Supporting GD&T Practices Through 3-D Modeling Activities

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Abstract
Geometric dimensioning and tolerancing (GD&T) has been recognized as an increasingly integral part of engineering design practice. Unfortunately, GD&T is a very difficult concept to teach and for students to apply to their activities in school. Part of the reason for this is the difficulty in representing the concepts using 2-D CAD tools. Whereas the 2-D CAD tools may have robust tools for notating drawings, they lack direct methods of capturing concepts represented in reading materials, lectures, and physical models. The new generation of constraint-based modelers provides a dynamic, 3-D environment where both size and geometric form constraints can be demonstrated and explored directly. This paper will present examples of exercises that can be used in an engineering design graphics course to demonstrate both the concepts of GD&T and good design practice. The examples include: 1) The relationship of datums in the 3-D modeling environment to the theoretical datums used in GD&T. 2) The transformation of implicit feature constraints in the 3-D model to explicit GD&T constraints. 3) How constraint modification in the model can be used to explore maximum and least material conditions. 4) Representation and constraint of symmetry in a model and its relation to GD&T controls.

I. Introduction

Geometric dimensioning and tolerancing (GD&T) is a difficult concept to teach students. This difficulty in grasping the basic concepts of GD&T becomes apparent when students are asked to apply these concepts to real world problems of mechanical design. What are the roots of these conceptual difficulties? Some of the problems lie in the fact that students have to be able to understand the differences between theoretical geometric elements and the actual geometry of the part. In addition, they have to have a firm grasp of the representation of geometry in both two and three-dimensional space. Finally, students have to appreciate how the form and size of a feature might change as dimensions on a part dynamically change or as parts in an assembly dynamically change position or orientation.

The conceptual difficulties of understanding GD&T can be coupled with the conceptual difficulties of understanding constraint-based, 3-D modeling software. How can students develop a mastery of applying GD&T to the design of mechanical parts using 3-D modeling software? What follows are three examples of how constraint-based, 3-D modeling software can be used to help support GD&T instruction while also helping to demonstrate the concepts of the how the modeling software functions.

II. Definition and use of datum planes

The concept of theoretical datums is central to both GD&T and 3-D modeling. Datum points, axes, and planes are theoretical geometric elements used to locate geometric features on the part. In GD&T, primary, secondary, and tertiary datum planes are established as a basis for both dimensioning the design and for setting up inspection tools (ASME, 1995; Neumann, 1995). These datums are established relative to each other and located relative to the part based on factors such as the functionality of the part and the ease of use in

inspection. Similarly, establishing three mutually perpendicular datums is also the typical starting point for constructing a part in 3-D modeling software.
Take for example the part shown in Figure 1a. An assumption of a student modeling this part might be to take advantage of the natural symmetry of the part and place datum C through the vertical center of the part and place datum B through the centers of the holes.

What are the GD&T implications of this model construction strategy? This model construction strategy makes sense if the goal is to have the hole centers act as the secondary GD&T datum (see Figure 1b). This, in turn. makes sense if the part mates in an assembly such that the hole centers are the controlling feature from which all width and length dimensions are based (Figure 1c).

If the part mating is dependent primarily on the meeting of end surfaces on the part (Figure 2c), another modeling scheme may be to establish datums B and C along the outer edges of the part. The datum planes now represent the 'ideal' surface (i.e., theoretical datum, or true geometric counterpart of the datum feature) from which dimensional constraints can be pulled (ASME, 1995) (Figure 2a). This alternate modeling scheme now supports the alternate GD&T specification (figure 2b) and matches the controls needed to assure the mating of the parts in the assembly (Figure 2c). If part modeling strategy is clearly addressed by the instructor and applied by the students, not only will modeling go smoother, but the clear connection between model datums and GD&T datums can be explicitly explored throughout the modeling *and* documentation process. Unfortunately, students often have a hard time visualizing the relationship of the part geometry to the datums and how different datum location schemes will affect the part's functionality in an assembly.

