

# A HIGH RESOLUTION STEREOSCOPIC COMPUTER PROJECTION DISPLAY FOR SURGICAL PLANNING

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## ABBREVIATED ABSTRACT

This paper details the construction of a high resolution, stereoscopic rear-projection display specially optimized for collaborative, computer-based surgical planning. The projection display was designed to address a number of drawbacks that exist in the use of other, more general-purpose projection displays for this task.

## EXTENDED ABSTRACT

This paper details the construction of a high resolution, stereoscopic rear-projection display specially optimized for collaborative, computer-based surgical planning. The projection display was designed to improve the image quality, reduce floor space, and to address a number of drawbacks that exist in the use of other, more general-purpose projection displays for this task. The presentation provides an overview of the scientific context in which this project was accomplished, addresses the technical challenges encountered and evaluates the practical results obtained. A complete technical description of materials used and assembly details are provided.

## TECHNICAL SUMMARY

### INTRODUCTION

The National Biocomputation Center has been conducting research in the area of computer-assisted surgical planning and training for a number of years<sup>10-13</sup>. One of the goals of the Center is the construction of a complete virtual reality environment used by surgeons to plan and train for surgeries. Such an environment can be used to train surgeons during residency, but also to train experienced surgeons for unusual or complicated surgeries.

A computer model of the patient is built directly from the actual patient's data, using imaging techniques such as MRI (Magnetic Resonance Imaging) or CT (Computed Tomography). The 3D data is used to produce a virtual model on which the surgeon can interact and operate. The virtual tissues generated from those scans are tissues that can be deformed, cut, sewed using our in-house soft-tissue simulation software based on a mass-spring mesh implementation.

Surgical instruments, augmented with tracking devices and linked to computers, are the necessary interface between the movements of the surgeon and the interaction with the virtual environment. To support this work, we have built our own custom surgery tools from actual instruments used in the operating room, such as forceps, endoscopes, dissecting scissors or syringes. These tools are augmented with 3D trackers and can even be linked to force feedback devices to allow a surgeon to see and feel the consequences of their movements in the virtual environment.

## BACKGROUND

Computer-based surgical planning and simulation<sup>1-6,8,9,15-21</sup> has demonstrated a number of benefits over the past 20 years. These include improved precision of surgery, improved surgical result, and decreased risk to the patient, among others<sup>7,14,19</sup>. In our experience with over 50 patients over the past 8 years, we have encountered similar benefits and realized a number of issues with how surgeries are planned. One central theme is that surgical planning, particularly of complex reconstructive procedures, is a team effort. Often, as many as six different physicians are brought into the consultation (ENT, reconstructive surgeons, oncologists, anesthesiologists, etc), and need to collaborate on planning the surgical procedure. Also evident in our experiences and those of others is the need for high-resolution stereoscopic imagery during the process. These two needs, for multi-person collaborative viewing and for high-resolution stereoscopic presentation, have led to the use of projection displays as a visualization medium.

While these devices were initially designed as multipurpose displays, this generality has necessitated certain design tradeoffs that reduce the optimization of the device for any specific purpose. Our early experiences with these devices therefore led us to discover a number of drawbacks for our application of surgical planning, which we sought to address directly in our own design.

A number of these drawbacks are described below. First, many early projection displays (such as the first generation Fakespace Immersive Workbench (IWB), among others) had decoupled the projector from the screen end of the device. In part, this was due to a desire to handle the long throw distances of the projectors, without intervening mirrors that add distortion and decrease effective lumen output. However, in actual use, the decoupling required a lengthy calibration process of up to 2 hours that would need to be repeated if the projector stand was bumped or moved.

Second, the fact that the projector was decoupled from the display end of the unit produced a number of other drawbacks as well. Since the back of the unit was open, dust buildup on the main mirror was a constant problem. Further, backlighting onto the screen from the ambient room light was such a problem that the system could only be used with the room lights off. In a dedicated room this is less of an issue, but within a shared lab space the impact on others can be substantial.

