

Shape and fluid drag: an experience with just-in-time learning

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Abstract

Engineering students at UW-Stout learned about the basics of fluid drag, and the influence of shape on it, from a short laboratory-based exercise. The students did not receive any background on the topic in the class-room. Instead, instruction was provided on an as-needed basis to guide the student groups in developing physical hypotheses, articulating their reasoning, and experimentally obtaining conclusive results. Beyond the benefits of efficiently covering an important topic, the exercise was useful in encouraging creative ways of finding and retrieving information, devising experiments and processing data, and learning to work effectively in a group to complete a series of complex tasks.

Introduction

Just-in-time learning involves learning on an “as-needed” basis. It can interface well with a Project-Based Learning environment (e.g., Kolar et al.¹), where students work toward a larger outcome, acquiring skills and information as needed. In such an environment, as in industry, group dynamics are especially important, with each member bringing unique strengths and perspectives that strengthen the whole, while managing conflict and differences becomes a necessary skill to learn.

Just-in-time has been used in the instruction of Physics, Engineering (e.g., Self et al.², Kolar et al.¹, Welch³), and a broad range of other fields (see overview by Ieta et al.⁴). As pointed out by Riel⁵, the internet has contributed to enabling this methodology in no small measure, opening up a world of hyper-linked information and virtual simulations that can support or supplant the traditionally sequential modes of dissemination.

In the past, the two-credit undergraduate course on Engineering Fluid Mechanics at the UW-Stout has been structured with a prominent emphasis on the control and fluid power aspects of the subject. In recent years, based on the broader requirements of the engineering majors it now serves, the course has continually evolved, and now covers the subject from a more general and fundamental perspective. The course will become a three-credit course in the near future.

Time constraints have necessitated prioritizing; this has led to the exclusion of the topics of external flow and fluid drag. Considering the significance of drag in engineering design and applications, a decision was made to integrate a one hour-long laboratory module for learning about the essentials of fluid drag. Students attend this laboratory session having learned about viscosity and the phenomenon of flow separation in preceding weeks, but without any formal background in fluid drag, developing non-dimensional groups, or experimental methods in fluid mechanics.

Just-in-time learning: Shape and Fluid Drag

The curricular objective of the exercise was for students to develop a basic understanding of blunt-body drag. More concretely, the deliverables involved qualitatively predicting the relative magnitudes of drag induced by objects of different shapes, and quantifying the effect of shape on drag with a suitably developed scaling parameter using experimental measurements. Briefly, a wind tunnel was used to take force and velocity measurements of flow over several drag models of identical scale, but whose shapes are different (Figure 1). Using measurements of drag from the composite shapes, it is possible to construct an understanding of blunt-body drag, especially if the flow patterns can also be visualized.

The exercise strongly emphasized a student-led approach. Presented with a sequence of leading questions, the students arrived at reasonable hypotheses by brain-storming with each other and the instructor, devising and running experiments with guidance, and using computing tools and web resources, as needed. Throughout this exercise, the instructor performed a relatively supervisory function, curating and providing any required specialized information, and guiding students in their reasoning and investigation of the physical problem. The instructional approach was often tailored according to the kind of questions and engagement style of the students. Some groups showed a distinct preference for animated discussion with the instructor; others were inclined to independently work on ideas within the group with minimal guidance.

Students initially took drag measurements of flow around a sphere (model A in Figure 1). Working in groups of two or three, they observed the non-linear variation of drag force with velocity. Each group was asked to obtain and mathematically express the scaling relationship. Some students attempted to obtain the scaling in a heuristic fashion. Others groups successfully used curve-fitting tools within spreadsheet programs to deduce the quadratic scaling behavior, often teaching their colleagues about their data processing methods.

By this point in the exercise, it was readily apparent that drag varied with velocity. Questions were posed: what other parameters did drag depend on? How would we attempt to obtain a parameter (“drag coefficient”) that was free of these dependencies, and better captured the effect of shape alone, if the flow regime remained similar? Each group grappled with the questions, and used their data to arrive at a parameter. Some students discovered from the web that their measured value of drag coefficient for a sphere from a relatively simple experiment agreed very well with published values.

It is worth pointing out at this point that UW-Stout is a laptop campus; every student receives a machine on arrival.

Flow visualization is a powerful tool to demonstrate real flow behavior in a concrete and memorable fashion. Smoke-based visualization of the flow over the sphere was performed, with students noting the strong fore-aft asymmetry of the flow pattern due to separation over the rear half of the sphere. Figure 2 shows such an experiment in progress in the laboratory at UW-Stout.

