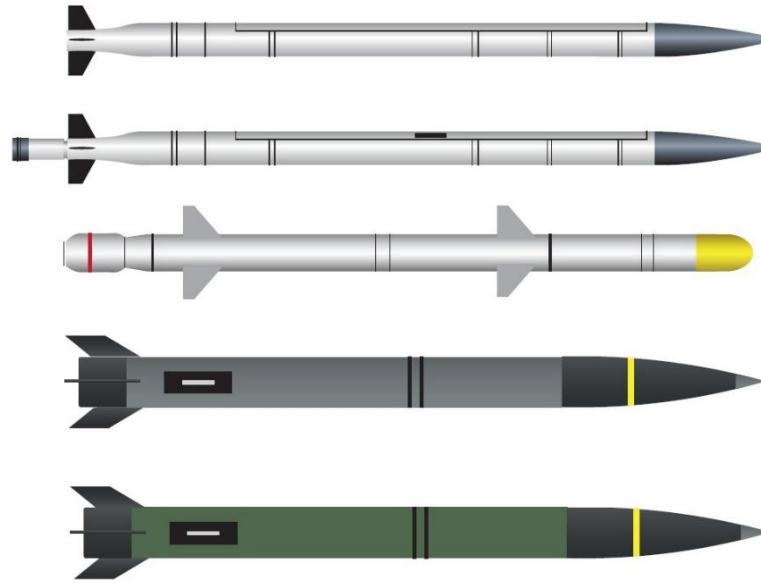




Hypersonics with Dr. Chuck Easttom

Labs

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General Instructions

Labs will each have an estimated time and a lab type. Estimated time is self-explanatory. Type indicates if this is a recipe lab or experiment lab. Recipe lab means you simply follow the specific steps in order and it will work as shown. There is nothing you need to figure out. Experiment labs have most of it spelled out for you, with something you have to figure out. These are meant to help you reach the next level in knowledge.

LAB 1 NASA Simulations

Related Lesson – Lesson 2

Estimated Time: 30 minutes

Lab Type: Recipe mixed with Experiment

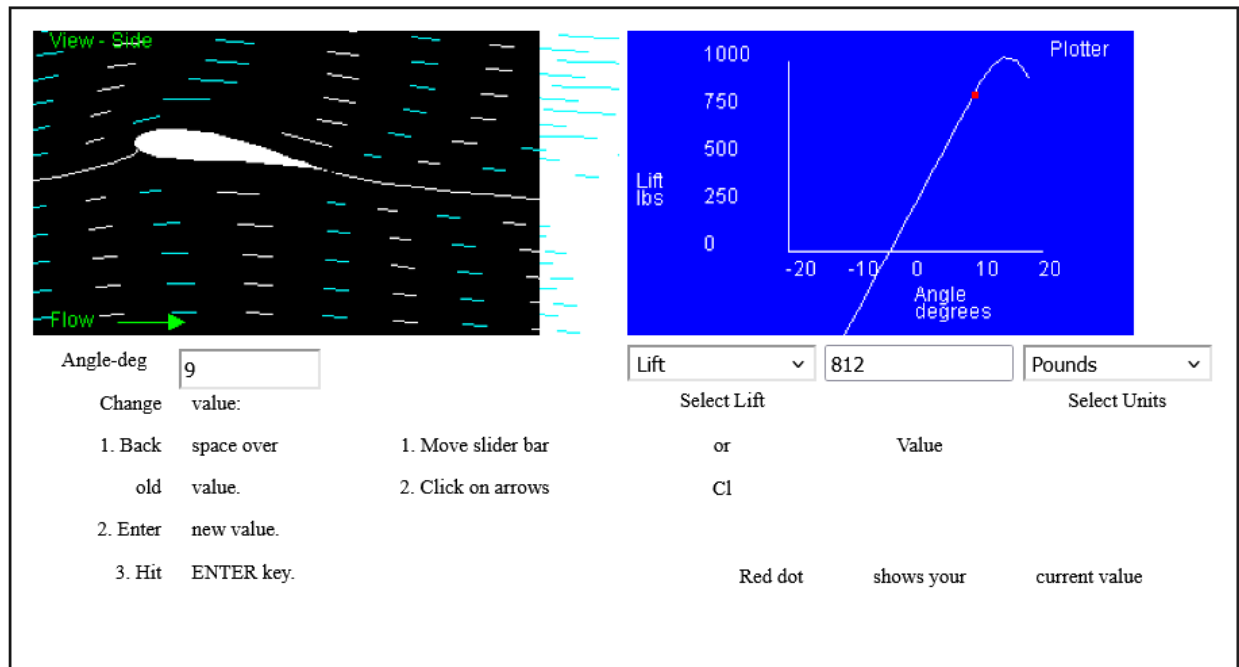
Note, we are selecting specific simulations, but you may wish to look at others