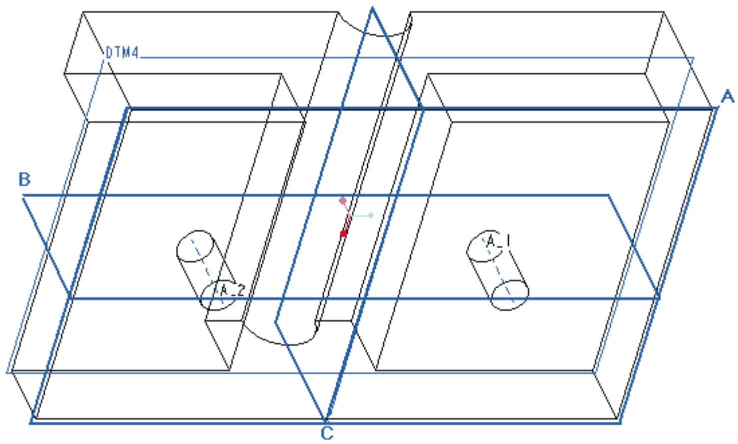
III. Implicit constraints and GD&T controls

Most constraint-based modeling systems can have their constraint mechanisms divided into two primary categories: implicit and explicit (Wiebe, 1999). Explicit constraints are the most obvious ones to associate with GD&T since they represent the dimensions used in GD&T notation. Implicit constraints, however, can also be tied to GD&T. When 2-D profiles – drawn as part of the feature generation process – are created, certain constraints are inferred by the modeler based on the configuration of profile lines. Examples of these implicit constraints include:

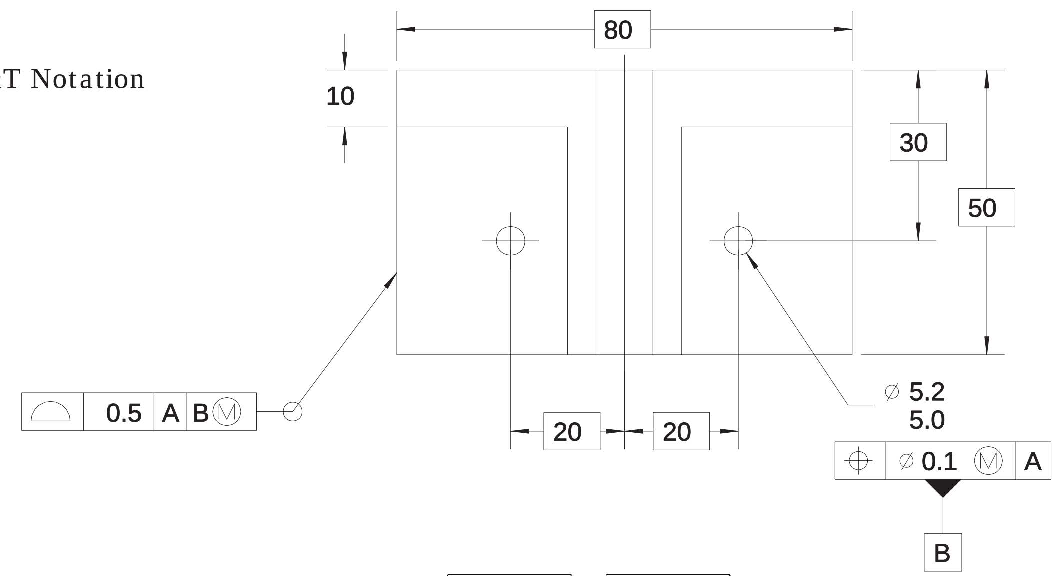
- parallelism
- perpendicularity
- collinearity
- symmetry