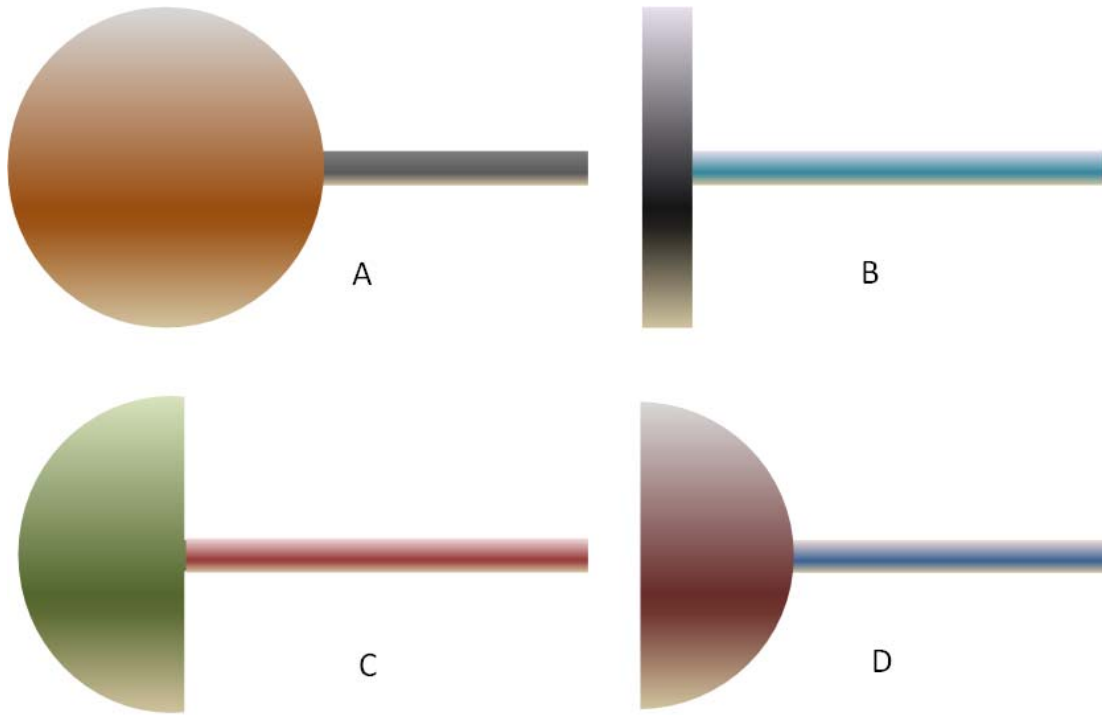


Figure 1. Schematics of the four drag models used for this laboratory exercise. The objects have identical diameters. The flow in all cases was from left to right.

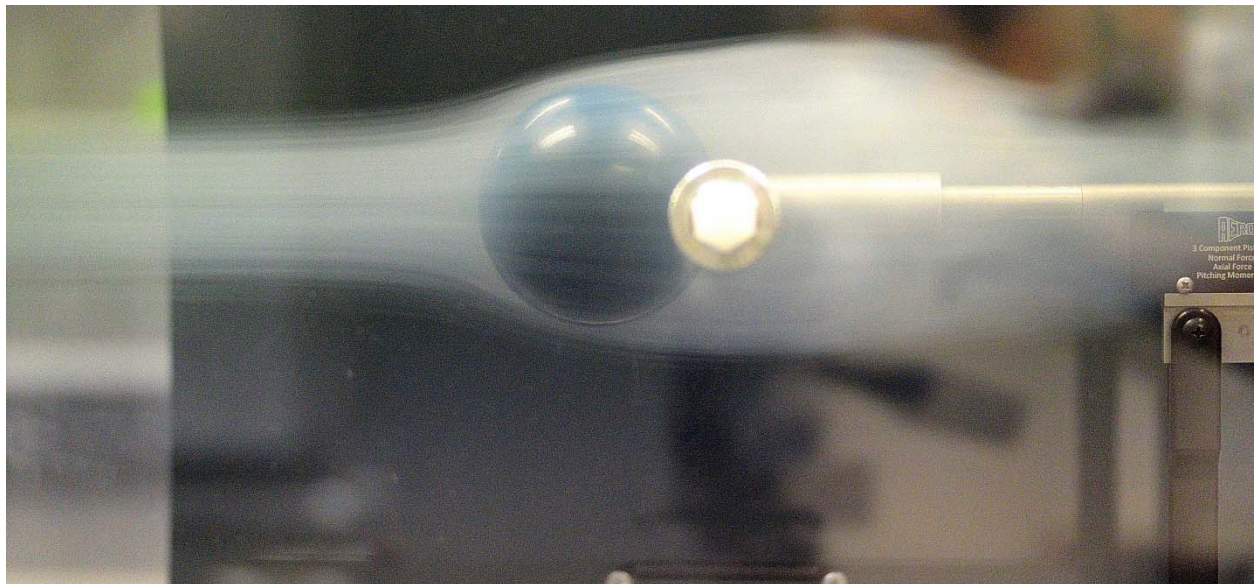


Figure 2. Laboratory photograph of smoke visualization of the flow around a sphere (object A of Figure 1), showing flow separation and a large wake.

