ACTIVITY

Model rockets: rocket calculations

Classroom resources for upper secondary

Nordic esero

NAROM | ANDØYA SPACE CENTER

Introduction

In this activity you are going to build and launch your own model rocket and do physical and mathematical calculations on the rocket.

Content

Teaching instructions

When launching a rocket, it is always based on safety measurements and calculations on both the rocket itself and the rocket engine. When launching model rockets we are doing the same thing.

In these activities you are going to calculate things like velocity, height of apogee, stability e.g.

Before your rocket is finished, use a theoretical mass of 0.1 kg. After finishing you rocket use the rockets real weight and do the calculations again.

Calculation tips:

- Assume acceleration and motor thrust as constant. For instance, the thrust force $F = \bar{F}$, for $t = t_b$
- Try to derive the equations before inserting numbers.
- Actual values for the rocket are calculated in task 6, after you have built your own rocket. Before task 6, set initial start mass to M = 0.1kg
- Remember to use SI-units in your calculation

Equipment

What you need	Where to buy	More information
Model rockets	www.Apogeerockets.com	
Glue		
Knife		
Rocket motor	https://www.raketenmodellbau-klima.de/	Model rockets can also be bought from here
Wadding		Fireproof cloth
Launch pad		

Safety precautions

Before launch of the model rockets go through this checklist

- Launch lug are on
- Nosecone is loose, not glued stuck
- Right rocket motor is in place
- Is launch area placed approximately 70m from buildings and cars
- Safety distance on operator 5m, while spectators is 10m.
- No people in front or back of the rocket in wind direction.
- Never adjust the angle of the launcher more than 30 degrees from zenith
- Check area for dangers such as drones, airplane and wind before countdown.

Activity 1: Rocket calculations

Exercise 1: Rocket engine

A. Find the rocket motor type, e.g. C6-5 (see table)

B. Find the total impulse, I_t, of the motor

C. Find the burnout time, t_b

D. Calculate the average thrust, $\overline{F}$

E. Find the engine propellant mass, m_d

F. Calculate average propellant mass consumption, q_p (mass per second)

G. Calculate the specific impulse, I_{SP}, of the motor

Exercise 2: Rocket Trajectory

A. Assume the rocket is in space, with no external force acting on it no influence of gravity and aerodynamic drag). Use the equations of motion and Newton's laws to calculate ideal end velocity, v_i , after burnout. (Determine the burnout mass, m_b and find an expression for $\overline{m}$).

B. Assume the rocket is launched vertical from the surface of the earth, influenced by the earth's gravity (neglect any atmospheric drag). Determine the burnout speed/maximum speed, v_{max}.

C. Determine the height at burnout, h_b , by using results from b

D. Find the coasting time, t_c, after burnout to apogee- How does this match the delay charge of the model rocket motor?

E. After burnout, the rocket will continue in free flight. Use Newton's laws and the equations of motion to determine the coasting height, h_c, (the height from burnout tot the maximum altitude/apogee).

   Determine the maximum altitude/apogee, H_{max}. Comment on the result.

Exercise 3: Aerodynamic calculations

A. Calculate the rocket frontal area, A_{max} and calculate the rocket air resistance factor:

$$\beta = \frac{1}{2} C_d \rho A_{max}$$

Assume that the density of the air is $\rho = 1{,}14 \frac{kg}{m^3}$ and the drag coefficient $C_d = 0{,}5$.

B. Calculate the maximal drag, based on v_{max}

$$F_{drag} = \beta v^2$$

Comment the results.

Exercise 4: Stability calculations

If the rocket has been built, you can now determine the centre of mass. Note that the rocket engine, recovery wadding, parachute and possible payload need to be mounted inside the rocket before you continue:

A. Determine the rockets Centre of Gravity (CG), by balancing the rocket on a ruler e.g. Note the placement as a distance from the rockets nose.

B. Try to find the Centre of Pressure (CP) for the rocket. To do this you can use the "cardboard cut-out" method. Draw the outline of the rocket on cardboard, cut it out and try to balance it on a ruler e.g. The CP on the cardboard rocket is where all the aerodynamic forces is in balance. Note the placement as a distance from the rocket nose.

C. Determine if the rocket is stable or not. Determine the stability margin, the distance between CP and CG divided by the rocket's diameter.

Exercise 5: Rocket equation

The Russian scientist, Konstantin Tsiolkovsky, is known for his rocket equation. This equation is useful when calculating the rocket's ideal velocity, v_i, in vacuum, with no influence of gravity. In the equation, M, is the rockets initial mass, while m_b, is the mass after burnout.

A. Calculate the rocket's ideal velocity by using the rocket equation:

$$v_i = -v_e ln \left| \frac{m_b}{M} \right|$$

Exercise 6: Update your calculation

Find the weight of your rocket. Then, update your calculation for the height, H_{max}. This is something you can present before you launch the rocket.

