

# First the Black and White Printer, Then the Color Printer, and Now the 3D Printer – Has Its Time Come

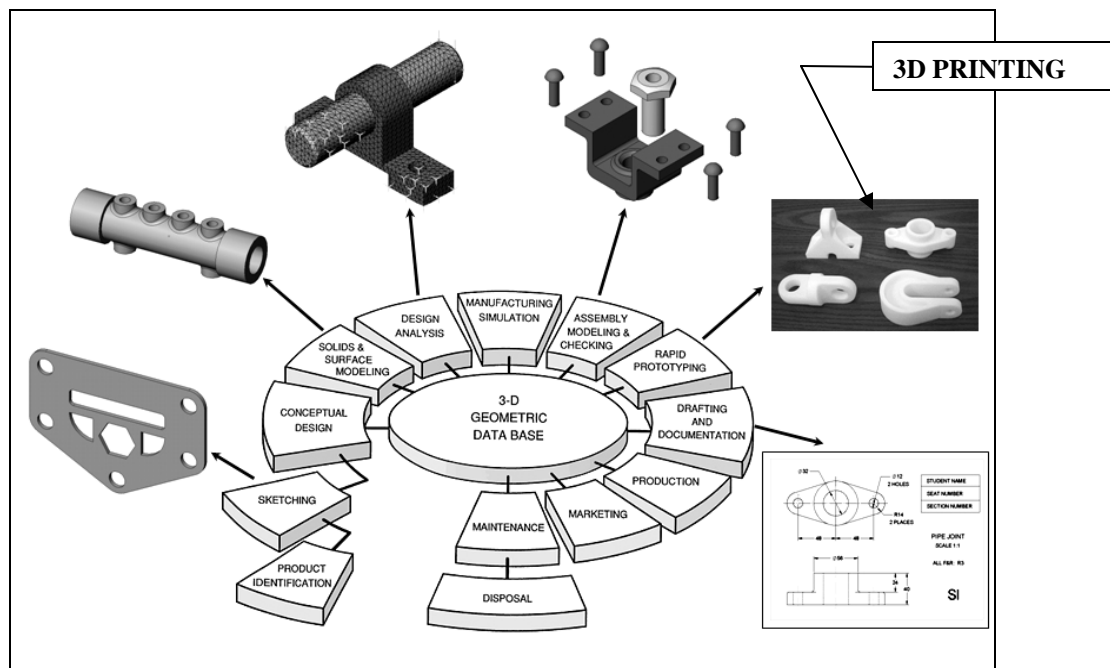
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## Abstract

For the past 15 years our group at the University of Texas at Austin has defined and promoted a “Concurrent Engineering Design Graphics” paradigm (Figure 1) for engineering education. Over the years, the practical implementation of this paradigm was confronted with many software and hardware hurdles. Selection of the proper 3D solid modeling software was an early concern, but now parametric and assembly modeling software like SolidWorks have become mainstream. Early efforts to implement a finite element analysis (FEA) unit in the class were met with failure.

However, analysis packages like COSMOS have now been seamlessly integrated into the modeling package. Educational experiences using rapid prototyping equipment have taken ten years to implement and the early low-cost systems were not very effective. But now, the cost of 3D printers has reached a stage where educational institutions can afford them. This paper will discuss the most recent extension to the Engineering Design Graphics paradigm using 3D printing as a means to produce a part that the students can feel and hold in their hand. The true long-term goal of “Art to Part” seems to now be realizable.



**Figure 1: The Concurrent Engineering Design Graphics Paradigm with 3D Printing Incorporated.**

## INTRODUCTION

In 1996, Rapid Prototyping and Desktop Machining systems were in their primary development stages and the cost of the hardware was simply out of reach for colleges and universities. In fact, even some corporate industries had difficulty in acquiring the equipment. The initial cost of one machine could run from \$100K to \$500K. Since the supply of machines as well as the material that it used was so prohibitive, it often proved more feasible to use traditional methods to build prototypes. During the past decade, these machines have been refined and have become more feasible. Some rapid prototyping companies are no longer in existence or have merged with others. The prices of the hardware and the build materials have come down to a range that are much more affordable. As can be seen in Table 1 below the prices of prototyping machines in 1996 were simply prohibitive for educational institutions to purchase and maintain.