<https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/bga-simulations/>

You will probably notice that some of the materials are for hobbyist rockets (Styrofoam, cardboard, wood, etc.) But you should also find materials suitable for real world missiles.

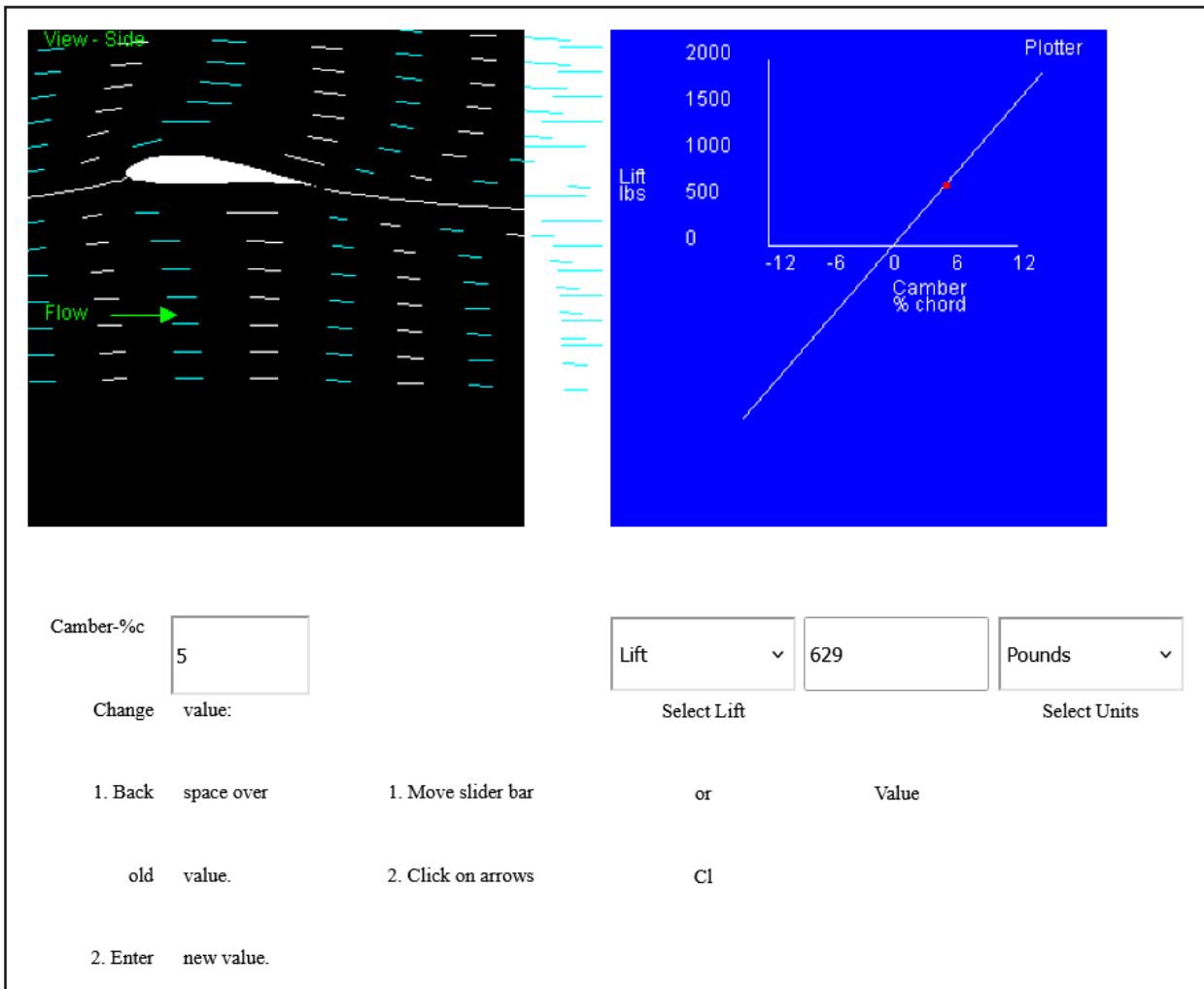
Fluid Dynamics Simulator

The first one is <https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/foiling/>