These constraints are labeled with appropriate symbols in the profile sketch (Figure 3a) and can be suppressed or added by the user. As compared to explicit constraints, implicit constraints can be most closely associated with the geometric control component of GD&T, more specifically, with certain orientation and location controls. Parallelism and perpendicularity constraints correspond with similarly named orientation controls, while collinearity and symmetry correspond with similarly named position controls. Also of interest is the fact that all of these implicit constraints can also be controlled by the profile control. The initial 2-D sketch profile in the model (Figure 3a) can be thought of as being controlled by a line profile control while the finished swept feature can be controlled by a surface profile control (Figure 3b). As with the previous example, planning prior to modeling as to what geometric controls are needed for the part will help guide the student in planning how they want to manipulate the implicit constraints on profiles. In turn, thinking in terms of geometric control when constraining model profiles will help reinforce the role these implicit constraints play in the model construction, documentation, and modification.

a. Model datum placement



b. GD&T Notation



c. Sample assembly

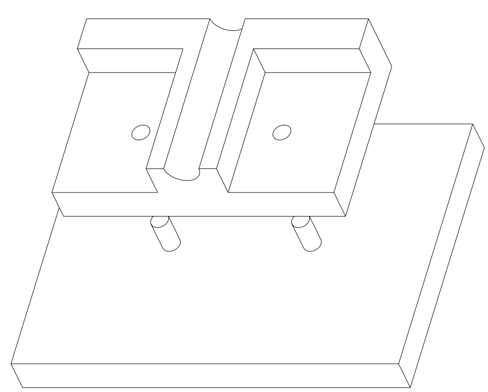
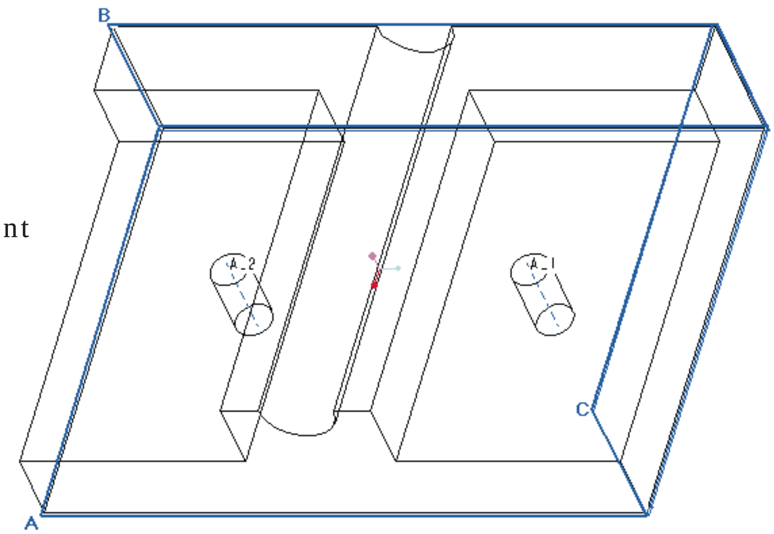
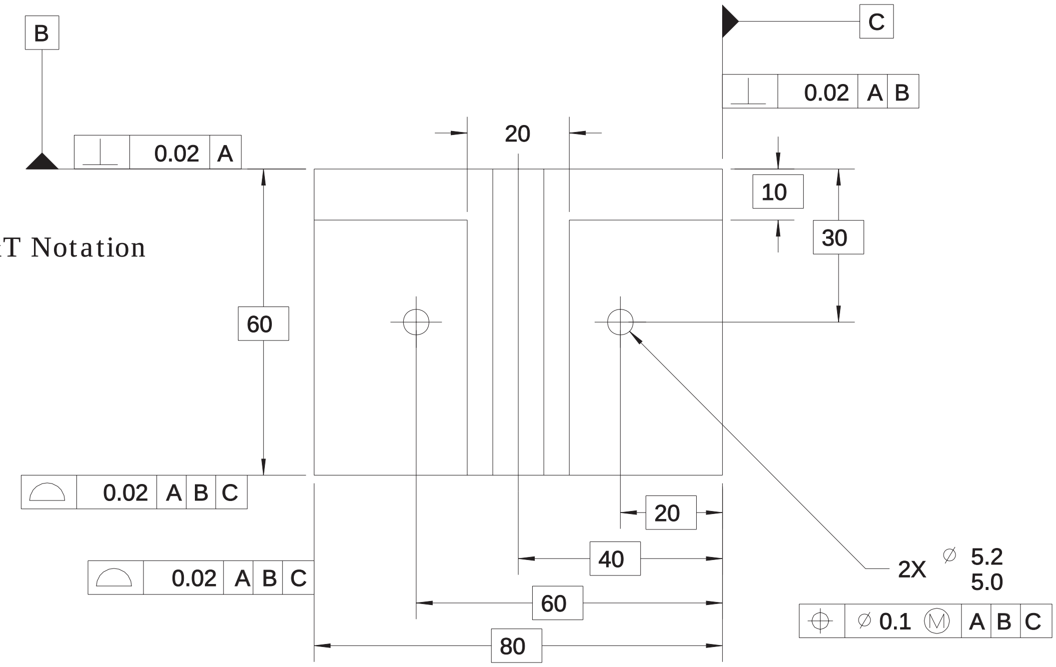


