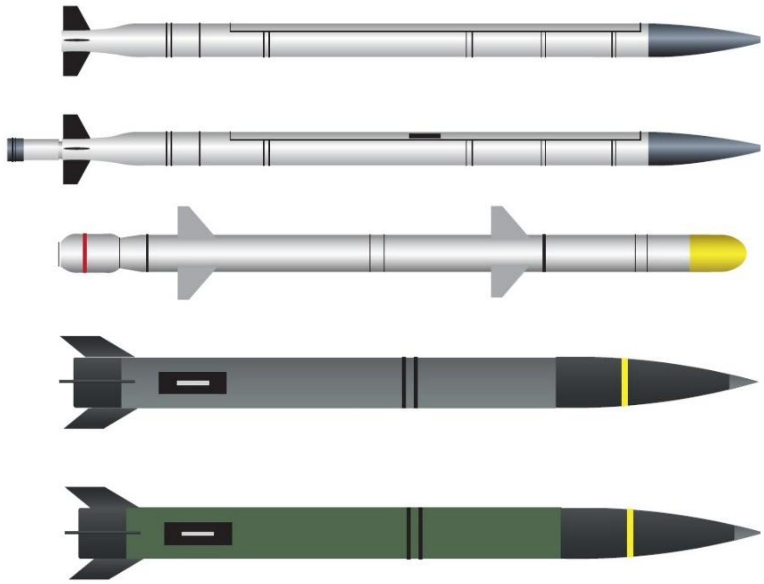


Hypersonics with Dr. Chuck Easttom

Labs

Contents

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

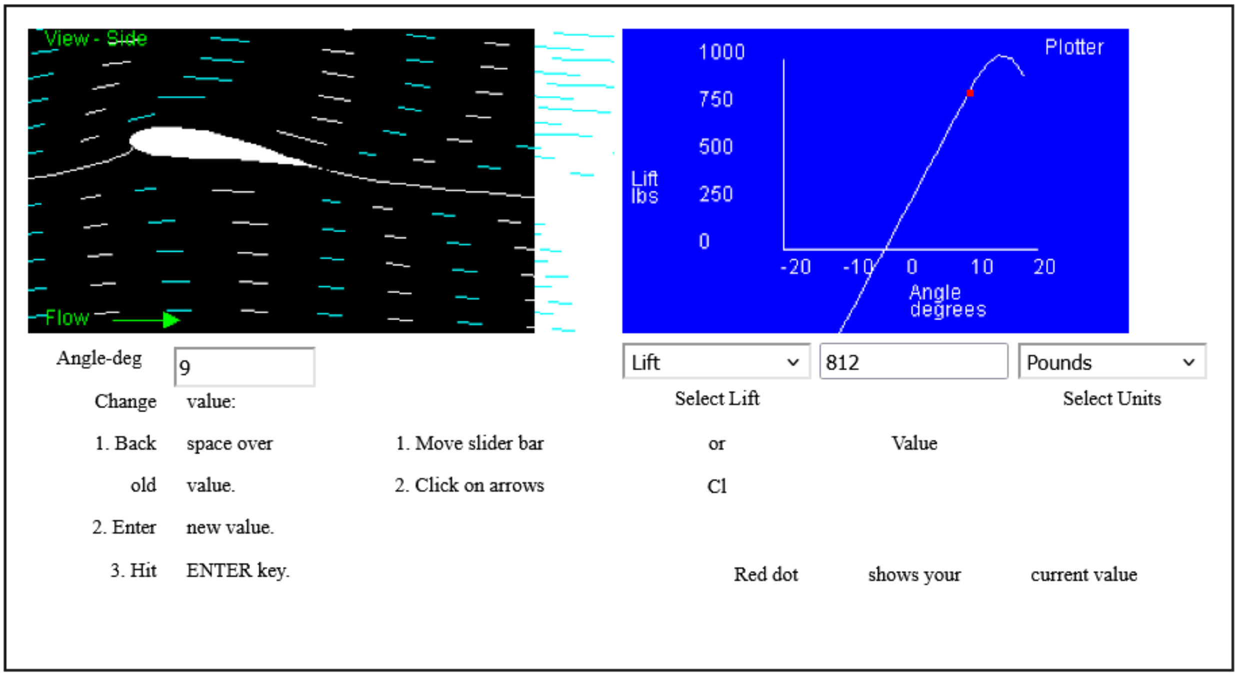
Note, we are selecting specific simulations, but you may wish to look at others

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.

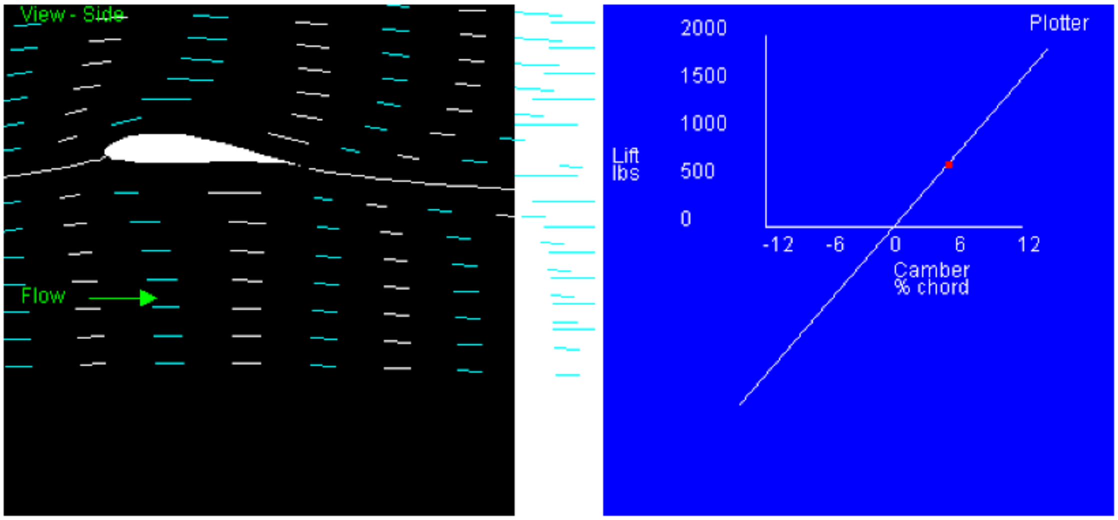
Fluid Dynamics Simulator

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



Effects of Shape on Lift

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



Camber-%c 5

Lift 629 Pounds

Change value:

Select Lift

Select Units

1. Back space over old value.

2. Enter new value.

1. Move slider bar

2. Click on arrows

or Value Cl

Normal Shocks Interactive

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

Normal Shock Calculator

Units: Imperial

Planet: Earth

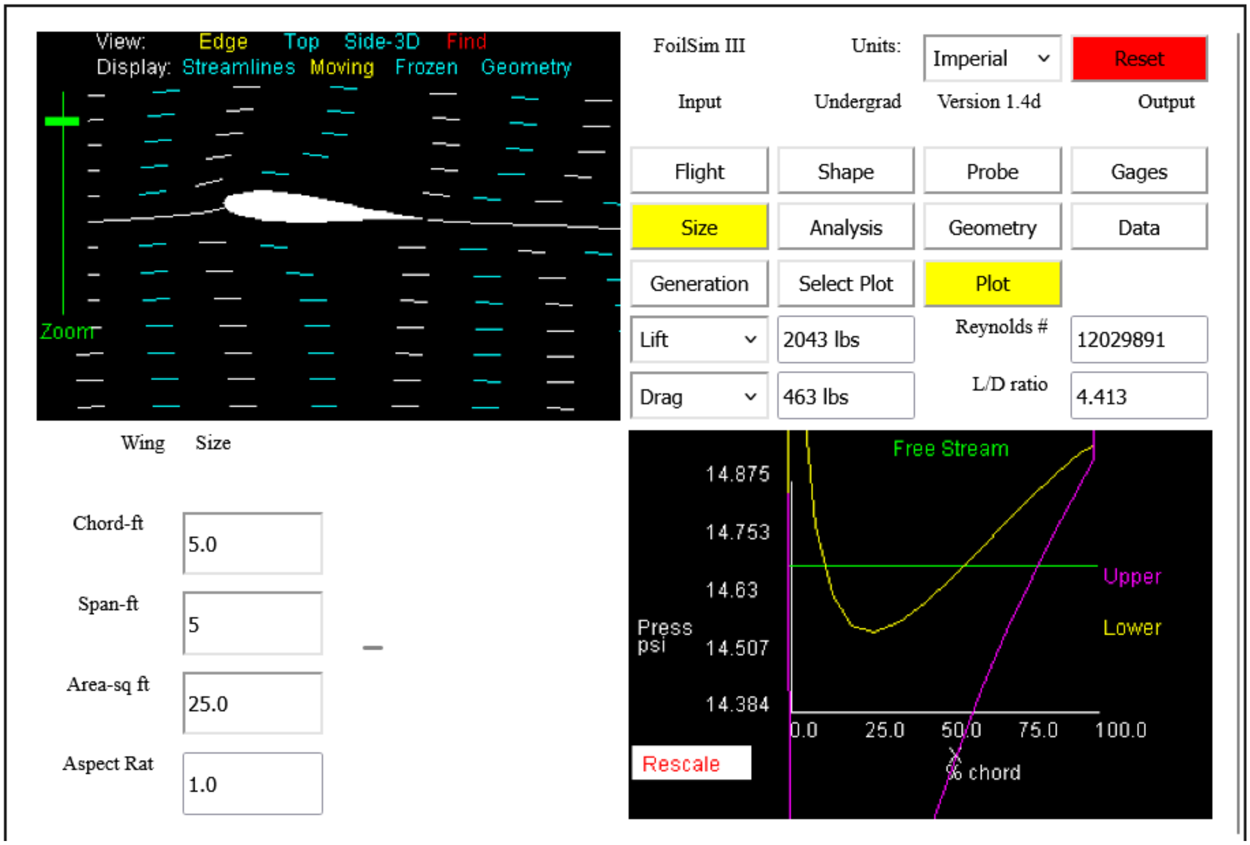
Input

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

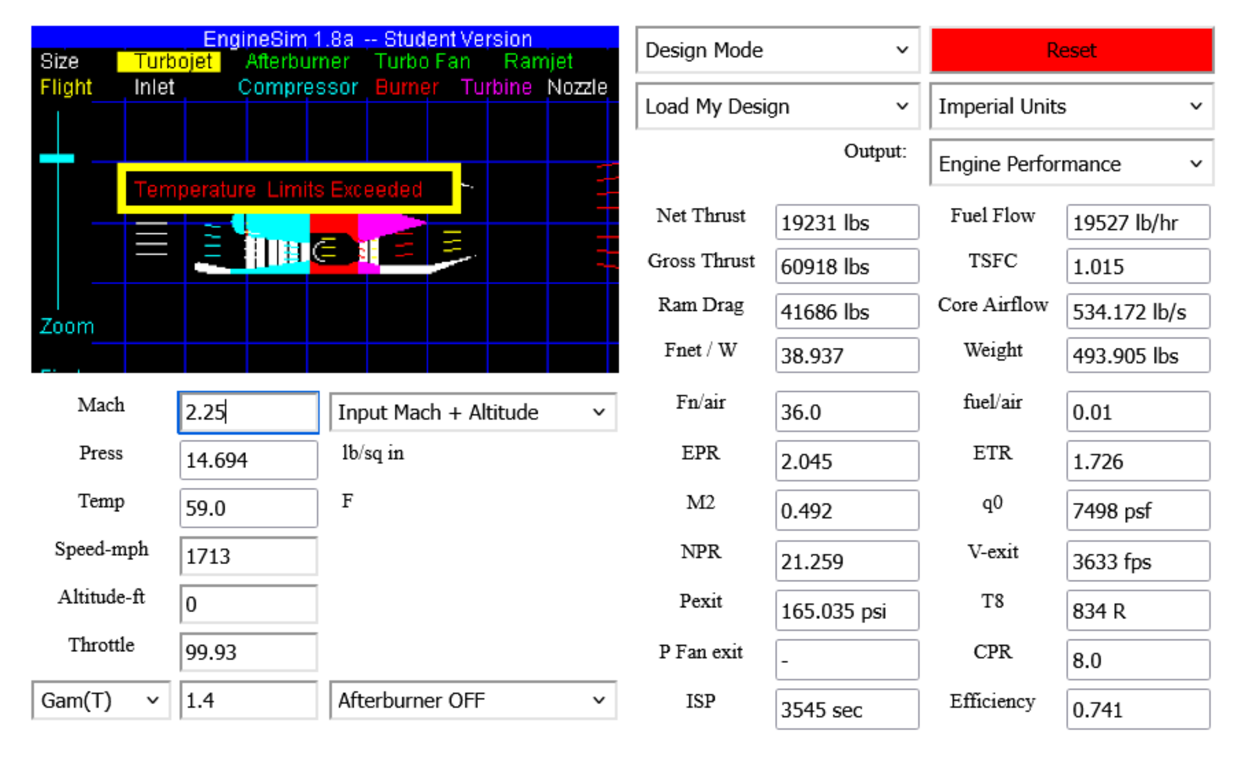
Aircraft Force Interactive

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



Jet Engine Interactive

https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/enginesim/



Lab 2 Bernoulli's Calculators

