AA103 2018–2019
Project 3

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1 Problem

In this project you will be testing a laboratory-scale hybrid rocket motor and conducting the data analysis to determine the performance of the system. You can use the software of your choice to process the data (Matlab, python, etc...) and you must submit an individual report using the AIAA JPC conference paper format.

The motor uses gaseous oxygen and an optically clear, solid fuel: polymethylmethacrylate, also known as Plexiglas. The ignition source is produced by a gaseous oxygen/methane torch. There are 4 pressure transducers installed on the combustion chamber. CP-2 and CP-3 are located at the fore-end of the motor and are symmetric with respect to the vertical plane. CP-4 and CP-5 are located just upstream of the convergent section of the nozzle and are also symmetric with respect to the vertical plane. The oxygen mass flow rate is measured with a Coriolis flow meter, and OP-8 is the pressure just upstream of a sonic orifice in the line. There is no divergent section to the nozzle so it is choked at the exit.

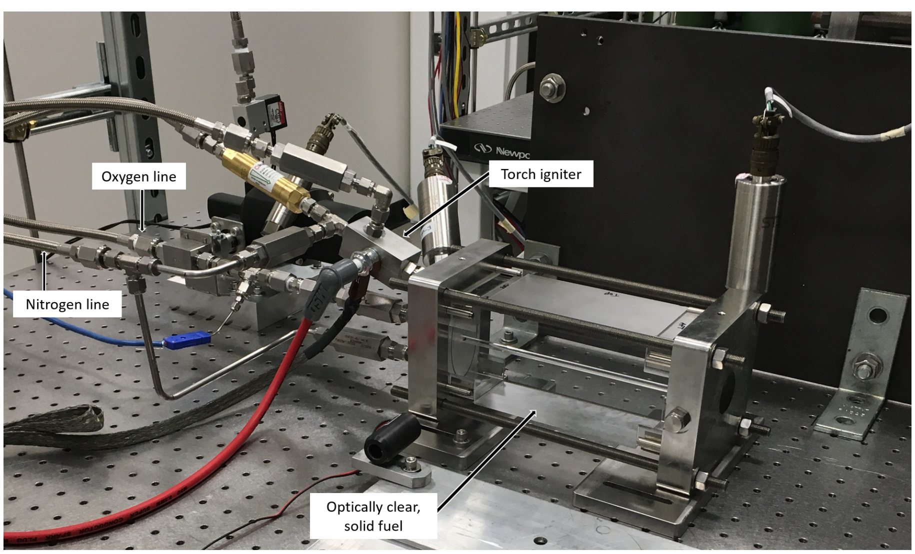

Figure 1: Picture of the experimental setup: gaseous oxygen/clear PMMA hybrid rocket motor.

A large part of this project is about processing experimental data and calculating uncertainties. You might need to do some research on **types of experimental errors** and **random error propagation**. Make sure you also understand the difference between **precision** and **accuracy**. In determining an uncertainty, there is no "correct answer". Processing experimental data is mostly about using good engineering practices and justifying the assumptions that you make. As a result, please pay close attention to how many significant digits you include in your answers! The proper way of reporting a value with an uncertainty is for example: $l = (1.15 \pm 0.01)$ cm. Experimental uncertainties should be rounded to one significant figure. In the following questions, only give the uncertainty when it is explicitly asked for. You can use the following notation for a time-averaged value: $\bar{x}$.

2 Motor Performance

1. The ignition system for this motor is a gaseous oxygen/methane torch. Write the stoichiometric equation for this combination. Knowing that the total mass flow rate from the torch must be 0.5 g/s, determine the mass flow rates of methane and oxygen that you would need to feed into the torch.

2. The fuel grain was weighed before and after the firing. The readability of the scale is ± 0.1 g. If you wanted to quantify the uncertainty in this mass measurement, what would you have done? Use $m_{f,i} = 2032.7$ g and $m_{f,f} = 1968.2$ g to calculate the mass of fuel consumed during the firing (with an uncertainty of ± 0.1 g.

3. Gaseous oxygen is fed into the motor and the mass flow rate is controlled by a pressure regulator and a sonic orifice. The orifice diameter is 700 microns. Using the pressure upstream of the orifice (OP-8), the Coriolis flow meter measurement, and assuming ambient temperature, estimate the average discharge coefficient C_d of the orifice. Demonstrate all of the steps in your procedure and include plots of your data processing.

4. You are provided with the pressure time history of the burn (4 measurements). Determine the start and end times of the burn. Carefully explain how you determined these values and what the resulting uncertainty in the burn time is.

5. Determine the time-averaged oxidizer mass flow rate from the Coriolis flow meter measurement. Estimate the time-averaged fuel mass flow rate from the mass measurements and the burn time. Calculate the total mass flow rate and the oxidizer to fuel ratio and their uncertainties.

6. Calculate the time-averaged chamber pressure. Determine the uncertainty related to this measurement.

7. The nozzle throat diameter is $d_{nt} = (5.01 \pm 0.02)$ mm. Calculate the time-averaged characteristic velocity (c^*) for this test and propagate the uncertainty. Assuming the ideal c^* in these conditions is 1570 m/s, determine the time-averaged c^* efficiency of the motor.

8. Assuming the flow between the combustion chamber and the nozzle throat is isentropic, calculate the average static pressure and temperature at the throat. Assume $\gamma = 1.2$ and the stagnation temperature in the chamber to be $T = 3000$ K. You do not need to include uncertainties.

9. Using the static temperature you just determined, calculate the exit velocity (at the nozzle throat). Assume the specific gas constant at that location to be $R_{nt} = 337$ J/kg/K.

10. Determine the thrust produced by this motor. Calculate the specific impulse. How does it compare to other chemical propulsion systems that you know? You do not need to give uncertainties in this question.

11. **Bonus question:** Assuming you needed the motor to deliver an average of 20 N of thrust in vacuum. What would be the area ratio that you would need? Assume that everything behaves ideally, $\gamma = 1.2$ and use R_{nt} at the exit.