**Table 1. A Cost Comparison of Rapid Prototyping and Desktop Machining Systems in the Mid – 1990's [1]**

| Method                           | Company                                | Machine Cost          | Materials Used                                     |
|----------------------------------|--|-----------------------|--|
| Stereolithography                | 3D Systems<br>Valencia, Calif.         | \$100K -<br>\$500K    | Ultraviolet Photopolymers                          |
| Select Laser Sintering           | DTM Corp<br>Austin, Texas              | \$200K -<br>\$400K    | Polycarbonate, nylon,<br>investment casting wax    |
| Robotically-Guided Extrusion     | Stratasys, Inc.<br>Eden Prairie, Minn. | \$100K -<br>\$200K    | Machinable wax, casting<br>wax, nylon-like plastic |
| Laminated Object Manufacturing   | Helisys, Inc.<br>Torrance, Calif.      | \$100K -<br>\$200K    | Paper, polyester                                   |
| Droplet Deposition on Powder     | Soligen, Inc.<br>Northridge, Calif.    | \$250K                | Alumina, Colloidal Silica                          |
| Ballistic Particle Manufacturing | BPM Tech., Inc.<br>Greenville, SC      | \$29K - \$35K         | Thermoplastic                                      |
| Layer Cutting and Gluing         | JP System 5<br>Mission, Kansas         | \$5K                  | Label Paper, Plastic Foam                          |
| Pattern Cutting and Folding      | Pentari, Inc.<br>Vashon, Wash.         | \$0.25K<br>(software) | Paper  |

## EDUCATIONAL APPLICATION OF RAPID PROTOTYPING TECHNOLOGY

In the middle of the 1990's, educational programs started to investigate the use of 3D rapid prototyping for making parts designed using solid modeling software [2]. Because of the affordability of the hardware from the Schroff Development Corporation, the Graphics area at the University of Texas started using 6 JP System 5 cutting units to build prototypes from adhesive paper. This suited our needs for several years from 1996 to 2003. However, alternative technology improved and the JP System 5 units were not giving us the quality that the 3D printers were offering. Also, the software for the JP Systems would no longer run on the latest versions of Microsoft® Windows, making it awkward to use. The machines were aging and the software was no longer being updated. This process had lost its effectiveness.

After several requests for funds and written proposals for grants we were awarded sufficient monies to purchase two 3D printers. During the 2004-2005 school year, the College of Engineering at the University of Texas allocated \$60,000 to the Graphics area for the purpose of purchasing rapid prototyping equipment (3D printers). We investigated several options as shown in Table 2.

**Table 2: Some 3DPrinter Options Available for Educational Purposes in 2004-2005**

| Company   | Cost per Unit |
|---|---------------|
| Stratasys BST with Educational Bonus Package and 1 year warranty        | \$26,000      |
| 3D Systems – ThermoJet Solid Object Printer – Ninety day warranty       | \$28,980      |
| Z Corporation 310 3D Printer With de-powdering system – 1 year warranty | \$28,420      |

Going out for bids during the early part of the spring semester, our faculty members were resigned to the fact that these machines could not be up and running until the summer, and that we could trouble shoot the effectiveness of the printers during the summer session. However, the Stratasys 3D machines were selected from the bids and delivered during spring break, and prototypes for the freshman engineering courses were actually built for the spring semester during which the machines were purchased. We went from delivery to operation in less than one month, which was a pleasing development for our faculty.

Cost comparison of the old JP System 5 to the new Stratasys 3D printers has some revealing information. The Graphics area has ten sections of freshman engineering students per semester, with 26 students per section. There are six teams per section, or sixty teams a semester. In their reverse engineering projects, the teams are required to build two to three parts. All of this adds up to approximately 365 parts per year needed for our Graphics program. The cost of JP System 5 paper for five years totaled \$17,600 (see Table 3). Divided by the 1825 parts that were built during that five-year period, each paper piece built cost an average of \$9.64. In contrast, since we have acquired the 3D printers, 635 parts were built at an average cost of \$7.50 per piece. Not only are the parts built by the 3D printers more durable and truer to shape and size, but the cost is significantly cheaper.