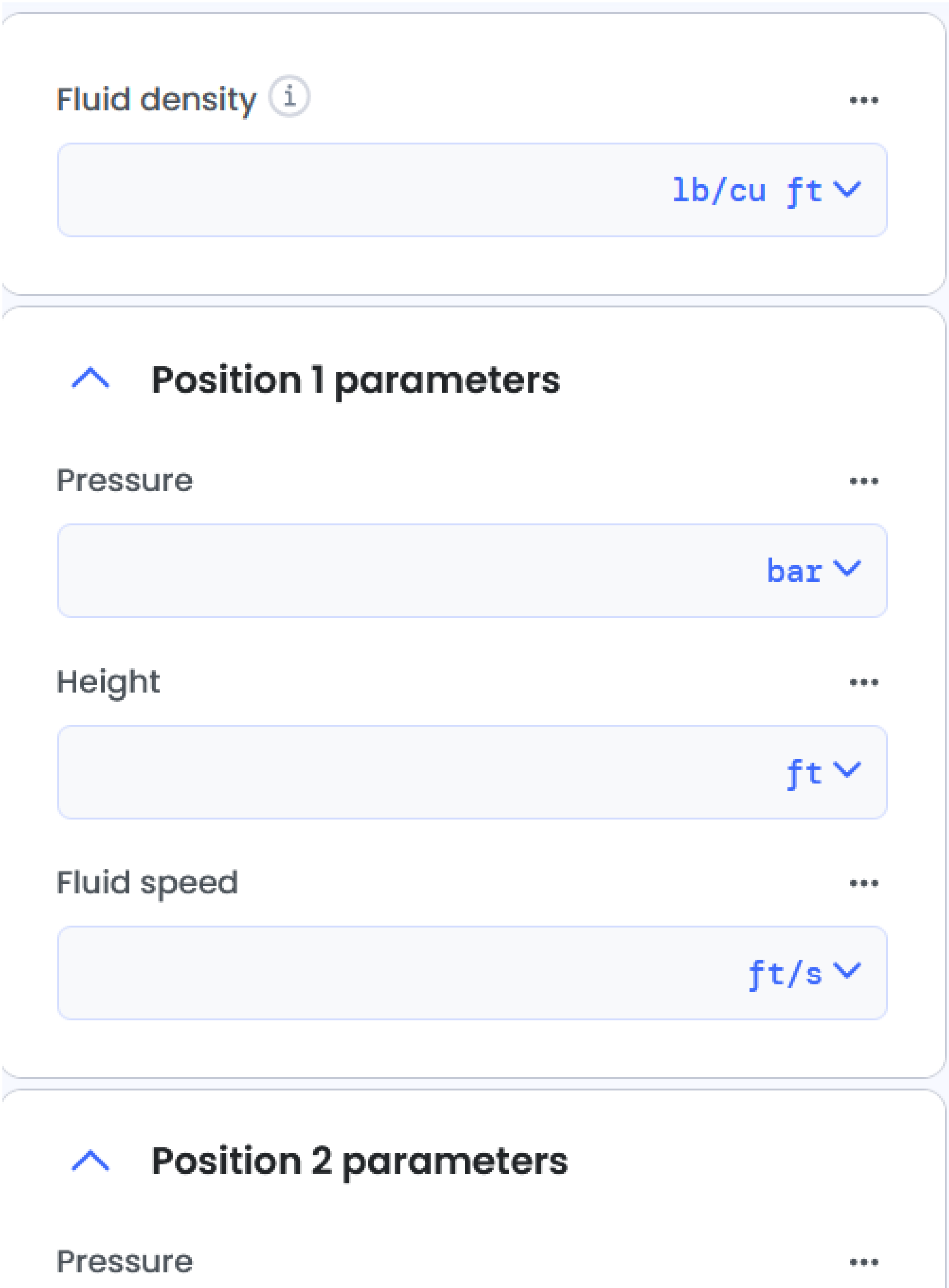
Related Lesson – Lesson 2

Estimated Time: 25 minutes

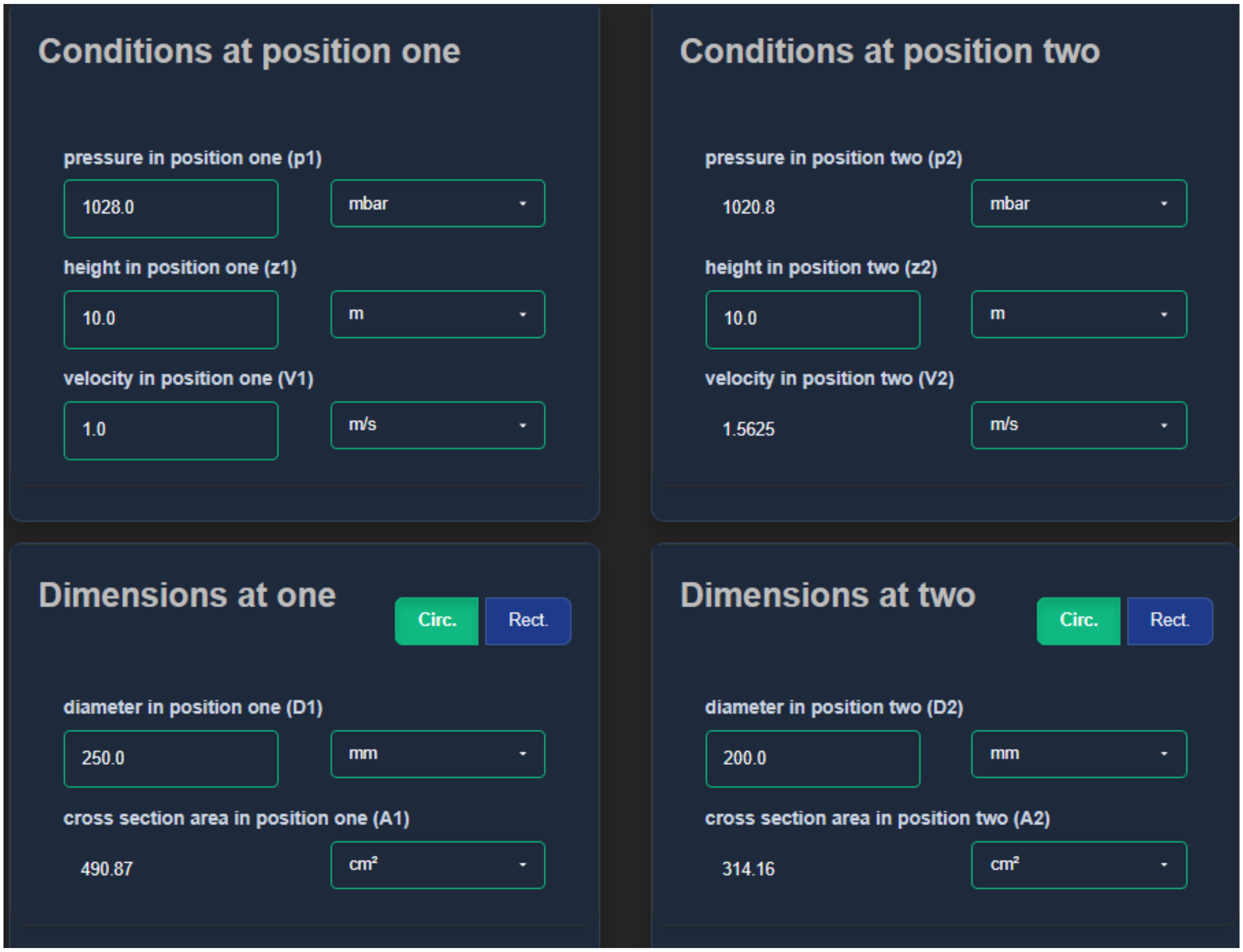
Lab Type: Recipe

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



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



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)/ft3
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/in2 (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:	311.7 kPa
» vertical displacement:	1 m
» downstream vertical displacement:	1 m
» speed:	5 m/s
» downstream speed:	1.25 m/s
» fluid density:	1000 kg/m^3
» gravitational acceleration:	1 g

