Physics Teaching Assistant Orientation
Team and Technical Aspects of Engineering

Delta Design Project

Write a brief report (1) summarizing your group's design that includes the technical specifications for each aspect--Architect, Project Manager, Structural Engineer, and Thermal Engineer, and (2) summarizing your group's experience and learning in the Delta Design Exercise.

Delta Design

Present your design, including the photo of your final design. Summarize the technical aspects of your design and compare them with the specifications. Include assumptions and interpretations.

Delta Design Review

Review your design, including the process your group used to develop it. Include the photo of your design team. Describe the things your group did well and the things that could be improved. Discuss the implications of your experience in the Delta Design Exercise for teaching engineering students. Use the additional questions on the back of this handout to help complete this section.

Engineering Design

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Physics Teaching Assistants Orientation

August 2005

Engineering = Design

Design in a major sense is the essence of engineering; it begins with the identification of a need and ends with a product or system in the hands of a user. It is primarily concerned with synthesis rather than the analysis which is central to engineering science. Design, above all else, distinguishes engineering from science (Hancock, 1986, National Science Foundation Workshop).

Design defines engineering. It's an engineer's job to create new things to improve society. It's the University's obligation to give students fundamental education in design (William Durfee, ME, U of Minnesota, *Minnesota Technolog*, Nov/Dec 1994).

Engineering Design

Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints.

Engineering Design Thinking, Teaching, and Learning -- http://www.asee.org/about/publications/jee/upload/2005jee_sample.htm

Skills often associated with good designers – the ability to:

- tolerate ambiguity that shows up in viewing design as inquiry or as an iterative loop of divergent-convergent thinking;
- maintain sight of the big picture by including systems thinking and systems design;
- handle uncertainty;
- make decisions;
- think as part of a team in a social process; and
- think and communicate in the several languages of design.

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Languages of Design

- verbal or textual statements
- graphical representations
- shape grammars
- features
- mathematical or analytical models
- numbers

Engineering Design Thinking, Teaching, and Learning -- http://www.asee.org/about/publications/jee/upload/2005jee_sample.htm

Delta Design

- Design as a social process
- Negotiation

Bucciarelli, Louis, L. 1996. **Designing engineers.** Cambridge, MA: MIT Press.

1

Delta Design Task

Design of a residence for the inhabitants of an imaginary world – an assemblage of red and blue triangles into an envelope anchored in two-dimensional space.

Design Team Roles

- Project Manager
- Structural Engineer
- Thermal Engineer
- Architect

Project Manager

Responsible for (1) Cost and schedule, (2) Interpretation and reconciliation of performance specifications, (3) Negotiations with the contractor and client.

E.g.,
Total cost = K x (delta cost + cement cost + module cost)

K = overhead factor = 1.5

Structural Engineer

Responsible for (1) Structural integrity, (2) Selecting and evaluating anchor points, (3) Ensuring strength of joints

E.g.,

$$\sum_{j=1}^{N}(f\times D_{ij}) = N\times F\times D_{i,cg}$$

Thermal Engineer

Responsible for (1) Comfort zone, (2) Maintaining suitable average temperature, (3) Ensuring no hot or cold spots

$$N_R\times q_0 = T^*\times N^*\times L^*\times k_R$$

Architect

Responsible for (1) Form of design, (2) Maintaining acceptable living space, (3) Creating a distinctive design

Blue Dispersion = $(B\cap R)/((B\cap B)+(B\cap R))$

2

Delta Design Schedule

1. Design Team Meeting ~ 10'
   Assemble team, Check Roles (Architect, Project Manager, Structural Engineer, Thermal Engineer)
2. Skill Development – Meet with your "expert" group – Review role and plan ~40' (Architects start initial design after ~20')
3. Designing – Work together (all 4 roles) to create the "best" design ~60'
4. Design Review – Each group presents their design including technical specifications – 5'/team ~30'
5. Discussion

3

Delta Design THE DESIGN TASK

Project Manager's Primer appended.

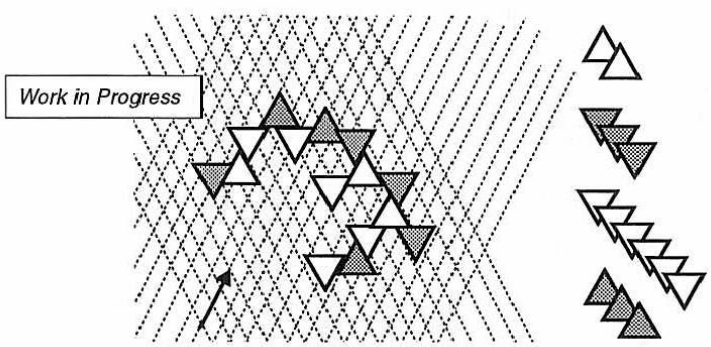
1.1 Introduction

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.



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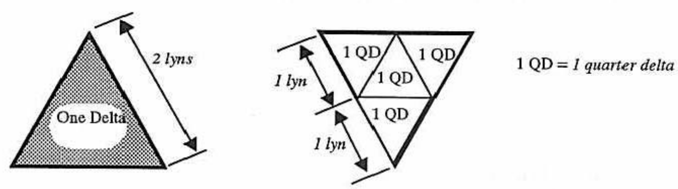
But there is no such thing as a "circle" on DeltaP, nor even the concept of continuity embodied therein. In this flat though angular world, residents construct their artifacts strictly with discrete triangular forms. Of these, the equilateral triangle -- with its three perpendicular sides (!)-- is considered 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 lyns* 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 system; in the measure of time, for example, there are both microwex (μwx) and megawex (*Mwx*). In relation to the attention-and life-spans of Deltans, these units are roughly equivalent to seconds and years, respectively, here on Earth.