Figure 1. A part modeling and GD&T scheme based on the hole centers being the secondary datum.

a. Model datum placement



b. GD&T Notation



c. Sample assembly

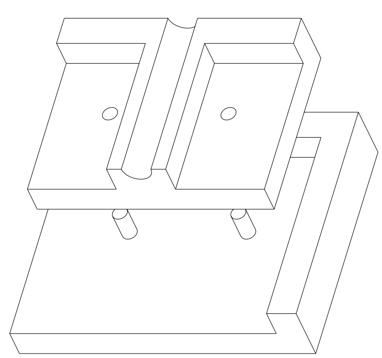
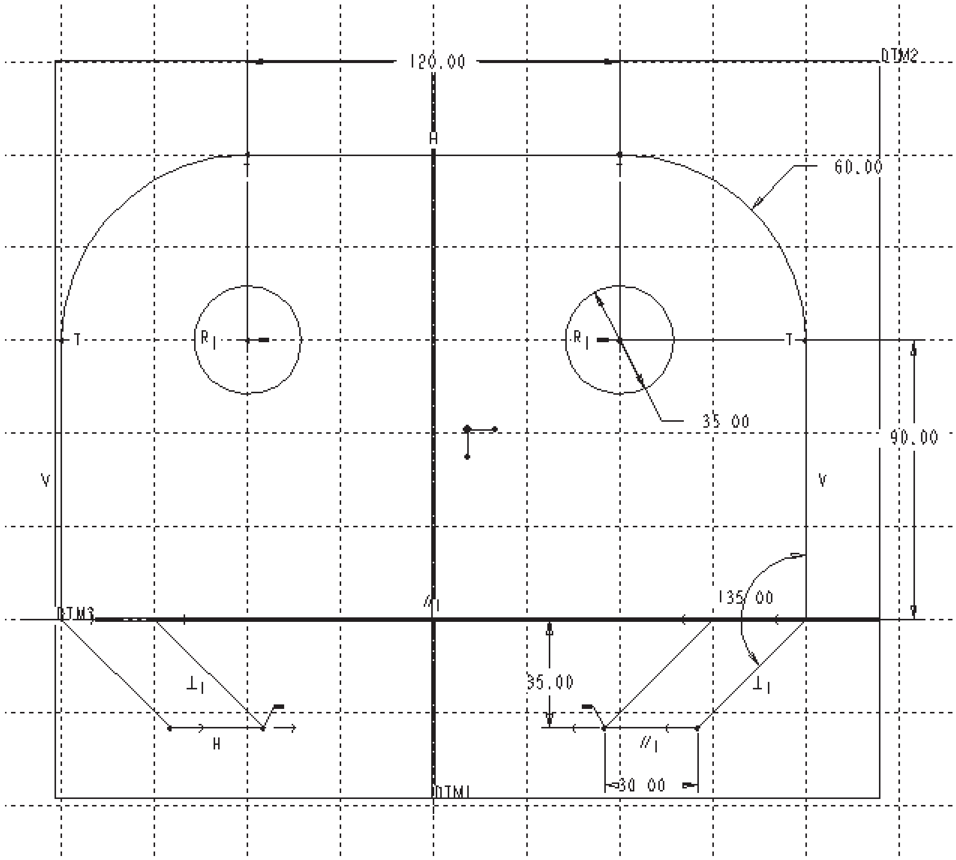
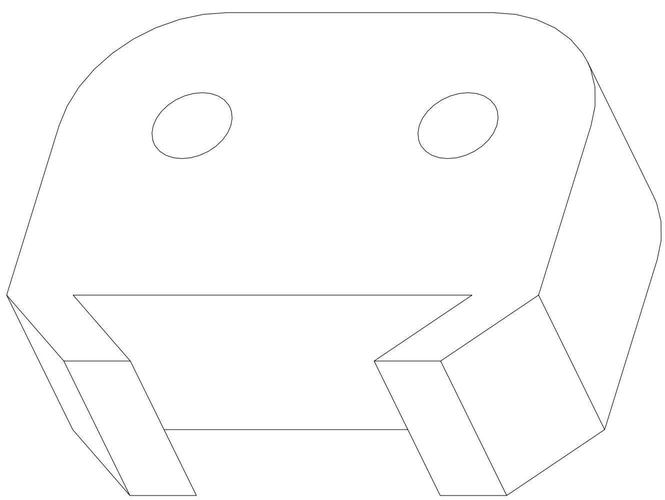


