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## Using Equations, Graphs, and Tables to Investigate the Maximum Volume of a Pup Tent

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## Abstract

When analyzing functions in mathematics, it is often helpful to multiple representations of the function. These multiple representations consist of analyzing a function in three different paradigms (symbolical, graphical, and tabular). One application central to calculus involves finding the maximum or minimum value of a real-valued function. In a traditional calculus class, this process is typically done by finding the solution by using the notion of derivatives on the algebraic or symbolic form of the function. Spreadsheets allow students to analyze optimization problems in the tabular form. As a consequence, students in an algebra or pre-calculus class can study optimization problems without the formal tools of calculus. This article provides an example of using spreadsheets to analyze the maximum volume of a pup tent used on a camping trip.

## Keywords

spreadsheets, graphs, tables

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# Using Equations, Graphs, and Tables to Investigate the Maximum Volume of a Pup Tent

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## Abstract

When analyzing functions in mathematics, it is often helpful to use multiple representations of the function. These multiple representations consist of analyzing a function in three different paradigms (symbolical, graphical, and tabular). One application central to calculus involves finding the maximum or minimum value of a real-valued function. In a traditional calculus class, this process is typically done by finding the solution by using the notion of derivatives on the algebraic or symbolic form of the function. Spreadsheets allow students to analyze optimization problems in the tabular form. As a consequence, students in an algebra or pre-calculus class can study optimization problems without the formal tools of calculus. This article provides an example of using spreadsheets to analyze the maximum volume of a pup tent used on a camping trip.

**Keywords:** spreadsheets, graphs, tables.

## 1. Introduction

Optimization problems in calculus class have long been used as an example for students to visualize an application of the first derivative. Studying optimization problems exclusively from this perspective often neglects a nice opportunity for students to analyze functions from different paradigms. In an elementary mathematics modeling course, students often come to class well versed in their practice of using algebraic methods for solving equations. With the advent of graphing calculators, students have also become indoctrinated into solving equations via graphing methods. Although the use of spreadsheets predates the use of graphing calculators and symbolic manipulators, their use in the classroom for analyzing functions have been minimal at best.

This article describes an optimization problem that can easily be physically modeled (and thus understood) with an 8.5 x 11 sheet of paper. In an elementary mathematics modeling course, students are expected to submit their solution using symbolic, graphical, and tabular analysis. For the purposes of this article, the spreadsheet analysis is included.

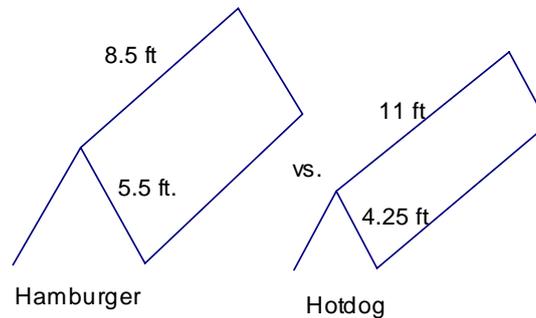


Figure 1: The two type of Pup Tent

## 2. Problem Statement

You are going camping with an 8.5' x 11' tarp that will be used as a pup tent. The pup tent can be set up in one of two ways. One possible method (hamburger) is to set up the tent by folding the tarp midway on the 11' side yielding walls with slant height of 5.5 ft. A second method (hotdog) is to set up the tent by folding the tarp at the midpoint of the 8.5' side yielding walls with slant height of 4.25'. Since space is limited under the tent, one needs to determine whether the hamburger or hotdog style construction yields the largest volume or whether their maximum volumes are equal.

## 3. Investigation

In class, students are divided into groups of two. They are initially required to discuss between them and agree on a guess of which method would yield the largest volume. They are then asked to find the maximum volume for each method of construction.

The equation for maximizing the volume of the pup tent for the hamburger construction can be calculated by finding the area of the base (triangle) multiplied by the length (8.5 ft.)

$$\begin{aligned}\text{Vol}_{\text{Hamb}} &= \text{BaseTriangle} \times 8.5 \\ &= \frac{1}{2} 2xh \times 8.5 \\ &= 8.5hx \text{ ft}^3\end{aligned}$$

The Pythagorean Theorem is then used to relate  $x$  and  $h$  by the following equation:

$$\begin{aligned}h^2 + x^2 &= 5.5^2 \\ \Rightarrow x &= \sqrt{5.5^2 - h^2}\end{aligned}$$

Substituting  $\sqrt{5.5^2 - h^2}$  for  $x$  into  $\text{Vol}_{\text{Hamb}}$  yields an equation for the volume of the pup tent using the hamburger construction in terms of the height ( $h$ ) of the pup tent.

$$\text{Vol}_{\text{Hamb}} = 8.5h\sqrt{5.5^2 - h^2} \text{ ft}^3$$

Similarly, the equation for maximizing the volume of the pup tent using the hotdog construction in terms of the height ( $h$ ) of the pup tent is as follows:

MAXIMUM VOLUME OF A PUP TENT

$$\text{Vol}_{\text{Hotdog}} = 11h\sqrt{4.25^2 - h^2} \text{ ft}^3$$

Now, we are at position to use a spreadsheet to find the maximum volume of the pup tent under each construction. First, consider the pup tent using the hotdog construction. From the equation for  $\text{Vol}_{\text{Hotdog}}$ , we note the function is real-valued on the interval  $[0, 4.25]$ . With this information, we can input height values within this interval. For initial analysis, we can choose increments of 0.5. After defining  $h$  as the cell values for the respective Height values, the corresponding volumes can be displayed in column  $\text{Vol}_{\text{Hotdog}}$  with the formula

$$=11*h*\text{SQRT}(4.25^2-h^2)$$

Filling this formula to the bottom yields the data in Table 1. The maximum value is located by conditional formatting in a way similar to the process described in Sugden [1], Colour by Numbers [1].

Height	Vol_Hotdog
0	0.000
0.5	23.213
1	45.437
1.5	65.612
2	82.500
2.5	94.516
3	99.343
3.5	92.820
4	63.190
<b>Max Vol.</b>	99.343

Table 1: Hot Dog Construction

Height	Vol_Hamburger
0.0	0.00
0.5	23.28
1.0	45.97
1.5	67.47
2.0	87.10
2.5	104.10
3.0	117.55
3.5	126.22
4.0	128.35
4.5	120.96
5.0	97.38
5.5	0.00
<b>Max Volume</b>	128.35

Table 1: Hamburger Construction

Similarly, we note  $\text{Vol}_{\text{Hamb}}$  is a real-value function on the interval  $[0, 5.5]$ . Following the process used for finding the maximum volume with the hotdog construction yields the data in Table 2. We note the maximum volume of approximately 128 ft<sup>3</sup> is larger than the maximum volume with the hotdog construction.

Inserting cells for start value and increment allow the user to “zoom” in on the maximum value for a closer approximation. Using 3.5 for a start value and increments of 0.1 yields the maximum value of 128.56 highlighted in Table 3.

To continue the process of “zooming” in on the optimal solution, a start value of 3.8 and increments of 0.2 yields the highlighted maximum value in Table 4.

increment	0.5
start	0
Height	Vol_Hotdog
0	0
0.5	23.21267165
1	45.43745702
1.5	65.6121416
2	82.5
2.5	94.51562371
3	99.34315528
3.5	92.82013857
4	63.19018911
Max Volume	99.34
increment	0.5
start	0

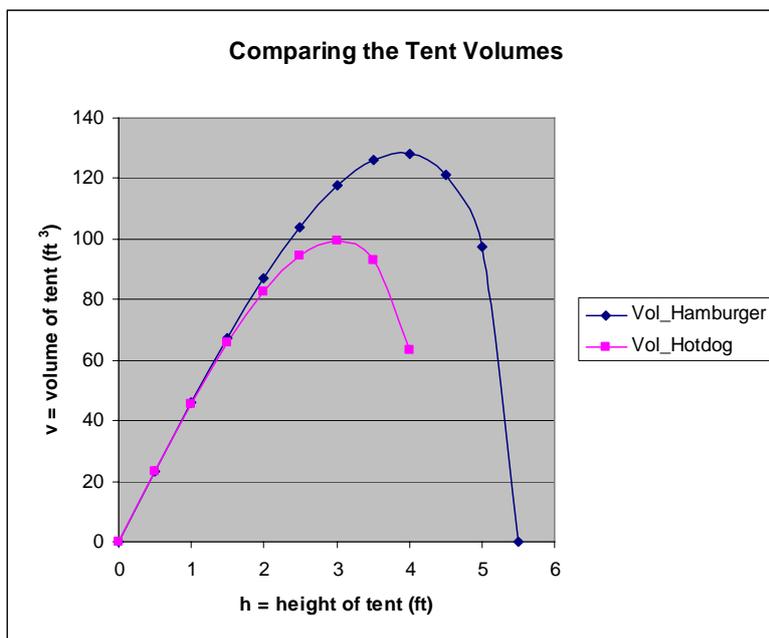
Table 3: Hotdog Zoom

increment	0.5
start	0
Height	Vol_Hamburger
0	0
0.5	23.27820869
1	45.97077876
1.5	67.46665843
2	87.09908151
2.5	104.1033141
3	117.5491918
3.5	126.2185604
4	128.3471854
4.5	120.9571205
5	97.37973352
5.5	0
Max Volume	128.35

Table 4: Hamburger Zoom

For further analysis comparing the volumes of the two constructions graphically, one can note the hamburger construction continually yields the maximum volume at any given height.

While not necessarily eloquent, the process of using a spreadsheet to analyze optimization problems is fairly straightforward and allows users to solve modeling problems from a different perspective.



**Reference**

1. Sugden, Stephen. "Colour by Numbers; solving algebraic equations without algebra" Spreadsheets in Education. 2 (106-017). 2005