

Delta Design THE DESIGN TASK

Thermal Engineer's Primer appended.

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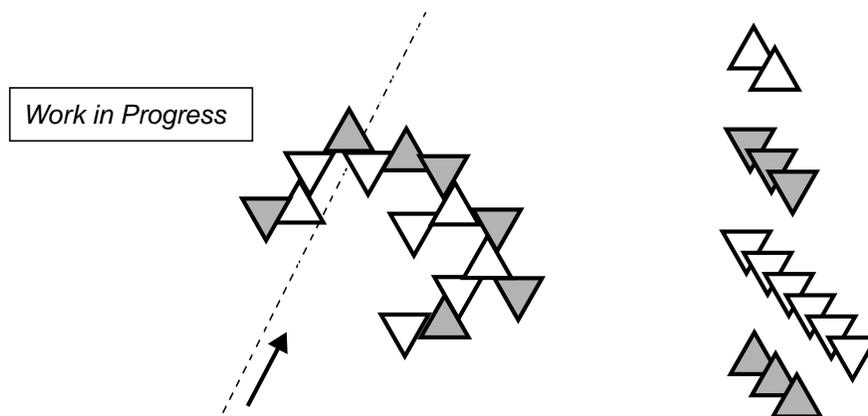
1.1 Introduction

Congratulations! You are now a member of an expert design team. Your collective task will be to design a new residence suitable for inhabitants of the imaginary Deltoid plane. These written materials, provided to help you prepare for this task, are organized in four sections.

The next section provides an overview of life on the Deltoid plane, DeltaP as it is known to the natives. The following section describes your team, and the final, your design task. A second handout, different for each team member, provides the specific information you will need to perform the role you have been assigned within your team. Each team member will contribute different expertise to the project, and each has different design responsibilities to fulfill. All must work together for your team to create a first-rate design.

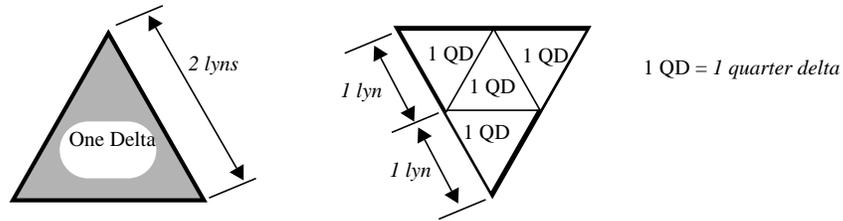
1.2 Life on DeltaP

Life on DeltaP, residential and otherwise, is quite different from what you have grown accustomed to here on Earth. First off, DeltaP is a plane, not a planet, so your team will be designing in two-dimensional rather than three-dimensional space. If your design "meets spec" and is considered attractive and functional by your Deltan clients, one view on a single sheet of paper will convey to those responsible for constructing it all the information they need to do so.



The view on this single sheet may not be quite what you expect, however, because in addition to lacking a z axis, Deltoid space has unfamiliar relations between the x and y axes as well. What we think of as “perpendicular” is hopelessly skewed to a Deltan, and vice-versa. In our units, a right angle on DeltaP measures 60° or $\pi/3$ radians. Thus all sides of an equilateral triangle form lines considered perpendicular to all others. If there were such a thing as a “circle” on DeltaP, it would be composed of only $4\pi/3$ radians.

But there is no such thing as a “circle” on DeltaP, nor even the concept of continuity embodied therein. In this flat though angular world, residents construct their artifacts strictly with discrete triangular forms. Of these, the equilateral triangle -- with its three perpendicular sides (!)-- is considered the most pleasing. Accordingly, your team will design the residence by assembling into a



cluster the most prized building materials on DeltaP, equilateral triangular components called “deltas.” Deltas come in red and blue versions and always measure *2 lynes* per side. Four “quarter-deltas”, *QDs*, triangular units of area measure with sides of *1 lyn*, fit within a delta.

