York University
PHYS 2010: Classical Mechanics (3 credits)
Winter 2020 Course Project

1 Overview

The goal of the project is for students to, working together in groups, create a testable hypothesis tied to a topic/system relevant to PHYS 2010 and address it via a computational approach. Why *computational* (especially since PHYS 2010 is not a computational course per se)? As demonstrated throughout the course, many problems in classical mechanics do not lend themselves well to closed form analytical solutions, unless significant simplifying assumptions are made (e.g., "ignore air resistance", "assume small deviations from equilibrium). That is, mathematical analysis quickly becomes relatively intractable. In the "real world", many of these assumptions are not valid (e.g., a child on a swing does not behave like a simple pendulum). It is thus useful to feel comfortable to approach problems numerically, not so much to replace mathematical analysis, but to complement it. Plus, experience and comfortability with computational approaches are essential skills in this day and age.

To be clear, the nature of the project does not rest upon expectations of your group developing novel/clever code. Instead, the goal is to use numerical methods to complement the concepts and theory developed in class. The focus is on developing a testable quantitative hypothesis and the computational machinery to address such. The basic procedure will go something like this:

- As a group, fchoose a particular area/concept to focus on (see subsequent section for examples)
- Develop a testable, hypothesis-driven question that revolves around the chosen concept. Your hypothesis should be set up so to be addressable in a yes/no (or true/false) fashion, so to confirm or refute an answer to the question.
- Write a proposal detailing what you aim to do, along with the appropriate background to frame the hypothesis
- Once approved, carry out the proposed work
- As a group, give an oral presentation on your project as if you were presenting a poster at a conference (see subsequent section)
- As a group, prepare a short written report (due after the oral presentation)
- Feel free to be creative!
- There is a possibility for your poster to actually be printed out! The "best" poster(s) (as determined by the instructors in some transparent fashion) may be printed out and placed up in Petrie for public viewing*.

*As such, your poster should be a digital file suitable for printing. Dimension-wise, 42"x60" should be the maximum dimensions. If we were to print a poster(s) out, we would likely use the CVR printer (`http://cvr.yorku.ca/content/cvr-poster-information-0`).

2 Specifics

Forming Groups – Group size will be limited to **four students**. Students will be given the option to self-organize into groups. You have until 3/2 to do such. If you choose to form your own group, obtain everyone's permission and email Reuben Blaff (nebuer@my.yorku.ca) by 11:59 PM on 3/2 with a list of names/student numbers/emails for everyone in your group. If we have not received such, students will be randomly placed in groups and a list of such will be posted on the course website. **At least one group member must have taken EECS 1541 and/or PHYS 2030** (so to have coding experience). If you choose to self-organize, please identify who has coding experience along these lines. We reserve the right to reassign members if needed.

Coding – It is possible to use external software (e.g., ddfield and pplane, as discussed in class; see https://math.rice.edu/ dfield/dfpp.html) to formulate ideas (e.g., obtain background "data" for your hypothesis). But given that these are somewhat of a "black box", a main learning goal of the project is that your group ultimately writes its own code so to understand how and where the relevant numbers come from. As such, you are free to use any programming language you like (e.g., Matlab, Python). The course instructor has the most experience with Matlab, and is happy to provide relevant pieces of code. For example, the course webpage has a section at the bottom dedicated to listing relevant/useful Matlab codes. Further, an older page for PHYS 2030 might have useful bits: `http://www.yorku.ca/cberge/2030W2018.html`

Poster – You and your group will make a digital poster, which you will present in class as if you were at an academic conference. The goal is to gain experience in both creation and presentation of a poster, as well as having a visual tangible that summarizes your hypothesis/motivation and key findings. Typically, posters are comprised of an Introductor/Motivation section, following by Methods, Results, Discussion, and Conclusions. Here are a few links to help provide a bit more context on getting an effective poster together (noting that some of these tips are more relevant to actually being at a conference):

- https://www.scientifica.uk.com/neurowire/tips-for-presenting-your-scientific-poster-at-a-conference
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1876493/pdf/pcbi.0030102.pdf
- `https://guides.nyu.edu/posters`
- `https://library.mtroyal.ca/c.php?g=436471&p=2975480`
- `https://physics.csuchico.edu/ayars/491/mermin.pdf`

Presentation – The presentations will take place in class. You will be allowed minutes total: 5 minutes for your presentation and 2 minutes for questions. You will be timed, so it is crucial that you do not exceed your allotted time (otherwise you may be penalized). Since you are working in groups, you will both be expected to contribute significantly to the content, but how to handle the presentation is up to your group. You must get your presentation to the instructor at least one day prior so the scheduled presentation date(s) (who will use the classroom computer to project them for visual presentation) .

