Project Proposal - Parachutes in Flight

Lovleen Kaur and Abinav Ramachandran Kamalakannan

I. Introduction

Parachutes are deployed and used in a varying applications ranging from aerospace, human descent and cargo delivery. Understanding the complex fluid-structure interactions during the deployment of a parachute is essential in developing robust and safe parachutes. By creating a numerical solver to study this behavior under various conditions, we hope to gain valuable insight on which factors affect the functioning of a parachute the most.

The numerical simulation framework used in this project is based on a mass-spring network model. Using numerical methods like Newton-Rhapson, we aim to simulate the forces and motion of the canopy, cords and the load. For the sake of simplicity, we avoid simulating the fluid around the parachute and have a simplified model to approximate the aerodynamic drag on the canopy.

The primary objectives of this study is to examine the steady state canopy profile under steady descent, and to determine the terminal velocities achieved across a range of operating parameters. These parameters include material properties, fluid properties and geometric factors. By studying the performance of the parachute for the various parameters, we hope to provide insights on parachute performances under different design choices and environmental conditions.

Extensive work have been previously done in simulating the behavior of deploying parachutes in supersonic regimes [2] and subsonic regimes [5]. Our paper aims to gain a broad understanding of which design parameters has the most significant impact on the performance of a parachute in various flow conditions and uses cases.

II. Numerical Solver

A. Equations of Motion and Discretization:

$$m_i \ddot{q}_i + \frac{\partial E_{\text{potential}}}{\partial q_i} + c_i \dot{q}_i = 0 \tag{1}$$

Discrete Representation:

$$f_i = \frac{m_i}{\Delta t}\left[\frac{q_i(t_{k+1}) - q_i(t_k)}{\Delta t} - \dot{q}_i(t_k)\right] + \frac{\partial E_{\text{potential}}}{\partial q_i} + c_i \frac{q_i(t_{k+1}) - q_i(t_k)}{\Delta t} = 0$$

B. Discretization of Domain and External Forces:

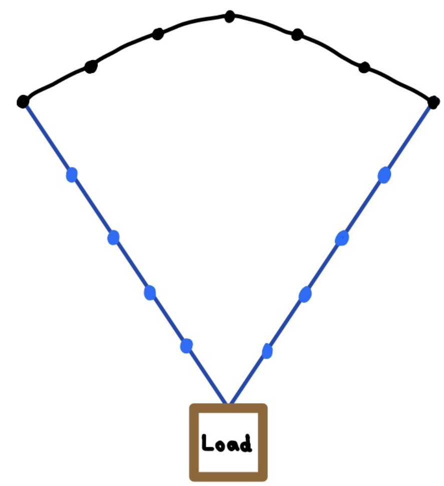

Fig. 1: Discrete Representation of a 2D Parachute and Load

Figure 1 shows the discrete representation of a 2D parachute, each node of the parachute (in black ink) has two main forces acting on it. There is the force of gravity pulling the parachute down and the drag force acting in the opposite direction. The magnitude of the drag force will depend on the shape of the parachute. In reality, the C_D (drag coefficient) varies heavily with the flow conditions, gas composition, parachute shape and other structural and material properties. In this case, we using a range of approximate C_D values that are not directly coupled for the sake of simplicity. The aim of the project is to study the behaviors of this flexible structure under varied applied loads and material properties. The high fidelity aero-structures coupling analysis is not the main target of this project.

$$F_D = C_D A \frac{\rho V^2}{2}$$

This equation above describe the drag force experienced in flight where an appropriate C_D value for a parachute can be used to estimate the loading on the parachute. The equation uses area, but in the simplified 2D case, the projected length is used. So, the force computed is has the units of [N/m].

The C_D values can be estimated using flight data from human landing or robotic landing missions depending on the which flight setting we examine this 2D case in. NASA has varieties of papers that describe parachute analysis and C_D for different flight envelops. One such paper provides C_D properties for Mars landing [1]. Another similar resource cover the numerical analyses that details the CFD work necessary to tackle this problem [3]. These resources

C. Choice of dt:

Time step size depends on the method, the system being analyzed, computational cost, and the speed needed. For schemes that are stable, we can select larger time steps and scheme that are less stable or unstable, the time step must be small. Initially for a simulation, a trial and error approach can also be taken within the stability range to start the simulation and then update the time step depending on convergence needs. In this case, the time step for the implicit scheme does not have a stability concern but rather its a matter of damping in the solution. With smaller steps there is more oscillation, with larger steps there is more damping. We aim to select a timestep that does not overdamped the system, but also not too small to run up the computation time. The minimum requirement is to be under the natural time scale of the spring mass system.

