Space Propulsion

Summary of flipped class on SRM internal ballistics

What we do together in class

We start from an experimental data set made by 9 different batches of nominally identical propellant. Each batch is characterized by three pressure curves: low, mid, high pressure. Remember that the curves are obtained changing the throat area of the nozzle. The motor and the table containing the nozzle information are supplied hereafter.

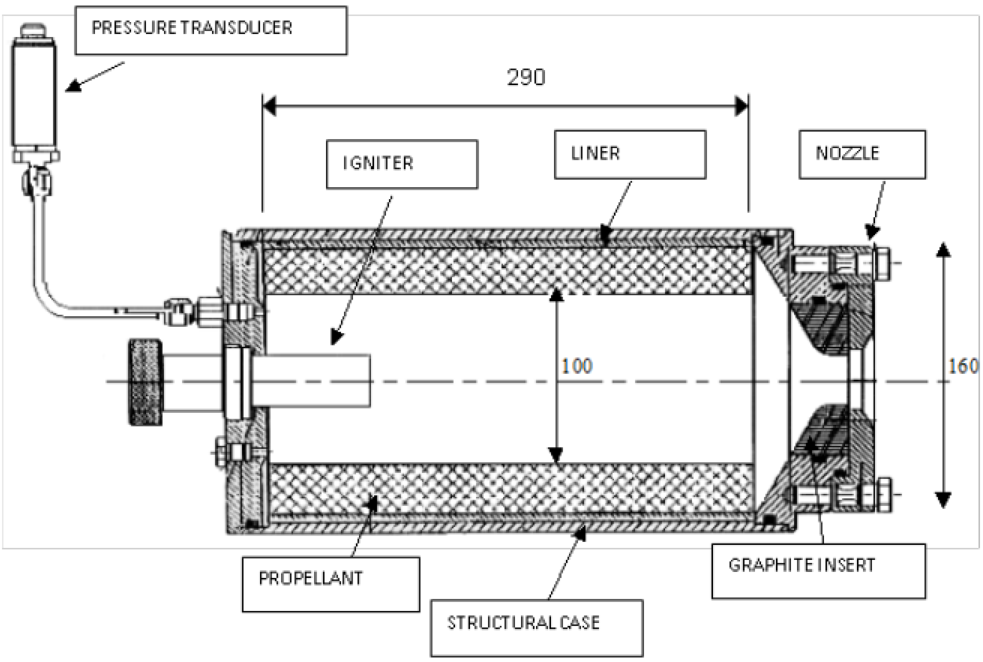

Figure 1: BATES-kind rocket motor

Table 1: Nozzle configurations

Pressure level	Throat diameter, mm
High	21,81
Medium	25,25
Low	28,80

Each curve represents a fired motor. A total of 27 motor pressure traces are available. Each trace reports the absolute pressure in bar with a sampling frequency of 1kHz. The ambient pressure (1 atm) should be removed from the traces to obtain the “relative pressure”.

Using the BC method on each curve we can define an ACTION time and a BURNING time (see the relevant document for procedure). The BURNING time defines the interval of integration for the pressure to define the EFFECTIVE pressure.

The burning rate is the web thickness divided by the burning time.

Now we have for each motor a couple (EFFECTIVE PRESSURE; BURNING RATE).

A total of 27 couples can be obtained. The function UNCERTAINTY can be fed by these two vectors to obtain the parameters of the Vieille’s law and the uncertainty estimation.

If we apply the definition of the c* integrated over time, the experimental value of the c* can be obtained for each pressure curve.

$$c*_{exp} \Rightarrow \frac{\int_{tB}^{tE} p_c A_t}{M_{tot}} \tag{1}$$

A total of 27 values are derived. Under the assumption that the c* is changing only negligibly with respect to pressure, we can average the entire data set and we can obtain a mean and an uncertainty estimation.

At the end of the experimental data analysis

We have the following data:

- Vieille’s law characterization of the whole propellant production (fitting over the full dataset)
- Uncertainty over “a” and “n”
- c* value and its uncertainty

Motor model

At this point we need to produce a model for the computation of a generic rocket firing.

The motor will have the grain geometry of the previous figure. The model will have these inputs and outputs:

- input: value for “a”
- input value for “n”
- input value for c*
- output: burning time.

The model should build up a new pressure trace using the relation for the computation of the SRM internal ballistics:

$$p(t) \Rightarrow \left(a \ \rho_p \frac{A_b}{A_t} c * \right)^{\frac{1}{1-n}} \tag{2}$$

Objective of the class and duration (flexible)

The class will take 3/4 hours in class (two modules of about two hours).