Compute

Lab 3 Ideal Gas Calculator

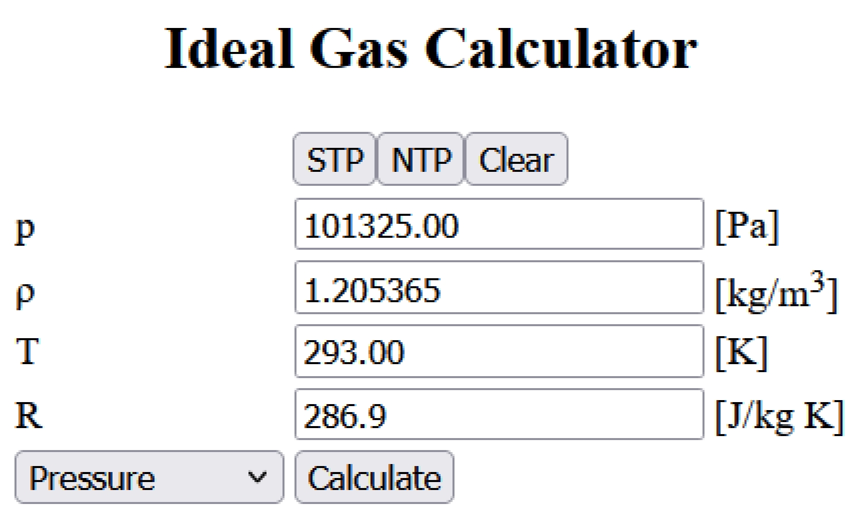
Related Lesson – Lesson 2

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:



Prandtl-Meyer Flow Calculator

Clear

M_1		
M_2		
γ	1.40	
θ		[deg.]
ν_1		[deg.]
ν_2		[deg.]

Calculate

Normal Shock

Clear

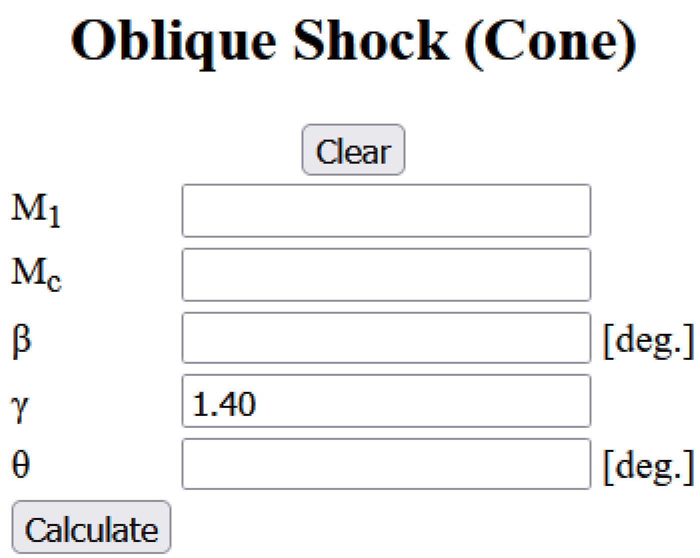
M_1	
M_2	
p_2/p_1	
$p_{o,2}/p_{o,1}$	
T_2/T_1	
u_2/u_1	
γ	1.40
ρ_2/ρ_1	
$p_{o,2}/p_1$	

Calculate

Oblique Shock (Wedge)

Clear

M_1		
$M_{n,1}$		
M_2		
$M_{n,2}$		
p_2/p_1		
$p_{o,2}/p_{o,1}$		
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	