Activity 2: Build and launch rocket

The model rockets are complete kits with instructions. As tools for the building use sandpaper, knife/scissors, glue and tape to build the rocket.

Pre-flight presentations

Before launch, you may present the rocket for the other groups.

- Present the rocket's name, type and mission
- Present the most important calculations for the trajectory (like v_{max} and H_{max}).

Launch schedule:

To make sure you'll have a smooth and safe launch, it is important to do some preparations.

- Make a schedule so every group is prepared and ready with their rocket when it's their turn.
- Each group should have a "Pad Supervisor" to press the "fire" button (the red button) at the end of countdown.
- Each group is responsible for rocket recovery after launch (for safety reasons, wait till all groups have launched).

Schedule

1. Group A – Avion (Precision)
2. Group B – Avion (Precision)
3. Group A – Payload (Height)
4. Group B – Payload (Height)
5. Group A – Courier
6. Group B – Courier

Tips to all groups

If it's cold, the parachute might not open. To avoid that, keep it warm and wait with packing the parachute to right before launch. This will increase your chances for a successful deployment.

If your group is launching a height-rocket you need to mount the height sensor right before it's your turn.

Raketenmotorfibel
Rocket Motor Primer

- Standard 18 mm Motoren
- Viele neue Motortypen
- Volle Leistung durch Kompositetreibstoff
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- Präzise Einzelfertigung
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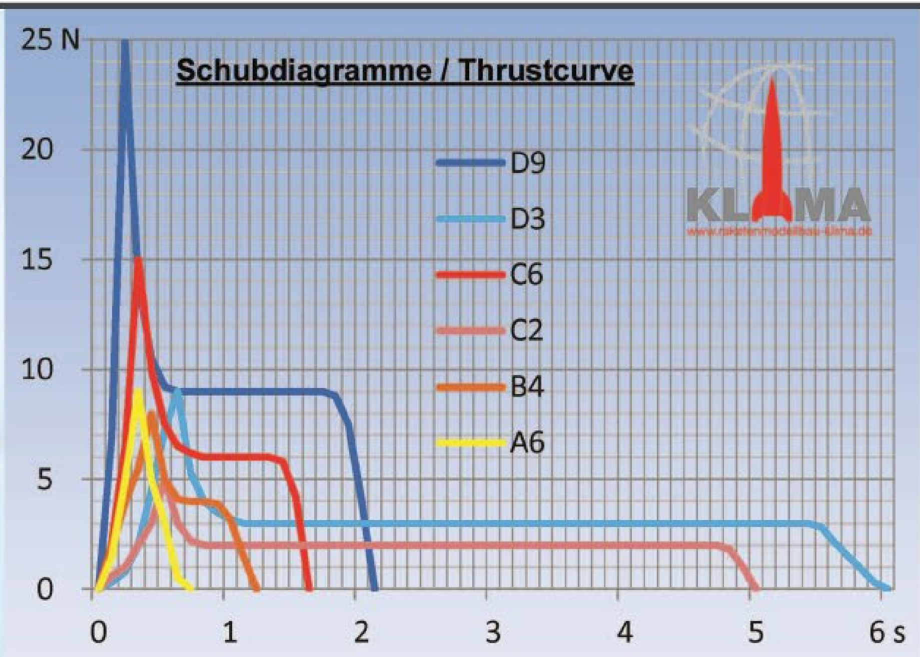

Elektroanzünder / Igniters
Best.-Nr. / Item No.: 7001

Sechs Stück Elektroanzünder zum Zünden der Treibsätze mit Zündgeräten (6 oder 9 Volt). Sichere Befestigung mit beiliegenden Stöpseln in den Treibsätzen.

Six electrical igniters for igniting rocket motors with electrical Launch Controllers (either 6 or 9 Volts). The igniters are secured in to the motor nozzles with the included plugs.

Aluhülse / Aluminum Sleeve
Best.-Nr. / Item No.: 8060

Sichere und einfache Befestigungsmöglichkeit der 18 mm Raketenmotoren. Gerne verwendet für Raketengleiter, Raketenautos und auch für Raketenmodelle. Eine Seite ist verschlossen, kann aber je nach Verwendungszweck aufgebohrt werden.

A safe and simple method for mounting 18 mm rocket motors. Often used for rocket gliders, rocket cars and also for flying model rockets. One side is closed, but can be easily drilled open, depending on the designated use.