Lyns? QDs? Not surprisingly, Deltan systems of measurement are as unfamiliar as that for spatial coordinates. Table 1 summarizes the measurement schemes on DeltaP that you will need to know to carry out your design task.

All of DeltaP’s units of measure share the divisibility and extensibility conventions of the metric

TABLE 1. Measurements on DeltaP

Measurement	Unit of Measurement	Symbol
Time	Wex	wx
Distance	Lyn	ln
Area	Quarter-Delta	qd
Heat	Deltan Thermal Unit	DTU
Temperature	Degrees Nin	$^\circ\text{Nn}$
Force	Din	Dn
Moment	Lyn-Din	LD
Currency	Zwig	!

system; in the measure of time, for example, there are both microwex (μwx) and megawex ($M\text{wx}$). In relation to the attention-and life-spans of Deltans, these units are roughly equivalent to seconds and years, respectively, here on Earth.

As building components, deltas have functional and aesthetic characteristics that are more complex than their simple form and even dimensions would suggest. Especially when assembled into a cluster, as you will be doing, they behave in interesting ways. Deltas conduct heat among themselves, radiate heat to outer space, melt if too hot, and grow if too cool. Red deltas produce heat. All deltas are subject to DeltaP’s two-dimensional gravity (which is itself subject to axial shifts during DeltaP’s not-infrequent gravity waves). Three different kinds of cement are needed to join them together, and joint alignment with respect to gravity affects ease of production as well as

structural integrity. Different colors and different quantities of deltas cost different amounts of money per delta, and can be assembled in clusters that are either exceedingly ugly or very attractive to the Deltans. Your task will be to create a design that meets prescribed goals for all of these characteristics.

1.3 Design Team Roles & Responsibilities

Your design team is organized such that each of you will be responsible for a subset of the design goals. One of you will be PROJECT MANAGER. Your main concerns will be with cost and schedule, the interpretation and reconciliation of performance specifications, and negotiations with the contractor and client. You want to keep costs and time-to-build at a minimum, but not at the expense of quality. When your team submits its final design, the project manager must report the estimated cost (in zwigs) and the time (in wex) that it will take to build.

Another of you will be the STRUCTURAL ENGINEER. Your main concern will be to see that the design “holds together” as a physical structure under prescribed loading conditions. You must see to it that the two points at which your structure is tied to ground are appropriately chosen and that continuity of the structure is maintained. When your team submits its final design, the structural engineer must attest to its integrity by identifying the strongest and weakest joints, and estimating the average load on all joints expressed as a percentage of the failure load.

Another of you will be the THERMAL ENGINEER. You will want to insure that the design meets the “comfort-zone” conditions specified in terms of an average temperature. You must also ensure that the temperature of all individual deltas stays within certain bounds. When your team submits its final design, the thermal engineer must estimate internal temperature and identify the hottest and coldest deltas.

Finally, one of you will be the ARCHITECT. Your concern is with both the form of the design in and of itself and how it stands in its setting. You must see to it that the interior of the residence takes an appropriate form and that egress is convenient. You should also develop a design with character. When your team submits its final design, the architect should be prepared to present a sketch and discuss generally how and why the Deltans will find the residence attractive and functional. The architect will also be asked to estimate a few more quantitative measures of architectural performance.

The following section describes the specifications that your design must meet to be accepted by your clients on DeltaP. Familiarize yourself with these specifications. Then, for schooling in your specialty, turn to the separate primer you have received that discusses the science and technology of your domain. The primer contains the knowledge and heuristics you will need to estimate the design parameters for which you are responsible. If you have questions that it does not answer, do not hesitate to ask. You should be expert in your role before your team begins the design phase.

1.4 The Design Task

Your Deltan clients have cleared the space shown on the site map and come to your team with their need for the design of a new residential cluster. The cluster itself must meet the following specifications.