Figure 2. A part modeling and GD&T scheme based on the part edges being the secondary and tertiary datums.



a. Profile with implicit constraints



b. Extruded profile

Figure 3. Implicit constraints on a feature profile

IV. Exploring Virtual Condition through model modification

One of the truly unique features of constraint-based modeling is the extent to which one can dynamically control the modification of part geometry through the manipulation of explicit constraint values. Again, this fundamental modeler function can be tied directly to instructional goals in GD&T. Though it would be difficult to create geometry (datums or otherwise) which directly represents the tolerance zones of features, constraints can be manipulated in such a way as to show the interaction of size and location with the tolerance zone. Virtual conditions and resultant worst case conditions can be examined for features by manipulating size and location dimensions.

In the example of the pins in holes (Figure 4), size constraints on the pin can be manipulated to reflect the virtual condition/inner boundary of the machined holes. Students can then manipulate the size and location dimensions on the holes to examine acceptable variations in hole sizes and positions. The part with the pins becomes a functional gage for testing maximum allowable variations in size and location. By zooming in on the feature, students will be able to see that violating the tolerance zone will mean an overlap between a hole and the virtual condition pin; not allowed in the real parts. Because this virtual condition/inner boundary is defined as a cylinder, manipulation of both the vertical and horizontal location constraints on the hole will show that the value with which these constraints can change depends on the vector direction of movement.

While the pins are still positioned at the basic locations, the size and location constraints of the holes can be changed to reflect a hypothetical part (Figure 4b). By manipulating the constraints, students are able to see how size and location dimensions interacts with bonus tolerance. This can be calculated mathematically using the position formula, but the graphical analysis is more appealing to most students and instructors.

V. Conclusion

Constraint-based, 3-D modeling software can be an extremely effective tool for presenting and supporting GD&T instruction. While demonstrating the concepts of the software, constraint-based, 3-D models provide a framework for instructors to discuss GD&T issues related to design, manufacture, inspection, and design documentation. Linking design goals via GD&T also provides a more structured approach for students to plan the placement and creation of datums in their 3-D models. This leads to a more meaningful strategic planning process for model construction and supports the documentation process after the model is finished. Though the examples used in this paper were using only one modeling software package, these concepts can easily be carried over to most constraint-based modelers.

VI. References

ASME. (1995). Dimensioning and tolerancing: ASME Y14.5M-1994. New York, NY: American Society of Mechanical Engineers.

