THIRTY YEARS OF MODEL ROCKETRY: A SAFETY REPORT

Prepared for

The National Association of Rocketry

and

The Hobby Industry Association

by

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TECHNICAL DETAILS OF THE MODEL ROCKET MOTOR

This Part goes into the scientific and technical details of both black powder and composite model rocket motors. Its purpose is to provide a background supporting the contention that model rocketry is like model aviation: it is a technically-based hobby and recreation that makes use of the technology, practices, and methodologies of full-scale astronautics and professional rocketry.

Internal Ballistics, Black Powder Model Rocket Motors:

A typical black powder model rocket motor is considered. Data was determined with the assumptions that the combustion process is adiabatic and isentropic, is in frozen equilibrium, and is complete. It is also assumed that the nozzle exit pressure is 14.7 pounds per square inch absolute. The exhaust products were assumed to behave as an ideal gas because the solid particles in the exhaust are assumed to be less than 0.0001 inches in diameter and thus have no effect on the thermodynamic properties of the exhaust gas. Insofar as possible, calculated results have been checked against measured test results with excellent agreement well within measurement tolerances.

Propellant: Black Powder consisting of 74% KNO_3 as an oxidizer and a combination of 15.6% C and 10.4% S a fuel-plus-binder. All percentages are by weight.

Delivered specific impulse (I_{sp}): 82 lb_f-sec/lb_m

Exhaust velocity: 2,650 ft/sec

Molecular weight of exhaust gas: 34.75 gms_m/mole

Ratio of specific heats of exhaust: k = 1.29

Nozzle area ratio: 1.75

Propellant density: 0.067 lb_m/in^3

Propellant burning rate: 1.15 in/sec @ 106 psia

Burning area ratio: 19.7

Ignition temperature: 550° F @ 14.7 psia

Chamber temperature: 2,300° F

Throat temperature: 895° F

Exit nozzle temperature: 540° F

Chamber pressure: 106 psia

Reaction products of propellant: 43% gas, 56% solid, 1% water

Gaseous exhaust products by volume: 30.6% N_2; 49.2% CO_2; 2.6% CH_4; 1.8% H_2S; 3.5% H_2

Solid exhaust products by weight: 44.4% K_2CO_3; 20.5% K_2SO_4; 25.8% $K_2S_2O_3$; 3.7% K_2S; 0.5% S; 3.3% KCSN; 1.6% $(NH_4)_2CO_3$; 0.2% C

Chemical equation of combustion reaction: $74\ KNO_3 + 96\ C + 30\ S + 16\ H_2O \rightarrow 35\ N_2(g) + 56\ CO_2(g) + 3\ CH_4(g) + 2\ H_2S(g) + 19\ K_2CO_3(s) + 7\ K_2SO_4(s) + K_2S(s) + 8\ K_2S_2O_3(s) + 2KCSN(s) + (NH_4)_2CO_3(s) + S(s)$ + 6184 Kcal

Internal Ballistics, Composite Model Rocket Motors:

A typical composite model rocket motor is considered. Data was determined with the assumptions that the combustion process is adiabatic and isentropic, is in frozen equilibrium, and is complete. It is assumed that 100% of the exhaust products are gaseous. It is also assumed that the nozzle exit pressure is 14.7 pounds per square inch absolute. Insofar as possible, calculated results have been checked against measured test results with excellent agreement well within measurement tolerances. Precise formulation of composite propellants varies depending on

requirements for burn rate and other performance factors. Numerous types of elastomers are used as both a fuel and a binder. Therefore, a range of parameters is shown below.

Propellant: Composite solid propellant consisting of approximately 82% ammonium perchlorate NH_4ClO_4, 18% elastomers such as synthetic rubber, less than approximately 1% stabilizers, burn rate enhancers, etc..

Delivered specific impulse (I_{sp}): 190 - 220 lb_f-sec/lb_m

Exhaust velocity: 6,112 - 7,077 ft/sec

Molecular weight of exhaust gas: approximately 23.7 gm_m/mole

Ratio of specific heats of exhaust: k = 1.25

Nozzle area ratio: 2.5 - 6.0

Propellant density: 0.058 - 0.076 lb_m/in^3

Propellant burning rate: 0.15 to 0.50 in/sec @ 1,000 psia

Burning area ratio: 82 to 400

Ignition temperature: 550° F

Chamber temperature: 4,283° F

Throat temperature: 3,831° F

Exit nozzle temperature: 1,982° F

Chamber pressure: 500 psia

Gaseous exhaust products: CO, CO_2, H_2, N_2, HCl, H_2

Chemical equation of combustion reaction: $21\ NH_4ClO_4 + 10\ (C_4H_6)_n \rightarrow 21\ HCl + 10.5\ N_2 + 34.5\ H_2 + 27\ H_2O + 23\ CO + 17\ CO_2$ (Generalized equation; the C_4H_6 represents the long-chain organic molecule present in the elastomer/binder.)

Standards:

All model rocket motors produced for sale in the United States are manufactured in strict accordance with international and national standards developed jointly by the Federation Aeronautique Internationale (Section 4b, FAI Sporting Code), the National Fire Protection Association (NFPA 1122 Code for Unmanned Rockets and NFPA 1125 Manufacture of Model Rocket Motors), the National Association of Rocketry (The United States Model Rocket Sporting Code § 4), and the Hobby Industry Association.

Testing And Certification

All model rocket motors in the United States are tested by the Bureau of Explosives of the Association of American Railroads and have the shipping classification of "DOT Toy Propellant Device" under the provisions of the Code of Federal Regulations CFR 49 § 173.100(u).

Model rocket motors may be shipped as "Flammable Solids" under the provisions of Department of Transportation Exemption DOT-E-7887 (First Revision).

All model rocket motor manufacturers conform to the standards established by NFPA 1122 Code for Unmanned Rockets. A minimum of 1% of each production lot or batch is selected at random and tested by the manufacturer before shipment and/or sale to determine whether the lot or batch meets the standards established for that motor type -- thrust-time curve, total impulse, burning time, time delay, etc.. Nearly all model rocket motor manufacturers test 2% of each production lot and preserve an additional 1% to 2% of each lot or batch for future testing contingencies.

All model rocket motors are tested and certified by the National Association of Rocketry in accordance with NFPA 1122 Code for Unmanned Rockets. The NAR re-tests and re-certifies every model rocket motor type every five years. The NAR also conducts unscheduled confirmation testing of random samples of model rocket motors purchased at randomly-selected retail stores throughout the United States on an irregular and unannounced basis to ascertain that production model rocket motors conform to the performance standards of the motors tested for certification. Model rocket motors bearing NAR Certification may be sold and used wherever NFPA 1122 Code for Unmanned Rockets and/or its derivative state and local codes are in force; currently, the FAI and 49 states recognize NAR Certification under the provisions of Section 4b of the FAI Sporting Code and NFPA 1122 Code for Unmanned Rockets. In Canada, testing and certification are carried out by the testing laboratories of the Department of Energy, Mines, and Resources.