Rocket Motors

Construction

Model Rocket Motor Physical Dimensions

Type	Manufacturer	Dimension in millimeters
micro	Quest	6 x ?
mini	Estes	13 x 45
standard	Estes, Quest	18 x 70
24 millimeter	Estes, Aerotech	24 x 70, 24 x 95
29 millimeter	Aerotech type F	29 x 98
29 millimeter	Aerotech type G	29 x 124
32 millimeter	Aerotech F & G	32 x 102

Gustaf de Laval

Gustaf de Laval (1845 to 1913) was a Swedish inventor of French descent. He is most famous for inventing the continuous-flow milk-cream separator and early milking machines. In 1890, he was working on steam turbines and invented the de Laval nozzle to increase the speed of the steam entering the turbine.

Dr. Robert H. Goddard

Dr. Robert H. Goddard (1882 to 1945) was a physics professor at Clark University in Worcester. One among many of his great contributions to rocket science was the application of de Laval's nozzle to rocket motors which increased the energy efficiency of a rocket motor from about 2% to 64%. As a result, rocket motors are the most efficient heat engines known. Goddard conducted some of his experiments at what is now called Little Mirror Lake here at Devens.

Basic Kinematics

one-dimensional equations of motion

$$s = v\,t$$

where s is displacement, v is average velocity, and t is elapsed time.

$$v = a\,t$$

where v is velocity, a is average acceleration, and t is elapsed time.

$$s = 1/2\ a\,t^2$$

where s is displacement, a is average acceleration, and t is elapsed time.

Force (Newton's Second Law)

$$F = m\,a$$

where *m* is mass and *a* is acceleration.

The unit of force in the MKS metric system is the *newton*.

newton = kilogram-meter / second^2

Momentum

$$P = m\ v$$

where *m* is mass and *v* is velocity.

Example: 0.0065 kilograms of black powder, exhaust velocity of 712.3 meters/second

$$P = 0.0065 \text{ kilograms} \times 712.3 \text{ meters/second}$$

$$P = 4.63 \text{ kilogram-meters/second}$$

$$P = 4.63 \text{ newton-second}$$

Conservation of momentum

$$P = \text{constant}$$

momentum of a system without external forces is a constant

$$P_{exhaust} + P_{rocket} = \text{constant}$$

Starting from rest, total momentum is zero

$$P_{exhaust} + P_{rocket} = 0$$

$$P_{rocket} = 0 - P_{exhaust}$$

$$P_{rocket} = -P_{exhaust}$$

$$m_r\ v_r = -P_{exhaust}$$

$$v_r = -P_{exhaust} / m_r$$

Example: $P_{exhaust}$ = 4.63 newton-second, m_r = 0.0748 kilograms

v_r = 4.63 newton-second / 0.0748 kilograms

v_r = 61.9 newton-second/kilogram = 61.9 kilogram-meters/kilogram-second

v_r = 61.9 meters/second = 138.5 miles/hour

How high will a rocket go if it is launched straight up at 61.9 meters/second, neglecting air resistance? First consider how long it takes gravity to slow the rocket to a stop:

$t = v / g$ = 61.9 meters/second / 9.8 meters/second^2
t = 6.32 seconds

Next consider how far a rocket travels in 6.32 seconds under the acceleration of gravity:

$x = {}^1/_2\ a\ t^2 = {}^1/_2 * 9.8 * (6.32)^2 = 195.7$ meters

Thrust

Newton's Second Law, revisited:

$$F = \Delta p / \Delta t$$

For constant mass,

$$F = m \ \Delta v / \Delta t = m \ a$$

But a rocket is not constant mass.

Assuming constant exhaust velocity c, the thrust F from a rocket engine is proportional to the rate of propellant mass flow through the rocket motor.

$$F = c \ \Delta m / \Delta t$$

In general, the mass flow rate is not constant; it varies with time.

$$F(t) = c \ dm/dt$$

Total Impulse

The *total impulse* of a rocket motor is the total momentum change it delivers to the rocket. It is the area under the thrust versus time curve, or the *integral* of the thrust function F(t).

$$I_t = \int F(t) \ dt$$

For example, assume a rocket motor generates 5 newtons of thrust for 2 seconds. The resulting total impulse is just the area of the rectangle 5 newtons high by 2 seconds long, or 10 newton-seconds.