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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.

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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

The Design Task

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.

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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 °Nin. 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.

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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 PROJECT MANAGER PRIMER

1.1 Introduction

As project manager, your main concerns are cost and schedule, the interpretation and reconciliation of performance specifications, and negotiations with 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, you must report the cost and time that you estimate will be required to build it. These estimates will be in zwigs (!) and wex, respectively.

As an experienced project manager, you know that all specifications are prone to slip during the conceptual design phase, and that budget and schedule, your specific responsibilities, are the most vulnerable. You have already realized that both are likely to be binding constraints, and further, that the Deltans are tight with a zwig and anxious to move in. Like clients everywhere, they desire a better residence then they can comfortably afford.

1.2 Estimating Project Costs

Your job of estimating project cost has been greatly simplified by finding a supplier-contractor that quotes material costs inclusive of delivery and most assembly charges. The cost schedules presented below for buying deltas and the cement needed to glue them together thus reflect near-final costs, with two important exceptions. One source of additional cost comes from the modular construction techniques used on DeltaP: material prices cover the labor cost to assemble deltas into modules, which is done at the factory, but not the on-site cost of positioning and joining these modules into the final structure. The second additional cost is overhead, which covers, among many other things, the cost of paying your design team.

To estimate the cost of your team's design:

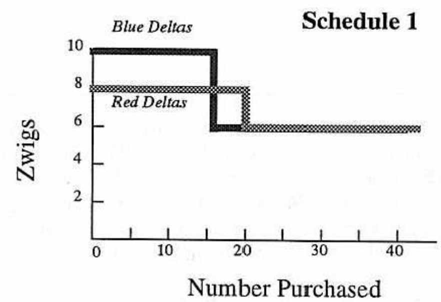
- figure the cost of the deltas used;
- figure the cost of the cement needed to joint them;
- figure the number of modules and the cost to join them; sum all these up and multiply by the overhead rate.

To estimate how long it will take to construct your design:

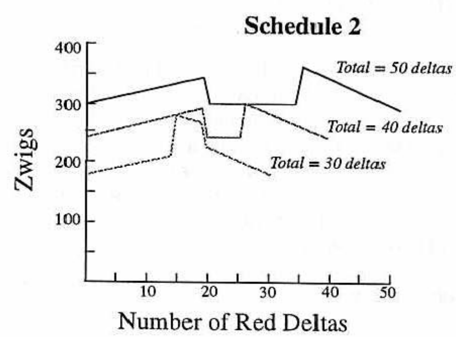
- identify the separate modules;
- determine how long it will take to construct each one;
- determine how long it will take to assemble them at the site;
- sum these up.

1.3 Delta Costs

The cost of deltas varies by color and quantity purchased. The price break for blue deltas is at 16 units: blues cost !10 apiece if fewer than 16 are purchased, !6 for 16 or more. The price break for red deltas is at 20 units: reds cost !8 each if fewer than 20 are purchased, !6 for 20 or more. These costs are shown in Schedule 1.



Schedule 2 illustrates how the total cost of deltas purchased varies with color composition. The y axis shows total ! cost and the x axis show the number of red deltas used. The three graphs show the color-mix variance in total delta costs for structures using a total of 30, 40, and 50 deltas, respectively. This schedule can help you calculate the most economical color mix for a given structure size.



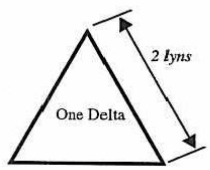
1.3.1 Cement Costs

You will need to purchase three different types of cement, at three different costs, to assemble deltas into your structure. Three types --R^2, B^2, and *RB* -- are required because different types of joints require different types of cement. R^2 (pronounced "r squared") is the red-red binder needed to bond one red delta to another red delta. *RB,* the most expensive, is the red-blue binder that bonds a red delta to a blue delta. Finally, B^2 is the least expensive and bonds two blue deltas. The following costs apply;

TABLE 1. **Cement Costs**

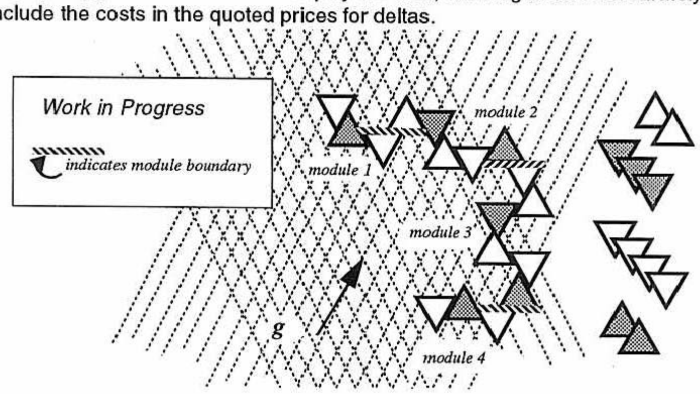
Cement Unit Costs	
R^2	!10 / lyn
RB	!20 / lyn
B^2	!5 / lyn

Note that the cost of fastening one delta to another will be determined by the length of contact between elements as well as by their respective colors: the longer the joint, the more glue is required. A fully overlapped 2 lyn joint between a red and a blue delta will cost !40; hardly pocket change.