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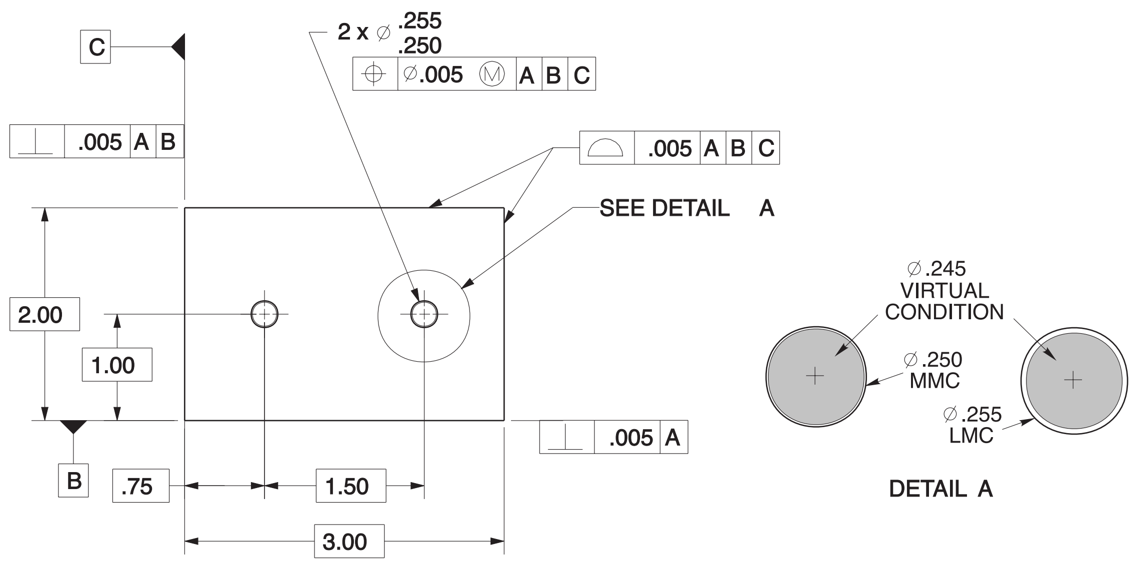
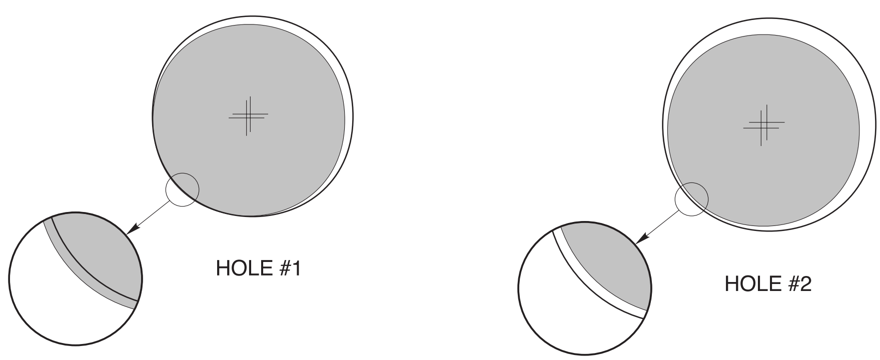
Wiebe, E. N. (1999). 3-D constraint-based modeling: Finding common themes. Paper presented at the ASEE Engineering Design Graphics Division Mid-Year Meeting, Columbus, OH.



a. Hole at MMC and LMC



Hole Number	Hole at MMC	Actual Hole Size	Deviation from Basic Location: X Direction	Deviation from Basic Location: Y Direction	Position Tol. Allowed	Actual Position Tol.	Accept or Reject
1	.250	.250	.002	.002	.005	.0057	Reject
2	.250	.255	.003	.003	.010	.008	Accept

b. Analysis of Hole Location

Figure 4. Manipulating size and location constraints to explore MMC and LMC.

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