Finally, it was desirable to build confidence by attempting to predict drag behavior for different shapes, and to verify informal predictions. The students were presented with the remaining models B, C, and D (Figure 1), and asked to comment on their expectation of relative magnitudes of drag due to these objects, compared to the sphere A and to each other.

This ordering activity was generally engaging, with much speculation and even informal bets being placed as the students discussed and argued about the shapes. The students often arrived at hypotheses more confidently and rapidly if they were advised to ignore everything they had learned formally, and take a first pass at ordering the items purely based on intuition before attempting a cogent explanation.

It is worth noting that a few students who often obtain modest scores in conventional assessment were outstandingly accurate and quick at this selection, sometimes going on to offer articulate explanations for their choices based on expected flow patterns.

The students tested their hypotheses by taking drag measurements with each of the drag models. Figure 3 shows a plot of a sample measurement set taken by a student group with object B of Figure 1. Students in a group were encouraged to rotate duties of operating the wind tunnel controls, taking velocity and drag measurements, and performing data reduction. It was desired that they individually experience the hands-on aspects of flow measurements, as well as basic data processing and plotting.

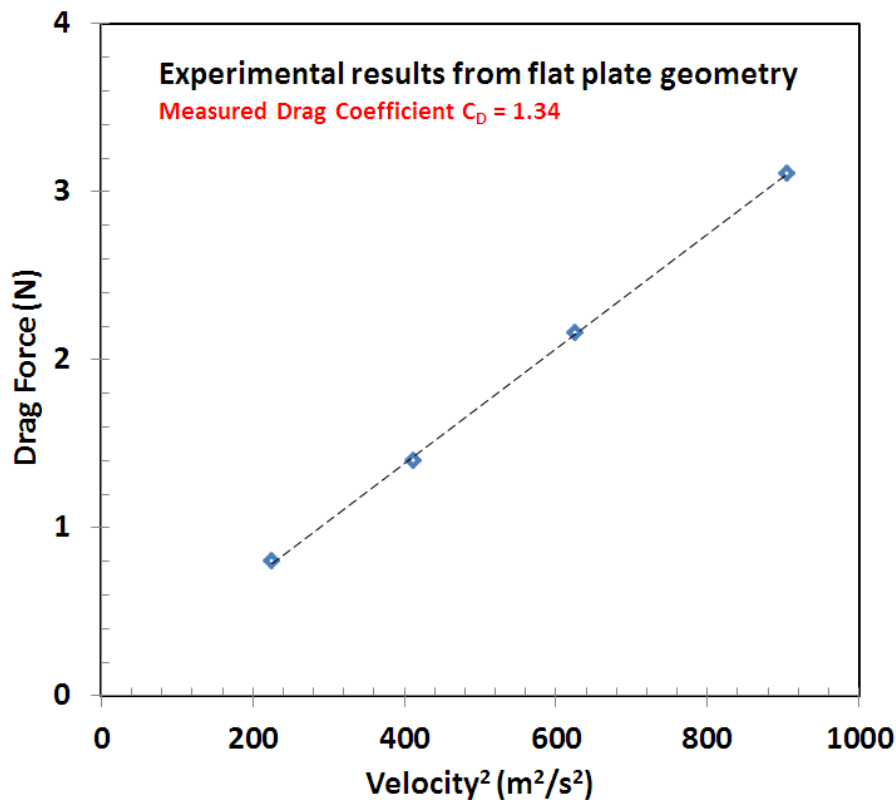


Figure 3. Sample experimental results obtained by a student group. The object used for the test was the object B of Figure 1.

Beyond the aspects of curriculum, the overall response to this exercise was very positive in terms of building rapport with the students, as well as offering a less constrained learning environment. Several students raised questions on the aerodynamic designs from everyday experience. Some student groups also included strongly positive (unsolicited) comments along with their data submissions to the instructor.

Summary

Just-in-time learning emphasizes an approach that tends to be learner-controlled, and relatively modular in nature. In an undergraduate course on Fluid Mechanics at the UW-Stout, students worked in small groups to learn about the essentials of form drag in a one-hour laboratory session. There was no prior lecture on this topic in class.

Based on observing the visualization of flow around a sphere, and analysis of the corresponding force measurements taken by them, students developed a working understanding of the nature of drag. They built upon this understanding by making informal predictions about the drag and flow corresponding to several other simple shapes, and tested out their hypotheses immediately in the lab.

The hands-on, learner-driven approach helped to build in the students a strong intuitive sense of how flows interact with different shapes. In the process, they were also exposed to a range of experimental methods in fluid mechanics, and the importance of relevant non-dimensional parameters from a utilitarian perspective.

From a pedagogical perspective, it was an interesting demonstration of the attributes of just-in-time learning: small groups of students with disparate strengths and interests worked together to understand a complex problem, and developed a refined sense of predictive ability by utilizing a broad range of tools and information bases.

Acknowledgements

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