1.3.2 Module Joining Costs

Should your team's design be selected, construction will proceed in two stages. In the first stage, individual deltas are joined into modules. This takes place at the factory, where the supplier firm has developed jigs and fixtures that simplify the task, allowing them to accurately predict and therefore include the costs in the quoted prices for deltas.



The individual modules into which a given structure will be decomposed and constructed at the factory are easy to identify, because the boundaries between them are defined by the orientation of the joints relative to gravity. To an earthly eye, any intersection of two deltas that runs left to right, across the page, is a module boundary. The figure shows how this works. The design has 3 such joints, and therefore 4 modules.

When all modules are complete, they are transported to the site, joined together, and anchored to the plane. This on-site work is more difficult to cost out in advance, so the client will essentially have to pay whatever costs are incurred. Your experienced contractor, however, has told you that her rule of thumb for predicting them is to figure the cost of glue needed for the module-to-module joints and double it. Thus the approximate on-site cost to joint Modules 1 and 2 in the figure could be estimated as 1 lyn of length times !5 per lyn of BB cement times 2, or !10. These module-joining costs are *in addition to* the cost of cement used in joining Module 1 to Module 2.

1.3.3 Total Cost

The total cost to execute your design may be estimated by summing up the cost of deltas, cement, and module joinery, and multiplying the result by an overhead factor K:

Total Cost = K x (delta cost + cement cost + module cost)

Because K takes into account the cost of living on DeltaP and must be updated frequently, it is not included in this primer. Refer to the earlier handout entitled "The Design Task" for its value, or ask the instructor.

1.4 Estimating Time-to-Build

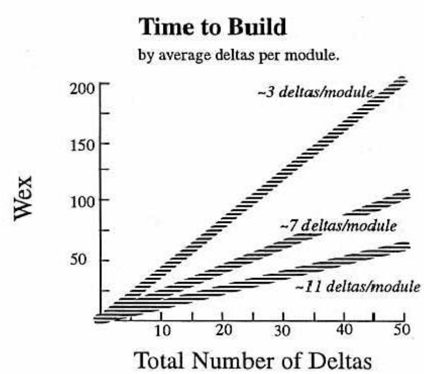
Estimating time-to-build is inexact, at best, but again your contractor has supplied some rules of thumb. Rough results are shown in the graph, but you will do better to figure them more precisely.

For each module consisting of three deltas or fewer, allow 2 wex;

For each module consisting of more than three deltas, allow 3 wex;

For each module-to-module joint, allow 4 wex;

Sum all of these up and double the result.



Delta Design THE DESIGN TASK

Architect's Primer appended.

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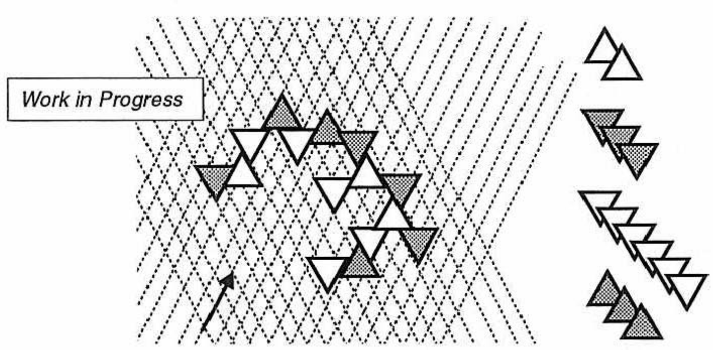

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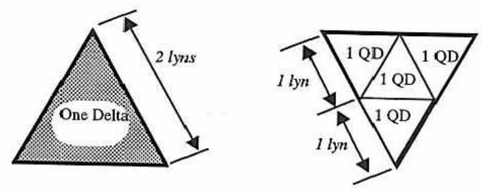

1 QD = *1 quarter delta*

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Maximum Internal Moment	40 LD
Overhead Factor -K	(varies)
Total Budget	! 1400.00

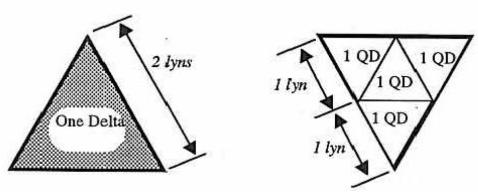
Delta Design ARCHITECT PRIMER

1.1 Introduction

As architect, your concern is with the intrinsic form and function of your team's design, as well as how it relates to the site. When your team submits its final design, you should be prepared to discuss how and why the Deltans will find the residence attractive and functional. You will also be asked to report some more quantitative architectural measures discussed below.

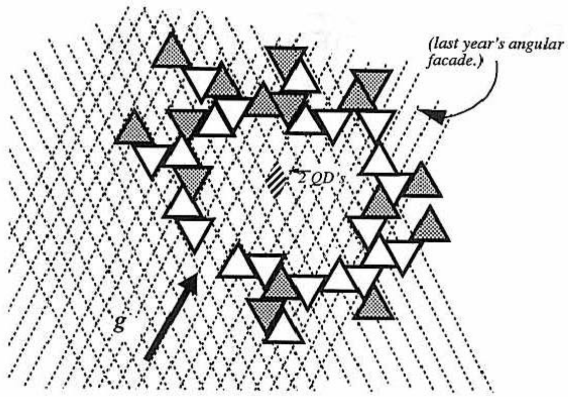
1.2 Function Follows Form

As simple as the fundamental building elements appear, quite complex, intricate and angular form can be composed out of deltas. As architect, it is your responsibility to create design that not only meets the clients' physical needs but in some way stands as an expression of their vision of themselves and their community.



