

# Uncertainty Calculation Sensitivity Wilfrid Laurier University

Terry Sturtevant

Wilfrid Laurier University

February 6, 2014

# Overview

# Overview

Whenever quantities are measured, they have *uncertainties* in them.

# Overview

Whenever quantities are measured, they have *uncertainties* in them.

When calculations are performed involving these quantities, then the **results** have uncertainty as well.

# Overview

Whenever quantities are measured, they have *uncertainties* in them.

When calculations are performed involving these quantities, then the **results** have uncertainty as well.

**When you discuss sources of uncertainty in an experiment, it is important to recognize which ones contributed most to the uncertainty in the final result.**

In order to determine this, proceed as follows:

In order to determine this, proceed as follows:

1. Write out the equation for the uncertainty in the result, using whichever method you prefer.

In order to determine this, proceed as follows:

1. Write out the equation for the uncertainty in the result, using whichever method you prefer.
2. For each of the quantities in the equation which have an uncertainty, calculate the uncertainty in the result *which you get if all of the other uncertainties are zero*.



In order to determine this, proceed as follows:

1. Write out the equation for the uncertainty in the result, using whichever method you prefer.
2. For each of the quantities in the equation which have an uncertainty, calculate the uncertainty in the result *which you get if all of the other uncertainties are zero*.
3. Arrange the quantities in descending order based on the size of the uncertainties calculated.

In order to determine this, proceed as follows:

1. Write out the equation for the uncertainty in the result, using whichever method you prefer.
2. For each of the quantities in the equation which have an uncertainty, calculate the uncertainty in the result *which you get if all of the other uncertainties are zero*.
3. Arrange the quantities in descending order based on the size of the uncertainties calculated.
4. The higher in the list a quantity is, the greater its contribution to the total uncertainty.

# Example

# Example

Suppose we have a function of two variables:

# Example

Suppose we have a function of two variables:

$$h(w, z) = \frac{\sqrt{w}}{z^2}$$

# Example

Suppose we have a function of two variables:

$$h(w, z) = \frac{\sqrt{w}}{z^2}$$

So, by inspection,

$$\Delta h \approx h_{max} - h = \frac{\sqrt{(w+\Delta w)}}{(z-\Delta z)^2} - \frac{\sqrt{w}}{z^2}$$

# Example

Suppose we have a function of two variables:

$$h(w, z) = \frac{\sqrt{w}}{z^2}$$

So, by inspection,

$$\Delta h \approx h_{max} - h = \frac{\sqrt{(w+\Delta w)}}{(z-\Delta z)^2} - \frac{\sqrt{w}}{z^2}$$

We can compute

$$\Delta h_w \approx \frac{\sqrt{(w+\Delta w)}}{z^2} - \frac{\sqrt{w}}{z^2}$$

# Example

Suppose we have a function of two variables:

$$h(w, z) = \frac{\sqrt{w}}{z^2}$$

So, by inspection,

$$\Delta h \approx h_{max} - h = \frac{\sqrt{(w+\Delta w)}}{(z-\Delta z)^2} - \frac{\sqrt{w}}{z^2}$$

We can compute

$$\Delta h_w \approx \frac{\sqrt{(w+\Delta w)}}{z^2} - \frac{\sqrt{w}}{z^2}$$

and

$$\Delta h_z \approx \frac{\sqrt{w}}{(z-\Delta z)^2} - \frac{\sqrt{w}}{z^2}$$



# Example

Suppose we have a function of two variables:

$$h(w, z) = \frac{\sqrt{w}}{z^2}$$

So, by inspection,

$$\Delta h \approx h_{max} - h = \frac{\sqrt{(w+\Delta w)}}{(z-\Delta z)^2} - \frac{\sqrt{w}}{z^2}$$

We can compute

$$\Delta h_w \approx \frac{\sqrt{(w+\Delta w)}}{z^2} - \frac{\sqrt{w}}{z^2}$$

and

$$\Delta h_z \approx \frac{\sqrt{w}}{(z-\Delta z)^2} - \frac{\sqrt{w}}{z^2}$$

Note that in the first equation, all of the  $\Delta z$  terms are gone, and in the second, all of the  $\Delta w$  terms are gone.