Effects of Shape on Lift

<https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/foilshape/>



Normal Shocks Interactive

<https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/normal/>

Normal Shock Calculator

Input

Units: Imperial v

Planet: Earth v

Mach 5

Gamma 1.4

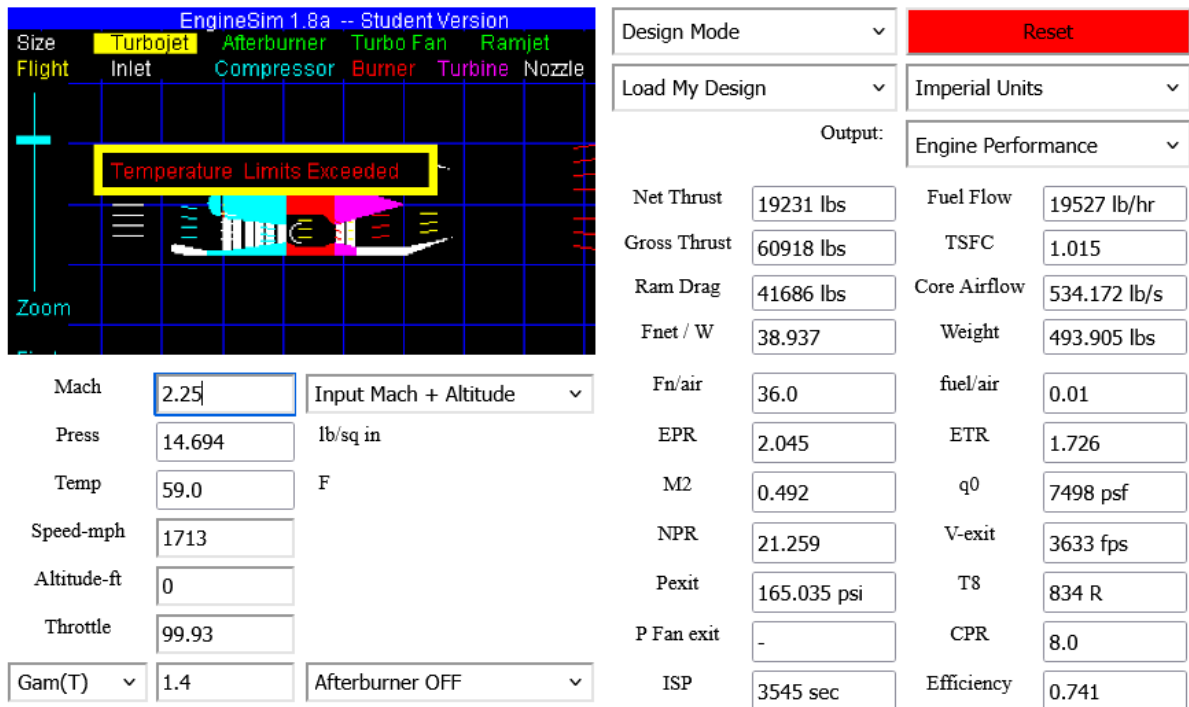
Altitude 0 feet

Press -> COMPUTE

Output	Upstream	Ratio	Downstream
Static Pressure-psf	2114.113	29.0	61309.3
Total Pressure-psf	1118556.0	0.06171	69033.16
Static Temperature-R	518	5.799	3007
Density-slug/cu ft	0.002372863	5.0	0.011864315
Mach	5.0	0.083	0.41522

Aircraft Force Interactive

<https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/foilsimu/>



Lab 2 Bernoulli's Calculators

Related Lesson – Lesson 2

Estimated Time: 25 minutes

Lab Type: Recipe

There are a few of these online. You should compare if they give you the same results from the same inputs.

<https://www.omnicalculator.com/physics/bernoulli-equation>

Fluid density ⓘ

...

lb/cu ft ▼

^ Position 1 parameters

Pressure

...

bar ▼

Height

...

ft ▼

Fluid speed

...

ft/s ▼

^ Position 2 parameters

Pressure

...

<https://www.pipeflowcalculations.com/bernoulli/calculator.xhtml#calculator>

Conditions at position one	Conditions at position two
pressure in position one (p1) 1028.0 mbar	pressure in position two (p2) 1020.8 mbar
height in position one (z1) 10.0 m	height in position two (z2) 10.0 m
velocity in position one (V1) 1.0 m/s	velocity in position two (V2) 1.5625 m/s

Dimensions at one	Circ.	Rect.	Dimensions at two	Circ.	Rect.