Third, the horizontal placement of the screen was suboptimal for a number of reasons. First, since the viewer could be located in any direction, the screen material needed to scatter light in all directions, resulting in a gain of 1.0. While our model of the IWB did tilt up by 30 degrees for viewing from the front, the fact that the top of the screen was roughly 5 feet away from the viewer required a remapping of perspective when doing stereoscopic viewing. Moreover, the maximum tilt of 30 degrees was insufficient for our purposes of surgical planning and made direct interaction with the models difficult (i.e., the user had to stretch over the table to directly interact with the model).

Finally, the cost of these systems typically runs around \$100,000. This represents a very significant capital expenditure within a research lab and is the equivalent of roughly three graduate student workers for a year. This fact in itself may be the largest barrier (followed by space and expertise issues) in the proliferation of projection displays for scientific research.

In conclusion, our early work with other projection displays led us to understand the great benefits of collaborative projection displays for surgical planning, but to also realize the limitations and drawbacks of generalized systems. We therefore sought to produce a projection display system optimized for our particular application and, simultaneously, address the drawbacks listed above.

Clearly, this rear-projection system would employ an integrated projector/screen (no recalibration issues), within a sealed enclosure (no backlight and minimized dust), with a vertical screen (to fit the team-based surgical planning paradigm better, to improve potential interaction with the model, for simplified stereo calculations, and to optimize light output toward the viewer), and to build such a system for a reduced cost. In essence, we wished to produce the first projection display system specifically designed for surgical planning.

## **MATERIALS AND METHODS**

The high quality video projector selected was a Sony VPH 1292Q/3D (see Appendix B for detailed characteristics) with fast phosphor coatings. The 120MHz RGB bandwidth of this projector enabled us to present the surgeons with 1600x1200 (60Hz, monoscopic) or 960x680 (112Hz, stereoscopic) resolution images of patient data. The projector then reflected the image off of two front-surface mirrors (see Appendix A) to decrease the floor space required for the nearly 3 meter throw distance, while minimizing light loss.

The specialized screen material was a DiamondScreen (Draper Shade and Screen, Inc) that embeds both horizontal and vertical lenses in order to concentrate light to a field of view of 48 degrees vertically and 180 degree horizontally, resulting in a gain of +5. This increase in gain enables the system to provide a very bright image, usable in normal room ambient lighting.

We had to build a solid and stable frame that could support all the weight of the screen and the two mirrors. Since we had special constraints and wanted a real custom-made projection system, we decided to make the frame in wood (redwood), thus facilitating custom cuts and frame assembly, as well as preventing ferromagnetic interference with electromagnetic-based tracking systems. To prevent the light from entering the optical system behind the screen, we hung removable thin black-painted wood panels on every side and top of the installation, thereby minimizing dust and backlighting.

To see the virtual environment in stereoscopic 3D, users wear liquid crystal shutter glasses (StereoGraphics, NuVision). These glasses alternate the opacity/transparency of their lenses for each eye, synchronized at high speed with the computer display. Those two different views correspond to what the two eyes of the observer would see from this point of view in a real situation, looking towards the screen. The impression to see in 3D (virtual reality) is thus achieved. To navigate and interact with the virtual environment, the surgeon uses tracked, custom surgical tools.

## **RESULTS**

The contrast, brightness and image quality greatly improved the virtual reality experience. The space occupied by the installation is significantly smaller than competing displays. Because ambient lighting is not an issue, it is now possible for the system to be used in room lighting, which facilitates interpersonal collaboration. The video projector is able to display 108 images per second, which allows the virtual environment to provide stereoscopic presentation at 54 images per second in each eye of each viewer.

This installation was realized in about 100 hours by one person, or two when some big panels or frames had to be displaced. This includes the time used for all the preliminary calculations, and the time to actually build the installation. The construction material cost was approximately \$1,000, the projector \$30,000, the mirrors \$1,000, and the screen was donated (value \$7,000), resulting in a total cost of \$32,000.

