C_L value of cambered membrane wings is about 1¹⁶. As such, we estimate that the two wings can generate F_L of $3.75 \times 10^4 \text{ N}$ in total, which is higher than the F_B of the balloon.

These calculations indicate that both forces are important for the flight of the air pirates, and that the force can lift a total mass of about 6000 kg into the air. Here, it needs to be noted that F_L is proportional to U^2 , whereas F_B does not

depend on U , which means that if the *Tiger Moth* flies slowly, the aircraft relies more on F_B . Although the helium-filled body is crucial for the flight of the *Tiger Moth*, its size can cause significant drag on the aircraft. Seen from the front [Fig. 2(a)], the balloon looks quite massive, which implies a high $C_D A$ value. However, when seen from the bottom [Fig. 2(b)], the body is actually streamlined to reduce C_D .

Fig. 2. (a) Forces on the *Tiger Moth*. F_B = buoyant force, F_L = lift force, F_W = weight, and U = flight speed. The force arrows are not to scale. (b) Streamlined profile of the *Tiger Moth*. Reproduced from "Castle in the Sky" (© 1986 Studio Ghibli).¹²

Flowlines on Pazu

When Pazu and Sheeta escape

Fig. 3. Streaklines formed around Pazu by cloudlets. Reproduced from “Castle in the Sky” (© 1986 Studio Ghibli).¹²

the thick cloud surrounding the floating castle of Laputa, we can see airflow visualized by the cloudlets around Pazu’s face (Fig. 3). Since clouds are composed of water droplets, the motion of condensed droplets can visualize the airflow around the face. Flow visualization is a critical technique for fluid mechanics since most fluids are transparent and thus their motion is invisible. One easy way to visualize invisible flow is to introduce a dye in the flow. In this example, the cloud plays this role.

There are four flowlines for fluid mechanics: streamline, streakline, pathline, and timeline. A streamline is a line tangential to velocity vectors in a flow velocity field at a given instant. A streakline is a line formed by particles released from a certain point in the flow field. A pathline is the actual path drawn by one single particle moving in the flow field. A timeline is a line connecting a set of particles that are released simultaneously and move together in the flow field at a certain instant. Based on these definitions, the flowline in Fig. 3 seems to be streaklines since the figure shows a snapshot of cloud streak originating from specific locations.

Students’ responses to anime examples

We used the suggested examples along with other anime-based examples in an undergraduate-level fluid mechanics class, and at the end of the semester we asked students how they thought about the examples and the approach. Students’ feedback was valuable because we did not initially know how the use of these examples would be seen by students. Here are some comments from students:

- “It was enjoyable and gave a good example to practice making ‘reasonable assumptions’ around a ‘real world’ application.”
- “They’re cool, just like any real-world or fictional relations they make you ask questions about realistic events of fluid mechanics.”
- “Very interesting and engaging! Helped me maintain attention and showed practical application of theory.”
- “They were great ways to easily visualize our theoretical knowledge in a somewhat practical way.”
- “I think they help me understand the concepts better because it is more intriguing than just equations. I seem to pay attention better.”

- “They were interesting and gave further insight on how to apply fluid mechanics to real life examples.”
- “I thought that the anime examples were very intriguing. It made learning fun and interesting which does not happen a lot in engineering.”

As shown by these responses, the larger number of students were for using anime for teaching fluid mechanics because the examples made them more engaged with the content that they learned and provided a break from the normal methods of teaching. Also, many students thought that they could transfer knowledge to real-world applications. This response is very encouraging because we were aware of the risk of students not being able to transfer knowledge, yet we believed that their engagement with the examples allowed them to better grasp the concepts. Some students gave suggestions on how to improve using anime examples: balance between fictional examples and non-fictional examples, and diversifying anime examples.

Summary

Many physics teachers look for ways to include visual pop culture in their instruction because it is a source of countless novel examples that capture students’ attention and connect with their personal interests. Japanese animation is a distinctive genre that is widely enjoyed by people around the world, but it is less commonly used to supplement instruction than other types of visual media. The three examples from Hayao Miyazaki’s “Castle in the Sky” presented here show that examples of fluid mechanics can be extracted from anime and analyzed for instructional purposes with key assumptions summarized in Table I. The concepts in these examples include

Table I. Key assumptions made for the shown calculations.