D. Pseudo-code:

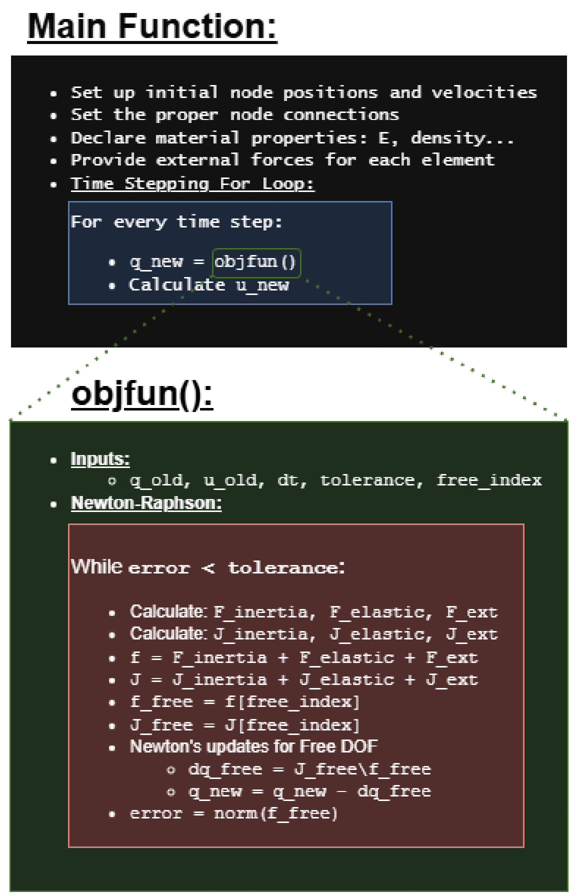

Fig. 2: Pseudo-code for the numerical solver

III. STUDY OUTCOMES

An ideal parachute will provide enough drag for a low terminal velocity and have a compact geometry after deployment. The numerical solver provided in the previous section enables us to simulate the deployment of the parachute and find its steady state solution. This steady state solution will provide the terminal velocity of the load and the shape of the canopy profile.

We expect the performance of the parachute to heavily rely on the drag force and the final canopy profile. The canopy profile will in-turn strongly rely on the material properties of the canopy itself, the chord and the actual sizes of the canopy to the chord. By using an approximation for the drag force coefficient, we restrict the focus of our initial study to the effects of the material properties and geometry of the parachute.

As mentioned earlier, parachutes have a wide range of uses in various environments. To reflect these varying use cases, the geometry and load weight can be scaled. For each case, different dimensions of canopy and chords, as well as material properties will be tested through simulations. Through repeated tests we hope to gather insights on how the materials and geometry of a parachute will affect its performance for diverse use cases.

IV. NEXT STEPS

Next, we aim to incorporate more accurate flow physics to get closer to the real parachute behavior with a classic CFD approach of Immersed Boundary Method [4]. This problem is very dynamic and has fluids and structures coupling that rapidly changes the drag profile of the parachute.

Another goal of this project is to make as much progress as possible for increasing complexity beyond this 2D proposal by using shells to simulate a 3D parachute. Advanced modeling analysis of parachutes like those covered in published works from NASA Ames [2] are highly complex and require computational resources well beyond the scope of a graduate class but they do provide insight into expected behaviors possible within numerical analysis.

ACKNOWLEDGMENT

The core of the python code and the numerical logic used in this project is directly taken from the course materials provided by Professor M. Khalid Jawed for MAE 263F.

References

[1] J. R. Cruz , "Estimates for the Aerodynamic Coefficients of Ringsail and Disk-Gap-Band Parachutes Operating on Mars ," Oct. 2017.

[2] J. Boustani, G. Anugrah, M. F. Barad, C. C. Kiris, and C. Brehm, "A Numerical Investigation of Parachute Deployment in Supersonic Flow," AIAA Science and Technology Forum and Exposition.

[3] L. Jiang et al., "Numerical Study on Aerodynamic Performance of Mars Parachute Models with Geometric Porosities," Space: science and technology, vol. 2022, Jan. 2022.

[4] Kim, Y., Peskin, C. S. (2006a). 2–D parachute simulation by the immersed boundary method. SIAM Journal on Scientific Computing, 28(6), 2294–2312. https://doi.org/10.1137/s1064827501389060

[5] G. Xing-long, Z. Qing-bin, T. Qian-gang, and Y. Tao, "Fluid-Structure Interaction Simulation of Parachute in Low Speed Airdrop," Proceedings of the World Congress on Engineering , vol. 3, no. WCE 2013, Jul. 2013.