## **ACKNOWLEDGEMENTS**

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# APPENDIX A:

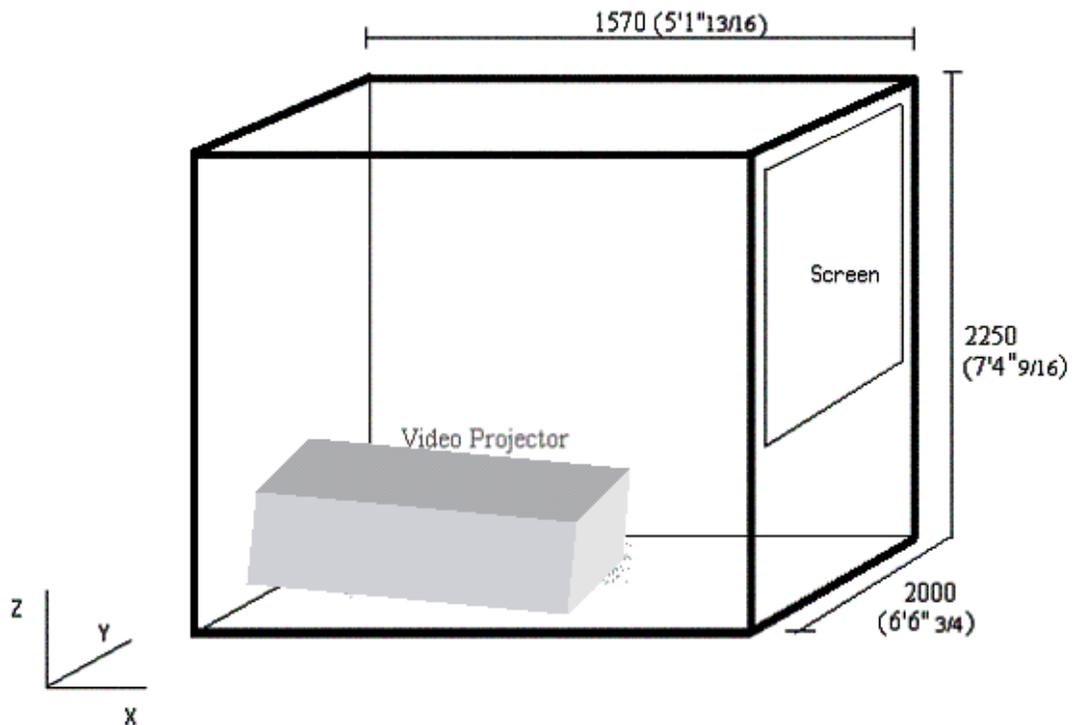
## TECHNICAL SPECIFICATIONS

### MATERIAL USED

Description	Qty	Dimensions	
		Europe (mm)	US (inches)
<b>OVERALL STRUCTURE</b>			
<i>PANELS:</i>			
- Side pannels (wood)	2	10 x 1550 x 2250	1/8 x 61" x 88"5/8
- Top & bottom panels (wood)	2	10 x 1570 x 1980	1/8 x 61"13/16 x 77"15/16
- Rear panel (wood)	1	10 x 2000 x 2250	1/8 x 78"3/4 x 88"5/8
- Front panel (same as rear panel, but cut to fit the screen dimensions)	1	10 x 2000 x 2250	1/8 x 78"3/4 x 88"5/8
<i>FRAME:</i>			
- Vertical axes (wood)	4	38 x 89 x 2230	1"1/2 x 3"1/2 x 87"13/16
- Horizontal axes (X) (wood)	4	38 x 89 x 1474	1"1/2 x 3"1/2 x 58"
- Horizontal axes (Y) (wood)	4	38 x 89 x 1904	1"1/2 x 3"1/2 x 74"15/16
<b>MIRRORS</b>			
- Mirror 1	1	508 x 1016	20" x 40"
- Mirror 2	1	1422 x 1803	56" x 71"