Buoyancy, drag force, and terminal speed of falling Sheeta	<ol style="list-style-type: none"> 1. C_D is assumed to be equivalent between young girls and adult males, and not affected by outfits. 2. Sheeta is assumed to have average height and weight of 13- to 14-year-old Japanese girls. 3. The average height of adults is assumed to be 1.75 m. 4. Scaling proportionality is assumed between Sheeta and average adult in terms of dimension.
Lift force on the Tiger Moth	<ol style="list-style-type: none"> 1. The helium balloon is mainly responsible for the buoyance force, so the buoyancy of other parts of the aircraft is assumed to be negligible. 2. Although the helium balloon section consists of three balloon compartments, it is assumed as an ellipsoid for easier calculation of volume. 3. The maximum C_L of the wings of the Tiger Moth is assumed to be 1.
Common assumption	<ol style="list-style-type: none"> 1. The properties of air (ρ_{air}, μ_{air}, and α) are assumed to be constant regardless of altitude.

buoyant force, drag and lift, key dimensionless numbers such as Reynolds number and Mach number, streamlined shape for drag reduction, and flow visualization and streamline. Though anime has been used less frequently than other types of visual pop culture, it has rich potential as a source of instructional examples that illustrate concepts from fluid dynamics and other areas of physics. Examples drawn from anime are likely to be novel to many students as it is more common for pop culture-based examples to be drawn from more mainstream sources.

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References

1. L. W. Dubeck, M. H. Bruce, J. S. Schmuckler, S. E. Moshier, and J. E. Boss, "Science fiction aids science teaching," *Phys. Teach.* **28**, 316–318 (May 1990); A. E. Segall, "Science fiction in the engineering classroom to help teach basic concepts and promote the profession," *J. Eng. Educ.* **91**, 419–423 (2002); M. L. Dark, "Using science fiction movies in introductory physics," *Phys. Teach.* **43**, 463–465 (Oct. 2005); C. Efthimiou and R. A. Llewellyn, "Avatars of Hollywood in physical science," *Phys. Teach.* **44**, 28–33 (Jan. 2006); S. Laprise and C. Winrich, "The impact of science fiction films on student interest in science," *J. Coll. Sci. Teach.* **40**, 45–49 (2010).
2. C. A. Frey, M. L. Mikasen, and M. A. Griep, "Put some movie wow! in your chemistry teaching," *J. Chem. Educ.* **89**, 1138–1143 (2012).
3. A. N. Spiegel, J. McQuillan, P. Halpin, C. Matuk, and J. Diamond, "Engaging teenagers with science through comics," *Res. Sci. Educ.* **43**, 2309–2326 (2013).
4. H. Furo, "Using anime as a teaching tool in U.S. undergraduate course," in *3rd International Conference of WorldCALL* (The Japan Association for Language Education and Technology, Fukuoka, Japan, 2008); D. R. Rich, "Global fandom: The circulation of Japanese popular culture in the U.S.," The University of Iowa, 2011.
5. J. Ruble and K. Lysne, "The animated classroom: Using Japanese Anime to engage and motivate students," *English J.* **100**, 37–46 (2010).
6. N. Fukunaga, "'Those anime students': Foreign language literacy development through Japanese popular culture," *J. Adolesc. Adult Lit.* **50**, 206–222 (2006); Y.-H. Chan, N.-L. Wong, and L.-L. Ng, "Japanese language students' perception of using anime as a teaching tool," *Indones. J. Appl. Linguist.* **7**, 93–104 (2017).
7. M. A. Griep and M. L. Mikasen, "Using movie clips to teach chemistry formally and informally," in *Hollywood Chemistry: When Science Met Entertainment*, edited by D. J. Nelson, K. R. Grazier, J. Paglia, and S. Perkowitz (American Chemical Society, 2013).
8. J. Hosler and K. B. Boomer, "Are comic books an effective way to engage nonmajors in learning and appreciating science?" *CBE-Life Sci. Educ.* **10**, 309–317 (2011).
9. M. Rogers, "An inquiry-based course using 'Physics?' in cartoons and movies," *Phys. Teach.* **45**, 38–41 (Jan. 2007).
10. V. W. Gerde and R. S. Foster, "X-Men ethics: Using comic books to teach business ethics," *J. Bus. Ethics* **77**, 245–258 (2008).
11. H. McCarthy, *Hayao Miyazaki: Master of Japanese Animation* (Stone Bridge Press, Berkeley, CA, 1999).
12. "Castle in the Sky," (天空の城ラピュタ), directed by H. Miyazaki (宮崎 駿), Studio Ghibli (スタジオジブリ), (1986), <http://www.ghibli.jp/>.
13. R. D. Blevins, *Applied Fluid Dynamics Handbook* (Van Nostrand Reinhold Co., New York, 1984).
14. スクスクのっぽくん (June 29, 2018), <https://www.suku-noppo.jp/data/>.
15. *Laputa Roman Album Extra* (Tokuma Shoten, Japan, 2002).
16. A. H. Wrist and J. P. Hubner, "Aerodynamic comparisons of flexible membrane micro air vehicle wings with cambered and flat frames," *Int. J. Micro Air Veh.* **10**, 12–30 (2018).

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