Short Report – As specified below, a short written report (3–4 pages) will be submitted following your oral in-class presentation.

3 Examples

You (as a group) will need to develop a physics-driven testable hypothesis around the context of mechanics topics covered (or intimated) throughout PHYS 2010. Examples could include (but are not limited to†):

- Differences between analytic approximations and numerics for projectile motion with drag
- Estimation of drag forces on complex-shaped objects
- Nonlinear oscillators (e.g., chaotic motions in the driven Duffing system)
- Limit cycle oscillations (e.g., van der Pol)
- Harmonic oscillator in 2-D and/or 3-D (see Fowles & Cassidy Sec.4.4 for theoretical considerations)
- Coupled (linear) oscillator systems (see F&C Sec.11ff for theoretical considerations)
- Biomechanics
- Rocket motion and variations of such (e.g., "ion rockets"; F&C Sec.7.7)
- Plane dropping a package w/ air resistance (see F&C Prob. C 4.1)
- Motion of charged particles in electric and/or magnetic fields (see F&C Sec.4.5)
- "Constrained" motions (e.g., particle on a cycloid) (see F&C Ex.4.6.2)
- Dynamic effects of a rotating coordinate system (e.g., Coriolis forces)
- Planetary motion as a 2–body problem
- "Constrained" 3-body motions (see F&C Sec.7.4)
- Double pendulum (see F&C Ex.11.3.1 for theoretical considerations)
- Pendulum attached to spring/mass (see F&C Ex.11.3.2)
- Vibrations of the diatomic molecule via the Morse function
- Linear motion of triatomic molecule (see F&C Ex.11.4.1)
- Calculations of center-of-mass and/or moments of inertia for objects with irregular shape and/or density
- Slipping in rolling objects (see F&C Sec.8.6)
- Simulation of the Bloch equations (underlying NMR and MRI)

†F&C below $\equiv$ to Fowles & Cassidy *Analytical Mechanics* (2005, 7th Edition).

You will need to then assess the validity of the hypothesis based upon a quantitative analysis that combines theoretical considerations (to some reasonable point) along with numerical results. All students are expected to contribute significantly, and you will be asked to assess your peer's contribution (as such will be factored into the final grade). To give a general idea for possible hypotheses, here are several possibilities. Note that while they are structured to be answerable in a yes/no (or true/false) fashion, the arguments supporting such are likely to be much more extensive:

1. The Duffing oscillator for harmonic forcing (of frequency ω) will exhibit oscillations at both ω and 3ω, but no other frequencies

2. For the damped harmonic oscillator, numerically, the following two are equivalent (in terms of both magnitude and phase): Fourier transform of the impulse response, & steady-state sinusoidally driven case (as a function of the driving frequency, ω)

3. Thermal agitations (i.e., noise) will preferentially excite resonant modes of of a triatomic molecule, leading to stability issues if damping is not present

4. The optimal launch angle (so to maximize projectile range) is larger for an object experiencing linear drag than one subject to quadratic drag.

5. To hit a home run (including realistic drag considerations), a batter would need to hit the ball so to have a launch velocity at least twice as great as that of the pitched speed.

6. A non-isotropic 2-D harmonic oscillator will always trace out a closed path (i.e., a Lissajou figure)

7. For a cylinder rolling down a non-smooth plane (at angle θ re the horizontal), the critical value of the relevant coefficient of friction representing the transition between rolling and slipping is proportional to θ

8. For the "constrained" three body program, perturbations to initial conditions on the order of 1% will lead to eventual divergence of orbits (i.e., chaotic behavior) [*Note: To validate such a hypothesis, one would need to determine an appropriate quantitative measure of chaos, such as a positive Lyapunov exponent*]

4 Grading

There will be several components to the project grade as follows:

- Proposal (10%) – This should briefly (but clearly!) provide motivation as to the chosen direction and a clear hypothesis-driven question related to what you aim to collect and how such will be analyzed. You will also need to develop a methods section that details how you will tackle the problem. The overall length should be 1 page. You will receive critical feedback from the course instructors/TAs and ultimately require "approval".