During the past 5 months we have produced 635 parts that averaged 1.67 cubic inches of model material and 0.42 cubic inches of support material. Over all we have used 1063 cubic inches of model material or the equivalent of 19 cartridges of material at a cost of \$250 per cartridge. That equates to \$4750 for the 635 parts or about \$7.50 per part.

**Table 3. Cost of Paper**

|       |          |        |                           |
|-------|----------|--------|---------------------------|
| 10/00 | 10 Cases | \$2750 |                           |
| 11/01 | 10 Cases | \$2750 |                           |
| 10/02 | 10 Cases | \$2750 |                           |
| 4/03  | 10 Cases | \$2750 |                           |
| 11/03 | 10 Cases | \$2750 |                           |
| 4/04  | 4 Cases  | \$1100 |                           |
| 11/04 | 10 Cases | \$2750 |                           |
|       |          |        | <b>TOTAL<br/>\$17,600</b> |

**THE STRATASYS 3D PRINTERS**

The Graphics Area selected the Stratasys 3D Printer BST for the machine best suited for its purposes. Figure 2 shows the present set up of the printers.



**Figure 2 The Stratasys 3D Printers**

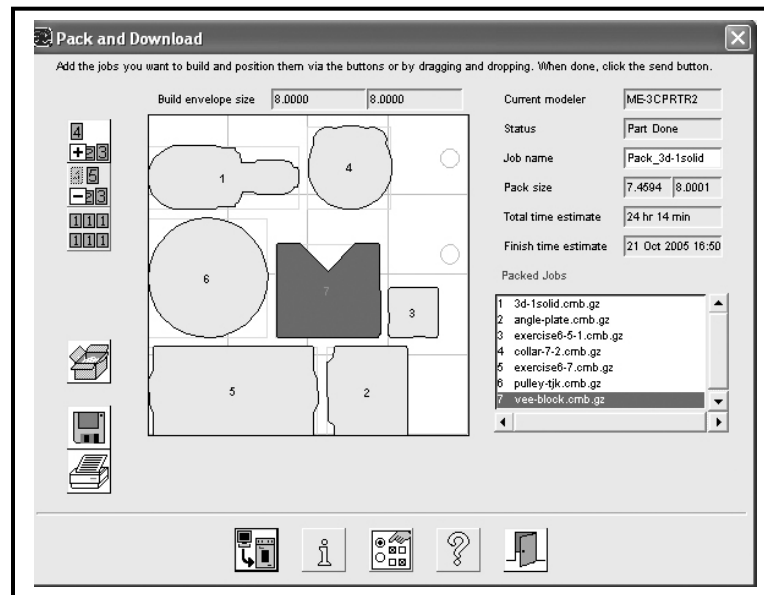
The printers use an ABS filament medium for its building material and it comes in cartridges that contain approximately 60 cubic inches of build material. It is clean, is relatively strong and can be used to illustrate an assembly. Figure 3 shows an example of a material cartridge.



**Figure 3. The Material Cartridge**

#### IV. THE BUILDING PROCESS

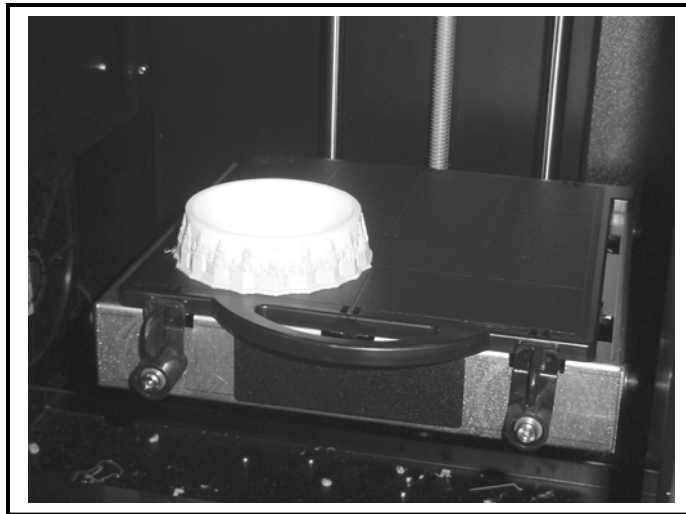
Using the software provided by the 3D printer, a build job is set up. Objects that have been saved as STL files are scaled, rotated and positioned on the build boards. The most efficient build process is to fill up each build board with as many pieces as will fit. Figure 4 shows an example of the placement of pieces to be built.