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

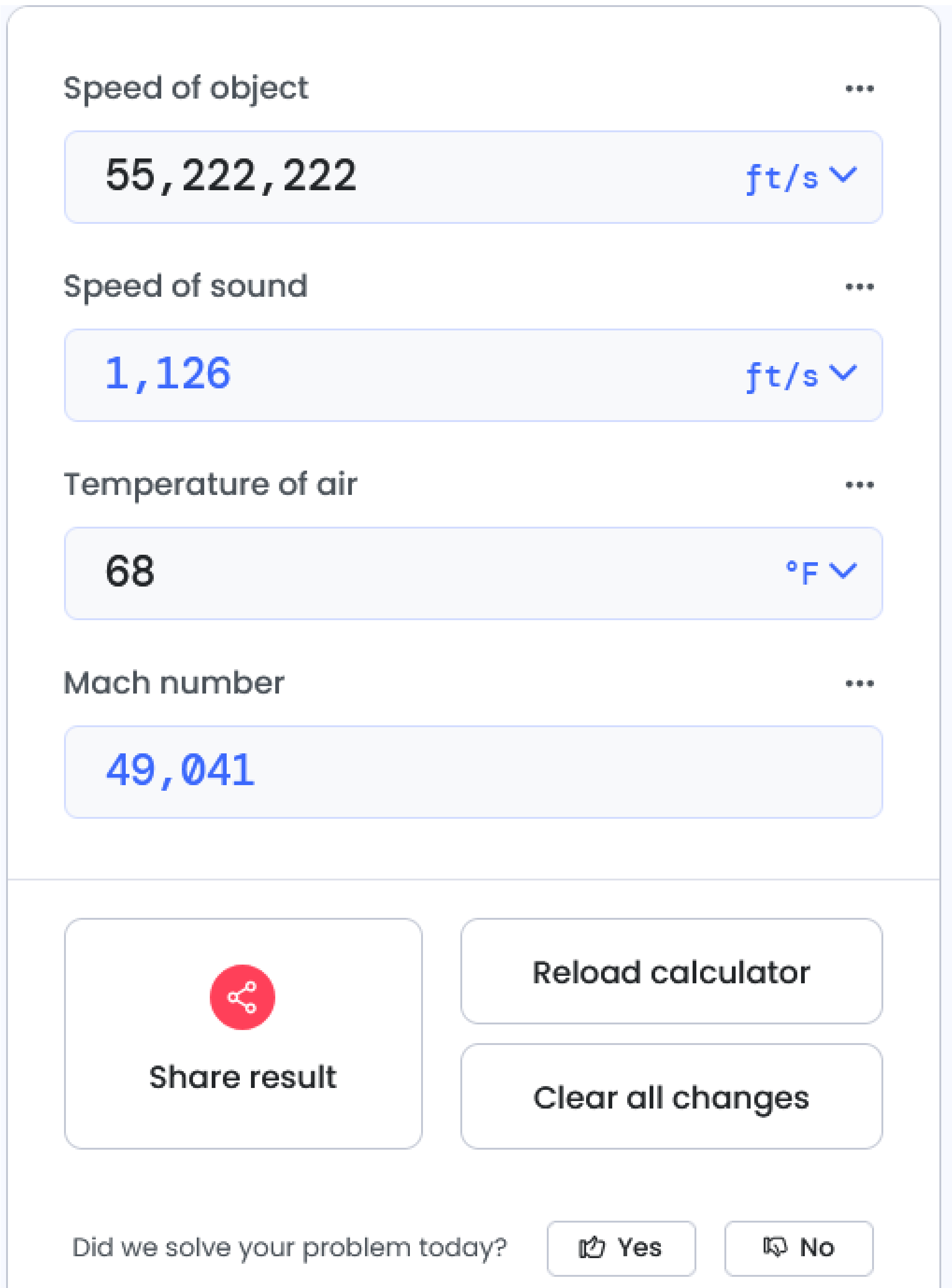
Estimated Time: 20 minutes

Lab Type: Recipe

This site has quite a few calculators relevant to hypersonics.

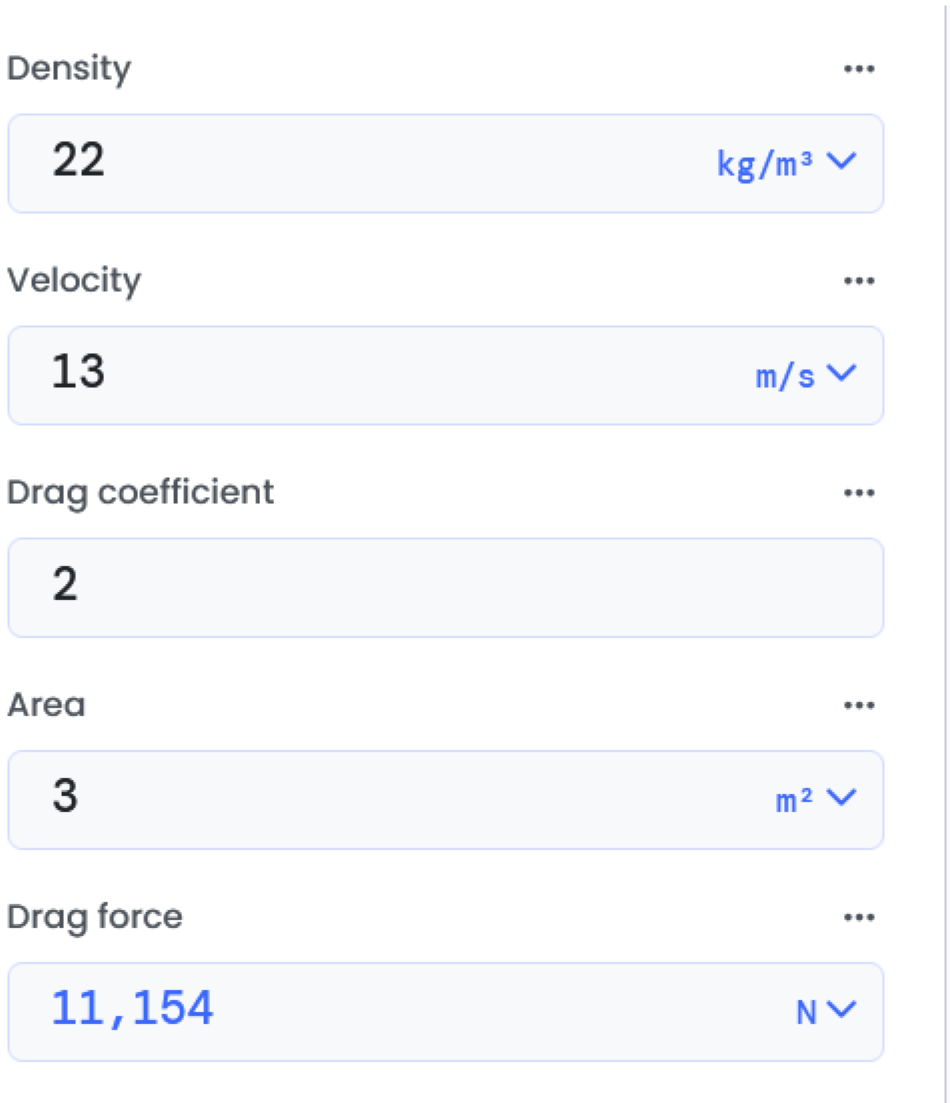
https://www.omnicalculator.com/physics/mach-number

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



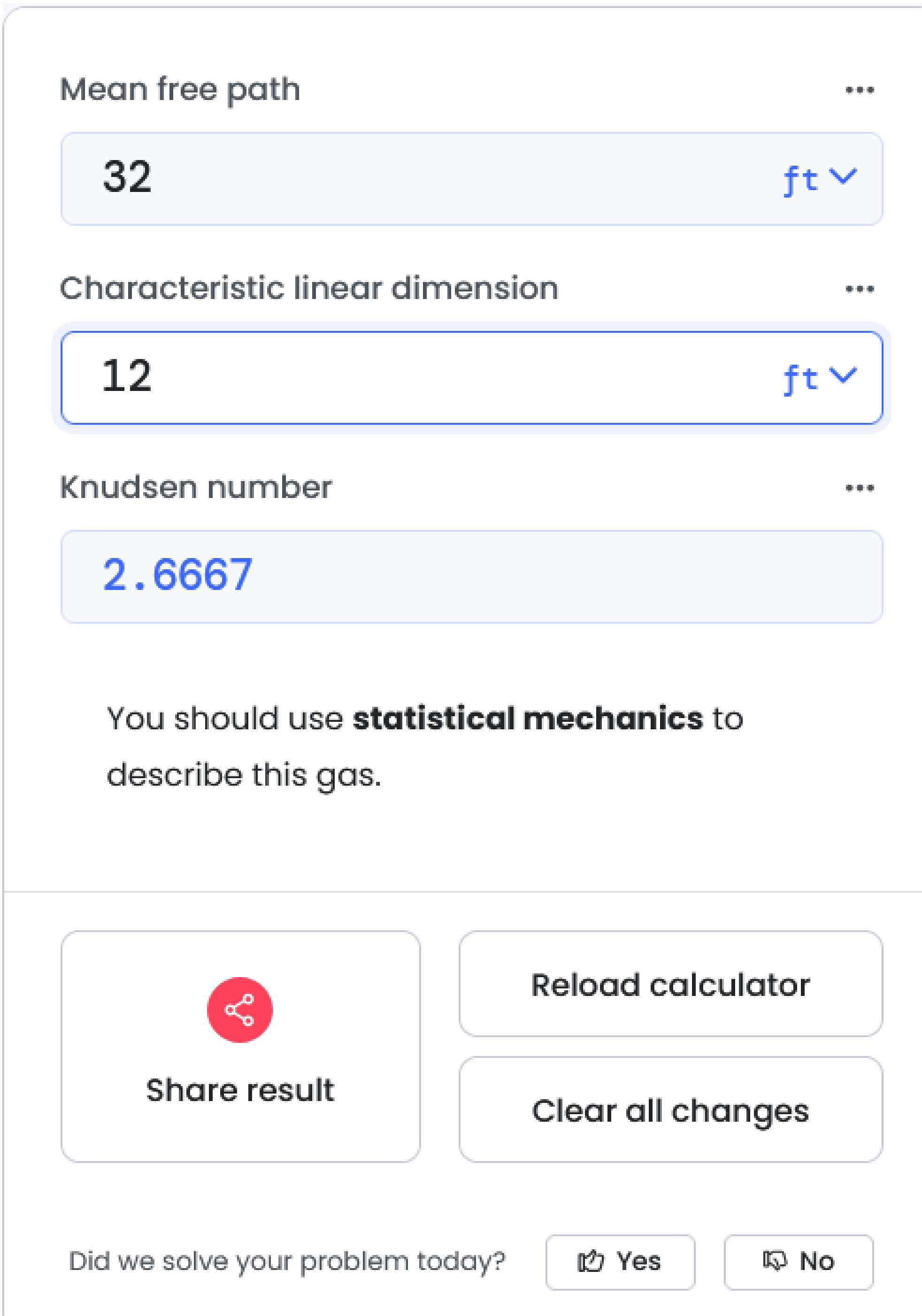
For this one you put in values and it will calculate the drag force