The client wants the cluster to provide a minimum interior area of 100 QDs (Each diamond on your girded site map defines an area of two QDs). The shape of this space, which can of course exceed the minimum, is a matter of design. The client has expressed enthusiasm for the newer

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mode of segmenting interior space, a mode that breaks with the two-equal-zone tradition and values the suggested privacy of nooks and crannies. Still the space must be connected, i.e. no interior walls can cut the space into completely separate spaces. There must be one and only one entrance/exit.

The client is known to be color sensitive blue; too much blue brings on the blues, so to speak. No more than 60% blue ought to be allowed; certainly blue deltas are not to exceed 70% of the cluster.

The residence, as all clusters, must be anchored at two points and two points only. There is a limit to the amount of force each anchor can support, as well as to the amount of internal moment each joint can withstand. Exceeding either limit would cause catastrophic failure and send the unwary residents tumbling into the void. The cluster should be designed for a life of thirty megawex. Gravity waves, rare but always possible, should be considered.

The average interior temperature must be kept within the Deltan comfort zone, which lies between 55 and 65 °Nn. The temperature of the elements themselves must be kept above the growth point of 20 °Nn and below the melt-down point of 85 °Nn. Delta temperatures outside of this range will result in catastrophic structural failure with little more warning than excessive load.

All of this -- design, fabrication and construction -- must be done under a fixed budget and within a given time period. At your team meeting you are to develop a conceptual design that meets or exceeds all design goals. When each team submits their design, individual members will be asked to report design performance on parameters for which they are responsible.

TABLE 2.

Summary of Design Specifications

Functional Internal Area	100 qd
Maximum Cool Deltas (% Total)	60-70%
Average Internal Temperature Range	55-65 °Nn
Individual Delta Temperature Range	20-85 °Nn
Maximum Load at Anchor Points	20 Dn
Maximum Internal Moment	40 LD
Overhead Factor -K	(varies)
Total Budget	! 1400.00

Delta Design

THERMAL ENGINEER PRIMER

1.1 Introduction

As thermal engineer, you are responsible for the comfort and thermal stability of your team's design. This primer will review some basics of heat transfer on DeltaP, then cover methods you may use to estimate the average temperature and extreme values for individual deltas. It assumes you have read the introduction to the exercise.

To insure the comfort of prospective residents, you want the average temperature of all deltas in the cluster, a good proxy for interior temperature, to fall between 55 and 65 degrees Nn . For stability, you want the temperature of each delta to stay above 20 $^{\circ}Nn$ and below 85 $^{\circ}Nn$, as they melt at 85 $^{\circ}Nn$ and begin to grow at 20 $^{\circ}Nn$. Either event would have catastrophic consequences, with your clients tumbling down the plane amidst the wreckage of their dwelling. When your team submits its final design, therefore, you will be asked to estimate internal temperature and the location and temperature of the hottest and coldest deltas.

1.2 Deltan Basics of Heat Transfer

Deltas, the building elements your team will use to design the residence, come in two flavors: red and blue. Red deltas are heat sources, while blue deltas are passive, neither a source nor a sink.

The red sources produce heat continually over time, at a rate, q_0 measure in Deltan Thermal Units per microwex ($dtu/\mu wx$). While q_0 varies from supplier to supplier and even from batch to batch due to manufacturing irregularities, your project manager has found a supplier willing to guarantee minimal variance around the value:

$$q_0 = \text{units of heat produced by each red delta per unit time} = 160 dtu/\mu wx$$

All deltas, red and blue, conduct heat to and from adjacent elements in the cluster. The amount of heat conducted per unit time is determined by three things:

- the temperature difference between the adjacent deltas;
- the length of the joint between the adjacent elements;