**Figure 4. The Build Board Layout**

As each piece is placed on the board the program informs you of the amount of material that will be used for the part and the length of time it will take to build it.

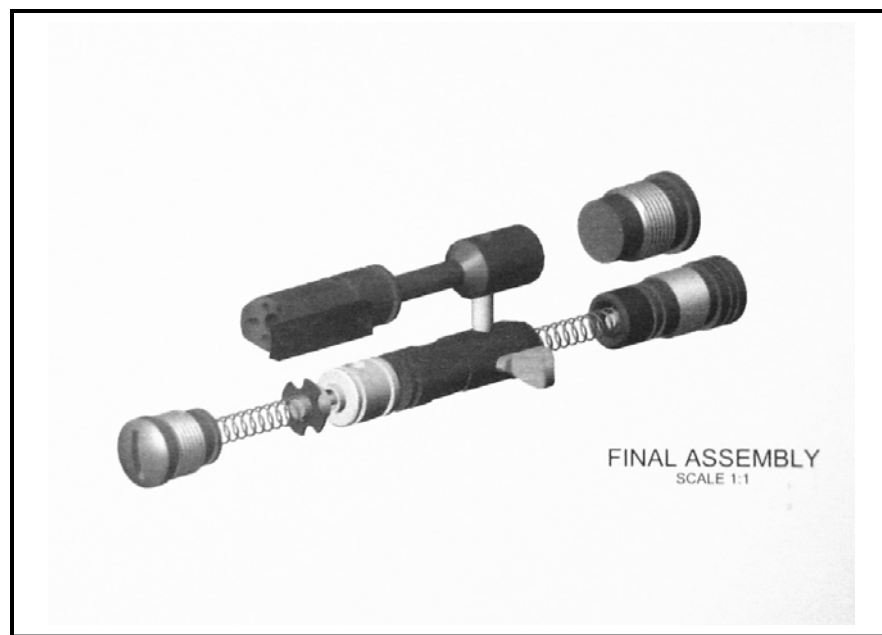
Once the build board is ready for the printer, the operator sends the job to the machine. A build board is placed into the printer and the building process is started. Figure 5 shows a build board in the machine with a built part that was recently completed.



