The Wizard: User Manual

1 Creating a Program

To create a Phys program, create a file with a '`.phys`' extension and enter the following **in this order**:

```
subject:
graph:
equation:
data: {}
```

2 Keywords

`subject` - Sets the domain: defines the equation set range and data entry method.

`graph` – Turns automatic graph generation on/off

`equation` – Specifies the problem within the domain to generate solution for.

`data` – Defines the input data to use with the equation.

3 Accepted Values

The table below lists the set of accepted values for each keyword. Providing values not in the set for each keyword will result in an error.

Keyword	Accepted Values
subject	mechanics, stats
graph	true, false
equation	1, 2, 3, 4, 5, 6

4 Entering Data

Data is enclosed within { } with white spaces ignored. The syntax depends on the subject domain.

4.1 Mechanics Data

When the subject is set to `mechanics`, data must be entered as a list of assignment statements (e.g., `x = 3`). The following rules apply:

1. Assignment values must be of type `int` or `float`.
2. *Variable names* consist of one or two letters followed by zero or more integers. The first letter may be upper or lower case. The second letter, if any, must be lower case. Note that `rho` and `theta` are exceptions to these rules. Examples:
   - Valid names: `y0`, `x`, `Z12`, `Cd`, `rho`.
   - Invalid names: `1a`, `bB`, `aaa`, `y_0`

4.1.1 Mechanics `data` Example

```
data: {v0 =10,g = -3.71, theta = 14}
```

4.2 Stats Data

When the subject is set to `stats`, the data must be entered as a single CSV file (comma separated value file with extension '.csv') and must contain columns titled 'x' and 'y' with rows consisting of numerical values only. The filename may contain alphanumeric characters, underscores, and dashes.

4.2.1 Stats `data` Example

```
data: {my_data.csv}
```

5 Equation Number

The equation number sets the specific case within the subject domain to generate.

5.1 Mechanics Equations

Each mechanics equation number is mapped to a specific differential equation and ODE solver (to see the differential equation for each case, see Table 11 on page 4). Table 1, below, lists each equation number corresponding case description:.

Equation	Description
1	Free fall: constant forces
2	Free-fall: non-constant drag
3	Free-fall: non-constant gravity
4	Free-fall: no constant forces
5	Projectile motion
6	Projectile motion: non-constant drag

Table 1: `mechanics` equations

5.2 Stats Equations

Equation	Description
1	Descriptive statistics of data file with data columns titled `x` and `y`

Table 2: `stats` equation

Currently only one stats solution is implemented and the requirements of the input file constrained. The descriptive stats calculations produce the following results:

- The mean, variance, and standard deviation of data set `x` and data set `y`.
- The correlation and covariance coefficient between the two data sets.

If `graph` is set to `true` then the following plots are generated:

- Histograms and overlaying probability density functions for each data set.
- A scatter plot of the values as y(x).

6 Data Terms

6.1 Required vs. Optional Data

Required data refers to data which must be included within the data section in order for a solution to be generated. and differ for each case. Optional data refers to parameters which have default values, and may be provided, but are not required to generate the solution (see section 6.2.1 and the data tables on page3).

6.1.1 Mechanics

Mechanics solutions are generated by twice integrating the differential equation of motion, i.e., the sum of forces divided by mass, corresponding to each case in Table 1 (page 1). A list of the differential equations are listed in Table 11 (page 4). The required data therefore include the term or terms involved in the differential equation itself as well as the initial conditions needed to solve for the constants of integration. If required data is not provided, a Python script will still be generated (including if no data is provided, i.e., the data section within the may be left empty), but an error message indicating that the solution generation failed will be printed, along with information on which required data is missing. Mechanics equations have several optional parameters which are listed on page 3.

6.1.2 Stats

If a file of the correct type is not provided, an error message will be printed and the process will exit. A script will not be generated.

6.2 Description of Parameters

The parameters listed below are used to generate free-fall solutions. Parameters below the horizontal line are optional and have default values set to Earth's values

`y0` :	Initial height of body (m)
`m` :	Mass of body (kg)
`Cd` :	Drag coefficient of body
`A` :	Cross-sectional area of body
`k` :	Drag constant (kg/m)
`v0` :	Initial velocity (m/s)
`c` :	Drag constant/mass
`theta` :	Initial projectile angle (degrees)
`g` :	Gravitational constant (m/s^2)
`M` :	Mass of planet (kg)
`R` :	Radius of planet (m)
`rho` :	Air density (kg/m^3)
`H` :	Atmospheric scale height (m)

6.2.1 Optional Parameters (`mechanics` only)

Optional parameters which are omitted are set to a default value. Atmospheric and gravitational parameters are optional and have default Earth values (see Table 9). The gravitational and atmospheric parameters are optional To overwrite default values, simply provide a value for the parameter. For example, including `g = -3.71` will set g to 3.71 (the value for Mars), while omitting the value will set g to Earth's value of 9.81 m/s^2.

NOTE: The drag force constant is calculated using the surface density, `rho`, of Earth. If you wish to calculate the drag constant for another planet, use `Cd, A, m, rho` and use `H` of the planet if using non-constant drag.

Summary of Mechanics Data

Free Fall

Required Parameters

Parameter	Description
`y0`	Initial height (m)
`m`	Mass (kg)
`k`	Drag force constant (kg/m)

Table 3: Free fall: `k` known

Parameter	Description
y0	Initial height (m)
m	Mass (kg)
Cd	Drag coefficient
A	Cross-sectional area (m^2)

Table 4: Free fall: k is not known

Optional Parameters

In addition to the planet parameters listed in Table 9: initial velocity v0 (m/s).