Model Rocket Motor Total Impulse Ranges

NAR Type	Total Impulse (newton-seconds)
1/8A	0.00 to 0.3125
1/4A	0.3126 to 0.625
1/2A	0.626 to 1.25
A	1.26 to 2.50
B	2.51 to 5.00
C	5.01 to 10.00
D	10.01 to 20.00
E	20.01 to 40.00
F	40.01 to 80.00
G	80.01 to 160.00

Specific Impulse

The *specific impulse* is the impulse per unit of propellant mass m_f.

$$I_{sp} = I_t / m_f$$

However, the US engineering practice is to use the weight of the propellant rather than the mass.

$$I_{sp} = I_t / w_f$$

$$I_{sp} = I_t / g\ m_f$$

where g is the acceleration of gravity, about 9.8 meters per second^2. As a result, the specific impulse has units of seconds.

Fuel and oxidizer	**I_{sp} (seconds)**
black powder	48 to 103
ammonium perchlorate	175
Lox and kerosene	248
Lox and LH_2	364
nitrogen tetroxide and hydrazine	249

Exhaust velocity

The exhaust velocity c is simply the specific impulse times g (to cancel out the factor of g that we put in when we used the weight of the propellant rather than its mass).

$$c = g\ I_{sp}$$

Mass flow rate

Assuming constant exhaust velocity, the mass flow rate versus time is simply proportional to the instantaneous thrust.

Empirical Data

The NAR tests each type of model rocket engine as part of its safety certification program. The model rocket engine performance data from these tests is available from the NAR Standards and Testing Committee.

ESTES C6

CERTIFIED VALUES

Total Impulse: 9.00 newton-seconds
Delays: 0, 3, 5, 7 seconds

Propellant Type: Black Powder
Propellant Mass: 10.8 grams

Casing Dimensions: 18 mm × 70 mm

Certification Date: Continuing
Contest Use Date: Continuing

Certification Type: Model Rocket

STATIC TEST DATA

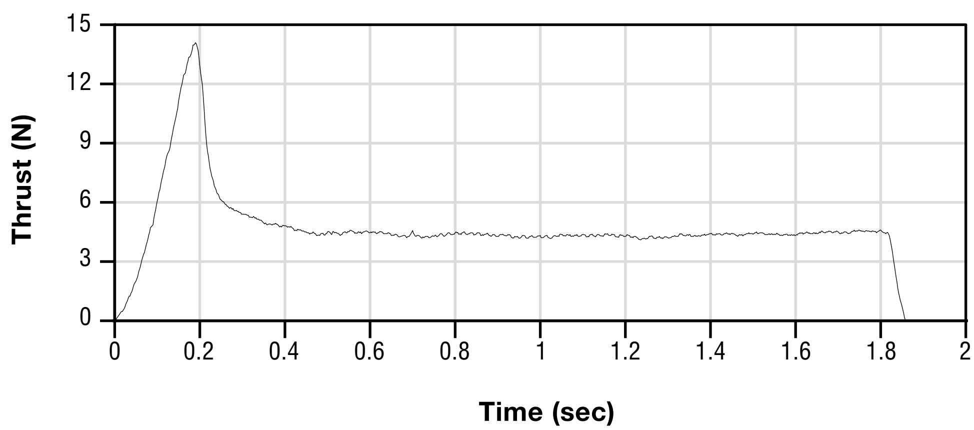
Date Tested: 95-March-25

Total Impulse: 8.82 newton-seconds (σ 0.18)
Peak Thrust: 14.09 newtons (σ 2.94)
Burn Time: 1.86 seconds (σ 0.31)
Average Thrust: 4.74 newtons

Mass After Firing: 9.4 grams

Delay Time	Average Measured Delay	Initial Mass	Mfg Recommended Max Liftoff Weight
0	0.00	20.2 g	113.2 g
3	2.47	24.1 g	113.2 g
5	4.28	24.0 g	113.2 g
7	6.24	24.2 g	70.8 g