Deltan Basics of Heat Transfer

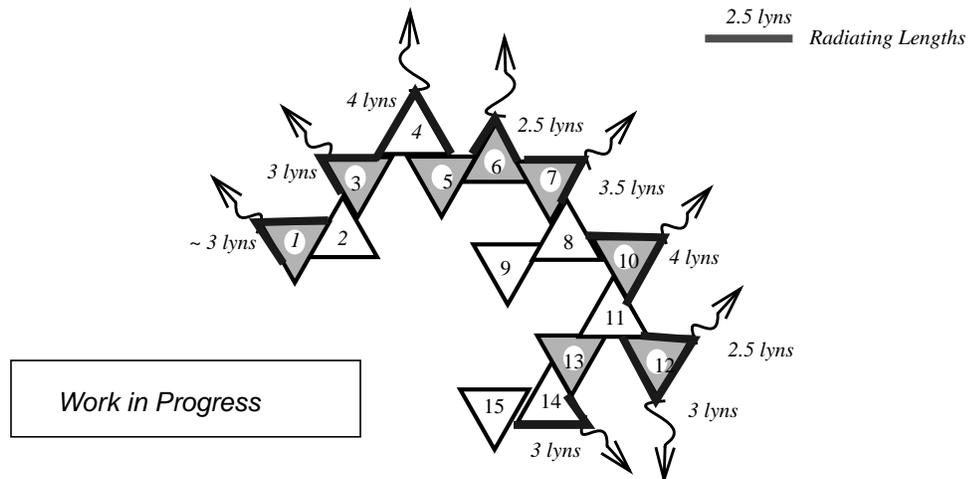
- a coefficient of conductivity, k_c

The coefficient k_c also varies by supplier, though because of differences in the cement used to join the deltas rather than in the deltas themselves. Your supplier has agreed to provide cement with conductivity that varies minimally around the value:

k_c = heat conducted per unit length, per unit time, per unit temperature difference

$$= 2 \text{ dtu/lyn}/\mu\text{wx}^\circ\text{Nn}$$

Deltas of either color also radiate heat into the Deltoid outer plane, but only when they have *outward-pointing, free nodes* on the exterior wall, as indicated in the figure below.



Like the rate of conductivity, the rate of heat transfer by radiation is proportional to:

- the temperature difference between the radiating element and the outer plane; since the plane's temperature is 0 degrees Nn , this term simply becomes the element's temperature
- the length of exposed edges on both sides of the free node, known as radiant length;
- a coefficient of radiative transfer, k_R

The coefficient k_R is fixed. Deltas with free nodes will radiate heat at the rate:

k_R = heat radiated per unit radiant length per unit time per unit temperature difference

$$k_R = 1 \text{ dtu/lyn}/\mu\text{wx}^\circ\text{Nn}$$

The figure shows a simple cluster to illustrate. Deltas #1, 3, 5, 6, 7, 10, 12 and 13 are red: each produces $160 \text{ dtu}/\mu\text{wx}$, together adding $1280 \text{ dtu}/\mu\text{wx}$ to the structure. This heat will be conducted through the cluster at rates dependent upon the length of the joints, which, starting with the joint

between #1 and #2 and working up, look to be about 1, 1, 1/2, 1 1/2,.... lyn respectively. Remember that the side of the delta is 2 lyns long.

Regardless of conduction flows, looking at all of the deltas together as a single ensemble, all of the heat generated by the 8 red deltas must be radiated away at the same rate at which it is produced through the 9 free nodes indicated in the figure. Deltas #1, 3, 4, 6, 7, 10, 12, and 14 have free, outward pointing nodes, and thus will radiate heat into the plane at rates dependent upon their radiant lengths. (Note that #12 has two free, outward pointing nodes). The radiant length for #1 looks to be about 3 lyns, allowing for the addition of an adjacent delta with further construction; #3 shows a radiant length of again 3 lyns; #4, a full 4 lyns; #6, 2.5 lyns and so on. (We anticipate that with further construction, #15 will be left with no free node and show no radiating length). Along with the basics just discussed, this is all the information we will need to estimate the cluster's thermal properties.