- In-class oral presentation (40%) – Details in preceding section. Note that part of this grade includes a short "progress report" due before the poster due date.

Presentation Structure (25%).
A: all information is well organized in proper sections with smooth transitions between sections. Visual elements were effective.
B: overall organization is understandable but could be improved in one section of the presentation or in minor instances throughout the presentation.
C: repeated organizational problems that interfere with presentation coherence. Poor presentation of visual information.

Delivery of Presentation (15%).
A: delivery was clear with appropriate use of non-verbal gestures. Verbal articulation and timing were appropriate.
B: several awkward moments or slips in verbal clarity.
C: repeated awkwardness in presentation, and/or repeated problems with verbal clarity. Presentation too long.

Clarity and Conciseness of Technical Information (15%)
A: technical flow is clear: introduction motivates a topic, results focus on that topic, conclusions follow from results, relevant methods are described.
B: no more than 1 major lapse in tech. clarity.
C: more than one major lapse in technical clarity.

Conceptual Correctness (20%).
A: interpretations of results are tech. correct.
B: interpretations are not well supported.
C: major errors.

Insightfulness (25%).
A: Recognized an interesting issue and developed at least one way to understand it.
B: Thorough description of WHAT happened without a clear understanding of WHY it happened.
C: Confusion about what happened.

Figure 1: Guidleines for poster presentation. These are also helpful regarding the report.

- Report (30%)
  – You will be expected to prepare a cohesive 3–4 page report[‡]. This should provide some background on the nature of the problem/data, and clearly outline the basis for your analysis strategy. Furthermore, the report should clearly summarize your key results. In addition to the report, you will need to include the relevant code used (such that the course instructors could reproduce your analysis). Guidelines for the presentation should also be helpful here. There will only be one report per group (i.e., each student need not write their own), so there will be an expectation for high quality of this component.
- Student assessment (20%) – You will be provided with an assessment sheet, which you will fill out for each member of your group (e.g., level and degree of contribution). Your evaluation will then be factored into the determination of their final grade. If you simply give everyone 100% without reasonable justification, you will likely be penalized.

Consideration to keep in mind –

- Your time is valuable, so use it wisely!
- Primary goal is to motivate your hypothesis and explain a technical finding
- If there is no content, there is no presentation

[‡]The report itself should be 3-4 pages, however you are free to include additional Appendices that contain relevant content, such as computer code, additional plots, etc... These will not be explicitly graded, nor are they required.

- Before getting your presentation together, you have one key task: **Complete your project!** First, organize your data/results. Then locate trends in your data and isolate specific results. Finally, distill information to key points.
- When creating the poster: **Introduction**: Explains the goals and purpose of the project. Ideally, these goals and purpose relate to the Discussion points. **Methods**: Distill Methods to key procedures. Numbered list is fine. Ideally, the fewer equations the better. **Results**: For your results, develop 2-3 relevant figures. Include key words in figures to remind yourself (and audience) of each bullet point. Figure should allow listener to fill in gaps due to lapses in attention. **Discussion**: should be limited to most important details (related to Results). Succinct is ideal[§].
- Prepare for Q&A: Anticipate questions not covered in the presentation. Typically, questions ask you to extend (or refute) an idea. Brainstorm, considering audience & scope. OK to acknowledge gaps in knowledge.

5 Key dates (2020)

- **2/27** – In-class overview
- **3/3** – Groups formed/assigned
- **3/5** – In-class discussion on proposals and objectives
- **3/12** – 1-page proposal due
- **3/13** – Feedback on proposals returned to students
- **3/26** – 1/2-page progress report (overview of progress and associated challenges/roadblocks; will contribute to 5% of the 40% "presentation" grade)
- **4/1** – Poster due (day before presentations start)
- **4/2&3** – In-class group "poster" presentations
- **4/3** – Reports due (though they will be accepted without penalty until 4/6)

[§] A very useful reference you may want to examine at some point is *The Visual Display of Quantitative Information* by Edward Tufte. Well worth the effort of tracking down, at least to get exposed to the idea that there is actually some deep thought already in place as to how to best visually convey complex sets of data.