Here it is using the algebraic method:

Here it is using the algebraic method:

$$h(w, z) = \frac{\sqrt{w}}{z^2}$$

Here it is using the algebraic method:

$$h(w, z) = \frac{\sqrt{w}}{z^2}$$

So, by algebra

$$\Delta h \approx \frac{\sqrt{w}}{z^2} \left( \frac{\Delta w}{2w} + \frac{2\Delta z}{z} \right)$$

Here it is using the algebraic method:

$$h(w, z) = \frac{\sqrt{w}}{z^2}$$

So, by algebra

$$\Delta h \approx \frac{\sqrt{w}}{z^2} \left( \frac{\Delta w}{2w} + \frac{2\Delta z}{z} \right)$$

We can compute

$$\Delta h_w \approx \frac{\sqrt{w}}{z^2} \left( \frac{\Delta w}{2w} \right)$$

Here it is using the algebraic method:

$$h(w, z) = \frac{\sqrt{w}}{z^2}$$

So, by algebra

$$\Delta h \approx \frac{\sqrt{w}}{z^2} \left( \frac{\Delta w}{2w} + \frac{2\Delta z}{z} \right)$$

We can compute

$$\Delta h_w \approx \frac{\sqrt{w}}{z^2} \left( \frac{\Delta w}{2w} \right)$$

and

$$\Delta h_z \approx \frac{\sqrt{w}}{z^2} \left( \frac{2\Delta z}{z} \right)$$

Here it is using the algebraic method:

$$h(w, z) = \frac{\sqrt{w}}{z^2}$$

So, by algebra

$$\Delta h \approx \frac{\sqrt{w}}{z^2} \left( \frac{\Delta w}{2w} + \frac{2\Delta z}{z} \right)$$

We can compute

$$\Delta h_w \approx \frac{\sqrt{w}}{z^2} \left( \frac{\Delta w}{2w} \right)$$

and

$$\Delta h_z \approx \frac{\sqrt{w}}{z^2} \left( \frac{2\Delta z}{z} \right)$$

Note that *until you plug values into these equations, you can't tell which uncertainty contribution is larger.*

In this example, if we use values of  $w = 1.00 \pm 0.01$  and  $z = 2.00 \pm 0.02$ , then the proportional uncertainties in both  $w$  and  $z$  are the same, 1%.



In this example, if we use values of  $w = 1.00 \pm 0.01$  and  $z = 2.00 \pm 0.02$ , then the proportional uncertainties in both  $w$  and  $z$  are the same, 1%.

However, using either inspection or the algebraic method,  $\Delta h = 0.006$ , and  $\Delta h_w = 0.001$  while  $\Delta h_z = 0.005$ ;

In this example, if we use values of  $w = 1.00 \pm 0.01$  and  $z = 2.00 \pm 0.02$ , then the proportional uncertainties in both  $w$  and  $z$  are the same, 1%.

However, using either inspection or the algebraic method,  $\Delta h = 0.006$ , and  $\Delta h_w = 0.001$  while  $\Delta h_z = 0.005$ ;

in other words, the uncertainty in the *result* due to  $\Delta z$  is **five times** the uncertainty due to  $\Delta w$ !

In this example, if we use values of  $w = 1.00 \pm 0.01$  and  $z = 2.00 \pm 0.02$ , then the proportional uncertainties in both  $w$  and  $z$  are the same, 1%.

However, using either inspection or the algebraic method,  $\Delta h = 0.006$ , and  $\Delta h_w = 0.001$  while  $\Delta h_z = 0.005$ ;

in other words, the uncertainty in the *result* due to  $\Delta z$  is **five times** the uncertainty due to  $\Delta w$ !

(As you get more used to uncertainty calculations, you should realize this is because  $z$  is raised to a higher power than  $w$ , and so its uncertainty counts for more.)

In this example, if we use values of  $w = 1.00 \pm 0.01$  and  $z = 2.00 \pm 0.02$ , then the proportional uncertainties in both  $w$  and  $z$  are the same, 1%.

However, using either inspection or the algebraic method,  $\Delta h = 0.006$ , and  $\Delta h_w = 0.001$  while  $\Delta h_z = 0.005$ ;

in other words, the uncertainty in the *result* due to  $\Delta z$  is **five times** the uncertainty due to  $\Delta w$ !

(As you get more used to uncertainty calculations, you should realize this is because  $z$  is raised to a higher power than  $w$ , and so its uncertainty counts for more.)

**In order to improve this experiment, it would be more important to try and reduce  $\Delta z$  than it would be to try and reduce  $\Delta w$ .**

Here's the math (first by algebra):

Here's the math (first by algebra):

$$h(w, z) = \frac{\sqrt{w}}{z^2} = \frac{\sqrt{1.00}}{2.00^2} = 0.25$$

Here's the math (first by algebra):

$$h(w, z) = \frac{\sqrt{w}}{z^2} = \frac{\sqrt{1.00}}{2.00^2} = 0.25$$

So, by algebra

$$\Delta h \approx \frac{\sqrt{w}}{z^2} \left( \frac{\Delta w}{2w} + \frac{2\Delta z}{z} \right) = \frac{\sqrt{1.00}}{2.00^2} \left( \frac{0.01}{2(1.00)} + \frac{2(0.02)}{2.00} \right) = 0.00625$$