Raketenmodellbau Klima GmbH
An der Laugna 1, D-86494 Emersacker,
Tel.: +49 (0) 8293/1734
www.raketenmodellbau-klima.de

Best.-Nr. Item No.	Typ Type	Gesamtimpuls Total Impulse	Schub avg. Thrust	Schubdauer Burning Period	Verzögerung Delay	Gesamtgewicht Total Weight	Pulvergewicht Powder Weight	Max. Startgewicht Max. Lift-Off Wgt.	Verwendung Usage
0164	A6-4	2,5 Ns	6 N	ca. 0,6 s	ca. 4 s	14,5 g	3,5 g	70 g	green, red
0240	B4-0	5,0 Ns	4 N	ca. 1,3 s	0 s	15,8 g	5,0 g	90 g	blue
0244	B4-4	5,0 Ns	4 N	ca. 1,3 s	ca. 4 s	16,8 g	5,8 g	90 g	green, red
0320	C2-0	10,0 Ns	2 N	ca. 5,0 s	0 s	22,3 g	11,5 g	150 g	yellow, magenta
0329	C2-P	10,0 Ns	2 N	ca. 5,0 s	verschlossen / plugged	22,5 g	11,0 g	150 g	yellow, magenta
0360	C6-0	10,0 Ns	6 N	ca. 1,6 s	0 s	18,7 g	8,9 g	160 g	blue
0363	C6-3	10,0 Ns	6 N	ca. 1,6 s	ca. 3 s	20,5 g	9,5 g	160 g	green, red
0365	C6-5	10,0 Ns	6 N	ca. 1,6 s	ca. 5 s	21,2 g	10,2 g	150 g	green, red
0367	C6-7	10,0 Ns	6 N	ca. 1,6 s	ca. 7 s	22,0 g	11,0 g	140 g	green, red
0369	C6-P	10,0 Ns	6 N	ca. 1,6 s	verschlossen / plugged	19,9 g	8,4 g	160 g	orange, black
0430	D3-0	19,0 Ns	3 N	ca. 6,0 s	0 s	28,0 g	17,2 g	200 g	yellow, magenta
0439	D3-P	19,0 Ns	3 N	ca. 6,0 s	verschlossen / plugged	27,7 g	16,7 g	200 g	yellow, magenta
0490	D9-0	20,0 Ns	9 N	ca. 2,1 s	0 s	26,3 g	15,5 g	300 g	blue
0493	D9-3	20,0 Ns	9 N	ca. 2,1 s	ca. 3 s	27,1 g	16,1 g	300 g	green, red
0495	D9-5	20,0 Ns	9 N	ca. 2,1 s	ca. 5 s	27,6 g	16,6 g	250 g	green, red
0497	D9-7	20,0 Ns	9 N	ca. 2,1 s	ca. 7 s	28,2 g	17,2 g	200 g	green, red
0499	D9-P	20,0 Ns	9 N	ca. 2,1 s	verschlossen / plugged	26,5 g	15,0 g	300 g	orange, black

Verwendung / Usage

- (green) Einstufige Raketen / Single Stage
- (red) Letzter in Mehrstufenraketen / Final Stage in multi-stage rocket
- (blue) Mehrstufen Treibsatz / Booster Stage
- (yellow) Raketengleiter / Boost Glider
- (magenta) Raketenauto / Rocket Car
- (orange) Raketen mit elektronischer Bergungssystemauslösung / Rockets with electronic recovery systems
- (black) Bündelung / Cluster

Die Motoren werden in Packungen zu 6 Stück mit beiliegenenden Zündschnüren geliefert. Alternativ sind Elektroanzünder erhältlich. Die Motorlänge beträgt 70 mm und der Durchmesser ist 17,8 mm.
Each motor type comes in a pack of six, including safety fuses for igniting. Electric igniters are separately available. Motor dimensions are 17,8 mm in diameter and 70 mm in length.

Appendix 2: Rocket name and model

Rocket name and model:			
Motor and Rocket characteristics:	1a)	Rocket motor:	
	1b)	Total impulse, I_t	
	1c)	The motor burn time, t_b	
	1d)	Average thrust force, $\overline{F}$	
	1e)	Motor fuel mass, m_p	
	1f)	The average fuel consumption, $\bar{q}_p$	
	1g)	Specific Impulse, I_{sp}	
Trajectory calculation:	2a)	Ideal end velocity (without gravitation), v_i	
	2b)	Maximum speed/burnout speed (with gravitation), v_{max}	
	2c)	Burnout height, h_b	
	2d)	Coasting time, t_c	
	2e)	Coasting height, h_c	
	2f)	Flight height, H_{max}	
Aerodyn amic	3a)	Air resistance factor, β	
	3b)	Maximum Drag, F_{drag}	
Stability	4a)	Centre of Gravity, CG	
	4b)	Centre of Pressure, CP	
	4c)	Stability margin	
Rocket equatio n	5	Rocket equation - Ideal velocity v_i	

Sources

- Content is developed by NAROM for Nordic ESERO
- https://www.raketenmodellbau-klima.de/