1.3 Estimating Average Temperature

To determine whether your team's design will provide the Deltans with a comfortable living space, you should estimate the average temperature of all deltas in the cluster as a best guess of interior temperature. The easiest way to calculate this average is to first estimate the average temperature of the subset of radiating deltas from a steady-state heat balance. The following equation describes this equilibrium, where the heat generated by the red deltas is balanced by the heat radiated by all deltas with free nodes:

$$N_R \cdot q_o = T^* \cdot N^* \cdot L^* \cdot k_R$$

where:

N_R is the number of red deltas

N^* is the number of radiating deltas;

L^* is the average radiant length of deltas with free nodes;

T^* is the estimate of average temperature of the radiating deltas.

Solving for T^* gives us:

$$T^* = (N_R \cdot q_o) / (N^* \cdot L^* \cdot k_R)$$

and plugging in the values from the sample cluster on the previous page gives us:

$$T^* = (8 \cdot 160) / (8 \cdot 3.5 \cdot 1) = 45.7^\circ Nn$$

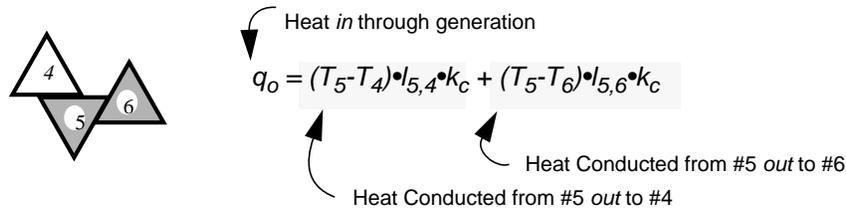
In this I have taken the average radiating length as 3.5 lyns.

One could at this point take T^* , the average temperature of the *subset* of radiating deltas, as the estimate of the average temperature of the *entire cluster*. That would be an adequate estimate as long as the deltas that are *not* in the subset of radiating deltas, — i.e., #2, #5, #9, #11, #13 — are blue, not red. We see this is not the case; #5 and #13 are red, heat generating elements.

Estimating Maximum Temperature

In this case we proceed to estimate the temperature of, let us call them the *interior reds*, as follows:

- Set up the heat balance for the interior red with its adjacent deltas. (We use #5 as an example). The heat *in* must balance the heat *out*.



- Assume the temperatures of the adjacent, radiating deltas are all equal to the average temperature of the subset, T^* , i.e., $45.7^\circ Nn$.
- Estimate the overlap lengths i.e., $l_{5,4} \sim 1.5 \text{ lyns}$; $l_{5,6} \sim 1 \text{ lyn}$.
- Given $q_o = 160 \text{ dtu/mwx}$ and $k_c = 2 \text{ dtu/mwx/lyn}$, solve for the temperature of the interior red, i.e.,

$$160 = (T_5 - 45.7) \cdot 1.5 \cdot 2 + (T_5 - 45.7) \cdot 1 \cdot 2$$

giving:

$$T_5 = 77.7^\circ Nn.$$

In a similar way, the temperature of the other, interior red delta is estimated to be the same, $T_{13} = 77.7^\circ Nn$.

The other, interior but blue deltas are all taken as T^* , the average of the radiating deltas. Our estimate of the average temperature of the entire cluster of 15 deltas, with 2 interior reds at 77.7 and the remaining 13 at $T^* = 45.7$ is just

$$T \sim [2 \cdot 77.7 + 13 \cdot 45.7] / (15) = 50^\circ Nn.$$

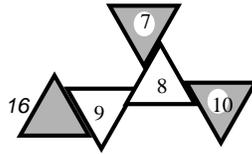
This estimate is within 5% of the value ($52.36^\circ Nn$) predicted by a sophisticated computer model of the cluster, and is certainly good enough for our purposes. We see that interior temperature is below the comfort zone, and hence that the design needs either another red or less radiant length.

Keep your calculations as simple as possible. Work only in integers and don't be reluctant to "eyeball" your estimates of average radiant length. It may be easier just to add up total radiant length, rather than figuring $N^* \cdot L^*$.