**Figure 5. The Build Board in the Printer**

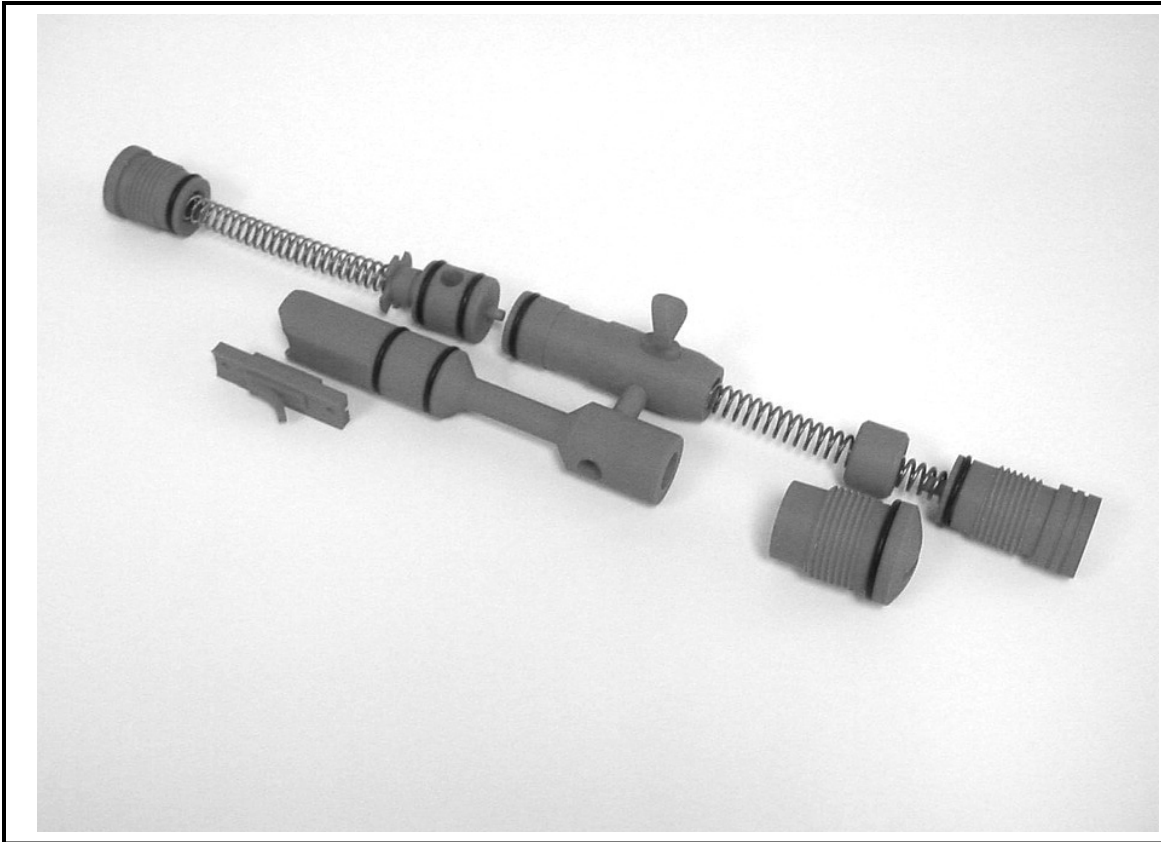
### A STUDENT PROJECT

An example of a student project, that uses 3D printing technology, is shown in Figures 5 and 6. The students are assigned to 4-member teams and are asked to reverse engineer a common mechanical assembly of parts. In this example, the team selected a Paint Ball Marker. Their first step is to build all the parts of the assembly using solid modeling software like SolidWorks<sup>®</sup>. They then save an .STL file for each part. As part of the overall experience, they create a mated assembly model of the parts, as shown in Figure 6.



**Figure – 6: Solid Model Image of the Student Project.**

In the next step, the students submit the .STL files to their graphics instructor. The instructor sets the files in the appropriate build positions using Stratasys software. The build and support materials are activated, and the machine starts printing the 3D parts. Typically, the full print cycle of a batch of parts (8" x 8" x 12" print volume) takes between 18 to 24 hours. The next day, the parts are ready for the students to peel out the gray support material to yield a clean, hand-held part. The parts for the paint ball marker, after manual re-assembly, are shown in Figure 7.



**Figure - 7: The Re-Assembled Parts After 3D Printing.**

### **VERIFICATION OF THE VALUE OF 3D PRINTERS**

In the summer of 2005, the Aerospace Engineering department approached us concerning the use of the 3D printers. They had a contract with NASA to construct and test a satellite project. Within this satellite there was a configuration of instrument boxes. They asked us to build these boxes so they could continue their work of designing the wiring harnesses and other configurations while the actual metal boxes were being manufactured. With the printed prototypes they were able to practice assembling of the satellite and design the wiring. They were able to continue their work and have stated that these prototypes saved them two months of development time.