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



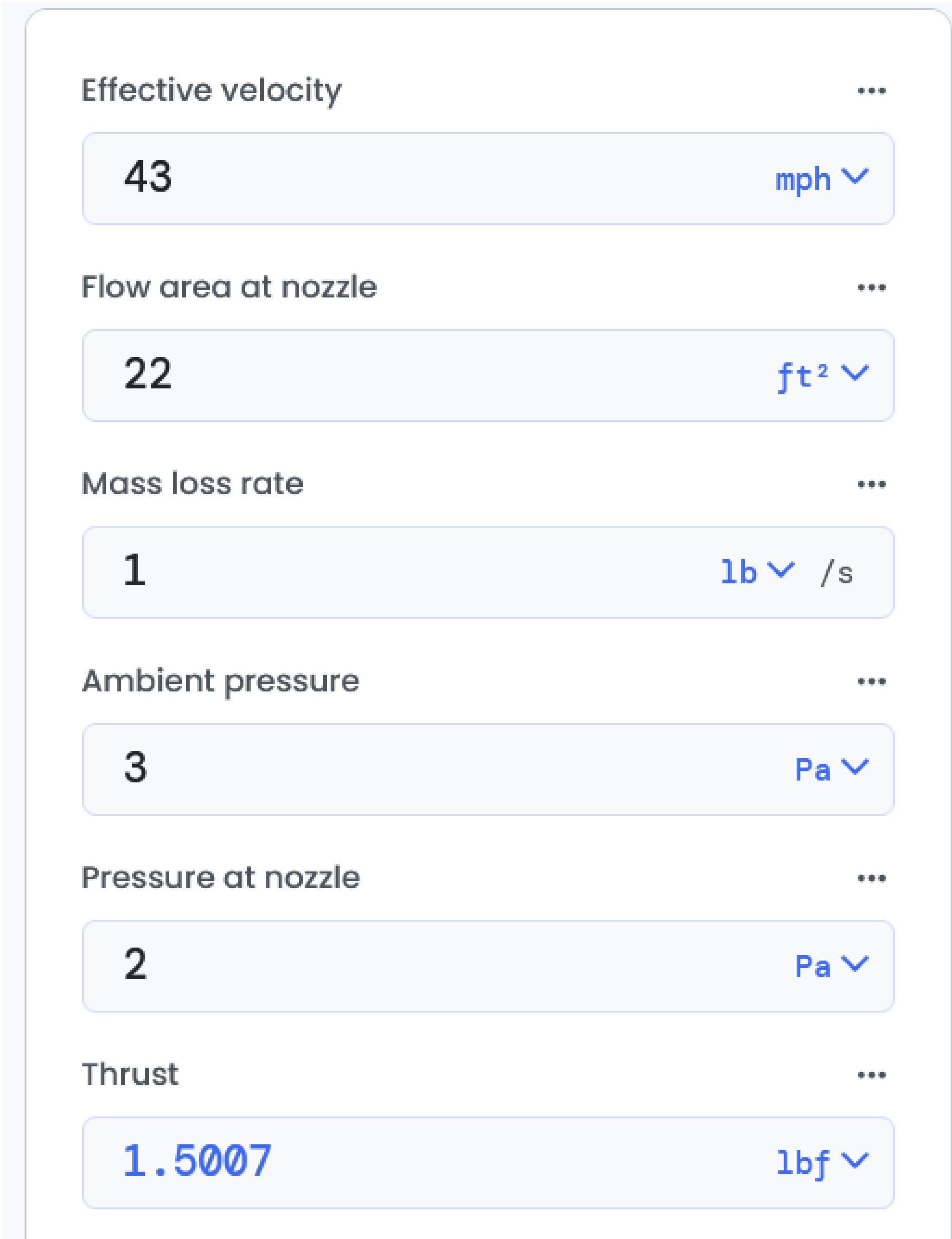
This one calculates the Knudsen number. Remember the Knudsen number (Kn) is a dimensionless quantity that indicates whether a fluid flow should be treated as a continuum or if particle effects become significant. It's defined as the ratio of the mean free path of a molecule to a characteristic length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