1.4 Estimating Maximum Temperature

The most likely "hot spot" occurs where there is an interior red, or where three or more red deltas are placed in sequence, as with elements #5-7 in the figure. As a general rule to prevent catastrophic overheating, you should avoid joining more than two red deltas in an unbroken string

and be very careful with interior reds. For example, if an interior red were added to the structure adjacent to #9,



too high a temperature is liable to result. An estimate of the temperature of the additional, interior red is again obtained from a heat balance, namely

$$q_o \sim (T_{16} - T_9) \cdot l_{16,9} \cdot k_c$$

with $k_c = 2$, estimating $l_{16,9} \sim 1.5$ and taking $T_9 = 45.7 = T^*$ we obtain:

$$T_{16} = 99 \text{ } ^\circ\text{Nn}$$

which is above the limit — meltdown is inevitable. A local fix would require ensuring a broad conductive path (good overlap) through #9 and #8 out to the radiating deltas. If the latter were blue as well as radiating, it is possible to keep the temperature of an interior red with spec

In a like manner, if your team's design does call for three reds in sequence, then you again must be careful: you ought to insist that at least two have free, outward pointing, nodes, as do #6 and #7. Even so you are walking on thin ice. Recall our estimate of T_5 was but 3 $^\circ\text{Nn}$ below the meltdown limit.

We might wonder about the temperature of #6. It no doubt is greater than T^* , the average of the subset of radiating blue as well as red deltas. An estimate of its temperature follows from assuming that all heat generated by this middle element is radiated away and none is conducted to (or flows in from) adjacent deltas. Thus we obtain:

$$T_6 = q_o / (L \cdot k_R)$$

where L- is the radiant length of the delta in question. Plugging in the radiant length shown in the example gives us:

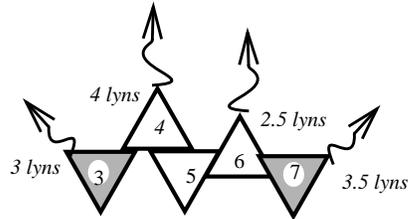
$$T_6 \sim 160 / (2.5 \cdot 1) = 64 \text{ } ^\circ\text{Nn}$$

which is high, but tolerable.

The computer model, however, gives the temperature of #6 as greater than 85 degrees, no doubt because #5 can't radiate and hence adds heat to #6. All of this merely reinforces the general rule: don't place more than 2 red deltas in sequence if you can help it, and arrange for ample radiant heat loss if you can't avoid doing so.

1.5 Estimating Minimum Temperature

A long string of radiating blue elements can result in very low temperatures. Consider, for example, the case where #5 and #6 of our original work in progress are blue instead of red. We can estimate the temperature of such a string, shown in the figure below, as follows:



The temperature of the blue string will stabilize when the amount of heat radiated by the string balances the amount of heat conducted into it. The red elements that bound the string will conduct this heat into the string at some rate $q_l + q_r$ where q_l and q_r are the rates of heat conducted into the string by the left and right red deltas respectively. This heat will radiate out of the string at the rate $T_4 \cdot 4 \text{ lyncs} \cdot k_r + T_6 \cdot 2.5 \text{ lyncs} \cdot k_r$.

If we take the sum $q_l + q_r$ to be on the order of q_o , that is, half of the heat generated by each of the two bounding reds is available to heat this sequence of three blues and if we further take T_4 equal to T_6 , we obtain $24.6 \text{ }^\circ\text{Nn}$ as an estimate for the temperature of #4 and #6. This is borderline. In fact, the computer program gives the temperature of all three blues to be just below $20 \text{ }^\circ\text{Nn}$: Note that once below 20 degrees Nn, the string would start to grow, the dwelling would deteriorate rapidly, and the clients and the insurance company would not be happy. You'd probably hear from their lawyer.

This completes the thermal engineering primer. These rules are not hard and fast, nor are they complete. But they should be sufficient to guide you in your task of assuring the comfort and thermal stability of your team's design.