At the end of the class you are expected to:

- perform a ballistic analysis of a small-scale rocket motor (first day)
- draft a ballistic prediction of the same rocket motor (second day)

What you need

- Prepare your personal computer with a running computing software such as MATLAB or OCTAVE. The file format used to save the pressure traces is the MATLAB V6 and should be compatible with both (saved and tested with OCTAVE 4.0.2).
- Study the following texts (loaded on BEEP)
    - Burning-rate-measurement-Fry: pages 1 to 4
    - Actual-Predicted-pressure: full document
    - Internal-ballistics: full document, quick review of concepts (just for reference)
    - Monte-Carlo: full extract of statistics book
- Download the MATLAB file tracesbar1.mat on your laptop
- Download the MATLAB file uncertainty.m on your laptop

Information on the experimental data

The file contains a set of pressure traces. Each variable contains three columns of some thousands of experimental points. The sampling rate is 1000 Hz. Each column is recorded from a rocket firing. Each labeled group is a propellant batch.

Each propellant batch is nominally identical and composed by Ammonium Perchlorate (AP) 68%, Al (aluminum) 18%, HTPB Binder 14%. The traces differ from each other due to production variability.

Table 2: Thermochemical and physical properties of ingredients

Name	Formula	Density, g/cm3	Standard enthalpy of formation, kJ/mol
Ammonium perchlorate	NH_4ClO_4	1,95	-295,77
Aluminum	Al	2,7	0
HTPB	$C_{7.075}H_{10.65}O_{0.223}N_{0.063}$	0,92	-58

The rocket motor used for such tests is a BATES (BAllistic Test and Evaluation System) motor. The scheme and the sizes are reported in 2.

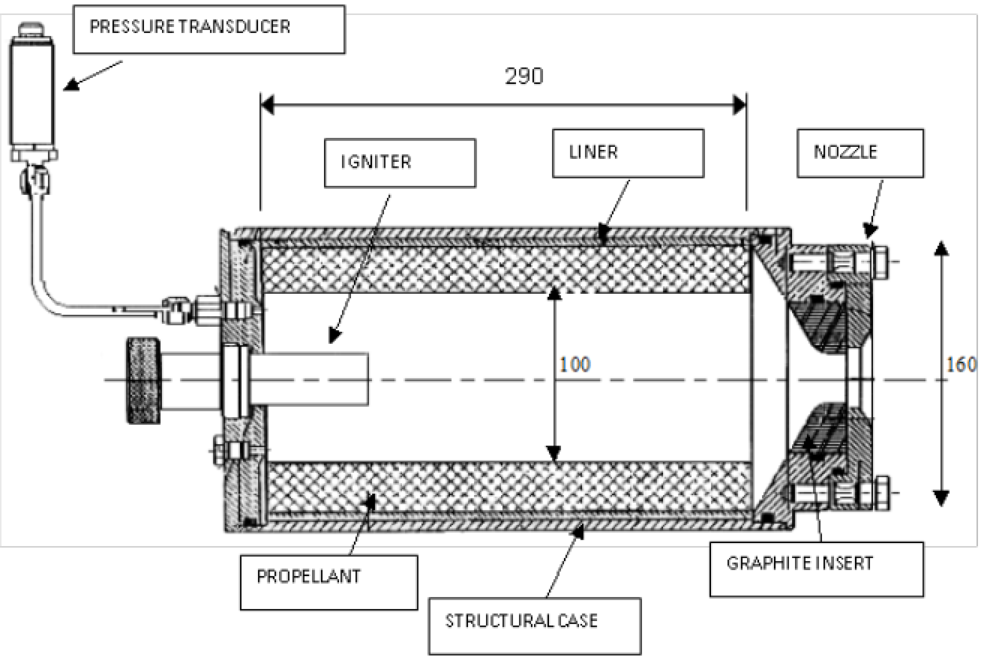

Figure 2: BATES-kind rocket motor

The rocket motor is equipped with a set of only-convergent nozzles having the throat diameters reported in 3.

Table 3: Nozzle configurations

Pressure level	Throat diameter, mm
High	21,81
Medium	25,25
Low	28,80

Final report (optional)

You will be requested to produce a final report, max 3 pages long PDF. Longer reports will not be considered at all. Time for delivery: End of May 2022.

The assignment will be disclosed on BEEP after the two classes.

Group size: two/three people max per report.

Results will be uploaded on FORMS. The link will be released later.

Benefit: 1 bonus for the theory part. With this bonus point you fix the worst answer in your classwork. The bonus is valid up to the session of September 2022, included, then it expires. Within this time frame, the bonus can be used multiple times.