diameter in position one (D1) 250.0 mm			diameter in position two (D2) 200.0 mm		
cross section area in position one (A1) 490.87 cm²			cross section area in position two (A2) 314.16 cm²		

<https://www.lmnoeng.com/Flow/bernoulli.php>

[Register](#) to enable "Calculate" button.

Select computation	Select fluid	Select geometry
Pitot tube in circular conduit ▾	Water at 20 C (68 F) ▾	Solve for Flow or Velocity ▾
Click to Calculate		Not registered user
Mass Density, ρ :	62.315592	lb(mass)/ft ³ ▾
Flowrate, Q:	Will be computed	gal/min U.S. (gpm) ▾
Fluid Velocity, V:	Will be computed	ft/s ▾
Downstream Velocity, V_2 :	Not used	ft/s
Pressure Difference, $P_2 - P_1$:	5	lb/in ² (psi) ▾
Elevation Difference, $Z_2 - Z_1$:	Not used	ft ▾
Pipe Diameter, D:	4	inch ▾
Downstream Diameter, D_2 :	Not used	inch

<https://www.wolframalpha.com/input?i=Bernoulli%27s+equation>

Computational Inputs:

Calculate: pressure ▾

» downstream pressure:

» vertical displacement:

» downstream vertical displacement:

» speed:

» downstream speed:

» fluid density:

» gravitational acceleration:

Compute

Lab 3 Ideal Gas Calculator

Related Lesson – Lesson 2

Estimated Time: 20 minutes

Lab Type: Recipe

Use the online calculator https://saemiller.com/flow/SAEMiller_Comp_Calc.html

You will use five of these calculators:

Ideal Gas Calculator

	STP	NTP	Clear
p	101325.00	[Pa]	
ρ	1.205365	[kg/m ³]	
T	293.00	[K]	
R	286.9	[J/kg K]	
Pressure v	Calculate		

Prandtl-Meyer Flow Calculator

Clear

M_1
 M_2
 γ
 θ [deg.]
 ν_1 [deg.]
 ν_2 [deg.]