1 QD = *1 quarter delta*

You read this vision as a vision of progress and innovation. You imagine a form that, while rooted in tradition, suggests a reaching out toward the unknown. Tradition has valued the angular exterior facade. You want to experiment with the smooth. Perhaps a rhythmic alternation of a smooth facade over a finite number of lyns with the traditional angular exterior will prove interesting



Coming more into vogue is the angular interior. There is some kind of reversal going on here. The interior traditionally has been made smooth, to maximize interaction ad communication. Nowadays privacy has become a common word in architectural discourse. While an argument can be made that the use of deltas to shape interior nooks and crannies is an inefficient use of this one resource, you think that this is a short-sighted view even though it is a view "rationally" argued by your engineering colleagues.

Your clients want to go even further. They seem to want some kind of "fractal" interior -- not just one space with nooks and crannies but sub-spaces which themselves suggest nooks and crannies. This is all very fuzzy in your mind but you are keen to experiment and have started sketching.

At the same time, you are keen to economize on space designated for circulation within the interior. You want, in other words, to maximize functional space. Note that a quarter-delta is an area within which three inhabitants could stand and talk comfortably, one to another. Several lyns are then required for circulation cross-section, not only within the interior but also at the entrance.

The single entrance/exit is conventionally aligned with the force field and "upstream" as viewed from outside; that is, one enters the cluster moving forward, in the direction of gravitational pull. This is so because Deltans are themselves subject to gravity. They have evolved over the many *gigawex* of their existence to the point where they now are able to maneuver in any direction without conscious attention to the force field. However, the entrance to most clusters is located so that the residents would fall into rather than out of the cluster if they were to lose this sense. This orientation is essential during passage of a gravity wave.

As noted in the description of the design task, your client is blue sensitive. While the allowable dosage of blue deltas in the environs is no set number, you conjecture that the blues ought not to constitute more than 60% of the elements. Dispersion of the blues is preferred as well, so that residents are not confronted with seemingly endless blue vistas when viewing the interior.

1.3 Some Quantitative Measures

Although the Deltans will ultimately judge the quality of your work by stepping back and casting a critical eye at the overall design, they have also requested that you provide some simple measures of design quality. These measures, and the methods to use to figure them, are as follows:

Some Quantitative Measures

- *Internal Area:* Estimate the internal area (in QDs) by using the grid on the site map. Each diamond has an area of 2 QDs.

- *Blueness:* Calculate the blueness of your design by figuring out how many of the deltas used are blue, expressed as a percentage of the total.

- *Blue Dispersion:* Count the total number of joints between deltas where either or both are blue. Now count how many of these do not join two blues, and express the result as a percentage of the total. 100% would mean you had achieved perfect dispersion.

- *I/E Perimeter Ratio:* Measure the interior and exterior wall lengths in lyns and divide the interior length by the exterior. Because a craggy wall will be longer than a smooth one, the higher this ratio is, the better you have met the clients desires discussed above. Certainly this ratio should be greater than 1.

A final note: unless told by the instructor that you will be remodeling the clients' existing residence rather than designing an entirely new one, you as architect are responsible for putting forward an initial configuration for consideration by your design team.

Delta Design THE DESIGN TASK

Structural Engineer's Primer appended.

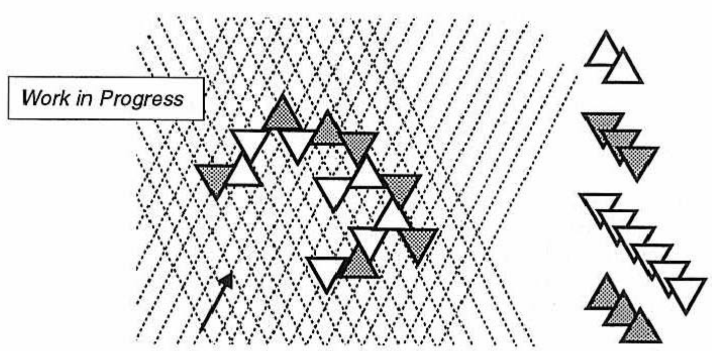
1.1 Introduction

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

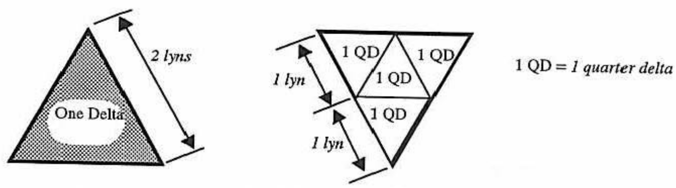
Life on DeltaP, residential and otherwise, is quite different from what you have grown accustomed to here on Earth. First off, DeltaP is a plane, not a planet, so your team will be designing in two-dimensional rather than three-dimensional space. If your design "meets spec" and is considered attractive 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.