Description	Qty	Dimensions	
		Europe (mm)	US
<b>MIRROR SUPPORTS</b>			
<i>FOR MIRROR 1:</i>			
- Back Panel (wood)	1	508 x 1272	20" x 50"
- Frame (vertical) (wood)	2	38 x 89 x 700	1½" x 3½" x 27"9/16
- Frame (horizontal) (wood)	2	38 x 89 x 1904	1½" x 3½" x 74"15/16
- Mirror slides (to be cut in 3)	1 (3)	2032	80"
- Screws	~20	10	3/8
<i>FOR MIRROR 2:</i>			
- Back Panel (wood)	1	1550 x 1854	61" x 73"
- Frame (vertical) (wood)	2	38 x 89 x 2250	1½" x 3½" x 88"5/8
- Frame (horizontal) (wood)	2	38 x 89 x 1904	1½" x 3½" x 74"15/16
- Mirror slides (to be cut in 3)	1 (3)	4647	183"
- Screws	~40	10	3/8
<b>SCREEN SUPPORTS</b>			
- Frame (vertical) (wood)	2	Adjusted to fit the screen size	
- Frame (horizontal) (wood)	1	38 x 89 x 1904	1½" x 3½" x 74"15/16
-			
<b>MISCELLANEOUS</b>			
- Screws	~200	32	1¼"
- Zinc Corners	32	150 x 150	5"14/16 x 5"14/16
- Mirror glue	1 tube	250 mL	
- White primer	1 bucket	3.8 L	1 Gallon
- Black paint	1 bucket	3.8 L	1 Gallon

## OUTSIDE VIEW



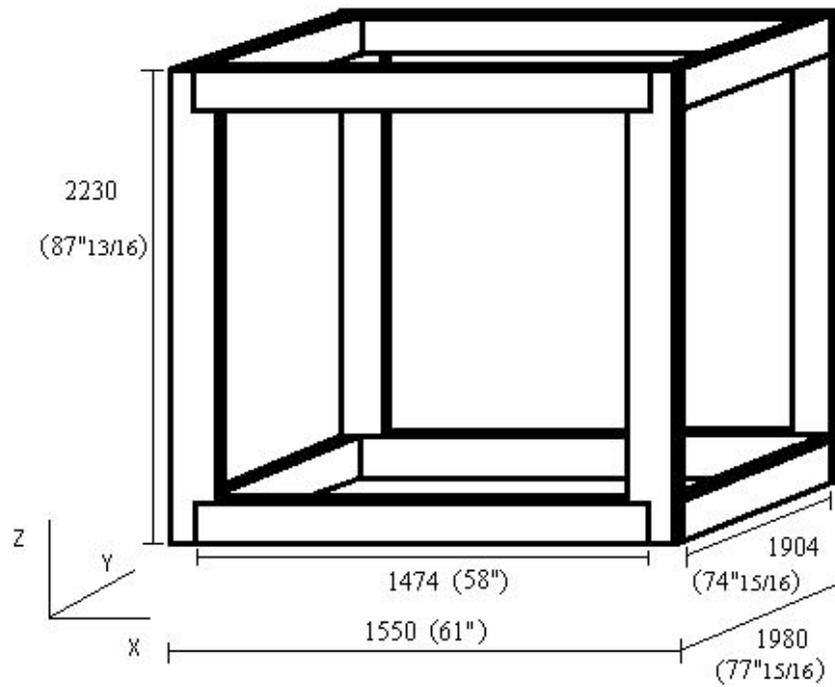
This system is designed for a 90 inch creen, dimensions (mm), ratio 4/3:

width : 1829.3

Height: 1372

The side panels are in thin wood and painted in black. The video projector is posed on the bottom of the system. Since the beam goes out of the machine making an angle of 13 degrees with the horizontal if it is posed as is on the floor, we need to set the position of the video projector such that the beam goes out in an horizontal manner. We built a support underneath the video projector to hold it in the correct position, the beam lighting in the correct direction (horizontal).

## MAIN FRAME



The main frame was built in redwood and special cuts were made at each angle to make the whole structure stable. More stability is brought with the building of the inner structures such as the two mirror supports and the screen support. There are 4 zinc corners and many screws at each angle also. The structure is very strong and we can hang very heavy panels on it without any fear.