Calculate

Normal Shock

Clear

M_1
 M_2
 p_2/p_1
 $p_{0,2}/p_{0,1}$
 T_2/T_1
 u_2/u_1
 γ
 ρ_2/ρ_1
 $p_{0,2}/p_1$

Calculate

Oblique Shock (Wedge)

Clear

M_1	
$M_{n,1}$	
M_2	
$M_{n,2}$	
p_2/p_1	
$p_{0,2}/p_{0,1}$	
T_2/T_1	
u_2/u_1	
v_2/v_1	
β	[deg.]
γ	1.40
ρ_2/ρ_1	
θ	[deg.]

Weak Shock ▾

Calculate

Oblique Shock (Cone)

Clear

M_1	
M_c	
β	[deg.]
γ	1.40
θ	[deg.]

Calculate

Change various parameters and note the changes this causes in the calculation.

Note what effect changes have and be prepared to discuss with the class.

Lab 4 Omni Calculator

Related Lesson: Lesson 3

Estimated Time: 20 minutes

Lab Type: Recipe

This site has quite a few calculators relevant to hypersonics.

<https://www.omnicalculator.com/physics/mach-number>

For this one, as you change parameters it will change. To demonstrate I put in a rather absurd number for ft/sec

Speed of object

55,222,222

ft/s

Speed of sound

1,126

ft/s

Temperature of air

68

°F

Mach number

49,041



Share result

Reload calculator

Clear all changes

Did we solve your problem today?

Yes

No

For this one you put in values and it will calculate the drag force

<https://www.omnicalculator.com/physics/drag-equation>

Density

...

22

kg/m³ ✓

Velocity

...

13

m/s ✓

Drag coefficient

...

2

Area

...

3

m² ✓

Drag force

...

11,154

N ✓

This one calculates the Knudsen number. Remember the Knudsen number (Kn) is a dimensionless quantity that indicates whether a fluid flow should be treated as a continuum or if particle effects become significant. It's defined as the ratio of the mean free path of a molecule to a characteristic length scale of the flow (e.g., the diameter of a pipe)

<https://www.omnicalculator.com/physics/knudsen-number>

Mean free path

...

32

ft ▾

Characteristic linear dimension

...

12

ft ▾

Knudsen number

...

2.6667

You should use **statistical mechanics** to describe this gas.



Share result

Reload calculator

Clear all changes

Did we solve your problem today?

 Yes

 No

This calculates Rocket Thrust

<https://www.omnicalculator.com/physics/rocket-thrust>

Effective velocity

Flow area at nozzle

Mass loss rate

Ambient pressure

Pressure at nozzle

Thrust

but what if a particle beam sends 1 billion (1.000,000,000)

0.000000000000000167262192595 What happens if that is accelerated to the speed of light
299,792,458?

What happens if 100 KG is sent at 300 mph /134.112 ms

What about 500 mph/ 223.52 ms?

Mass (m) ...

234 kg ▾

Acceleration (a) ...

3 m/s² ▾

Force (F) ...

702 N ▾

Share result

Reload calculator

Clear all changes

Did we solve your problem today?

 Yes

 No

This calculator calculates blast radius, note: The "All Up Weight" (AUW) of an explosive refers to the total weight of the munition, including any packaging and palletization, if applicable

<https://www.omnicalculator.com/physics/blast-radius>

All-up weight of base explosives (W) ⓘ ...

44

lb ▼

Type of munition ...

☒ Fragmented munitions

☐ Bare exposed explosive

Public access ⓘ ...

☒ Yes

☐ No

Distance ⓘ ...

3,426

ft ▼

The distance estimated by this calculator does not guarantee safety. It is the distance outside of which no more than one fragment would be expected. However, the areas outside the distance remain UNSAFE.