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



This calculates Rocket Thrust

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



This one calculates force

https://www.omnicalculator.com/physics/force

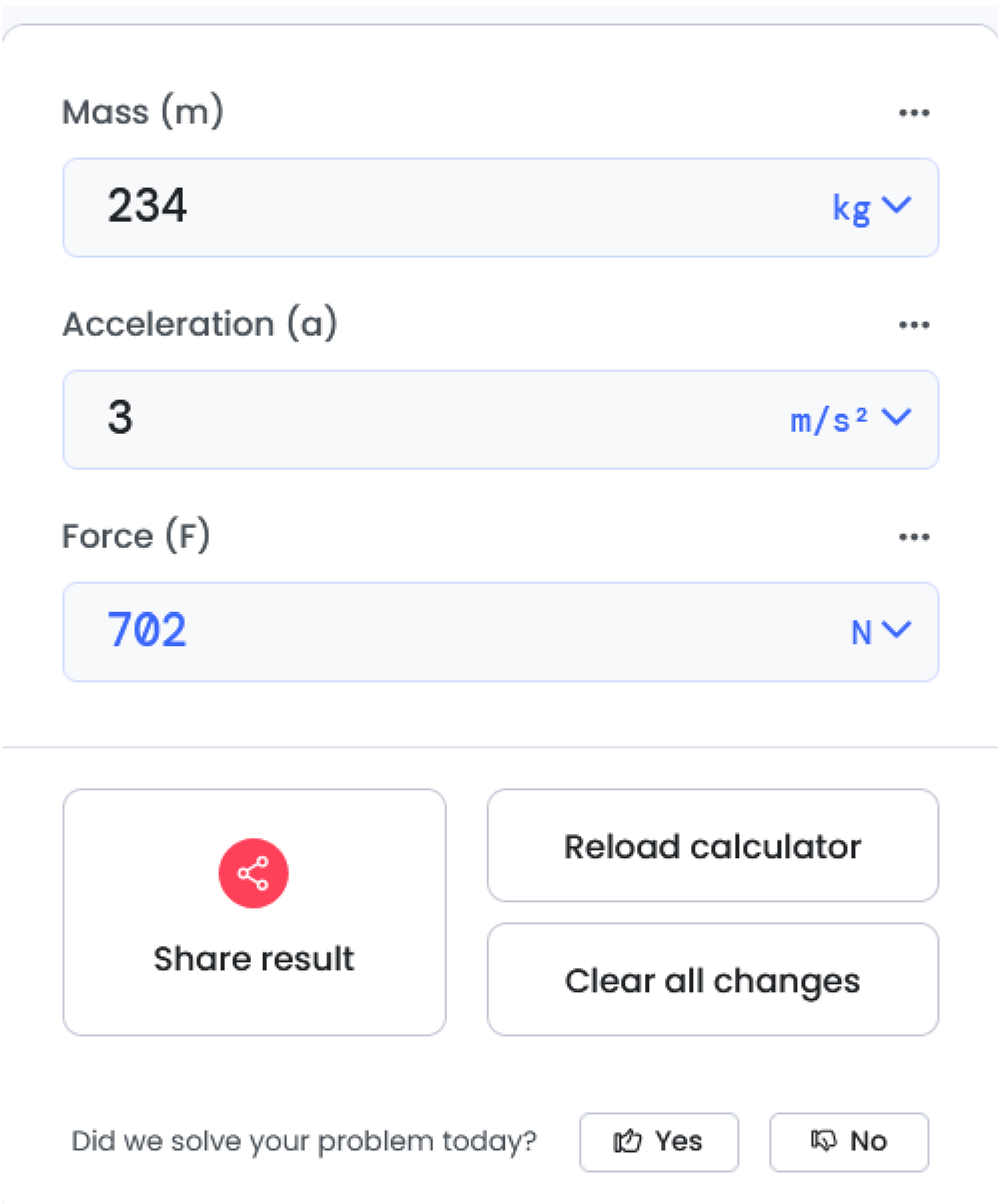
Expiriment a bit. The mass of a proton is too small

0.00000000000000000000000167262192595 the calculator cannot process that 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?

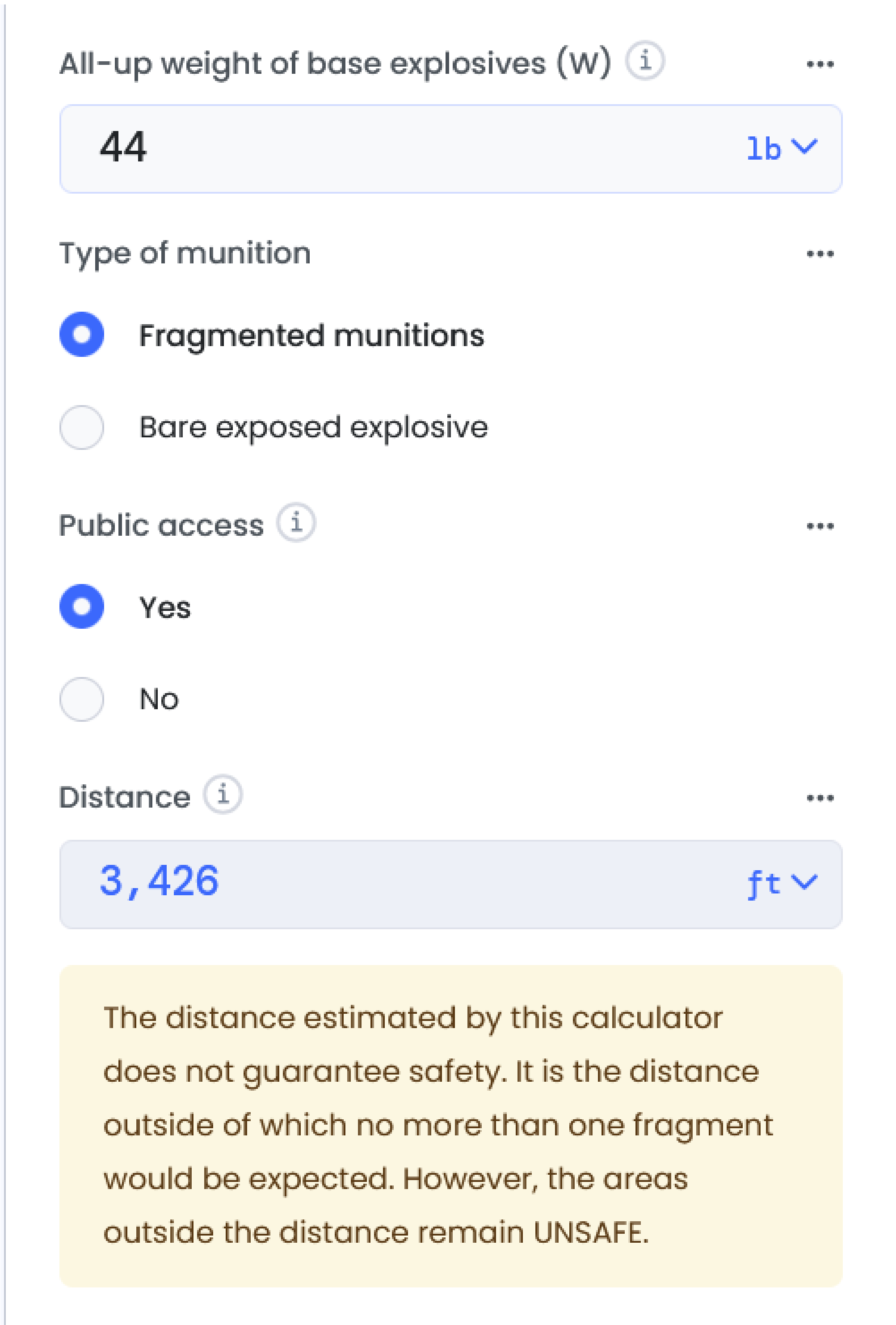
What happens if 100 KG is sent at 300 mph /134.112 ms

What about 500 mph/ 223.52 ms?