Life on DeltaP

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 lyns* 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
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Heat	Deltan Thermal Unit	DTU
Temperature	Degrees Nin	°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 (*Mwx*). 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

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 °Nin. 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 STRUCTURAL ENGINEER PRIMER

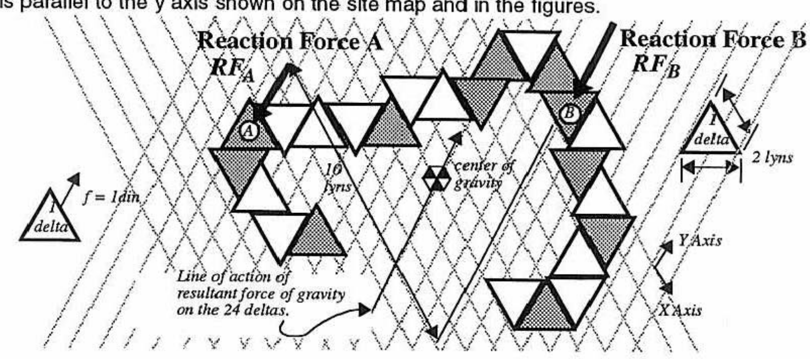
1.1 Introduction

As structural engineer, you are responsible for the physical integrity and robustness of your team's design. You must insure that the residence you propose will hold together under prescribed loading conditions. You should see to it that the two points at which your structure is anchored to the plane are appropriately chosen, that all joints are sufficiently strong, and that the overall shape of the cluster does not violate sound structural engineering practice. You should also strive for an elegant and efficient design, one that provides the requisite strength and durability with minimum costs and materials.

When your team submits its final design, you will be asked to attest to its quality by explaining the location of the anchors, identifying the strongest and weakest joints, and estimating, as a measure of robustness, the average load on all joints expressed as a percentage of failure loads. You may be asked to predict what will happen to your design during the next gravity wave.This primer will give you the tools, essentially the methods of static equilibrium analysis, with which to do your work. It assumes you have read the introduction to the Delta design exercise.

1.2 The Gravitational Field — The Center of Gravity

A uni-directional, gravitational force field acts on each delta in the plane. The direction of this force is parallel to the y axis shown on the site map and in the figures.



The Gravitational Field — The Center of Gravity

Each delta experiences a force of one *din*. Thus for the cluster of 24 elements shown in the figure, we can say

- that it has a total weight of *24 dins*, and
- that the resulting force due to Deltan gravity acts in the plane along a line parallel to the *y* axis and running through the cluster's center of gravity, as shown.

The structure is kept stationary despite this force by offsetting reaction forces at the anchors, marked in the figure as points *A* and *B*.

The first step in structural analysis is to locate the cluster's center of gravity (*CG*). For our initial purposes, we actually only need the CG's *x* coordinate, which gives us the line of action of the gravity force shown on the previous page. We do not need to know the *y* coordinate until we consider DeltaP's recurrent gravity waves, which flip gravity between axes, and when the time comes, you can determine it by similarly flipping the following moment equilibrium calculation. You may also use the moment equilibrium technique to locate the *CG* of any subsection of a cluster.

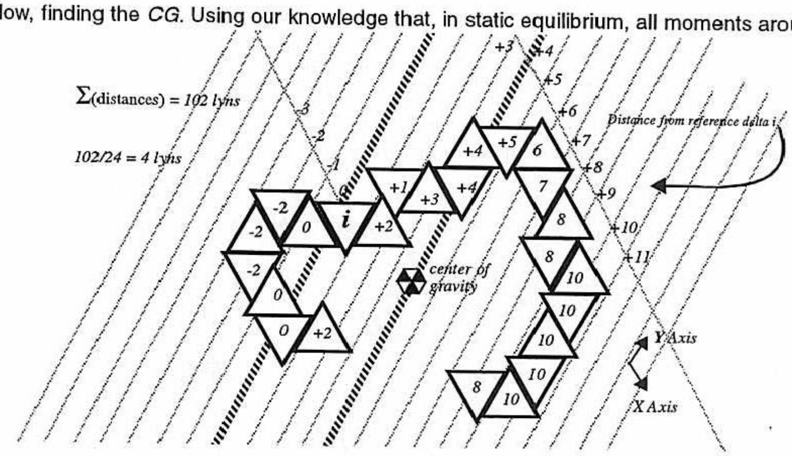
There are two things to keep in mind throughout your calculations. First, keep them as simple as possible. Work only in integers, always rounding up or down and estimating distances, forces and moments to the nearest *lyn, din*, or *lyn-din* respectively.

Second, keep in mind the peculiarities of Deltan space, where "perpendicular" describes an arc measuring only 60 degrees or $\pi/3$ radians in our units, and where distance measurements are made only along lines parallel to the axes. On DeltaP, the distance between anchors *A* and *B*, for example, measures *10 lyns*, as shown in the previous figure.

This distinction is critical in the calculation of *moment, the turning effect of a force about a point*. As on Earth, moment is still the product of the force and its distance from the point, but the distance must be measured in Deltan space. The moment that force RF_A exerts about point *B*, for example, is the product of the distance in *lyns*, measured parallel to the *x* axis, from the line of action of RF_A to anchor *B* (*10 lyns*), and force RF_A measured in *dins*. Not surprisingly, moment, M, is measured in *lyn-dins*, abbreviated *LD*:

M (RF_A about *B*), in *lyn-dins* = *10 lyns* XRF_A dins

Now, finding the *CG*. Using our knowledge that, in static equilibrium, all moments around any



given point will sum to zero, we can find a cluster's *CG* in reference to any delta, call it the *i*[th], by equating the sum of moments around it generated by gravity acting on each individual delta to the moment of the entire cluster around it:

$$\sum_{j=1}^{N} (f \times D_{ij}) = N \times f \times D_{i,cg}$$

where:

- N is the number of deltas in the cluster;
- f is the gravity force experience by each delta, equal to 1;
- D_{ij}, is the distance between the i^{th} and each other delta;
- $D_{i,cg}$ is the distance between the i^{th} delta and the *CG*'s line of action du to gravity.

