UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa

Design and thermomechanical study of the case of a solid rocket motor of small dimensions

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Author:
Jan Canet Vidal

Director / Co-director:
Dr. Juan Carlos Cante Terán
Dr. David Roca Cazorla

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Chapter 1

Characteristics

The M5004 motor is a solid propellant rocket motor that uses an Ammonium Perchlorate Composite Propellant (APCP) to generate thrust. It uses a total of 10 BATES grains of propellant with a circular core.

The motor casing is made of a 6061-T6 aluminium alloy and has a thrust ring at the bottom end, so as to enable the thrust transmission when assembled in the desired rocket. The forward closure is not conditioned for an ejection charge housing, however, it is also made of an aluminium alloy, the 7075-T6, which is stronger than the 6xxx series. With respect to the nozzle, it uses a conical nozzle with a flat throat of 2 mm length, made of molybdenum.

Both the forward closure and the nozzle contain two sealing o-rings and are attached to the casing by means of a total of 48 radial steel bolts (24 bolts each).

The propellant grains are bonded to their respective casting tubes, which in turn, also act as insulators. The 10 grains are located in series inside the main insulator (a 2 mm thick cardboard tube). The insulator is then located inside the case and is substituted each time the motor is used. Between the grains and the forward closure, a 4 mm thick insulation disk made of cardboard is placed.

A layout of the motor assembly can be seen in figure 1.1.

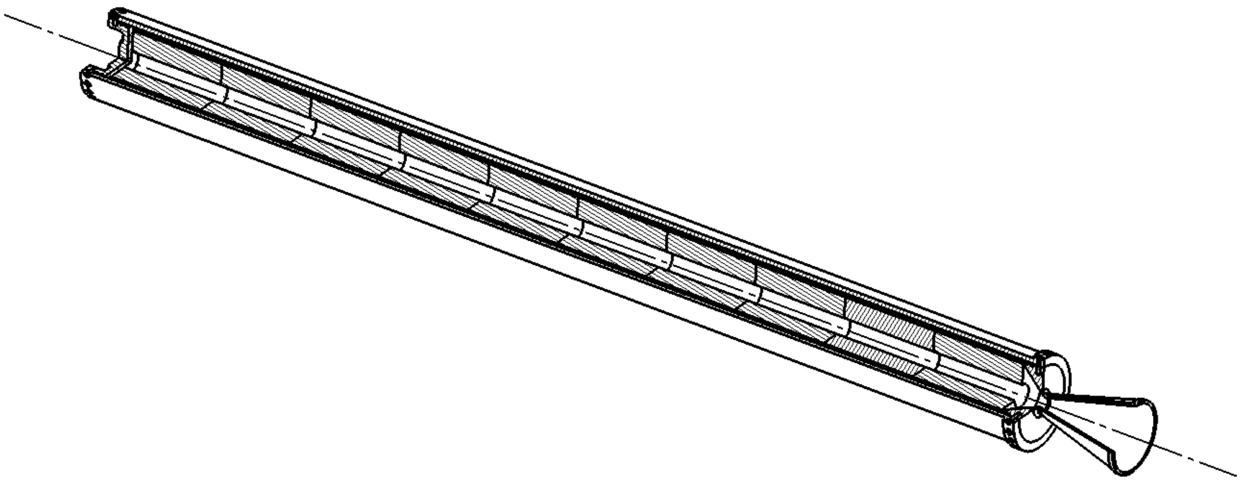

Figure 1.1: Three quarter section of the M5004 motor.

Chapter 2

Specifications

The main characteristics of the solid rocket motor are gathered and presented in the following tables.

The propellant formulation, the ingredient's mass fraction and their respective density is presented in table 2.1.

Table 2.1: AP/HTPB/Al propellant ingredients and proportions.

Ingredient	**% wt**	**Density [g/cm^3]**
Ammonium Perchlorate, 200 μm	75.8	1.95
Hydroxyl-Terminated Polybutadiene	17.0	0.90
Dioctyl Adipate	2.5	0.92
MDI Isocyanate	1.6	1.22
Aluminium Powder	3.0	2.70
Lampblack	0.1	1.76

Table 2.2 presents the total propellant density and the burn-rate constants of the aforementioned propellant.

Table 2.2: AP/HTPB/Al propellant properties.

Property	**Value**
ρ	1.5879 g/cm^3
a	1.9509 $mm/(s \cdot \text{MPa}^n)$
n	0.6231

The combustion properties of the propellant such as combustion temperature, specific heat ratio, molecular weight, and characteristic velocity, are showed in table 2.3.

Table 2.3: AP/HTPB/Al propellant combustion properties.

Parameter	**Value**
T_c	2262 K
γ	1.250
MW	21.714 g/mol
c^*	1414.25 m/s

Table 2.4 presents the main geometric parameters of the nozzle, which directly affect the motor performance.

Table 2.4: Nozzle geometric parameters.

d_{throat}	13.44 mm
d_{exit}	62.32 mm
ε	21.5 : 1
α_{conv}	47.1°
α_{div}	15°
L_{cone}	91.21 mm

The real nozzle effects taken into account in direct performance losses are gathered in table 2.5.