## MIRROR SUPPORTS

### MIRROR 1

#### Equations (in mm):

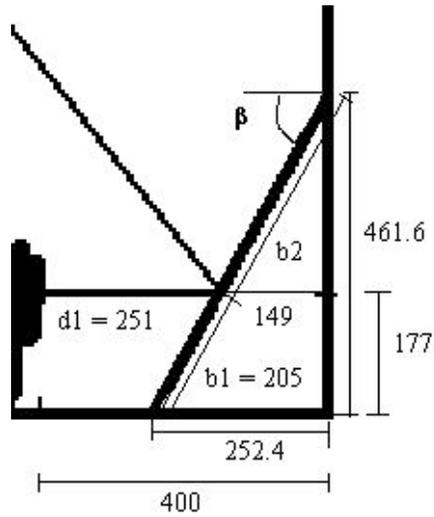
$$b1 \cdot \sin(\beta) = 177 \Rightarrow b1 = 205.03$$

$$b2 \cdot \cos(\beta) = 400 - d1 = 149 \Rightarrow b2 = 294.96$$

$$b1 + b2 = 500$$

$$500 \cdot \sin(\beta) = 431.63$$

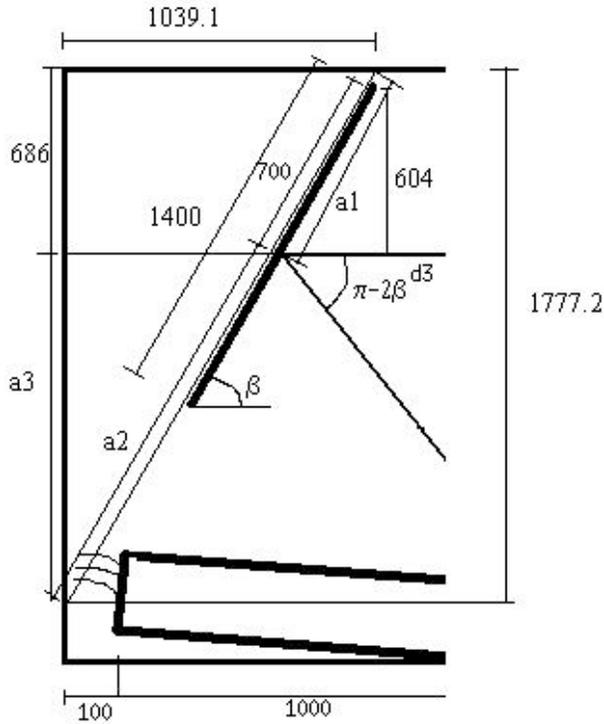
$$500 \cdot \cos(\beta) = 252.37$$



#### Configuration:

The assembly of the different parts of the wood support for this mirror is the same as the one depicted for the second mirror (see the figure in the configuration part of the description of the second mirror).