Here's the math (first by algebra):

$$h(w, z) = \frac{\sqrt{w}}{z^2} = \frac{\sqrt{1.00}}{2.00^2} = 0.25$$

So, by algebra

$$\Delta h \approx \frac{\sqrt{w}}{z^2} \left( \frac{\Delta w}{2w} + \frac{2\Delta z}{z} \right) = \frac{\sqrt{1.00}}{2.00^2} \left( \frac{0.01}{2(1.00)} + \frac{2(0.02)}{2.00} \right) = 0.00625$$

So

$$\Delta h_w \approx \frac{\sqrt{w}}{z^2} \left( \frac{\Delta w}{2w} \right) = \frac{\sqrt{1.00}}{2.00^2} \left( \frac{0.01}{2(1.00)} \right) = 0.00125$$



Here's the math (first by algebra):

$$h(w, z) = \frac{\sqrt{w}}{z^2} = \frac{\sqrt{1.00}}{2.00^2} = 0.25$$

So, by algebra

$$\Delta h \approx \frac{\sqrt{w}}{z^2} \left( \frac{\Delta w}{2w} + \frac{2\Delta z}{z} \right) = \frac{\sqrt{1.00}}{2.00^2} \left( \frac{0.01}{2(1.00)} + \frac{2(0.02)}{2.00} \right) = 0.00625$$

So

$$\Delta h_w \approx \frac{\sqrt{w}}{z^2} \left( \frac{\Delta w}{2w} \right) = \frac{\sqrt{1.00}}{2.00^2} \left( \frac{0.01}{2(1.00)} \right) = 0.00125$$

and

$$\Delta h_z \approx \frac{\sqrt{w}}{z^2} \left( \frac{2\Delta z}{z} \right) = \frac{\sqrt{1.00}}{2.00^2} \left( \frac{2(0.02)}{2.00} \right) = 0.005$$

By inspection it looks like this:

By inspection it looks like this:

$$h(w, z) = \frac{\sqrt{w}}{z^2}$$

By inspection it looks like this:

$$h(w, z) = \frac{\sqrt{w}}{z^2}$$

So, by inspection

$$\begin{aligned}\Delta h &\approx h_{max} - h = \frac{\sqrt{(w+\Delta w)}}{(z-\Delta z)^2} - \frac{\sqrt{w}}{z^2} \\ &= \frac{\sqrt{(1.00+0.01)}}{(2.00-0.02)^2} - \frac{\sqrt{1.00}}{2.00^2} \approx 0.0076\end{aligned}$$

By inspection it looks like this:

$$h(w, z) = \frac{\sqrt{w}}{z^2}$$

So, by inspection

$$\begin{aligned}\Delta h &\approx h_{max} - h = \frac{\sqrt{(w+\Delta w)}}{(z-\Delta z)^2} - \frac{\sqrt{w}}{z^2} \\ &= \frac{\sqrt{(1.00+0.01)}}{(2.00-0.02)^2} - \frac{\sqrt{1.00}}{2.00^2} \approx 0.0076\end{aligned}$$

So

$$\Delta h_w \approx \frac{\sqrt{(w+\Delta w)}}{z^2} - \frac{\sqrt{w}}{z^2} = \Delta h_w \approx \frac{\sqrt{(1.01)}}{2.00^2} - \frac{\sqrt{1.00}}{2.00^2} \approx 0.00125$$

By inspection it looks like this:

$$h(w, z) = \frac{\sqrt{w}}{z^2}$$

So, by inspection

$$\begin{aligned}\Delta h &\approx h_{max} - h = \frac{\sqrt{(w+\Delta w)}}{(z-\Delta z)^2} - \frac{\sqrt{w}}{z^2} \\ &= \frac{\sqrt{(1.00+0.01)}}{(2.00-0.02)^2} - \frac{\sqrt{1.00}}{2.00^2} \approx 0.0076\end{aligned}$$

So

$$\Delta h_w \approx \frac{\sqrt{(w+\Delta w)}}{z^2} - \frac{\sqrt{w}}{z^2} = \Delta h_w \approx \frac{\sqrt{(1.01)}}{2.00^2} - \frac{\sqrt{1.00}}{2.00^2} \approx 0.00125$$

and

$$\Delta h_z \approx \frac{\sqrt{w}}{(z-\Delta z)^2} - \frac{\sqrt{w}}{z^2} = \Delta h_z \approx \frac{\sqrt{1.00}}{(2.00-0.02)^2} - \frac{\sqrt{1.00}}{2.00^2} \approx 0.0051$$

# Summary of Uncertainty Principles

# Summary of Uncertainty Principles

All measurements have uncertainties.



# Summary of Uncertainty Principles

All measurements have uncertainties.

Because of this, all calculated results have uncertainties.

# Summary of Uncertainty Principles

All measurements have uncertainties.

Because of this, all calculated results have uncertainties.

When you discuss sources of uncertainty in an experiment, it is important to recognize which ones contributed most to the uncertainty in the final result.