Table 2.5: Real nozzle effects of performance reduction.

Loss effect	**Exhaust velocity reduction (%)**
Nozzle divergence angle	1.7
Boundary layer effects	1.0
Heat transfer through the nozzle walls	0.51

In terms of performance, table 2.6 presents the main performance specifications of the motor, and figures 2.1 and 2.2 show the predicted evolution of chamber pressure, thrust, web regression, and burn-rate over time.

Table 2.6: Performance parameters of the M5004 motor.

Specific Impulse, I_{sp}	Total Impulse, I_t	Motor Designation
236 s	7271 $N \cdot s$ (42%M)	M5004
Peak Thrust, T_{max}	Average Thrust, $\tilde{T}$	Burn Time, t_b
6033 N	5004 N	1.453 s

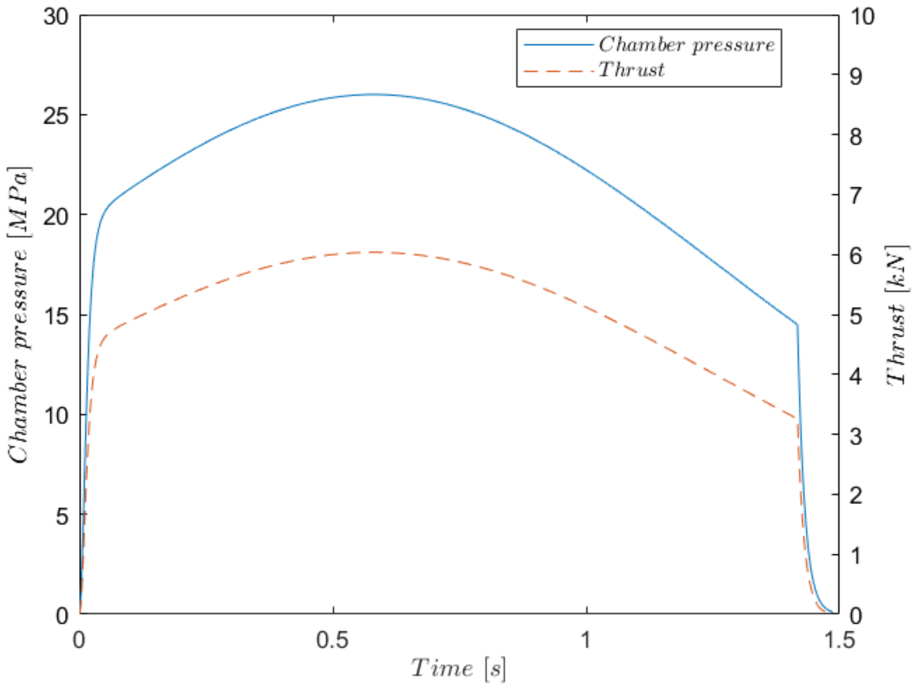

Figure 2.1: Predicted chamber pressure and thrust profiles over time.

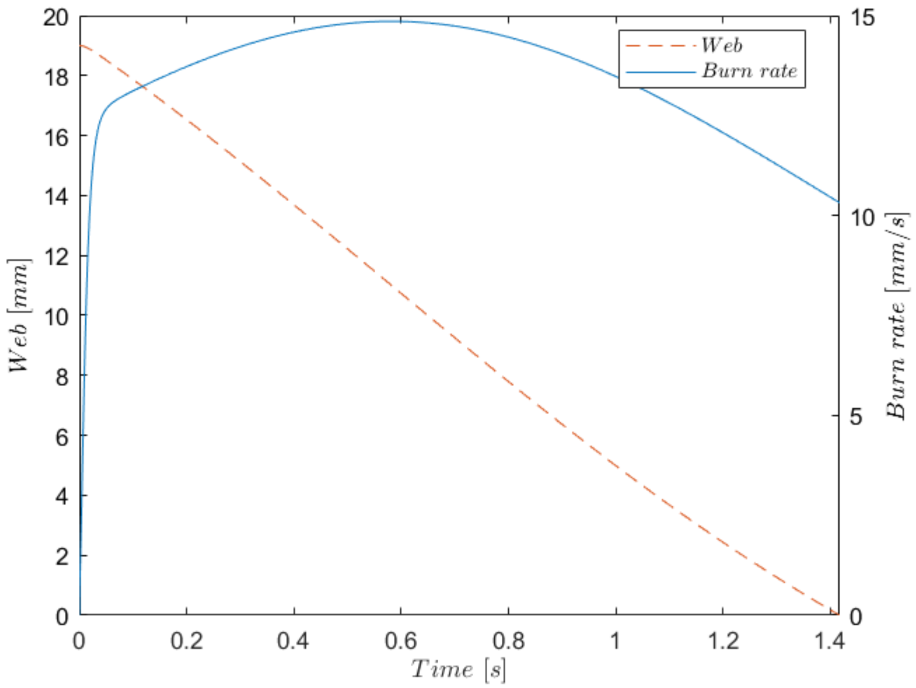

Figure 2.2: Predicted evolution of propellant web regression and burn-rate over time.