Following are the statements from Millan F. Diaz-Aguado from the FASTRAC team in Aerospace Engineering Department at the University of Texas. [3]

“This document explains four different uses of the prototype boxes:

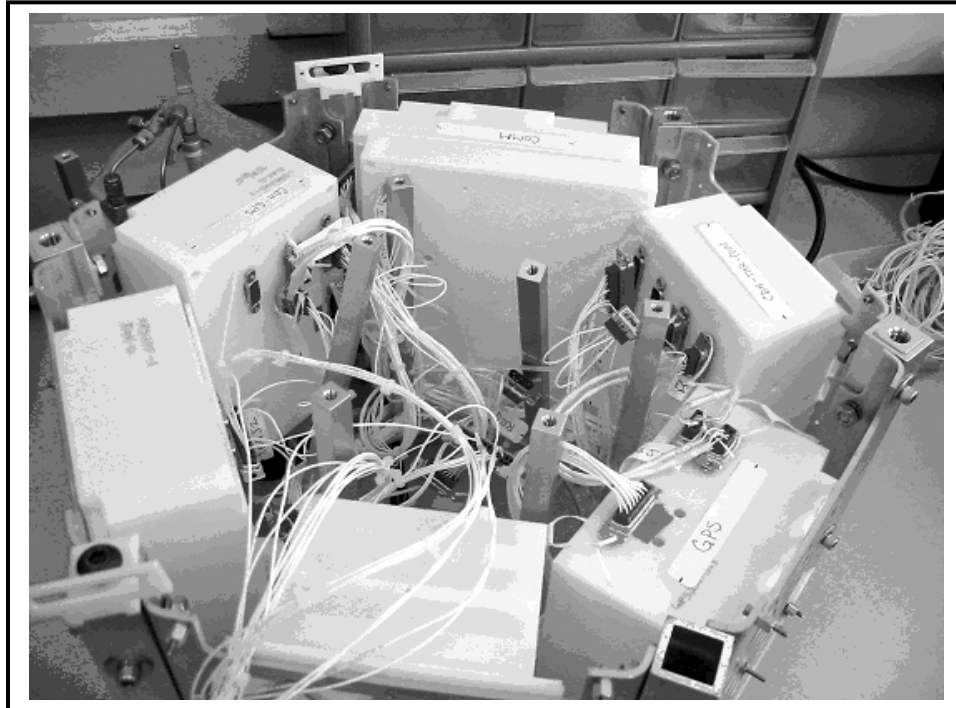
1. Design wire harness
2. Test flight connectors
3. Test subsystem, and subsystem integration
4. Write accurate satellite assembly plan

1. The boxes have been invaluable as a tool to plan the procedures involved in integrating all the subsystems. Both internal and external wire harnessing could not progress without the boxes because it is very difficult to design the harnesses in CAD. Figure 7 shows the harness before installation in the prototype boxes. Figure 8 and Figure 9 show the wire harness being installed in the prototype satellite.