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



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 M1 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	11.5370	76.9202	529.0898	6.0000
M	μ (°)	ν (°)	p_o/p	T_o/T
88.1816	0.0036	0.2000	0.0179	25.0000
ρ_o/ρ	p/p^*	T/T^*	ρ/ρ^*	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 (°) (weak shock = 3

Calculate

3.0000	13.5608	1.1724	0.8599	4.6916
θ (°)	β (°)	$M_{n,1}$	$M_{n,2}$	M_2
1.4369	0.9952	1.2937	1.1107	
p_2/p_1	$p_{0,2}/p_{0,1}$	ρ_2/ρ_1	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

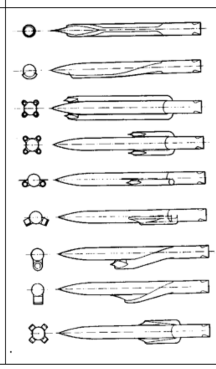
Lab Type: Experimentation

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

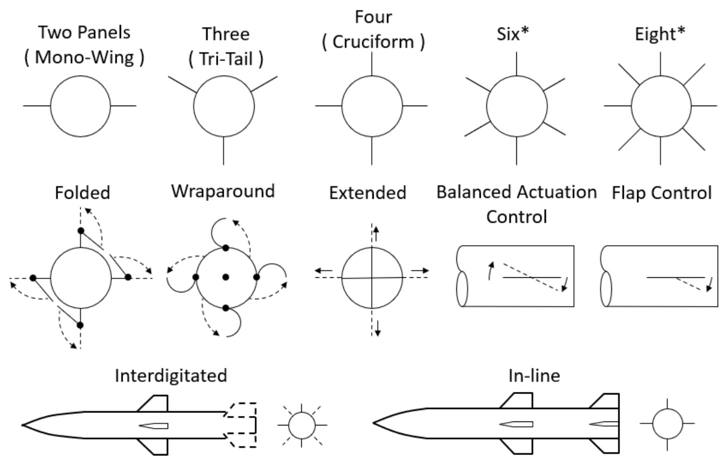
2. Select fuel
    a. Solid
    b. Liquid
    c. Hybrid
3. If your device has any wings, select a wing type:

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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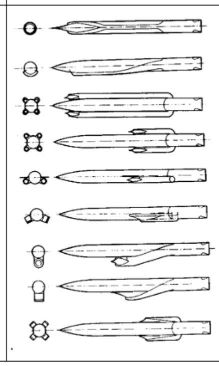

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    b. Scramjet
    c. Turbojet
    d. Turbofan
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        i. Hall effect
        ii. Gridded ion
    f. Pulse Plasma Thruster

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    a. Solid
    b. Liquid
    c. Hybrid
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Laminar Flow	Yes	Low drag, delayed transition	Gliders, UAVs
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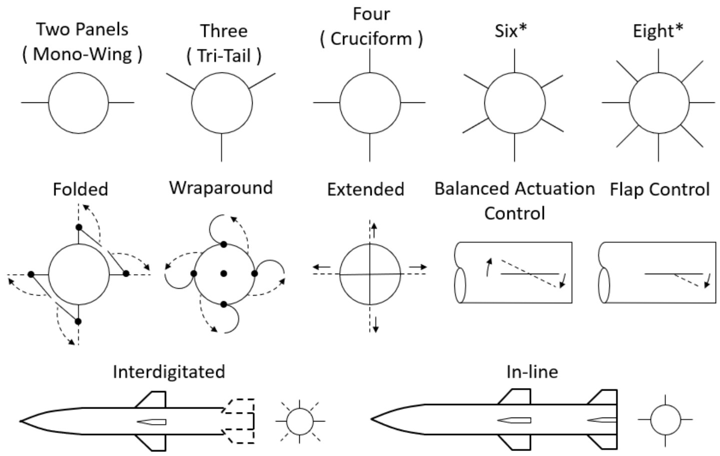
5. You need to consider Body Fineness Ratio
6. You need to account for stabilizers



7. Other items you should consider
    a. What payload will your missile deliver?
    b. What is the weight of your missile?
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        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?

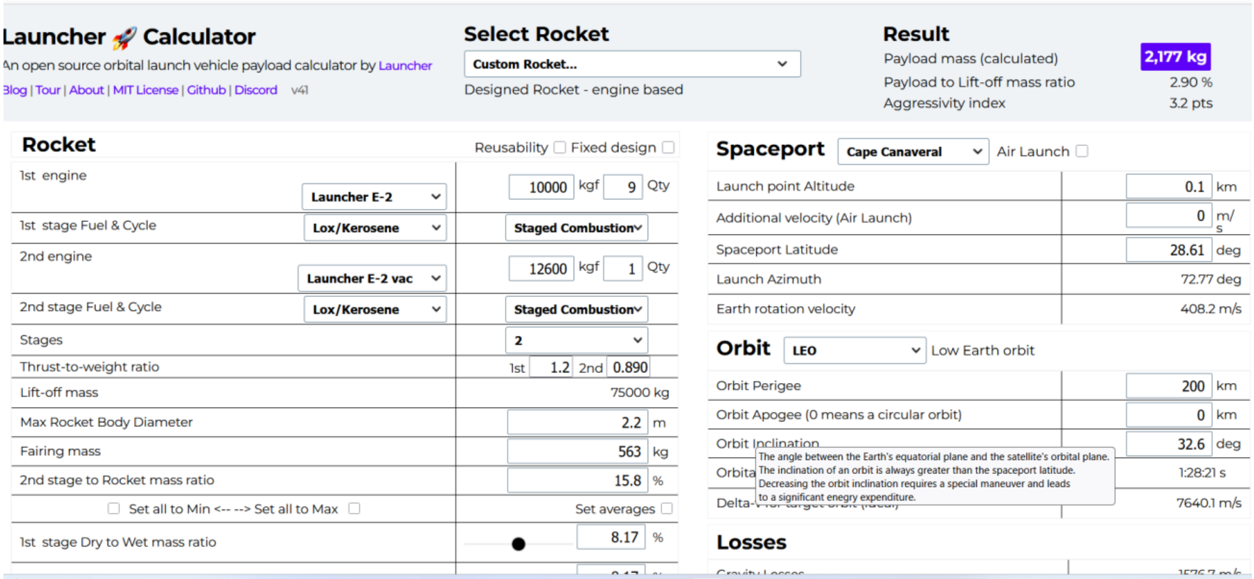
Isentropic Flow Relations

INPUT:	Mach number	=	2.0
Gamma =	1.4		(perfect gas)
	Compute		(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	=	2.0
Gamma =	1.4		(perfect gas)
	Compute		
M_1 =		M_2 =	
p_{02}/p_{01} =		p_1/p_{02} =	
p_2/p_1 =		rho_2/rho_1 =	
T_2/T_1 =			

Oblique Shock Relations



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 the 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.