TYPICAL THRUST-TIME CURVE



REMARKS

Updated: 8/96

ESTES D12

CERTIFIED VALUES

Total Impulse: 17.00 newton-seconds
Delays: 0, 3, 5, 7 seconds

Propellant Type: Black Powder
Propellant Mass: 21.1 grams

Casing Dimensions: 24 mm × 70 mm

Certification Date: Continuing
Contest Use Date: Continuing

Certification Type: Model Rocket

STATIC TEST DATA

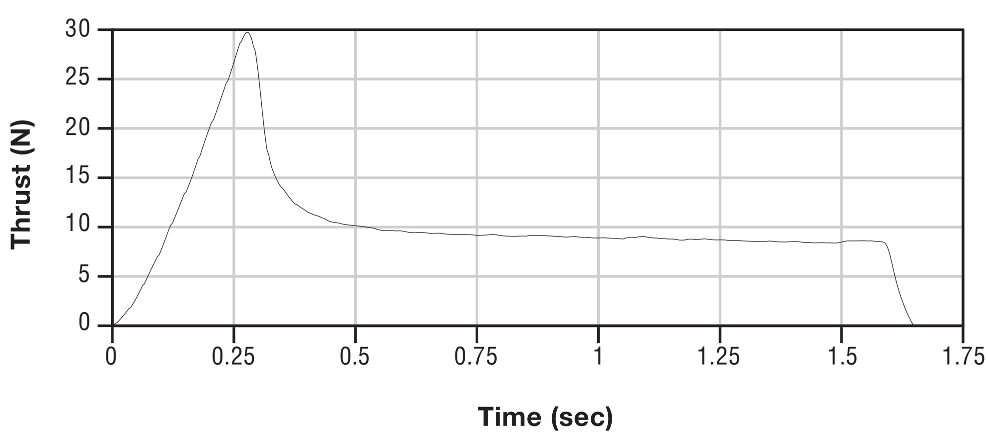
Date Tested: 94-September-17

Total Impulse: 16.84 newton-seconds (σ 0.53)
Peak Thrust: 29.73 newtons (σ 4.59)
Burn Time: 1.65 seconds (σ 0.30)
Average Thrust: 10.21 newtons

Mass After Firing: 16.0 grams

Delay Time	Average Measured Delay	Initial Mass	Mfg Recommended Max Liftoff Weight
0	0.00	39.2 g	396.2 g
3	2.39	41.4 g	396.2 g
5	4.25	45.2 g	283.0 g
7	5.75	44.9 g	226.4 g

TYPICAL THRUST-TIME CURVE



REMARKS

Updated: 8/96

AEROTECH E30

CERTIFIED VALUES

Total Impulse: 40 newton-seconds
Delays: 4, 7 seconds

Propellant Type: Composite
Propellant Mass: 19.3 grams

Casing Dimensions: 24 mm × 70 mm

Certification Date: 88-April-18
Contest Use Date: 88-July-17

Certification Type: Model Rocket

STATIC TEST DATA

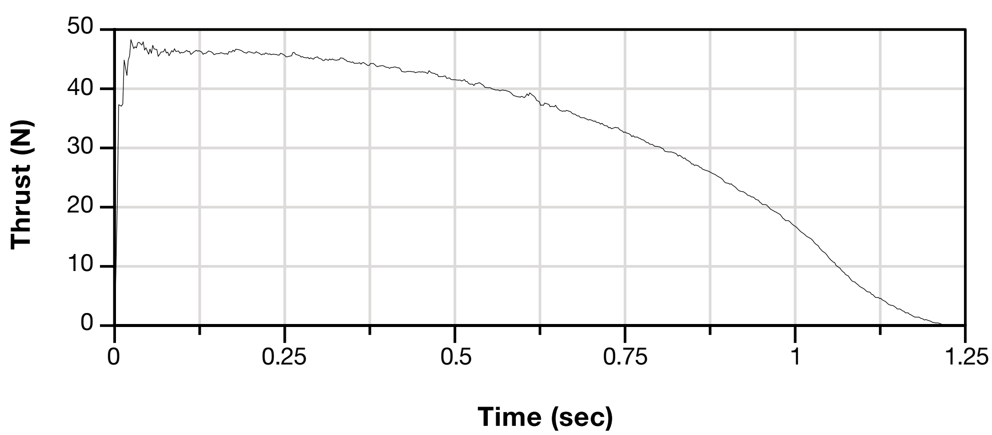
Date Tested: 95-September-3

Total Impulse: 39.51 newton-seconds (σ 0.29)
Peak Thrust: 48.27 newtons (σ 0.81)
Burn Time: 1.22 seconds (σ 0.01)
Average Thrust: 32.38 newtons

Mass After Firing: 19.8 grams

Delay Time	Average Measured Delay	Initial Mass	Mfg Recommended Max Liftoff Weight
4	4.25	43.4 g	454 g
7	6.56	43.2 g	301 g

TYPICAL THRUST-TIME CURVE



REMARKS

Updated: 8/96