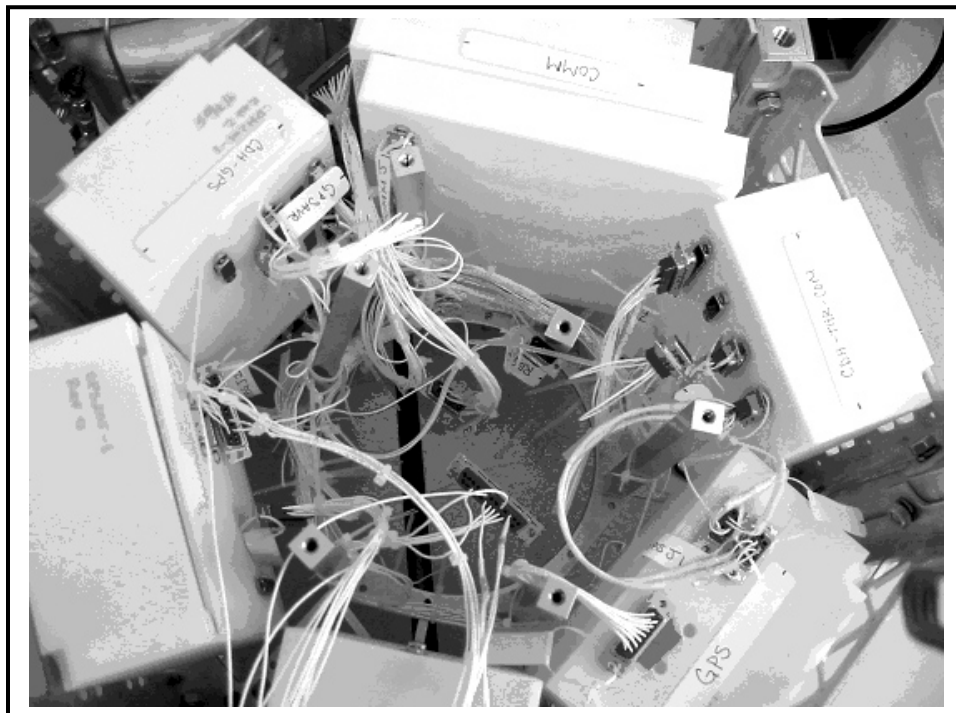


**Figure 7. Wire Harness Before Installation**



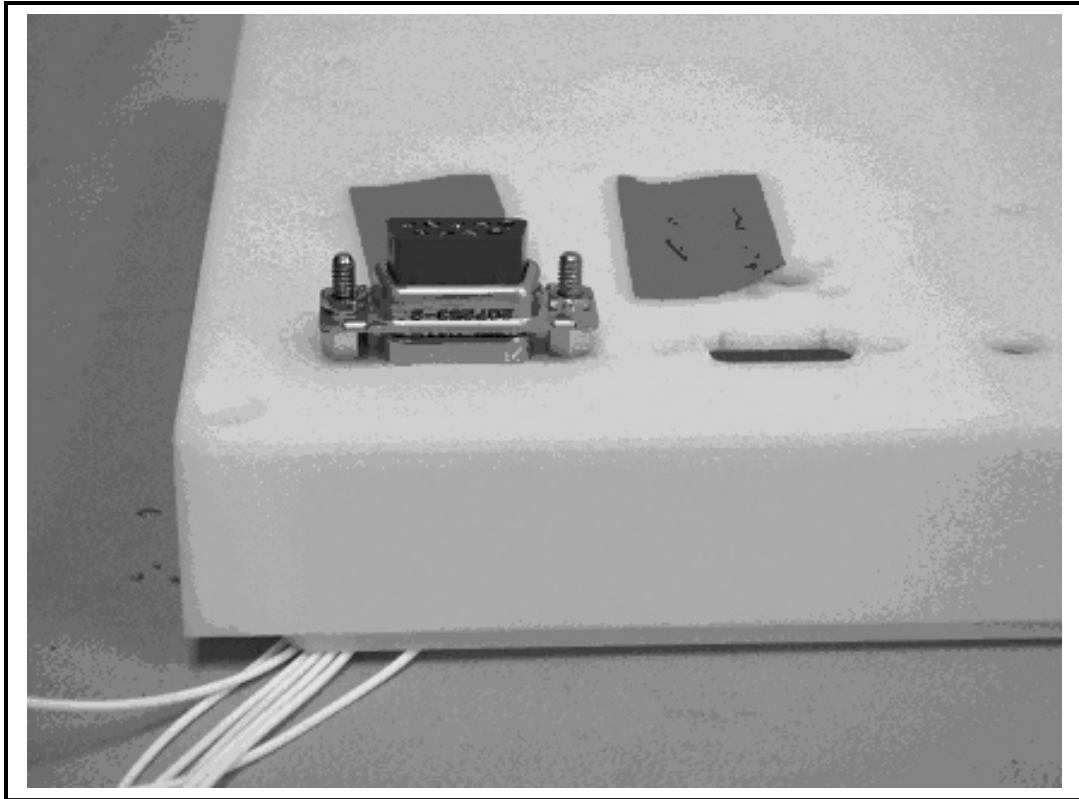


**Figure 8. Installation of Wire Harness using Prototype EMI Boxes**



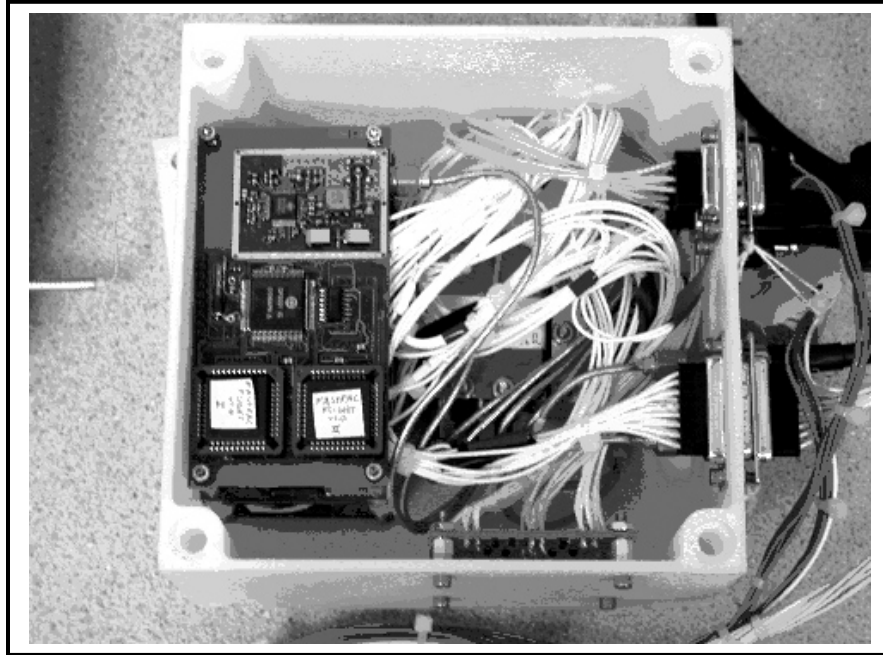
**Figure 9. Installation of Wire Harness using Prototype EMI Boxes**

2. The boxes were also used to test the connectors (See Figure 10 below.) The connectors must be used with specialized spaceflight hardware which results in a small spacing between the male and female connectors. The spacing was measured using the prototype box to ensure that the limited gap was not passed. The connectivity was also measured with a milliohm meter to ensure that all the pins had low impedance.



**Figure 10. Connector Ready to be Tested on Prototype EMI Box**

3. The EMI boxes were used to protect the subsystems as there were being tested. The subsystem integration was also designed with these boxes. Figure 11 shows the GPS subsystem with the actual flight hardware inside the prototype box during subsystem testing.



**Figure 11. GPS Subsystem Integrated in Prototype Box**

4. Finally, the boxes were used to write a satellite assembly plan. This assembly procedure would have been impossible without the white prototype EMI boxes. The satellite was assembled and disassembled numerous times to finalize the assembly plan. The real hardware would have been affected by the abuse of these procedures. Figure 12 shows the satellite with 4 EMI boxes integrated in the structure.”