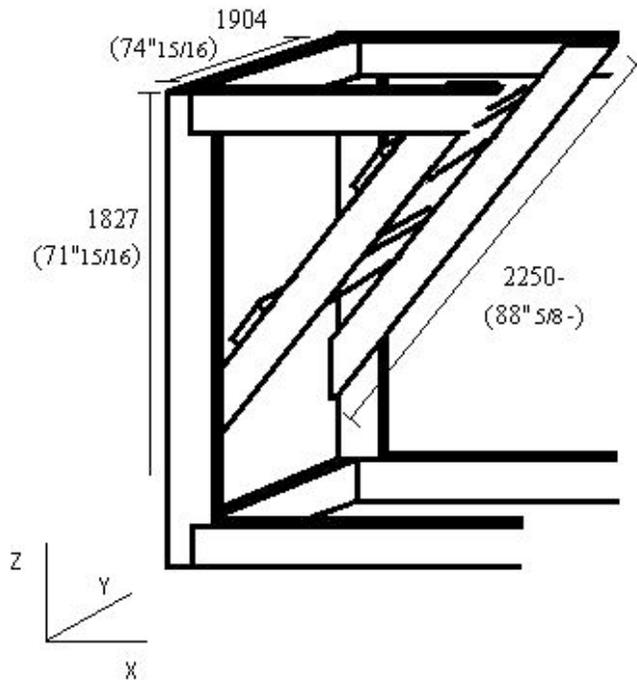
**MIRROR 2**



**Equations (in mm):**

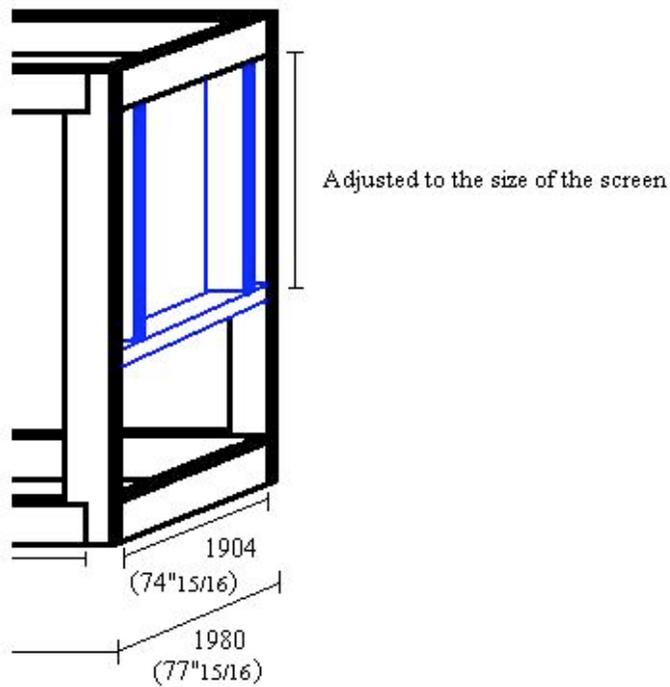
$$\begin{aligned}
 a1 \cdot \sin(\beta) &= 686 \\
 \Rightarrow a1 &= 794.65 \\
 a2 \cdot \cos(\beta) &= 1500 - d3 = 638 \\
 \Rightarrow a2 &= 1264.02 \\
 a1 + a2 &= 2058.67 \\
 a3 &= a2 \cdot \sin(\beta) = 1091.19 \\
 a3 + 686 &= 1777.19 \\
 (a1 + a2) \cdot \cos(\beta) &= 1039.09
 \end{aligned}$$

**Configuration:**



The panel with the mirror glued on it is hung on the above structure.

## SCREEN SUPPORTS



The screen supports were designed to fit the screen we were using (Draper screen). The shape of the screen, and the way to hang it depend highly on the case. The wood was arranged to make a solid and stable structure the hang the screen.





$$w(d) = 0.4746136736.d + 611$$

## QUESTIONS AND ANSWERS

**Q: Does the beam touch the ground?**

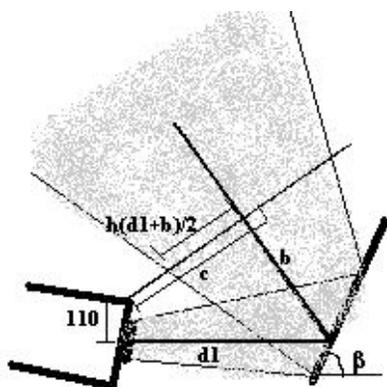
**A: No**

The beam touches the ground for  $h(d)/2 = 177$ , that is to say  $d = 401.96$ , which is much more than  $d_1$ .