Projectile Motion

Required Parameters

Parameter	Description
v0	Initial height (m)
theta	Launch angle (degrees)
c	Drag constant (kg^{-1})

Table 5: Projectile: c known

Parameter	Description
v0	Initial velocity (m/s)
m	Mass (kg)
Cd	Drag coefficient
A	Cross-sectional area (m^2)

Table 6: Projectile: c is not known

Optional Parameters

In addition to Table 9: initial height y0 (m) and x-coordinate x0.

Drag Parameters

1. C_d is an experimentally determined value which quantifies how aerodynamic a body is. The higher the value, the less aerodynamic the body. E.g., a bullet: $C_d = 0.3$, sphere: $C_d = 0.47$, human in skydiving position: $C_d = 1.2$.
2. k is the drag $force$ constant and is the coefficient multiplied by the drag force in the equation of motion $\mathbf{F} = m\vec{a}$:

$$k = \frac{1}{2} C_d A \rho$$

Free-fall problems will generally either be provided with a value for k or values for A and C_d (or C_d is not provided, but can be easily looked up in most cases).
3. The term c is

$$c = \frac{k}{m}$$

i.e., c is the drag *acceleration* constant, multiplied by the drag acceleration component in the equation of motion $\vec{a} = \frac{\mathbf{F}}{m}$, which is the differential equation which a solution is being generated for

Required Drag Parameters: Free Fall vs Projectile

Often in projectile problems, the mass is not directly provided and is instead coded into the value c, which will be provided. Otherwise m and A will be provided and C_d is either provided or can be looked up.

Generally, for free-fall problems the drag force constant k is provided instead of c, since, again, generally, m is provided, so $c = k/m$ is used.

In most cases however, m, A, and C_d (either in the question or easily looked up) will be provided. If, in the chance of a projectile motion problem, k and m and not c were provided, then the value for c may be easily calculated by the user. However, this unfortunately would require a slight amount of effort, as, currently, my variable assignment values cannot be mathematical expressions.

7 Example Problems

A Common ~~Boeing~~ Physics Problem

The landing gear of a Boeing 737 fails to retract after takeoff. To burn off enough fuel to make an emergency landing, the pilot climbs to a circling altitude of 4,200 meters. Unfortunately, during this time, the aircraft loses a main gear tire. According to Boeing's website, the tire has a mass of around 290 kg and a cross-sectional area of approximately 1.5 m^2. Assume the tire falls perpendicular to the surface, subject to a non-constant drag force with a drag coefficient of 1.0 (a reasonable approximation for a cylinder). How fast is the tire moving when it hits the ground?

Boring Question

A soccer ball is kicked at angle of 45^o with an initial velocity of 20 m/s. If the drag acceleration constant (the drag constant divided by the mass) of the ball is around 0.02, how far does it go?

The Carronade Cannon

Developed in the late 18th century, the Carronade cannon can fire a 10 kg cannonball with a cross sectional area of 0.015 m^2 at an initial velocity of 400 m/s. Given that the standard launch angle is 40^o, what is the total time and distance of the trajectory?

Parameter	Description	Default Value
`g`	Gravitational Constant	$9.81\,\mathrm{m/s}^2$
`M`	Planet mass	$5.97 \times 10^{24}\,\mathrm{kg}$
`R`	Planet radius	$6.371 \times 10^{6}\,\mathrm{m}$
`H`	Atmospheric scale height	$8.5 \times 10^{3}\,\mathrm{m}$
`rho`	Air density	$1.225\,\mathrm{kg/m}^3$

Table 8: Optional planet parameters and default Earth values.

Equation(s)	Description	Minimum Required Data
1-4	Free-fall equations	`y0`, `m`, `k` **or** `y0`, `m`, `Cd`, `A`
5-6	Projectile motion	`v0`, `theta`, `c` **or** `v0`, `theta`, `m`, `Cd`, `A`

Table 9: Summary of mechanics equations, descriptions, and minimum required data.

Subject	Equation(s)	Description	Minimum Required Data
`mechanics`	1-4	Free-fall equations	`y0`, `m`, `k` **or** `y0`, `m`, `Cd`, `A`
`mechanics`	5-6	Projectile motion	`v0`, `theta`, `c` **or** `v0`, `theta`, `m`, `Cd`, `A`
`stats`	6	Descriptive Statistics	.csv file with columns '**x**', '**y**'

Table 10: Summary of equations, descriptions, and minimum required data.

Equation	Description	Differential Equation(s)
1	Free-fall equation	$\frac{d^2y}{dt^2} = -g - \frac{k}{m}v\lvert v\rvert$
2	Free-fall, non-constant drag	$\frac{d^2y}{dt^2} = -g - \frac{k}{m}e^{(-y/H)}v\lvert v\rvert$
3	Free-fall, non-constant gravity	$\frac{d^2y}{dt^2} = -g\left(1 + \frac{y}{R}\right)^{-2} - \frac{k}{m}v\lvert v\rvert$
4	Free-fall, non-constant drag and gravity	$\frac{d^2y}{dt^2} = -g\left(1 + \frac{y}{R}\right)^{-2} - \frac{k}{m}e^{(-y/H)}v\lvert v\rvert$
5	Projectile motion, constant drag	$\frac{d^2x}{dt^2} = -cv_x\lvert\vec{v}\rvert$ $\frac{d^2y}{dt^2} = -g - cv_y\lvert\vec{v}\rvert$
6	Projectile motion, non-constant drag	$\frac{d^2x}{dt^2} = -ce^{(-y/H)}v_x\lvert\vec{v}\rvert$ $\frac{d^2y}{dt^2} = -g - ce^{(-y/H)}v_y\lvert\vec{v}\rvert$

Table 11: The differential equation(s) corresponding to each equation number.