Just for fun Warp speed calculator

<https://www.omnicalculator.com/physics/warp-speed>

Lab 5 Flow and Shock Calculators

Related Lesson: Lesson 3

Estimated Time: 30 minutes

Lab Type: Experiment

Each of these has more limited use than previous calculators. Your goal is to get comfortable with each of them.

Isentropic Flow Relations (for a Calorically Perfect Gas)

<https://cdgriffin.me/compressible.php>

The values are listed on the calculator, such as For example M_1 is Mach number upstream of shock wave, T_0 is total temperature, etc.

In the first case I put in the ratio of specific heat of air and Mach 5 and this produced values for me from that.

Isentropic Flow Relations (for a Calorically Perfect Gas)

Ratio of Specific Heats, γ

1.4

Desired Input

Mach Number

▼

=

5

Calculate

5.0000

M

11.5370

$\mu (^{\circ})$

76.9202

$\nu (^{\circ})$

529.0898

p_o/p

6.0000

T_o/T

88.1816

ρ_o/ρ

0.0036

p/p^*

0.2000

T/T^*

0.0179

ρ/ρ^*

25.0000

A/A^*

I did something similar with Oblique shock relations

Oblique Shock Relations (for a Calorically Perfect Gas)

Ratio of Specific Heats

1.4

$M_1 =$

5

Desired Input

Deflection Angle ($^{\circ}$) (weak shock

▼

=

3

Calculate

3.0000

$\theta (^{\circ})$

13.5608

$\beta (^{\circ})$

1.1724

$M_{n,1}$

0.8599

$M_{n,2}$

4.6916

M_2

1.4369

p_2/p_1

0.9952

$p_{0,2}/p_{0,1}$

1.2937

ρ_2/ρ_1

1.1107

T_2/T_1

Max Deflection Angle for a Mach number of 5.0000 = 41.1176°

Corresponding Wave Angle = 67.1139°

Note differences with Mach 1, 5, 10, and 20. Do any values become disconcerting you at any given speed?

Lab 6: Hypersonic Missile design

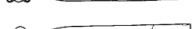
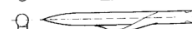
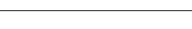
Estimated Time: 30 minutes

Lab Type: Experimentation

Related Lesson: Lesson 7

Students will form into groups and perform a general design of a hypersonic missile. To make this manageable in the time allocated there are some boundaries

1. First select some type of propulsion
 - a. Ramjet
 - i. You should also consider the inlets

Type Inlet	Sketch	Placement
Nose		Annular nose inlet
Chin		Forward underside in nose compression field – partial annular
Forward Cruciform Annular		Forward in nose compression field - cruciform (four) annular inlets
Aft Cruciform Annular		Aft-cruciform (four) annular inlets
Under Wing Annular		In planar wing compression field - twin annular inlets
Twin Two-dimensional		Aft - twin cheek-mounted two dimensional inlets
Underslung Annular		Aft underside - full annular
Underslung Two-dimensional		Aft underside - belly mounted two dimensional inlet
Aft Cruciform Two-dimensional		Aft - cruciform (four) two dimensional inlets

- b. Scramjet
 - c. Turbojet
 - d. Turbofan
 - e. Ion propulsion
 - i. Hall effect
 - ii. Gridded ion
 - f. Pulse Plasma Thruster
2. Select fuel
 - a. Solid
 - b. Liquid
 - c. Hybrid
3. If your device has any wings, select a wing type:

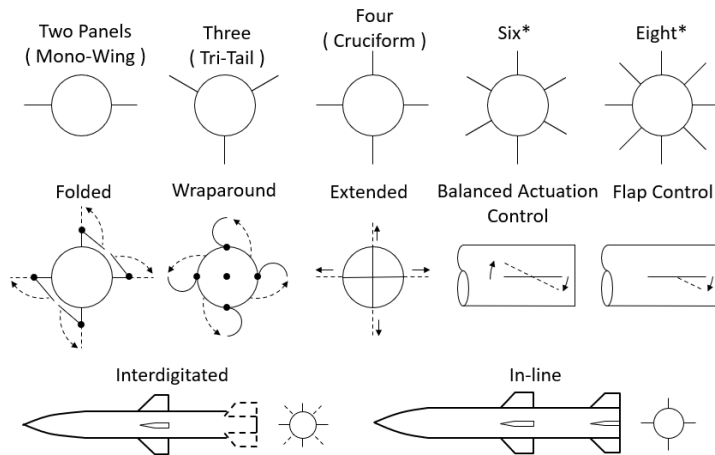
Airfoil Type	Lift at AoA=0	Unique Feature	Common Use Cases
Symmetrical	None	Same shape top/bottom	Control surfaces, aerobatics
Cambered	Yes	Curved top, flat bottom	General aviation, commercial jets
Laminar Flow	Yes	Low drag, delayed transition	Gliders, UAVs
Supercritical	Yes	Flat upper, rounded lower	High-subsonic jets
Reflexed	Yes	Upturned trailing edge	Flying wings, tailless aircraft
Flat Plate	Limited	Simplest form, used in models	RC planes, small drones
High-Lift Devices	Enhanced	Uses slats/flaps	STOL aircraft, heavy lifters

4. You will need to select materials. Some that were introduced in class include:

Material	Strength	Temperature Resistance	Weight
Aluminum Alloy	Moderate	Low (~150°C)	Light
Titanium Alloy	High	Moderate (~600°C)	Medium
Carbon Composites	Very High (anisotropic)	Good (depends on resin)	Very Light

5. You need to consider Body Fineness Ratio

6. You need to account for stabilizers



7. Other items you should consider
 - a. What payload will your missile deliver?
 - b. What is the weight of your missile?
 - i. Weight of propulsion system
 - ii. Weight of casing
 - iii. Weight of electronics
 - c. Nose cone shape
 - d. Is your device maneuverable?
 - i. What is your mechanism of maneuverability?
 - ii. How maneuverable is it?

Lab 7 Compressible Flow Calculator

Related Lesson: Lesson 8

Estimated Time: 30 minutes

Lab Type: Experiment

You have worked with other calculators, this one calculates the same values. You may wish to experiment with this compared to previous calculators. This site has three calculators for you to use <https://aerospaceweb.org/design/scripts/compress.shtml>

Lab 8: Hypersonic Missile design

Estimated Time: 30 minutes

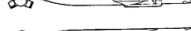
Lab Type: Experimentation

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Aft Cruciform Two-dimensional		Aft - cruciform (four) two dimensional inlets

b. Scramjet

c. Turbojet

d. Turbofan

e. Ion propulsion

i. Hall effect

ii. Gridded ion

f. Pulse Plasma Thruster

2. Select fuel

a. Solid

b. Liquid

c. Hybrid

3. If your device has any wings, select a wing type:

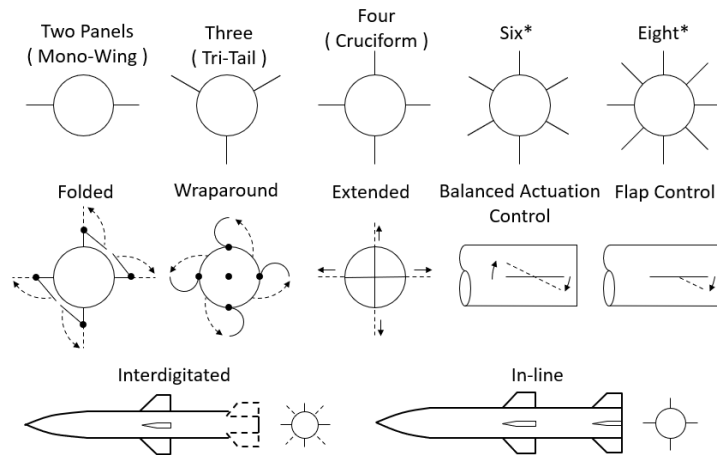
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 - d. Is your device maneuverable?
 - i. What is your mechanism of maneuverability?
 - ii. How maneuverable is it?