Simplifying and solving for $D_{i,cg}$ gives us:

$$D_{i,cg} = \frac{\sum_{j=1}^{N} D_{ij}}{N}$$

So finding the *CG's x* coordinate is as simple as summing up the distances between any delta and all others, dividing by the total number of deltas, and adding the result to the x coordinate of the delta used as a reference. Just be sure to adhere to Deltan measurement technique, and express distances to the left and right of the reference as negative and positive numbers respectively.

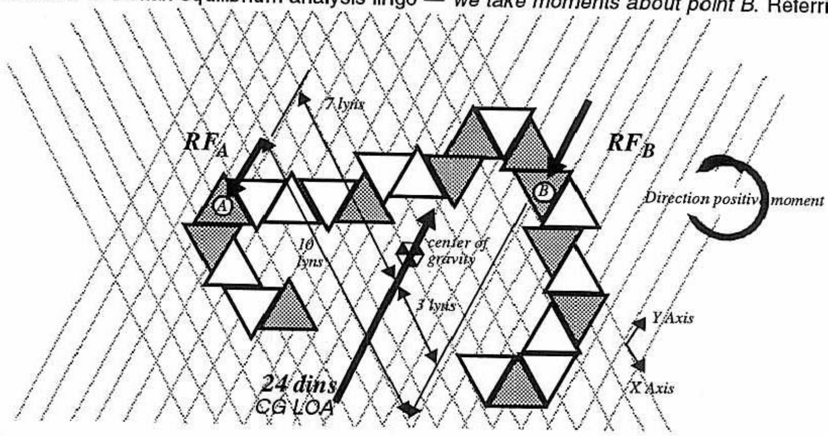
In the example shown in the figure, the distances from the i^{th} delta sum to *102 lyns*. Dividing by *N=24* gives us *4 lyns*, which we then count over, and *viola*, we have the location of the *CG's line of action* of the force due to gravity. Call this the *CG LOA*.

1.3 Estimating Support Loads

Each of the two anchors has sufficient strength to support a load of *20 dins*. They can resist no twisting effect, no moment, about their axes, i.e. they act as frictionless pins holding the cluster in place. To estimate the support loads that they will be subject to, first sum up the total force due to gravity acting on all deltas in the cluster. We know that this force, measured in *dins* as discussed above, is equal to the total number of elements *N* since each element experiences a force of *1 din*. We also know that, for equilibrium, the two reaction forces at the anchors, marked on the figure as RF_A and RF_B must also sum to this total force:

$RF_A + RF_B = N X f = 24$ *dins*

We need a second equation to solve for the reaction forces, which we can get by calculating the moment equilibrium of the entire cluster with reference to either anchor. We will use anchor *B* as a reference. In Deltan equilibrium analysis lingo — *we take moments about point B.* Referring



to the figure, assume that a positive moment acts to rotate the cluster counter-clockwise. Measure the distance from the *CG LOA* to anchor *B*: these *3 lyns* are the distance over which the *24 din* gravity force acting on the entire cluster creates a moment about *B*.

Since we know that, in equilibrium, the (positive) moment of RF_A about anchor *B* must balance the (negative) moment of the entire cluster about B, we have that:

10 lyns X RF_A *- (24 dins X 3 lyns) =0*

We solve for RF_A

RF_A *= 72 lyn-dins/ 10 lyns = 7 dins*

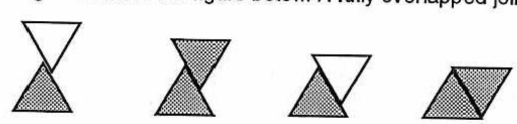
And, with the first equation, for RF_B

RF_B *= 24 -* RF_A*= 17 dins*

Since anchors can withstand *20 dins*, anchor *A* is in fine shape. Anchor *B*, however, only has a safety margin of *20/17*, or roughly *1.2*. This is ok, but you won't win awards for robustness. Can you see how to relocate the anchors for a better balance of reaction forces?

1.4 Internal Moments and Fastener Requirements

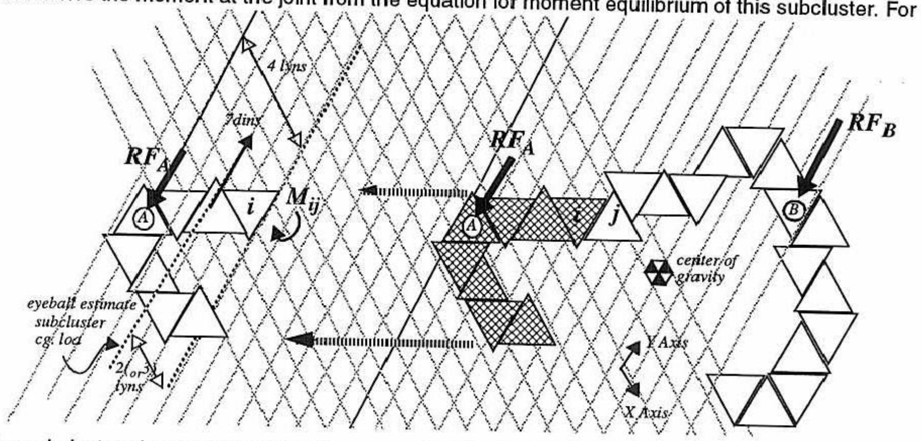
Adjacent elements are held together by cement. The cement is necessary because otherwise the structure could not support the internal forces and moments, again due to gravitational loading. T internal moment is the most critical of these. Although the ***strength of the cement*** varies by supplier, your source has certified hers at ***20 LD per lyn of contact***, resulting in the linear relationship between length and strength shown in the figure below. A fully overlapped joint fastened with



this cement will have a maximum allowable internal moment of *40 lyn-dins.*

Internal Moments and Fastener Requirements

Given this length-strength relationship, how do we estimate the actual internal moments that joints will experience and must withstand? Simply treat each joint as the boundary of a subcluster, and derive the moment at the joint from the equation for moment equilibrium of this subcluster. For



the subcluster shown in the figure the moment at the intersection of deltas i and j, denoted M_{ij} is found in the following steps:

- find the sub-cluster's *CG LOA* and its distance from the joint: here, about *2 or 3 lyns*;
- find the force exerted due to gravity by the subcluster, a quantity equal to the number of deltas in t: here *8 dins*;
- find the product, which gives us the moment of the subcluster about the joint;
- if the subcluster contains any anchor points, figure the moments of resulting reaction forces around the joint; in this case, we know that RF_A=*7 dins,* and measure the distance as *4 lyns*;
- taking moments about the joint as positive if they tend to rotate the section clockwise, express the fact that for equilibrium the sum of all the moments must be zero:

M_{ij} + *(moment of subcluster about joint) - (moment of* RF_A *about joint) =0*

- solve for M_{ij}

M_{ij} = *(moment of* RF_A *about joint) - (moment of subcluster about joint)*

So in our case, we get

M_{ij} *=(7din x 4 lyn)-(8 dn x 2 or 3 lyn) = 12 or 4 LD.*

This sounds pretty tame, since the joint is fully overlapped and can withstand *40 LD.* In fact, it sounds like a waste of cement, because a joint 25% shorter would still provide a hefty safety margin.

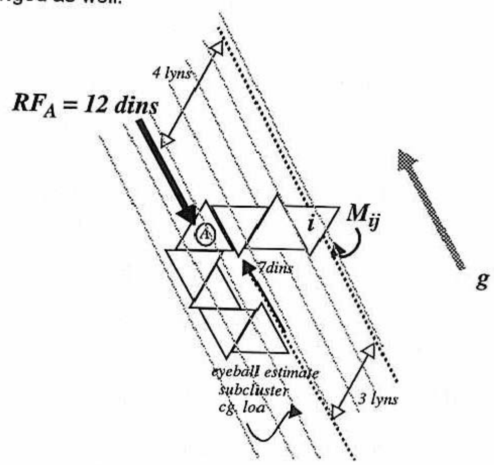
With these same six steps, we can estimate the internal moment at any joint we choose to examine, and compare it to the strength of the joint.

1.5 Gravity Waves

Finally, although the gravitational force across the Deltoid plane is forever constant in magnitude, the rare but inevitable gravity wave will, when it comes, instantaneously shift its direction orthogonally; from that of the y axis shown on the site map to that of the x axis. Gravity will then retain that direction until the next wave arrives and causes it to shift back. The figure shows the change in internal moment that the joint just discussed would undergo in the event of such a wave. We now obtain

$$M_{ij} = (12 \text{ dins} \times 4 \text{ lyns}) - (7 \text{ dins} \times 3 \text{ lyns}) = 27 \text{ LD}$$

which is significantly greater than the value previously obtained. Note that the reaction force at the anchor point has changed as well.



The last gravity wave passed through about 40 megawex (*Mwx*) ago, causing widespread destruction. The time period between waves is a random variable — a Poisson process with a mean arrival time of 80 *Mwx*. The statistics are generally considered "good" only for the past gigawex or so, and myths of old suggest that but ten Mwx separated two waves at the time of the flood. Should you worry about it?

Delta Design THE DESIGN TASK

Thermal Engineer's Primer appended.

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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.

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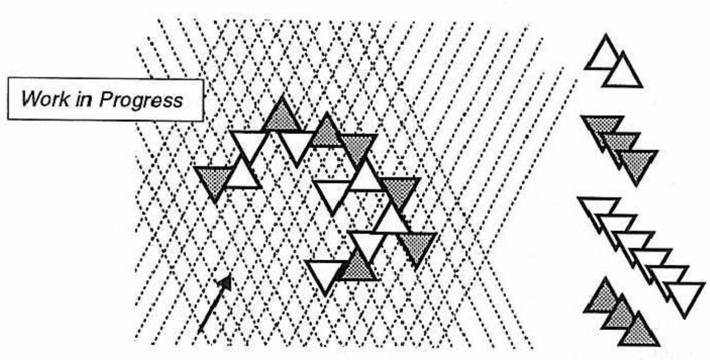

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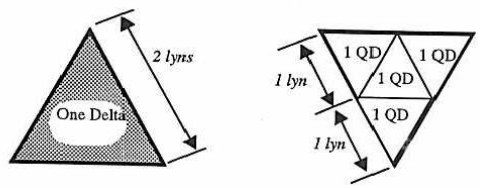

1 QD = *1 quarter delta*

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

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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

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 °Nin. 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 °Nn* and below 85 °*Nn* , as they melt at 85 °*Nn* and begin to grow at 20 °*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/µwx*). 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 = units of heat produced by each red delta per unit time = *160 dtu/µwx*

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;