**Figure 12. FASTAC Satellite with Four Prototype EMI Boxes Integrated**

## CONCLUSIONS

Under graduate computer labs are generally equipped with computers, black and white printers, color printers and plotters. With the 3D printers coming down in cost and the parts that they build more viable than earlier products, it seems feasible and logical that consideration should be given to the possible purchase of 3D printers that can be utilized by the engineering students. The 3D printers (prototyping machines) can provide the students with a visualization and learning tool that they have not had access to until this technology came along. The models have the strength of ABS plastic and can be assembled to show the relationship of each part in the assembly. Colleges of Engineering might consider 3D printers as part of their computer laboratories as a new tool in the design classes.

## REFERENCES

- [1] Barr, R., Juricic, D., Krueger, T., Wood, B, and Miller, L.: *Engineering Design Graphics Workbook: A Concurrent Engineering Approach*, Schroff Development Corp., Mission, Kansas, 1997.
- [2] Barr, R., Juricic, D., Krueger, T., and Miller, L.: Report on a Concurrent Engineering Workshop on Three-Dimensional Modeling, Analysis, and Prototype Manufacturing, *Proceedings of the 1996 Midyear Meeting of the Engineering Design Graphics Division of ASEE*, Raleigh, North Carolina, October 1996.
- [3] Millan F. Diaz-Aguado and the entire FASTRAC Team. Aerospace Engineering and Engineering Mechanics Department. 210 E. 24th St. WRW 305C, 1 University Station, C0600, Austin, TX 78712

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