**Q: Does the beam collide with the video projector?**

**A: No**

Because  $h(d_1+b)/2 < c$  (see figure below)



$$d_1 = 251.12$$

$$b = \sqrt{(110 \cdot 110 + d_1 \cdot d_1) \cdot \cos(\pi - 2 \cdot \beta - \text{Atan}(110/d_1))}$$

$$c = \sqrt{(110 \cdot 110 + d_1 \cdot d_1 - b \cdot b)}$$

$$\delta \quad b = 136.85$$

$$\delta \quad h(d_1+b)/2 = 173.55$$

$$\delta \quad c = 237.93$$

$$\delta \quad h(d_1+b)/2 < c$$

**Q: Is Mirror 1 big enough?**

**A: Yes**

IN HEIGHT:

Because  $h(d_1 + x) = 353.08 < M1 \cdot \sin(\beta) = 431.63$

IN WIDTH:

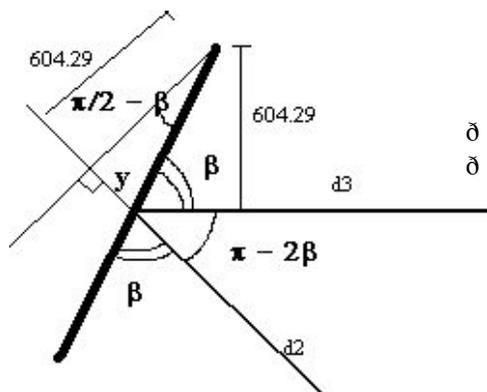
Because  $w(d_1 + x) = 800.84 < \text{Width of } M1 = 1000$

**Q: Is Mirror 2 big enough?**

**A: Yes**

IN HEIGHT:

Because  $h(d_1 + d_2 + y)/2 < M2 \cdot \cos(\pi/2 - \beta)/2$  (see figure below)



$$y = M2 \cdot \sin(\pi/2 - \beta)/2 = 353.31$$

$$M2 \cdot \cos(\pi/2 - \beta)/2 = 604.29$$

$$\delta \quad h(d_1 + d_2 + y)/2 = 566.4$$

$$\delta \quad h(d_1 + d_2 + y)/2 < M2 \cdot \cos(\pi/2 - \beta)/2$$

IN WIDTH:

Because  $w(d_1 + d_2 + y) = 1587.91 < \text{Width of } M2 = 1800$

**Q: Does everything fit in the box, Fred?**

**A: It sure fits!**

## APPENDIX B:

### Technical specifications of the video projector

Source: <http://www.extremeprojections.com/projectors/vph1292q.html>



### SONY VPH-1292Q

SONY VPH-1292Q VIDEO DATA PROJECTOR (NTSC/PAL/SECAM)

- | **Multiscan capability** : horizontal 15kHz to 135kHz, vertical 38Hz to 150Hz. Incorporates new, high resolution 9-inch electromagnetic focus CRTs.
- | **Incorporates a Universal Optical Coupling**. Remarkable light output of 225lm (ANSI lumen), 1000lm (peak white), 300lm (all white. High resolution of 700 TV lines/2000 x 1600 pixels (RGB) in at fH : 94kHz, fV : 60Hz.
- | **Wide RGB bandwidth of 120MHz**. Registration adjustment at 21 points on the screen for accurate registration. HACC lens for superior and stable picture performance.
- | **Video decoder circuit** for enhanced video picture quality. Responds to both analog/digital RGB signals.
- | **Supplied wired/wireless remote control** unit RM-PJ1292 controls all the projector functions such as set-up adjustments and operational functions.
- | **Various optional accessories** available for system versatility. Desk top mounted projection, ceiling mounted projection, floor mounted projection and rear projection capabilities.
- | **Can be used with screens from 90-inch to 300-inch** in size with simple adjustments.

## APPENDIX C:

### Photos





## **APPENDIX D: Useful links**

**Description of the SONY video projector:**

<http://www.extremeprojections.com/projectors/vph1292q.html>

**Draper, rear projection screen maker:**

<http://www.draperinc.com/projection.html>

**About caves and VR projection-based environments:**

<http://www.evl.uic.edu/EVL/VR/>

**Selecting the Right Rear Projection Screen Surface:**

<http://www.da-lite.com/Education/Manuals/RearProj/rearpage10-12.html>

**To adjust the display:**

<http://orpheus.ucsd.edu/mediaservices/testpattern/main.htm>

**Link to the Electronic Visualization Laboratory:**

<http://www.evl.uic.edu/EVL/VR/>