Isentropic Flow Relations

INPUT: Mach number =
Gamma = (perfect gas)
 (all angles in degrees)

Mach number =	Mach angle =
$A/A^* =$	P-M angle =
$p/p_0 =$	$p/p^* =$
$\rho/\rho_0 =$	$\rho/\rho^* =$
$T/T_0 =$	$T/T^* =$

Normal Shock Relations

INPUT: M1 =
Gamma = (perfect gas)

$M_1 =$	$M_2 =$
$p_{02}/p_{01} =$	$p_1/p_{02} =$
$p_2/p_1 =$	$\rho_{02}/\rho_{01} =$
$T_2/T_1 =$	

Oblique Shock Relations

Launcher Calculator

An open source orbital launch vehicle payload calculator by Launcher

Blog | Tour | About | MIT License | Github | Discord v41

Select Rocket

Custom Rocket...

Designed Rocket - engine based

Result

Payload mass (calculated) **2,177 kg**

Payload to Lift-off mass ratio 2.90 %

Aggressivity index 3.2 pts

Rocket

1st engine

Launcher E-2

10000 kgf

9 Qty

1st stage Fuel & Cycle

Lox/Kerosene

Staged Combustion

2nd engine

Launcher E-2 vac

12600 kgf

1 Qty

2nd stage Fuel & Cycle

Lox/Kerosene

Staged Combustion

Stages

2

Thrust-to-weight ratio

1st 1.2 2nd 0.890

Lift-off mass

75000 kg

Max Rocket Body Diameter

2.2 m

Fairing mass

563 kg

2nd stage to Rocket mass ratio

15.8 %

☐ Set all to Min <-- --> Set all to Max ☐

Set averages

☐

1st stage Dry to Wet mass ratio

8.17 %

Reusability ☐ Fixed design ☐

Spaceport

Cape Canaveral

Air Launch ☐

Launch point Altitude

0.1 km

Additional velocity (Air Launch)

0 m/s

Spaceport Latitude

28.61 deg

Launch Azimuth

72.77 deg

Earth rotation velocity

408.2 m/s

Orbit

LEO

Low Earth orbit

Orbit Perigee

200 km

Orbit Apogee (0 means a circular orbit)

0 km

Orbit Inclination

32.6 deg

Orbita

1:28:21 s

Delta

7640.1 m/s

The angle between the Earth's equatorial plane and the satellite's orbital plane.

The inclination of an orbit is always greater than the spaceport latitude.

Decreasing the orbit inclination requires a special maneuver and leads to a significant energy expenditure.

Losses

Lab 9: Hypersonics Counter Measure

A group of 2 to 3 will setup requirements and specifications for a hypersonics counter measure. This should include:

1. Is it ground based? Sea based? Why?
2. Is it projectile? Energy Based?
3. What are its parameters?
 - a. Speed
 - b. Range
 - c. Response time
4. Power and/or ammunition requirements?
5. Time to setup?
6. Time to reload?

Lab 10: Python Calculations (optional)

There is a zip file with complete working python scripts you can start from

Reynolds number

There are two scripts, one has everything hard coded the other prompts for data. Both work. You may wish to modify these to tell whether the flow is laminar or turbulent. Remember

$Re < 2000$ – laminar

$Re > 2000$ – turbulent

Mach Number

There is a script that calculates this, but assumes a particular speed of sound. You could modify this to prompt the user for the particular inputs that would allow you to calculate the speed of sound and use that in your Mach calculations.

Görtler number

There is working code to calculate this, it is hard coded, you can modify it to take in input of some values.