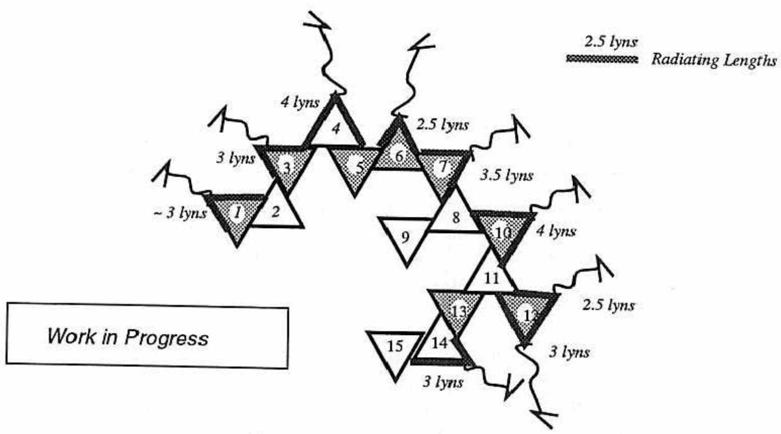
- a coefficient of conductivity, k_c

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 dtu/lyn/µwx/°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 dtu/lyn/µwx/°Nn*

The figure shows a simple cluster to illustrate. Deltas #1, 3, 5, 6, 7, 10,12 and 13 are red: each produces *160 dtu/µwx*, together adding *1280 dtu/µwx* 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:

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

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:

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

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

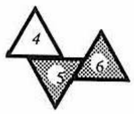
$$T^* = (8 \bullet 160) / (8 \bullet 3.5 \bullet 1) = 45.7\,^{o}Nn$$

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.

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*.



Heat *in* through generation

$$q_o = (T_5 - T_4) \cdot l_{5,4} \cdot k_c + (T_5 - T_6) \cdot l_{5,6} \cdot k_c$$

Heat Conducted from #5 *out* to #6

Heat Conducted from #5 *out* to #4

- Assume the temperatures of the adjacent, radiating deltas are all equal to the average temperature of the subset, T^*, i.e., $45.7\ ^oNn$.

- Estimate the overlap lengths i.e., $l_{5,4} \sim 1.5$ *lyns*; $l_{5,6} \sim 1$ *lyn*.

- Given $q_o = 160$ dtu/mwx and $k_c = 2$ 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:

$$T_5 = 77.7\ ^oNn.$$

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

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

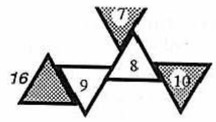
$$T \sim [2 \cdot 77.7 + 13 \cdot 45.7]/(15) = 50\ ^oNn.$$

This estimate is within 5% of the value ($52.36\ ^oNn$) 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

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

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

$$T_{16} = 99\ ^oNn$$

which is above the limit — meltdown is inevitable. Alocal 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 $3\ ^oNn$ 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:

$$T_6 = q_o / (L^* \bullet k_R)$$

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

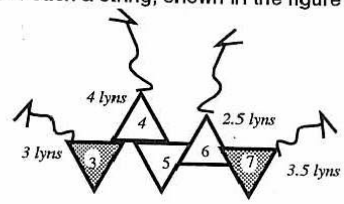
$$T_6 \sim 160/(2.5 \bullet 1) = 64\ ^oNn$$

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 $T_4 \bullet 4\ lyns \bullet k_r + T_6 \bullet 2.5\ lyns \bullet k_r$.

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 °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 °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.

Rationale for the UMn Model

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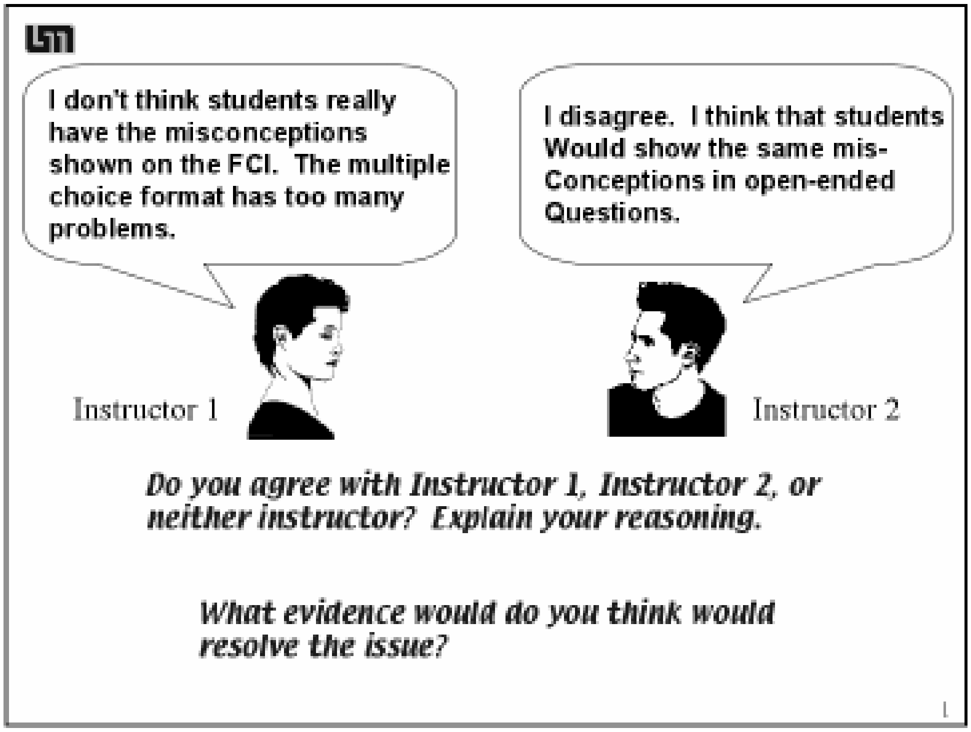
The FCI and Alternative Conceptions



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